Location Sensing Mobile System for Campus Touring

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ABSTRACT

The location sensing mobile system for electronic campus tours runs on a laptop computer, to provide users with a “you are here” view of their current location and a direction finder feature to help them tour a campus area. The system operates on a network of access points that allows users to detect and share their location information, and provides an interface to query and monitor the location information. This system implements the location sensing network using Ekahau Real-time Location System (RTLS) and 802.11 Wi-Fi stations. Ekahau RTLS is an automatic location identification software that relies on storing and remotely retrieving data using Wi-Fi access points. 802.11 is a standard for wireless local area network (WLAN) with over-the-air modulation techniques. The focus of the system is on designing a building-wide location infrastructure, location middleware to allow location data to be handled in a uniform and secure way, and a tour guide application to demonstrate the system and serve new visitors. This project prototypes a location sensing system for the second floor of the university library.
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1. BACKGROUND AND RATIONALE

The explosive growth of technology has lead to the demand for more functional portable handheld devices like cellular phones, PDA’s (personal digital assistant), GPS etc. These mobile devices play a major role in satisfying user needs. The proposed system requirements includes an Ekahau client application installed on a laptop computer, and an Ekahau server installed on a server machine or server laptop.

Developing a tour guide application system requires a laptop computer (application can be deployed easily onto a PDA), to provide the users with a you are here view of their current location, and a direction finder feature to help them find another room from their current location.

A tour guide application notifies new visitors with campus information by developing a building-wide location sensing infrastructure using commercial software technologies like Ekahau and 802.11 [WFESA 2008] Wi-Fi stations [Tour-Guide 2006]. Location sensing enhances the interaction of users with the surroundings. The main objective is to build an open infrastructure that connects the user and introduces the user to required information based on the physical location. Creating such an interface which is scalable, powerful, and respectful of a user’s privacy is important [Prakash 2005].

The rationale behind developing such an application is to automate the process of a campus tour. New students and visitors find it hard to locate new places in the campus, and this type of application will help in guiding them to the correct location (similar to what a GPS does)

1.1. Whereabouts

Whereabouts is a project at the University of Michigan, to build a location sensing network using widely available components, such as RFID [Garfinkel 2005] sensors and 802.11 stations [Whereabouts Project 2006]. The project includes a network of sensors that allows users
and computers to detect and share their location information, and to provide an interface to query and monitor the information. Different technologies like Aero Scout, 802.11 access points, and Passive and Active RFID were tested. Ekahau was selected as a best application to build the infrastructure campus wide.

802.11-based Ekahau [Ekahau 2008] was used for developing a building-wide location sensing infrastructure and a statistical model to estimate the location. A map of the area is first surveyed with the software, and then clients supply Received Signal Strength Indication (RSSI [WFESA 2008]) readings to a server to get their location [Whereabouts Project 2006].

802.11 [WFESA 2008] is a useful technology for location sensing since many users already have wireless technology in their laptops and PDAs. In many cases the cost to the client is zero, and there’s no additional installation problem since they’re already carrying around the devices [Gifford 2005]. 802.11 signal strength is used to compute the distance between an access point and an 802.11 client, which seems to remain fairly stable in the same room. Ekahau creates a statistical model when the application is provided with signal strength measurements of the visible access points in precise locations throughout the building. The software then uses Bayesian techniques to give a location estimate based on signal strength readings.

The server is Java-based, and runs on Windows or UNIX with a working Java virtual machine. The client can run on any Windows-based laptop, or Windows CE-based PDA [Whereabouts Project 2006]. The infrastructure requires a fairly intense 802.11 network, and the location information for access points on the campus.

A tour guide application is a part of the Whereabouts project that runs on a PocketPC platform and provides the user with campus information [Tour-Guide 2006]. To keep the information for the tour up-to-date, the data is stored on a tour guide Wiki. Figure 1.1 shows an Electronic Tour Guide system running on the PDA to find the directions in a campus building.
Local tour data is built from the Wiki data and loaded onto the PDA with hyperlinks to connect to pages in the Wiki [Prakash 2005]. This Wiki provides the information about the test building to generate electronic tours of the building.

The primary location-sensing installation for the Whereabouts project is done in the Computer Science (CSE) building at the University of Michigan. The entire building is instrumented for locating 802.11 and the system is able to find the location of a PDA, laptop, or tag running the location client [Tour-Guide 2006]. The accuracy is about 4 meters, and can place users in the correct room 80% of the time. Location information is managed by location middleware [Location Middleware Server 2006], which efficiently processes the queries by implementing privacy rules. Tour guide location calculations are done through Ekahau.

The Whereabouts middleware software is a privacy-observant middleware application for location queries [Location Middleware Server 2006]. It handles location information in an efficient and application-independent way; therefore it's straightforward to include new sources of location information without any changes to the clients. It includes a server written in Java,
and clients written in Java, C#/.NET, and Perl. The server processes incoming location reports, and updates clients with new information, according to their query and the user’s privacy preferences [Gifford 2005]. Clients easily interact with the server laptop to inform it of their location and get information about other locations.

1.2. Ekahau Real-Time Location System (RTLS)

Ekahau RTLS [Ekahau RTLS 2008] is a commercial real-time location sensing application, known as the leader in location-enabling an enterprise of Wi-Fi networks [Ekahau 2008]. It is a fully automated system that can quickly, easily and continually monitor the location of assets and personnel in real-time. Once in use, Ekahau RTLS decreases the time taken to find the vital pieces of equipment, provides accurate positioning solutions for locating Wi-Fi objects and makes sure that people and things can be found in the right place, at the right time. Here assets are utilized more efficiently and the workflow is optimized.

It can also track wireless laptops, PDAs, VOIP phones, Wi-Fi tags [Wi-Fi Tags 2008] and other 802.11 enabled devices. Ekahau RTLS uses signal strength measurements from existing Wi-Fi (802.11 a/b/g) access points to deliver a comprehensive real-time location tracking system for locating Wi-Fi enabled devices. Because the existing wireless network infrastructure is used, work is more cost effective and decreases the overall application payback time. This provides additional justification for installing new networks. The Ekahau RTLS process does not interrupt or affect the network activities and it improves the overall level of security, workflow and customer service [Prakash 2005].

With Ekahau RTLS [Holloway 2007], the positions of equipment or personnel are automatically updated and delivered to other systems that call for this information. It provides location estimates using client reports of what 802.11 access points are visible and reachable based on their signal strength, in combination with sample data provided by client’s readings of
signal strengths at hundreds of access points throughout a building. Individual signal strength reports are evaluated against the sample data using a location tracking algorithm and location estimates are calculated. This information is accessible via the Ekahau query interface and the server software gets this information from Ekahau to execute it through its own query interface. RTLS [Ekahau RTLS 2008] consists of Wi-Fi tags (T301-A), site survey tools (Ekahau Location Survey), wireless data networks, server software (Ekahau Position Engine), tracker software (Ekahau Finder), client software (Ekahau Client Controller) and end-user application software (Ekahau Application Programming Interface (API)). Figure 1.2 provides a visual idea of how all components communicate in Ekahau RTLS.

Figure 1.2 Ekahau RTLS Components [Ekahau Positioning Engine 2007]
A brief description of Ekahau RTLS software components is provided below:
- **Ekahau Positioning Engine (EPE):** EPE is the key element of Ekahau Real-Time Location Sensing System (RTLS). This is the server software that relies on standard 802.11 wireless networks and consists of location tracking algorithms termed as Ekahau Location Survey (ELS) [Ekahau Location Survey 2007] to locate people or assets using Ekahau Wi-Fi location tags or any supported Wi-Fi enabled laptop or PDA that has Ekahau client software (Ekahau Client Controller (ECC)).

  Ekahau Positioning Engine is a Web service that runs on some specific Window servers for location tracking. The EPE [Ekahau Positioning Engine 2007] Web service design makes integration to mobile devices or client systems simple by using Ekahau Client Connector. Ekahau Client Connector is a software adapter running on the EPE server to enable location tracking of client systems running specific version of Ekahau Client Controller (ECC) [Ekahau Positioning Client 2008] software. The Ekahau Client Connector converts Ekahau Client Protocol (ECP) to a new Ekahau Location Protocol (ELP) format used by Ekahau Positioning Engine (EPE). When client systems are connected to EPE, Ekahau Client Connector is seen in the ECC software with the EPE properties (IP address, IP port number). Figure 1.3 gives a visual idea of what EPE actually does for getting location information of client and tag devices.
The Ekahau Positioning Engine has an easy-to-use Web browser interface and it provides various functionalities for wireless configuration and management of Wi-Fi tags [Ekahau Positioning Engine 2007] and client systems (Wi-Fi enabled laptops or PDA’s or other devices with Ekahau Client Controller software). When these devices are connected to Ekahau Positioning Engine, they report certain parameters like their tag number, name, Mac address [Mitchell 2000], battery level, link to an image of a map, zone information, location time, and maintenance time to the server, that can be later used to call the client systems using Ekahau HTTP based API routine’s (Application Programming Interface) [Ekahau API 2008]. HTTP based APIs are accessed through a browser and virtually called on to any platform and programming language for running applications that make use of the location tracking information. The API routines provide location feedback, location queries and events to the application. The location information of applications is available through an open HTTP
request/XML response based API. Applications should be developed for translating the location update events into valuable information. Figure 1.4 gives a general idea on how HTTP request/XML response communicates with EPE and third party applications.

