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A Software Engine for the Rapid Development of Mobile Asset Management Systems

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by

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UNIVERSITY OF CALGARY

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Abstract

Developments in computing, location and wireless technologies have caused great advances in the field of Location Based Services (LBS). A particular subset of LBS, Mobile Asset Management Systems (MAMS) has attracted the attention of industry because of its potential for improving productivity, safety and security. However, obstacles remain that have hindered the adoption of MAMS by corporations. These obstacles include the large number of technologies and providers that are available, plus the isolated nature of MAMS development that creates duplication of effort and resources. This research has focused on creating a development platform that offers the fundamental functionality required by MAMS, enabling developers to use it as a foundation for their applications while reducing duplication of efforts. This platform is created using Java and leverages object-oriented application frameworks to realize advantages in maintenance and ease of integration for developers. It offers two-way communication and control capabilities in conjunction with remote sensors and a widespread cellular network. Data management and storage capabilities are provided and access to assets is available through the Internet with just a browser. The location of assets can be overlaid against maps in vector and raster form. Testing was successfully conducted using vehicles in multiple locations in Canada and the USA.

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List of Symbols and Abbreviations

AMPS	Advance Mobile Phone Service
AS	Page Server
ASP	Active Server Pages
AVL	Automatic Vehicle Location
CAD	Computer Aided Design
CDPD	Cellular Digital Packet Data
CGI	Common Gateway Interface
CS	Client-Server
CSMA/CD	Carrier Sense Multiple Access/Collision Detection
DS	Data Server
FCC	Federal Communications Commission
FOCC	Forward Control Channels
GIF	Graphic Interchange Format
GIS	Geospatial Information Systems
GPRS	General Packet Radio Service
GPS	Global Positioning System
HTML	Hypertext Markup Language
HTTP	Hypertext Transfer Protocol
IMAMS	Internet-based Mobile Asset Management Systems
IMEMS	Internet-based Mobile Equipment Management System
ISAPI	Internet Server Application Program Interface
*i*VCAMS^3	Internet-based Vehicle Control And Monitoring System for Safety and Security
JDBC	Java Database Connectivity
JPG	Joint Photographic Experts Group
JSP	Java ServerPages
JVM	Java Virtual Machine
LBS	Location Based Services
MAMS	Mobile Asset Management Systems
MAMSDev	MAMS Development Platform
MEMS	Mobile Equipment Management System
MIN	Mobile Identification Numbers
MLSS	Multi-Layer Storage Scheme
MOM	Message-Oriented Middleware
ODBC	Open Database Connectivity

OO	Object-oriented
PNG	Portable Network Graphics
RECC	Reverse Control Channels
RPC	Remote Procedure Call
RTT	Radio Transmission Technology
TCP/IP	Transmission Control Protocol/Internet Protocol
UHF	Ultra High Frequency
WWW	World Wide Web

Chapter 1

Introduction

1.1 Background

Developments in widespread, robust yet inexpensive location and wireless communication technologies have resulted in an explosion of activities in the field of **L**ocation **B**ased **S**ervices (LBS). Timely and relevant information enables informed decision-making and benefits productivity, safety and security. A particular subset of LBS, known as **M**obile **A**sset **M**anagements **S**ystems (MAMS) have garnered significant interest from corporations desiring more efficient means of managing their asset fleets. As assets move and perform their assigned tasks, corporations using a MAMS can effectively monitor how they are being used, how often they are idling and find the most optimal route for their assets to take. Modern mining operations involve hundreds of support equipment such as lightplants, heaters, welding units, electrical generators, graders, dozers and trucks [Ramsaran, 2000]. The location, maintenance and scheduling of available equipment at a mining site are critical to day–to-day operations, since a typical open-pit mining operation can easily cover an area of 40,000 hectares in size. Each piece of equipment therefore has to be at the right place, at the right time and in working condition to prevent any downtime in operations [Gao & Ramsaran, 2000]. Downtime for mining industries is costly to production and can result in millions of dollars of losses [Carter, 1999]. Other promising applications for MAMS include personal vehicle monitoring and security systems because of the large number of automobiles that are stolen or are involved in accidents each year.

The impetus for LBS came out of the demands of the United State's FCC (**F**ederal **C**ommunications **C**ommission) for cellular operators to be able to provide the position of any cellular devices operating on their network to public emergency services, accurate to within 125 meters, as part of the FCC's Enhanced 911 program [Prasad, 2001]. While the deployment of systems actually capable of meeting the FCC requirements by the original deadline of October 2001 has been troubled by technological obstacles and cost [FCC, 2003], the new technologies that have been developed to try to meet the FCC demands have also given arise to new opportunities. Technologies developed originally for positioning within a cellular network or phone designed for emergency location have formed the basis for exciting new developments enabling innovative applications. Figure 1.1 [Prasad, 2001] shows some of the areas that LBS could be potentially used for.

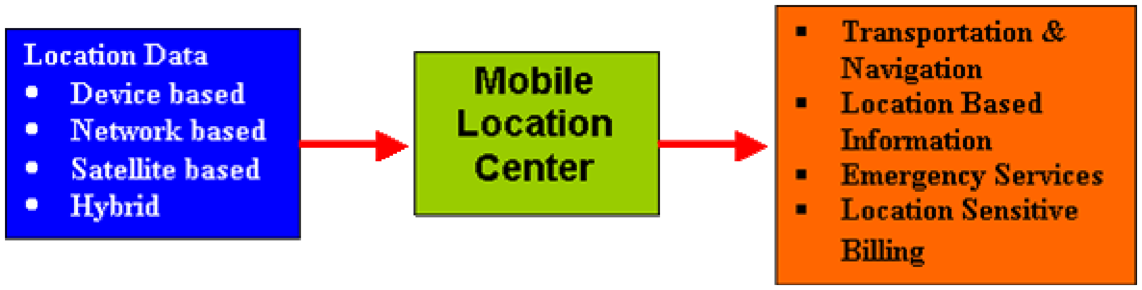


Figure 1.1: Potential Areas for LBS

There are also many possible applications for MAMS. Devices integrating wireless and positioning capabilities could be attached to corporate vehicles and assets for monitoring. Resource operations and corporations with large asset fleets would be the primary beneficiaries here. MAMS could also form the basis of services targeting individuals by providing nearby points of interests or relevant information on demand, using location-aware cellular phones or other wireless devices. The sheer number of applications that can utilize a MAMS are expected to drive the expansion of the MAMS and LBS market [Prasad, 2001; EUROPA, 2003] and have attracted significant attention from industry, users and service providers. Some organizations believe that revenue for the global LBS market will be in the tens of billions of dollars range by the year 2006. One such estimate is shown in Figure 1.2 [EUROPA, 2003].

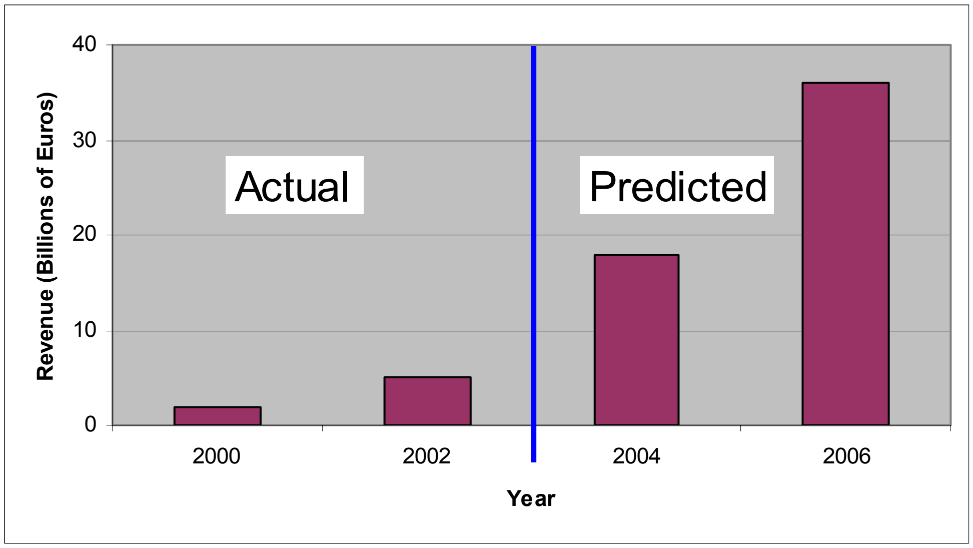


Figure 1.2: Estimated Global LBS Revenue

While these applications can vary greatly in purpose and intended markets, they all share common requirements. MAMS applications have a data acquisition component in the field where location and other important attributes must be acquired. They need to transmit the data back to a central location for storage and analysis. A user component where the data is presented to users must also exist. Continuing advances in computing technology enables more and more computing power to be packaged into smaller devices. Accurate positions can now be determined quickly and inexpensively by using GPS (**G**lobal **P**ositioning **S**ystem). GPS is an all-weather, globally available radio navigation system originally developed by the United States for military purposes but has now become an important component in numerous scientific and civilian applications. The United State's commitment to maintaining GPS as a freely accessible system for the foreseeable future along with the usefulness of accurate position information ensures that the number of GPS-based applications will continue to grow. GPS receiver technology has also advanced to the point where they can be placed onto a microchip, enabling the creation of integrated devices ideally suited for data acquisition on mobile vehicles. Such devices now have the computing power to get positions from GPS, monitor key vehicle attributes and intelligently respond to events such as emergencies.

As the nature of MAMS involves with remote assets that are on the move and users needing to receive asset data in a timely manner for the most effective and safe utilization of assets, the data must be transmitted using wireless communication technology. Wireless technologies have now become ubiquitous in everyday life, from widely available cellular networks for voice and data traffic to wireless networking for convenient access to the Internet. Numerous wireless options can be used, depending on the bandwidth, availability and cost requirements of the MAMS. This availability of an existing wireless communication infrastructure has enabled MAMS to be deployed by service providers without the need to build their own wireless systems and thereby save time and money. By using wireless communication to connect mobile assets with a central office site, the latency can be reduced to seconds [Liu, 2002].

However, once at the office, the data still needs to be provided to the user. One solution to this problem is the Internet. In recent years, the Internet has become a popular method for sending data to users because of its platform independence and global reach. Remote Internet access is also now possible through multiple wireless sources. By using an Internet-based method for accessing asset data, advantages can be realized by simplifying the storage of asset data at only one or just a small number of centralized sources, which aids administrators and allows for changes and new data to propagate through the system quickly. Users can also be confident that they have the most up-to-date information.

There are numerous technologies involved in a MAMS. There are also functionality that overlaps between different MAMS applications. This offers an opportunity for a platform, supplying a suite of useful functionality that can simplify the use of the many technologies and provide common functions. Without such a platform, there would be significant waste of time and resources because each new MAMS being developed would be forced to recreate these common requirements repeatedly. Developers would also need to deal with a multitude of heterogeneous technologies. These challenges have hindered the quicker adoption of MAMS by industry. A platform dedicated for MAMS development would solve many of these challenges by providing a foundation where many of the common requirements are provided and working with the various technologies is simplified. This platform will follow object-oriented principles so it can be used in as many potential MAMS applications as possible and allow developers to further expand and customize it to meet their needs.

1.2 Objectives

In this thesis, the concept of a software engine in support of MAMS has been investigated. This software engine is location aware and helps augment MAMS development by providing critical functionality required in MAMS applications, allowing developers to reuse these functionality and maximize their time and resources on the unique aspects of their applications. While MAMS are the primary application for the engine, it will remain flexible enough so that it could also be extended to other LBS activities in the future. This engine, known as **MAMSDev**, will act as a development platform by offering a complete suite of important low-level functions that developers can utilize as an important foundation for their MAMS applications. **MAMSDev** builds and expands upon the existing work done previously by Liu in creating a wireless framework Liu, 2002] and by Ramsaran in creating a mobile equipment management system [Ramsaran, 2000]. **MAMSDev** expands upon Liu's wireless framework to include functionality to aid all aspect of MAMS, from asset to users. It also expands upon Ramsaran's work by taking advantage of newer technologies and supporting multiple potential MAMS applications, instead of focusing on specifically for a single mining company. **MAMSDev** will undergo real-world testing using existing commercial equipment and networks with interested industrial partners. Major objectives in this research include:

1) Investigating the requirements and specifications of MAMS and examine existing MAMS applications for their pros and cons. The results will be used to create a development platform to meet these requirements.

2) Investigating enterprise capable, client-server technologies plus available sensor and wireless communication technologies suitable for use in MAMS and integration into **MAMSDev**.
3) Development of communication capabilities for **MAMSDev** to interface with selected remote sensors and wireless technologies.
4) Development of data storage and management capabilities for **MAMSDev** to handle incoming asset data.
5) Development of an Internet accessible Web Client component for **MAMSDev**. The Web Client will be used for data serving to remote users and support simultaneous access. Supported data will include geospatial data in vector and raster format plus non-spatial data retrieved from databases.
6) Development of a prototype system performing real-world MAMS tasks that utilizes the new platform for its foundation. This prototype system will help evaluate the value of the platform and provide useful experience and feedback to improve the platform further.

1.3 Thesis Outline

Chapter 2 will review the concept of MAMS and their benefits of improved productivity, safety and security for corporations and individuals. Their requirements and their general architectures are also examined. The Chapter will also look at a number of real-world MAMS in order to discover beneficial aspects that should be part of **MAMSDev**.

Chapter 3 will examine various software and hardware technologies that could be utilized in a MAMS and therefore would be of interest for a platform, such as **MAMSDev**, which is targeted for MAMS development. This Chapter will also examine object-oriented application frameworks and how it improves the reusability of **MAMSDev**.

Chapter 4 will discuss the developmental process of **MAMSDev** and the fundamental architecture and philosophies that were followed throughout its development.

Chapter 5 will detail the actual implementation of **MAMSDev** and its various components. Problems encountered will be discussed, as well as solutions that were used to overcome the problems.

Chapter 6 presents an actual real-world application that was developed using **MAMSDev**. The system's goals and purposes will be presented, along with the details of how **MAMSDev** is used to achieve a system that meets its goals.

Chapter 2

Mobile Asset Management Systems

Advancements in LBS have led to the emergence of a wide range of MAMS applications that are beneficial for many industries. Such systems have already gained attention from corporations with large asset fleets seeking to maximize the efficient and safe usage of their vehicles and equipment by providing up-to-date location information. They have also emerged as a viable commercial business, enabling providers to sell location services to consumers. A powerful new development has been the recognition that instead of having just a one-way flow of information from the asset to the user, benefits can be realized from having two-way interaction between assets and users. With two-way capability, it is possible to remotely issue commands and control assets in real-time, creating a true management system for assets and enabling new and innovative services for the future.

2.1 MAMS for Industry and Individuals

MAMS can be used for corporations, individuals and governments. For corporations, delays or shutdowns in an operation due to equipment not being at the right place or unexpected failures can result in the loss of profits. Even worse, failures that result in injury, loss of life or environmental damage can result in severe harm to corporate image and incur long-term legal costs. Investments spent on systems such as a MAMS are an ideal way to improve the bottom-line as they provide methods for predicting and preventing asset failure [Kane, 2002]. However, many previous MAMS implementations remained limited to simply acquiring equipment locations only. Furthermore, information generated from assets in the field would be stored in centralized data warehouses that typically did not have remote methods for accessing the data [Bistroem & Ray, 1999]. A more useful system would provide additional data and functionality beyond only locations, to become a complete solution for operational decision-making and be able to provide the solution to all end users, whether they are working at the centralized office or in the field. For an example of where this capability can be beneficial, assets operating over a large work area may be left idling in the field due to the inconvenience of manually turning them on and off. It could become possible to shut them off remotely by issuing the command to onboard sensors linked to the asset's electrical systems or engine. Being able to remotely shutdown or turn on an asset reduces costs by allowing idle assets to be turned off, saving fuel, wear and tear and reducing pollution. The last benefit is especially important in light of ever-toughening pollution and environmental protection regulations. A MAMS can also be used for monitoring commercial fleet vehicles, such as those for long haul trucking and public transit. Recent studies have indicated that over one million fleet vehicles in the United States were equipped with GPS-based location system by 2003 and had doubled from 2000 [Driscoll, 2003].

MAMS can also be used to provide location-based services to individuals or corporations. The most common and visible of these services are for vehicles and are commonly referred to as telematics applications. Telematics refers to a combination of telecommunications and computing technologies in the monitoring, processing and relaying of vehicle locations [Honeywill, 2002]. Automotive telematics services integrate cellular and/or satellite telecommunication technologies, location technologies such as GPS with the electronics and computers onboard automobiles to provide navigational, safety and security services [Allan (1), 2003].

The most common use of telematics currently involves vehicle navigation. Navigation systems have become popular in luxury vehicles in the North American market. In foreign markets, such as in Japan and Europe, where cities tend to be more difficult to navigate compared to cities in North America, they have become commonplace in all types of vehicles. Navigational systems are usually divided into autonomous systems and call center systems. For autonomous navigation, vehicles are equipped with an onboard GPS receiver, along with a CD or DVD based computer system containing maps of the driving area. Using the GPS-determined position of the car, the computer system provides audio and/or visual directions to the driver. With call center guidance, drivers interact with a call center for navigational assistance. The GPS receiver remains on the car, but there is no onboard map data. The vehicle's location is sent to the center and a human operator guides the driver to their intended destination through a cellular voice link. An advantage of this system is that there is less distraction for the driver compare to the autonomous system, which can reduce the chances of accidents occurring [Allan (1), 2003]. In addition to navigation, a call center can provide additional useful services for their clients, such as conceriege services and safety monitoring, with safety being an especially compelling selling feature of telematics [Allan (2), 2003]. OnStar, a popular call center based service, handled 500 stolen vehicle requests, 5000 emergencies, 13,000 roadside assistance requests, 27,000 door unlock requests and 220,000 requests for directions on a monthly basis in 2003 [Allan (1), 2003]. Future developments in telematics could result in a more automated control center, whereby systems in the vehicle communicate directly with control centers. Other possible advances include systems that offer drivers the capability to interact with the vehicle and other services through the Internet.

Finally, a MAMS could find its way into government usage. The cost of maintaining the road infrastructure for vehicles and trucks is costly and there are new plans in Europe to utilize telematics and MAMS technologies to implement a pay-per-use system [Vicenti, 2002]. Drivers that drive more, use busier roads or drive at busy periods of the day will be charged more. Programs have already been initiated by the Swiss and German governments for trucks to be installed with telematics hardware [Vicenti, 2002].

2.2 Assets

When referring to assets in the context of MAMS, an asset is anything that has inherent value, or value due to having knowledge of location and other information for a corporation. A wide variety of assets can be managed with a MAMS. The most common uses of MAMS generally have assets of corporate-owned vehicles such as in trucking fleets. In a resource mining operation, there are a variety of vehicles and equipment each with different capabilities, requirements and tasks. For an electrical utility, many of its assets are immobile distribution substations and other electrical network infrastructure along with mobile units that perform maintenance and repairs [Bistroem and Ray, 1999].

For telematics service providers, the managed assets of interest are those owned by clients who have purchased services for their assets.

2.3 MAMS Requirements

To be an effective tool for industry, a MAMS must be capable of aiding in or even performing operational decision-making. It must be able to differentiate between dissimilar assets while seamlessly handling spatial and non-spatial data. To have such capabilities, a MAMS must have an open modular architecture and a seamless flow of information. An open architecture is needed because a MAMS must be capable of collecting and storing information from the field and process data from a variety of databases for performing data retrieval, manipulation, analysis, presentation and decision-making functions. By being open, a MAMS can be more readily integrated with other applications [Ramsaran, 2000]. One of the major problems that have faced corporations in creating MAMS is the short life cycle of new technology investments, resulting in a poor return on their investment and difficulties in integration of different technologies and end-user training [Peck & Murphy, 1997]. A seamless information flow is required because information pertaining to the mobile assets need to be collected from the field, stored into pre-assigned databases, accessed, manipulated and edited by a variety of users. All these steps must be done in a timely manner in order to contribute to the operational decision-making process. Advanced wireless communication, mobile computing along with Internet technologies has now made it possible to have a continuous information flow [Gao & Ramsaran, 2000].

A MAMS must be capable of addressing a number of problems in order to be a credible system capable of aiding the operational decision-making process. Such problems include [Lee & Gao, 2002]:

- The location data of assets, by itself is usually not particularly valuable for most MAMS applications; rather it is additional asset attributes combined with location that is valuable. These additional attributes depend on the application and could possibly include temporal, asset performance and status data. The monitored asset data also needs to have timely availability. The system must be capable of receiving, organizing and distributing these additional data and there must be acquisition capabilities that can provide the desired data from the assets. Accurate real-time data is an important foundation of an effective MAMS (Kane, 2002).
- The system must provide functions and services that allow users, after making decisions, to update the relevant databases.

2.4 MAMS Architecture

In most work environments where a MAMS would be used, the environment can be separated into three domains, that of the Field, Office and User. The Field domain consists of all the in-field assets. The Office domain consists of the systems used to store the asset data. The User domain is the users and workers who require access to the asset data to perform their jobs. The architecture of MAMS has four distinct components that span across these domains. These components are described in the following [Ramsaran, 2000; Gao & Ramsaran, 2000]:

- Mobile component – data acquisition by people and sensors in the field (Field domain).
- Wireless Communication component – communication between the Mobile component and central servers for data warehousing (Field, Office and User domains).
- Data Management and Service component – data processing, management and service provision (Office domain).
- Decision Making component – analysis and presentation of data for decision-making purposes (User and Office domains).

Figure 2.1 shows graphically how the different components and domains are connected with a typical MAMS architecture where the User domain remains inside the Office domain so all decision-making tasks have to be done within the Office. Potential users in the field are therefore outside of the User domain so they do not have access to the asset data or the decision-making capabilities of MAMS, even though they are likely to be the ones that benefit from a MAMS the most.

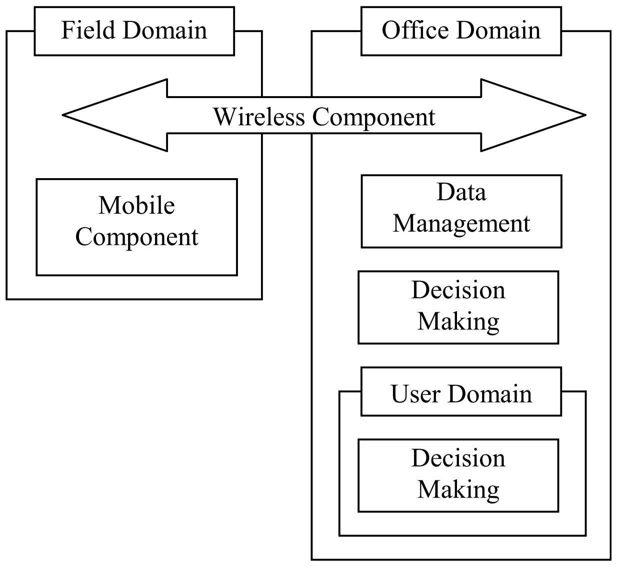


Figure 2.1: MAMS Architecture

2.5 Internet-based MAMS

New MAMS should be developed with the requirements of Section 2.3 in mind. Such MAMS would have an open architecture and seamless information flow, be able to utilize technologies such as GPS for location and GIS for data management and analysis. Radio is commonly used to provide real-time wireless communication between mobile assets in the Field and Office servers. However, the limitation of these types of MAMS is that asset information and services can only be provided to users physically connected to it or near the Office systems since there are no means to provide access to data or tools for remote users. This restricts the usefulness of a MAMS for many potential applications since users who need to access the system's data and analysis tools may be located geographically far away from the physical location of the MAMS. For instance, modern energy exploration corporations with operations throughout the world require such systems to be accessible from any location and by multiple levels of users that can range from field employees to users at a corporate office. As well, radio requires specialized infrastructure and hardware, which can increase the cost of deploying a MAMS.

To overcome these problems, the concept of an Internet-based MAMS (IMAMS) has been investigated [Gao & Lee, 2003]. IMAMS combined the conventional MAMS with Internet technologies, offering new capabilities due to a number of benefits for using the Internet in MAMS. One benefit is that a wireless Internet infrastructure is readily available. Cellular providers now offer direct Internet connection capabilities for both their analog and digital networks. The Internet also has advantages in reliability and speed as even data transmissions using older wireless Internet methods are more reliable and faster than using radio transmissions [Park & Gao, 2002]. Next generation cellular networks will offer even more data bandwidth. Wireless Internet technologies can be used to augment or replace radio as the primary means of field data transmission. The Internet is also an effective means of publishing data to users through the World Wide Web (WWW), or commonly called the Web for short. The Internet bridges the physical distances between content and viewers by enabling access to text and graphic content from anywhere in the world. Internet content can be dynamically generated and interacted with by users. The Internet is also platform independent, enabling a variety of hardware and software platforms to view the content.

The main deficiencies in the Internet that remain include a lack of access in many remote areas, privacy and security issues and limited bandwidth. For Canada, where cellular networks have poor coverage outside of populated areas, this can be a problem but can be overcome in the future as cellular networks expand in coverage area. Companies can also setup their own wireless Internet network with existing hardware as well if they have a relatively small work area like in a mining operation. Privacy and security has been a major concern for the Internet for a long time and is important given the sensitive nature of asset data. Limited bandwidth will also restrict the design of a MAMS, as it would not be possible to send large amounts of data to a remote user. Most processing would need to be done at a central site.

