MapUme: Smartphone Localisation as a Service

A cloud based architecture for providing indoor localisation services

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***Abstract*—Accurately determining the user's position is considered the key enabling technology for the provision of location based services on smartphone devices. The most promising approaches to date for achieving accurate indoor coverage are based on WiFi fingerprinting in combination with complex estimation and filtering algorithms. In order to meet these computational requirements for a large number of devices a localisation system must be inherently distributed to provide real time responsiveness to all users at all times. Furthermore, to make such a system commercially feasible those computational resources sometimes cannot be maintained by the localisation service provider itself but have to be dynamically allocated in the cloud always based on current and not on peak demand, which depending on the application can vary significantly and thereby render static systems commercially infeasible in these cases. In this paper we will propose such a cloud based architecture enabling the immediate demand driven provision of computational resources to connected devices.**

***Index Terms*—Smartphone localization, Indoor localization, Integration platform, Cloud computing**

I. Introduction

Smartphones have long since moved from being a mechanism to access email on the move for business people to an affordable commodity in the mainstream consumer market. As a result smartphone devices have woven themselves in to the fabric of our everyday lives and users expect much more than simple email access. Driven by user demand many application developers are creating new and innovative applications that take advantage of the smartphones capabilities such as mobile gaming, social networking, news, maps to name a few. Location-based services plays a key role in empowering developers and users to take advantage of a vast array of applications such as geo-social networking, multimedia guides,targeted advertising and health and safety. Must of the location based applications are built on the freely available GPS technology and as a result are restricted to outdoor scenarios. A significant number of research works have been published presenting solutions for indoor location tracking that utilise Wi-Fi fingerprinting in combination with complex estimation and filtering algorithms [1], [2], [3], [4], [5], [6], [7]. Although this approach is not without its challenges [8] it has proven to be the most promising when providing accurate indoor coverage. However this results in significant computational requirements to maintain real time responsiveness to all users at all times for a large number of devices. Furthermore, depending on the specific application the demand for location information can vary dramatically requiring an architecture that is inherently dynamic in nature when allocating resources. By statically allocating resources to meet peak demand can render the system commercially infeasible in some cases.

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In this paper we will present MapUme, an opportunistic location system for smart phone devices that enables localisation services that work seamlessly in heterogeneous environments including indoors as opposed to GPS based outdoor-only systems. MapUme is built on a cloud based architecture enabling the immediate demand driven provision of computational resources to connected devices. The presented indoor localisation system allows the simultaneous accurate localisation of a large number of users without relying on heavy client side processing, which would use up the limited smartphone's computational and energy resources. We will describe the proposed architecture and demonstrate the systems performance under varying peak demand scenarios and show how commercially feasible smartphone indoor localisation services can be provided utilising the elastic infrastructure of the cloud.In particular we will report on our experience in the trade show application space and the challenges it poses by requiring the system to provide localisation services to thousands of exhibitors and visitors over a very short period of time in a highly dynamic environment.

II. MapUme Architecture and Components

The advances of Cloud computing brings new opportunities for location based services. Using a cloud-based architecture, sensory information is still generated in each client device but is processed and aggregated within the cloud. This information is then available for users or services to share among each other via the cloud or for knowledge mining of these location datasets across a large numbers of users. The benefits of cloud computing for location based services are clear, there is minimum large up-front capital on data centres, eliminates the need to plan ahead for provisioning and allow companies to invest in increasing resources as needed [9]. Companies such as Trimble and Qualcomm offer cloud based solutions however mostly as a content delivery mechanism rather than a dedicated positioning service.

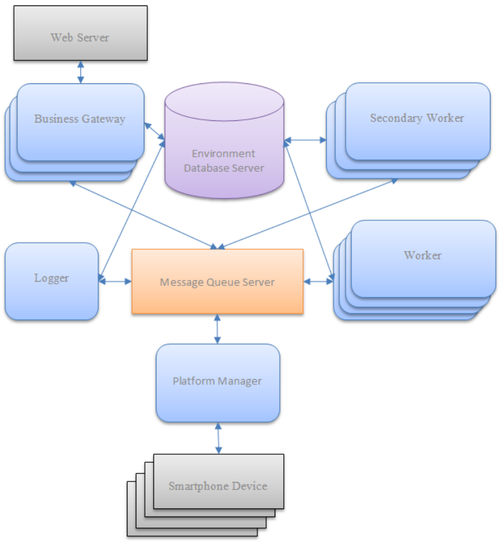

Fig. 1. MapUme General Architecture

MapUme is a computational platform which is built around the concepts of an event driven architecture combined with dynamic service composition and invocation principles. The design goal of the computational platform architecture is to create a scalable, distributed and extensible platform that allows for the collecting of sensor data from a large number of subsystems, to provide computing resources to process those measurements into meaningful quantities and finally make this processed information available to business applications on top of the platform. From the end-users point of view the platform therefore serves the purposes of providing an abstraction layer between the sensor/actuators subsystems and the application that through its scalable and distributed design allows the leveraging of the processing capabilities of cloud based server infrastructures. From the developers perspective the platform offers an architecture that provides interfaces to the devices, context information and to the business application while at the same time providing scalability and distributed processing capabilities.

