# Green IT: People Counting and Detection of Patterns of Movement

António Novais
antonio.novais@ist.utl.pt

Instituto Superior Técnico
Av. Prof. Dr. Aníbal Cavaco Silva
Lisbon, Portugal

## Abstract

Energy saving plays a key role, not only for the growing need of cost reduction, but especially by the expected significant reduction of natural resources. The knowledge of the location and patterns of mobility of people inside buildings can help reduce consumption, making it possible, for example, to adjust the air conditioning and lighting to the real occupation of the building. We propose a system capable of counting people and learn their patterns of mobility inside buildings by giving the ability to integrate several technologies. This thesis also contributes to a multi-functional monitoring platform by integrating a service discovery module. In this document, we also analyze the state of the art technologies and protocols used for service discovery and locating people.

**Keywords:** People Counting, People Tracking, Generic Data Acquisition, Service Discovery

## 1 Introduction

Energy saving plays a key role, not only for the growing need of cost reduction, but especially by the expected significant reduction of natural resources. The knowledge of the location and patterns of mobility of people inside buildings can help reduce consumption, making it possible, for example, to adjust the air conditioning and lighting to the real occupation of the building. The cost to determine location should be inferior to the savings. Nowadays, people carry communication devices. Those could be used to infer their location and to assess their mobility patterns. Current systems tend to use only one technology to achieve location and user mobility patterns. Most systems are even intrusive by needing people to carry specific devices or installing applications on their mobile devices.

Considering this, we propose a system that makes use of several communication technologies and terminals to be capable of counting people and learning their patterns of movement inside buildings to estimate and reduce energy consumption. This system will then be installed at Instituto Superior Técnico – Taguspark's campus as part of a project concerning Green IT in an association with MIT – Portugal. This system will also function as a use case of a multi-functional monitoring platform. This platform handles all communication between services and abstracts the applications from the problems that arises from that. Furthermore, adds filters that aide the application to respect some requisites like synchronization, aggregation of packets and network monitoring. However, we felt that a platform of this kind, especially for pervasive environments, should also provide service discovery. Services and clients need to communicate between themselves to obtain information even though they don't know each other, what they are and how they should communicate. Therefore a service discovery module will be integrated into the platform which takes into account the scalability of such systems and the numerous types of services existent.

This document is organized as follows. Section 2 provides an introduction to current protocols and previous projects related to any of the areas of this work. Section 3 introduces the designed architecture of the system as long as all its components. In section 4 the corresponding implementation is discussed and the specific developments made for installation of a prototype in IST-Taguspark. Section 5 evaluates the implemented solution. Finally, section 6 concludes this document by summarizing its most relevant points.

## 2 State of the Art

### 2.1 Service Discovery in Pervasive environments

Considering the goals of the proposed platform, we consider that directory-less protocols are more suitable to a platform that can be used in very different scenarios, i.e., nodes may have very low processing capabilities, and therefore the complexity imposed by directory-based protocols in pervasive environments is not indicated.

In directory-less architectures the major challenge faced is the flooding control of broadcast or multicast advertisements and requests. The main techniques used for dealing with this issue are[1]: Scheduling and prioritization of service advertisements; Advertisement range bounding/scoping; Selective, probabilistic, and intelligent forwarding of advertisements and requests; Peer-to-peer (P2P) information caching; Intermediate node responding to service requests.

In [2], service providers periodically advertise their services along with services that they became aware of to the neighbor nodes. When a provider receives an advertisement that contains its own services, it postpones advertising its services and back-offs for a fixed amount of time since the nodes in his vicinity already know his service.

In the Group-based Service Discovery (GSD)[3] and Alliance-based Service Discovery (Allia)[4] protocols, advertisement range bounding is used by specifying the number of hops by which the advertisement message will be dropped. For nodes to become aware of all the services provided in the network, these protocols also implement P2P information caching: Nodes merge services learnt from previous advertisements and re-advertise them along with their service using range bounding. Regarding service discovery, these approaches employ selective forwarding to avoid network flooding. When a node does not match the service request it forwards the request only to neighbors that are known to match the requested service or host similar services.

In [5], intermediate nodes are allowed to answer service requests of services they do not provide but are aware of. However, this may decrease the number of discovered services since intermediate nodes may not be aware of all the corresponding services that match the request and therefore respond with a less suitable service provider. To deal with this issue, the authors propose that when answers come to a service requestor from different servers and different paths, intermediate nodes and servers along those paths be updated to become aware of all the services that were returned to the requestor.

### 2.2 People Counting

In this section we will describe the main technologies and methods used for people counting as some real implementations.