![Figure 1.4 Application Interactions with EPE](Ekahau Positioning Engine 2007)

The EPE’s location tracking algorithm receives signal strength measurements from Ekahau Client systems or Wi-Fi tags, compares the received measurements to an existing reference data and a positioning model that is created using Ekahau Location Survey (ELS) and uploads the data to the EPE, to calculate accurate location estimates. The configured client systems and Wi-Fi tags can contact the Ekahau Positioning Engine service every 3 seconds by default (or a given interval of time greater than 3 sec) to update the location information.

The EPE user interface or administration page can be accessed using supported Web browsers at address http://<Engine host IP address>:8550. The default username/password is admin/admin. Figure 1.5 is a screen shot of the login page for EPE.
The EPE user interface provides various functionalities through different tab options or pages, where the user can view, integrate, upload and activate positioning models for client systems and Wi-Fi tags. EPE Pages include **System** page which displays information pertaining to the EPE status and activity and **Tags** page which displays the list of client systems (laptops) and Wi-Fi tags that are connected to EPE. **Configs** page is used to create and edit Ekahau Wi-Fi tag configurations [Ekahau Positioning Engine 2007] (Only Ekahau tags, not clients); **Models** page displays a list of models created using ELS. Each model is a survey performed for the client systems or Wi-Fi tag in the application area. **Users** page is used to add new users to the system.

- **Ekahau Location Survey**: Ekahau Location Survey (ELS [Ekahau Location Survey 2007]) is a software application for creating and editing positioning models to enable accurate location tracking. Using ELS, one can track local Wi-Fi devices, such as laptops, PDA’s, Wi-Fi tags and Wi-Fi network adapters. ELS can also be used to analyze and optimize the wireless network and location tracking accuracy of an area. With a supported Wi-Fi adapter ELS is used for surveying the area to create a new positioning model. ELS runs on a laptop computer for
recording the surveys. The reason for choosing a laptop computer instead of a desktop is that for recording the surveys, the person with the computer has to follow a certain trail. Carrying a desktop in these situations is near impossible. ELS records signal measurements, defines the environment like the length between two points in an area, open spaces, path of walking trails and zones. ELS performs a survey on a map section and communicates the results to the EPE by saving the positioning model to EPE [Kealy1 2009]. All these signals and site characteristics together form a positioning model.

The ELS user interface has three main elements, **Map** section, **Menus** and **Toolbar** section and **Lists** section as shown in Figure 1.6. **Map** section is the place where an image map is added and allows defining the environment like scale width between two locations, path of walking, opens Spaces, and zones to analyze the location accuracy and radio frequency measurements. **Menus** and **Toolbar** section is used to access the tools necessary to perform the survey by analyzing the accuracy and set the required properties. **Lists** section is used to get the information on the access points, surveys recorded and zones created.

![Figure 1.6 Ekahau Location Survey Interface](image-url)
• **Ekahau Finder (EF):** Ekahau Finder is a Web browser based software tool for visually locating Wi-Fi tags and client systems (laptops or PDA). It is a multi-user Web application for quickly locating, grouping, and viewing the location of people and assets in real time. It can also monitor events, and invoke notifications or alarms using any Web browser enabled PC, or other device. Using Ekahau Positioning Engine, Ekahau Finder [Ekahau Finder 2005] automates the search and find processes of client devices or Wi-Fi tags. Ekahau Finder provides a Web interface for finding people and resources based on user defined lists, rules, name, tag id, group, battery level, or location. The Ekahau Finder user interface can be accessed with a Web browser at address http://<Finder host IP address>:8560. The default username and password of EPE can be used to login into the Ekahau finder software. Figure 1.7 shows the screen shot of the login page of Ekahau finder. Ekahau Finder interface consists of a **Home** page, **Find** page, and **Maps** page.

![Ekahau Finder Login Page](image)

**Figure 1.7 Ekahau Finder Login Page**

The **Home** page provides a rich set of client systems and Wi-Fi tags search parameters and the possibility to save shortcuts to frequently accessed information. The **Find** page is used to
list the location of all client systems and Wi-Fi tags present in the system or to find client systems and Wi-Fi tags that match a defined search criterion. The Maps page displays the map image of the active model from EPE and shows the client systems and Wi-Fi tags positions by blue dots on the image with real-time location tracking.

- **Ekahau Client Controller (ECC):** Ekahau Client Controller is a software based solution that provides location tracking of Ekahau clients. Appropriate Ekahau client software must be installed and running on the mobile devices for them to be tracked. Ekahau Client running on a laptop or a PDA appears as a “software tag” in the EPE [Ekahau Positioning Engine 2005] user interface. The Ekahau client properties window is launched on installing the software as shown in Figure 1.8.

![Ekahau Client Properties](image)

**Figure 1.8 Ekahau Client Properties**

The Ekahau client properties window has three most important tab options that help to see whether the client system is connected to the EPE server or not and for setting the client system properties. **Status** tab displays a dot (green or orange) indicating whether the client system is connected or not. A green dot indicates successful connection where as an orange dot indicates that the client system is searching for the EPE server. **Engine** tab displays the EPE properties if connected using Ekahau Client Connector. **Scan Set up** tab includes two options,
site survey/calibration mode to find out signal strength at various locations in the area and location tracing mode when the EPE server is actually tracking the user location information.

- **EPE API Reference:** Ekahau Positioning Engine Web service API is used for developing applications that use location tracking information. Ekahau API is based on HTTP/XML Web service technology. HTTP functions are used as the transport protocol and XML describe the encoding scheme for the data. The API [Ekahau API 2008] routines can be tested using a Web browser. All the API routines can be found at http://<Engine host IP address>:8550/epe/developer. An API call is performed by making an HTTP request through a URL in the engine, and the engine sends back a response as an XML document. Each URL in the engine represents a separate API command and defines its own input parameters and output responses. Most commonly used API service for tracking client systems or Wi-Fi tags to display the real time $x$ and $y$ co-ordinates is /epe/pos/.

/epe/pos/ positioning service provide the positioning data of the tags or client systems, either from the database or from real-time using the positioning algorithm. A command used in this service is /epe/pos/taglist, for listing the tags and their properties. This command provides powerful search and sorting functions. New location coordinates are displayed as fast as the EPE calculates them. The following are the different option fields used to call the client system properties: http://localhost:8550/epe/pos/taglist?tagid=81344905883&fields=all, http://localhost:8550/epe/pos/taglist?name=Intel Corporate 88:C2:9B&fields=all, http://localhost:8550/epe/pos/taglist?mapname=LIB-II&fields=all, http://localhost:8550/epe/pos/taglist?mac=00:12:F0:88:C2:9B&fields=all

- **Ekahau Wi-Fi Tag (T301-A):** Ekahau T301-A tag is a small battery powered active Wi-Fi tag [Ekahau Positioning Engine 2007] for tracking people and assets like PDA’s, laptops, large server machines, projectors etc. Tag location is identified using a standard 802.11 a/b/g
[WFESA 2008] Wi-Fi network and it uses a system-on-chip architecture with a radio transceiver to detect the motion automatically. The tag activation is performed using *Ekahau Activator* software, which initially configures T301-A tag wirelessly and lets one connect the tag to EPE over the network. Once the connection is established with EPE, remaining configurations are managed by *Configs* page of EPE. Testing of Ekahau Tags was included in the project and is presented in chapter 4.

In the later chapters, there is a detailed description of the location sensing Electronic Tour Guide application including the design, analysis, evaluation and results. Chapter 2 discusses the location sensing mobile system for campus touring application. Chapter 3 discusses the Electronic Tour Guide system design and major components. Chapter 4 discusses the evaluations and results of the Electronic Tour Guide application.
2. LOCATION SENSING MOBILE SYSTEM FOR CAMPUS TOURING

Location Sensing Mobile System for Campus Touring is an Electronic Tour Guide application, for location tracking of client systems (laptops). The Electronic Tour Guide helps new visitors and future students to explore different directions on the campus (a prototype was implemented for the second floor of the library). Location-aware applications are becoming increasingly attractive due to the widespread distribution of wireless networks and the emergence of small and cheap location tracking technologies. A location-tracking infrastructure based on 802.11 Wi-Fi networks is key to system functionality. Users carry laptop that enable their location to be tracked by the Wi-Fi network and provides them with the directions to the destination room. Electronic Tour Guide introduces people to location-aware technology and runs on laptop computers to give self guided tours of the second floor of the library. This Electronic Tour Guide system shows the current location of the user, provides guided directions for touring the second floor of the library and displays the information of the closest room or important location or point of interest.

A commercial 802.11-based Ekahau RTLS [Ekahau Location Survey 2007] software application is used for the location-tracking infrastructure, in conjunction with the Wi-Fi access point network. Once locations are identified, the Ekahau client software on a user’s laptop is used to provide the data that determine the user’s location within accuracy of a few meters. Ekahau positioning engine software is installed on the server machine and Ekahau client software on laptops. The Ekahau client software communicates with any wireless router installed on the campus. By the use of the available wireless routers throughout the campus the Ekahau client on the laptop communicates with the Ekahau server.
An Electronic Tour Guide system was developed with the second floor map of the library at Texas A&M University – Corpus Christi (TAMUCC), by using the concepts of the Whereabouts project from the University of Michigan.

The Electronic Tour Guide system runs on a laptop and has a graphical user interface (GUI) developed using Microsoft Visual Basic.NET (VB.NET). VB.NET is a high level programming language that provides graphical development features and is typically used to develop complex applications which demand the use of GUI. Figure 2.1 shows the user interface of Electronic Tour Guide system.