The MapUme platform comprises of a set of interacting components as depicted in Fig. 1. An important design paradigm within the platform is inversion of control and dependency injection. This concept allows the decoupling of the interface a service provides from its actual implementation, thereby removing dependencies between the individual components. Furthermore every service of the platform is wrapped up automatically within a proxy enabling monitoring of the service execution as well as a transparent remote service invocation. The components can be distributed over the network or into the cloud so that each of those components runs on an individual machine in order to increase the amount of processing power necessary to deal with large number of smartphone devices connected to the system. The platform implements a communications infrastructure provided by transparent message services. The web-server, message queue server and database server that are used within the platform are all off the shelf components and can be interchanged with other technologies where needed. All these components come with the ability to run on a cluster, so it can be expected that they will be able to meet MapUme scalability requirements without further modifications. The business gateway provides data and knowledge to end user applications and published via the web-server. In case the web-server is clustered the business gateway will run several instances across the cluster, so it scales with the demand driven from the business perspective. The platform manager and workers are the key components of the architecture and will be described below.

A. Platform Manager

The creation of a worker service is usually (but not necessarily) triggered by a device subsystem transmitting its data to the platform. The platform manager will in this case assign a service to the device and request it to be created if necessary. If the appropriate service for the device already exists the data will be passed on to this service. At the same time broadcast events in the platform are monitored and relevant messages are sent back to the device subsystems. The platform manager is also responsible for monitoring the worker services and keeping its device to worker service mapping database up to date. This mechanism allows distributing the worker services over the network and provides a scalable infrastructure for meeting extensive processing demand.

B. Workers

The central component of the MapUme platform is the worker service known as the Localisation System Manager which is an requestable service within the localisation platform. The task of the Localisation System Manager is to manage a thread pool of Localisation Engines, one for each device, and to pass on the sensor data received from the Device Interface Listener. It receives back the estimated position data and finally broadcast it through the Position Receiver queue to all interested services. The Localisation Engine uses the sensor measurements together with environment data such as floor plans and fingerprints from an Environment and Configuration Manager in order to estimate the position of the device. The MapUme localisation dynamic model is hierarchically structured and non-deterministic using probabilistic graphical models (PGMs)[10]. It offers a compact graph-based representation to model a joint probability distribution of latent and observed random variables exploiting conditional independencies. These statistical independence properties are exploited for efficient inference and learning. Every time the position is updated it is broadcasted to the Position Receiver queue, which distributes it to the Logger service that writes everything to the database, to the Instant Data Generator service, which is responsible for pushing the updated position back to the devices, as well as to the Business Gateway. The Business Gateway is then used by the web server in order to make all the information available to business applications. The processing intensive parts of the platform are the localisation engines for each connected

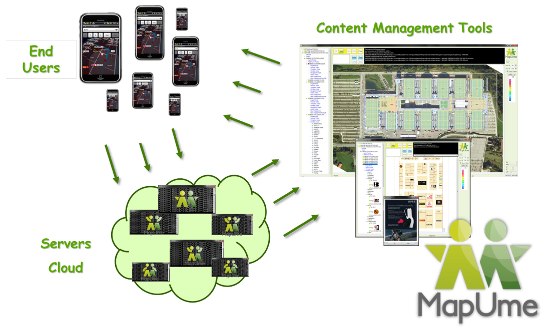

Fig. 2. MapUme Platform for Trade Show Scenario

phone which run within the primary workers. Those workers are running in the cloud so as to meet this processing demand by allocating additional processing resources if needed. Certain computational resource intensive tasks could also be outsourced to the secondary workers by the platform. However from the scalability point of view it makes no difference if the primary or the secondary workers are used.

The MapUme computation platform utilises it own cognitive capabilities to predict and plan the computational requirements in order to optimally provision computational resources to the components with the goal of keeping the costs under control and thereby making the approach feasible in a real-world commercial application. This context aware processing approach goes beyond the state of the art of current cloud-based middleware platforms, which are by design general purpose processing engines that cannot take any such context information into account and have to base their load prediction solely on statistical analysis of past workloads[11], [12]. MapUme's location services are built on this computation platform for online data collection, aggregation and logging, for online/offline data processing and analysing and environment modelling.

III. Case Study

To analyse the performance of the MapUme technology, a number of deployments have been carried out in various sites including an office buildings, college campus, shopping centres, lab environments and at large trade fair venues. The most challenging of these environments was the trade fair scenario, due to the dynamic nature of the environment and the large number of users that require location and context information over a short period of time. For large trade show events visitors wish to utilise their time as efficiently as possible, exhibitors want to communicate and connect to the right people, organisers want to provide an experience for all parties involved that is memorable to ensure repeat business. The ability to achieve these features is only enhanced by the availability of real time location and context information that can be provided by the MapUme platform. Fig. 2 shows the architecture for the trade fair environment the services provided include:

- Visualisation of your current position in a 3D hall map and provide navigation to any exhibitor or facility (toilets, restaurants, etc.)
- Locate your colleagues without disturbing them with a phone call (especially useful for exhibitors)
- Exhibitors can add any information they like to their stand in the map (dynamically and in real time from a web browser)
- Provide targeted information to visitors (suppliers of X product are highlighted for visitors who have said they are interested in X product)
- The system allows real time communication and updating for example event/meeting scheduling.