When transforming MAMS into an Internet-based system, the architectural changes that can occur include enhancements to the existing methods of communications in the Wireless Communication component with Internet methods. As well, the User domain is extended outside of the Office domain so that decision-making tasks can be performed either locally at the Office or remotely in the Field. The User domain is extended via the addition of the Web component. The new architecture of IMAMS is shown in Figure 2.2. By comparing Figure 2.2 with Figure 2.1, it is apparent that in order to convert to an Internet-based architecture, the Wireless component will require modification and the development of a new Web component will be needed. For the Web component, standard Internet content creation and presentation technologies can be employed to provide users with access to real-time asset information and decision-making capabilities.

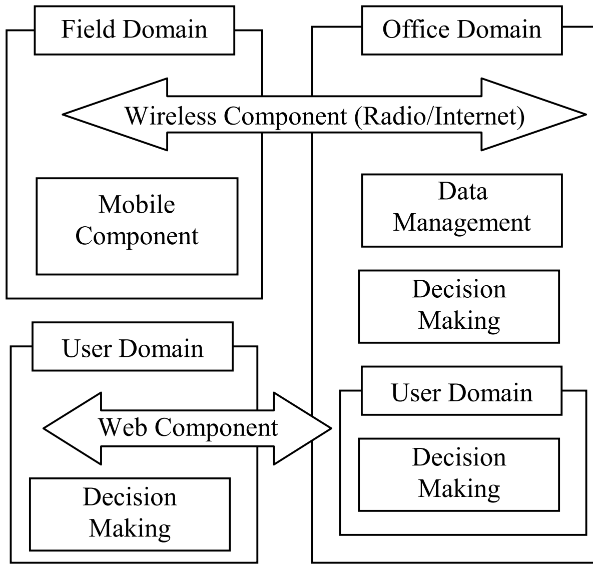


Figure 2.2: Internet-based MAMS Architecture

While it is possible to alter MAMS to support a remote user domain without resorting to the use of Internet technologies, several obstacles would have to be overcome. Such obstacles include the building of a radio infrastructure for the work area. This may be feasible for resource corporations whose assets are concentrated into relatively small areas where short distances between radio modems would be the norm, but radio will not be practical for other corporations with assets scattered across whole provinces or countries. By comparison, Internet access is already available through cellular networks with speeds ranging up to broadband levels. Connective hardware, such as modems, interface cards and routers, are readily available, standardized and inexpensive. The Internet also enables access from any location, not just in the Office or at the work area. This is a great advantage because multiple levels of users, ranging from field employees to users at faraway corporate offices, can all access the same system and use it for their own purposes. A second obstacle is the necessity of developing applications that can use radio as a data link. The communication protocols used for the Internet are well known and numerous libraries are available to convert data into a form that can travel across the Internet. Using a radio link on the other hand would likely necessitate custom transmission protocols and add unnecessary work. Users can use wireless Internet services to access data and services at the local office or at remote locations, resulting in a seamless transition between local and remote workspaces [Lee & Gao, 2002]. By providing the most up-to-date information and make it widely available, users are able to make better decisions regarding assets and ensure that they are used optimally [Ramsaran, 2000]. This will help reduce the cost and time for corporations to deploy a MAMS and improve the portability of the system technology, making the benefits even more compelling. These reasons are why using the Internet with MAMS is the best solution for enabling a remote user domain for providing all users the information they require and as alternate method for communication with the field. **MAMSDev** itself is heavily influenced by the design and architecture of Internet-based MAMS and incorporates many ideas and design choices from it.

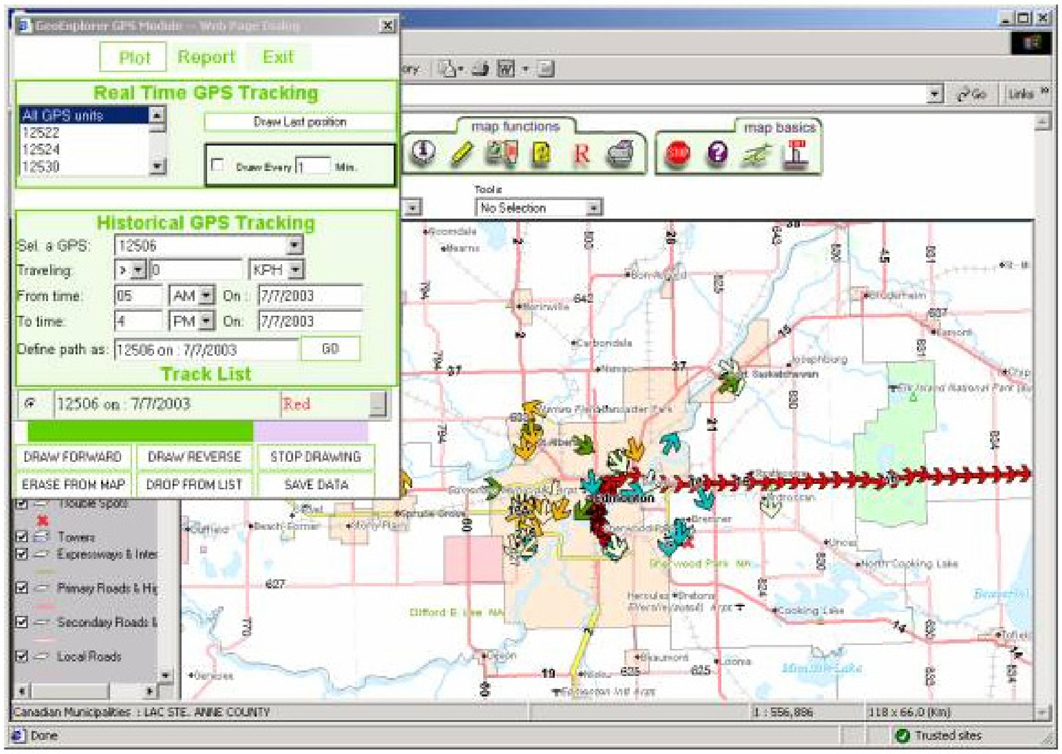
2.6 Existing MAMS Applications

In MAMS applications, a common element is that the location of assets is monitored. For some application, only asset locations are monitored but with more powerful and useful MAMS applications, additional asset attributes are monitored as well. Finally, having a two-way capability with assets enhances the usefulness of a MAMS even more as decisions can be quickly sent to assets and workers and be acted upon.

2.6.1 One-Way MAMS Applications

The simplest form of MAMS is a one-way system that monitors only asset locations and uses asset location as the primary source of information for decision-making purposes. An example of such a system is Telus's AVL services.

The Telus AVL system utilizes a GPS modem for its Mobile component, which integrates a GPS receiver with a modem that enables wireless communication using cellular networks such as Telus's digital cellular network [Telus, 2004]. The GPS receiver automatically determines the asset's location and sends it back at predetermined intervals. Asset data is sent to a Telus server where it is stored. The User Component is an Internet-based application called GeoExplorer, which integrates map data with asset data. GeoExplorer is shown in Figure 2.3. The asset data can be overlaid with a variety of map data, including street networks and corporate buildings and infrastructure. The map data could come in the form of raster or vector data [Telus, 2004].

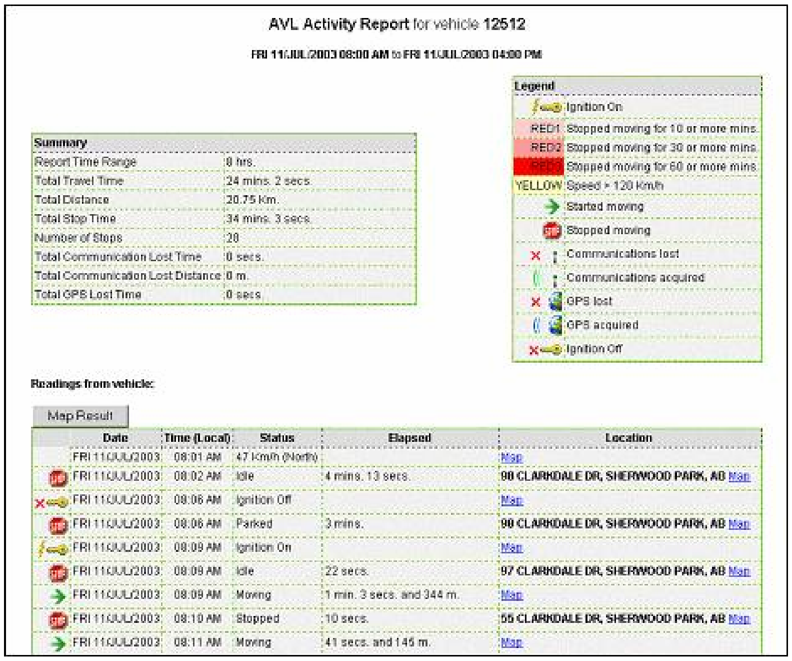


Sel. a GPS: 12506
Traveling: > 0 KPH
From time: 05 AM On: 7/7/2003
To time: 4 PM On: 7/7/2003
Define path as: 12506 on : 7/7/2003
12506 on : 7/7/2003 Red

Canadian Municipalities : LAC STE. ANNE COUNTY 1 : 556,886 118 x 66.0 (Km)

Figure 2.3: Telus User Component (www.telusgeomatics.com)

Using the vehicle location data, the Telus AVL system can infer a variety of additional asset data. These attributes include asset speed, travel distances and idle periods. Vehicle locations can also be used to identify when an asset leaves or enters specified areas. These inferred data can be summarized into a report that allows users to see the activities of an asset over a period of time and can make informed decisions for assets regarding efficient utilization, maintenance during idle periods and optimized routes. A sample report is shown in Figure 2.4.



AVL Activity Report for vehicle **12512**

FRI 11/JUL/2003 08:00 AM to FRI 11/JUL/2003 04:00 PM

Summary	
Report Time Range	8 hrs.
Total Travel Time	24 mins. 2 secs.
Total Distance	20.75 Km.
Total Stop Time	34 mins. 3 secs.
Number of Stops	20
Total Communication Lost Time	0 secs.
Total Communication Lost Distance	0 m.
Total GPS Lost Time	0 secs

Legend	
	Ignition On
RED1	Stopped moving for 10 or more mins.
RED2	Stopped moving for 30 or more mins.
RED3	Stopped moving for 60 or more mins.
YELLOW	Speed > 120 Km/h
	Started moving
	Stopped moving
	Communications lost
	Communications acquired
	GPS lost
	GPS acquired
	Ignition Off

Readings from vehicle:

Map Result

Date	Time (Local)	Status	Elapsed	Location
FRI 11/JUL/2003	08:01 AM	47 Km/h (North)		Map
FRI 11/JUL/2003	08:02 AM	Idle	4 mins. 13 secs.	90 CLARKDALE DR, SHERWOOD PARK, AB Map
FRI 11/JUL/2003	08:06 AM	Ignition Off		Map
FRI 11/JUL/2003	08:06 AM	Parked	3 mins.	90 CLARKDALE DR, SHERWOOD PARK, AB Map
FRI 11/JUL/2003	08:09 AM	Ignition On		Map
FRI 11/JUL/2003	08:09 AM	Idle	22 secs.	97 CLARKDALE DR, SHERWOOD PARK, AB Map
FRI 11/JUL/2003	08:09 AM	Moving	1 min. 3 secs. and 344 m.	Map
FRI 11/JUL/2003	08:10 AM	Stopped	10 secs.	55 CLARKDALE DR, SHERWOOD PARK, AB Map
FRI 11/JUL/2003	08:11 AM	Moving	41 secs. and 145 m.	Map

Figure 2.4: Telus User Component Reports (www.telusgeomatics.com)

Because the Telus AVL system only uses asset locations, there is a limit on how much information it can provide to users for making decisions. While attributes such as speed, travel distances and idle times can be inferred from asset locations, they remain estimated values only and can be inaccurate. As well, with only one-way capabilities, all decisions that users make cannot be sent to the asset in real-time and instead must go through other methods which may be slower, causing a disconnect in the information flow of the MAMS. A final limitation of the current Telus AVL system is the asset data is hosted on Telus's own server, it is not possible to have the data be sent directly to a client's own server where they could use it for their own purposes, such as setting up their own custom reports or data mining methods.

Being able to monitor additional attributes increases the usefulness of a MAMS. For example, rather than using only the asset locations to roughly estimate travel distance and fuel consumption, a better option is to use an odometer and fuel tank sensor to get the actual values. Other important attributes such as temperatures, pressures and weights cannot be inferred from an asset's location at all. These attributes can be vital for analyzing how well assets are being utilized and to predict when they need maintenance. A multi-attribute MAMS therefore has a great advantage in providing relevant data for informed decisions.

An example of such a multi-attribute system is FleetLink, a MAMS that tracks the location and additional attributes of mobile assets and sends the data back to a central office. One application that FleetLink is used for is in the area of waste management [Fleetmind, 2004]. FleetLink can track the locations of waste pickup vehicles, plus the engine RPMs, vehicle speed and actual fuel consumption. For data acquisition, FleetLink uses a device that integrates vehicle monitoring and location capabilities, using a GPS receiver, to acquire the waste vehicle attributes automatically. FleetLink's data acquisition hardware is also capable of wireless communication using radio and cellular networks. Information regarding the specifics of the pickup of waste for clients is also tracked. This however is done manually, with the driver inputting the pickup task information via a terminal. The combined monitored asset data can be sent in real-time back to a central office if a wireless network is available or stored into memory until the waste vehicle returns to its base. The data acquisition hardware can be seen in Figure 2.5, the onboard device is on the left while the terminal is on the right.

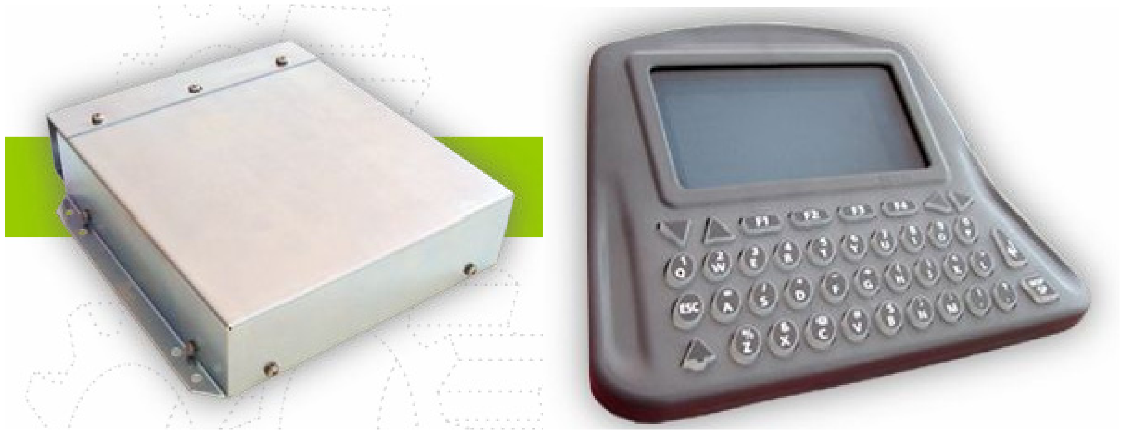
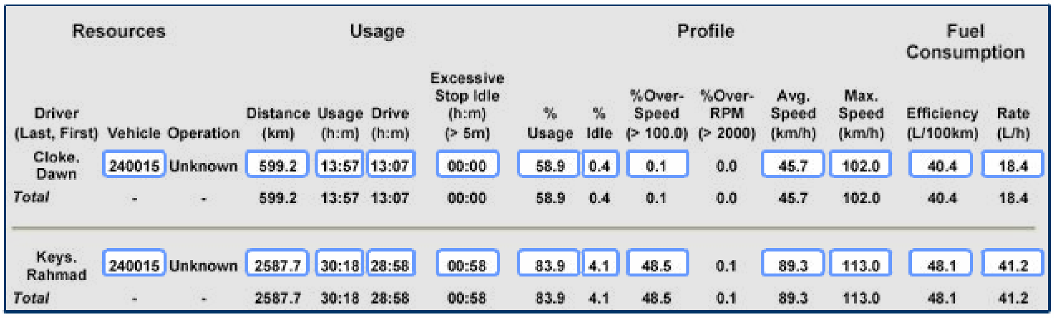


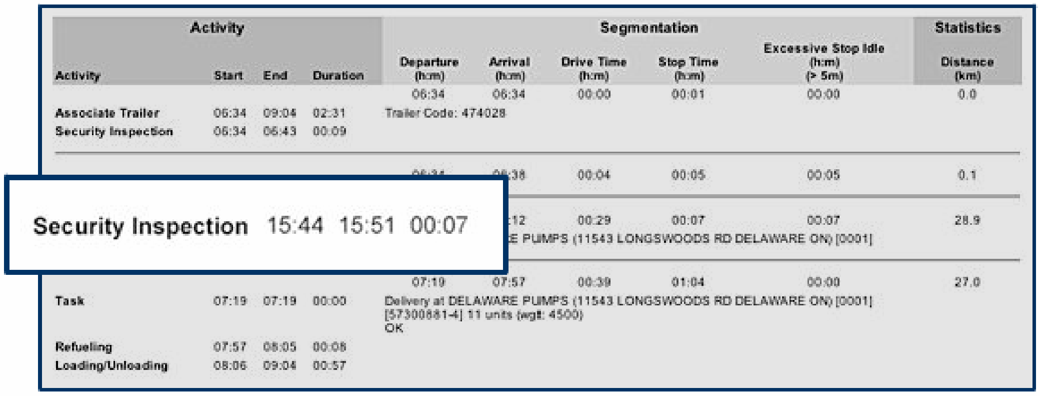
Figure 2.5: FleetLink Data Acquisition (www.fleetmind.com)

Once the waste vehicle information is at the office, office workers can use it in a variety of ways to improve their operation. FleetLink’s User Component is targeted at managers at a central office. With vehicle locations available, the route taken by the waste vehicle as it performs its job can be plotted onto mapping software and examined to see if a more optimal route exists [Fleetmind, 2004]. The engine RPMs and vehicle speeds data can also be used to analyze how optimal the route is, by seeing how often the waste vehicle is idling and how fast it can go at different sections of the route. A sample FleetLink's report can be seen in Figure 2.6. It is also possible to check on drivers and to ensure that they are not wasting time. Having detailed information relating to the pickup is useful in ensuring that all required tasks are completed and client inquiries can be answered with accurate information [Fleetmind, 2004]. Figure 2.7 shows a report detailing the activities of the waste vehicle and its driver.



Resources			Usage				Profile						Fuel Consumption	
Driver (Last, First)	Vehicle	Operation	Distance (km)	Usage (h:m)	Drive (h:m)	Excessive Stop Idle (h:m) (> 5m)	% Usage	% Idle	%Over-Speed (> 100.0)	%Over-RPM (> 2000)	Avg. Speed (km/h)	Max. Speed (km/h)	Efficiency (L/100km)	Rate (L/h)
Cloke, Dawn	240015	Unknown	599.2	13:57	13:07	00:00	58.9	0.4	0.1	0.0	45.7	102.0	40.4	18.4
Total	-	-	599.2	13:57	13:07	00:00	58.9	0.4	0.1	0.0	45.7	102.0	40.4	18.4
Keys, Rahmad	240015	Unknown	2587.7	30:18	28:58	00:58	83.9	4.1	48.5	0.1	89.3	113.0	48.1	41.2
Total	-	-	2587.7	30:18	28:58	00:58	83.9	4.1	48.5	0.1	89.3	113.0	48.1	41.2

Figure 2.6: FleetLink Asset Data (www.fleetmind.com)

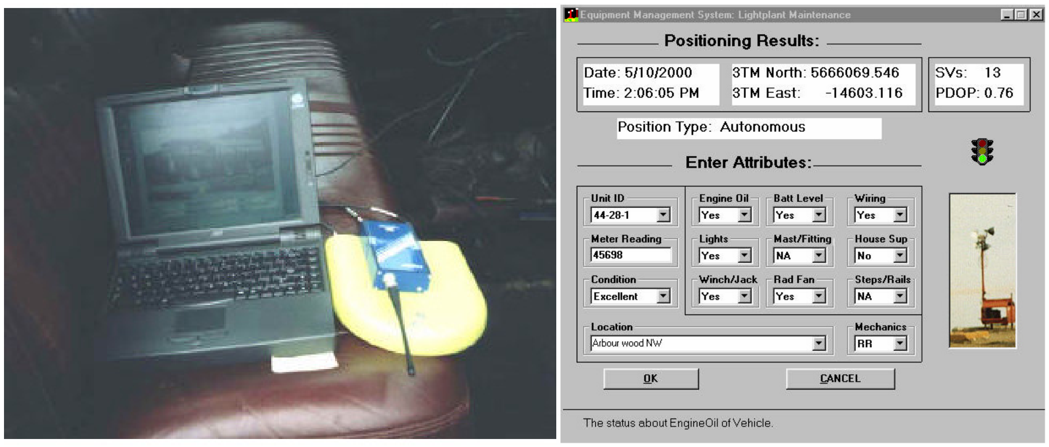


Activity				Segmentation					Statistics
Activity	Start	End	Duration	Departure (h:m)	Arrival (h:m)	Drive Time (h:m)	Stop Time (h:m)	Excessive Stop Idle (h:m) (> 5m)	Distance (km)
				06:34	06:34	00:00	00:01	00:00	0.0
Associate Trailer	06:34	09:04	02:31	Trailer Code: 474028					
Security Inspection	06:34	06:43	00:09						
				06:34	06:38	00:04	00:05	00:05	0.1
Security Inspection	15:44	15:51	00:07	:12		00:29	00:07	00:07	28.9
				E PUMPS (11543 LONGSWOODS RD DELAWARE ON) [0001]					
				07:19	07:57	00:39	01:04	00:00	27.0
Task	07:19	07:19	00:00	Delivery at DELAWARE PUMPS (11543 LONGSWOODS RD DELAWARE ON) [0001] [57300881-4] 11 units (wgt: 4500) OK					
Refueling	07:57	08:05	00:08						
Loading/Unloading	08:06	09:04	00:57						

Figure 2.7: FleetLink Asset Activities (www.fleetmind.com)

A limitation of the FleetLink system is that the mapping component is not included; any company using FleetLink must purchase it separately from another software vendor and ensure that the location data can be transferred from FleetLink into the mapping software. In addition, the system is meant for workers in a central office to use, the drivers have no way of accessing it. Drivers could not use the system for route guidance or updates regarding their daily tasks while they were out driving their waste vehicles.

Another example of a one-way, multi-attribute MAMS is **MEMS** (**M**obile **E**quipment **M**anagement **S**ystem**)**, which helps the resource industry in managing and maintaining key assets. The primary purpose of **MEMS** was monitoring lightplants, which are equipment designed to light up work areas and allow for night work [Ramsaran, 2000]. **MEMS** collected information regarding the maintenance and fuel status of these support equipment. For the Mobile component, data acquisition was done by field workers performing manual inspection of the lightplant. Position and time information was obtained from a separate GPS receiver. The lightplant inspection report was entered into a custom application by a field worker and then tagged with its position and time of measurement, which was obtained from the GPS receiver. The application, running on a conventional Windows-based laptop was also connected to a radio modem, which was the chosen implementation for the Wireless component of **MEMS**. The asset data was sent through the radio modem back to the Office for long-term storage. The data acquisition hardware and software can be seen in Figure 2.8.



Date: 5/10/2000
Time: 2:06:05 PM
3TM North: 5666069.546
3TM East: -14603.116
SVs: 13
PDOP: 0.76
Position Type: Autonomous

Unit ID: 44-28-1
Meter Reading: 45698
Condition: Excellent
Engine Oil: Yes
Lights: Yes
Winch/Jack: Yes
Batt Level: Yes
Mast/Fitting: NA
Rad Fan: Yes
Wiring: Yes
House Sup: No
Steps/Rails: NA
Location: Arbour wood NW
Mechanics: RR

The status about EngineOil of Vehicle.

Figure 2.8: MEMS Data Acquisition [Ramsaran, 2000]

Once a server located at a central office had received the data, it was stored into databases. Users were able to retrieve, view, maintain, edit and analyze data and eventually make informed decisions regarding the lightplants using the User Component of **MEMS**. Administrators were able to perform maintenance on the databases, ensuring that there were no errors in the records. Maintenance workers could use this component to view the current statuses of all lightplants in the field, allowing for an up-to-date view of the fleet at a glance. Lightplants could be tracked over time, by viewing its historical conditions and locations as past information is kept. This historical information is useful in improving the efficient utilization of the lightplants.

The User Component also offered the option of viewing the lightplants in a graphical form. This tool utilized ESRI MapObjects, which is a set of mapping software components that add dynamic mapping and geospatial information capabilities to Windows applications. The current and/or historical data could be overlaid on top of the work area map, which is stored in the form of vector data. The lightplant points could be queried for further information. Basing this component on MapObjects allowed many GIS functions designed for map manipulation, such as zooming and panning, and data querying to be used with the lightplant data. A sample screen of this graphical tool is show in Figure 2.9.