Figure 2.1 Home Page of Electronic Tour Guide System
The Electronic Tour Guide system interface consists of the second floor map of library with three important buttons to click and one status label to check the status information. Buttons include **Free Walk Start**, **Stop** and **Guided Walk Start**. Label includes **Status** to display the user’s location information.

The Electronic Tour Guide operates in two modes, **Guided Walk Tour** and **Free Walk Tour**. When the tour guide application is launched on the laptop computer, the user will be directed to the home page of the application as shown in Figure 2.1. The user has the flexibility to choose the type of tour to take before starting to explore the library second floor, by clicking on one of the tour modes. After selecting the desired option, the user is free to proceed on the tour. If the user wants to shift to the other tour mode option, he has to first stop the current tour mode, and then select the other tour mode. In **Guided Walk Tour** mode, the user will follow a predefined tour path that begins at user’s current location, whereas in **Free Walk Tour** mode, the user is free to move anywhere. The sections below describe in detail the two modes of the tour guide system.

### 2.1 Free Walk Tour Mode

The user selects the **Free Walk Tour** mode by clicking the **Free Walk Start** button from the home page. In **Free Walk Tour** mode, the user is free to move anywhere in the building. When the user enters a new area, information pertaining to the area is displayed in the **Status** label of the form.

When the application is in **Free Walk Tour** mode, the user’s position is indicated at all times on the map as a green dot and is updated as the user moves using location coordinate values obtained from the Ekahau RTLS. Users are free to move around and tour all locations that are of interest. The information pertaining to the main locations on the floor are always displayed to the user. These location area ranges are captured in a database as **Free Zone** areas in order for
the application to display information pertaining to that area. When the user moves into a *Free Zone* area, the *Status* label displays the corresponding information referring to the area. If the user moves into a different *Free Zone* area, the *Status* label shows updated information relevant to that area. Figure 2.2 displays a screenshot of the user in *Free Walk Tour* mode.

![Figure 2.2 Free Walk Tour Mode](image)

In the *Free Walk Tour* mode the application will display status information only if the user is in the *Free Zone* area, if not it displays a message “Keep Walking…”. For example, the second floor of the library has main collections, conference room, special collections, science lab etc. When the user is in the main collection area, the *Status* label on the form displays “You are
at Main Collections”. If the user is in Conference room area Status label on the form displays “You are at Conference room”. When the user is not in one of the Free Zone areas the Status label on the form displays “Keep Walking…”

2.2 Guided Walk Tour Mode

The user selects the Guided Walk Tour mode by clicking the Guided Walk Start button from the home page. In Guided Walk Tour mode, the user will follow a predefined tour path that begins at the user’s current location and covers all the details about the second floor of the library.

The user’s position is indicated at all times on the map as a green dot and is updated as the user moves using location coordinate values obtained from the Ekahau RTLS. On the second floor of the library there are some main locations that a Guided Walk Tour should cover. At the same time the application has to track the initial direction in which the user is moving, to correctly guide the user. If this direction is not determined accurately then the user will receive wrong directions (e.g. instead of turning left, the user may get directions to turn right).

The user’s direction is determined based on the recent x and y coordinates values obtained from the Ekahau RTLS using Ekahau API. The logic to determine the user’s direction is outlined in the following paragraph.

As the user starts walking in this mode, the x and y coordinate values are stored to a text file. When the user reaches a pre-defined turning point, the last ten x and y coordinate values are examined to determine the rate of change for both x and y coordinates. For example if the rate of change of y is greater than x, it means that the user is walking in the y direction which is vertical to the screen. To determine the direction (up or down) in which the user is walking, subtract the y values relative to the first value, and then determine the count of the positive and negative values. If the number of positives is greater than the number of negatives, the user is walking up
relative to the screen and if the number of negatives is greater than the number of positives the user is walking down relative to the screen. A similar procedure can be followed to determine whether the user is walking either to the left or right, relative to the screen.

Once the direction is determined using the above procedure the application instructs the user by displaying “Turn Left”, or “Turn Right” or “Keep Walking” in the Status label. The user will be instructed about his location status or important locations by using the Free Walk Tour mode concept. Figure 2.3 displays a screenshot of the user in Guided Walk Tour mode.
In this mode, the user should always be moving as guided by the application to complete the full tour of the second floor of the library. Once the user starts moving in some direction i.e. either left or right, he must continue in the same direction until the tour ends. If the user doesn’t want to continue in the direction he has started walking, he has to first stop the mode by clicking on the Stop button, and then restart the same mode in a new direction. This is the only restriction that users have to follow in this mode. The application will display status information whenever the user has to take a turn and at Free zone areas, otherwise it displays a message “Keep Walking...”.
3. SYSTEM DESIGN AND ANALYSIS

The Electronic Tour Guide system is implemented using location-aware computing technology that includes developing a cost effective floor-wide location sensing application using Ekahau RTLS [Ekahau RTLS 2008] for a large-scale application to accommodate many participants in the tour. Location-aware projects are focused on ways of gathering and processing location information from different access points. Creating an interface to the system which is scalable, powerful, and respectful of user’s privacy is important. The system performance is very dependent on the quality of the Wi-Fi signals, user issues and the structural environment. For the location tracking infrastructure, commercial 802.11 based Ekahau RTLS software is used. Once the locations are identified using the access points, the Ekahau client software on the user’s laptop utilizes the provided data to determine the user’s location and to direct them to tour the second floor of library based on the specified path created by ELS.

To develop the design for the Electronic Tour Guide application, the following minimum hardware and software requirements are required initially:


- Ekahau Positioning Engine (EPE) software was installed on a server laptop machine to communicate with the client system on the laptop, and the Ekahau Client Connector software installed on the same server machine to enable the EPE to locate the client system. Minimum requirements to install EPE on a computer are Intel Pentium 4 processor with 1 GB RAM, and 500 MB Hard disk space. Windows® XP Professional was used for the prototype.
- Ekahau Finder software installed on the same server laptop machine to visually locate the client systems (laptops). Minimum requirements to install EF are a computer with Intel Pentium 4 processor, 512 MB RAM, and 500 MB Hard disk space.

- Ekahau Location Survey software installed on same server laptop machine with a compatible Wi-Fi adapter found at the link http://www.ekahau.com/products/real-time-location-system/support/supportedadaptersrtls.html to survey the location needed to track the client systems (laptops), and for creating and editing positioning models to enable accurate location tracking. Minimum requirements to install ELS are a laptop computer with Intel Pentium 4 processor, 512 MB RAM, a500 MB Hard disk space

- Microsoft Visual Basic.Net with .net framework installed on the client laptop to develop the software for the Electronic Tour Guide application.

Figure 3.1 shows the general idea of location tracking infrastructure of the Electronic Tour Guide system using Wi-Fi access points, Wi-Fi enabled devices, the Ekahau positioning engine and the application server. Once the locations of different access points are identified using ELS, the Ekahau client software (ECC) on the user’s laptop compares the ELS provided data with the received measurements of an existing reference data from EPE, determines the user’s location and displays it on the Electronic Tour Guide application map as a green dot with appropriate instructions to the user.
Electronic Tour Guide was developed to help introduce new visitors to campus in a non-threatening way with respect to their privacy. The VB.NET programming language was used to develop the application. The backend infrastructure consists of location tracking infrastructure (ELS) and the EPE server that allows users to receive updates and to modify the tour information.

On the server machine, EPE, EF, Ekahau Client Connector, and ELS are installed. On the client machine, Ekahau client software (Ekahau Client Controller) is installed. The appropriate Ekahau client version is installed to communicate with the version of EPE that is available in the Ekahau RTLS package. If any existing port numbers specified by Ekahau RTLS are used by any other application on the system, a different port number should be chosen for the corresponding entity. The Wi-Fi connection is enabled and the firewall is turned off for both the server and the client machines in order for them to communicate.

The default username and password is used to login into the EPE once the installation is complete. The EPE status and activity information can be seen on the System page. The ELS software with a supported Wi-Fi adapter creates and edits the positioning model using the tools provided in the software. The positioning model is created according to the instructions.
described in section 3.2. After the model is created it is saved to the EPE, and the created positioning model is seen in the **Models** page of the EPE.

The Ekahau Client Connector in the EPE server machine should be started in order to recognize the Ekahau Client Controller which is in client system. The Ekahau Client Controller on the client machine should be setup according to the instructions described in the section 3.2. If the IP address and the port number seen in the **Engine** tab of Ekahau Client Controller software correspond to the EPE server, then a proper connection is established between the client and the EPE server, and a green dot appears on the **Status** tab of the Ekahau Client controller. The next step is to verify the existence of the client machine (by the MAC address [Mitchell 2000]) in the **EPE Tags** page of the Ekahau server. If it exists, it means that the Ekahau client machine is connected to the EPE server machine.

The above process is repeated for any new client machine. A detailed description of the Electronic Tour Guide systems design and analysis is included in section 3.1 and section 3.2. Section 3.1 discusses the design of the Electronic Tour Guide system using Microsoft Visual Basic.NET and Ekahau HTTP/XML API. Section 3.2 analyzes the major components of Ekahau RTLS in detail for building the necessary elements needed for the Electronic Tour Guide application.

