A Distributed and Parallel Sampling System for Efficient Development of Radio Map

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Abstract - *Received Signal Strength based positioning systems can enable many potential context aware ubiquitous computing scenarios. Accuracy of such positioning is based on radio map reference database that provides mapping function between user location and signal strengths. Previously, the development of radio map remained major issue in wide scale adoption of this technology. We propose an integrated distributed and parallel sampling approach to facilitate radio map database development. Results show faster development of radio map and noticeable reduction in database size.*

Keywords: Radio Map, Received Signal Strength, Indoor Positioning Systems

1 Introduction

Position of client is very important parameter for Context-aware Ubiquitous computing applications. WLAN signal strength based localization applications include, but not limited to, a wide range of services to the end user like automatic call forwarding to user's location, robotic global localization, and exploration and navigation tasks. [16], Finder, Guiding and Escorting systems, finding first hop communication partners, liaison applications, location based advertisement and positing of entities in large warehouses.

Positioning using Wireless LAN received signal strength (RSS) is increasingly popular choice due to IEEE 802.11 (a, b, g) standard's pervasive adoption and cost effectiveness. Such positioning systems require calibration of target site in order to map locations with respective RSS. This mapping is referred to as location map, radio map, location fingerprints or calibration data in various Location Awareness systems [3] [8] [10] [15] [14] [17]. We will refer this entity as "radio map" in rest of this paper. In site calibration phase, all target locations in physical space are mapped to respective signal strengths in signal space. Resulting data is then stored in radio map database as ordered sequences. Fig. 1 shows typical methodology for generating radio map. This technique is gaining increasing attention for indoor applications mainly because other popular techniques e.g. GPS do not perform well in indoor environments. Widespread deployment of Wireless Local Area Networks (WLAN), so called WiFi (Wireless Fidelity), has given a rise to development of WLAN based Location awareness in modern context-aware ubiquitous computing environments. 802.11 (a) standard operates in the 5-GHz unlicensed national information infrastructure (UNII) band. On the other hand 802.11 (b, g) standards operate in 2.4 GHz band. Which provides a total available signal bandwidth of 300 MHz and 85 MHz available for a, b and g respectively. 802.11a standard supports channel bandwidths of 20 MHz, with each channel being an OFDM modulated signal consisting of 52 sub-carriers. [4]

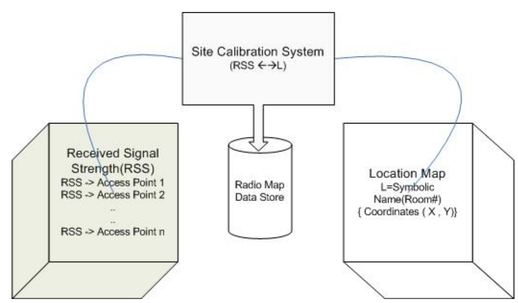

Fig. 1. Development of radio map

Performance of WLAN localization systems can be measured in two aspects namely; accuracy and precision. Accuracy accounts for the distance error that system yields over a period. It has been represented in terms of statistical measures e.g. average, standard deviation or median error in previous work. By precision we mean the granularity that localization technique provides in square meters. Evidently, in order to achieve finer granularity of localization, up to 3 meters, system requires detailed calibration of target site and complexity of localization algorithm increases. Precision aspect also defines the maximum distance error that system can tolerate. Fig. 2 shows the conceptual relationship between site calibration effort, system complexity and target granularity of localization system. Since radio map plays the role of reference map for localization techniques, the accuracy of location estimation is directly linked with the correctness of radio map. As the measurements of RSS become less reliable, the complexity and error of the position algorithm increases. Therefore rapid and accurate calibration of target site is established as major issue in adoption and deployment of Location Aware systems. One approach to this problem is to develop radio wave propagation models to predict the RSS at a given location. Later this information can be used to map locations with predicted RSS and positioning algorithms can use this radio map. Since indoor radio wave propagation is too complex to be modeled and predicted at finer granularity levels, model based localization systems do not provide fine grained location information. Second approach is to facilitate the calibration process in a way that it becomes easier for generating radio map and repairing it in case of any topological changes in the environment. Despite an extensive research being put into location estimation techniques, to the best of our knowledge, no dedicated effort is reported to rapid and comprehensive radio map generation. Earlier, site calibration for location awareness has been limited to a stand alone system, residing on handheld devices, that allows user to insert his current position while detecting signal strengths. We present a distributed and parallel computing approach to expedite development of comprehensive radio maps for Location Awareness. A novel method of RSS data collection is presented. Results show noticeable improvement in calibration speed and reduction in radio map database size.