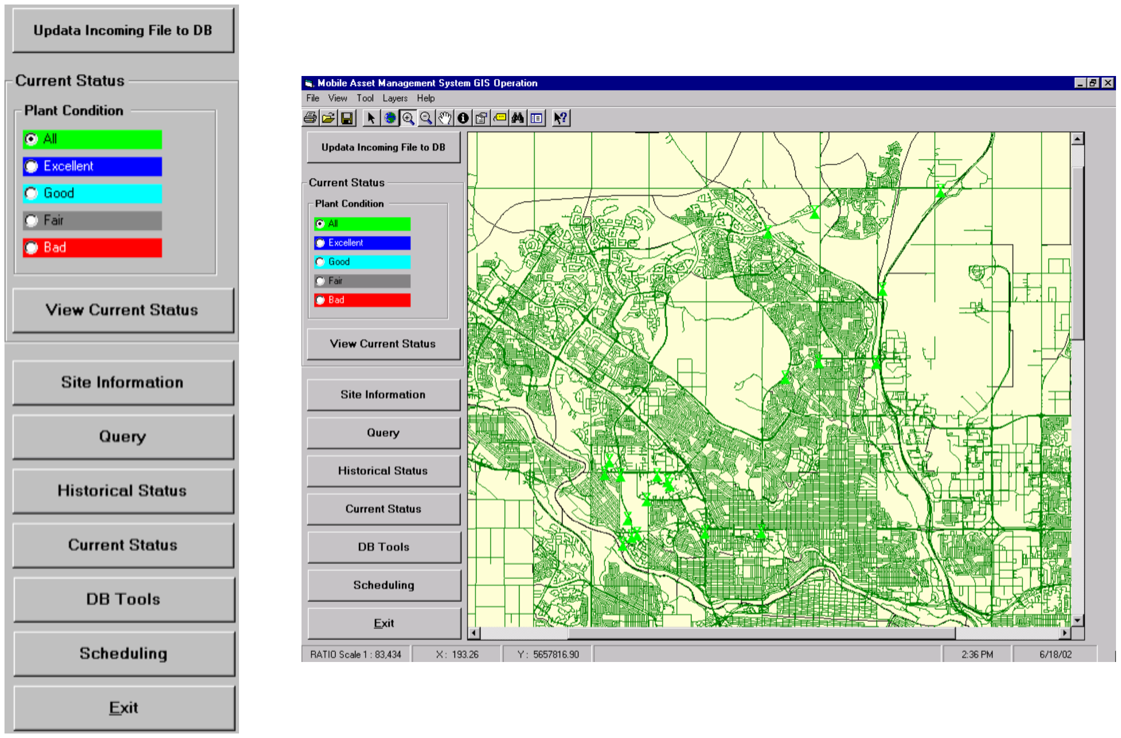


Figure 2.9: MEMS User Component

The User Component also provides decision-making functionality. The goal of the decision-making functions is to provide a set of procedures, that when followed ultimately results in efficient utilization of assets, through the deployment of assets at the right locations and at the right time and in working condition [Ramsaran, 2000]. For maintenance personnel, lightplants in need of refueling can be quickly found using preexisting queries that filter assets based on the time since the last refueling date and their observed fuel consumption. These selected lightplants can be scheduled for refueling at the earliest opportunity, reducing any possibility of downtime. The service history can also be seen for each individual lightplant, which allows for the tracking of the lightplants's condition over time and seeing when previous maintenance had taken place. By proactively scheduling maintenance checks and refueling, downtimes due to preventable failures can be significantly reduced which will improve the productivity of the entire resource mining operation.

A major limitation of **MEMS** was the use of manual data acquisition, which is costly, as it requires a worker to perform the inspections. This also limits the frequency that data can be collected from the lightplant, making it difficult for tasks such as route tracking and determining idle and busy periods. The one-way nature of the system also meant that scheduling decisions could not be sent to the lightplants immediately.

As **MEMS** was only a conventional, non-Internet based MAMS system, it therefore did not utilize the Internet and was subject to the problems inherent to such systems such as limited wireless communication options and limited access to the User Component. The next stage in the development of **MEMS** was to make it fully Internet-based, through the addition of wireless Internet methods to transmit lightplant data from the Field back to the Office and a new Internet accessible client component to allow users access to data and tools from outside of the physical area of the Office domain. This new Internet-based system was called **IMEMS** (**I**nternet-based **M**obile **E**quipment **M**anagement **S**ystem).

IMEMS offered the choice of wireless Internet or radio methods to communicate with the Office. Application developers can switch between either transmission method without the need to make any changes to code or data. Important performance and security functions such as compression and encryption were also available. The options that were available in this framework can be seen in Figure 2.10.

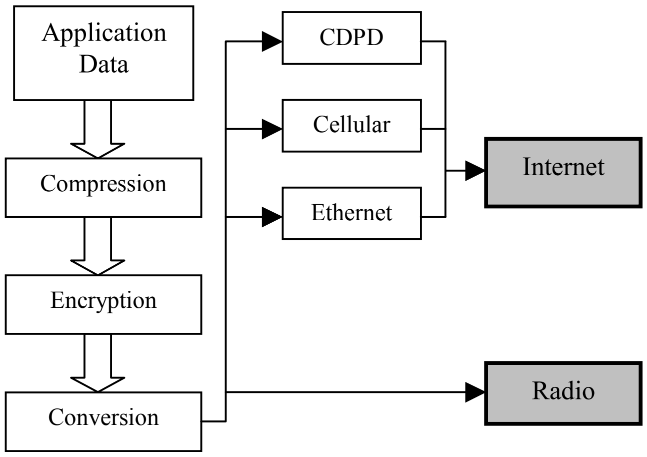


Figure 2.10 Seamless Internet/Radio Data Transmission

The User Component in **MEMS** has also been converted into an Internet application to allow a high level of data analysis functionality to be accessible by remote users while requiring only a browser and an Internet connection. The purpose of the **IMEMS** Web Client is the same as the original **MEMS**; to provide users with an interface that facilitates access to the data stored but this time over the Internet and only requiring an Internet browser. There was no need for further third-party software such as Map Objects. The interface of the **IMEMS** Web Client can be seen in Figure 2.11 and has many similarities with the earlier MapObjects-based application. While **IMEMS** offered improvements in many areas, it still shared the same problems in terms of using manual data acquisition and one-way capabilities inherent in **MEMS**.

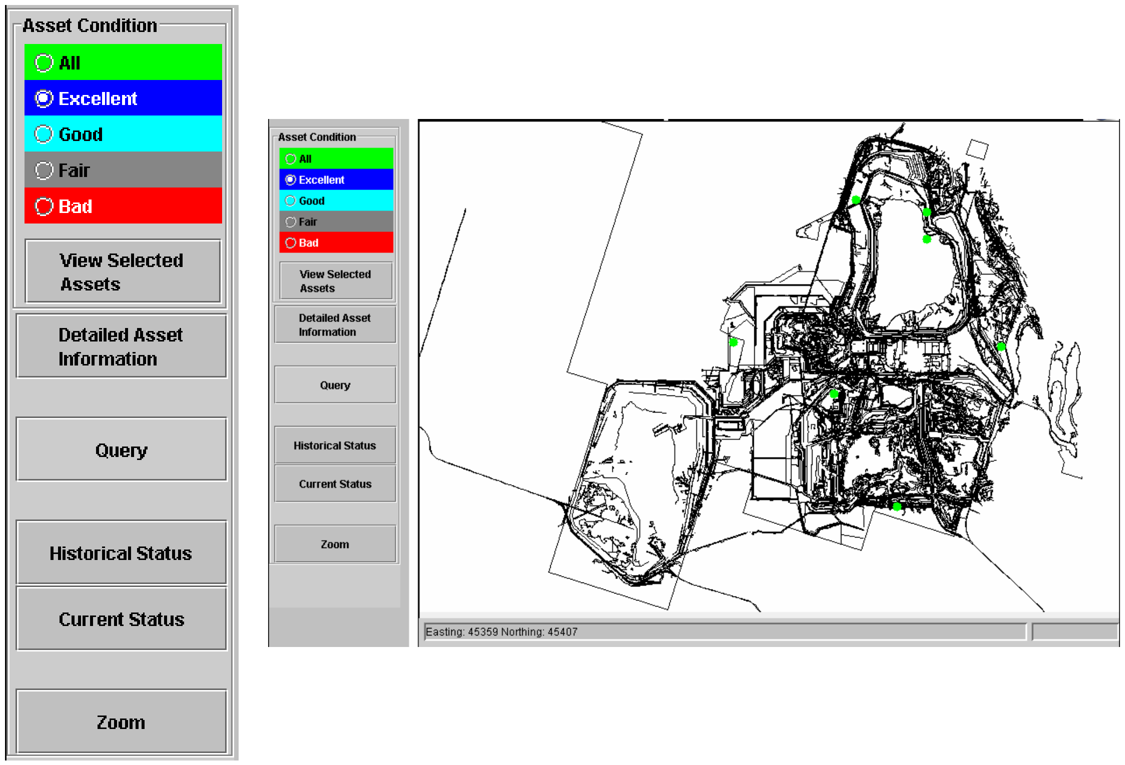


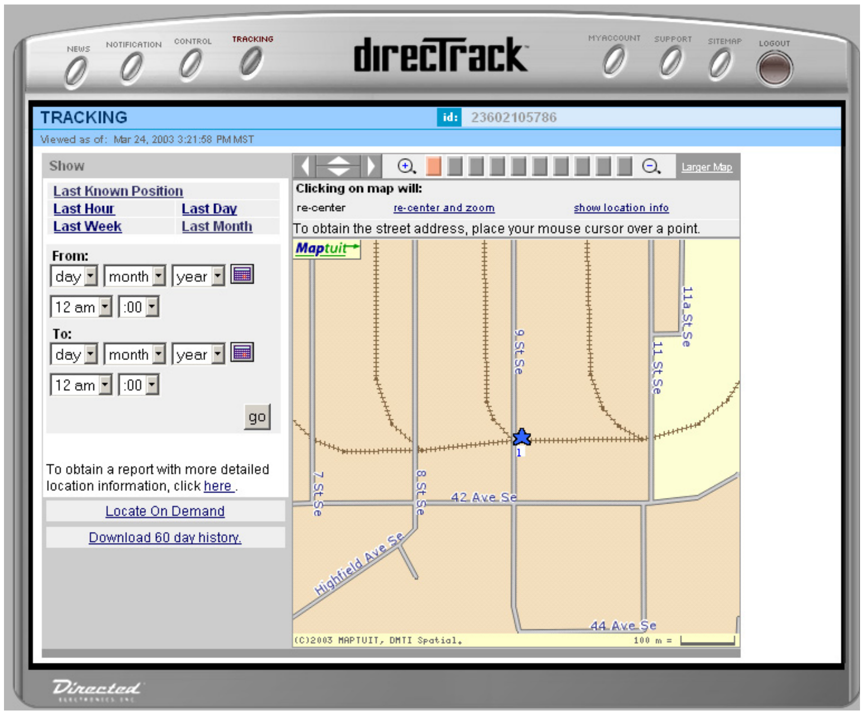
Figure 2.11: IMEMS: Web-based User Component

2.6.2 Two-way MAMS Applications

Two-way MAMS are more useful because users can make decisions that can be sent back to the asset in near real-time. Such systems can be used for on-the-fly route optimizations or changes to the route due to accidents or new tasks that must be performed.

Like for one-way MAMS, two-way MAMS that use only asset locations are limited in terms of the types of applications that they could be used for. It is adequate though for many asset security applications. This is because security applications utilize a “geo-fence”, which designates an area where an asset must be. If the asset leaves the geo-fence, then it can be assumed that the asset has been stolen and authorities can be notified. The asset can broadcast its location continuously for rapid recovery. Geo-fences can be set to a small area around the asset when an asset is parked or to a larger area, allowing the asset to move freely within a work area but not out of it. The market for asset security is large, especially for automobiles. It is estimated by the National Insurance Crime Bureau of the USA that 1.2 million automobiles were stolen in 2002.

DirecTrack is one such security system and is a subscription service that works with third-party alarm systems that have GPS and cellular capabilities. These alarm systems can be purchased by individuals or corporations to place on their assets with automobiles being the most commonly protected assets [DirecTrack, 2003]. DirecTrack is Web-based, allowing users to access the service through the Internet. It follows the basic MAMS architecture, with the alarm system acting as a data acquisition component and cellular networks as the wireless link between the field and a central office. Vehicle data is stored at the central office and users access it through the Internet. Users log into the services through the Internet and then are able to locate their vehicle on a map. Users can also view the previous location of their vehicles in text form. It offers two-way capabilities by allowing users to locate their vehicle on demand, giving them peace of mind in knowing their vehicle is where it is supposed to be. If the vehicle is stolen, recovery is also easier and faster. The user interface of DirecTrack can be seen in Figure 2.12.



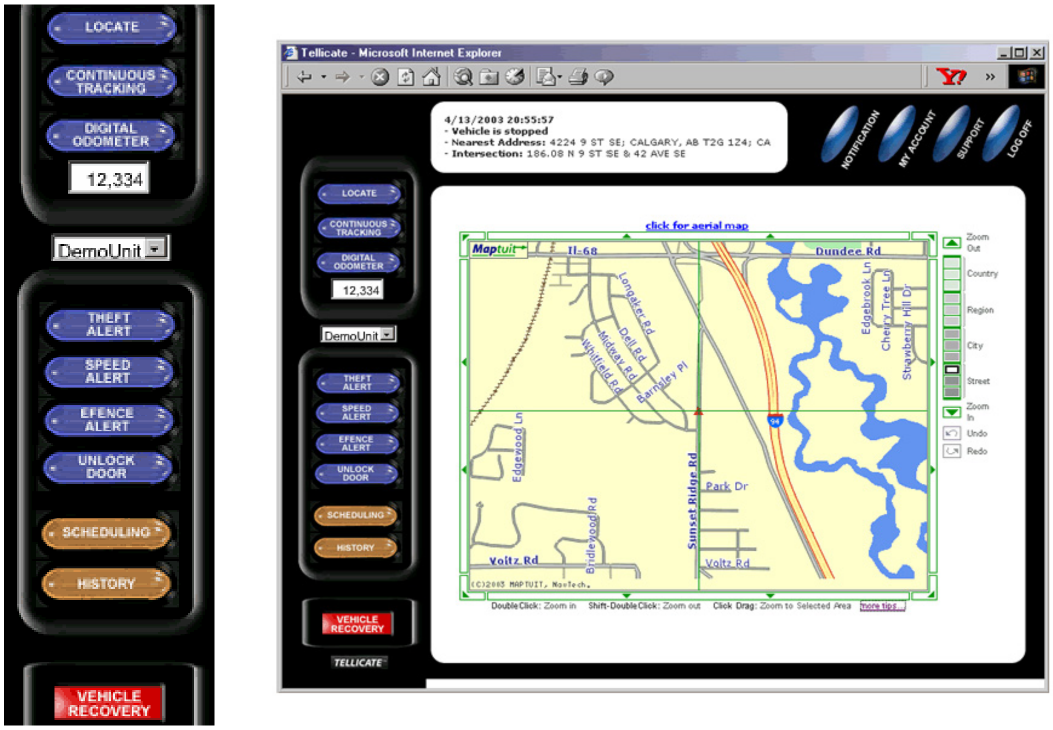
Viewed as of: Mar 24, 2003 3:21:58 PM MST

To obtain the street address, place your mouse cursor over a point.

To obtain a report with more detailed location information, click here.

Figure 2.12: DirecTrack User Interface [DirecTrack, 2003]

The limitation of DirecTrack is that it only utilizes vehicle positions so it is limited in terms of additional functionality. Tellicate is another security system that shares the same basic architecture as DirecTrack but has the advantage of being a multi-attribute two-way MAMS. This offers more utility to clients and makes it a more useful system. Along with position, Tellicate can monitor the vehicle's odometer, speed and also report emergencies or alarms that are issued by the onboard vehicle sensor. These emergencies and alarms can occur when the vehicle's alarm is triggered, when the vehicle is traveling faster than a preset limit or when the vehicle has gone outside of the geo-fence [Tellicate, 2003]. Tellicate, being a two-way system also allows users to issue commands back to their vehicle. Like DirecTrack, users can locate their vehicle on demand but they can also command the Tellicate onboard sensor to go into Continuous Tracking mode, where it will send the vehicle locations at regular intervals. Finally, the user can also unlock the door of their vehicle remotely [Tellicate, 2003]. Tellicate's User Component can be seen in Figure 2.13.

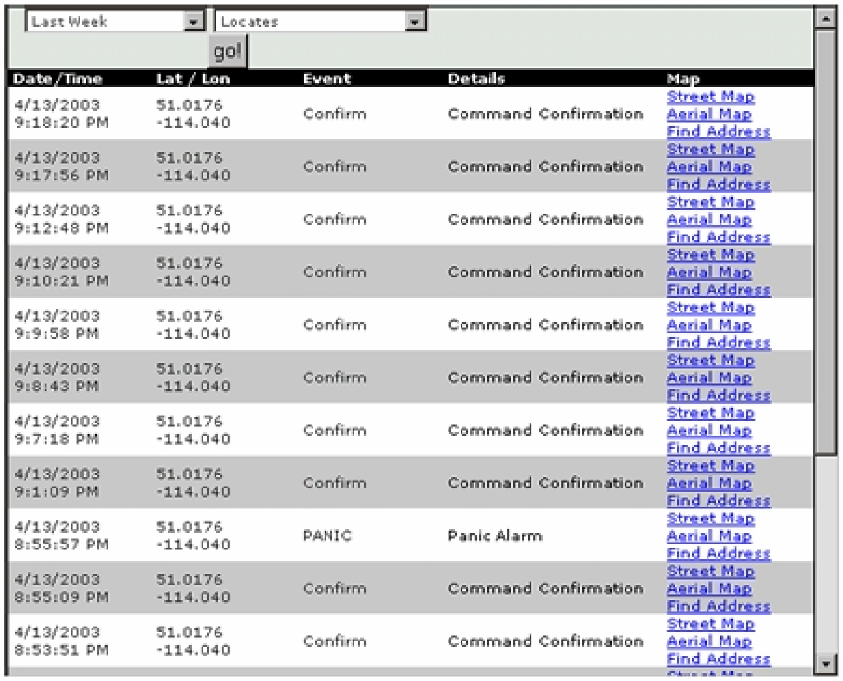


4/13/2003 20:55:57
- Vehicle is stopped
- Nearest Address: 4224 9 ST SE; CALGARY, AB T2G 1Z4; CA
- Intersection: 186.08 N 9 ST SE & 42 AVE SE

DoubleClick: Zoom in   Shift-DoubleClick: Zoom out   Click Drag: Zoom to Selected Area   more tips...

Figure 2.13: Tellicate User Component [Tellicate, 2003]

Like many of the previously examined MAMS, Tellicate also allows users to view the historical information regarding a vehicle. An example of such a report can be seen in Figure 2.14. The historical information for Tellicate consists of a vehicle's previous locations as well as alarms and confirmation of the successful completion of user issued commands.



Date/Time	Lat / Lon	Event	Details	Map
4/13/2003 9:18:20 PM	51.0176 -114.040	Confirm	Command Confirmation	Street Map Aerial Map Find Address
4/13/2003 9:17:56 PM	51.0176 -114.040	Confirm	Command Confirmation	Street Map Aerial Map Find Address
4/13/2003 9:12:48 PM	51.0176 -114.040	Confirm	Command Confirmation	Street Map Aerial Map Find Address
4/13/2003 9:10:21 PM	51.0176 -114.040	Confirm	Command Confirmation	Street Map Aerial Map Find Address
4/13/2003 9:9:58 PM	51.0176 -114.040	Confirm	Command Confirmation	Street Map Aerial Map Find Address
4/13/2003 9:8:43 PM	51.0176 -114.040	Confirm	Command Confirmation	Street Map Aerial Map Find Address
4/13/2003 9:7:18 PM	51.0176 -114.040	Confirm	Command Confirmation	Street Map Aerial Map Find Address
4/13/2003 9:1:09 PM	51.0176 -114.040	Confirm	Command Confirmation	Street Map Aerial Map Find Address
4/13/2003 8:55:57 PM	51.0176 -114.040	PANIC	Panic Alarm	Street Map Aerial Map Find Address
4/13/2003 8:55:09 PM	51.0176 -114.040	Confirm	Command Confirmation	Street Map Aerial Map Find Address
4/13/2003 8:53:51 PM	51.0176 -114.040	Confirm	Command Confirmation	Street Map Aerial Map Find Address

Figure 2.14: Tellicate User Component Reports [Tellicate, 2003]

The primary limitation of Tellicate and DirecTrack is their targeted focus on only vehicles. The information that is monitored is inadequate for assets being used in mining and only providing street maps would be inadequate for remote work areas where street maps are only available to company operating the work area. Capabilities like unlocking doors may also not be necessary.

2.6.3 Real World MAMS Summary

A summary of the examined real world MAMS's capabilities and implementation is show in Table 2.1.

Table 2.1: Real World MAMS Sumary

	Two-way capable?	Data Acquisition	Monitored attributes	Wireless component	User Component
Telus AVL	No	Remote sensor	Location only	Cellular	Internet-based
FleetLink	No	Remote sensor + manual input	Location, speed, engine parameters	Cellular, radio	Local office only
MEMS	No	Manual input + GPS receiver	Location, vehicle conditions	Radio	Local office only
IMEMS	No	Manual input + GPS receiver	Location, vehicle conditions	Radio, Internet	Internet-based
DirecTrack	Yes	Remote sensor	Location, only	Cellular	Internet-based
Tellicate	Yes	Remote sensor	Location, speed, alarms and emergencies	Cellular	Internet-based

2.6.4 Desirable MAMS Traits

After the examination of various real world MAMS, common features were found and traits that offer benefits have been discovered. These features and traits should form a part of **MAMSDev,** the Platform that is being created in this thesis for MAMS development. One other aspect of the examined MAMS noticed was that they all focused on specific applications and would be difficult, if not impossible, for users to modify the MAMS to better suit their needs. A platform that allowed a high level of customization would be unique and extremely beneficial by allowing users to tailor a MAMS to their specific needs and not be stuck with a proprietary system using only specific software, hardware and monitored attributes.

The two-way, multiple attribute MAMS is the ideal MAMS. Not only does it offer the most functionality and usefulness, it is also the superset of all other types of MAMS, allowing it cover a wide range of potential applications and scale to any combination of one or two-way and single or multi-attribute as needed. **MAMSDev** therefore should target two-way, multi-attribute MAMS.

The best choice for data acquisition is remote integrated sensors that are placed onboard an asset. Remote sensors allow data to be obtained at much higher frequency than is possible using manual inspection. They can be set to acquire data automatically from a variety of asset sources, including locations, engine parameters and alarm statuses at preset intervals, in any condition and at all times. Many remote sensors also allow two-way MAMS with the option of control where users can issue commands and have the sensor perform the assigned task and report the results in near real-time. With current technology, small and compact integrated sensors that include GPS, wireless communication and computing capabilities are now available. The small footprint of these sensors enables them to placed, or hidden, into a wide variety of assets for use in asset tracking, monitoring and security.

Using wireless communication to send asset data back to a central site was also commonly used in real-world MAMS. This is beneficial because it is the best choice for getting asset data back to users in the fastest time possible, giving users the confidence that they have the most up-to-date information possible for decision-making. Without wireless communication, the asset data could not be entered into a MAMS until it returned to a central site, which could interrupt the flow of information by a day or even longer as there are assets that stay out in the field for long or indefinite periods of time.

Data management and storage was a key component of every examined MAMS. Typically, the asset data was stored into databases and useful reports were generated from the data. Providing text reports that gave relevant information to users regarding an asset was a feature that was found on several of MAMS. Such reports offered a summarized overview of assets that allowed users the ability to see the current conditions of the asset, including its location and attributes that were being tracked by the system and would be of relevance to the user. Other reports provided historical information for an asset, allowing users to view the trend of various asset conditions for maintenance and repair purposes. These types of reports were an important part of the real-world MAMS and **MAMSDev** should offer functions that help in the creation of such reports. **MEMS** and **IMEMS** also offered direct access to the raw data and databases for maintenance reasons. Some MAMS, such as Telus, DirecTrack and Tellicate stored the databases on their server while **MEMS**, **IMEMS** and FleetLink allowed the databases to be held on company servers. Having the databases managed by another company reduces equipment and support costs for the MAMS user but it also makes it difficult to access the raw data for custom data analysis and mining purposes. **MAMSDev** should be capable of supporting both form of database management for more flexibility.

An Internet-based User Component is a feature used in several of the examined real-world MAMS, like that of Internet-based MAMS described in Section 2.5. It enables access to the asset data for as many users as possible. Users that are at the office or those in remote areas all have access and the only requirement is that an Internet connection is available. The Internet is a hardware and software independent network so that a variety of computing devices could be used as the client hardware.