### 3.1 Application Design

The Electronic Tour Guide system interface is designed using VB.NET since it offers many graphical development features using a toolbox. The toolbox consists of a **Picture** box, **Button**, **CheckBox**, **ListBox**, **Label**, **Panel**, **TextBox** [Kiong 1996] and a lot more to assist in the design of a good GUI interface on a VB.NET form. The Electronic Tour Guide system interface is designed using several toolbox icons. The following is a brief explanation of the
functionality of some toolbox icon’s that are used in developing the GUI for the Electronic Tour Guide application:

- **Picture box**: The tour guide interface consists of one picture box, with the library second floor image as a map. This map helps the user to know his current location by displaying a green dot on the image.

- **Labels**: The tour guide interface consists of three labels, one for the displaying the project’s title, one for displaying the status title and the other for displaying the **Status** information to the user.

- **Buttons**: The tour guide interface consists of three buttons, one for the **Free Walk Tour** mode, the other for the **Guided Walk Tour** mode and the third for **Stopping** the tour. These buttons help the user to select the appropriate tour mode and to stop [Kiong 1996].

The properties window of each toolbox option, allows setting the color, background image, size, location, alignment, text, etc. for designing a interface. Using VB.NET, the appropriate Ekahau API is called and the XML output generated by the API is used to obtain the coordinate values of the user, guaranteed that the connection between the EPE server and Ekahau client machine is established. The appropriate Ekahau APIs used for the tour guide application are located at `epe/pos/taglist` service. These APIs generate the output as an XML file format which contains information about the client system. The following API is used in developing the Electronic Tour Guide application and is called using the Web browser:


The MAC address of the client system (00:12:F0:88:C2:9B) that is of interest is specified in the URL along with `fields=all` option, to obtain the full information about the client system. Similarly the appropriate fields that are of interest can be specified in order to only obtain the required details about the client system. The output of the above API is shown below:
The output contains the tag id given by the EPE for the client, the MAC address of the
client, the type of client (Ekahau tag, Software client), the date and time the client was first seen
by the EPE, the current position of the client on the map(x and y coordinates), the name assigned
to the map, the time when the EPE received the signal from the client, the name of the client
system etc.

From the above XML output, the values of tags <posx> and <posy> (position of x and y)
are most important as they determine the exact positions of the client system in real time. These
values are continuously extracted by the VB.NET code and are utilized to update the location of
the user on the map using a green dot. Both tour modes in the tour guide application utilize the x
and y coordinate values.

In the Guided Walk Tour mode the person starts from a specific area in the second floor
of the library and the application will direct him through all the important locations and the
rooms on that particular floor, and displays the information either to take a turn or keep walking,
thus enabling the person to know all the details about the floor. The application displays the current location of the user at all times with a small green dot on the map image.

In the Free Walk Tour mode the person can move anywhere on the second floor of the library. In this mode the Electronic Tour Guide application displays the information pertaining to a certain location dependent upon the presence of the person in that specific area. The application displays the current location of the user at all times with a small green dot on the map image.

3.2 Application Analysis

Designing the Electronic Tour Guide application required the necessary background information of all the components present in the Ekahau RTLS software. The components in Ekahau RTLS software make the connection between the server machine and the client machine for tracking the client systems coordinate values. The tour guide uses the position model created by the Ekahau RTLS software for deciding the path the user has to walk. Section 3.2.1 discusses the EPE, section 3.2.2 discusses the ELS, section 3.2.3 discusses the EF, section 3.2.4 discusses the Ekahau Client Controller and section 3.2.5 discusses the Ekahau API (Application Programming Interface)

3.2.1 Ekahau Positioning Engine (EPE): As previously described, EPE is the main server software of Ekahau Real-Time Location System (RTLS). It locates client laptop computers that have Ekahau Client Controller (ECC) software installed, using the position model created by ELS software and the wireless access point network of the designated area. The EPE user interface or administration page is accessed by a Web browser at address http://<Engine host IP address>:8550 using the default username and password. After logging into EPE, the user is provided with multiple Web pages, to help locate the client system. Sections 3.2.1.1-3.2.1.4 provide a detailed description of the functionality provided by EPE [Ekahau Positioning Engine 2007] pages to locate the client system.
3.2.1.1 System Page

After logging into the EPE with necessary information, the first page in the EPE interface is the System page. This page displays information pertaining to the EPE status and activity. Figure 3.2 provides a screen shot of the System page. This page displays the various system status and activity details, as described in the following paragraphs:

- **System Status:** Displays the software version number and the build number of the EPE, time when the EPE server was started, uptime (current time - start time) of the server, and the number of current active tags that the server is able to discover.

- **Activity:** The count values can be used to verify that the EPE system is working as expected. Displays the number of Location Update Events received from client systems or tags, number of location estimates that passed the location quality filter, number of location estimates
that did not pass the location quality filter, maintenance related calls from tags, and the time since the counters started tracking the tags, and a link to reset all the counter values.

At the end of the **System** page, there is a link named **Log File**. The **Log File** page contains information about EPE system activity, including errors and warnings. Figure 3.3 provides a screen shot of the Log File page that displays complete information about the use of EPE with date, time, errors and outputs received by accessing the EPE. This information helps to understand, what each EPE processor service thread is doing at a time and the results from those services and threads.

![Figure 3.3 Log File Page of EPE](image)

**Figure 3.3 Log File Page of EPE**

### 3.2.1.2 Tags Page

The next page in EPE is **Tags** page; it displays the list of client systems (laptops) and Wi-Fi tags connected to the EPE server in a tabular form. The listed client systems (laptops) and Wi-Fi tags are linked to EPE, having sent their location update event information to EPE when a communication connection is established. Figure 3.4 provides a screen shot of the **Tags** page.
Figure 3.4 Tags Page

The page displays the client systems (laptops) and Wi-Fi tags that the EPE engine discovered recently along with their necessary parameters described in the following paragraphs:

- **Tag**: Displays unique serial numbers associated to a client system or a Wi-Fi tag. Placing the mouse pointer over the serial number will display further details. Tag properties like name, custom text, group name, deleting tag, movement profile can be viewed and edited by clicking the tag serial number link. Figure 3.5 provides a screen shot of the Tag properties page.
**Figure 3.5 Tag Properties Page**

- **Name**: The name parameter displays the name assigned to the client systems or Wi-Fi tags. Each system or tag is named by the asset or individual associated with the tag.

- **MAC**: The MAC parameter displays the MAC address of the client system (laptop) or Wi-Fi tag [Mitchell 2000].

- **Config**: Displays the name of configuration currently in use for the Wi-Fi tag. This is a unique parameter for the Ekahau Wi-Fi tags. The **Configs** page of the EPE is used to configure a new tag [Ekahau Positioning Engine 2007].

- **Battery**: Displays the battery level received from the client systems or tag during the latest location update. The battery level is highlighted in color red when the percentage is below the configured “low battery” limit. This limit can be set through the `epe.properties` file, by default located at `\Ekahau\Ekahau Positioning Engine\conf\` folder.
- **Map**: Displays the name of the map on which the client system is constructed using ELS. On clicking the map link, a map image is displayed with the latest location update of the client systems as a blue circular dot, as shown in Figure 3.6.

![Figure 3.6 Tag Map Page](image)

- **Zone**: Displays the zone number of the last successful location update of a client system. Zones are created in a map during the surveying of the map area. They represent areas of interest that are to be used in the location tracking application in this project, the Electronic Tour Guide.

- **Loc**: Displays relative time duration of when the last successful location update was received. Loc column data is highlighted in red color if the system is not receiving location updates for a long period of time. The location is highlighted in orange color if the engine receives successive location update events.
- **Maint**: Displays the relative time duration of when the tag performed a maintenance call. Maint is highlighted in red color if the tag has not completed a maintenance call for a long period of time or according to the set configuration parameters.

The Tags page also provides many different search options (*tags, groups, config, and find field*) and buttons to display the output based on a search criteria. The search option allows filtering the listed client systems (laptops) and Wi-Fi tags using a combination of the search options from the drop down list and also through the find field to search for any client system (laptop) or Wi-Fi tag based on the specific data criteria. The client systems (laptops) and Wi-Fi tags are also sorted in order by clicking on the column headers. The check box on the left side of each row is used to select a tag and from the actions drop down menu an option can be selected for adding the selected tag to a group, creating a new group or setting a configuration. The Advanced button at the bottom of the page can be clicked to display more actions about one or more selected tags as shown previously in Figure 3.5.

### 3.2.1.3 Models Page

Displays a list of position models created using ELS software. Each model is created by a survey performed by the server system to recognize the client system. The user can upload and store many model files in the EPE database using the **save to engine** option present in the ELS, but only one model can be active at any given point of time. If there is no active model, the tags cannot be located when EPE receives the location update events. Using **Upload a New Model** link on the Models page, ELS model files can be uploaded if the models are already available in the .esx format. The model page shown in Figure 3.7 has six parameters that give a detailed description of the model:

- **File Name** displays the name of the uploaded file.
- **Description** displays information given to the model file at the time of uploading from the ELS. The model description can be edited here.

- **Version** displays the model version number. Application developers may use this information to find out if the active model file has been edited or not. The version number displays the number of times the same model has been uploaded with some changes. The version number is set automatically.

- **Size** displays the size of the file in kilo bytes.

- **Modified on** displays the date and time when the model is modified.

- **Status** displays the words *Active model* for the model that is currently active.

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**Figure 3.7 Models Page**

By clicking the *model name*, a **Properties** page is displayed as shown in Figure 3.8 with more information on the position model. On clicking the **Show model details** link, the system
displays the model properties page including map name, zones created in the map and access points present in the position model file.