**Infra-red** When using this technology to count people there are two main methods used: through infra-red beams or infra-red thermopiles [6]. In the first case, the beams are positioned horizontally at door entries and when the beam gets broken it means a person is passing and therefore is counted. This simple approach doesn't take in account directional flow and so a dual beam approach is often used. Consequently, information about entrances and exits is available. The accuracy of this approach is limited, especially when high volume flow or uninterrupted traffic occurs. It is also possible to position the beams vertically which can increase somewhat the accuracy. The second method is based on people detection through body temperature. This method has the advantage that these sensors are passive and so do not require to radiate energy to the environment, additionally, thermopiles measure heat and therefore are not affected by direct lighting as infra-red beams [6]. On the other hand, this is a more complex detection algorithm as the human body does not emit temperature uniformly and can vary with different clothes and time of day [7].

**RFID** Radio frequency identification is a wireless communication technology for data exchange between a reader and a tag. Each tag has their own ID that is emitted to the reader. RFID tags can either be active or passive [8]. Passive tags operate without the use of battery. They reflect the RF signal received from the reader and add information by modulating the reflected signal. These tags are much cheaper and have a virtually unlimited lifetime. However, they have a limited range. Active tags contain a battery to power the transceiver and so can achieve much higher ranges. Besides being more expensive, its battery life is of course limited although it can go up to several years. The main purpose of this technology is for the identification of objects, for instance, commercial products, cars and others. However, it may also be used for people counting, location and tracking. Specifically for people counting purposes, when considering entrances and exits of divisions, it makes sense to use low-range passive RFID tags not only for their lower cost but also to get information more accurately from readers situated at door entries. The main setbacks of using this technology for people counting are the requirement of people to carry or wear RFID tags, and also the privacy issues that must be considered since an RFID tag can hypothetically identify the person.

### 2.3 Location and Tracking of People

In this section we will describe the main technologies used to achieve location and tracking of people as some localization systems.

**GPS** The GPS technology is currently the most used localization system worldwide [9]. It provides physical absolute self-location through GPS devices that receive Satellite signals. Therefore, the computation of the location is made on the device which makes recognition not possible. GPS is highly scalable given that twenty-four satellites cover location all over the world, however, the infra-structure is highly expensive and each person's GPS device cost is fairly high. This technology also has a high value of accuracy (1 to 5 meters) and precision (95% to 99%).The main setback of this technology besides the cost is the need to have line of sight to at least three satellites to compute a position due to the triangulation method. This is generally not a problem for outside environment but indoors the signal from satellites is usually too weak.

**Wi-Fi** The Wi-Fi (IEEE 802.11 family) technology is widely embraced. It is currently on our notebooks, netbooks, PDAs and Smartphones and is available in buildings, hotels, cafes and others. This makes the Wi-Fi technology very attractive to use in localization systems because it enables localization with lower costs as the infra-structure is already present in most places. The major techniques used for localization through Wi-Fi are lateration and proximity, either by RSS (Received signal strength) or cell based positioning. Since the Wi-Fi is generally used indoors, when the RSS method is used, reflection and multi-path issues arise, therefore the accuracy is affected and can go from 3 to 30 meters [11]. When the cell based positioning is used, the location is made by either querying access points for connected clients through SNMP or by getting this information from RADIUS authentication system, the accuracy in these cases is fairly low tough because it depends on the size of the WLAN cell which can go from 50 to 300 meters [12]. This technology can provide either physic or symbolic position and the location computation can either be on the device or in the infra-structure. The scalability of these location systems is limited due to the infra-structure needs. Thus, this technology is more commonly used indoors.

**Bluetooth** Bluetooth is a wireless communications technology standard. It is best suited for data transfer through Personal Area Networks (PANs), however, it can be used for localization systems. Bluetooth is a low-cost technology and is currently built-in in most of our mobile phones which makes this technology interesting to use for people localization. This technology allows self and remote positioning. In self positioning the method most commonly used is through received signal strength of beacons from one or multiple known points like in [13]; The main disadvantage of this approach is that specific software on the device is needed to perform the positioning. In remote positioning there are two methods used, connection-based and inquiry-based[14]. Connection-based systems measure device signal strength while connected to Bluetooth access points [15]. This can be intrusive to the owner since it establishes a connection at least once every time it is on range. Furthermore, it has limited scalability due to the Bluetooth limitation of seven simultaneous connections [16]. Inquiry-based positioning refers to periodically inquiring for in range devices and then store signal strength and compute location [14] or assume cell-based positioning [17]. In either case the main disadvantage is the fact that the devices must be in "visible" mode to be detected. Also, when in indoor environments, signal strength can be affected by many factors like multi-path and reflection which can difficult triangulation or distort cell shapes and consequently lower the accuracy.

**Vision-based** By processing video images it is possible to infer people's shapes and movement and pinpoint their position resorting to scene analysis. Regarding the infra-structure, most buildings already have surveillance cameras which can reduce the cost of deployment. Vision-based localization can provide physical or symbolic position. This type of localization is very accurate, in order of centimeters to a few meters[18]. On the other hand, video processing is very demanding in terms of computational capabilities which can increase the cost of localization processing units [7], furthermore it has a limited scalability as a result of this intensive computation and also the infra-structure needed to connect to video processing units. Another challenge it faces is the need to merge cameras vision to a single plane due to the overlay of camera vision or the lack of sight of certain areas [19].

