

Real Time Location System over WiFi in a Healthcare Environment

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ABSTRACT

Objective: To establish a Real Time Location System (RTLS) using WiFi in a healthcare environment.

Design: Pilot study.

Setting: A home for the elderly in Belgium with 180 residents.

Methods: Any standard WiFi compliant network can be used. The main requirement is a minimum availability of 3 access points at any place where location of a person is required. The wireless network and its (usually) wired backbone can still be used for other purposes (file transfer, internet, e-mail, etc). Meetings were held with key stakeholders to identify their requirements. A commercial RTLS system (Ekahau) was customised to meet these requirements and installed to cover an area of 1800 square metres.

Results: The customised software took 5 months to develop and the system was installed and tested over a period of 2 days. The final system was capable of monitoring and logging the movement of patients, and receiving alerts in emergency situations. The cost to purchase and install the hardware was about 3500€. The costs of the licence for the RTLS system and the tags are related to the number of people to be tracked. To track 200 people it is approximately 35,000€.

Conclusion: We have successfully implemented a customised RTLS system using a WiFi network in a home for the elderly. The implementation is relatively easy and cheap in terms of the hardware required. Further studies are now planned to evaluate if the system can deliver benefits to patients and staff and also to determine its cost-effectiveness.

INTRODUCTION

The implementation of fully automated systems capable of monitoring or locating people or objects in real-time have many potential applications in healthcare. These include for example:

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- Emergency management – enabling more efficient and faster emergency responses
- Patient monitoring – enhancing patient safety
- Workflow management – improving staff utilisation
- Equipment management – reducing the need for inventory
- Information delivery – improving workflow, reducing errors

Real time location systems (RTLS) are more complex than RFID (Radiofrequency Identification) systems. A typical RTLS tag is battery-powered and communicates with not one but several different receiving devices. Each received message arrives at a slightly different time and at a different radiofrequency signal strength enabling the position of the tag to be calculated. RTLS can be combined with other wireless technologies e.g. WLAN (wireless local area network) and WiFi (Wireless Fidelity) networks, and this offers a number of different potential systems to exploit the benefits of RTLS. Before discussing the merits of individual potential systems, some of the key principles utilised in real time location systems should be understood.

Real time location systems are based on the presence of Access Points (APs) or Location Receivers that are able to detect tags and Wireless Fidelity (WiFi) devices in the surrounding area. Two different methods can be used for locating an object

- Time Difference on Arrival (TDoA)
- Received Signal Strength Indicator (RSSI)

TDoA calculates the position of an object by measuring the time taken from a packet being sent from a transmitting device to being received by a receiver. Using WiFi this means that a client sends out a time stamped signal which is received by the APs. From the difference in time between sending and receiving the signal, the distance between the AP and the client can be calculated. When 3 access points are used, by the principle of triangulation, it is possible to establish the location of a client to an accuracy of less than 5 metres.

For RSSI, the client device measures the signal strength of the access points and sends the values to a server. If at least 3 values are sent the server can reliably calculate the location of the client.

RSSI performs better in indoor walled environments, e.g. hospitals, while TDoA has advantages in unobstructed, outdoor environments, e.g. shipping yards. With TDoA the access points need to be specially designed to be able to measure the time difference. This makes TDoA a hardware based and thus relatively expensive solution. RSSI on the other hand is a software based, hardware independent solution, and costs are determined principally by the price of the software. RSSI can also be combined with “fingerprinting” – a technology where several positions are calibrated so the engine can refine its calculations within the triangulation area.

RTLS IN COMBINATION WITH OTHER TECHNOLOGIES

RTLS and Wireless Local Area Networks (WLAN) – The IEEE 802.11 standard was developed for high-speed data communications with the architecture designed to operate at data rates of a minimum of 1Mbps. Communication at these data rates over ranges of several metres requires approximately 100mW of power. As a consequence radios are normally installed in devices that have rechargeable batteries. In addition, locatable tags must remain operable for years in order to be maintenance free and cost effective. Consequently, the data rates of these tags are much slower, trading data rate for range, while still requiring only very low power transmissions from the tags.

RTLS and WiFi – A typical WiFi setup contains one or more Access Points (APs) and one or more clients. An AP broadcasts its SSID (Service Set Identifier, "Network name") via packets that are called beacons, which are usually broadcast every 100 ms. The beacons are transmitted at 1 Mbps, and are of relatively short duration. If there are 3 or more access points, WiFi can be used in combination with RTLS to locate an indoor object with an accuracy of 1-3 metres.