![Figure 3.8 Model Properties Page](image)

The **Delete** button is used to delete the model. The active model cannot be deleted. To activate a positioning model, click the **Set Active** button. Once the model has been activated, it is displayed in bold font in the model list.

### 3.2.1.4 Users Page

The **Users** page as shown in Figure 3.9 is used to add new users to the system, or to edit the password of the admin user. On clicking **Create a New User** link, new users can be created through the form displayed.
Figure 3.9 Users page

The following information is required to create a new user as shown in Figure 3.10:

- **Login Name**: The login name of the user. The Web browser asks for the user credentials when the system is accessed. The browser will cache the user name and password. The user must authenticate again if the browser application is closed.

- **Description**: An optional free-form description of the user.

- **Organization**: Optional organization information.

- **Password**: The user password must be entered twice.

- **Role**: There are four different user roles in the system; administrator has access to all system features. The administrator is also the only role with rights to create new users and edit existing user profiles. Power users can access all the features that an administrator can, except for user management. Tag Operator is allowed to edit tag properties, change tag configuration, send commands to tags and delete tags, but not allowed to change the active positioning model.
or add/edit user profiles. Viewer is not allowed to edit any data in the system. A viewer only has privileges to view the tag list and the tag locations.

Figure 3.10 New User Creation Page

3.2.2. Ekahau Location Survey (ELS): As previously described, ELS is an easy-to-use point and click survey software for creating positioning models, verifying Wi-Fi signal strength and verifying location tracking accuracy of an area during system set-up. The created position models are saved to EPE, as it calculates the location of client system using Wi-Fi signals, and the ELS data. ELS software runs on a laptop computer and creates the position model by recording the location area (second floor of the library) using different tools and options present in the software as shown in Figure 3.11. ELS supports 802.11a/b/g [WFESA 2008] Wi-Fi network for conducting surveys. ELS is also suitable for large-scale deployments as it supports larger maps and multiple floors. It can also merge several ELS projects to one file using the options present in the software.
With a supported Wi-Fi adapter and a laptop computer, the ELS is started for surveying
the area to create a new positioning model. Sections 3.2.2.1 – 3.2.2.5 provide a detailed
explanation of the different sections present in the ELS user interface, and other tools and
options.

![Figure 3.11 Ekahau Location Survey Interface](image)

**Figure 3.11 Ekahau Location Survey Interface**

### 3.2.2.1 Map Section

The Map section corresponds to a location where a map image is inserted, and defines the
environment of the map area using options like scale width between two locations, path of
walking, open spaces, and zones to analyze the location accuracy and radio frequency
measurements. The Map section conducts surveys by clicking frequently on the current location
on the map to associate the signal measurements with the location. The Map section also displays
location accuracy information based on visualizations selected in the Toolbar section. Figure

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3.12 provides a screen shot of the *Map* section. The different icons available in the *Map* section are useful in creating a position model, and are explained in the following paragraphs:

**Figure 3.12 Map Section**

- **Record Survey icon:** This icon records signal measurements based on the network capacity. Enable the icon by selecting it, and walk around the map by clicking on the current location when you stop, start walking or change direction.

- **Rail icon:** Indicates the logical paths of movement of the tracked persons or devices on the map image.
- **Open Space icon**: Indicates open areas, where the paths of movement of the tracked devices are not known. The icon can draw a rectangular or a free-form polygon open space.

- **Zones**: Define areas of interest that need to be used in the location tracking application.

- **Scale icon**: Indicates the scale of the map. It can be used as a distance measurement tool between two location points. Scale can be set in meters or feet’s.

- **Inspection icon**: Helps to investigate the visualization in more detail by clicking an area on the map.

### 3.2.2.2 Menu and Toolbar Section

Menu options *File*, *Edit*, *View* and *Map* are used to access file operations, positioning model options, zooming the map, adding or removing maps, setting the required properties and more. Figure 3.13 provides a screen shot of *Menus* and *Toolbar* section. The following paragraphs provide a brief explanation of the menu options:

**Figure 3.13 Menus and Toolbar Section**

- **File Open/Save option**: Opens and saves the positioning model project to a folder on the desktop or any location or to a file on a disk. The project file has an extension .esx and contains
all the information about maps, survey data, its route, access points, signal readings, topology, and zones.

- **File Open from Engine/Save to Engine**: Opens/from and saves directly to EPE instead of opening/saving the project file from/to a folder or a disk.
- **File Merge**: Join several projects together as one. This can be used to combine multiple survey projects to one survey project.
- **File Preferences**: Display a window to select the length unit (meters or feet).
- **Edit Undo/Redo**: These options allow undoing and redoing the actions performed on the map image.
- **View Zoom In/Out/ Fit/ 1:1**: Zooms in/out on the map image.
- **View Rails**: Shows/Hides rails information on the map image.
- **View Surveys**: Shows/Hides all surveys.
- **View Calibration**: Shows/Hides calibration surveys only.
- **View Test**: Shows/Hides test surveys only.
- **View Zones**: Shows/Hides zones information on the map image.
- **View Live Signal**: Displays the live signal window, which has complete information of Wi-Fi signals in the area.
- **View Devices**: Displays Devices window, which has complete information on the client systems or Wi-Fi tags that are connected to the EPE including the Wi-Fi adapter used to access the ELS.
- **View Accuracy statistics**: Displays Accuracy Statistics window that has complete information of location accuracy throughout the map site in numerical values. It provides average of locations errors of all location estimates and percentage of location estimates located in the current map, inside the zone area and in filtered locations.
- **View Location quality filter:** This window helps to set the quality filter level. These filters block low-quality location estimates while filtering high-quality locations through. At filter level 0 no estimates are blocked; the higher the filter level, the less location estimates are let through and the expected accuracy of the remaining estimates is high.

- **View Model setting:** This menu option helps to set the rail width in feet. By default, the rail is 8 feet wide, meaning that survey data will be associated to the rail if it is closer than 4 feet perpendicular from the rail. With this setting, in most indoor environments, majority of the data is collected in hallways and small rooms.

- **View Access Point Binding options:** This option helps to automatically bind different access points if present in the Wi-Fi network. By default, the check boxes of all the different access points are checked.

- **View Replaced access points:** This option helps to update the replaced access point information to the ELS software.

- **Map Add/Remove:** Adds/Removes map images. Removing also deletes all the data such as survey data and rails on the map.

- **Map Active Map:** Displays the active positioning model’s map.

The Toolbar section present below the Menus section is used to access the tools necessary to perform the survey by analyzing the location accuracy. A brief explanation of the different toolbar options is provided in the following paragraphs:

- **Map:** This toolbar option is used to select, rename, and add a map image on which the survey is conducted. The image is browsed by clicking on the Add button.
- **Show**: This option is used to select the appropriate visualization to be displayed; these visualizations help to determine the access point signal quality at different areas in map image. Options to select are: empty, calibration quality, location coverage, map accuracy, zone accuracy, location accuracy, number of access points, signal strength, zone similarity and location quality. A detailed explanation of these visualizations is provided in the section 3.2.2.5.

- **For**: This option is used to select access points groups to be included in the visualization. Use of access points included in location tracking can be limited using this For option. Options to select are: *All Access Points, My Access Points, Other Access Points, or Highlighted Access Points*. A detailed explanation of these options is provides in the following paragraphs:

  - **All Access Points**: Selecting this visualization option displays the map with information from all the access points detected during the survey. To see the total number of access points on a given map, select *Show* option as *Number of APs* and *For* option as *All Access Points*.

  - **My Access Points**: Selecting this visualization option displays the data of the access points checked as *My* from the access points list. To see if the network is solid enough for location tracking, select *Show* option as *Location Coverage* and *For* option as *My Access Points*. Selecting *All Access Points* instead of *My Access Points* includes neighboring and rogue access points.

  - **Other Access Points**: This visualization is the exact opposite of *My Access Points* option. To show the signals from access points that are not under the control, select *Show* option as *Signal Strength* and *For* option as *Other Access Points*. 
- Highlighted Access Points: Selecting this visualization option displays only the access points that have been highlighted in the access points list. To see the coverage area of a single access point, first highlight that access point from the access points list, and then select Show option as Signal Strength and For option as Highlighted Access Points. When this option is chosen, highlight one or more access points, and then click the Refresh icon to apply the changes made.

- Options: These options help to adjust the estimate value in feet or meters. Adjusting the granularity does not affect location tracking accuracy.

On clicking the Option icon a window as shown in Figure 3.14 is displayed. There are three visualization modes here that can be chosen. The Detailed mode is used when in-depth analysis is needed. By default this modes provides fine extrapolation and accurate results. This mode does not allow adjusting the density of extrapolation data. The Smooth mode enables the user to adjust the density of detail, as the user can set the extrapolation in feet or meters, and in the Zone mode the average signal strength for each zone is displayed. This mode also does not allow adjusting the density of extrapolation data. The Extrapolation option data is based on the width of the Rail.

![Figure 3.14 Options Tool](image)
The visualizations are not refreshed automatically in all cases. If changes are made to the topology, the visualization needs to be refreshed to see up-to-date results. The **Refresh** button turns grey whenever the visualization is not up-to-date. The *Signal History* check box in the *Options* window is enabled for tracking the client system based on history of signals. *Signal History* impacts the accuracy of well location quality. In EPE, the location accuracy is better if several signal strength updates are received from the tracked device within a short period of time since EPE [Kealy1 2009] utilizes information of the signal strength readings received in the past, with the currently reported signal strength readings to pinpoint the current device location accurately.

