Abstract—An often heard critique on the use of ICT in a heritage context is the individualized nature of the experience. Group communication is an important aspect within a cultural experience, because it can encourage participants to interact with one another and to stimulate each other. Another aspect of great importance is the blending in of the virtual and the real achieved by using context-based information to provide relevant information and services to the user. Nowadays, there is no square and ready solution for the transferring of context information and visitor-related data. There is a clear need for a high-level network architecture, reusable for the mobile opening up of historical heritage locations. In this paper we present such an architecture, which will be mapped to a specific heritage site. We also focus on the location info collection of the users, which makes it possible to create location-aware services. Therefore, we implemented and evaluated a location determination system containing three algorithm classes which use receiver signal strength information to infer locations.

Keywords: mobile location-based services, wireless networks, context awareness, cultural heritage

1. Introduction

The mobile revolution has changed the way people experience cultural heritage and how they communicate with each other. We saw an evolution from interpretative panels or markers to an environment where visitors equipped with a mobile device receive unobtrusive, location-specific multimedia content. Intelligent services can provide content that is automatically triggered, on the visitor’s position on the site, allowing them to understand and appreciate better what actually happened. Furthermore, automatic filtering of content could also be improved on the basis of the user known interests by usage of an user profile.

The stipulation of the most optimal network configuration to transfer heritage content and context information is not evident because of the sometimes exceptional conditions on the historical sites (e.g. big concrete walls, old buildings). Moreover, each network technology has a set of constraints and characteristics like maximum bandwidth, minimum delay, interoperability, maximum range, required number of devices to realize a certain topology, cost and inherent possibility of location determination.

Incorporating context information in existing or new applications and services could greatly improve the user experience. Location information can be considered as the core component of user context while at the same time provides opportunities for user location registration and tracking. Determining the location of a mobile device is a fundamental problem in mobile computing.

Nowadays, ongoing research (see section 3) resulted in a wide variety of location determination techniques. Examples include GPS [1], wide-area cellular-based systems [2], infrared-based systems [3], computer vision systems [4], physical proximity systems [5] and radio frequency (RF) based systems [6]. Because each approach solves a slightly different problem or supports different applications, they vary in many parameters, such as the physical phenomena used to determine the location, the required infrastructure and portable elements, accuracy, cost and precision of the positioning.

In this paper we present the research results of the Heritage 2.0 project [7]. Firstly, we present a high-level network architecture usable to pass location-based information within the context of heritage sites (see section 2). We use this architecture to create a network configuration for a specific site. In section 3, we provide a brief overview of existing localization techniques. Section 4 describes the use case developed in the context of the project. Next, section 5 gives an overview of the architecture and implementation of the developed prototype. An evaluation was done of the implemented location determination system, some results are presented in section 6. Finally, in section 7 future work is stated, section 8 concludes this paper.

2. Network Architecture

Figure 1 presents the designed network architecture which is partly based on the work performed in the IBBT Wireless Building Automation project [8]. In this section we will discuss each of the different layers.

Ethernet Backbone Network Interconnects various pieces of the network, providing a path for the exchange of information between different LANs or subnetworks. It ties together diverse networks in the same building, in different buildings, or over wide areas.

Wireless Mesh Network Consists of mesh clients and mesh routers. Mesh routers form a wireless infrastruc-
ture/backbone and interwork with the wired networks to provide multihop wireless connectivity to the mesh clients. Different from traditional wireless networks, wireless mesh networks are dynamically self-organizing and self-configuring. In other words, the nodes in the mesh network automatically establish and maintain network connectivity. The gateway and bridge functionalities in mesh routers enable the integration of wireless mesh networks with various existing wireless networks, such as wireless sensor networks, wireless-fidelity (Wi-Fi) and WiMAX.