RTLS and Global Positioning Systems (GPS) – Global Positioning Systems, or GPS, is a type of RTLS technology that has demonstrated its value in vehicle tracking. However GPS is not appropriate technology for tracking several hundred tags in a fixed space, especially indoors, as GPS signals are not designed to penetrate buildings.

RTLS and Ultrawide Band (UWB) – The term "ultrawide band" refers to the development, transmission and reception of extremely short duration bursts of radio frequency energy – typically ranging from a few hundred picoseconds (trillionths of a second) to a few nanoseconds (billionths of a second) in duration. UWB technology supports read ranges in excess of 200 metres, resolution and accuracies of better than 30 cm, battery lifetimes in excess of 5 years, fewer tag components and micro-miniature tag sizes. When combined with RTLS applications, UWB can provide good performance and robust operation in severe multi-path environments, e.g. office buildings or hospitals. Multi-path, or "multi-path cancellation" occurs when a strong reflected wave, e.g., off a wall, file cabinet, ceiling, vehicle, building, etc., arrives partially or totally out of phase with the direct path signal, causing a reduced amplitude response at the receiver. With very short pulses, the direct path has essentially come and gone before the reflected path arrives and no cancellation occurs. UWB systems are approved for unlicensed use within the United States. European regulators are currently considering the authorisation of UWB-based RFID and RTLS systems within the 6.0-9.0 GHz range.

When RTLS is used in a good environment (low interference, low levels of disturbing signals), accuracy from 1 to 3 metres can be obtained. For most applications this is sufficient. The range on which the application works is about 100 metres in an open space and inevitably less in a building. When the access points are intelligently placed the covered area is theoretically unlimited. The only requirement is that every spot in the covered area is covered by at least 3 access points, and that one of the APs has a network connection to the Engine.

One of the biggest RTLS vendors is Ekahau¹ who offer a RSSI-fingerprinting based, stand-alone RTLS solution for asset and people tracking. The Ekahau system is capable of continually monitoring and reporting the real-time locations of tracked resources. Its proprietary location determining technology, Ekahau Position Engine 3.1, is capable of achieving location accuracies of up to 1 metre.

Unlike competing solutions, which are based on Time Difference on Arrival (TDoA) technology, Bluetooth or active RFID, and therefore require deployment of costly RF antennas or receivers, Ekahau's patented RF modelling technology leverages standard WiFi access points, so no proprietary infrastructure is needed. By using standard 802.11 access points and WiFi tags, any WiFi network can be used as the backbone and sensor network for a real-time location system. This quickly translates into faster deployment and improved cost-effectiveness.

We have chosen to use the system provided by Ekahau for a number of reasons:

- (i) Its ability to be implemented with WiFi is highly suitable to our needs and its software engine is able to provide relatively accurate location.
- (ii) The cost of the system is cheaper than a hardware based system.
- (iii) The system can be adapted and customised as the Software Development Kit is in the Java environment. This provides a way of communicating with the software engine, with end users building their own application using the Ekahau engine. The main advantage of this is that the user application is only limited by the programmer's imagination or the needs of the end user. It is also possible for end users to communicate using their own applications with the Ekahau engine, via Telnet. This is a common way to remotely control Web servers. Telnet is a terminal emulation program for TCP/IP (Transmission Control Protocol/Internet Protocol) networks such as the Internet. The Telnet program runs on a personal computer (PC) and connects it to a server on the network. Commands can be entered through the Telnet program and will be executed as if they were entered directly on the server console. This makes it possible for end users to use other development environments to build their own applications.

METHODS

A home for the elderly in Antwerp was chosen to implement the RTLS. The home has 180 residents and over 100 staff during the day but only 4 carers at night.

Meetings were held with key stakeholders to identify their key requirements from the system. These included:

- Logging all location histories.
- The availability of a user-friendly program to query the logged histories and extract specific statistics (e.g. measure the activity of individual patients).
- The ability for patients to notify staff in an emergency and for staff to be able to quickly and clearly identify which patient had triggered the alarm and his or her location.
- The availability of a real time view of patients and staff current locations so that any patient or staff member can easily be found at any time.
- A program to easily configure the tags.

The Ekahau software is designed to run on a Windows platform and consequently a Windows Service was built with the capability of meeting the first requirement. The service links to a library that saves all the data provided by the Ekahau Engine. Four main types of data are saved:

- Location – an absolute position
- Area estimate – an area where a person is located
- A device property change, e.g. a battery change or a status change as when the device triggers an alarm
- Addition or removal of a device from the network

The database model simply maps these four different types of captured data to individual but normalised tables.