- **Track**: On clicking this option, it opens an image window that locates a laptop or a Wi-Fi tag on the map. ELS calculates the current location of Wi-Fi device using the same location tracking algorithm as in the EPE. The tracking can be activated by clicking the *Track* option, or by selecting *View -> Track* from the menus.

- **Signal View**: Displays the currently measured signal strength in color green and the noise in color red. The Red Cross in *Signal View* indicates that the Wi-Fi adapter is not supported.

All the above toolbar options help to visualize the accuracy at a location and set some options for high-quality tracking of client systems or Wi-Fi tags. The *Toolbars and Menus* section is very useful section as it gives many options for the user to accurately survey the location area and create a positioning model where the location signal is good.
3.2.2.3 Lists Section

The Lists section shown in Figure 3.15 is used to acquire the information about the access points, surveys recorded and zones created. The following paragraphs provide a brief explanation of the various options present in the Lists section.

**Figure 3.15 Lists Section**

- **Access Point List:** In this option, detected access points are automatically listed with their MAC address and SSID information after performing a survey. In addition to listing and sorting access points using the column headers, one can select certain access points for location tracking. The access points checked as *My* are used in location tracking by the EPE. The other access points are disregarded in location tracking. By default, all access points are selected as *My* APs.

- **Survey List:** Surveys performed for creating a positioning model are listed here with survey name and the map in which they are created. There are two types of surveys:
- Calibration Surveys: These surveys are used to train the positioning engine about the measured signal environment throughout the site. The calibration surveys cover the whole area where location tracking is used.

- Test Surveys: These surveys are used for analyzing the location accuracy of the map area. If survey data is assigned as a test survey, the system will use the location algorithms to post-calculate the location accuracy throughout the areas covered with the test surveys. By default, all the surveys performed are defined as calibration surveys for EPE. Before visualizing the location tracking accuracy, one needs to define some surveys as test surveys.

  - **Zone List:** The Zones list shows the zones and the related map they are created in. Zones are created on the map image for defining the areas of interest that need to be used in the location tracking application.

3.2.2.4 Steps to Creating a Positioning Model in ELS

To track the location of client system or Wi-Fi tag, one must create a positioning model by surveying the map area, and saving the model to EPE. The following steps describe how to create a positioning model:

- Insert the map using the toolbar option **Map Add** button. For optimal performance, one must use maps smaller than 2500 x 2500 pixels and supported image formats are BMP, WBMP, JPG, JPEG, PNG, and GIF. For multi-floor building, add multiple maps, one for each floor during the time of creating rails.

- Set the scale using the **Map** section icon **Scale**. One must measure the real-world distance between two points on the map to set the scale. This was done with a measuring tape to calculate the distance between the two points. Once measured the distance, select the **scale** icon and indicate the distance between the two points by clicking the first point, and holding down the left
mouse button, while moving the mouse pointer to the second point. A line between the two points and a tool tip indicating the number of pixels is shown, click on the tool tip on the “ft/m” field and type in the distance between the two points in feet or meters.

- Define the tracking environment by creating a path of movement of the tracked devices on the map image using the Map section icon Rail. Select the Rail icon; place the tool on map image, click at starting path and move the mouse to the end of the path. Once finished, double-click the left mouse button or click the right mouse button. To connect the Rails, move the mouse pointer on an existing Rail, and an indication appears that the Rails will connect. Rails improve the location accuracy as it indicates the routes the client system will walk. Rails do not force the tracked device to be located on the Rails, and they do not completely disallow the tracked device to take the paths that are not indicated by the Rails. Instead, the Rails just indicate that some paths are more likely than others. Rails and survey data must be close to each other.

- Optionally create open areas using the Map section icon Open Spaces. Open spaces are defined for the larger areas and meeting rooms. Select the Open space icon and keep left-clicking the map to define the Open space polygon or rectangle. Once finished, double-click the left mouse button or click the right mouse button. Open spaces with areas smaller than 250 square feet are not acceptable. For the highest possible room-level accuracy and if location coverage is excellent in the room areas, define each room as an Open space.

One cannot draw the Rails inside Open spaces; Open spaces and Rails should never overlap. Rails and Open spaces need to cover the whole area that is used for location tracking. Calibration survey data should be collected wherever Rails and Open spaces exist. Use the calibration quality visualization to see if enough surveys have been performed on the Rails and Open spaces.
- Optionally define zones using the Map section icon Zones. Zones are the areas of interest that are communicated via EPE to the applications. Zones are created in human-understandable names for locating the map to represent restricted areas. Zones must not be smaller than 250 square feet in size and in open areas the zones should be at least 10 feet. For the purpose of the prototype, six zones were defined in the map.

- Conduct the survey using the Map section icon Record Survey. The recorded survey data acts as the basis of the reference model used by the location tracking algorithm. When the system tracks a Wi-Fi device, the live signal readings are compared to the previously recorded data. To perform a survey, click the Record Survey icon, click the current location on the map with left mouse and start walking by moving the mouse over the path and click on the location to form a sample point in the map whenever one stops, starts walking or changes direction. By default the data is recorded continuously during a survey, not just when one clicks on the map. One should record more sample points in the areas that have very less accuracy.

Two way continuous recording helps to gather more data during the survey, which eventually means higher location accuracy. In addition, one only needs to click twice at the beginning and at the end, when walking a straight line in a hallway. Right click on the map to finish the current survey. Release the Record Survey icon when finished recording. To move or delete survey points, right-click on a survey point and select Move Survey Point or Delete Survey Point options. If several persons are surveying the areas at one time, the results are merged as one at the end using Merge option in Menus section. To merge, select the files, open the first project, select File -> Merge, browse for the second project that needs to be merged with the first one. It imports survey data, rails, open spaces, and zones.

- Perform real-time testing of location accuracy using Track icon in the Toolbar section.
- Analyze and optimize the location tracking accuracy using visualization (calibration quality, location coverage, map, zone and location accuracy and more) and access point selection (All, My, Other and Highlighted AP’s)

- Save the model to EPE using File -> Open/Save to/from Engine from Menus section. Start using the new model in the EPE, leave the Activate checkbox checked when saving the model to EPE. Insert the engine IP address login information prior to connecting to the EPE using default user name, password and port number (8550). Use File -> Open from Engine option to open a previously stored model from the EPE. Models are stored in the EPE as a list. The screen shots of opening and saving the positioning models from/to EPE are shown in Figure 3.16 and Figure 3.17.

![Figure 3.16 Open a Model from the EPE](image-url)
The uploaded position model is shown in the **Models** page of the EPE.

In creating a positioning model using ELS [Ekahau Location Survey 2007], one must consider the following:

- The ELS software becomes unstable if images are larger than 5000 x 5000 pixels, maximum image size recommended is 2500 x 2500 pixels
- The ELS software becomes unstable if more than 50 hours of data is recorded

### 3.2.2.5 Analyzing Location Tracking Accuracy

Accuracy of an Ekahau RTLS [Ekahau Location Survey 2007] system depends on several factors. The two most important factors are number of access points and accuracy visualizations for the map area. In the following paragraphs these factors are examined to design and improve a location-aware 802.11 network:

- **Access Points:** Accuracy depends on number of access points used in an area, the more the access points, the better the accuracy. Accuracy is good near the access points and is better in closed space than outdoors. Accuracy degrades if the environment is very dynamic, like people walking all the time, closing and opening doors and moving larger items. The more survey data collected, the better the accuracy.
- **Visualizations:** Visualizations use EPE algorithm to calculate and display the map location accuracy in different areas. The different visualizations present help to know and improve the accuracy of a map location. Calibration surveys are used in some of the visualizations as the reference data to initiate the location tracking model. Test surveys are used in some of the visualizations to represent the data sent by the tracked device. A few visualizations are presented in the following paragraphs:
  
  - **Calibration Quality:** This visualization [Ekahau Location Survey 2007] is selected to ensure that enough surveys are recorded to start using location tracking. It also shows how well the surveyed data covers the *Rails* and *Open Spaces*. Figure 3.18 shows the output after selecting calibration quality visualization for all access points.

![Figure 3.18 Calibration Quality Visualization](image)
The green color on the path of the map image represents high calibration quality; survey data fully covers the *Rail* or *Open Spaces*. Here there is no need to perform more surveys in the area. If yellow color is present on the path of the map image, it represents moderate calibration quality; survey data covers the *Rail* or *Open Spaces*, but more surveys may be required for high accuracy. If red color is present on the path of the map image, it represents low calibration quality; i.e. survey data does not cover the *Rail* or *Open Spaces*. In Figure 3.18 there is no need for surveying any more as the calibration quality is high and is indicated by the green color along the full path.

- Location Coverage: Location Coverage estimates the wireless network performance in the location tracking area. The estimate is done by looking at a combination of signal strength and signal overlap. Location coverage is displayed with colors, ranging from red to green. If there is not enough coverage in the Wi-Fi network to start with, achieving high accuracy will not be likely. Figure 3.19 shows the output after selecting the Location coverage visualization for all access points.
Figure 3.19 Location Coverage Visualization

The green color on the map image represents excellent coverage, the yellow color on the map image represents good coverage, the orange color on the map image represents moderate coverage and the red color on the map image represents low coverage.