2 Related Work

As WLAN positioning systems are becoming a viable choice, a lot of research has been carried out in this direction. From radio map database point of view such systems can be categorized in two classes, Beacon-based WLAN positioning and Fingerprint-based WLAN positioning. Intel's Place-Lab [18] positioning system is often referred example of radio beacon based positioning systems. RADAR positioning system of Microsoft [1, 2] is pioneering work in Fingerprint-based positioning systems. Two main differences between both methods are i) granularity of target location and ii) total coverage area that they provide. Radio beacon-based systems focus on greater coverage, such as campus wide, and provide coarse granularity of location information, up to 25 meter. On the other hand fingerprints based systems provide fine-grained location information, up to 3 meters, and cover relatively smaller areas, such as in side the building. Although both kinds of systems require radio map as backbone of the system, our work can more effectively be employed for Fingerprint-based positioning systems. Essentially fingerprints are received signal strength vectors from available wireless access points (AP) in the area taken at discrete locations. Radio map database hosts fingerprints data as reference point for the positioning system. Recently, some researchers have proposed statistical manipulation of RSS data to reduce the effort and time required for building a radio map. John *et al* employed radial basis functions to interpolate the missing data of un-calibrated locations [6]. Binghao Li *et al* employ krigging interpolation used in mining variograms to reduce the number of calibration locations for building a radio map and used 12 samples for each location. [11] [9] proposed a method of using unlabeled samples for reducing the sampling rate at each location and number of locations. One subtle dependency of these approaches is that, they calibrate the denser set of reference points first, and then remove less influential points out of them. It is still hard to calibrate only the few reference points without the knowledge of signal strength at un-calibrated points. Since number of samples taken at each location and number of locations calibrated affect the accuracy of positioning technique. Creating a denser radio map by interpolating sparsely calibrated locations implies critical trade offs between accuracy of Location estimation technique and completeness of the radio map. Most of the work has oversimplified the complex nature of radio wave propagation by using few samples of signal strength for a target location. It gets more hypothetical when one tries to interpolate un-calibrated locations using the insufficiently calibrated set of locations. Despite reducing the number of calibration points, these techniques still need to calibrate the area. That makes our work beneficial for previous approaches also.

3 Our Approach

We propose an integrated distributed computing approach that can support multiple roaming devices to take part in site calibration simultaneously, thus facilitating the faster radio map generation. Location Aware applications are best implemented with the support of middleware infrastructure, namely Location-ware, as described by Uzma [21] and Mahrin [22]. Location-ware essentially provides an API and framework for implementing distributed system in a highly dynamic mobile computing environment. Moreover same API can be used for testing and evaluation of a positioning system. Since Wireless LAN based positioning techniques are strongly relative to a particular site and no general system can be developed for all wireless sites. Testing and evaluation task faces with the same problems as site calibration. So the same distributed and parallel computing approach can be employed for gauging the performance (accuracy and precision) of a positioning system. In section 4, we elaborate the API and reference implementation of Location-ware. Besides, our system allows real time visualization of RSS of all available wireless base stations, giving more insight into the nature of wave propagation at different locations. Thus, providing an efficient way to analyze the properties of WLAN and achieve optimal WLAN coverage, enhancing the positioning system performance. Besides, we developed a novel method for capturing and storage of RSS data. Since the radio map size and complexity increases exponentially as the area of interest becomes larger. We integrate histogram based data collection method in calibration system that reduces radio map size without compromising on the quality of radio map.