## 3 Architecture

### 3.1 Location and Tracking System

**System overview** The location system is composed by nodes that are spread in monitored buildings. Each node have a set of sensing devices that enable it to retrieve important information about people location in its neighborhood. There may be different sensing devices in different nodes, that may complement each other. Thus, Wifi technology may be used to perform long-range location, bluetooth to perform short-range location, infrared to count people and RF-IDs to track persons. At the end, the information gathered by each one of the nodes should be collected by a sink node and sent to a server to be stored.

An example physical topology of this system is illustrated in figure 1.

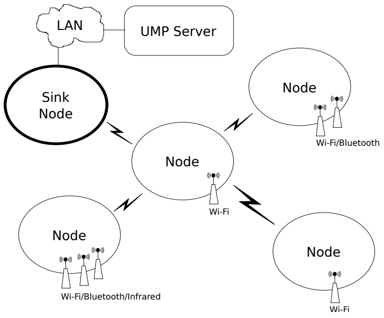

**Fig. 1.** Example physical topology of the system.

In order to have a scalable network architecture, we used an hierarchical network structure, as illustrated in figure 2. The nodes in the bottom of the hierarchy perform the most low-level operations, such as handling hardware communication for sensing people, and the nodes in the higher levels perform high-level operations, such as grouping information.

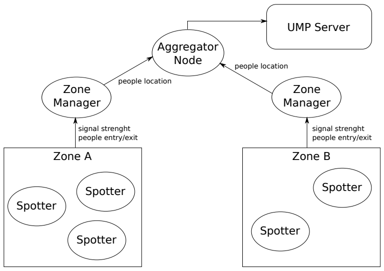

**Fig. 2.** Logical topology of the system.

A building may divided in different zones, each one of them having a set os spotters that are exclusively associated to that particular zone. Each spotter retrieves signal strength and people entry/exit information from sensors and sends it to its own Zone Manager. The Zone manager collects information from spotters and use it to compute the physical or symbolic location of users within the zone. Each Zone Manager communicates with the Node Aggregator that is responsible for aggregating location information of all zones and transmit it to the User Mobility Patterns (UMP) server. This node also acts as sync node, as it is the node that is connected to the local area network (LAN). The UMP server is located on the LAN. The UMP server has virtually unlimited power and processing capabilities. It periodically receives the global state of localization and counting and stores the user mobility history. Based on this history, it continuously computes the user mobility patterns Nodes announce their capabilities using the service discovery protocol that we developed in the Multi-Function platform. Furthermore, each node uses this platform to handle the data transport and synchronization. Each node can operate more than one component.

The next sections will describe the specific architecture of the the Multi-Function Platform and of each one of the components that have been described.

**Service Discovery** Service discovery is starting to assume a more important role in today's networks since networks are becoming widely available in our houses, streets, pockets and even on our clothes. These networks are more and more dynamic and automated. For this reason we felt the need to integrate such a service into the platform. To integrate such a service in the referred platform without tampering with it's own architecture, this module is no more than an application in the perspective of the platform. However, it functions as an add-on to the platform, since other applications make use of it through an API.

### 3.2 Location System Components

**Spotter** The Spotters are the leaf nodes of the location system. They are responsible for all the sensing that occurs in the system. This means that these nodes differ from the rest in the fact that they must have access to the hardware that enables them to sense people or related information. The spotter architecture can be seen in Figure 3.

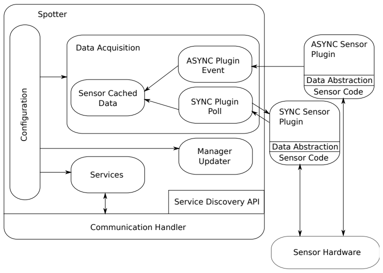

**Fig. 3.** Spotter architecture

One of the requisites of this system was to integrate multiple and new technologies for sensing people. For that reason, we designed a plugin based architecture. Therefore, for each type of sensor existent in the system a plugin has to be written so that the spotter can handle the technology. These plugins implement the protocol with the sensor hardware and process it's information so that it can filter noise data, and create an abstraction of the data in such a way that all nodes can understand. Plugins can be of two types: synchronous or asynchronous. Synchronous plugins only activate their sensing mechanisms when prompted by the spotter. On the other hand, asynchronous plugins react to events triggered by people's movement or appearance, for instance, when an infrared beam located in an elevator's door gets interrupted, it usually means that a person just walked in or out of the elevator, therefore an asynchronous event occurs. As for the abstraction of the sensor data, and regarding our location system it can be of four types:

- *PEOPLE COUNT* - Type of sensor data that represents the number of people present in a certain area. For instance, infrared heat sensor plugins that process the infrared image to infer the presence of people.
- *PEOPLE ENTRY/EXIT* - Indicates an entrance or exit of a number of people to a certain area. For instance, infrared beams located at the entrances of an area can detect the entrance or exit of people.
- *PEOPLE PINPOINT* - This type of data indicates the exact location of one or more people. For instance, an RFID reader with short range can pinpoint people associated with an RFID tag to the reader's self location.
- *Radio Signal Strength (RSS)/DISTANCE TO SENSOR* - This data type indicates the radio signal strength of in range people's devices. For instance, a Bluetooth sensor can find in range Bluetooth nodes and get their signal strength. Through the signal strength the plugins can also try to achieve the distance to the sensor. This data type is used for post-processing by the Manager node and it will be discussed later.