- Map Accuracy: Displays signal colors if the client device is located on the correct floor and when both calibration survey and test survey is checked present in the *Lists* section. Figure 3.20 displays the map accuracy. The green color on the map image represents that the client device is located in the correct map and the red color on the map image represents that the client device is located in the incorrect map. The path of the trail is also indicated by red color when the test survey is selected.
Figure 3.20 Map Accuracy Visualization

- Zone Accuracy: Displays the accuracy inside the zones when both calibration survey and test survey is check marked present in the Lists section. Accuracy is indicated as a percentage number of location estimates calculated inside the zone when the client system is physically inside the zone during the test survey. Figure 3.21 displays the screen shot of zone accuracy. The green color inside the zones represents excellent percentage of accuracy, the yellow color inside the zones represents good percentage of accuracy, the orange color inside the zones represents moderate percentage of accuracy and the red color inside the zones represents low percentage of accuracy.
Figure 3.21 Zone Accuracy Visualization

- Number of Access Points: This visualization displays the number of clear access points in each location on the map image. Signal overlap is required for achieving high location tracking accuracy, but does not guarantee high accuracy. Figure 3.22 provides a visualization of the number of access points present in the map image. Blue color on the map image indicates that there is only one access point; green color on the map image indicates that there are more than one access points; red color on the map image indicates that there are 20 or more access points. For purpose of clarity, the locations of actual physical access points are marked with a large X by the researcher.
Zone Similarity: This visualization investigates if the signal environment is unique for each Zone. A unique signal environment is required in order for the zones to be distinguishable from each other. This is used for analyzing measured accuracy of the zones. If the zones are similar and the access point infrastructure cannot be modified, bigger zones need to be defined, which are further away from each other. Zone similarity highlights the inaccurate zones. One must mark the check box of calibration surveys in the Lists section for verifying the zone similarity. Figure 3.23 presents zone similarity visualization on the map image. In Figure 3.23 zone 5 is highlighted in a different color, indicating that the tracked client system may be incorrectly located, when present in this zone.
3.2.3 Ekahau Finder: As previously described, Ekahau Finder (EF [Ekahau Finder 2005]) is Web browser based software that displays location of client systems (laptops) and Wi-Fi tags as a blue dot on the map image only when there is connection between the EPE server machine and Ekahau client system. Ekahau Finder is installed on the same server with the EPE and is accessed using the address http://<Finder host IP address>:8560 with default user name and password. Finder users are created and managed through the EPE user interface.

After logging into the EF, access to all the finder interface options for viewing the tag or client system are obtained. EF interface consists of a Home page, Find page, and Maps page. Home and Find pages include features like finding and listing Wi-Fi enabled devices in a given map or zone. The Maps page displays an interactive map view with real-time location tracking.
of all Wi-Fi devices. The **Maps** page displays the map image of the active model from EPE and shows the client position with a blue dot on the image as shown in Figure 3.24. To list and switch between available maps, click the *Map* dropdown list present above the map image.

**Figure 3.24 Maps Page**

Map view displays the location of all client systems and tags present on the selected map only when the map image belongs to a positioning model that is active in the EPE. By placing the mouse pointer over a dot on the map, the name of the tag or client system is displayed. Clicking the dot will display a tag or client system information window from where LED/Buzzer of the tag can be enabled. To zoom the map image click on the map and then select zoom in or zoom out from the pop-up menu. The zoom slider on the left side of the map image can also be used to zoom in and out. To highlight one or all zones on a map, select a name or all from *Zone* drop down list. The **Maps** page must not be refreshed at a rapid pace when viewing system
movement as this causes the Ekahau Finder to get stuck. The updated location of all client systems and tags is seen on the map.

3.2.4 Ekahau Client Controller (ECC): As previously described, ECC is a software service that runs on the background in client laptops for the EPE server to track the location of it. After installing ECC, Ekahau Client Properties window is displayed as shown in Figure 3.25.

![Ekahau Client Properties Window](image)

**Figure 3.25 Ekahau Client Status Tab**

The Ekahau Client Properties window has five tab options that help to see whether the client system is connected to the EPE [Ekahau Positioning Engine 2005] server or not, and for setting the client system properties. The following sections detail the functionality of each tab.

3.2.4.1 Status Tab

The Status tab displays a green dot indicating that the client system is recognized by the EPE server machine as shown in Figure 3.25.

3.2.4.2 Setting Tab

The Setting tab displays two check boxes that allow starting the Ekahau client software automatically as the computer starts and displays the path to the Ekahau client log file.
3.2.4.3 Engines Tab

This tab displays the EPE information if the server engine is connected using Ekahau Client Connector software as shown in Figure 3.26. When using the default positioning engine settings, all available positioning engines appear in the Recently discovered Engines list box. Positioning engines properties like the name, IP address, and IP Port are viewed by clicking the Properties button.

![Ekahau Client Properties](image)

**Figure 3.26 Ekahau Client Engine Tab**

To only allow requests from known positioning engines the Accept by default checkbox must be unchecked. The positioning engine settings are saved by clicking the Add button, and then choosing a name for the positioning engine from the drop-down list box. The Accept column checkbox can be unchecked to block positioning requests from specific positioning engine.

3.2.4.4 Scan Set up Tab

This tab as shown in Figure 3.27 has two radio buttons, either one of them can be selected. Site Survey/Calibration Mode is useful when the user is trying to find out signal
strength at various locations in the area. *Location Tracking Mode* is selected when the EPE server is actually tracking the user location information. The appropriate network band is selected in these modes for tracking the client system.

![Ekahau Client Scan Setup Tab](image)

**Figure 3.27 Ekahau Client Scan Setup Tab**

### 3.2.5 EPE API Reference:

As previously described, EPE API routines are the Web services provided in the developer page of Ekahau. These API routines help to create applications that make use of location tracking information and are based on HTTP/XML Web service technology. Most of the API routines are accessed by a Web browser found at the address `http://< Engine host IP address >:8550/epe/developer`. In the following paragraphs there is detailed explanation of the Web service technologies and some of the most important API services.

- **HTTP:** HTTP is a request-response protocol. Request something from the server, and the server sends a single response. Single API call is executed using a HTTP request through a Web browser in the engine with input parameters. Now the engine sends back a response as an XML document. Each API URL present in the developer page represents a separate API command and
defines its own input parameters and output responses. All the HTTP URLs are located under the single root /epe/ as shown in Figure 3.28.

![Figure 3.28 Ekahau Developer Page](Image)

Ekahau API [Ekahau API 2008] supports both HTTP GET and HTTP POST type requests. HTTP GET request has no enclosed XML document to describe the input parameters. Here the input parameters are provided with a standard HTTP query notation. The output response from the engine is always an XML document. Calling methods are different in both HTTP GET and HTTP POST, but logically both the request and the engine response are the same. The following examples show the use of the HTTP GET and HTTP POST calling methods.

HTTP GET request:

http://localhost:8550/epe/pos/taglist?fields=posgood&mapname=LIB-II-Floor
HTTP POST request:

```
<?xml version="1.0" encoding="utf-8"?>
<request>
  <PARAMS>
    <fields>posgood</fields>
    <mapname>LIB-II-Floor</mapname>
  </PARAMS>
</request>
```

- **XML**: XML is the primary data encoding scheme of Ekahau APIs. The engine sends output response as an XML document. Top levels of XML document have objects or messages, and the intermediate levels have properties of object. The response from the engine starts with an XML preamble that specifies the character set for the XML document. Following the preamble is the root element <response>. The actual output response is always enclosed inside the <response>. The following example shows the XML output when the API present in /epe/pos/taglist/ service is called:

URL request `http://localhost:8550/epe/pos/taglist?fields=posgood&mapname=LIB-II-Floor` displays list of tags that are located in the map “LIB-II-Floor”.

```
<?xml version="1.0" encoding="utf-8" ?>
<response>
  <TAG>
    <tagid>81344905883</tagid>
    <mac>00:12:F0:88:C2:9B</mac>
    <posx>148</posx>
    <posy>402</posy>
    <posmodelid>115</posmodelid>
    <posmapid>0</posmapid>
    <poszoneid>-1</poszoneid>
    <posmapname>LIB-II-Floor</posmapname>
    <posquality>30</posquality>
    <posreason>3</posreason>
    <postime>1246895788296</postime>
    <postimestamp>2009-07-06 10:56:28-0500</postimestamp>
    <poscounter>210770</poscounter>
    <battery>100</battery>
  </TAG>
</response>
```
Services: On the developer page there are many different API services available for the programmer to use. These APIs are grouped into several logical services. Some of the most common and useful services are discussed here.

/epe/pos: This is a positioning service that provides the positioning data of the tags, either from the database or from real-time, i.e., directly from the EPE using positioning algorithm. Two most important commands in this service are: /epe/pos/taglist and /epe/pos/tagstream.

/epe/pos/tagstream continuously get tags or client systems positions in real time. Here the connection stays up forever and receives multiple responses for a single request. Location coordinates are updated as fast as the Engine calculates them. The URLs described here displays x and y coordinate values continuously of a client system that is called with different options in real time:

http://localhost:8550/epe/pos/tagstream?mapname=LIB-II-Floor

/epe/pos/taglist lists the tags and their properties. This command provides powerful search and sorting functionality. The URLs described here displays x and y coordinate values of a client system that is called with different options real time:

http://localhost:8550/epe/pos/taglist?mapname=LIB-II&fields=all

/epe/mod: This is a model service that uploads and downloads positioning models created using Ekahau Location Survey. Two most important commands in this service are:
/epe/mod/mapview to displays map image of a given model and /epe/mod/modelbrowse to list the maps and zones information of a given positioning model.