Several of the examined MAMS also featured graphical map data integrated into the User Component and allowed asset data to be overlaid onto the map data. Being able to place asset locations to the context of city streets or work areas is an important part of the decision-making process. The map data could also be used to provide addresses and directions for route guidance as well as hold a database of points of interests. Map data can come in a variety of forms and can be provided by third parties or be owned by the company that operates the MAMS.

Chapter 3

MAMS Hardware and Software Technologies

In every MAMS, there are a large number of varied technologies at work. Useful asset information must be obtained and transmitted back to a central office site, using a wireless network. The asset data must be stored, managed and then presented to users in a useful fashion. In this chapter, technologies that could be used in a MAMS are investigated for their benefits and drawbacks.

3.1 Wireless Communication

While data could be potentially stored for later upload, wireless transmission of data is the best solution for providing up-to-date and relevant information to users. Having the shortest latency possible from the time the data is acquired and the user viewing the data is critical for informed decision-making and necessary for gaining the maximum benefits from the MAMS.

3.1.1 Radio

Radio modems that broadcast in the UHF commercial band between the frequencies of 450 to 470 MHz of the radio band have become a popular tool for providing wireless communication for applications such as asset management, as well as high accuracy GPS services. There are no service costs for airtime usage and the deployment of a radio system is done by purchasing enough modems to cover the work area.

However, some drawbacks exist that make it a less than ideal solution for MAMS. This particular UHF radio band is highly crowded and can result in noise and interference. The channel separation used by such modems is only 12.5 KHz, which can result in significant cross-channel interference and reduced data transmission speed and reliability [Park & Gao, 2002]. These problems also reduce the effective range of radio modems, which in best-case situations is only as good as the line-of-sight with a neighboring modem. For worst-case scenarios, such as in an urban environment, the effective range of a radio modem drops to a few kilometers only and require additional modems for effective coverage. As well, radio modems do not provide a direct connection to the Internet, so it is not suitable for extending the User domain outside of the Office.

There are additional problems associated with their use in a MAMS. For example, the Pacific Crest RFM96 radio modems have been used previously for some MAMS applications. When the modems are active, data collisions can occurs if they send a message simultaneously on the same radio frequency. To avoid this problem, the modems use the Carrier Sense Multiple Access/Collision Detection (CSMA/CD) protocol [Ramsaran, 2000]. This protocol, also used in Ethernet networks, defines how the radio modems react to avoid collisions. With CSMA/CD, the modem monitors the frequency if it is being used. If it is being used when a modem needs to send a message, the modem waits a random amount of time before checking again. If the frequency remains unavailable, the wait time is increased until the frequency finally becomes free [Ramsaran, 2000]. In a busy MAMS with a large number of assets, the amount of collisions could become a problem by delaying the transmission of asset data.

3.1.2 AMPS/CDPD

Due to the widespread coverage of cellular networks, wireless access to the Internet is now available in large portions of Canada, even in remote areas. The Internet is a global network utilizing multiple routes and methods for data transmission for high reliability and its transmission range is not constrained by physical factors like radio. AMPS/CDPD (Advance Mobile Phone Service/Cellular Digital Packet Data) is a common and mature method for wireless access to the Internet in North America [Park & Gao, 2002]. AMPS was the first-generation cellular telephone system developed during the 1970s. AMPS is an analog system and uses a frequency of 900 MHz. CDPD is a specification for supporting wireless access to the Internet using the AMPS network.

Data transmission via a Wireless Internet connection is also a much more reliable than that via radio. For example, CDPD is a packet-switched data service that transmits data at a rate of up to 19.2 Kb/s and has full duplex capability, so packets can be sent and received at the same time [NovAtel, 2001]. Like other Internet connections, data is transmitted using TCP/IP, the primary communication protocol of the Internet. TCP/IP offers built-in redundancy, error checking and other reliability measures to ensure the data that arrives at the destination matches the data that was sent out. CDPD uses authentication measures and encryption of data packets for better security of sensitive data. The connection is “always-on” as there are no interruptions, need to dial-in or to wait for other transmissions to complete first. A dense transmission tower network is already in existence, allowing for constant and consistent signal power across a wide area and cellular technology is used to assign neighboring transmission towers different frequencies in AMPS to avoid frequency collision. Finally, the channel separation is set to 30 KHz, a much larger channel separation than that used in the UHF commercial band and helps reduce cross-channel interference [Park & Gao, 2002].

3.1.3 Aeris.NET MicroBurst

This wireless data communication product offered by Aeris.Net is a low-cost solution for applications that require widespread availability and high reliability but only have small message sizes. The Aeris.Net service, known as MicroBurst, is similar to CPDP in that it utilizes the analog portion of existing cellular networks to transfer data. However, this is the only aspect that these two services share in common.

The major advantage that MicroBurst has over CDPD is its availability. A CDPD subscriber is tied to a specific CDPD provider and the areas where their coverage exists. While there are roaming agreements between different providers, the overall coverage of CDPD is not great outside of urban areas in North America. Aeris, on the other hand has made agreements with major cellular providers in North and Central America, allowing MicroBurst subscribers the seamless use of multiple networks covering much of North America. For a company whose asset fleet may be spread over a nationwide or continent-wide area, working with one service provider that can provide coverage almost anywhere in North America is beneficial through simplified access and billing. In Figure 3.1, the coverage area of the MicroBurst service can be seen for the United States, Mexico and

Canada. Coverage is available for nearly the entire geographical area of the continental USA. The majority of the populated areas of Canada and Mexico are also covered.

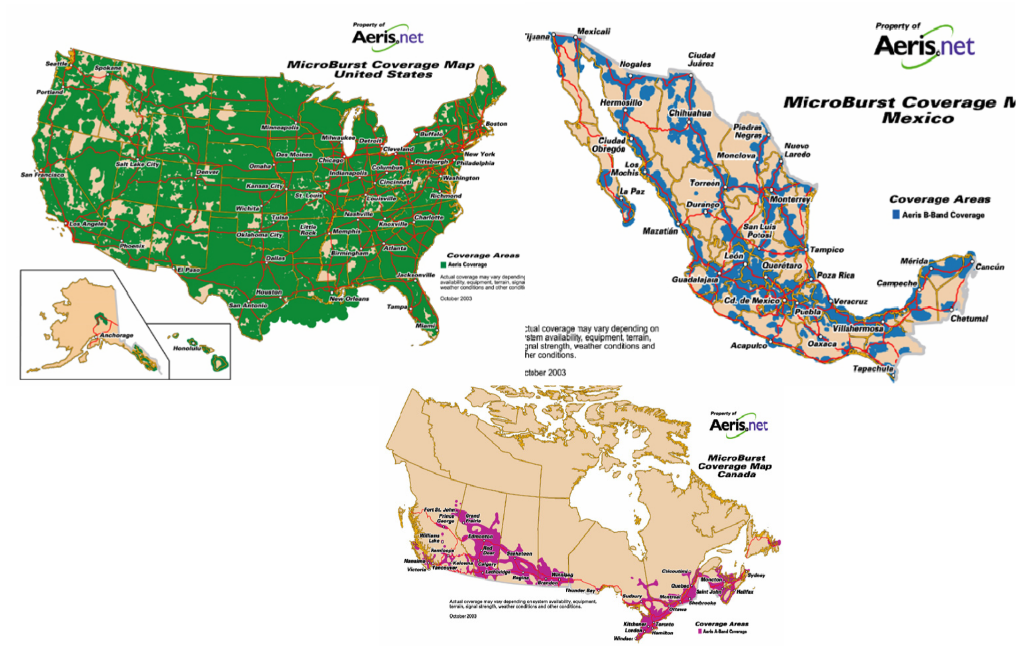

MicroBurst Coverage Map United States
MicroBurst Coverage Map Mexico
MicroBurst Coverage Map Canada
Coverage Areas
Aeris.net

Figure 3.1: Aeris.Net MicroBurst Coverage Area (http://www.aeris.net/aeris_web/products_coverage.html)

Aeris.Net's MicroBurst service is not a wireless Internet service like CDPD. Rather it is a hybrid service that relays messages issued by a MicroBurst-enabled remote sensor from the AMPS cellular network onto the Internet to asset owners. MicroBurst utilizes the **Fo**rward **C**ontrol **C**hannels (FOCC) and the **Re**verse **C**ontrol **C**hannels (RECC) of an AMPS cellular network [Aeris.Net (2), 2004]. FOCC messages are transmitted from the cellular switch to the MicroBurst-enabled devices. RECC messages are transmitted from the MicroBurst-enabled devices back to the cellular switch. These RECC messages are then sent to the Aeris.Net central hub, which finally relays the messages through the Internet back to the asset owners. Together, they enable two-way communication and control with assets.

FOCC messages, otherwise known as pages in MicroBurst terminology, are sent to devices that are onboard assets and are meant to trigger responses from the device or to get the device to perform a desired operation [Aeris.Net (1), 2004]. Each MicroBurst-enabled device can have up to 10 Mobile Identification Numbers (MIN) [Aeris.Net (1), 2004]. Each MIN can be used to trigger a different event or operation on the device. FOCC messages are initiated by the asset's owner or users, who send the page in a MicroBurst specific format to Aeris.Net's central hub. Aeris.Net then sends out the page as a FOCC message to the desired device.

MicroBurst-enabled remote sensors send responses and data back to Aeris.Net's central hub via the RECC messages. Each message packet's data is encoded into a number string. Once the number string is received at the central Aeris.Net center, the number string is finally relayed to the asset's owner through the Internet [Aeris.Net (1), 2004]. To obtain data in real-time, the asset's owner must be continuously connected to Aeris.Net through the Internet. Otherwise, Aeris.Net will store the data until the owner connects with the server. The maximum length of a number string is 32 digits for a maximum of 100 bits for data only [Aeris.Net (1), 2004]. While the data bandwidth of the MicroBurst service is limited in comparison to CDPD, it is still possible, through efficient usage of each available bit in the number string, to send useful amounts of data through a MicroBurst message packet. Splitting large amounts of data across multiple message packets is also possible. From experience, MicroBurst is most commonly used in applications such as vehicle tracking, security systems and remote asset monitoring.

3.1.4 Next Generation Cellular Networks

Continued developments and upgrades to cellular networks have created digital networks that offer greater bandwidth capabilities than previous analog-based Wireless Internet methods. Ultimately, all of the areas currently covered by analog will be upgraded to digital, thus providing the necessary infrastructure for these advanced digital Internet services. Some of the new digital services, such as GPRS (**G**eneral **P**acket **R**adio **S**ervice) and RTT (**R**adio **T**ransmission **T**echnology) have already been introduced by cellular providers in Canada. These services work similarly to CDPD, with the same benefits of having a continuous connection and built-in encryption and authentication, but with speeds of about 56 Kb/s instead of 19.2 Kb/s. As these new digital networks grow, it is expected that CDPD coverage will be gradually withdrawn from the market. For example, a major Canadian telecommunication company has stated that it will completely transition away from CDPD as of February 28, 2006 and support only its next generation digital data network [http://www.telusmobility.com/ab/business_solutions/cdpd.shtml]. However, at this time the coverage area of various next generation digital networks are inferior to older, analog-based data services such as Aeris.Net's MicroBurst and devices that support the new networks are only beginning to appear. This makes the next generation networks not yet suitable for MAMS in terms of linking assets with the Office. However, their improved performance is ideal for extending the User domain outside of the Office for users that are within the coverage area of these networks.

3.2 Data Acquisition

Two data acquisition methods are commonly used in a MAMS. These methods are manual inspection and automated remote sensors. The manual inspection method relies on visual inspection by workers of assets. This was the data acquisition method used by two of the MAMS examined in Section 2.6. While manual data acquisition is usable for MAMS, remote sensors have the advantage of always being at the asset and ready to provide information. The examination of real-world MAMS in Section 2.6 shows that remote sensors have advantages in terms of when and how often they can acquire data over manual inspection. Newer remote sensors even integrate several different sensors into a single package to monitor multiple attributes and trends that cannot be detected by an infrequent inspection. The majority of the examined MAMS utilized remote sensors.

FleetLink was a MAMS that utilized remote sensors. The FleetLink remote sensor consists of a GPS receiver, inputs and outputs for connecting with asset sensors and the ability to send the monitored asset data using cellular networks or radio. Table 3.1 lists relevant specifications of the FleetLink remote sensor.

Table 3.1: FleetLink Remote Sensor Specifications (http://www.fleetmind.com/flash/components/flash.html)

GPS Receiver	8 channel, continuous tracking 1 Hz <130s to first location after power-on
Data Acquisition	31 inputs/outputs
Data Delivery	Wireless cellular Radio

The CSI Asset-Link is another remote sensor and like FleetLink, combines cellular communication, GPS technologies and the ability to monitor asset attributes. Asset-Link sensors utilize an onboard high-sensitivity GPS receiver chip to provide location data and supports data transmission through several different wireless methods. These methods include AMPS and GPRS. Figure 3.2 has a picture e of the Asset-Link sensor.

Figure 3.2: CSI Asset-Link Sensor (www.csi-wireless.com)

However, the Asset-Link has greater "intelligence" that makes it more flexible and useful for mobile asset management compared to FleetLink. It supports programmable geo-fences, allowing the Asset-Link to be used in security applications such as DirecTrack and Tellicate. The Asset-Link also supports programmable exceptions, which allows it to act automatically when monitored attributes reach preprogrammed values. Finally, the

Asset-Link also has two-way capability, allowing commands to be sent via cellular networks enabling the Asset-Link to be used in all types of MAMS. The Asset-Link will also report the results of the command, including if it has been completed successfully or not. This is extremely useful because not knowing whether a command was received or completed successfully is just as bad as the command not being received by the asset [Segal, 1996]. The Asset-Link is small, so it can be easily hidden in an asset and has low power consumption. Table 3.2 lists some of the Asset-Link's relevant specifications.

Table 3.2: Asset-Link Specifications (http://www.csi-wireless.com/products/documents/NewAssetLink.pdf)

GPS Receiver	12 channel, continuous tracking 1 Hz <50s to first location after power-on 10m 2D RMS
Data Acquisition	8 inputs/outputs 50 geo-fences 32 programmable exceptions
Data Delivery	Wireless cellular On-board storage for up to 10,000 records
Size and weight	Length:155mm Width: 103mm Height: 26mm Weight: 360g
Power Consumption	Sleep: <0.1W Typical: <1W Transmit: <7W

3.3 Asset Data Management and Storage

In a real world MAMS, large amounts of data can be generated. For example, a recent Alberta Government MAMS project for tracking snowplows estimated that it would handle 550 snowplows each sending about 3000 messages daily back to a central office [Alberta Transportation, 2004]. This results in approximately 1.65 million new records every day and 50 million records per month. This requires a well-designed database management system to store and manage and to achieve fast query performance. With the wide variety of hardware and software platforms available for computer servers, desktops and mobile computing devices, technologies that offer standardized methods for accessing and manipulating databases are also important.

ODBC (**O**pen **D**ata**b**ase **C**onnectivity) is a technology that makes enables access to many types of databases from an application. The only requirement is that both the application and the database are ODBC compliant. ODBC provides a standardized set of specifications that ensures that an ODBC compliant application can "speak" to an ODBC compliant database in a manner that the database understands and vice versa [MSDN, 2004]. ODBC also ensures that data that is received back from the database is in a form that the application can use. This allows different database products, ranging from a simple, inexpensive database product like Microsoft Access to enterprise level products from Oracle or Microsoft SQL Server to be used in a MAMS without needing major changes. ODBC is also programming language independent and is supported on the Microsoft Windows, Macintosh and several UNIX platforms [MSDN, 2004].

SQL (**S**tructured **Q**uery **L**anguage) is a programming language that can be used to obtain, add, delete and modify information from databases. Many databases are SQL-compliant, which means they conform to the SQL standards and should respond identically when given the same SQL query [Brockwood, 2001]. Similar to ODBC, SQL allows different database products to be used without needing to change existing SQL queries. ODBC and SQL work together in providing a standardized method for applications in getting data from a database in a usable form and follow the same ideas as those of OO programming in terms of black box objects. The application and databases are black boxes to one another in the sense that one does not know the other's implementation details. They only communicate using a standard public interface, in this case ODBC and SQL. How the database performs the SQL query is hidden from the application while the application's use of the queried results is hidden from the database.

3.4 Spatial Data

Spatial data are available in vector and raster formats. Vector data are popular in GIS and CAD applications and for companies who produce their own data, such as the resource industry. Spatial data in raster form are commonly used for street maps.

3.4.1 Vector Data

From Section 2.6, Telus, **MEMS** and **IMEMS** all used or supported vector data for their User Component. Vector data stores spatial information in the form of points, lines and areas. Each of these elements is encoded using data that describe its magnitude, direction and connectivity [CAD Resources, 2000]. These three MAMS supported vector data because they targeted resource and mining companies. Such companies typically create their own infrastructure of roads and buildings to support their operations and the vector data is already available, as it has been created as part of the infrastructure planning and building process.

One of the most widely used form of vector data is the ESRI Shape format popularized in ESRI's GIS products. It supports various types of data, including polygons, polylines, lines and points and can handle 3D features as well but ultimately each different type can be reduced to a collection of points. For example, to represent a line in the Shape format, only two points are needed. One point contains the coordinates of the start of the line and the other has the coordinates for the end of the line. A Shape file contains the vector features in a binary file plus an associated simple flat database, which contains the attributes of the features [ESRI, 1998]. ESRI Shape has several advantages. First, a large amount of spatial data is already available in this format. Second, ESRI Shape is an open format as ESRI provides the technical specifications for the format, making it easy to develop software to use Shape data. Finally, there are also software converters that can convert spatial data in other CAD formats into Shape.

3.4.2 Raster Data

In DirecTrack and Tellicate, two MAMS that were examined in Section 2.6, the map data that they used was in raster form and was provided by a third party. Raster data consists of a grid of cells that cover an area of interest and each cell is the smallest unit of information possible [CAD Resources, 2000]. There are providers of raster data that cover much of the world with detailed maps that go down to the street level of detail. Such providers include Microsoft MapPoint Web Service and MapQuest and their products are deployed using the Internet. Using a third party to provide spatial data offers the advantage for companies of gaining access to high quality spatial data at low upfront cost. There is no need to acquire and maintain spatial data or have to store vast amounts of spatial data onto their computer systems [Microsoft, 2004]. They also offer services as geo-coding, travel directions and finding nearby points of interest, services that are of great interest to individuals and companies that operate within the standard street and highway networks of cities and countries.

MapQuest offers comprehensive coverage of over twenty countries in North America, Europe and Latin America plus more than a hundred major cities in the rest of the world. MapQuest also provides a database of two million points of interest in North America and 770,000 in Western Europe [MapQuest, 2004]. MapQuest can be used for mapping, geo-coding, routing and finding nearby points of interests. Accessing MapQuest is done through the Internet with clients accessing a main MapQuest server and MapQuest provides class libraries for developers to aid in connecting to MapQuest. MapQuest is supported on several platforms, including Microsoft Windows, Sun Solaris and Red Hat Linux. Multiple programming languages are also supported, including Java and C++ [MapQuest, 2004]. MapQuest uses a proprietary HTTP (**H**yper**T**ext **T**ransfer **P**rotocol) based protocol for client to server communication [MapQuest, 2004]. HTTP is the primary protocol for communication used on the Internet. An example of the MapQuest service is shown in Figure 3.3.

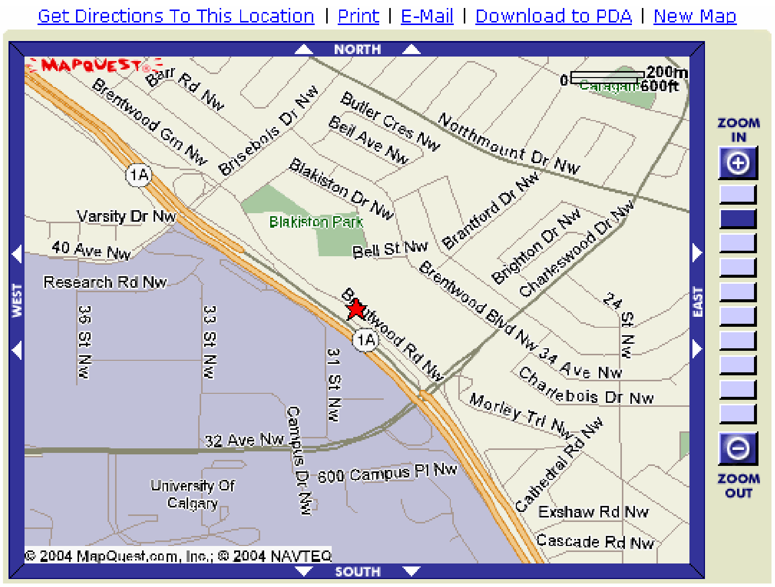


Figure 3.3: MapQuest Service Example (http://www.mapquest.com)

Microsoft MapPoint also offers street level maps of Canada and the United States. There is also extensive street level coverage of Europe and major cities in Mexico and South America. The road coverage totals 8.8 million kilometers in North and South America and 4.6 million kilometers in Europe with a global database of 15 million points of interest [Microsoft, 2004]. MapPoint can also be used for mapping, geo-coding, routing and finding nearby points of interests. MapPoint is primarily targeted at the Microsoft Windows platform and its development tools and languages. However, other platforms can be supported because the MapPoint service is accessed over the Internet and communication is done using open and standardized protocols [Microsoft, 2004]. There also exists class libraries and sample code for Java. Like MapQuest, MapPoint uses an HTTP based protocol to transfer map data. A sample application that uses MapPoint's raster data is shown in Figure 3.4.

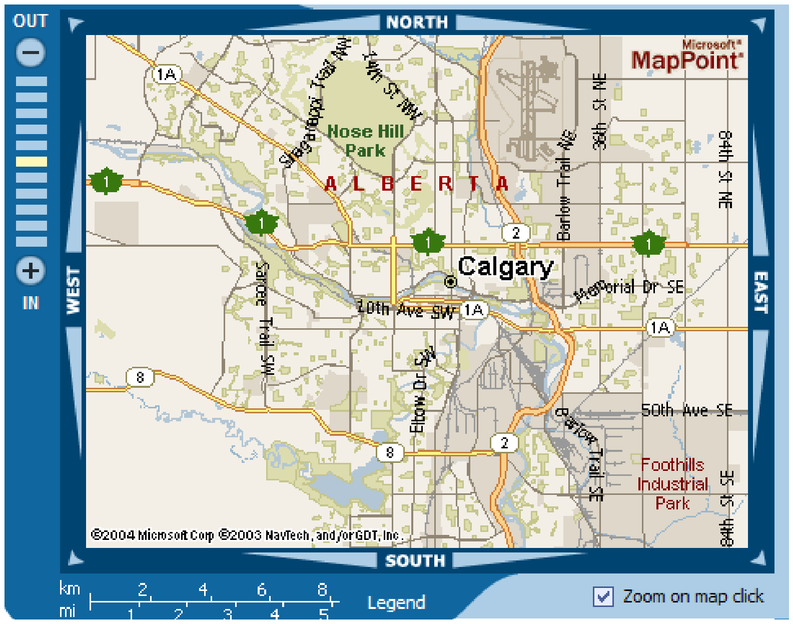


Figure 3.4: Microsoft MapPoint Service Example (http://mappoint.msn.com)

After examining both services, MapPoint was found to be better. While MapQuest and MapPoint offer comparable levels of spatial data and services, MapPoint had superior developer support. Sample code and documentation for using Java with MapPoint was readily available and MapPoint offers a free 45-day account for developers to test their service. There is also an affordable one-year account available that offers developers unlimited access for development as well as 50,000 transactions for commercial usage.

3.5 Object-Oriented Programming

The goal of this thesis is to create a new software development platform that can be easily utilized for MAMS. To be a true platform, it must offer a full suite of functionality dedicated to MAMS. This functionality has to be easily reused by third-party developers for a variety of MAMS applications. In this regard, the Object-Oriented (OO) philosophy and OO application frameworks in particular, is suitable for **MAMSDev** as it promotes and facilitates reusable and maintainable software. High reusability results in better software that can be more easily modified, extended and maintained [Berard, 2000]. OO has the potential, if used in an effective manner, to reduce software development times, while increasing feature levels and reliability. Maintainable software is essential because it has been estimated that 80% of the cost of software over its lifetime is incurred for maintenance and it is rare that any complex software is maintained by the original author(s) for its entire life cycle [Fei, 2001]. In this chapter, a brief examination of OO will be conducted and principals and ideas that are important to the creation of **MAMSDev** will be discussed.

3.5.1 Object-Oriented Application Frameworks

OO application frameworks are a form of reusable software. They can be used in any application that is relevant to the intended purpose of the framework while requiring only a minimal effort [Biddle, 1995]. A common definition used by Ralph Johnson for a framework is that they are "*a reusable design of all or part of a system that is represented by a set of abstract classes and the way their instances interact*". Their purpose is to be "*the skeleton of an application that can be customized by an application developer*" [Johnson, 1992]. A framework typically has existing objects and data already targeted for specific real-world applications. In essence, a framework is an already semi-complete application, which can be taken by developers to create a complex and fully complete application [Johnson & Foote, 1988]. Because a framework is already semi-complete, a framework is typically targeted at specific fields.