The way the network is built is not different from any other TCP/IP network, but there are some extra rules that need to be followed. For example it is necessary to ensure the availability of three access points for each area in which a person may need to be located. This requirement is more of a practical matter (where to place the access points) than a network matter. A key difficulty is making sure that the access points don't interfere with each other and 'neutralise' each other's signals. To prevent this it is important to ensure that the channel space between the overlapping access points is 4 channels or more². When this requirement is met, the system should work properly. The network should also be built taking into consideration other applications that it will be used for. The Ekahau solution is able to co-exist along with other network applications such as Internet access, network sharing, VoIP (Voice over Internet Protocol) and other network applications.

Linksys access points were chosen to work with due to their high fidelity, large range, easy configuration and maintenance features. The configuration software provided by Ekahau is designed to run on a Windows platform and the host in the network on which the Ekahau engine runs is a Windows 2003 server. Besides running the solution, the other tasks it has to do are:

- Run a DHCP (Dynamic Host Configuration Protocol) server, so every host in the network can obtain an IP-address.

- Run a Microsoft SQL (Structured Query Language) Express server, which is a database engine. This database application is used by the log service to store all the gathered data.
- Run a Log Service (developed by the University College of Antwerp) which makes it possible to analyse the location data at any time.
- Enable VPN (Virtual Private Network) so that control and communication with the network are possible from external locations.

To customise the application C# (from Microsoft's Visual studio IDE 2005) and the .Net framework were chosen as the development language³. The primary reasons for choosing these were the ease with which server related applications can be written, resulting in fast development. Other toolsets used in the development consisted of NUnit⁴ an automated unit testing framework, nPerf⁵ a class performance comparison tool and nProf⁶ a program instance profiling tool. Besides the .Net framework the nPlot⁷ library was used for all graphical needs. This library is an open-source project without commercial restraints.

The Ekahau development kit contains several tools to assist users in implementing and testing the solution. A manager application tool is provided to control and to 'learn' about the engine, including fingerprinted⁸ positions. The development kit contains a set of 3 tags, which can be used as clients for testing the accuracy of the system in locating people/objects.

A map of the area in the care home that the RTLS was required to locate/track people was loaded into the engine (Figure 1), and the system was fine tuned

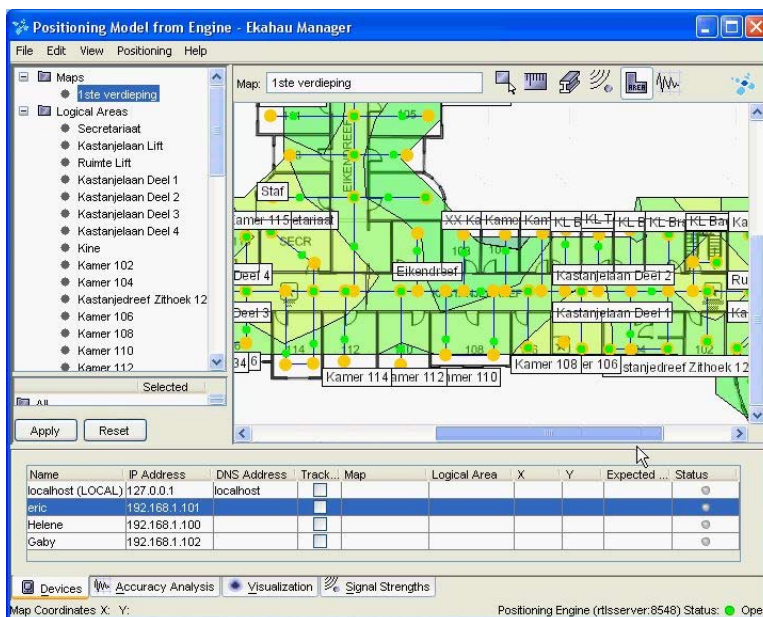


Figure 1. Ekahau Manager

(fingerprinted) to increase the accuracy of locating people. This was done by a person carrying a tag standing on a place that needed to be calibrated, and informing the engine to calibrate this spot. This process is fairly time-consuming because every spot that needs to be calibrated takes about 10 seconds. However the accuracy of the system increases with more calibrated spots.

The manager is also used for setting the map scale. This scale is expressed in pixels per metre and is done by the user drawing a line on the map for which he knows the distance in metres. In this manner, the engine is able to determine distances between points. The screenshot in Figure 1 shows the list of visible areas in the home that the RTLS system can locate a person. These areas are the so-called 'logical areas'. When the engine is tracing people, it produces several types of results. One of these results is the logical area in which a person is. This information is very useful in this pilot project, because at this initial stage it is more important to know in which room or area a patient is, than to know exactly how many metres he or she has moved during the day.