4 System Architecture

Location-ware architecture follows distributed component approach to realize the concept of distributed and simultaneous site calibration. Whole system is divided in three sub systems. I) Calibration Agent: deployed on handheld devices, ii) Calibration Server: deployed on stationary workstation iii) Radio map: provides target database wrapper API, and radio map manipulation components. We shall present only the calibration agent and calibration server subsystems in the scope of this paper.

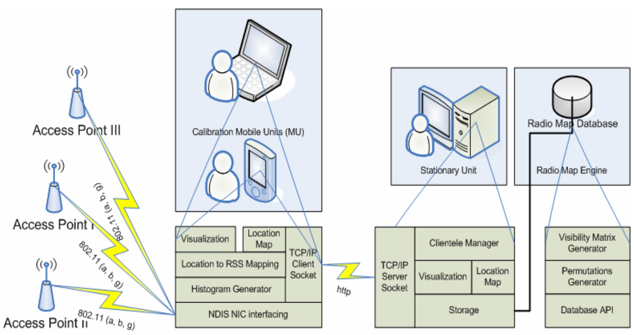

Fig. 2. System Architecture Building Blocks

Figure 3 provides architectural view of how subsystems integrate into Location-ware and their respective components. Since component based approach is used in building up the whole system, this feature allows on demand addition or removal of the components from the system. That means handheld devices can use only WiFi scanning component as classical site surveying tool. And combined with Visualization component charting of the WiFi signal patterns is possible. Similarly at the stationary unit, statistical analysis component can be used for analysis of any time series. And visualization component provides charting of the radio map stored in the database. All components expose their functions through standard API (Application Programming Interfaces) that allows the programmer not only to plug in/out these components from there applications but also use its features without knowing the internal details of the implementation. In the next section we will present details the core components involved in system.

4.1 Calibration Agent

We refer to the subsystem that resides on hand held device as Calibration Agent. Although these components can be deployed on other small handheld devices, for actual calibration task we used TOSHIBA M-30 notebook with built in Intel PRO/Wireless 2200 BG Network card and HP iPAQ Pocket PC h4150. Calibration Agent sub system API are shown in Figure 4.