When a plugin is done processing the information, it delivers the abstracted data to the spotter so it can later send it to the Manager (will be analyzed in the respective section) along with all other sensor data. In order to do that, the spotter must have an associated zone manager. This may occur in two manners, both using the service discovery module described in section 3.1. The manager can request the spotter service with a given frequency of update or the spotter can request for it's manager to the service discovery and, upon discovery, spontaneously register with the manager to start providing it's service. Either way, both services negotiate and agree the frequency in which the spotter updates the manager, taking into account the minimum time the spotter takes to acquire sensor information. Moreover, the spotter also provides a service for requesting instant sensor data available in the node. This means that different purpose systems can subscribe for information to the spotter or even get it's current information at a specific instant, which makes the spotter easily portable to other systems.

Finally, the configuration module acts upon the other modules present in the spotter. It is used so that it can adapt more accurately to the associated environment. For instance, it tells the data acquisition module what are the plugins available, what are their respective types (synchronous or asynchronous) and what is the frequency for polling the synchronous plugins. It also configures what is it's own physical position and what is the minimum period between updates to the manager.

### Zone Manager

Zone managers are nodes that contain location information about the zone they are managing, therefore, there is only one manager per zone. The manager architecture can be seen in figure 4.

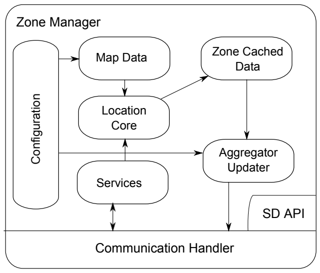

**Fig. 4.** Zone Manager architecture.

The map data is an important module in this application. This module characterizes the area which the manager is responsible and it is useful for aiding the location core to better calculate the location of people. A map is represented by a bi-dimensional group of hexagonal cells. The cell size can vary between maps, depending on the actual region size and desired accuracy and precision. This module also has information about the floor in which this region is located and the number of horizontal and vertical cells. Furthermore, each cell indicates if there is an obstacle present (and therefore impossible for a person to be), or if it is a transition cell. Transition cells are a special kind of cell that indicates a possible transition to another region, and specifies to what region and destination cell that transition is made. These cells are usually located at the edges of a map which are associated with doors or hallways but they can also exist in the middle of a map, for instance stairs in the middle of a division, and therefore a transition to a different floor is possible. Although these transition informations are present in the manager, this node does not make much use of it as it will be more suitable for the aggregator.

The Location Core module is where all computations of locations occur. When a spotter delivers data to the corresponding service, this delivers it to the location core. The behavior of this module depends on the number of associated spotters as long as the type of information that is receiving. It is important to notice that the use of the platform synchronization module is used in this context to detect data out of order and relative to older instants. As it was mentioned in section 3.2, there are four types of sensor data, we will now present the behavior of the module for each type.

– *PEOPLE COUNT* - For this kind of data the module assumes that the spotter from which is receiving the data is capable of counting the people in the whole area, and that it should only exist one spotter with this type of sensing per area. Therefore, it changes directly the state of the number of people in the area with the received value. If it is impossible for one spotter to count the whole area one of two solutions should be used: divide the area in two or more areas so that it can count the whole area, or maintain the state in the spotter of how many it can see and transform these values to entrances or exits of people.
– *PEOPLE ENTRY/EXIT* - Inside any area there may be only one between the two types of sensors: PEOPLE COUNT or PEOPLE ENTRY/EXIT. As this type of data is received it is straightly added or subtracted to the counter of people in area. If this counter becomes less than zero and the manager has still information to receive from other spotters, it is most likely that it has still entrys to receive since it is possible for an area to have more than one entrance or transition cell.
– *PEOPLE PINPOINT* - As it was explained earlier this type of data is used when a spotter is sure of a physical location of people. Therefore, by receiving this information, the spotter straight forwardly adds a representation of the people to the corresponding locations. There may be several nodes of this type in an area.
– *RSS/DISTANCE TO SENSOR* - This type of data is the one that requires the most computation from the node. The behavior of the module when receiving this type of data depends on the number of spotters that supply this kind of information. In the case that only one spotter is supplying this information then the manager assumes a symbolic location such that it only considers that the person is situated in his own area. If instead, it receives more than one data of this type, it will try to calculate each person's physical position inside the area through triangulation mechanisms. In this case the mechanism used is lateration since that knowing the location of three points to any reference and their distance to another point it is possible to calculate the exact position of that point. However, when the manager only receives information of a certain person from two spotters we assume that by not being in range of a third node, it will be further away from the maximum range of the technology and, therefore, we use the coordinates of the spotter closer to the other two and with a distance corresponding to the maximum range of the technology plus the size of a cell. For each triangulation made, the result is converted to cell coordinates and the cell is checked for obstacles. If an obstacle exists in the resulting cell, the modules analyzes the neighboring cells without obstacles and chooses the most probable cell in which a person is located. For each person it discovers the location, it will add a representation of the person to the corresponding cell position. Note that this type of data can not be processed at the time of delivery since the manager needs to receive the data from all spotters who have this information to a given instant so that it can be process all locations.