**Wireless LAN** Uses radio waves to enable communication between devices in a limited area. Wireless LANs complement existing fixed networks by providing mobility to users, but they are not able to completely replace the wired technology. Unlike wired networks, the physical medium is much more dynamic. Radio waves bounce off objects, penetrate through walls, and can suffer from a number of propagation problems that may interrupt the radio link. Furthermore, radio waves tend to travel outside their intended location, there is no abrupt physical boundary of the network medium.

**Mobile Ad Hoc Network** Consists of a collection of wireless mobile nodes (or routers) dynamically forming a temporary network without the use of any existing network infrastructure or centralized administration. The control and management of the mobile ad-hoc network is distributed among the participating nodes. Each node has the responsibility to forward packets to other nodes in the network. The nodes also collaboratively implement network routine functions such as security and are free to move randomly and organize themselves arbitrarily.

Using this architecture, we have done a mapping to a pre-defined heritage site which is shown in Figure 2.

Based on the use case presented in section 4, we identified a number of points where location and historical information should be available to the user. Because of the high amount of data and potential users we choose for the installation of a wired backbone as close as possible to these information points both indoor as outdoor. A number of wireless mesh nodes is connected to this wired network acting as gateways to the different wireless mesh networks.

3. **Localization**

Today, the Global Positioning System (GPS) has been used in many commercial applications, but unfortunately is not usable indoor due to the lack of indoor satellite coverage. Other technologies exist like Radio Frequency Identification (RFID) or WLAN based localization, but all have their disadvantages, which makes them only suitable in certain applications. This section gives an overview of the necessary requirements that have to be considered during the selection of the location determination techniques. Next, a short overview is given of existing technologies that were considered for retrieving location information in our use case. This section concludes with a motivation and overview of the selected technique.

3.1 **Requirements**

The location determination system can be implemented on a *centralized* server or for the most part on the mobile devices. A centralized implementation has the advantage of reducing the computational demand on the mobile device. Furthermore, because the location system will serve mobile users, it is important the system doesn’t impose high computational requirements on these mobile devices which are energy-constrained.

The main goal of the location determination system is to achieve a *high positioning accuracy*. Although the de-
sired accuracy is dependent on the application in use, the higher the accuracy, the wider the range of applications it can support. The desired accuracy is approximately one meter, especially for location-based services such as getting information at points of interest in the surroundings of the end user.

The system should be scalable, it must support a large number of users, be applicable in large areas and in the best case both indoor and outdoor. Extensibility is also an important requirement; the platform should not be restricted to one positioning technique. It must be possible to extend it with other localization systems.

Cost is an important factor; expensive dedicated hardware should be avoided as much as possible because it often puts a restriction on the scalability. A system which is interoperable with the existing infrastructure is the most preferable.

Finally, the system should be easy to use for the end user. In the best case, no user interaction should be needed for locating a user. If interaction is needed, it should be as easy as possible.

3.2 Location determination techniques

Global Positioning System (GPS) currently poses the most commonly and accurate means of outdoor location determination generally available. GPS-signals depend on a direct line of sight to the satellites and therefore cannot be received within buildings.

Determining location in ad-hoc networks as described in [5] has been an active area of research. In the 802.11 ad-hoc mode, location determination systems cannot assume any pre-processing of the environment. Received radio signal strength information (RSSI) is used to estimate the distance. Tagged people and objects inside the room can then be located relative to one another or absolutely if the fixed tags are configured to know their absolute location. Exchange of measurement history allows any node to quickly aggregate a global view needed to perform location calculations.

CyberCode [9] is a visual tagging system used to make a link between physical and digital spaces. Inexpensive low-resolution CCD cameras are used as sensors for 2-dimensional visual codes. These codes [10] can be printed on paper documents, displayed on electronic screens, or attached to physical objects. Once the ID embedded in the barcode is decoded, the mobile device can easily retrieve all data relating to the object by accessing a database. When these 2D-barcodes have a known location or when the location is embedded in the tag, the user can infer its own location. This is a very accurate positioning technique; the accuracy is approximately 1 meter.