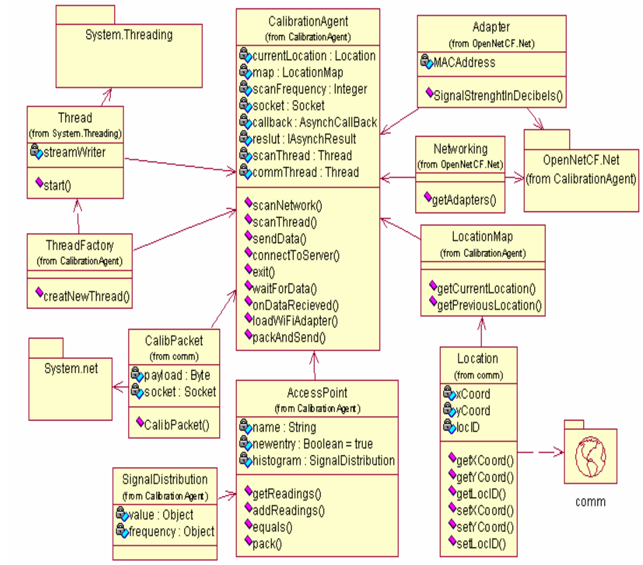

Fig. 3. Calibration Agent UML class diagram

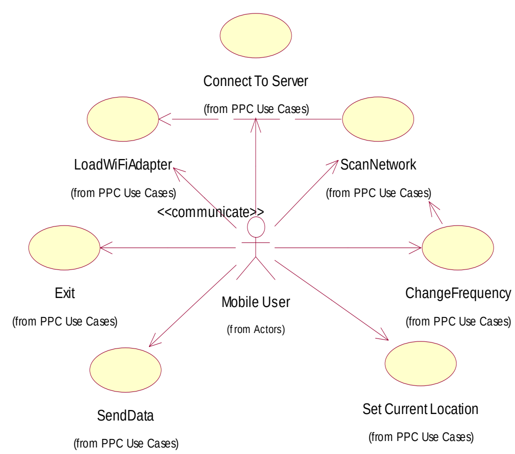

Fig. 4. Calibration Agent Use Cases

Calibration Agent allows users to perform different tasks related to calibration. Fig. 5 shows use cases that specify the user – system interaction scenarios. As we discussed in section 2, taking few samples at location is not sufficient enough for building a reliable location estimation technique for real world scenario. Insufficiently calibrated point might lead to misleading conclusions about the location at the time of positioning. Figure 3 shows histograms of RSS observations at a stationary point for two different periods of time. It is obvious that short term RSS observations exhibit different variations than long term observations.

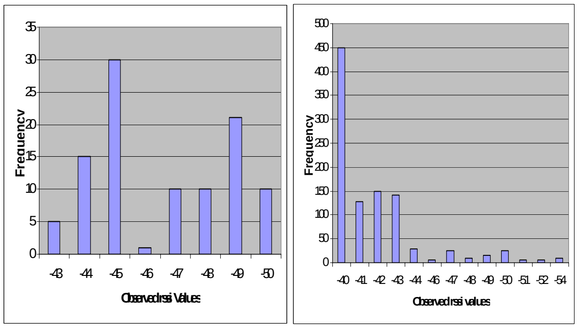

Fig. 5. RSS observations at stationary location Left) 100 Observations Right) 1000 Observations

4.1.1 Network Scanning

'Scan Network' operation allows user mode applications to start the process of scanning network properties. It sends a probe packet to nearby APs and captures required information from the response packets. Essential capability of a site calibration system is to capture properties of wireless network e.g bssid (Basic Service Set Identifier), rssi (Received Signal Strength Indicator). Commercially available and open source like netstumbler[13] meet this requirement but these systems are more focused on network traffic analysis, intrusion detection, layout management and are not meant for collecting data for location awareness. While site calibration system requires a subset of there capabilities, still these systems fall short of providing capture, storage and analysis of received signal strength data for location awareness. This capability can be implemented as software driver at the top of Wireless Network Interface Card (NIC). This layer hides vendor specific implementation of hardware and allows user mode applications to query NIC in a standard way with uniform accessibility and representation of required information. IEEE 802.11 (a, b, g) specifies that signal strength measurement must be reported by the network interface card (NIC) as part of standard compliance. [4]. The RSSI is measured in dBm, normal values for the RSSI value are between -10 and -100. [18] Capturing wireless signal from available Access Points remains the fundamental task in building site calibration systems. A standard library for signal capture should be employed that can hide different hardware vendor specific details of signal capture. MAC driver then interprets the response frame and takes note of the corresponding signal strengths. Figure 7 shows the list of Wireless Access Points in range of handheld device after a probe. For laptop Calibration Agent Subsystem, we used rawehter API [23] for Windows XP for capturing the wireless packets. It allows a user-mode application to "directly" access NDIS network interface card (NIC) drivers from Win32 applications. Network Driver Interface Specification (NDIS) is a common programming interface[18]. Media-access controller (MAC) device drivers "directly" access NDIS network interface card (NIC) drivers from Win32 applications using a NDIS protocol driver. On the other hand for Pocket PC device we employed OpenNetCF smart device framework [24].