**Aggregator** The Aggregator node is responsible for maintaining the global state of localization of all areas, movements of people between areas and resolve location conflicts such as people being located in multiple areas or by more then one technology. The architecture of the aggregator can be seen in figure 5.

Maintaining the same logic of services provided by the other nodes, the aggregator also provides a subscription service, an instant state service, a spontaneous register and a service for delivery of data both from zone managers. Once again, this node uses the discovery of service to find all the zone manager nodes and subscribe them.

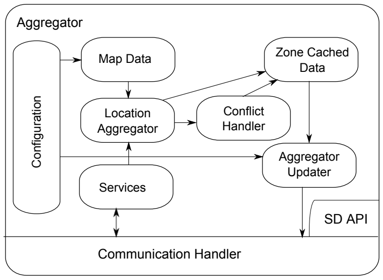

**Fig. 5.** Aggregator architecture.

The map data module is also similar to the one existent in the zone manager, however, this one contains information of all the areas that are being monitored. It also gives support to the location decider and conflict handler by supplying them transition cells, adjacent cells to a given cell, translates cell coordinates into distances and vice-versa. More description on how each map is characterized was provided in section 3.2.

As for the global cache, it does not only provide the updater with the current data for sending but also to improve the computation of the location aggregator and conflict handler. This cache maintains the current state of the location system, the data still to be processed and the state of the previous instant so that the other modules can better decide based on the location of people in the previous moment.

The location aggregator module, as the name suggests, aggregates the location information received from each zone manager and transforms into a unique source of global location and saves it into the cache. This module also checks for the existence of location conflicts and, if so, reports the conflicting locations to the conflict handler that will process the information and decide which of them is the correct location. This module is also responsible for cleaning up old information from the cache.

The conflict handler is triggered when a location conflict is detected by the location aggregator. This module receives the data relative to the previous location of the person and the new conflicting locations. Based on this information, checks whether the previous and conflicting locations have adjacent transitions. From this point, several resolutions may occur:

- In case the previous position does not have adjacent transitions and one of the new conflicting positions belongs to the same area, then the module resolves with this location.
- In case both conflicting positions have or do not have adjacent transitions to the previous area then it will calculate the distances of both to the previous location and return the position with the shortest distance.
- In case only one of them has an adjacent transition to the previous area then that position is chosen.

**User Mobility Pattern (UMP) Server** The UMP server is the system that performs the computation of patterns of movement. This node is situated in the local network and has superior processing capabilities, memory and storage resources when in comparison with the nodes that contain the other components. The architecture of this system can be seen in figure 6.

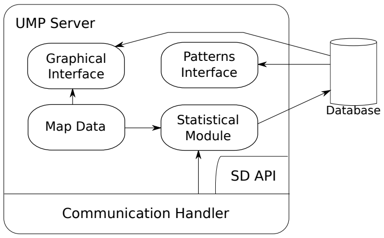

**Fig. 6.** UMP Server architecture.

Just like the other components, this application also uses the multi-functional platform and as such, can also use the discovery of services module even though it is located in a distinct network. There may be several aggregators on the network, and this server, can even subscribe to more than one. However, following the ideal topology created for the system, the data provided by each aggregator could not be correlated since they would belong to distinct environments.

This application when subscribed to an aggregator, periodically receives the global state of location. This information is passed to the statistical module that processes this information to obtain the movement between cells from the previous instant to the current position and conveniently writes to a database in a statistical manner, such as day and time of movement, origin of the initial movement, among others.

The graphical interface module, as the name suggests, is the module that provides an user interface to visualize diverse statistical data concerning the patterns of movement, giving the possibility to visualize the last location state received from the aggregator and define specific time intervals and areas to calculate the respective patterns.

The export interface module is the module that provides the services so that other applications can obtain the patterns of movement relative to a building or space. This module is useful, for instance, for applications that control domotics so that they can act on the devices in a more intelligent way. For instance, turning on and off individual air conditioning systems based on the observed patterns to a certain area.