OO application frameworks are an integral part of application development nowadays because of the complexities and cost associated with any large application development nowadays. To create a new application from scratch that not only works, but is also efficient and portable across a diverse array of hardware architectures and operating systems is simply not possible without significant investments of time, money and human resources [Fayad, 1997]. By using application frameworks, costs can be greatly reduced by not having to recreate core components. Another benefit of using an application framework is a reduction of errors and bugs in completed software because the framework would have already been heavily optimized and debugged by the framework provider, which can also reduce development times [Fayad, 1997].

Not only do application frameworks promote reusability, they also help improve the modularity and extensibility of systems. Modularity occurs because of information hiding and encapsulation, resulting in classes or groups of classes whose interface methods remain stable while their actual implementations can be volatile. Changes to code or implementation also remain local to a specific classes or group, resulting in fewer unintended system effects when changes are made within a class's private details. Extensibility allows applications to be developed beyond the initial scope of the application framework. This is done by adding specific methods in the framework, which custom applications can extend. Application-specific processing can be done without needing to access or alter any of the framework code.

3.5.2 OO and MAMS

Many of the concepts in OO will be followed and utilized during the course of developing **MAMSDev**. Developing a reusable MAMS-targeted OO application framework is highly beneficial for MAMS development for a number of reasons. While the purpose of MAMS applications can vary greatly due to the numerous fields that such systems could be used for, there are common elements that remain, thus allowing opportunities for reuse. All MAMS need some form of data collection from assets and the data must be uploaded to one or more central locations. Once the asset data has been received, then it must be entered into a database management system for long-term storage. Finally, users need to access the data, such as through a software interface, so that they can manage and analyze the data in an effective manner. These common elements can also be seen in Figure 3.5.

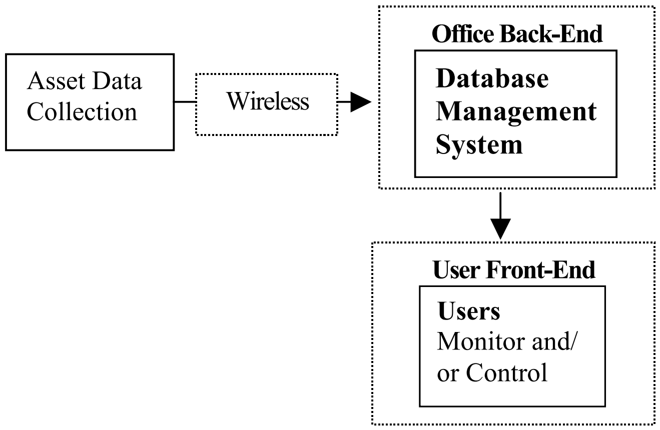


Figure 3.5: Common MAMS Elements

MAMSDev will be developed as an application framework as it best fits the needs of MAMS development. **MAMSDev** can become the skeleton of a new MAMS, providing the infrastructure and allowing the developer to concentrate their resources on the custom aspects of their application. OO also allows for a modular structure for the Development Platform, helping to segregate dissimilar elements from another. This has the benefits of allowing developers to select only the elements they wish to use from **MAMSDev**.

3.6 Client-Server System Architecture

A common model found in computing is the Client-Server (CS) architecture. The CS architecture utilizes servers that contain data resources and may perform some or all of the data processing function. The Client's primary purpose is to present data and processing results from the Server to users but may also process data depending on the CS design used. The CS design is further split into additional subcategories, depending on the fatness or thinness of the client layer. The thin client is a lightweight application, which only displays data and processing results retrieved from the server. On the other side of the spectrum, there is the fat or thick client where by most processing functions are on the client side and only the data is retrieved from the server. Between these two extremes, there are also hybrid clients who split the processing workload between the server and client [Peng & Tsou, 2003].

Internet-based MAMS follow the CS concept as asset data management, storage and most processing is done at a central server. The Web-based User Component acts like a thin client, as its primary purpose is to display asset data to users and needs to run on less powerful, mobile devices. Many other Internet web services follow the same CS concept, including MapQuest and MapPoint.

3.6.1 System Partitioning and Multi-Tier Architectures

In some CS architectures, system partitioning is also used to split the server layer logically into three basic elements, that of data, application logic and presentation. These partitions are independent but remain capable of communicating and working with one another [Peng & Tsou, 2003]. Multi-tier or *n*-tier architecture breaks an application into multiple levels of layers held at physically separate locations. The previously mentioned client-server architecture is in fact also a two-tier architecture, having separated the application into separate client and server layers. The server layer acts as an interface between the client and data. Increasing higher tier architectures split the server layer into more and more layers and the complexities of a higher tier architecture increase as well.

System partitioning and multi-tier architectures while similar in idea differ in how they divide the client and server layers. Partitioning refers only to the logical separation of the client and server layers, while a multi-tier architecture refers to the actual physical separation of the client and server layers and the hardware and software configurations used to support the physically separate layers [Peng & Tsou, 2003].

3.6.2 Middleware

Usually, in between the server and the client is a Middleware layer. This layer serves as a translation layer between servers and clients and helps to hide the organization of computers, databases and networks on the server side [Peng & Tsou, 2003]. A middleware layer implementation commonly takes the form of standardized methods for communication between the server and the client. An observation that can be made is the concept of Middleware is very similar to encapsulation in OO programming and offers much of the same benefits. The only difference is that instead of hiding the implementation details of classes from one another, now the implementation details of entire server-side and client-side systems are hidden from each other, with the separate systems communicating using a standard public interface.

3.6.3 Message-Oriented Middleware

Message-Oriented Middleware (MOM) is a middleware system based upon a message-queuing system. A client makes requests that are stored into a queue, which will be retrieved by the server in the future to process. The results are then stored back into the queue, which will be retrieved by the client. The asynchronous nature of MOM means that a real-time persistent connection between the client and the server is unnecessary. If no connection is available, messages can be delayed from sending and stored into a queue. Once a connection can be made, the entire queue of messages can be sent out [Peng & Tsou, 2003].

3.6.4 Remote Procedure Call

Unlike MOM, Remote Procedure Call (RPC) uses a real-time direct and synchronous connection between the server and the client. The client calls remote procedures on the server, which the server services and sends the results back to the client. The client must remain connected to the server until it receives the response back, therefore locking the client from performing any other operations. RPC is generally used in situations when an immediate response from the server is necessary [Peng & Tsou, 2003].

3.7 Dynamic Internet Content Presentation Technologies

For much of the Internet, content is stored as static web pages and a standard web server application, such as Apache or Microsoft IIS, is all that is required to handle requests from users. However, a MAMS is not static as there are assets that are moving and frequently sending back new data. A Web-based User Component would need to offer dynamic content creation capabilities and be able to display to users real-time information. Popular technologies that are currently used today include Common Gateway Interface, Server Extension and server-side scripting.

3.7.1 Common Gateway Interface

One of the oldest method for creating dynamic content is the Common Gateway Interface (CGI) technique, which utilizes an external program along with a web server. The web server would pass requests for dynamic content to this external CGI application, which performs any necessary processing and returns the results back to the web server to send back to the requesting user's browser software. An advantage is that CGI applications can be written in almost any language, as long as the application implements CGI's standardized method of communication with the web server. CGI is also generally browser independent as the output consists only of HTML and images that nearly all browsers can interpret. However, a large disadvantage is the life cycle of a CGI request.

Each request requires that the web server create a new process for the CGI program, a time and computer resource consuming process. Even when requests are made for the same CGI application, separate CGI processes must be created. This greatly limits performance and scalability [Hunter & Crawford, 1998]. As well, since the output that CGI produces must be HTML-compatible to ensure compatibility with Internet browsers also means that only text information and static images can be created dynamically for viewing. Figure 3.6 shows how the CGI request process works.

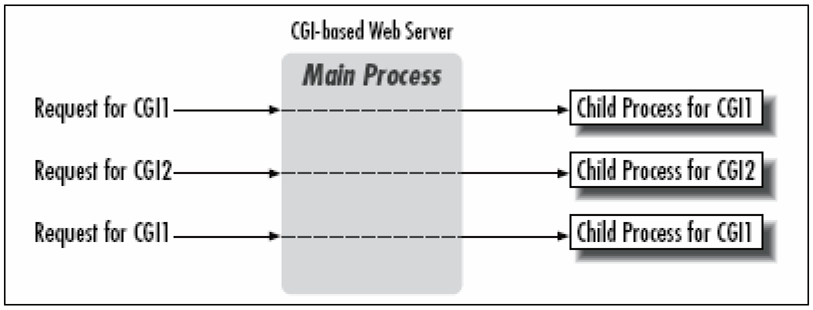


Figure 3.6: CGI Request Process [Hunter & Crawford, 1998]

3.7.2 Server Extensions

Server extensions created using APIs, including Microsoft's Internet Server API (ISAPI), are improvements upon CGI by creating proprietary server extensions that allow developers to enhance the functionality of web servers. This allows the web server to process requests directly, instead of resorting to an external program. Performance and scalability is high, as server extensions often use optimized C or C++ libraries. Server extensions also avoid the expensive process of continuously creating and destroying new processes as in CGI.

However, there are several disadvantages to server extensions. One is potential security and stability issues, while the other is platform independence. As any server extensions will be running in the same process as the web server, a crashed server extension can cause the crash of the rest of the web server. Poor security in the extension could result in unauthorized access to secure data in other Internet content served by the web server or elsewhere on the host computer. As these server extension APIs are generally tied to a single web server product, which themselves may only run on certain operating systems, portability and platform independence becomes difficult if not impossible. Figure 3.7 shows how server extensions operate.

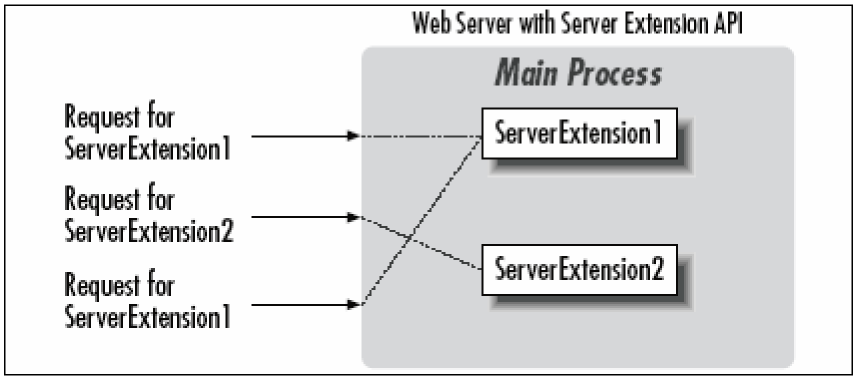

Web Server with Server Extension API
Main Process
Request for ServerExtension1
Request for ServerExtension2
Request for ServerExtension1
ServerExtension1
ServerExtension2

Figure 3.7: Server Extension Request Process (Hunter & Crawford, 1998)

3.7.3 Server-Side Scripting

Another method to create dynamic content is through server-side scripting. Rather than writing a full-blown application or extension to handle dynamic content, small sections of code can be embedded into a web page directly, in between the HTML code. The HTML code is used to define the static sections of the web page, while the scripting code is used to for dynamic sections. Such code can be written in many different languages and popular languages include JavaScript, VBScript or Jscript, all languages that have an easy to learn syntax. The code is read and executed by the web server whenever the web page is requested. Popular server-side scripting techniques include Active Server Pages (ASP), which is included in Microsoft's IIS web server product, Perl and PHP. Scripting is easy to implement but is limited typically to dynamic text and simple graphics.

3.7.4 Java Dynamic Internet Content Presentation Technologies

Java was introduced in 1995 as a brand new platform that promised to revolutionize how software applications were created. A key part of the platform was the Java programming language, which had many similarities to C++ in syntax and idea. Among the initial advantages touted by Java over existing programming languages were:

- The ability to write code once and have it run anywhere, no matter the hardware or software platform and without any additional effort.
- Designed from the ground up for object-oriented programming.
- Better inherent system security and safer memory management compared to the C/C++ programming languages.
- Allow full-fledged applications to run completely within an Internet browser.
- Developing server-side applications for dynamic and interactive Internet content.
- Usable on a wide range of consumer devices.

While the current situation of Java has not lived up to the expectations generated by Java's introduction nearly a decade ago, it has been highly successful in several niches and the whole Java Platform now consists of the Java programming language, compilers, interpreters, tools, libraries and integrated development environments. Java in recent years has become heavily used for Internet and server-type applications, as Java offers a wide range of technologies well suited for such applications, such as in the area of Web applications and services. As well, Java being designed from its beginning to be an OO development language makes it a suitable choice for developing **MAMSDev**. This platform consists of a powerful programming language and offers numerous low-level classes, which are of great utility for performing fundamental operations such as string and binary data handling. Higher-level Java components are typically used as building blocks for end-user applications.

To achieve its high level of platform independence and the ability to “write once, run anywhere”, the source code of a Java application is not compiled from source code into machine specific code, like in C or C++. Rather they are compiled into an intermediate, non-machine specific level of code, called byte codes. Whenever a Java application is run, its byte codes are used by a Java Virtual Machine (JVM) to compile at run-time into the final machine specific code. The JVM is specific to each platform so that the specifications and optimization requirements of the platform is handled by the JVM. The JVM usually also provides the built-in classes and libraries of the Java Platform, so that developers of a Java application need not provide any of these classes in their application package, helping to reduce its size. This is especially useful for Internet applications by minimizing download times.

Like Java, the Internet has always been platform-independent, allowing content to be created, stored and viewed on a wide spectrum of platforms. Not surprisingly, these similarities has resulted in great success for Java in Internet application development and spawned many Java technologies designed to aid in the creation, serving and presentation of content through the Internet and for Internet-based enterprise applications. Three Java technologies, namely Applets, Servlets and Java ServerPages, have features that are especially useful for the serving and presentation of asset data to users in a MAMS. Since each technology has their own specific strengths and targeted areas of use, they are described in detail separately in the following sections.

3.7.5 Java Applets

An Applet is a Java application designed specifically to work within the confines of an Internet browser. An Applet is used whenever complex or graphical information needs to be presented as it has all the capabilities of a Java application, such as a graphical user interface. However, as the Applet runs on the remote user's computer, it is a client-side process and is therefore barred by Java security practice from accessing resources on the server directly. To get access to these resources, some application must be available on the server that can respond to the Applet's request and provide it with the resources it needs. For this task, the Servlet is used.

3.7.6 Java Servlets and ServerPages

A Servlet is also a Java application, but one that resides on a server and listens for requests from the outside. Potential requests could be initiated by Applets. A Java Server Engine or a fully Java Servlet enabled web server is needed to properly operate Servlets.

As seen in Figure 3.8, a Servlet uses different child threads to handle different incoming request. Creating only a new child thread, which can share global memory with other child threads of the Servlet, is much faster and consumes less computer resources than creating a new separate process in CGI, thus providing an effective solution for dynamic content that is also high performing and scalable. Child threads also have local variables that are only visible within a thread context, so that data meant for one client does not go to another client and clients do not interfere with each other in any way.

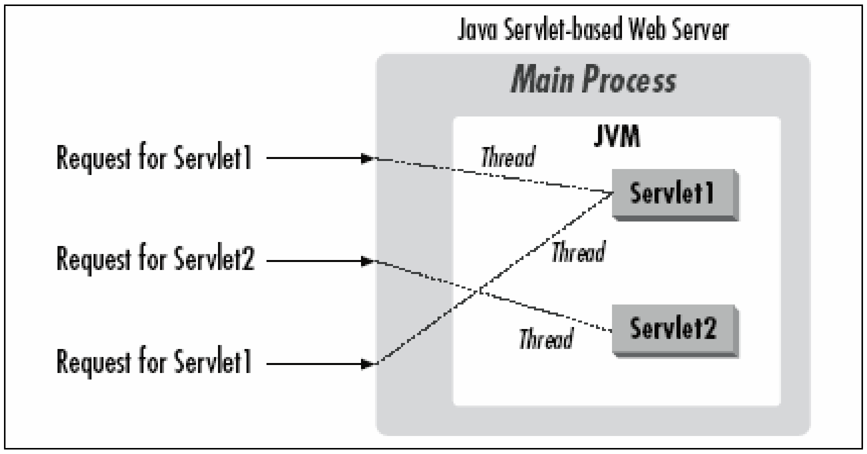


Figure 3.8: Servlet Request Process (Hunter & Crawford, 1998)

Java **S**erver**P**ages (JSP) is Java's answer for server-side scripting. A JSP file is simply a normal web page that contains HTML code intermixed with Java source code and the web page has an extension of JSP to identify it. The JSP, like Servlets are processed by a Java Server Engine. When a JSP file is called by a user, it is executed by the server engine. After execution, the results are outputted as HTML code in place of the Java source code in the JSP and sent to the user for display. Because the JSP is a server-side application, it also has access to all the resources that are available on the server-side. They are considered a special form of the Servlet. The advantage that JSP has over other server-side scripting methods is that JSP allows the full use of the Java Platform class libraries, which are much more extensive as compared to any other scripting language. Any new development in Java is automatically available to JSP and Servlets and greatly enhances the reuse of software and code. Another advantage is that JSPs are precompiled, as compared to most other scripting methods, which are typically compiled per request. This benefits response time and performance. While JSPs can communicate with existing Servlets and makes requests to them, JSPs still are primarily designed to handle simple dynamic content, such as querying databases and returning the results in a tabular form and consisting primarily of text. Servlets, being a more general form of the JSP can transfer any form of data to a requester, including complex class objects containing desired data. The class is transformed into a binary stream and sent to the user application. The user application casts the binary data back into the original class object and use it directly. The only requirement is that this class must be part of the source code of both the Servlet and Web Client and be identical.

Chapter 4

Platform Methodologies and Architecture

In this chapter, the process in developing the theoretical design and capabilities of **MAMSDev** will be described. This stage is important in ensuring a smooth developmental process when the actual implementation of **MAMSDev** is conducted.

4.1 Process

The process to create the Development Platform is shown in Figure 4.1. Input and requirements given by industrial partners were achieved first before development began.

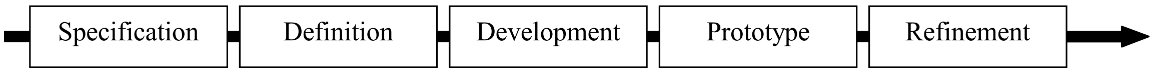


Figure 4.1: Development Platform from Start to Finish

4.1.1 Determining Platform Specifications

The motivation for **MAMSDev** is to act as a foundation for real world MAMS, to help reduce duplication of effort and resources. Therefore, it would need to work in a fashion demanded by the real world. The examination of existing real-world MAMS that was described in Section 2.6 was also to determine the common and desirable functions that would be part of **MAMSDev**. The key feature of **MAMSDev** is that it will provide a complete set of basic functions used in a MAMS, from asset to user but is structured in a way that allows developers to pick and choose which functions they needs. This allows them the freedom to develop their MAMS to best meet their needs and not be locked into a specific configuration that they would be if they used the real world MAMS examined previously. In cooperation with industry, specifications were drawn up for hardware, infrastructure and software systems that **MAMSDev** would have to support in an operational environment. Specifications were also created for the encoding, storage and management of geospatial and non-spatial data.

4.1.2 Platform Definition

With these specifications and requirements determined, **MAMSDev**'s architecture was defined and the components and features that were necessary were identified. Vital at this definition stage was creating a platform that is reusable, modular, extensible and open in order for **MAMSDev** to be embraced and used by third-party developers.

4.1.3 Platform Development

With the architecture defined, the **MAMSDev** architecture details and implementation were the next areas focused on. Initially, a beta but still fully functional version was created, building on existing research and software developments to achieve the desired Platform architecture. Java was heavily utilized, as it is an ideal programming language for achieving the desired OO principals of reusability, modularity, extensibility and openness for **MAMSDev**. These are the key requirements for **MAMSDev** becoming a successful application framework for MAMS development. Reusability results in less duplication of efforts and reduced development times; both factors are important for time-to-market considerations. Modularity improves application quality and stability by localizing the impact of code changes and reduces the effort needed to maintain code. Code extensibility allows developers to extend Platform components beyond their initial limits without altering the inner workings of **MAMSDev**. An open structure allows for reuse of **MAMSDev** across a spectrum of related applications and data sets and be integrated with products from other vendors. Java also has a number of feature-rich libraries that significantly help in areas of communication, data management and content presentation for greatly reduced development effort and time.

4.1.4 Prototype System Development

A Prototype System that interoperates with industrial partner's specified hardware, wireless, software and data requirements was created to assess the value of **MAMSDev**. It meets the specifications and requirements given by industrial partners and validated the value of **MAMSDev**. The procedure used to create the system is as follows.

1) Creating the Prototype System that satisfies a need or application for our industrial partners while utilizing **MAMSDev** for its foundation.
2) Reliability and robustness is of vital importance in any enterprise application, especially in a MAMS with its remote, hard to access hardware, significant automated operations and consequences to profits caused by undiscovered bugs or system downtime. Significant testing of the Prototype System was necessary and using varying numbers of clients and sensors to stress test the prototype. This also

helped isolate and eliminate bottlenecks in the system, improving performance. The testing also established guidelines for sensor, hardware and software needs that future developers can use in building new MAMS applications.

3) An important factor for the adoption of **MAMSDev** is the ease of use of Web Clients and administration. Usage tests conducted with project researchers, industrial partners and outside people were used to gather comments and criticisms regarding the user interface to help create one that is intuitive to use but still offering the necessary functionality and tools. The dynamic nature of a MAMS also requires administrative tools that allow MAMS administrators to register new clients and assets quickly. The testing period helped clarify what types of tools were necessary and enabled **MAMSDev** to become more easily configurable.

4.1.5 Platform Refinement

Lessons learnt from the prototype system development and testing stages were propagated back into **MAMSDev** to refine it into a stable, high performing and flexible engine capable of commercial use. All features and functions were well documented to allow for use by third-party MAMS application developers.

4.2 System Architecture

MAMSDev can be described as having two distinct layers. The first is the Platform Layer, which contains the basic fundamental operations provided by **MAMSDev**. The other layer is the Application Layer, which contains both the functions that interface between the Platform Layer and third-party MAMS application as well as the unique application functions.

4.2.1 Platform and Application Layer

Classes in the Platform Layer are fully realized classes that provide the important low-level foundations that are useful in different MAMS applications. These classes will be typically used without modification on the part of the developer. The Application Layer is where the custom functionality of individual MAMS application is enabled and interfaces with the Platform Layer.

MAMSDev provides many existing functions already for the Application Layer, which have been created based on the experiences of previous prototype system developments and the examination of real world MAMS. Functions in the Application Layer can be grouped into three types. There are abstract classes, which are the super-classes that define the minimum functionality and behavior for child classes to be compatible with **MAMSDev**. These act as a template for developers to create compatible classes to interface with **MAMSDev**. The second level of classes is considered concrete, as they provide concrete and fully realized examples of the abstract classes. The concrete classes are fully featured enough to be used in a MAMS application without modification. Finally, there is the custom level of classes, which are classes that have been sub-classed from the first two levels of classes by developers and then modified to have custom functionality and behavior or to work with brand new classes created by the developer.

4.2.2 Client-Server Architecture with Partitioning

MAMSDev's design is a flexible one in that it can have either a CS or a multi-tier architecture. This is because it has separated the server-side layers into different and independent modules. **MAMSDev** utilizes system partitioning in order to achieve modularity and better potential performance and scalability through distribution of the modules across different servers if necessary. The partition scheme follows the standard practice of separating data, logic and presentation but further subdivides the data and logic partitions for greater modularity. The modules can all run on a single server, resulting in a standard CS system with the presentation modules running at the client computer, while the application logic and data run on the server. The modules can also be separated across several servers, resulting in a multi-tier system whereby the application logic and data can be split across several physically different servers for enhanced performance. The CS/multi-tier design is well suited for the architecture of MAMS because it fits with the segregated architecture of MAMS. The Office domain acts naturally as a server, containing all asset data, plus the management and analysis tools. The User domain acts as the client, allowing users to view data and utilize tools from the server via the Web component. Data acquisition systems are also clients that must connect back to the servers at the Office domain. **MAMSDev** acts as the middleware, joining all domains together in a transparent manner. It provides the methods for data handling, application logic and presentation.

By having central sites where mobile assets send their data consistently to and where users can access the data from, it greatly simplifies matters for users. Their client software does not have to concern themselves with how the Office domain is setup or how different databases are integrated and which servers have what data. The client software only needs to contact the server in a standardized manner and it will receive the most current version of the requested data.

A thin client is the preferred choice for most MAMS applications due to the remote nature of common applications. Most processing is done at the server and all the data and Web component software is stored at the server as well. This reduces the processing requirements of the client computer, allowing smaller and more mobile computers to be used by users in the field [Park and Gao, 2002]. To access the Web component, a user only needs a connection to the Internet and a recent graphical web browser. No asset or system data or Web component software needs to be preloaded. This ensures that when users access the Web component, they will work with up-to-date asset data and system tools. This is an appealing feature and results in great flexibility not only to the users but also to the service providers in terms of system revision and update. With a fat client, the majority of data processing is done at the client while data remains at the server. A fat client is not suitable for MAMS type applications because of the large size of asset data. Large amounts of asset data would have to be first sent to the client for processing, making it unfeasible for use in remote work areas where the data would travel over a wireless Internet connection.