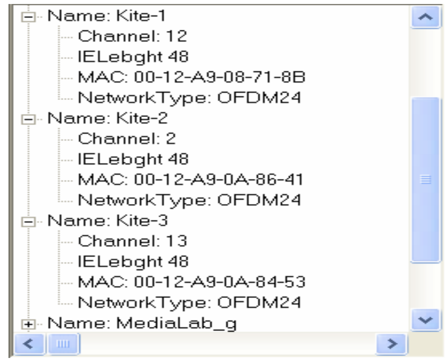

Fig. 6. List of Wireless Access Points

Another unique feature of Calibration Agent network scanning operation is aggregation of all observations into a histogram. Listing 1 shows the histogram algorithm which constructs an rssi data aggregation in Calibration Agent memory.

Listing 1: Histogram making Algorithm

1 Create a two dimensional array *'Histogram[m,n]'*

2 Create a flag 'newEntry'

3 Create a node 'HistogramSize'

INPUT: rssi value as integer
OUTPUT: *histogram* of rssi values

4
For Each count **In** 'Histogram' **Do**
  If rssi **is same as '**Histogram[Count,0]' **Then**
    Set 'newEntry' = false
    Increment Histogram[Count,1] ++
    Return Histogram
  Else
    Set 'newEntry' = true

5
If newEntry **is** true **Then**
  Set Histogram[HistogramSize,0] = rssi
  Increment Histogram[HistogramSize,0] ++

4.1.2 Lazy Sampling

'Change Scan Frequency' allows user to change scanning frequency through GUI. This provision allows signal capture at dynamically configurable intervals. By increasing the sampling interval, one can avoid temporal spikes in signal strength due to environmental factors. Fig 8 shows time series graph of signal strengths at one location from Kite 3 access point. Red circles show the temporary drop in signal strength that can be filtered out using lazy sampling.

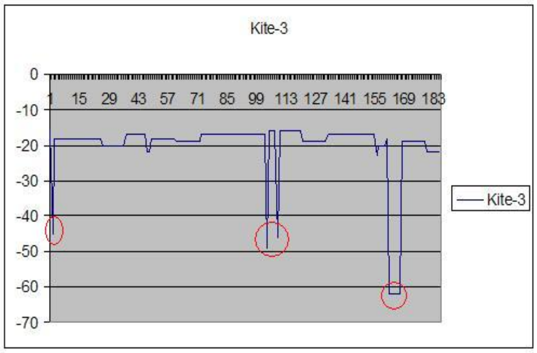

Fig. 7. Temporal spikes in signal strengths

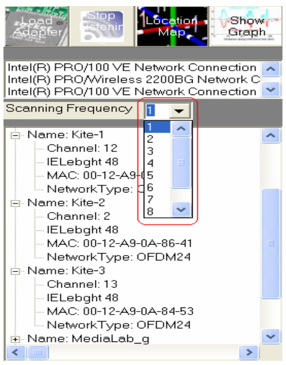

Fig. 8. Controlling WiFi signal scanning rate

Fig. 8 shows GUI for controlling sampling frequency dynamically. Our scanner component exposes this capability through standard programming interface. Client mode applications can choose their preferred rate of network scanning. This capability is implemented in our system as GUI control.

4.1.3 Location Map

This facility provides a reference map of target area that needs to be calibrated. User specifies his location and Calibration Agent binds the respective location with received signal properties. Calibration Agent provides active location map of the site in order to allow the user to pinpoint the current location of observation.