# 4 Implementation

## 4.1 Location System

The implementation of the location system may be divided into two categories: the generic platform of the location system and the specific use-case prototype for installation in IST-Taguspark. The platform was implemented taking into account the logic architecture described in section 3.1. In all the different components that are part of the system there are common structures they use. The communications handler provided by the multi-functional monitoring platform is one of them. Upon initiation, these applications register the handler so they can use the platform and be accessible by other services. In every outgoing communication wanted, the handler is used to send the data to another application either in the same node or external node. Furthermore, the GSD Application Programming Interface (API) is used by every application to use the discovery service module to find, in this case, their corresponding logical parent. All applications also use a common library to send data in Javascript Object Notation (JSON) format and translate JSON data into a recognized data structure. Finally, there is a common map library that contains operations over map data like the loading of maps and the translation between physical coordinates to cell coordinates and vice-versa.

Considering the installation in IST-Taguspark we have built a laboratory prototype in which we monitored two areas: One only counting entrances and exits, and the other also doing pinpoint of physical location of people within the area. In order to choose the most adequate technologies to use we considered the following requirements: cost - the cost of possible devices should be low and preferably using already present technologies to lower infrastructure costs, also, the computation needed should also be low as nodes have scarce computation capabilities; acceptability - acceptance from people to be localized using one technology (usually concerning privacy issues); accuracy and precision - the technology should provide localization accuracy of up to 20 meters; intrusion - people should not need to use specific devices or install specific applications in their mobile devices (remote-positioning); scalability - it should allow the scaling to large buildings and campus without greatly increasing complexity and difficulty; technology limitations - it should work indoors. Regarding people counting we can conclude that the video-based counting has associated high costs of infrastructure and computation capabilities; the Radio Frequency Identification (RFID) technology fails on the acceptability of people to wear RFID tags and their distrust concerning privacy. Although infra-red technology provides less accuracy in people counting than the previous technologies, it still provides an acceptable accuracy and it has a better evaluation on all the other properties. As for people localization we deduce the following: using Global System for Mobile Communications (GSM) technology is intrusive (self-measuring) and it does not provide good enough accuracy; infrared and video-based localization have high computational needs; the use of RFID in localization besides the acceptance issue, it has limited scalability and high infrastructure costs; the Wi-Fi and bluetooth technology are both a good fit for localization considering the previous requirements. Therefore, we chose a solution using the infrared technology for people counting and bluetooth technology for localization.

## 4.2 Spotter

This component implements all the features described in section 3.2. As for the data acquisition, there are several methods for implementing plugins. Our implementation is based on dynamically linking the plugins in runtime. The spotter interacts with the plugins through well-defined function signatures that they must implement:

*void start_plugin(void (* sensor_result)(SensorData *))* This function initializes the plugin. It receives a pointer to a callback function that receives the resulting sensor data. This should be stored in the plugin and called when there is available data.

*void stop_plugin()* This should implement the cleansing of structures and termination. After this function is called the plugin is usually unlinked from the spotter.

*void start_sense()* This function is only used for synchronous plugins. The spotter periodically (SENSE_INTERVAL) calls this function on every synchronous plugin available that should implement the actual sensing of the environment to later provide the results.

The configuration module lets the spotter know which are the plugins to be used, those are dinamically linked and for each one the spotter loads the *start_plugin* symbol (returns a pointer to the method) and calls it. At this point all plugins are initialized and contain the pointer to the callback function in the spotter that receives the sensor data. When in this state, the asynchronous plugins are already sensing the environment/ready to be triggered by an event and report it to the spotter. On the other hand, the synchronous plugins are not active and only start sensing when probed by the spotter. When the sensing is finished, executes the callback with the resulting data.

For the application scenario of the location system in IST-Taguspark we decided to implement two technology plugins:

- An infrared beam sensor plugin that detects the entrance/exit of people in a division in an asynchronous manner.
- A bluetooth sensor plugin that detects the radio signal strength of in range devices.

**Infra-red** We used two types of infrared sensors that operate in distinct ways. The first type of infrared sensor is a short range sensor (approximately 80cm) that is simultaneously emitter and receiver. The sensor is constantly emitting an infra-red beam, and when in open space it does not receive any signal. Whenever the sensor is in this is state its output is HIGH. When the beam is obstructed at a short distance it reflects on the person or object and is received by the sensor. In this case the sensor changes its output to LOW. Thus, this output is directly connected to a Digital Input/Output (DIO) Header in the TS-7500 board that is capable to read this signal. This sensor is ideally placed on the sides of single passage doors since the sensor range is sufficient to detect any passage. In order to detect the direction of movement of a person (entrance or exit) we use two of these sensors placed in parallel and each one connects to an individual DIO. These sensors are powered directly by the board with 5 volt power source. The prototype is displayed in figure 7.

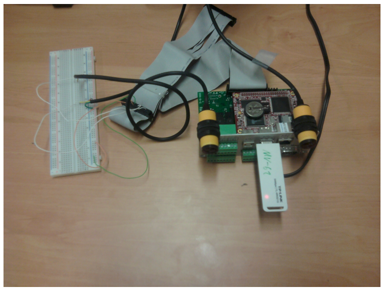
**Fig. 7.** Prototype of a node with short range infrared sensor capabilities.