The other output information from the server is the coordinates on the map. For each tag an X and Y coordinate are calculated. The values of these coordinates are presented in the upper left corner of the map and are used to indicate a tagged person on the map. The engine also provides an estimation of the expected error of this coordinate. All the information the engine provides is available via Telnet communication with the engine, and is thus available on any local networked PC.

To make sure the final solution would work, profound testing was conducted after each implementation stage. If initial tests were not satisfactory the system (solution) was modified until we were happy that it would provide good working and accurate location. This included performing tests after setting up the network to ensure that a network connection was available at each desired spot.

As a second test, which was often combined with the first test, we checked to ensure there were at least 3 access points available at each point we wished to track (Figure 2). If not, the position of the access points had to be adjusted until optimal spreading was achieved. This process was very much trial-and-error, because it is very hard to predict what the influence of the environment (walls, elevators, windows, etc.) will be on the signal strength (Figure 2). The process did however gave us valuable experience for estimating the time and costs required for future implementation projects. This information may potentially be extrapolated to larger areas or other environments.

As mentioned earlier one of the requirements stipulated by stakeholders was the ability for patients to notify staff in the event of an emergency from anywhere in the home and at anytime. To be able to track a person, at all times the WiFi-tag has to be attached to the person and this can be done conveniently in the form of a wrist attachment. The tag contains all the necessary equipment needed to communicate with the WLAN infrastructure, and measure signal strengths. To enable a patient to notify staff in the event of an emergency situation, the tag incorporates

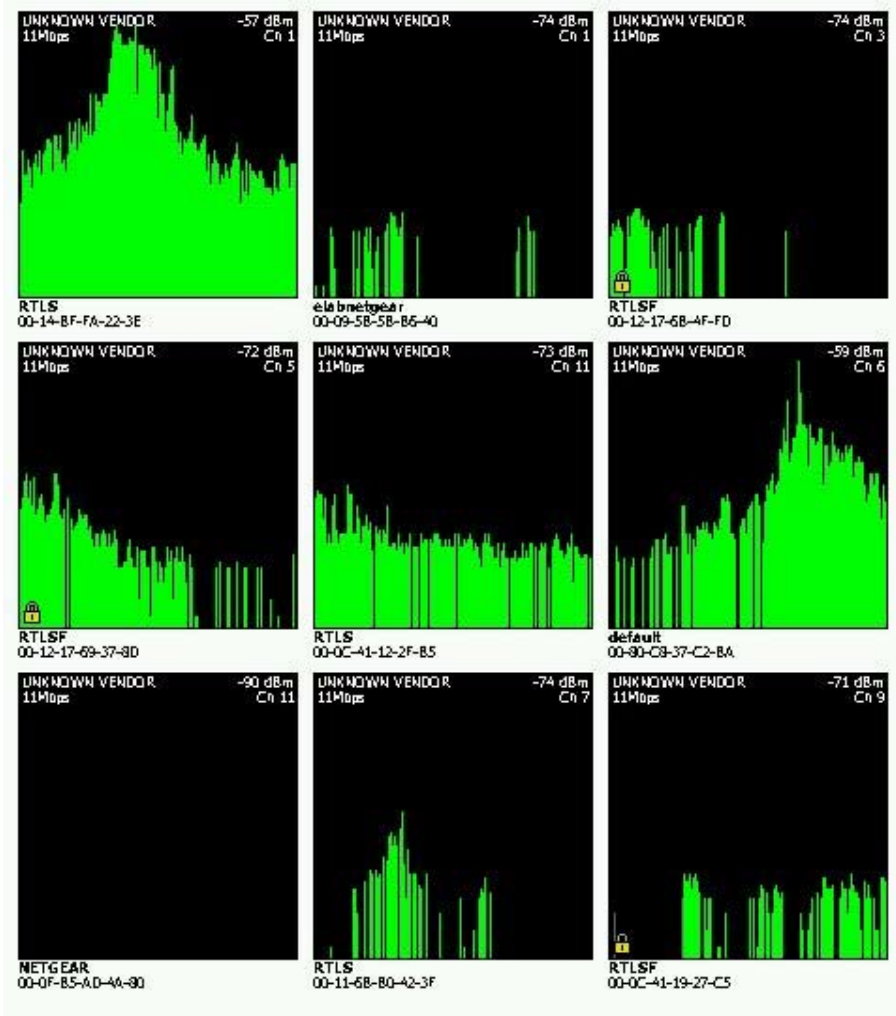


Figure 2. *Measured Signal Strengths*

The bottom row indicates that only 2 access points receive signals and therefore the third access point needs to be repositioned or an additional access point inserted to allow the RTLS to function.

a red emergency button (Figure 3). When this button is pressed, the tag immediately sends its received signal strengths, together with a signal indicating that the user is in need of urgent assistance. The engine will then process this emergency signal, and an appropriate response (depending on the application) will be initiated.