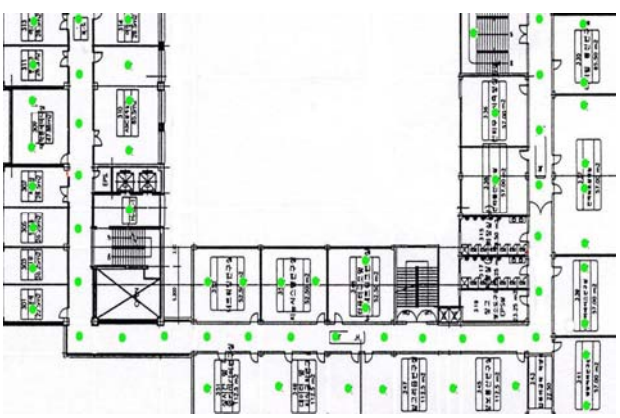

Fig. 9. Example Location Map

Fig. 9 shows sample Location map which is used in prototype of site calibration system. Location of all reference Access points is marked as red circle. And different calibration points are marked with green circles.

4.1.4 Communication Scheme

After calibrating one location, "Connect to Server" use case establishes connection between Calibration Agent and Calibration Server. TCP/IP sockets are used for communication. Network communication component on handheld device registers itself with the Calibration Server and get and MU-ID response from server. Later this MU-ID is used to report WiFi signal information, acquired from all Access Points in range, back to the Calibration Server. At the SU side, network communication component registers every MU roaming in site and manages all the incoming information using client management system using multiple independent threads of communication. Once connection is established, "Send Data" use case allows user to send calibration data of that location to server and let user know about the received acknowledgement from server. Calibration Agent uses Wireless LAN to establish connection and send/receive data to/from Calibration Server. On the other hand Calibration Server is connecter with local Ethernet network. Above this layer both subsystems use TCP/IP protocol to address each other. Sockets layer implements asynchronous mechanism for communication. Asynchronous communication allows distributed collaborations of multiple mobile devices with Calibration Server run smoothly. Figure 10 shows layered view of infrastructure that allows communication between Calibration Agent and Calibration Server.

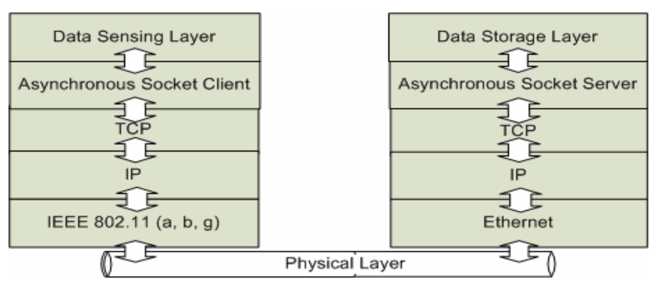

Fig. 10. Layered Model for Communication between Mobile Units and Calibration Server

4.1.5 RSS Visualization for Optimal WLAN layout

Real time visualization of captured radio signal properties is provided as plug in feature. A very unique feature of indoor positioning applications is that the size of the coverage area is much smaller than outdoor applications. This makes it possible to conduct comprehensive planning of the placement of Wireless Access Points. Careful planning of a Wireless network can significantly reduce measurement errors of location metrics caused by NLOS (Non Line Of Sight) propagation. RSSI measurement may (either deliberately or incidentally) include adjacent channel energy that can influence the performance of positioning algorithms [4]. Therefore layout of the Access Points and adjustment of frequency channels, to be used by each Access Point, in order to minimize the adjacent channel noise is very helpful for not only optimal coverage but also for positioning system. Graphical representation of radio wave gives visual clues to mapping function between location and received signal properties. An open source charting library ZedGraph is employed to visualize received signal strength of each Wireless Access Point [19]. Each point of the graph corresponds to the scanning frequency set by the user. Fig.11 snap shot shows graph of received signal strengths captured by Calibration Agent from three signal sources.