The other type of infrared sensors have a range of tens of meters and require a pair of emitter and receiver. Thus, its operation is inverse to the prior sensor. In this case, when the receiver is receiving the beam, it means that there are no obstructions. In case it is not receiving, then the beam was obstructed by a person or object. Furthermore, we faced some issues when using the same method as above for detecting movement direction. This was due to the fact that the emitter has such an emitting power and the restriction of the beams being closer then the width of a person in profile (would lead to a misinterpretation of people standing between the beams), that when a beam was obstructed, both receivers still got the signal from the unobstructed beam. The solution was to resort to sensors that could operate in synchronous mode, that is, that one pair is never operating at the same time as the other and alternate at a high frequency. This is achieved by feeding the sensors with alternate current in which each pair is in inverted polarities. Thus, we use 220 to 12 volt transformers with alternate current. The physical prototype can be seen in figure 8. These receivers contain relays powered by the board with 3.3 volts that are switched when the beam is obstructed. The output of this relay is then directly connected to DIO headers in the board so that it can interpret the state of the sensor.

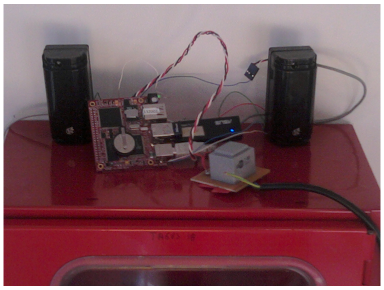
**Fig. 8.** Prototype of a node with long range infrared sensor capabilities.

The plugin structure is the same for both cases, the difference is in the expected states which are opposed to each other (HIGH and LOW).

**Bluetooth** The Bluetooth sensor is an USB device that provides the technology functionalities to the system it is connected. In order to be used, we enabled the bluetooth support on the ts-7500 installed operating system. The bluetooth version of the device is 2.1 and the its range is approximately 10 meters.

We also used the BlueZ library that implements the bluetooth protocol.

The bluetooth plugin is a synchronous plugin that, upon request, enters the inquiry mode to discover all in range nodes. An inquisitions takes about ten seconds. During this period it is possible to check the signal strength of each discovered node. Since the signal strength is fairly inconstant and is subject to several factors that can increase the attenuation, during the period of inquisition it is calculated the average signal strength for each node. This value is then used to calculate the corresponding distance. This distance can be achieved with two methods, depending on the plugin configuration:

*Open space method* This method calculates the distance to the node based on the propagation and attenuation laws of radio signals in open space. This is ideal for outdoor areas like gardens, clearings and others. The attenuation is related with the emitting power over the square of the distance.

*Fingerprinting method* This method is based on the pre-observation of the behavior of signal strength in account for the distance to the node. This is best for indoors, since the radio signals are substantially affected by the obstructions, reflections and multi-path effects. In this case, the plugin receives a configuration of the signal strength intervals that correspond to a determined distance step. However, we can also configure the plugin with nonuniform steps if we have more certainty of the possible distances of people to the spotter. This method may increase both accuracy and precision but requires more study to proper analyse the area and the signal strength.

### 4.3 Manager

The manager implements all the modules described in section 3.2. Just like the spotter, the manager's configuration module loads the handler file to register the handler and define the minimum interval in seconds to update the aggregator, its handler address and the map file to load. This map file contains all the map data information that will be loaded into memory. This file is in JSON format and may become complex of configuring depending on the size of the area, desired accuracy and quantity of obstacles and transitions. Based on the plant of a room we can do a close enough map approach a determined cell size. In figure 9 is the representation of a room using hexagonal map cells. The red cell represents a transition cell.

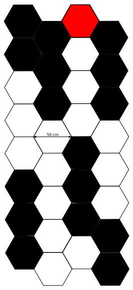

**Fig. 9.** Cell representation of the example location area.

### 4.4 Aggregator

The aggregator node implements the majority of functionalities described in section 3.2. This node aggregates the information from all the managers, tries to resolve location conflicts and exports the results to a specific format. The Configuration module is similar to the manager, but in this case, the loading of map data is not done to a single file but several (and probably all). Thus, the implementation of this component is based on the iteration of a given folder, to read and load all corresponding maps into memory.

The Aggregator updater was not implemented accordingly to the architecture since the UMP Server was not yet been implemented. Instead, the aggregator exports the current state of global location data into files so they can be post-processed. The aggregator exports data into two different files: a people counter file and a people location file. The prior is mainly organized by time per area and the later by people location over time. These files can be processed for instance to generate statistical graphics, analyse movement patterns, or to create an animated representation of the movements over time.

### 4.5 UMP Server

In order to simplify the implementation of the whole project and give emphasis to the other components, we did not implement the UMP Server during the period of this thesis. However, it is possible to obtain the patterns of movement by post-processing the export files provided by the aggregator. With these files we can infer information like the entries and exit of people to a number of areas throughout the day, the percentage of people who walk the same path from one area to another, and others.