RFID can be used to attach information to objects or persons as described in [11]. When a reader detects a tag it will map the received unique ID to information. When either the reader or tag has a known location, one can use the system for location determination similar to the 2D barcode approach. Accuracy of this technique depends on the type of RFID.

The proximity principle is the easiest method. The client will look for the unique address of a communicating device in range and use this address as a key to lookup the position in a database. The server for this database can run locally or on a different computer in the network. If the position is known, the client will be in a maximum range of 10 meters (class 3) from the communication device. If more than one position is collected, triangulation is done in order to get a more accurate position.

Location determination can also be done using a radio propagation model, which describes the relationship between the signal strength and the distance. This model indicates that the received signal power decreases logarithmically with the distance. This relationship exists for both outdoor and indoor conditions. With the model, the objects position can be determined using a standard triangulation algorithm. If signal levels from three different base stations are known, the location of the mobile device can be approximated as the unique intersection point of the three circles. In the next section, we give an overview of the WLAN determination technique using a radio map.

3.3 WLAN Based Localization

Wireless LAN based location determination systems gained attention the last years ([12] and [13]), especially for indoor applications ([14] and [15]). RF-based systems use the underlying wireless data network, which is often already present in indoor environments, for user location determination. However, using a wireless network for location determination has the challenge of dealing with the noisy characteristics of the wireless channel.

These signal strength based techniques are purely software based, having the advantage of no extra hardware cost. They can be categorized into model based techniques (see subsection 3.2) and radio-map based techniques. Model based techniques use an empirical model (modelling signal strength loss over space) to determine the distance from a wireless device to an access point. This approach suffers from the noisy characteristics of the indoor wireless channel. Therefore, capturing the relation between the signal strength and distance is very difficult. The radio-map based (or fingerprinting) technique uses a different approach, which tries to capture the signature of the access points at selected locations in the area of interest. The system works in two phases. In the offline phase a radio map is built which stores the distribution of the signal strengths received from each access point at each location. During the online phase the user location is estimated based on the received signal strengths from each access point and the radio map. The disadvantages of this approach are the database generation and maintenance requirements.
We used this localization technique in our use case (as described in section 4) for locating people, both indoor as outdoor [16]. The main reason we choose for this technique, is that it uses the underlying wireless data network and requires no additional hardware cost.

The usage of a radio map is more accurate than using a propagation model, therefore we only considered that approach. The implemented algorithms which are outlined throughout section 5 are all based on this principle. In the context of cultural heritage sites it is not always feasible (because of cost and installation efforts) to deploy an outdoor WLAN network. For this reason, we propose the switching to GPS-based localization where no accurate positioning is possible using Wi-Fi.

4. Use Case

The use case we present in this paper is the usage of handheld devices (e.g. PDA) in the context of cultural heritage. First of all, visitors should be able to browse information at their own pace, according to their own interests. Change of location during the visit triggers the mobile guide, presenting artefact information (e.g. attention drawn to surrounding objects) according to the appropriate context. The mobile guide should also fulfill an important role of social interaction. By using Voice-over-IP, visitors can communicate directly regardless their locations without the need of an extra device like a GSM. Furthermore, collaborative games should be possible. Imagine a scenario where every player is dependent on the concrete actions of other players; and only through cooperation and correct interpretation of location-based content they can come to a good end.

Localization plays an important role in this use case, therefore we focus in the remainder of this paper on the platform allowing to create context-aware applications.

A client-server architecture was chosen to obtain location data, which is illustrated in Figure 3.

![Fig. 3: Illustration of the client-server approach for obtaining position fixes.](image)

The client periodically pushes data (signal strength readings) to the location server. The server estimates the users location and updates the profile of the client. Next, the determined location is returned to the client which can also be obtained by another mobile station at a later time. This approach has the advantage that the locations are centrally available for all users. Furthermore, because the server has more power and less computational restrictions it is more suitable to perform the calculations centrally than on the mobile devices.