Chapter 5

MAMS Platform Implementation

From Chapter 2, the examination of existing real-world MAMS helped identify the beneficial capabilities that should exist in a MAMS development platform. Chapter 3 examined the technologies that could be used to implement the capabilities of **MAMSDev** and to enable it to be easily reusable. Following the initial development process used in Chapter 4, the actual implementation of **MAMSDev** was started. Using the research conducted in Chapters 2, the most suitable technologies from Chapter 3 were chosen to be included in **MAMSDev** and details on how they are utilized will be presented in this chapter.

5.1 Java Technologies and MAMSDev

The **MAMSDev** Platform is written and based upon Java because of its OO support and its platform-independent characteristics. Java's extensive library of useful classes allows it to be used as an application framework for building **MAMSDev**. As a framework, Java provides the necessary tools for network and Internet communication, data storage and data presentation.

5.1.1 Java Framework

It is common for OO application frameworks to be built upon one or more frameworks and this is the case for **MAMSDev** as well, using the Java Platform for its foundations. **MAMSDev** takes advantage of the feature-rich, optimized and tested Java Platform. A primary area where Java is used as a framework for **MAMSDev** is for network communications and file input/output operations. Java also offers extensive networking functions that **MAMSDev** benefits from for networking and Internet. Java also has functionality for working with databases. Java is compatible with ODBC, the standardized protocol for communicating and working with databases. This compatibility is enabled by using JDBC (**J**ava **D**ata**b**ase **C**onnectivity). JDBC is the standard method for Java programming to connect with a wide variety of databases. JDBC consists of two elements, the API and the JDBC driver. The API is used by application developers and the JDBC driver is used to connect a Java application to a database. The JDBC API is used for creating SQL statements that perform queries and updates. It is also used to process the results of the SQL statements. The JDBC driver is used to connect to a database, typically in the form of a JDBC-ODBC bridge. In this form, the JDBC driver translates database queries in the Java application into the ODBC format and sent to a database. Once the database is finished with the application’s queries, the driver then translates the results back into a format recognizable by the application. This allows database queries to be called from within a Java application and the results from database operations are sent back to the Java application where the results can be stored into variables for use or processing in the application. JDBC enables database to be thought of as objects and collections in the source code, rather than as tables and records. This way of thinking is useful in reducing the amount of code that needs to be changed whenever databases are changed or replaced. Finally, Java is also used for developing the functionality in **MAMSDev** for presenting data to users over the Internet. The main Java technologies used for data presentation are Java Applets, Servlets and JSP.

5.1.2 High Level Java Components

High-level Java components are used as the building blocks for major functions of **MAMSDev**. Applets and Servlets form a partner relationship in **MAMSDev**'s Web Client, with Applets being the front-end of this relationship, as it interfaces with users and presents asset data and tools. Servlets acts as the back-end, residing on the server and receiving requests from the Applet and responding with the desired data or results. JSP has been used to display asset data in a tabular form. The asset information are not hard coded into the JSP source page, rather snippets of Java code are written to automatically retrieved the asset attributes from databases whenever the JSP is run. In this way, users can be assured that the data they see is the most current. Figure 5.1 shows how these Java technologies are used for the presentation of asset data to users.

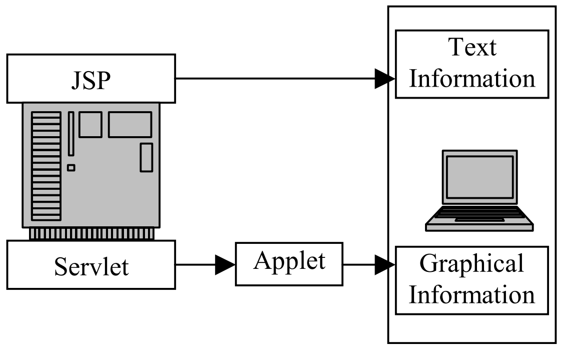


Figure 5.1: Use of Java Technologies In MAMSDev

5.2 MAMSDev Modules

MAMSDev features numerous useful functions for a MAMS application. These functions have been separated into data, application logic and presentation partitions and are further subdivided into independent module, as they are referred to in Platform documentation and this thesis. They consist of the Communication, Data and Application Modules. These modules can be used fully by a developer or just partially or even customized depending on a developer's needs. Much of the configuration for the modules is done with configuration files and databases, thus allowing for significant customization without any need to change the code. While these modules are logically separated, they can be deployed on the same server or be physically distributed across different servers. A physical separation can realize improvements for scalability and performance while still working seamlessly with each other.

5.2.1 Communication Module

The Communication Module contains the functionality to make and maintain the connections to assets. The current implementation of the Communication Module has the capability to interact with CSI Asset-Link sensors using the Aeris.Net MicroBurst wireless data service. These two technologies were chosen because they best meet the specifications given by industry partners. The Communication Module is part of the Platform Layer; there is no need for developers to modify the source code. The only configuration required is to input settings regarding the IP address of the Aeris.Net servers and account settings to login to Aeris.Net's servers. Table 5.1 summarizes the capabilities of the Communication Module.

Table 5.1: Communication Module Capabilities

Features	Description
Connecting, authentication and reconnection	Makes initial connection with Aeris.Net servers, provides the proper authentication and automatically reconnects if interruptions occur.
Automatic Message Response	Responds to any inquiries sent by the Aeris.Net server and issues regular messages to the Aeris.Net server to maintain connection.
Message Decoding/Encoding	Aeris.Net message packets are encoded in a binary form; the Module decodes the packet back into the original human-readable form. Messages to be sent to the Aeris.Net server are also encoded into the necessary binary form.

The Communication Module connects to the servers at Aeris.Net's central hub using the Internet with network socket connections. Two connections are made; one connection is to the Aeris.Net Data (DS) Server; this server relays messages sent from a remote Microburst-enabled sensor back to the Office. The other connection is with the Aeris.Net Page (AS) Server; the AS Server relays the commands or pages sent by users to the sensors and assets. The Java implementation of a network socket is "blocking", or in other words, stop all activity in the thread or process that the socket is running in while waits for new data to be sent from the Aeris.Net server. This feature helps reduce processor utilization since a non-blocking implementation would require a continuous loop to constantly check on the state of the socket and determine if any new data has been received. This continuous, endless loop would consume a significant amount of processor time. However, by blocking, the socket is only activated when data is received and as this is done automatically, there is no need to waste any computer time in a loop or additional coding efforts to check for data availability. The disadvantage of blocking is that it completely halts the execution of its thread whenever it waits. Therefore, any socket connection must be placed into their individual thread so as not to interfere with the rest of the Communication Module, as well as other **MAMSDev** modules and processes running on the Office server.

The Communication Module is also responsible for maintaining a continuous connection to the servers at the Aeris.Net central hub. These servers send regular “pings” to any connection that is made to it, to ensure that the connection is still valid. If no acknowledgement message is sent back, then the connection will be terminated. As well, other messages that are initiated by the Aeris.Net server usually require an acknowledgment or it will disconnect. The Communication Module has the necessary logic to recognize the message type and to return a suitable response or acknowledgement back to the servers to ensure the connection is not terminated. For messages sent from an asset, the raw data is extracted from the Aeris.Net message and passed onto the Data Module for further processing.

While there are a large number of unique message types that are used on the Aeris.Net MicroBurst service, all share a common format and binary encoding method. Each type has a header and limiter plus the actual message contents in between. The message contents include the metadata, such as the message length, message identification number to distinguish its message type and the message body. As the messages share a similar structure, then it is natural to implement the different Aeris.Net message types as objects in **MAMSDev** by implementing Java classes to represent each message type.

A generic message class is implemented, acting as the overall parent or super-class on which all concrete Aeris.Net message classes will be based upon. This parent class defines certain basic and common behaviors for encoding and decoding the message contents to and from binary, which is relevant to all message classes. Further generic message classes subclass from the parent. These additional levels of generic message classes will be differentiated based on the message's purposes, such as responses and data messages. They are more specific than the original parent and further add to or enhance the behaviors of the class. Ultimately, each Aeris.Net message type has their own concrete message class, supporting unique behaviors and functionality but inheriting from previous generic parent classes to reuse as much existing code as possible.

When a message is received from either of the Aeris.Net servers, the parent message class is first instantiated and given the message's binary data to decode. The implementation of the decode function at the parent level is limited to decoding only the first few bytes to determine exactly what type of message it is. Once the message type is found, the parent class is cast into the identified message's associated concrete class and the rest of binary data can be decoded into the raw message body using the concrete message class' fully implemented decode functions.

When a message is required to be sent to the Aeris.Net servers, the message must first be encoded into the standard Aeris.Net format. The parent message class features an abstract implementation of this binary encoding function to encode the message contents into the binary format. This function contains the necessary code to encode the elements that are common to all messages, such as the header and delimiter. However, the code to encode the actual message body is left up to the concrete classes to implement.

A unique ability offered by **MAMSDev** for MAMS applications is the ability for users to remotely check on and control assets in real-time. This is possible through the integration of the Aeris.Net MicroBurst service with CSI Asset-Link sensors in **MAMSDev**. Users can issue a specific command through the Web Client to this module, which resides on an Office domain server. The Relay Server, using the Communication Module, sends the message onto the Aeris.Net's AS server. Aeris.Net then proceeds to deliver the command by paging the onboard Asset-Link sensor which then performs the desired operation and reports back the success or failure of the operation as well as any results that may have occur. The Relay Server, like the Data Module, uses Servlets as its foundation because of the likelihood that multiple users would be accessing the Relay Server simultaneously. Once a command or page is received by the Relay Server, it then adds it to a queue at the Communication Module. The Communication Module will send out the pages to the Aeris.Net server, receive the response back from Aeris, and pass it back to the Relay Server, which will notify the user of the success or failure of the page. This module is also part of the Platform Layer and requires a small amount of configuration to work.

An Asset-Link sensor can be preprogrammed to perform a series of operations, with each operation represented by a unique string of numbers. Operations that are of interest in real-world applications include requests for current positions, unlocking doors, arming and unarming alarm systems, enabling or disabling engine ignition, speed limiters and continuous tracking. The configured operation and their numbered command strings are stored into the sensor database as the configuration can be unique for different sensors and/or asset combinations. For security reasons, the actual command strings and sensor identification numbers are never shown to users. Only users with sufficient security credentials have the ability to activate these commands.

5.2.2 Data Module

The Data Module is responsible for serving data from geospatial sources, such as vector data store in ESRI Shape files or raster image data, to local or remote users through the Internet. It features a highly optimized code base and the ability to provide simultaneous multi-user access. This module is responsible for receiving the raw asset data from the Communication Module, to store into databases and serve the asset data to users. Its primary purpose is to serve requests from the **MAMSDev** Web Client, though third-party applications can be compatible as well. It can be configured using external configuration files, so that the source code does not need to be changed and allows for rapid setup of new MAMS applications and projects. The Data Module is composed of both Platform and Application components. The two main classes that belong to the Application Layer are the class involving the database management and the Servlet. Template versions of both classes exist which can used as is, or as a guide for customization to meet specific needs. Specifications for the Data Module are summarized in Table 5.2.

Table 5.2: Data Module Specifications

Geospatial Vector Data support	ESRI SHP datasets
Geospatial Raster Data support	GIF/PNG/JPG
Non-Spatial Data	Asset and geospatial information stored into databases and accessed through standard ODBC protocol
Features	Automatic support of simultaneous multi-user access
Performance Optimization	Vector data caching into server memory High performance hierarchical storage scheme Non-visible data culling Data sharing among users for reduced memory requirements

The Data Module works in conjunction with the Communication Module. The Communication Module decodes the Aeris.Net message into the original raw number string before passing it to the Data Module. The Data Module then decodes the number string into meaningful information, based on the configuration set in the remote sensor and stores the information into databases. A separate component within the Data Module is used to handle the database management aspects. Because the database is among the most variable aspect in a MAMS, any changes in asset, or collected asset information would have to be reflected in the database. This use of information hiding or encapsulation helps minimizes the effect that any changes to the asset data collection would have to the whole Data Module. The database classes finally decode the number string into usable information. The classes also have the necessary queries and update functions to work directly with databases.

The Data Module is expected to work in a one-to-many environment. This is an environment where multiple users are expected to access the module at any given time.

The Java Servlet technology fits this requirement well, given its seamless handling of multi-user access. It also makes it possible for only one instance of the Data Module to handle all the clients, thus minimizing its memory footprint on its server. When the Data Module is initialized, it determines what type of spatial data it is handling. If it is vector data, it opens the associated vector data stored in the ESRI Shape file, to decode into an array of separate vector features. An ESRI Shape file can contain point, line, polyline or polygon features. While these different types of features utilize slightly different encoding schemes, the process of decoding and storage is similar. Therefore, in this situation, it is also beneficial to follow OO principals and create a parent class for a generic ESRI Shape feature, then subclass new concrete classes for each type of vector features. After the array of vector features is created, it is then broken apart into a **M**ulti-**L**ayer **S**torage **S**cheme (MLSS), which is an important optimization to reduce the search time for a given request and improve response times. This storage scheme works by having several levels that cover the entire vector map area and is similar to pyramidal schemes used for large raster data in many GIS and image processing software packages where each level contains the same image but at a different level of resolution. However, in the case of the MLSS, each level contains geospatial features of varying size, with no feature being duplicated between the levels. Furthermore, each level partitions the map area into certain cell size, with lower levels having smaller cell dimensions and a greater number of cells than at higher levels. The topmost level has only one cell that contains the entire map. As each vector feature is decoded from the ESRI Shape file, its boundary coordinates is then checked to find the smallest cell in the storage scheme that it fits into.

By sorting the vector features into different cells, most client requests will only need to search through a fraction of the vector data set. The MLSS is fully customizable; the number of levels, the number of cell partitions in the horizontal and vertical can be adjusted to match the density characteristics of a particular dataset.

All of the decoding, storage and request functions are built into the concrete Shape feature classes. As the Data Module is built upon Servlet foundation, the vector data is stored into global memory, so that threads created to service requests from multiple users share the vector data and thereby reduce memory usage. The vector data is persistent in memory, even after client threads have been destroyed once requests have been serviced. This ensures that the time and processor consuming procedure of decoding the ESRI Shape file only occurs once during the Data Module's initialization phase. This is unlike the life cycle of CGI, which would have to undergo the vector data decoding process for every request had it been used to implement the Data Module.

For the handling of raster data provided by Microsoft MapPoint Web Service, the Data Module maintains a connection with the MapPoint server. Data received from assets via the Communication Module is stored into relational databases. The database system currently used has been Microsoft Access, but all transactions with databases between **MAMSDev** and the databases involve the ODBC standard protocol, which will allow different database software packages to be readily used instead of Microsoft Access. As the format of the tables and data used will likely vary between different MAMS implementations, certain requirements are placed on how the database is structured to maintain the OO design philosophy in **MAMSDev**. A database wrapper class, acting as the database management system, is also required to encapsulate the inner workings of a particular database and communicates with the rest of the modules in **MAMSDev** through standard public interface methods.

Requests for spatial or non-spatial data are received by the Data Module through the Servlet communication method. All forms of user request follow a standard protocol, which indicate the type of request and other associated information required by the server to perform the request. The server then performs the request and then packages the requested data into a single message and sends it back to the user. After receiving a request, the Servlet performs the operations necessary to accomplish the request and sends the results back to the requesting Applet [Lee & Gao, 2002].

Within an ESRI Shape file, only the geometry or coordinates of the vector data are available. The vector data's attribute information, such as name or feature type, is stored into a separate relational database. A database query must also be conducted for any vector data request from the client. Once the list of vector data to be sent back to the client is determined, the module then precedes to query the database for the selected vector feature's information. The combined data is then sent to the client. To streamline this process, a preprocessing requirement is necessary when using Shape files. Rather than use the original database, which still uses the legacy dBASE format, the information in the database is imported into a modern relational database, such as Microsoft Access for better performance, new querying features and ease of editing and maintenance. The new database also must contain certain queries that will be used by **MAMSDev** to query for information. The queries are used as the interface, allowing the actual structure of the database to be hidden from **MAMSDev**.

In order to reduce the size of the vector data that is transmitted to the Web Client, several optimization techniques are applied. These steps are able to provide a significant reduction in size, but there is still enough information remaining for the Web Client to reconstitute the data in a graphical form viewable by the user. These optimizations are:

1) Since only a fraction of a work area would be viewed by a user at a given time, culling of the vector data can be performed, as it is only necessary to send the visible vector data to the Web Client.
2) The concrete classes derived from the parent generic ESRI Shape class is used to store and manage vector data. These classes feature the necessary functions and data structures to query through the entire set of vector data efficiently. However, these functions are not necessary for the Web Client and causes significant overhead while the data structures greatly increasing the size of the data being sent to the user. Therefore, the vector data instead is transformed from a complex form into much simpler standard arrays with greatly reduced memory overhead.
3) For the final optimization, the vector data is compressed using the GZIP compression algorithm to reduce the size even further.

Even when the selected map is in vector form, raster images are stilled used for performance reasons, as vector data consumes a large amount of space and displaying the entire vector data would not be feasible with current wireless Internet means. A raster image of the entire selected map area is much smaller in space. Raster and vector data are used to complement each other in **MAMSDev** as they compliment each other's strengths and weaknesses. Vector data, as mentioned previously, are large and therefore it is not possible to display the entire set of data without consequences for performance and download time. Raster data while capable of providing a low data size for large overviews of a work area, is poorer at resolving details or showing views of the map area at resolutions other than its native level. When zooming in on raster data, it can be resized but with distortions and lacking in detail. A pyramidal scheme is also commonly used, where an extremely large and detailed original image map is set at the bottom level and the higher levels use lower detail versions of the map area. When zooming, the displayed image can use the nearest level to resample from, thus providing a less distorted, more detailed image. However, this procedure is complex and requires significant preprocessing and storage for the various levels and it is not always possible to have the necessary high-resolution raster image of the work area. Geospatial features stored in a vector form like in an ESRI Shape file, on the other hand, can be resolved to virtually infinite levels of precision thanks to the fact that vector data is stored in coordinate space. By re-projecting the vector features from coordinate space to the pixel coordinates of the display, there is no need for resampling or interpolation and the features remain sharp and detailed even at high zoom levels.

To request raster data of a specific area using MapPoint Web Service, the parameters for the coordinate center of the desired area and the width of the map in kilometers are passed to the MapPoint server from the client. The raster data is returned in the form of a GIF image stored in the form of a byte array. The metadata that is returned are the coordinate center and extents of the map image, the map scale and view distance. The byte array and metadata are then sent to the requesting client.

Configuration of the Data Module can be done through two methods. The primary method is through adding parameters into a standard text based configuration file used for each Servlet. The second supported method is to have the configuration file provide the location of a separate configuration file, which would be parsed by the Data Module. These configuration methods provide the Data Module with important parameters such as the location of the vector data, the ODBC name of associated databases and the coordinates of the desired map extent. In this way, different projects can be created using the same template Data Module and without the need to modify the source code or to write any additional code.

5.2.3 Application Module

Similar to several real world MAMS examined previously, a Web Client is the method for users to interface and work with the data. Recognizing the advantages of an Internet accessible software component in which users access the MAMS by using just an Internet browser and data was stored on a central server; the Application Module has been developed based on the same principles. The Application Module consists of a server component and the Web Client, which enables users access to data and tools. Whenever a user connects to the Application Module through a browser, the Web Client is downloaded and executed on the user's computer. By centralizing the storage and distribution of the Web Client, benefits can be realized through reduced support and administrative costs. Administrators need only to apply updates and bug fixes to the Application Module code base held at the central server. Users can also be confident that they are using the latest version of the Web Client whenever they connect to the Application Module, as the Web Client will be updated if necessary and without requiring any user intervention. The Application Module is the embodiment of the Web component that was outlined in the description of the IMAMS architecture in Section 2.5.

The basis of the Web Client is the Java Applet. Basing the Web Client on an Applet foundation allows for the creation of a software application that offers graphical user interface that would be familiar to users. It also enables the application to run on multiple platforms without any need to rewrite the source code. The Web Client itself is also broken into several separate components to make it easier for future customization. This module is primarily considered a part of the Application Layer, though there are some classes that can serve as a skeleton to reduce development effort. In the Web Client, information about assets can also be provided in text and tabular form using JSPs to query the Data Module's database for current or historical information.

These Web Client components include a Toolbar component, a Statusbar component and a Map component plus a Parent Shell. The Toolbar controls the Web Client as it is responsible for receiving inputs from users and controlling the application based on the inputs. The Parent Shell contains the majority of the Web Client's logic. It also links all the other components together, passing controls and notifications the Map component and for communicating with **MAMSDev** server-side modules. The Statusbar component is used to display text information passed to it from either the Map or Toolbar components.

The Map component is used to display the spatial data graphically. Both the Statusbar and Map components help present information and processing results to the user.

For the Web Client, all of the user accessible tools appear to be part of the Toolbar, at least as seen from the user's point of view. However, the implementations of these functions are actually in the Parent Shell. The Toolbar is only used to activate the proper functions in the Parent Map. The tools that have been created include typical GIS-type functions for map viewing and manipulation as well as for viewing and querying geospatial and non-spatial information. These functions interface with the Data Module and retrieve data from it. Another category of functions is used for asset control, which sends user-issued commands to the Remote Asset Control Relay Server. The type of control functions available vary depending on the asset and the configuration of the onboard remote sensor but typically include positioning, tracking and safety and security related controls. The current configuration of the remote sensor and asset combination is part of the information stored into the database dedicated to assets. This database is queried by the Web Client to determine which command functions, if any, to show to a user when a certain asset is selected.

In addition to asset information that can be queried using the Web Client, information regarding the current address of assets or nearby streets can also be queried using the geo-referencing tools in the Web Client. Each vector feature has metadata that includes the necessary identification numbers that allow the Parent Shell to request extended information regarding the feature. When the map is in raster form, then the mouse click is converted into the geographical coordinates and sent to MapPoint server for geo-coding.

While the Web Client can run on a multitude of platform, there are still certain requirements that must be met in order for a computer to run the Web Client properly. The major requirement is that the client computer must have a recent Java Virtual Machine (JVM) available. A JVM is necessary in order to run the Java based Web Client and to provide the built-in Java classes that are used by the application, so that the downloaded application can be as small as possible. The JVM is also necessary to run any other Java applications. Fortunately, JVMs are offered by numerous providers for multiple platforms and operating systems. The version developed by Sun is the most popular and featured-filled, which is not surprising since Java is Sun's creation. It is freely available for download from Sun's website.

When a user first accesses the Application Module, the Web Client is downloaded onto the user's computer, compiled and executed within the Internet browser environment. Once the initialization processes are complete, the Web Client is in a blank state with no data or parameters stored in the Web Client's memory. It must then request an initial set of parameters from the Application Module back at the Office server. This first set of parameters provides important details regarding the map and data that would be needed for the rest of the client session. It provides the access addresses for the Data and Relay Server modules, the coordinate extent of the selected map area as well as information regarding other map data sources that are available from the Data Modules.

When a vector data message is received from the Data Module, the Parent Shell passes the message to the Map component. The contents of a vector data message includes the coordinate extent of the new visible area, the vector feature type (polygons, polylines, etc.), metadata regarding each distinct vector feature's class as well as any assets that are within the visible area. The Map decodes the packed vector and asset data into an array of coordinates, converting from coordinate space to the display space using the coordinate extent of the visible area. Each vector feature is drawn onto the display using Java drawing functions and features can be differentiated by color using their associated metadata if it is available. When a raster map is received from the Data Module, the binary data is converted into an image and drawn by the Web Client. There is also metadata providing important details regarding the map, such as the scale, the coordinate extent and mathematical parameters to convert between pixel coordinates and geographical coordinates accurately.

5.3 Common Client-Server Protocol

One of the main benefits offered by **MAMSDev** is its ability to act as middleware. By acting as a middleware layer, the complexities of sever-side implementations can be hidden from the Web Client. **MAMSDev** uses the RPC middleware method to allow Web Clients to make requests on the server-side.

To act as a middleware, a common protocol was created in order to enable and server to be able to communicate with one another and allow the Web Clients to be able to access server-side data and other resources. Having a common protocol achieves the desired middleware capabilities through the isolation of client and server systems. This allows development of server systems and the Web Client to be separate and not dependent on each other in any way. As long as both systems conform to the standardized message formats, then they will communicate properly. The client-side invokes requests through the RPC method. RPC is the middleware method used because the operations of a MAMS Web Client typically demand immediate response, such as for map viewing.

5.4 Scripting

A scripting engine has also been implemented into **MAMSDev**. This scripting engine can be used to modify the behavior of the server-side and client-side modules by changing parameters held in text-based configuration files. In this way, a new MAMS can be quickly developed by using pre-existing templates and modifying the configuration files. Developers do not always have to modify and compile the source code in order to deploy their MAMS.

- Scriptable Data Module - by using the scripting engine, the Data Module can be switched to provide different maps and default geographical parameters.
- Scripting Application Module - the type of tools and functions that is accessible through the Application Module can also be modified via scripting. This enables a single MAMS to be easily transformed from one application to another, or to allow easy configuration changes of units. The scripts are held at the Server and passed onto the Web Client to generate the tools dynamically.