For the Alert or notification application a Windows system tray application, (a system tray application is an application that shows an icon in the system tray i.e. the bar on the bottom right hand corner of a standard Windows screen), was developed. This invokes balloon tips or dialogs to notify the user of a changed situation.



Figure 3. *Ekahau Tag*

The dimensions of the tag are approximately 5cm by 5cm by 2cm.

The System tray warning contains sufficient information to identify and locate the person who pressed the button.

Another feature of the tag is a LED (light emitting diode) which flashes to indicate when there is an abnormal tag status, e.g. no communication between the tag and the server, or the tag battery needs to be replaced. The life of the battery depends on its use and its configuration. The tag can be programmed to run in a variety of modes. For example in 'calibration-mode' the tag transmits the RSSI-information it collects every 2 seconds. Other configuration modes allow the tag to only transmit RSSI-information every ten minutes, or any other custom time interval. It is also possible for a tag only to transmit RSSI-information when it is in motion by incorporating a motion detector in the tag. The battery consumption of the tag is directly related to its configuration. In these three examples, the first is obviously the most power-consuming. The second and the third examples use less power as they communicate less frequently with the server. Different types of tags can be provided depending on expected use, e.g. tags requiring long operation times may have a battery with a large capacity, or tags may be in the shape of a wristwatch, so a person can easily wear them.

The tags can also be configured in a variety of ways. For example, the tag can be configured to make a sound when the button is pressed, or the time it takes to go into standby after activation can be adjusted. By tweaking these settings in an intelligent manner, the tags can be optimised for individual applications. For example if a person spends most of their day sitting in a chair it is not sensible for the tag to transmit the patient's location every 30 seconds. A more practical option would be for the tag to only send data when the person moves. This can be achieved by incorporating a motion detector in the tag.

A program was written to create a tool to automatically configure the Ekahau tags. This application allows tag configurations to easily be created, locally stored,

backed up, restored and extended through custom properties. To make the binding between a person and a tag less error prone the configuration of the tag can be done based on an e-ID. When an e-ID is entered in the reader and the tag is connected to the computer, the tool will automatically configure the tag with the information of the person.

Since the log viewer and the real time tracking viewer show the same information, i.e. people on a map, it is preferable to use one application to incorporate both functionalities. When using the Log view mode, tracked entries can be viewed for all or individual tags. The application makes it possible to replay the route taken by individual people and also include the positions where they pressed the alert button. In addition to this visual representation an important requirement was the ability to generate a value or figure to represent the activity of individual patients or group of patients. This can be measured in two ways using the data that is automatically recorded:

- A distance calculation based on area estimates. The calculation is based on the distance travelled by logging the sequence of areas that are passed. To make this possible an arbitrary distance needs to be assigned to each area.