5. Implementation Details

5.1 Location Server

Figure 4 presents an overview of the architecture of the location server. In this subsection we will discuss each of the components.

![Fig. 4: Overview of the architecture of location server.](image)

**Persistence layer** A MySQL database was used as persistence. This database stores the radio map, static user info (e.g. login info) and building information (such as geocoordinates of the rooms and walls).

**Web Service layer** A web service was used through which the client can communicate with the server. It allows a user to obtain locations, provide signal measurements and register itself with a certain location service. The communication is done using the SOAP standard and messages are using the XML format.

**WiFi Location Service layer** Consists of different location services each implementing a certain algorithm. Each service is deployed as OSGi bundle [17] and provides context information for the existing Context Aware Service Platform (CASP) [18]. In the context of the use case, we implemented and evaluated several types of algorithms, they can be divided in three classes and are described in subsection 5.2.

**Context Framework Layer** Each layer in CASP is designed in a modular way with a limited number of dependencies. The framework uses an application life cycle model and service registry, in this way components can be deployed, removed or replaced at run-time. Components can
discover each other during normal operation without the need to restart the entire platform. The context framework consists of the following services:

- Context provider service: This context gathering layer takes care of the acquisition of specific context information.
- Context interpreter: This component is responsible for the aggregation of the context information according to a formal context model and the derivation of implicit information by reasoning.
- Query service: When a service needs information related to several kinds of context information, a complex query has to be executed on the knowledge base. This layer helps to map various application needs of context information into the underlying corresponding context queries.

OSGi (Open Services Gateway initiative) [17] was used as implementation technology. The OSGi specifies an open low-footprint platform for the delivery and management of services. Software components also known as bundles can be installed, removed, updated or removed on the fly from any local or remote location. This platform is very suitable in this use case, because it makes it possible to provide additional location services in an easy way.

5.2 Algorithm Description

We implemented and evaluated three classes of WLAN location determination algorithms. A brief overview is given in this subsection.

**Deterministic algorithms** Four basic deterministic algorithms were implemented: the average, maximum, median and highest frequency matching algorithm. The algorithms are very similar. During the offline phase, the received signal strengths of each access point at each location are recorded. Next, the average, maximum, median and the one with the highest frequency are selected and stored in separate database tables. During the online phase, the RF signal strengths are compared with the values of the corresponding database tables and the closest match is returned as the most probable location.

**Probabilistic clustering algorithms** Probabilistic algorithms store information about the signal strength distributions from the access points in the radio map and use probabilistic techniques to estimate the user location. The implemented algorithms are based on the Horus system [19]. During the offline phase, the Horus system estimates the signal strength histogram for each access point at each location. The parametric distribution that fits the signal strengths received from a single access point has the following probability density function:

$$ P(x) = \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} $$  

where $\mu$ and $\sigma$ are the mean and standard deviation of the distribution respectively. These values are stored in the radio map. Two algorithms were implemented based on this principle. The average Gaussian distribution matching algorithm searches for matches according to the average values of the recorded histograms. The frequency table based Gaussian distribution algorithm tries to find matches according to the highest frequency signal strength values. These algorithms were improved using clustering [20]. Clustering of radio map locations is an approach to reduce the computational requirements of the location determination algorithms, because a match is calculated for only a small subset (a cluster) instead of the full set of positions. The principle of the implemented clustering algorithms is as follows:

- **Joint Clustering** considers two locations with the same subset of access points covering these locations as belonging to the same cluster.
- **Incremental Triangulation** considers radio map locations that are covered by the same access point belonging to the same cluster. Search space is then restricted by looking at other access points incrementally.

**User profile algorithms** Bad or incomplete measurements may result in location fixes which are way off of the actual users location. To filter out these measurements, a user profile is maintained. By using this profile the probability is also considered that a certain move is made from one position to another (taking the previous position, the current movement direction and the current speed) during the location determination. If the distance between the estimated location and the previous user location is above a threshold, based on the user movement rate and estimation frequency, the system ignores the estimated location.