5.5 Server Implementation

In Figure 5.2, the architecture of a vector map MAMS implementation using **MAMSDev** is shown. The modular nature of **MAMSDev** is seen, separated based on the principles outlined earlier in this chapter. The Asset Message Listener and the Page Relay Server represents the Communication Module and are responsible for receiving asset messages and sending asset pages respectively. The System DBMS and Vector Data Sets represent the Data Module. The System DBMS decodes, stores and manages the asset data as well as other system information such as users and sensors. It is also used by the Communication Modules to log messages for data mining purposes. The Vector Data Sets each contain a separate and unique data set of a particular geographic region. The Servlet Manager and the Web Client running on the client side computer represent the Application module. The Servlet Manager provides important metadata that informs the Web Client on how to access the Vector Data Sets.

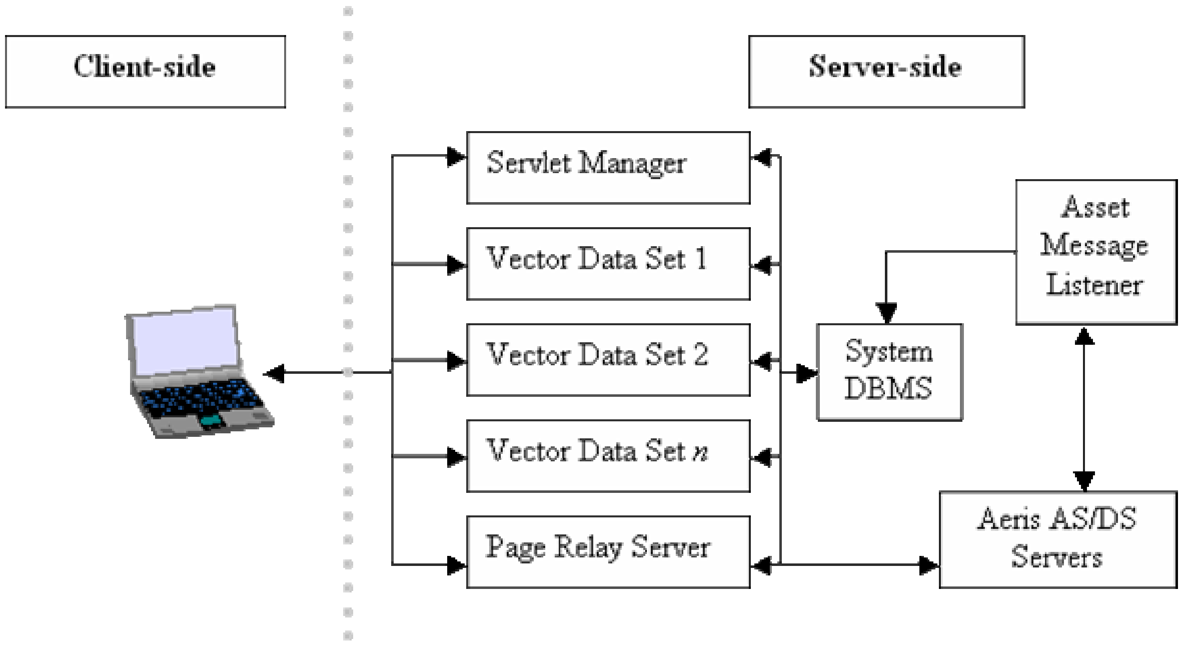


Figure 5.2: MAMSDev Implementation Architecture (Vector Maps)

The raster version is shown in Figure 5.3; the primary change that has occurred is that the Servlet Manager now acts as an intermediary between the Web Client and the map data that is being held on raster map server.

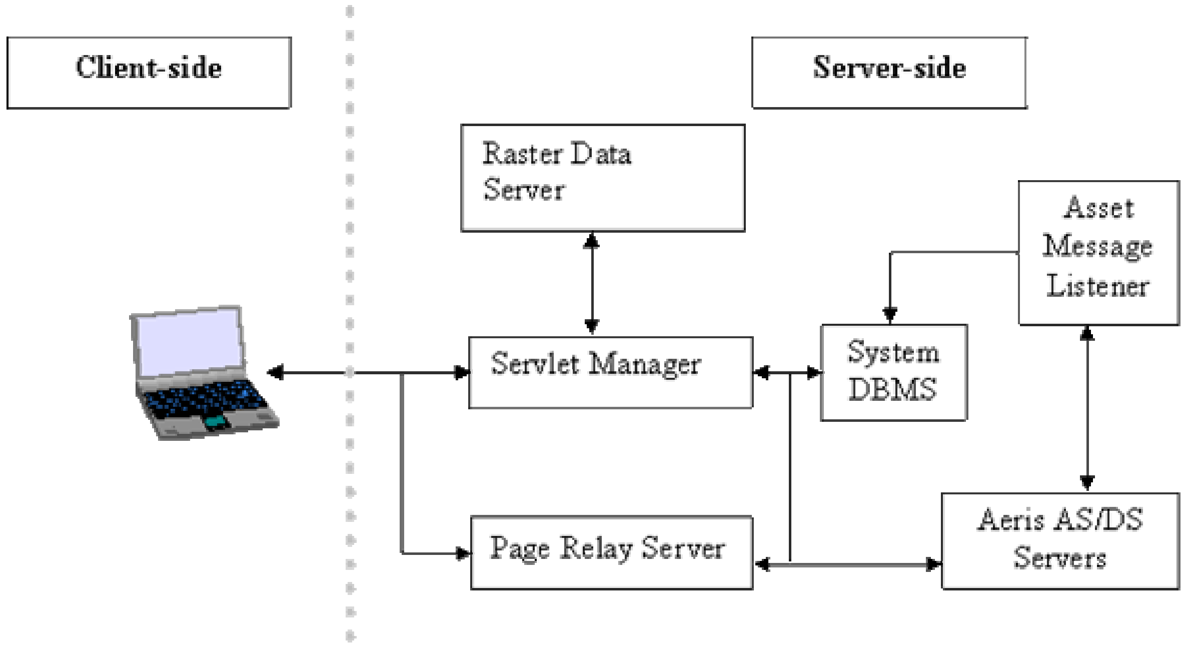


Figure 5.3: MAMSDev Implementation Architecture (Raster Maps)

Chapter 6

Application Prototype Development

A prototype system, named as ***i*****VCAMS**^{3} (**I**nternet-based **V**ehicle **C**ontrol **A**nd **M**onitoring **S**ystem for **S**afety and **S**ecurity) was created as a demonstration application for vehicle control and monitoring and to highlight the advantages of **MAMSDev** for developing a MAMS. This system offered monitoring and controlling of vehicles for safety and security purposes. The corporation's business activities targeted a market area covering the United States and Mexico, including remote areas. This limited the type of wireless technologies that could be used. Even CDPD access would not always be available, let alone newer wireless Internet technologies. The best option was the Aeris.Net MicroBurst service, as it would work with the more widespread AMPS analog cellular networks. Therefore, it was selected as the wireless method for communicating with remote sensors. The CSI Asset-Link 200, with its integrated data acquisition capabilities and built-in MicroBurst support, was an ideal choice as the remote sensors for use in data acquisition. Its small size, sensitive GPS and cellular antennas enabled it to be easily hidden, which is ideal for security applications. The Asset-Link's ability to control vehicle operations is also of great benefit by allowing ***i*****VCAMS**^{3} to offer useful remote control features. ***i*****VCAMS**^{3} meets the requirements of a MAMS in that it monitors attributes including vehicle locations, speed, heading and alarm statuses and enables users to make decisions that are updated into the system seamlessly.

6.1 Implementation

Several regions were used for the testing of ***i*****VCAMS**^{3}. These regions included Calgary, Edmonton, Fort Lauderdale (Florida), Phoenix (Arizona) and a region covering Montreal and the New England region of the USA. The detailed street network of Calgary, Edmonton and Florida as well as a major road and highway network of North America were used. Up-to-date street network data sets of Calgary, Edmonton and Florida are available from sources such as Statistics Canada and the Florida government. These data sets, stored in the ESRI Shape format, offer extremely high levels of detail and even included minor side streets and alleyways. However, finding detailed road data sets of North America proved to be a much greater challenge. Ultimately, separate highway datasets for Canada, the United States and Mexico obtained from a variety of sources had to be combined together to form a single North American dataset and only has highways and major roads. Microsoft MapPoint was used to provide the detailed street network of all the testing regions in raster form.

For the ***i*****VCAMS**^{3} implementation, only one computer was used as the Office domain server. This resulted in **MAMSDev** being used in its Client/Server form with all of its logic and modules running on a single server. The server consisted of dual 500 MHz Pentium III Xeons with 1 GB of memory and running the Microsoft Windows NT 4.0 Server operating system. Asset data, sensor configurations and other related information was stored into Microsoft Access databases. Apache Tomcat 5.0 was used as the Java Server Engine for handling the JSP and Servlet requests and also as the web server.

The next two figures show the realized implementation of the theoretical system displayed in Figure 5.2. In Figure 6.1, the architecture of ***i*VCAMS^3** when used with vector based maps from ESRI Shape files is displayed, while Figure 6.2 shows the architecture for when raster based maps from Microsoft MapPoint is used.

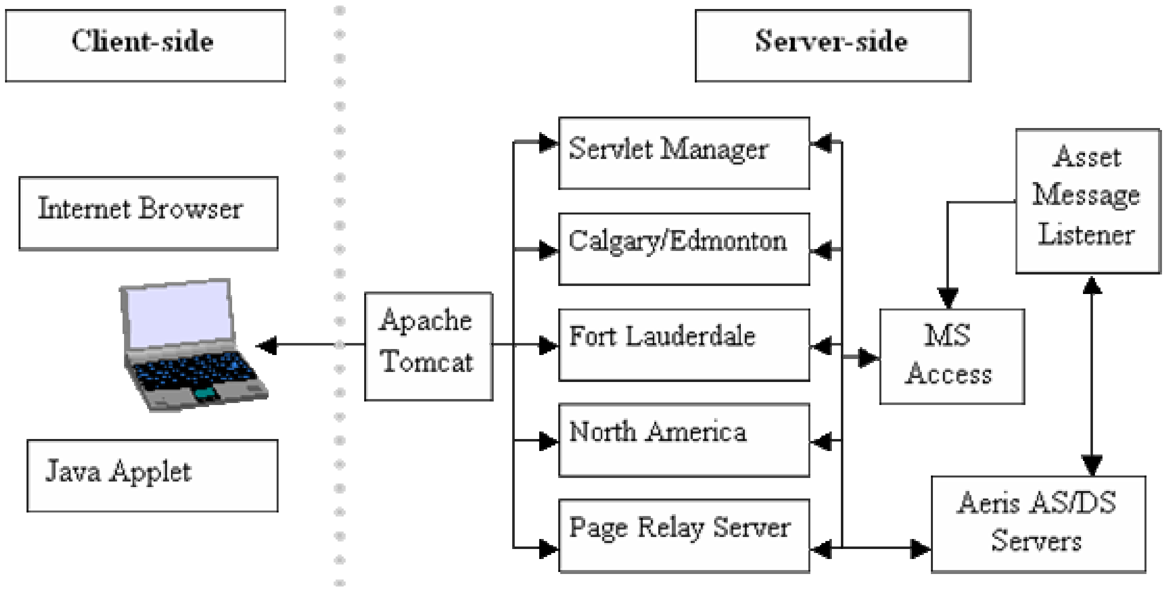


Figure 6.1: *i*VCAMS^3 Architecture (Vector Maps)

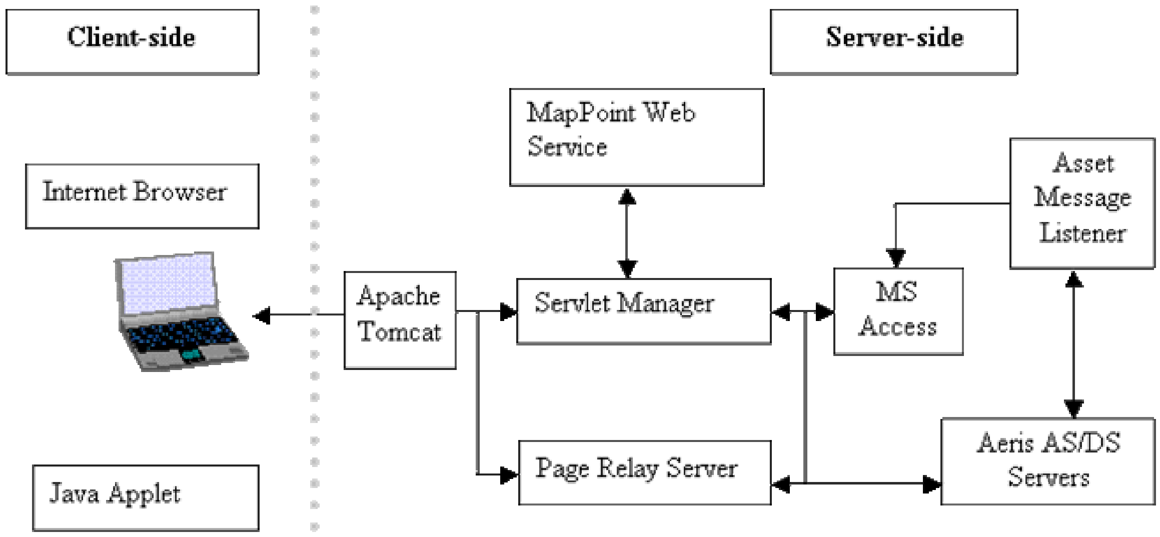


Figure 6.2: *i*VCAMS^3 Architecture (Raster Maps)

The Web Client as developed for ***i*****VCAMS**$^{\mathbf{3}}$ was tested on various desktops and laptops. Since the most intensive computing operations are done at the server-side, the Web Client's processor and memory requirements are not high. The Web Client is designed for a display size of 1024 x 768 pixels in dimension or higher. This minimum display size is necessary in order to show all the information and available tools. Moreover, this resolution is commonly found on laptops. The testing platforms consisted of a Sony Vaio Z505 laptop equipped with a Pentium III 750 MHz processor and several desktop computers of various speeds.

Through testing, it was determined that the configuration storage scheme most suitable for a wide range of data sets was a three-layer pyramid. The bottom layer was divided into 31 x 31 cells, the middle layer was divided into 2 x 2 and the top layer has only one cell. This particular configuration results in cells that overlap each other, so that no cell of one layer shares the same border edge as a cell in a lower or upper layer. This overlapping reduces the likelihood of a small vector feature that straddles the border of a cell in multiple layers. This configuration resulted in a balanced storage of the vector data, with each cell having similar numbers of features thus promoting quick and consistent response times for queries.

The CSI Asset-Link sensor was selected as the sensor to be placed onboard the vehicles. It can completely act as the data acquisition component of a MAM and has two-way capabilities making it suitable for use with ***i*****VCAMS**$^{\mathbf{3}}$. Because of its small size, the Asset-Link sensors can be discretely hidden into vehicles, making it an effective alarm and monitoring system. Its low power consumption ensures that it does not detrimentally affect the performance or usability of a monitored asset, even if the asset is put into storage or is inactive for weeks or months.

Despite the data limitations of MicroBurst, it is still possible to encode useful information such as location, speeds, heading, battery voltage and engine status into one or several number strings. The sensor can also send multiple types of messages. This can increase the number of attributes that can be monitored as each message type can contain unique information. Industrial partners provided the configuration setting of the CSI Asset-Link sensors, which were also used to configure the database management component of the Data Module. The configured capabilities of the sensor were also needed to customize the Application Module to provide the necessary tools to access the available asset data and control the asset. The information that the sensor could send back were:

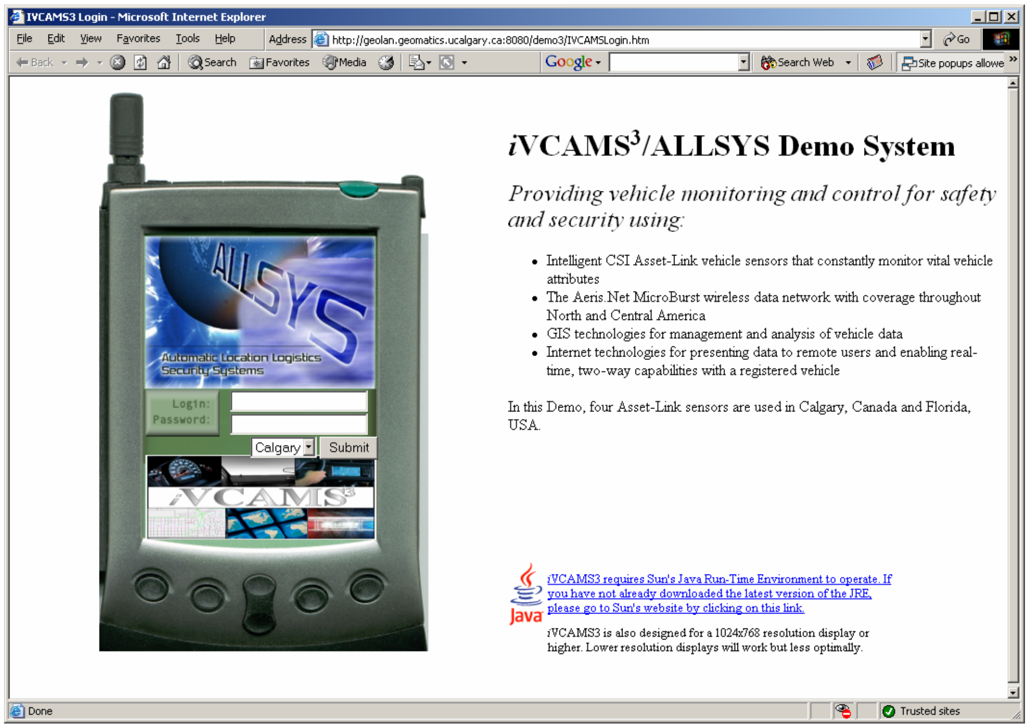
- Asset locations in the form of latitude and longitude.
- Asset speed, heading and odometer readings.
- Alerts for low battery voltage, emergencies and speed violations.
- Acknowledgements to pages and commands.

The sensor accepted the following commands:

- Request for current position.
- Start continuous tracking and automatically send back its position every 5 minutes for one hour.
- Unlock the door of the asset connected to the sensor.
- Enable or disable a 75-mile per hour speed limit. When the speed limit is enabled, the sensor will automatically send a speed violation alert back to the server.

6.2 Client Application

Access to ***i*VCAMS**^{3} is obtained using an Internet browser like Microsoft Internet Explorer and Java. The first step is to login to the ***i*VCAMS**^{3} as shown in Figure 6.3.


IVCAMS3 Login - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Address http://geolan.geomatics.ucalgary.ca:8080/demo3/IVCAMSLogin.htm
Go
Back Search Favorites Media
Google Search Web Site popups allowe
ALLSYS
Automatic Location Logistics Security Systems
Login:
Password:
Calgary
Submit
iVCAMS3
Done
Trusted sites

***i*VCAMS^3/ALLSYS Demo System**

Providing vehicle monitoring and control for safety and security using:

- Intelligent CSI Asset-Link vehicle sensors that constantly monitor vital vehicle attributes
- The Aeris.Net MicroBurst wireless data network with coverage throughout North and Central America
- GIS technologies for management and analysis of vehicle data
- Internet technologies for presenting data to remote users and enabling real-time, two-way capabilities with a registered vehicle

In this Demo, four Asset-Link sensors are used in Calgary, Canada and Florida, USA.

iVCAMS3 requires Sun's Java Run-Time Environment to operate. If you have not already downloaded the latest version of the JRE, please go to Sun's website by clicking on this link.

iVCAMS3 is also designed for a 1024x768 resolution display or higher. Lower resolution displays will work but less optimally.

Figure 6.3: *i*VCAMS^3 Login Screen

The main screen of ***i*VCAMS**^{3} can be seen in the top figure in Figure 6.4 and has an interface that is similar to GIS and mapping applications. There is a large display dedicated to displaying map data and asset locations in a graphical form. For this figure, a map of Calgary, in raster form provided by MapPoint, is being displayed. The right side of the client is used for tools to manipulate map and asset data and to issue pages to assets. Figure 6.5 shows the vector version of the Calgary while Figure 6.6 and Figure 6.7 show the raster and vector maps of Fort Lauderdale and North America respectively.

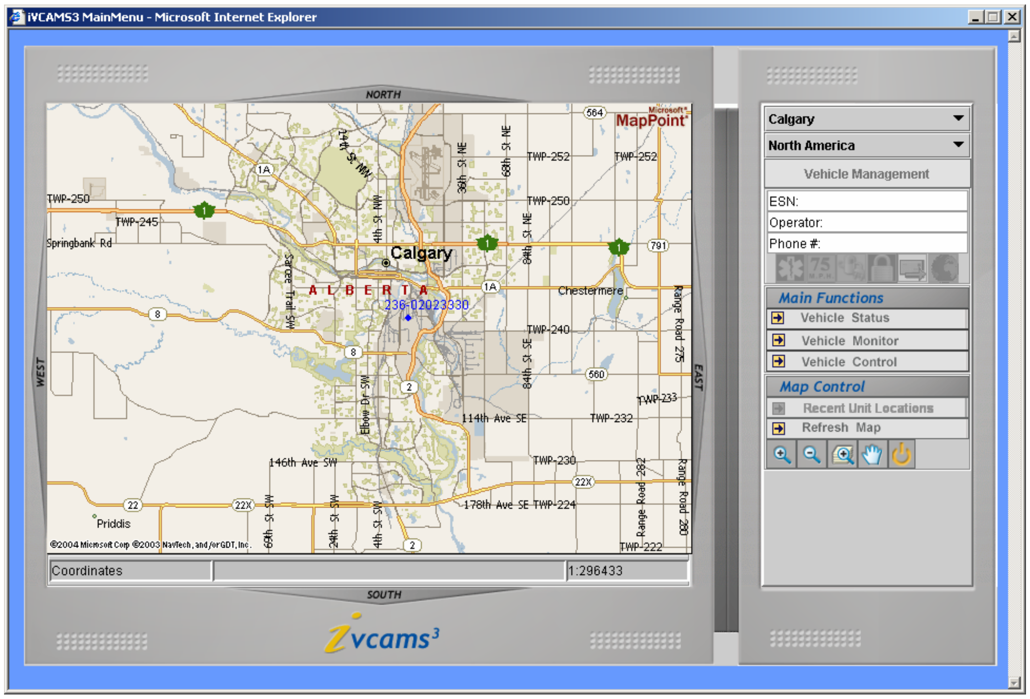


Figure 6.4: *i*VCAMS^3 Main Screen with Calgary Raster Map

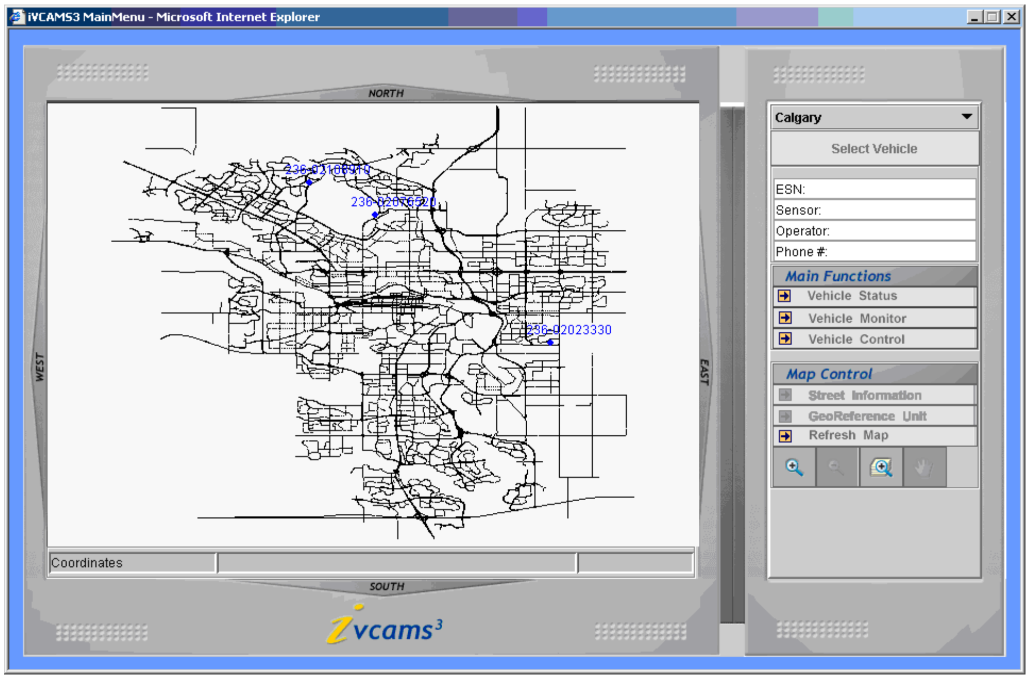
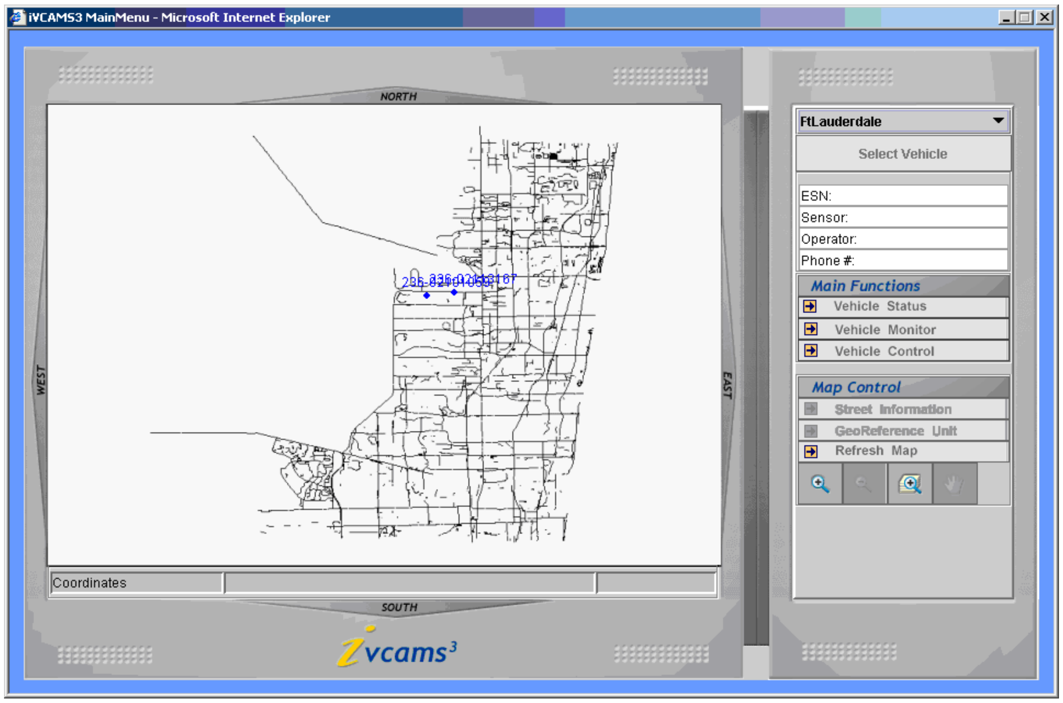