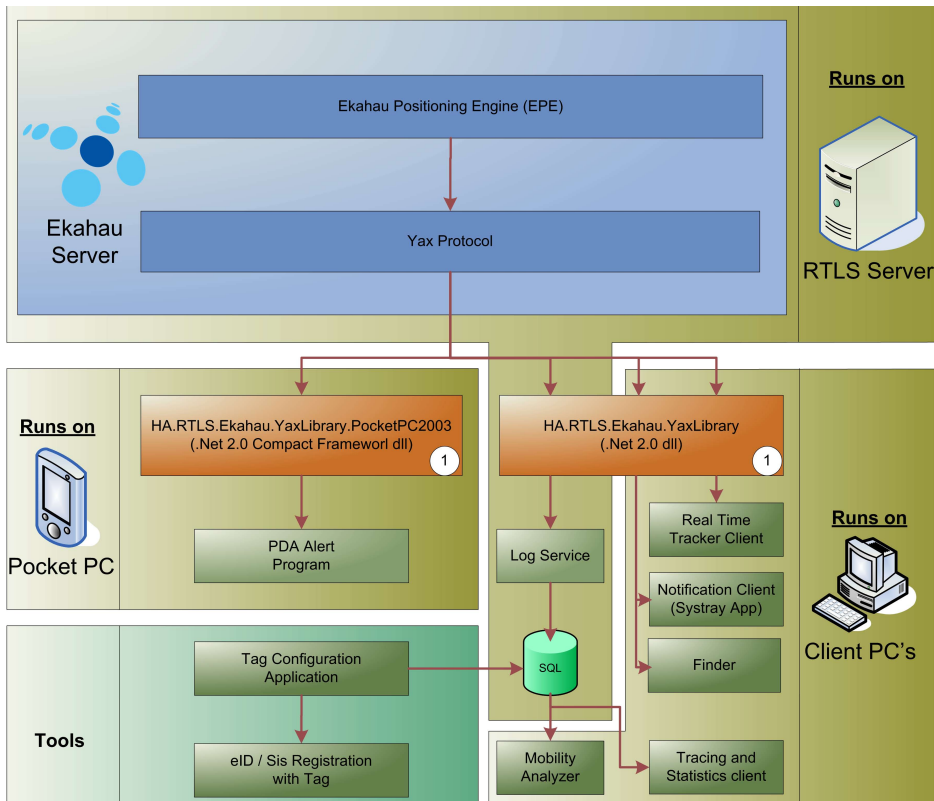


Figure 4. Ekahau architecture

- A distance calculation based on the location coordinates. The major problem with this method is the potential for errors to arise due to the nature of the location system. This uses signal strength positions and statistical algorithms on a collection of different samples to calculate a position. However these calculations have a small error which may be within a 3 metre radius from the actual position. As a consequence it is theoretically possible for calculations to show that a person has moved several metres over a few minutes or hours when in reality they have been standing still.

Figure 4 shows the architecture of the Ekahau system. This includes a library that handles all the trivial communication with the Ekahau platform. This library makes it easy to write any further applications. The core of the library is a method factory⁹. This factory returns an object that corresponds with a received text message from the Ekahau Server. This conversion is achieved by means of a parser¹⁰.

RESULTS

Implementation of the system consisted of 2 components – installation of the hardware and development of the customised software. Development of the software took approximately 5 months. Installation of the hardware and testing took place in February 2006 and was completed within 2 days.

For the database engine Microsoft SQL-Express was chosen for its integration with the .Net framework and support by the development tools¹¹. The biggest restriction and future problem with this product is the 4GB Database limitation. Analysis of the database gives the following projected table growths and sizes:

- AreaEstimate table – growth size of 44 bytes per row and growth of 23 rows per day.
- TagActivity – growth size of 36 bytes per row and growth of 6 rows per day.
- TagProperties table – growth size of 232 bytes per row and growth of 5285 rows per day.
- Location table – growth size of 96 bytes per row and growth of 47 rows per day.

These estimates give a total Database growth of 6.56 MB per day or 2.4GB per year. At this rate the database will take 624 days or approximately 1 year and 8 months to reach capacity.

The first Parser implementation was based on regular expressions¹² a widely used, powerful native language included in the .Net framework. However, during operation, we noticed a big performance impact when the connection was lost during a message-receive event. Tests that reproduced this situation showed that the regular expression needed a lot of time when parsing incomplete messages. To address this problem we developed a custom parser. This is illustrated in Figure 5 where the red dotted line shows the performance of the regular expression parser algorithm compared to the custom parser (the blue solid line), the custom parser outperforms