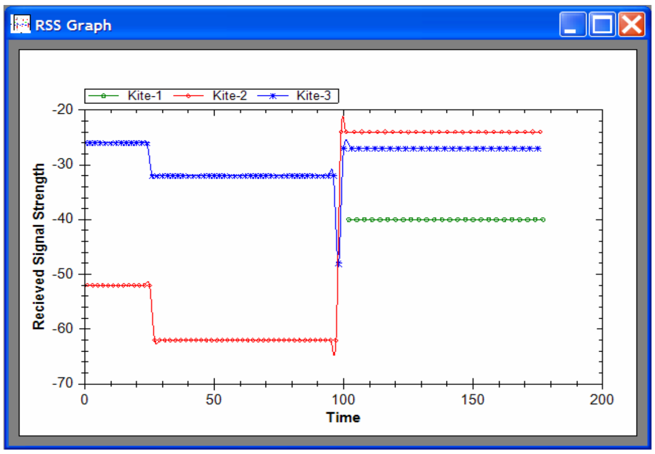

Fig. 11. Real Time visualization of received signal strengths

4.2 Calibration Server

On the other hand, stationary unit performs the important task of managing simultaneous incoming information of every MU. Calibration Server has three main components: i) Communication Component ii) Clientele Manager iii) Real Time Charting Component. Communication component is responsible for receiving rss data from multiple roaming devices and send acknowledgement packets to individual device. Calibration server classes and their interrelationships are shown in figure 12 class diagram. CommServer class encapsulates wireless communication details, storage mechanisms, calibration data parsing, parallel client processes and exposes standard functions to the developers for making web browser or other GUI calibration server applications. XL class provides interfacing with excel sheets to store calibration data while Calibration Data class represents a histogram structure for in memory storage of rss data of each access point.

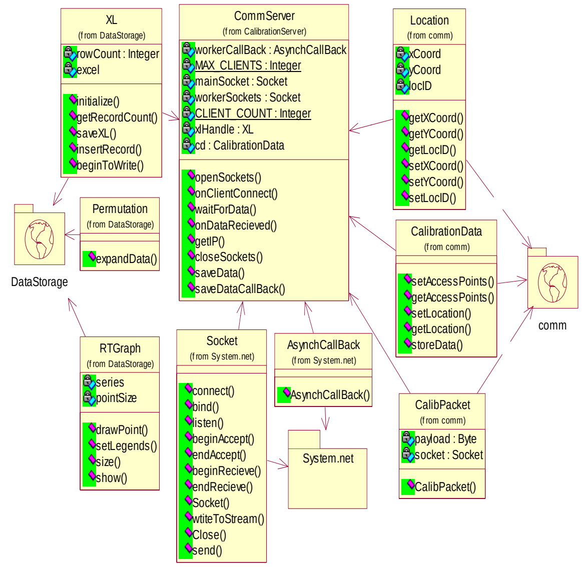

Fig 12. Calibration Server Class diagram

4.2.1 Clientele Manager

This component is responsible for registering remote calibration devices in clientele registry and managing communication with individual devices in separate processes. Calibration Server sends an acknowledgement to individual devices containing the receipt of total number of records saved in database on behalf of that particular device. Clientele Manager Component manages this operation and sends respective information to each mobile device. Besides, clientele manager allows broadcasting some message to all mobile devices on behalf of Calibration Server.

5 Prototype Implementation Results

In this section we will present comparative results that make Location-ware a considerably competent system against previous approaches. Firstly we shall present the affect of calibration speed due to the simultaneous calibration and concept implemented by Location-ware using asynchronous communication model. Then network load analysis is presented in order to help reader appreciate histogram based communication protocol. Since our data collection method differs considerably from previous approaches, we shall present its affect of radio map database size while considering the scalability issue.

5.1 Affect on Calibration Speed

Figure 13 shows affect of simultaneous calibration on calibration speed.

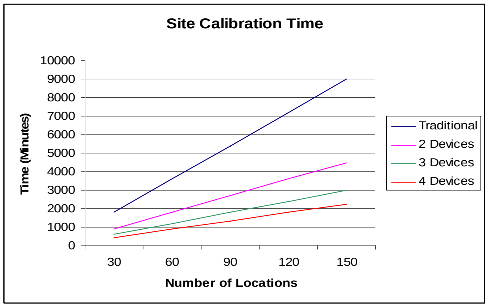

Fig. 13: Affect simultaneous calibration on Calibration Speed

As the number of handheld devices increases the calibration time tends to decrease proportionally. If N is the number of collaborating devices to calibrate L locations, where n indexes over all locations such that $\{L_1, L_2, L_3 ... L_n\} \subset L$, and calibration time spent on one location is t then the total calibration time is $T = \frac{t \times L_n}{N}$.