A key requirement from the venue organisers is the ease of installation and management, the process employed must be efficient with easy to use tools. The procedure to set up a new deployment in a trade fair using the MapUme tools takes just three steps before localisation can take place:

1) Define the map of the environment including the position of specific area of interests, i.e. exhibitor booths, facilities
2) Using a smart phone application calibrate the system by collecting a fingerprint of the received signal strength in the area you wish to cover
3) Submit calibration measurement to the server for automated processing

The remaining steps involve users of the system populating relevant context information that is communicated to all other users where appropriate. Fig. 3 shows a screen shot of the phone application with the users location displayed on the map of the environment.

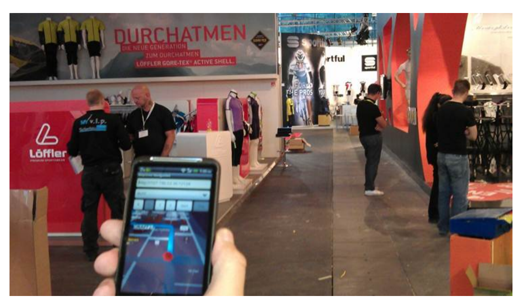

Fig. 3. MapUme phone application

The localisation accuracy was measured by collecting an independent set of calibration data using the fingerprint application. This data was then fed into the system using a device simulator and the deviation between the actual positions and the positions returned by the system were recorded. The histogram of these localisation errors in a real trade-fair environment of approximately $6270m^2$ is shown in Fig. 4. It can be seen that on average a localisation accuracy of better than 10m is achievable by the system. The following sections outline the evaluation of system performance in terms of system scalability.

To evaluate the performance of the platform in terms of the number of devices that it can handle workers were deployed on

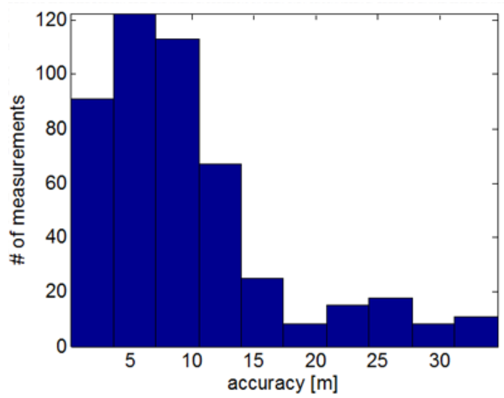

Fig. 4. Histogram of Localisation Accuracy

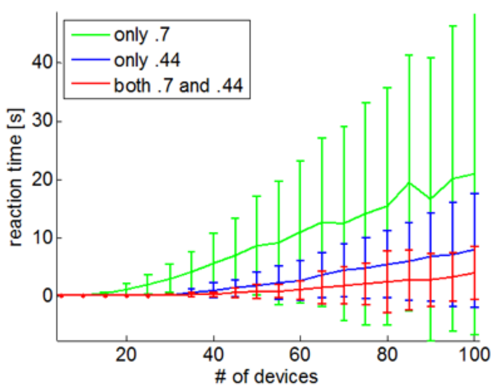

Fig. 5. Evaluation of System Scalability

two different machines and the response time was measured, i.e. the average time between sending an RSSI reading to the platform and receiving a position estimate back. This was done for different numbers of devices served simultaneously by the platform. Fig. 5 plots the response times against the number of simultaneously served devices. We used an older and slower machine (.7), which was able to serve up to 10 devices simultaneously before the response times and their standard deviation started to deteriorate. On a faster server (.44) the response times worsened after 30 simultaneous devices were utilising the platform. However, even with 100 devices the average response times remain below 10 seconds, although the increasing standard deviation means that some users have to wait unacceptably long in this case. To overcome this limitation one of the major design goals of the platform was to run distributed and therefore allow for scalability, i.e. allow serving more devices simultaneously using more servers. It can be seen in Fig. 5 that if we use both servers together the number of devices that can be served simultaneously without any performance degradation increases to 40, which is the sum of the number of devices served by the individual machines alone indicating a linear dependence between the number of devices and the number of servers as desired. Even above that limit, i.e. when the platform becomes overloaded, the response times are better if both servers are used together.

IV. Conclusion

The future of indoor location based services requires an architecture that is low cost, dynamic in nature and one that scales with the varying user demands depending on the environment utilising these services. This paper presents such an architecture known as MapUme built on concepts of distributed and dynamic service composition and invocation. MapUme was deployed at a large trade fair and was shown to provide location accuracy within 10m which is more than sufficient to support the location based services delivered through its scalable platform for the event. The platform was designed to meet the challenges posed by the trade fair environment i.e. the dynamic nature of the environment and user need for context information.

Acknowledgment

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