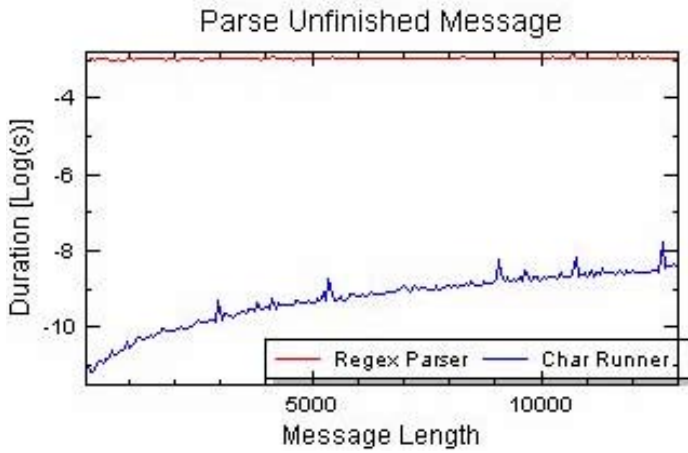


Figure 5. Parsing message loop

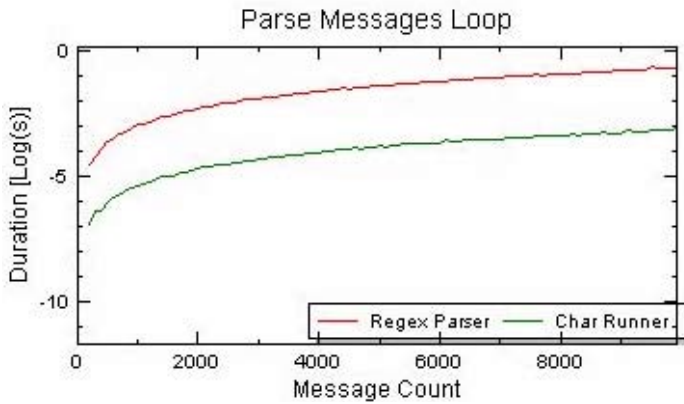


Figure 6 : Parsing messages with different lengths

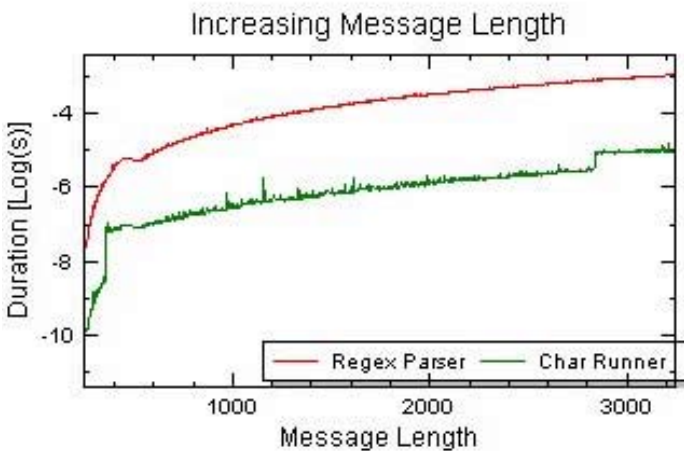


Figure 7 : Parsing unfinished messages

the regular expression parser when parsing unfinished messages. Besides handling unfinished messages, the time to handle n-messages in loop and the time to handle one message of variable length were examined. The results in Figures 6 and 7 show a clear improvement. The improved parser represented by the green line shows better performance than the regular expression parser (red line).

The cost of the solution is determined by two main factors:

- The surface area over which people need to be tracked.
- The number of people to track. This relates to the costs of the Ekahau software license and the number of tags that need to be purchased.

The actual floor area to be covered in the home is approximately 1800 m² and each access point can cover an area of 690 m². However the area is not rectangular or square, but T shaped. Taking this shape into consideration and the requirement for all areas to be covered by at least 3 access points, we calculated that the effective area to be covered was just under 4000 m². This required a total of 8 access points and 2 switches as one switch is required for every 4 access points. The cost of the server is approximately 1500€, the Windows Server 2003 license is 450€, and the costs for installing the system was approximately 250€. The cost for calibrating the system, using fingerprinting, although manually intensive, was approximately 130€ and had little impact on the total cost of the installation (Figure 8). The time and costs of customising the software also need to be taken into consideration. These will inevitably be related to the degree of customisation required.

The cost with respect to the number of people that the system is required to track is primarily determined by Ekahau's pricing policy (Figure 9). The licence to track 200 people is approximately 25,000€. The cost of the tags are volume related – the