5.2 Network load

Since multiple devices can be involved in site calibration, intelligent mechanism should be used to save on network calls and handheld devices power resources. Figure 14 shows how much network load is decreased in terms of network calls. In case each observation is sent over the network, ScanNSend scheme, then for 210 locations there shall be more than 10000 network calls. Keeping in view the intermittent availability of Wireless LAN infrastructure and limited battery resource on handheld device this scheme is prohibitive. Given the fact that multiple devices are calibrating the area, it is highly difficult to manage parallel executing threads on Calibration Server to avoid illegal write operations on shared memory data structures. On the other hand, StoreNSend scheme provides a graceful method allowing longer battery life, many times less network calls and aggregated rssi observations. Although StoreNSend scheme results in nearly ten times more payload in comparison with ScanNSend.

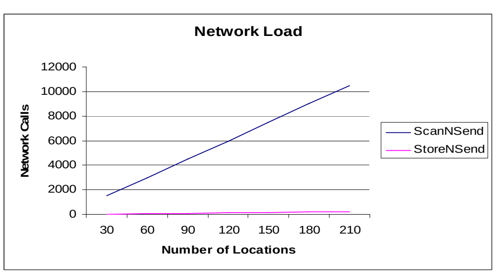

Fig. 14: Decrease in Network Load using StoreNSend communication scheme

5.3 Radio Map database size

Radio Map database size is dependent on three factors: i) Number of Location ii) Samples per Location iii) Number of Access Points. Figure 15 shows three graphs for different values of three factors. In left graph second and third factors are constant (100 samples per location and 3 Access Points).

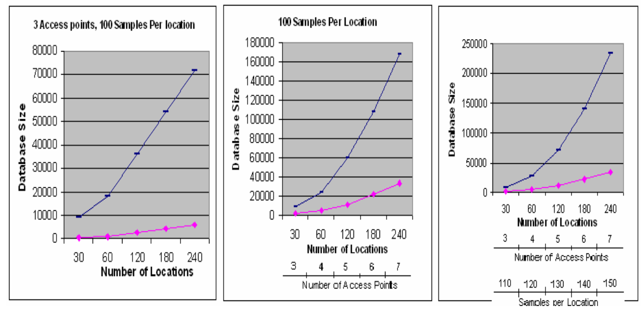

Fig 15: Affect of Histogram Based approach on radio map database size

In the middle graph Number of Locations and number of access points are increasing and listed on x-axis. In the right graph all three factors are listed on x-axis. As the area of interest gets larger, the number of locations increase and it becomes impractical to keep number of Access Points constant because in farther locations radio signals tend to fade away. Histogram based approach drastically reduces the radio map database size without any loss of information.

6 Conclusions

Wireless site calibration for location awareness is fundamental task in the process of developing WiFi based positioning systems. Time and effort required for site calibration is major tradeoff for accuracy and precision of such systems. Wireless LAN calibration has been limited to standalone applications running on resource constrained handheld devices. We employed a distributed parallel computing approach to facilitate the calibration task. This approach allows sufficient sampling of radio map and multiple devices can take part in this process simultaneously. Besides calibration, our system helps planning the layout and channel allocation of Wireless LAN Access Points for optimal coverage. Asynchronous communication and histogram based calibration significantly help smooth collaboration of multiple devices in calibration task. Store and Send communication scheme reduce network traffic with negligible increase in payload. Moreover, a considerable reduction in radio map database size saves memory and location estimation computational time.

7 Acknowledgement

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