5.3 Client Implementation

The client side of the application is intended to run on mobile devices. In our case, the prototype was developed and tested on a HP iPAQ 214 PDA running Windows Mobile 5.0. The PDA was equipped with a WiFi network card and a GPS module. The application makes it possible to present location-specific information to the user. Furthermore, position fixes retrieved from the location service are shown on a map, allowing visitors to locate each other.

6. Evaluation Results

The key metric for evaluating a localization technique is the accuracy which is defined as, how much is the estimated position deviated from the true position. Several tests were done for evaluating the implemented algorithms. They were performed in a rectangular area of 17 by 88 meters which is illustrated in Figure 5. During the offline phase, 70 sample points were taken each within a distance of approximately 1.5 meter from each other. The already present wireless access points were used, but some were filtered out and only 8 base stations were used during both phases.
6.1 Accuracy Comparison of the implemented algorithms

First of all, an accuracy comparison is given between the implemented simple matching algorithms. The results are presented in Figure 6. Results from the tests were very depending on the scanned location, sometimes an algorithm performed very well on one position but very bad at another one. The overall conclusion is that the algorithms gave similar results, and can give a position fix within an accuracy of 9 meters. Notice, that the average algorithm gave the best results for the closest distances.

The same accuracy comparison was done for the probabilistic matching algorithms, but only satisfying results were achieved in conjunction with clustering algorithms. Because the Joint Clustering technique gave slightly better results we used this clustering method in conjunction with the different implemented probabilistic matching algorithms. Results from the accuracy comparison are shown in figure 7.

The probabilistic matching algorithms gave significantly better results compared to the simple matching algorithms.

6.2 User Profile Accuracy

Previously evaluated algorithms treated determined locations independent from each other. Because the positioning will be used to track people, a user profile will narrow the search area for the matching algorithms based on taking the previous position, the current movement direction and the current speed. During this test locations were determined along a path. During the actual signal strength measurements the client was standing still or slightly moving to give an idea of the best achievable accuracy. Test results of the implemented clustering algorithms without the usage of an user profile is given in figure 8.

We see an overall decrease of the location error by using a user profile, positions which are too far from the previous
position are filtered out. This is illustrated in Figure 9.

Fig. 9: Accuracy comparison of the implemented clustering algorithms, with usage of the user profile. We see an overall decrease of the location error by using the user profile.

7. Future Work

Shortened battery life in handheld devices using Wi-Fi is an issue of high importance. The 802.11 specification specifies a power-saving mode which puts the mobile device in standby at regular intervals. Further research is necessary for evaluating the impact of this mode on the network performance in the context of the use case.

The used localization approach requires a radio map, which takes some time to build. Research could be done on approximating radio maps, reducing the number of reference points needed and providing the same or better results in terms of accuracy and efficiency, than the basic sampling methods.

We noticed from our user profile algorithm evaluation a minor improvement in average system accuracy, improbable locations were better filtered out. Research in the near future will focus on the improvement of the user profile algorithm in order to increase the overall accuracy. A possible improvement is also to consider the layout of the building. For example, when a user is located at a point of interest it will be more likely that he or she will stand still for a moment.

8. Conclusions

In this paper we presented the research results conducted as part of the Heritage 2.0 project. In this project research was done on a social, interactive, location-based heritage experience via mobile devices in the context of cultural heritage sites.

First, we presented a high-level network architecture usable to distribute location based heritage information which was followed by a mapping to a specific demonstrator site. Next, we focused on the enabling platform for context-aware applications, making location information available to services. Several location algorithms were implemented and evaluated. All of them make use of the existing WLAN infrastructure, resulting in no extra hardware cost. The probabilistic algorithm in combination with a user profile could achieve accuracies from 1 to 6 meters with high probability, which was sufficient enough for our use case.

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