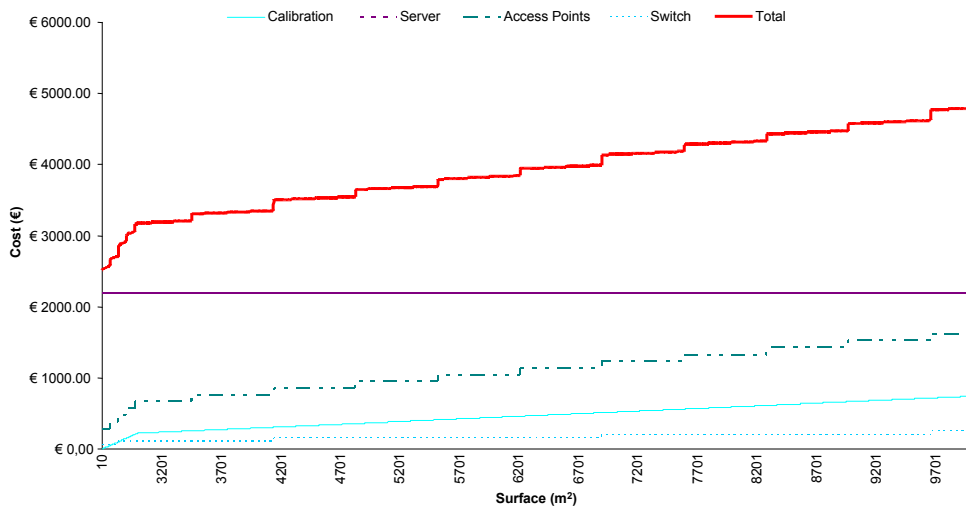


Figure 8. Cost calculation

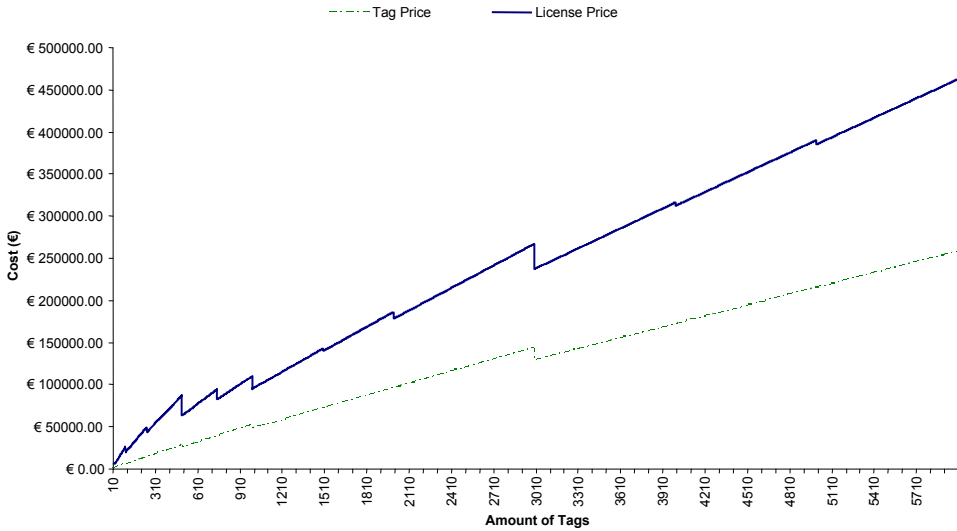


Figure 9. Ekahau licence and tag prices

first 99 tags cost 74€ per tag, but for 100 or more tags the price falls to 57€. This information is only provided as an indication. Anybody interested in implementing an Ekahau RTLS should obtain accurate and up to date pricing directly from the company.

DISCUSSION

In this pilot project we have implemented an RTLS system in a home for the elderly in Antwerp. The system provides real-time location of all patients and staff and also stores data for subsequent analysis. A key features of the system is its ability to be customised to meet individual requirements

The costs of the major hardware and server licence was less than 3500€ and the system only took 2 days to install and test. The costs of the tags and the Ekahau licence are related to the number of people that need to be tracked. For 200 people this will be approximately 35,000€. In addition to these the time and costs associated with customising the software must also be taken into consideration. These inevitably will depend on the degree of customisation required.

The system was customised to meet the key requirements stipulated by stakeholders. These included:

- The availability of a user-friendly program to query the history and extract specific statistics (e.g. measure the activity of patients).
- The ability for patients to notify staff in an emergency and for staff to then be able to quickly and clearly identify which patient had triggered the alarm and his or her location.

- The availability of a real time view of the locations of patients and staff so that any patient or staff member can easily be found at any time.

These functionalities could be beneficial in a number of ways. For example the system could be used to monitor the activity of someone returning to the home after a hospital stay to ensure that they perform the daily activities specified by a physiotherapist. It could also be used to query the history and extract specific statistics to monitor the daily activity of patients with knee and hip osteoarthritis. This is desirable as there is evidence that those who perform physical activity achieve improvements in pain, disability and functionality¹³. The system could also be programmed to detect and notify staff of changes in a patient's daily activity as this may be an early sign of an unrecognised illness. The alarm button can obviously be used by patients to notify staff when they feel suddenly unwell. The alert function can also be combined with the real time monitoring function to notify staff when patients are in potentially unsafe situations. An example of this would be to warn staff when a patient is leaving an area of safety. This can occur fairly commonly in the home as many of the residents suffer from Alzheimers or some other form of dementia. It can also be used to alert staff if a patient remains too long in an area, for example if a patient collapses in the bathroom and fails to press the alert button.

It is possible that some of the features although designed to improve efficiency and response times may in fact be counter productive. For example it is possible that a confused patient may unintentionally press the alarm button or deliberately press it on several occasions because it elicits 'a response'. It may consequently be necessary to inactivate the alarm feature on some tags or provide specific patients with tags without an alarm button. Inevitably any benefits that can be obtained from the system, potential drawbacks and ways to optimise use of the system must be obtained by formal studies and experience of using the system. These are planned for the future.

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