## 5 Conclusions

In this thesis, we have analyzed the state of the art in the areas of service discovery presenting standard protocols and pervasive environment protocols, researched methods for generic data acquisition and low-level sensor communication protocols, referred classification properties of localization systems, the main technologies and techniques used for people counting and tracking, and means of assessing user mobility patterns. We have designed and implemented a location system that is able to integrate multiple technologies through plugins, and detect people through the corresponding sensor technologies. The localization system uses a multi-functional monitoring platform so that it can benefit of the abstraction from the communication problems. We also integrated a service discovery module into this platform. This work provide the information about the location of people and their mobility patterns so that other projects may act accordingly for reducing energy consumption, i.e., adjust the air conditioning and lighting to the real occupation of the building.

## References

1. Ververidis, C., Polyzos, G.: Service discovery for mobile ad hoc networks: a survey of issues and techniques. Communications Surveys Tutorials, IEEE **10**(3) (2008) 30 –45
2. Campo, C., Munoz, M., Perea, J., Mann, A., Garcia-Rubio, C.: PDP and GSDL: a new service discovery middleware to support spontaneous interactions in pervasive systems. In: Pervasive Computing and Communications Workshops, 2005. PerCom 2005 Workshops. Third IEEE International Conference on, IEEE (2005) 178–182
3. Chakraborty, D., Joshi, A., Yesha, Y., Finin, T.: Toward distributed service discovery in pervasive computing environments. Mobile Computing, IEEE Transactions on **5**(2) (2006) 97 – 112
4. Ratsimor, O., Chakraborty, D., Joshi, A., Finin, T.: Allia: alliance-based service discovery for ad-hoc environments. In: Proceedings of the 2nd international workshop on Mobile commerce. WMC '02, New York, NY, USA, ACM (2002) 1–9
5. Motegi, S., Yoshihara, K., Horiuchi, H.: Service discovery for wireless ad hoc networks. In: Wireless Personal Multimedia Communications, 2002. The 5th International Symposium on. Volume 1. (2002) 232 – 236 vol.1
6. Honorato, J., Spiniak, I., Torres-Torriti, M.: Human detection using thermopiles. In: Robotic Symposium, 2008. LARS '08. IEEE Latin American. (2008) 151 –157
7. Linzmeier, D., Vogt, D., Prasanna, P.: Probabilistic signal interpretation methods for a thermopile pedestrian detection system. In: Intelligent Vehicles Symposium, 2005. Proceedings. IEEE. (2005) 12 – 17
8. Ni, L., Liu, Y., Lau, Y.C., Patil, A.: Landmarc: indoor location sensing using active rfid. In: Pervasive Computing and Communications, 2003. (PerCom 2003). Proceedings of the First IEEE International Conference on. (2003) 407 – 415
9. Dong, S.: Node Placement, Routing and Localization Algorithms for Heterogeneous Wireless Sensor Networks. (2008)
10. Hightower, J., Borriello, G.: Location systems for ubiquitous computing. Computer **34**(8) (August 2001) 57 –66
11. Vossiek, M., Wiebking, L., Gulden, P., Weighardt, J., Hoffmann, C.: Wireless local positioning - concepts, solutions, applications. In: Radio and Wireless Conference, 2003. RAWCON '03. Proceedings. (2003) 219 – 224
12. Ikonen, J., Porras, J.: Extracting and using position information in wlan networks
13. Zhou, S., Pollard, J.: Position measurement using bluetooth. Consumer Electronics, IEEE Transactions on **52**(2) (May 2006) 555 – 558
14. Pei, L., Chen, R., Liu, J., Tenhunen, T., Kuusniemi, H., Chen, Y.: Inquiry-based bluetooth indoor positioning via rssi probability distributions. In: Advances in Satellite and Space Communications (SPACOMM), 2010 Second International Conference on. (2010) 151 –156
15. Bandara, U., Hasegawa, M., Inoue, M., Morikawa, H., Aoyama, T.: Design and implementation of a bluetooth signal strength based location sensing system. In: Radio and Wireless Conference, 2004 IEEE. (2004) 319 – 322
16. Hallberg, J., Nilsson, M., Synnes, K.: Positioning with bluetooth. In: Telecommunications, 2003. ICT 2003. 10th International Conference on. Volume 2. (march 2003) 954 – 958 vol.2
17. Gonzalez-Castano, F., Garcia-Reinoso, J.: Bluetooth location networks. In: Global Telecommunications Conference, 2002. GLOBECOM '02. IEEE. Volume 1. (2002) 233 – 237 vol.1
18. Bertozzi, M., Broggi, A., Fascioli, A., Tibaldi, A., Chapuis, R., Chausse, F.: Pedestrian localization and tracking system with kalman filtering. In: Intelligent Vehicles Symposium, 2004 IEEE. (2004) 584 – 589
19. Lee, L., Romano, R., Stein, G.: Monitoring activities from multiple video streams: establishing a common coordinate frame. Transactions on Pattern Analysis and Machine Intelligence **22**(8) (2000) 758–767