/epe/map: This is a map service that renders map images with tag positions. Command /epe/map/render display tags or client systems location on the map; /epe/map/mapview displays an image of a map and /epe/map/render displays location of a client machine on the map image.

The URLs described here display client system location on the PNG map


/epe/test: This is a test service that helps to test HTTP communication and code of client application in various cases.

Most of the services discussed above use the HTTP interface; however there are some services that don’t use the HTTP interface. HTTP is only used to provide status information for applications. Services like /epe/tag and /epe/rec execute protocols for Ekahau tags and they don’t show up as interface.
4. EVALUATION AND RESULTS

The initial concept of the location sensing mobile system for campus touring was to have a complete tour guide prototype for the whole campus. After installing the complete Ekahau RTLS package on a server and the client on a laptop computer, the researcher started to evaluate the Ekahau RTLS for a single floor (3rd floor) of the CI building by creating several positioning models using ELS and saving them to EPE to track the client system. After some initial experiments and careful observations, it was soon discovered that the client was not being tracked accurately by Ekahau RTLS. Ekahau RTLS [Holloway 2007] needs a strong network of AP’s to locate the client system accurately, whereas the third floor of the CI building had only one access point for the Wi-Fi connection. According to the campus networking department, one AP was sufficient on this particular floor, but they ignored the fact that there were some blind spots [Huang 2006] (where there is no Wi-Fi signal). They were not ready to install more AP’s on the floor.

The tour guide application for the entire campus would be difficult to implement as there are many open areas between the buildings which result in numerous blind spots. This resulted in the tour guide application shifting to the second floor of the library as this floor has 3 AP’s which provide better coverage. Several positioning models using ELS on this floor were created to know the accuracy of each position on a trail which covered all the important locations that a user would follow.

After creating a trail with more accuracy than that in the CI building, several positioning models were created using one way and two way survey modes. All these models were saved to the EPE, and only one model is active at tour time to track the location of a client system with ECC [Ekahau Positioning Client 2008] software installed on it. The movement of the client system is seen in the EF software on the active model map as a blue dot. Even with many
different types of surveys performed and with more than two access points the client system was not tracked continuously as the user was moving. When the client was close enough to an AP, then a blue dot could be seen in the Ekahau Finder exactly where the client was located at that instant of time. But, when the client is in a blind (or weak signal) spot, then the blue dot moves in a random fashion on the trail, and is spotted at random locations on the trail.

Ekahau T301-A tags were evaluated next for their performance on the same trail as the client system. As described previously, Ekahau T301-A is a small battery powered active Wi-Fi tag [Wi-Fi Tags 2008] for tracking assets and people. It is attached to any mobile object or equipment or asset and is carried by people in a pocket or worn as a wristband.

The tag as shown in Figure 4.1 contains two configurable buttons for switching the tag on and resetting the tag to its factory settings. These buttons send alarms or other messages from the tag to integrated applications. Location reporting is triggered by a button or by a periodic timer. The tag is also equipped with two multi-color (red/green/orange) LEDs that provide status signal. The tag’s LEDs and buzzer can be remotely triggered for visually and audibly identifying the correct tag or for alerting personnel.

![Figure 4.1 Tag T301-A](image)
The tag activation is performed using Ekahau Activator T301 software that initially configures Ekahau T301-A tags wirelessly and allows connecting the tag to EPE over the network. Once the connection is established with the EPE, all configurations can be managed through tag Configs page in EPE [Ekahau Positioning Engine 2007]. In the Ekahau Activator software window, the Engine activation tab parameters Positioning Engine settings, Scan settings, WLAN Settings and IP Settings associated with the Wi-Fi network and EPE server are entered for the tag to be activated. When the Activate button present in the Ekahau Activator software window is clicked, the Activation window opens and displays all the parameter settings that are entered. A tags left blue button is pressed until both LED’s blink orange. Later the right white LED starts blinking in orange, red and green. If the activation is successful the right white LED stop’s blinking with 2 green blinks, and the tag’s MAC address appears in the Activation window, displaying ‘Ok’ status. This process is repeated for all the tags requiring activation. After successful activation, the MAC address of the tag appears on the EPE list on the Tags page. Once the MAC address of the tag is seen in the EPE, its location can be tracked in a fashion similar to the client.

The results with tags were very similar to the client system. If the tag was close to an AP, a blue dot was seen in the Ekahau Finder exactly where the tag was located at that instant of time. But, when the tag was in a blind spot [Huang 2006], the blue dot moved in a random fashion on the trail, and was spotted at random locations on the trail. Moreover, the battery on these tags was quickly depleted.

Reviewing the results of the client system and the tag, a conclusion was reached to discontinue testing with tags. In addition the tags were not useful for a touring application.

Using the real time coordinate values of a client system, the Electronic Tour Guide application was developed in two modes: Free Walk Tour and Guided Walk Tour. The tour guide
application was developed using VB.net and works in both directions of a path in the second floor of the library.

The $x$ and $y$ coordinate values of the client system (laptop) were stored into a file by walking the trail. These values are used for the two tour modes to verify if the status information is displayed accurately or not based on the client location. Figures 4.2 – 4.16 are the screen shots of the Electronic Tour Guide application in two tour modes. For the purpose of debugging, the $x$ and $y$ coordinate values were displayed on the Electronic Tour Guide interface.

In the Free Walk Tour mode, when the user is moving on the right side of the path, the status information is displayed at various locations as seen in Figures 4.2 – 4.8. The green dot indicates the current location of the user with the client. The images of the tour using the left side path are not shown because the results are exactly the same.
Figure 4.2 displays status information “You are at stairs” when the user is located near the stairs.

Figure 4.2 Free Walk Tour Mode on Right Side Path - Stairs
Figure 4.3 displays status information “You are at Main Collection” when the user is located near the Main collection area.

Figure 4.3 Free Walk Tour Mode on Right Side Path - Main Collection
Figure 4.4 displays status information “You are at Reference Collection” when the user is located near the Reference collection area.
Figure 4.5 displays status information “You are at Science Lab” when the user is located near the Science Lab area.

Figure 4.5 Free Walk Tour Mode on Right Side Path - Science Lab
Figure 4.6 displays status information “Keep Walking…Not a Location” when the user is not located in any of the designated areas.
Figure 4.7 displays status information “You are at Conference Room” when the user is located near the Conference room area.

Figure 4.7 Free Walk Tour Mode on Right Side Path - Conference Room
Figure 4.8 displays status information “You are at Stairs” when the user is back at the end of the free walk tour and near the Stairs.

![Bell Library Tour](image)

**Figure 4.8 Free Walk Tour Mode on Right Side Path - End of Tour**

In *Guided Walk Tour* mode, when the user is moving on the right side of the path, the status information is displayed at various locations as seen in Figures 4.9 – 4.16. The green dot indicates the current location of the user with the client. Note that the guided tour system displays the appropriate left and right turns if the tour is started as a left side path.
Figure 4.9 displays status information “You are at Stairs…Keep Walking” when the user is near the Stairs area.

Figure 4.9 Guided Walk Tour Mode on Right Side Path - Stairs
Figure 4.10 displays status information “Approaching Main Collection…Turn Right” when the user is moving on the right side path and his next location is Main collections area.

Figure 4.10 Guided Walk Tour Mode on Right Side Path - Approaching Main Collection
Figure 4.11 displays status information “You are at Reference Collection…Keep Walking” when the user is located near the Reference Collections area.
Figure 4.12 displays status information “Keep Walking…”, as the user is not located near any of the specified areas present in the Guided Walk Tour.

Figure 4.12 Guided Walk Tour Mode on Right Side Path - Keep Walking
Figure 4.13 displays status information “You are at Science Lab…Keep Walking”, as the user is located near the Science lab area.
Figure 4.14 displays status information “Approaching Conference Room…Turn Left” when the user is moving on the right side path and his next location is Conference room area.
Figure 4.15 displays status information “You are at Conference Room…Keep Walking”, as the user is located near the Conference room area.

Figure 4.15 Guided Walk Tour Mode on Right Side Path - Conference Room
Figure 4.16 displays status information “You are at Stairs...Keep Walking” when the user is back at the end of the Guided Walk Tour and near the Stairs.
5. CONCLUSION AND FUTURE WORK

Many new students and visitors struggle to find their way around campus especially as it continues to expand. The Electronic Tour Guide application generates interest in the University as this is an automated tool which assists students and visitors to move around the campus. The application developed is useful in guiding the user to a point of interest, and to let him know the current location. The whole process is accomplished using Wi-Fi access points, Ekahau RTLS, and an application developed using Microsoft VB.NET. The system supports the extension of the application by adding new buildings maps and Wi-Fi access points.

The Electronic Tour Guide application can be extended for multiple floors and later for multiple buildings using ELS software. This software has the option to join the survey data of multiple floors and buildings into one positioning model to be saved to the EPE to identify the client system or a user on any floor and any building. A possible approach to explore in the future would be to incorporate more AP’s, sensors, and Radio Frequency Identification (RFID) [Polizzi 2004] tags to overcome the problem of Wi-Fi blind spots. Options such as displaying the photo image of the client’s location and surroundings, displaying the history of the area and map zoom functionality can be incorporated into the Electronic Tour Guide application.
BIBLIOGRAPHY AND REFERENCES