Figure 6.5: *i*VCAMS^3 Main Screen with Calgary Vector Map



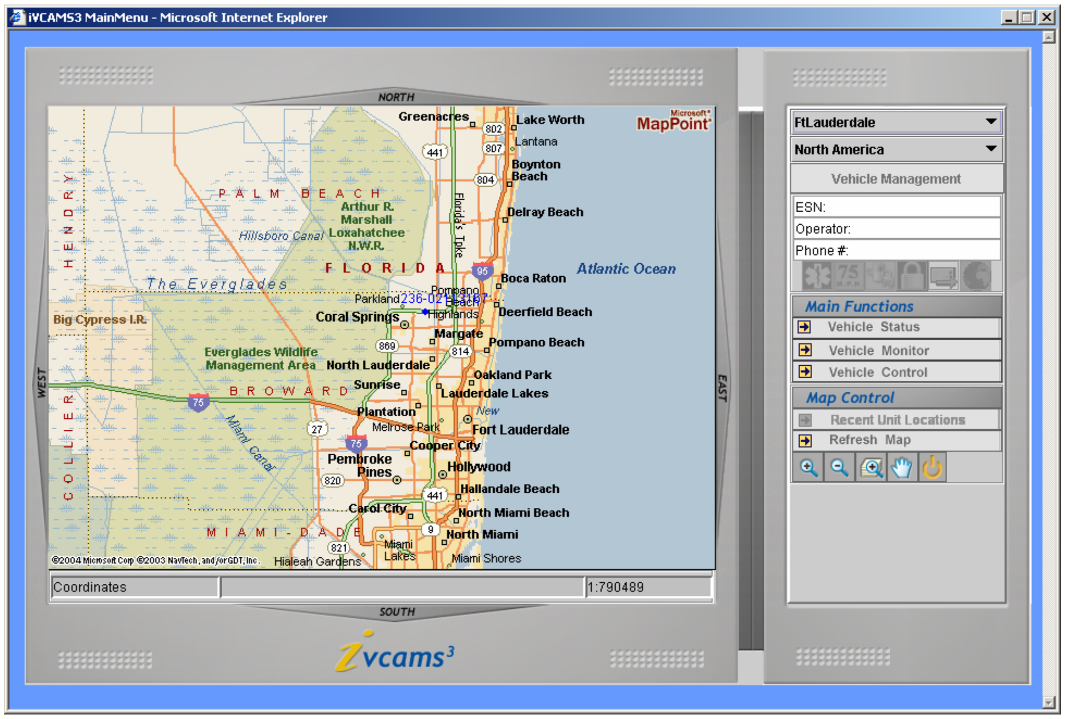
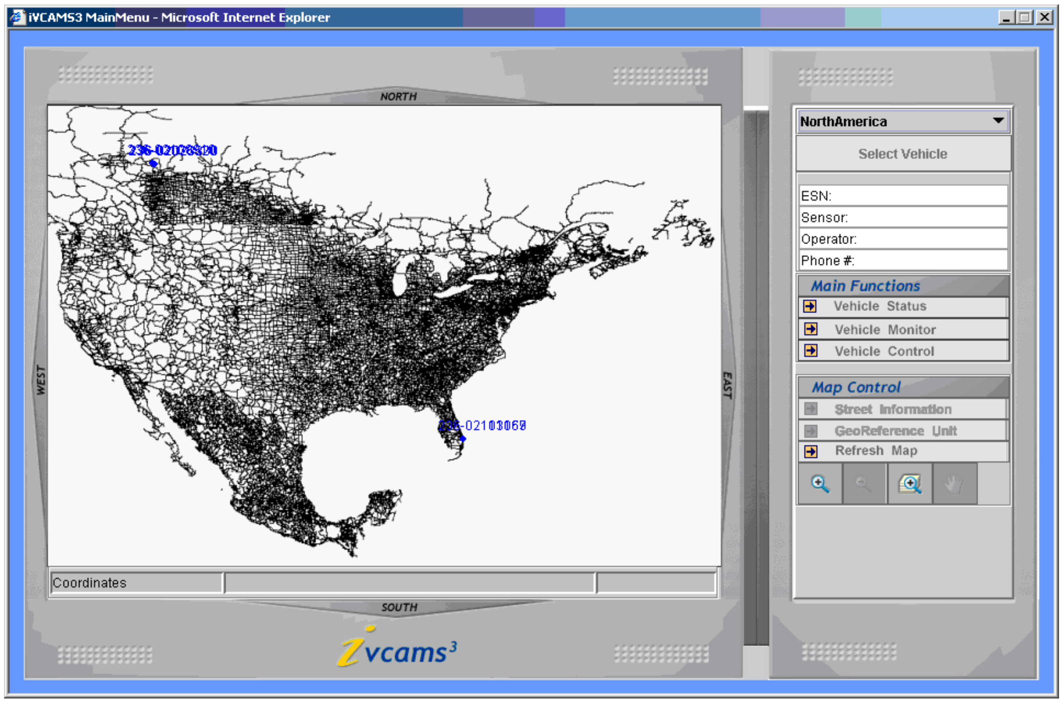


Figure 6.6: Fort Lauderdale Vector and Raster Map



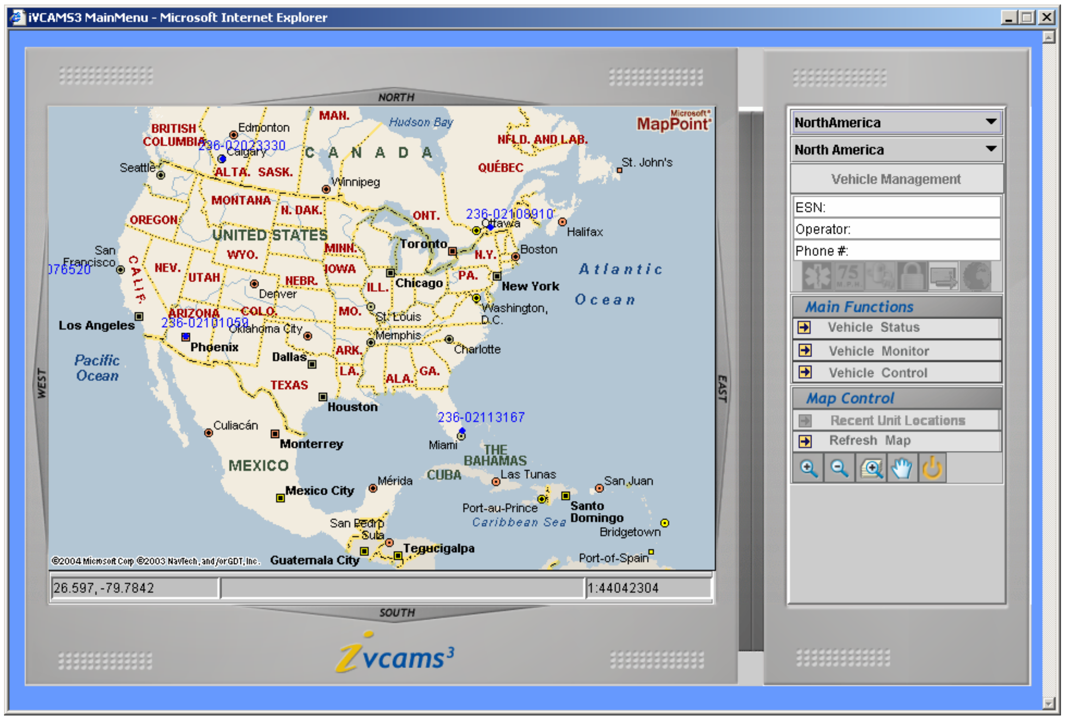
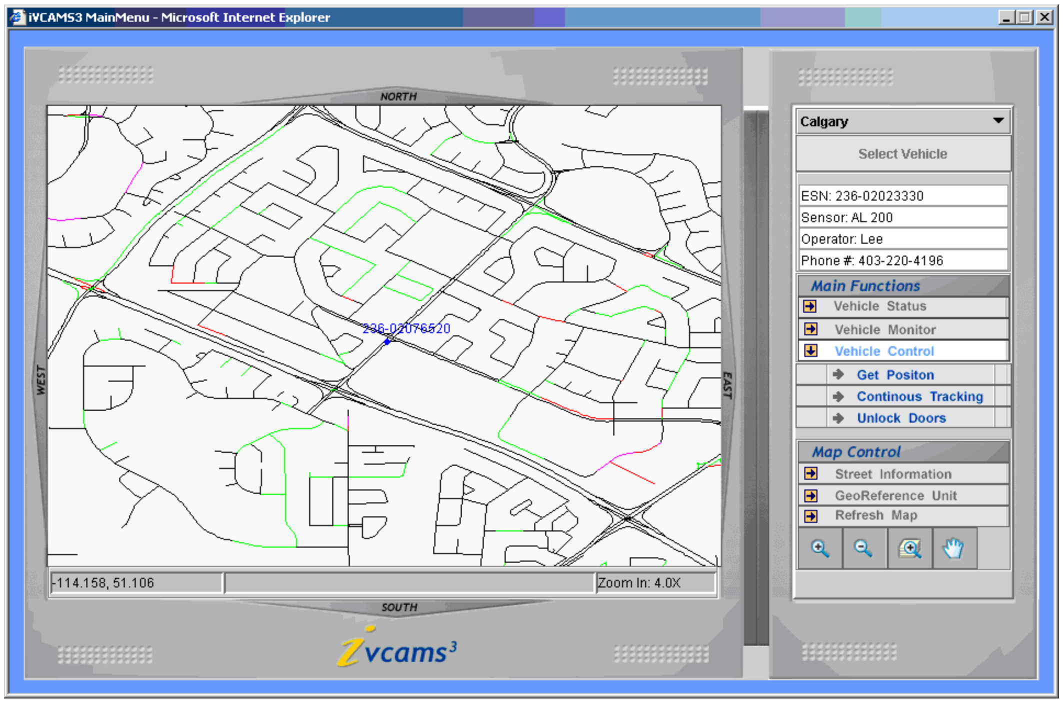


Figure 6.7: North America Vector and Raster Map

Figure 6.8 shows a session where the user has zoomed into a small area around an asset while working with an ESRI Shape dataset of the Calgary street network. In addition, a small map overview screen appears when a user is zoomed in, to give an indication of where they are on the map. This overview is seen in Figure 6.9. Also observable in Figure 6.8 on the Toolbar is the Vehicle Control tools. This is a list of commands that a user can issue to their asset. For ***i*VCAMS**^{3}, it offers the capability to locate on demand, perform continuous tracking of the asset's position or unlocking of the vehicle's doors.



ESN: 236-02023330
Sensor: AL 200
Operator: Lee
Phone #: 403-220-4196

Figure 6.8: Typical *i*VCAMS^3 User Session Using Vector Maps

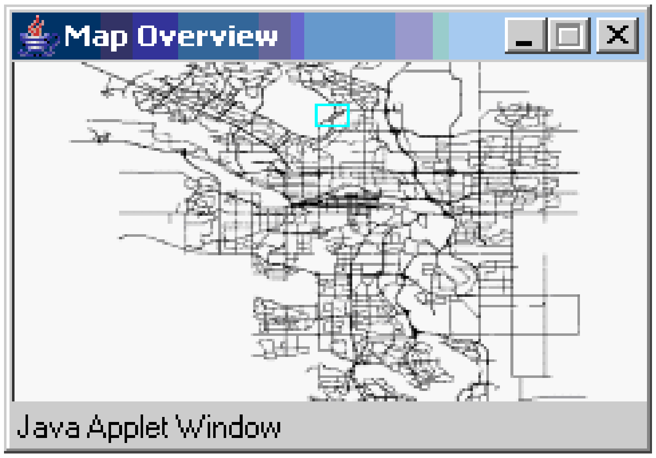
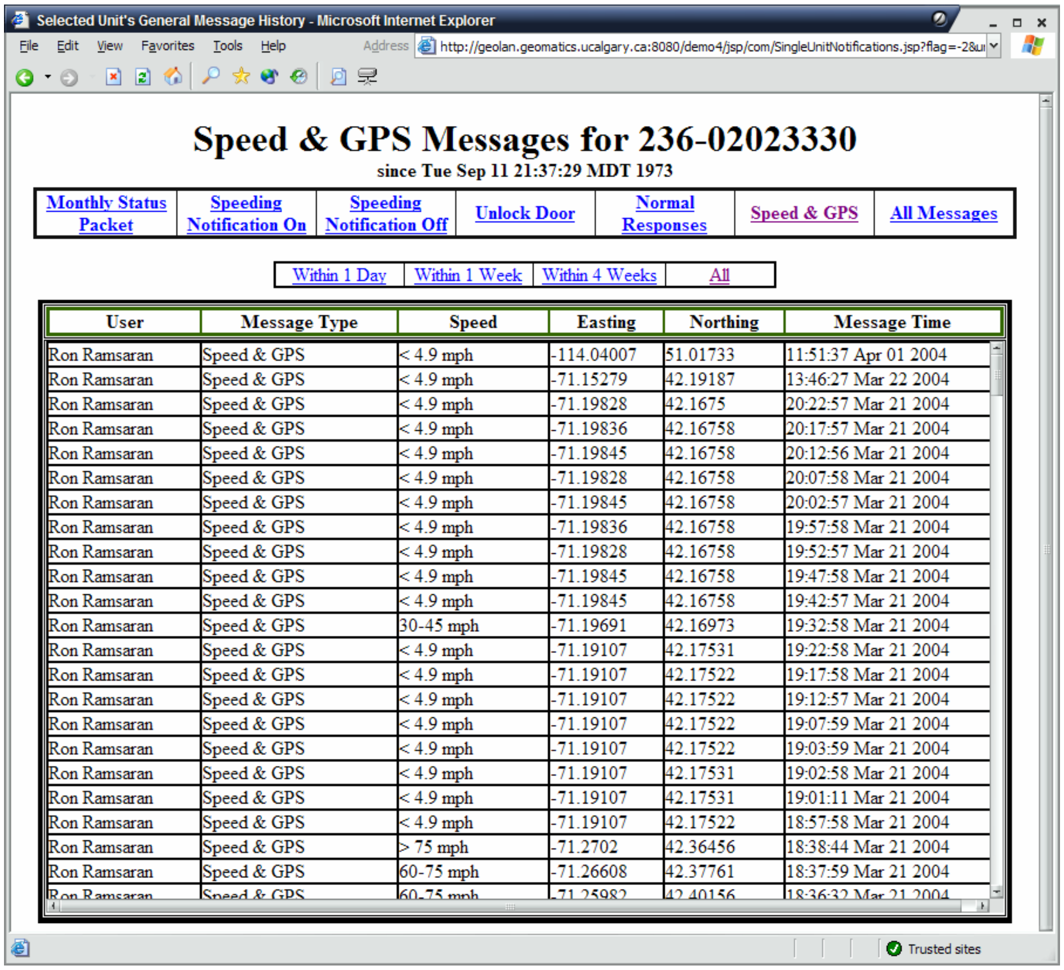


Figure 6.9: *i*VCAMS^3 Overview Map

Along with the graphical information, it is also possible to get asset information in text form. These functions call JSPs to query the Data Module databases for current or historical information regarding an individual asset or the entire fleet and present the information in a separate window. An example of this function can be seen in the following figure where historical information for a particular asset is shown. It is possible to filter the information shown by the type and age of the messages.


Selected Unit's General Message History - Microsoft Internet Explorer

Address http://geolan.geomatics.ucalgary.ca:8080/demo4/jsp/com/SingleUnitNotifications.jsp?flag=-2&u

Speed & GPS Messages for 236-02023330

since Tue Sep 11 21:37:29 MDT 1973

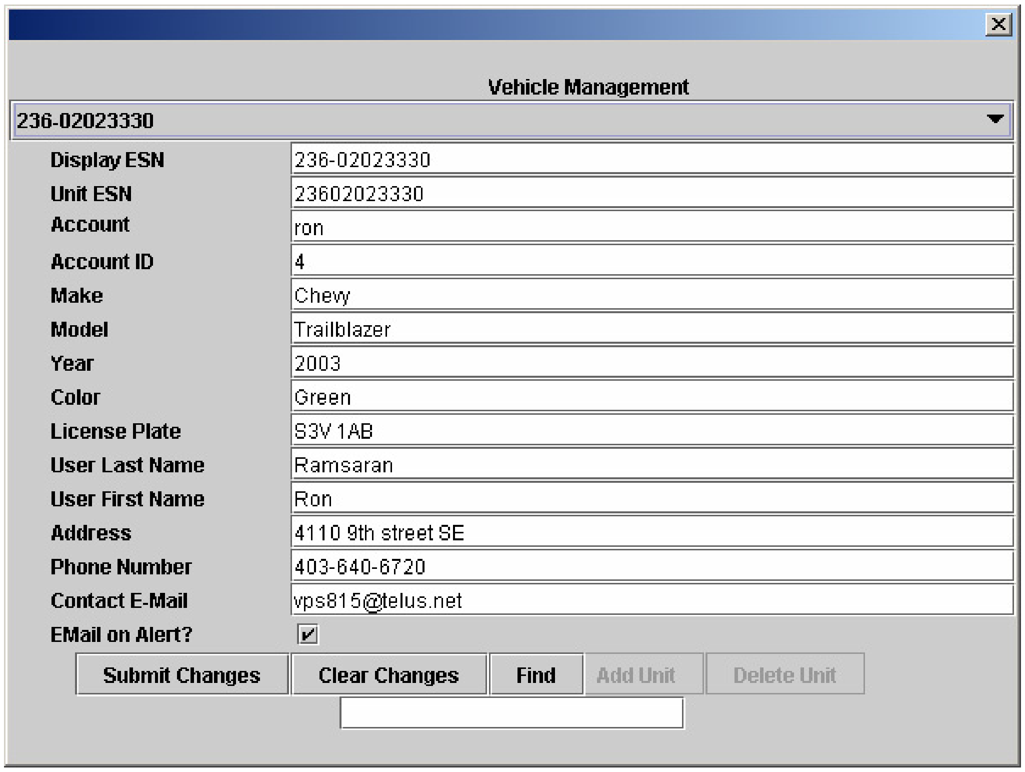
Monthly Status Packet	Speeding Notification On	Speeding Notification Off	Unlock Door	Normal Responses	Speed & GPS	All Messages

Within 1 Day	Within 1 Week	Within 4 Weeks	All

User	Message Type	Speed	Easting	Northing	Message Time
Ron Ramsaran	Speed & GPS	< 4.9 mph	-114.04007	51.01733	11:51:37 Apr 01 2004
Ron Ramsaran	Speed & GPS	< 4.9 mph	-71.15279	42.19187	13:46:27 Mar 22 2004
Ron Ramsaran	Speed & GPS	< 4.9 mph	-71.19828	42.1675	20:22:57 Mar 21 2004
Ron Ramsaran	Speed & GPS	< 4.9 mph	-71.19836	42.16758	20:17:57 Mar 21 2004
Ron Ramsaran	Speed & GPS	< 4.9 mph	-71.19845	42.16758	20:12:56 Mar 21 2004
Ron Ramsaran	Speed & GPS	< 4.9 mph	-71.19828	42.16758	20:07:58 Mar 21 2004
Ron Ramsaran	Speed & GPS	< 4.9 mph	-71.19845	42.16758	20:02:57 Mar 21 2004
Ron Ramsaran	Speed & GPS	< 4.9 mph	-71.19836	42.16758	19:57:58 Mar 21 2004
Ron Ramsaran	Speed & GPS	< 4.9 mph	-71.19828	42.16758	19:52:57 Mar 21 2004
Ron Ramsaran	Speed & GPS	< 4.9 mph	-71.19845	42.16758	19:47:58 Mar 21 2004
Ron Ramsaran	Speed & GPS	< 4.9 mph	-71.19845	42.16758	19:42:57 Mar 21 2004
Ron Ramsaran	Speed & GPS	30-45 mph	-71.19691	42.16973	19:32:58 Mar 21 2004
Ron Ramsaran	Speed & GPS	< 4.9 mph	-71.19107	42.17531	19:22:58 Mar 21 2004
Ron Ramsaran	Speed & GPS	< 4.9 mph	-71.19107	42.17522	19:17:58 Mar 21 2004
Ron Ramsaran	Speed & GPS	< 4.9 mph	-71.19107	42.17522	19:12:57 Mar 21 2004
Ron Ramsaran	Speed & GPS	< 4.9 mph	-71.19107	42.17522	19:07:59 Mar 21 2004
Ron Ramsaran	Speed & GPS	< 4.9 mph	-71.19107	42.17522	19:03:59 Mar 21 2004
Ron Ramsaran	Speed & GPS	< 4.9 mph	-71.19107	42.17531	19:02:58 Mar 21 2004
Ron Ramsaran	Speed & GPS	< 4.9 mph	-71.19107	42.17531	19:01:11 Mar 21 2004
Ron Ramsaran	Speed & GPS	< 4.9 mph	-71.19107	42.17522	18:57:58 Mar 21 2004
Ron Ramsaran	Speed & GPS	> 75 mph	-71.2702	42.36456	18:38:44 Mar 21 2004
Ron Ramsaran	Speed & GPS	60-75 mph	-71.26608	42.37761	18:37:59 Mar 21 2004
Ron Ramsaran	Speed & GPS	60-75 mph	-71.25982	42.40156	18:36:32 Mar 21 2004

Figure 6.10: Historical Information Regarding a Specific Asset

Users can also view and edit the detailed information for their vehicle using the Vehicle Management tool. This vehicle information includes the serial number, or ESN, of the Asset-Link sensor onboard the vehicle and information regarding the vehicle itself such as the make, model and license plate of the vehicle. The vehicle owner's contact information is also included. This information can be modified by the user using the Web Component and any modifications are updated to the ***i*VCAMS**^{3} database immediately. Finally, ***i*VCAMS**^{3} also has the capability to email a message to the user at the provided email address whenever an alert is received automatically. The option to enable or disable this function is found here. The Vehicle Management tool is shown in Figure 6.11.



Vehicle Management

236-02023330

Display ESN	236-02023330
Unit ESN	23602023330
Account	ron
Account ID	4
Make	Chevy
Model	Trailblazer
Year	2003
Color	Green
License Plate	S3V 1AB
User Last Name	Ramsaran
User First Name	Ron
Address	4110 9th street SE
Phone Number	403-640-6720
Contact E-Mail	vps815@telus.net
EMail on Alert?	✓

Figure 6.11: Vehicle Management Tool

6.3 Field Testing

Field-testing was conducted to ensure that ***i*VCAMS**^{3} could successfully receive messages from Asset-Link equipped assets using the MicroBurst network and send commands back. Asset-Link sensors were placed onto cars in Calgary, Edmonton, Fort Lauderdale, Phoenix and Eastern Canada/USA. During the tests, pages were issued to the Asset-Link sensors for their locations. Their locations were sent back to the server and instantly updated into ***i*VCAMS**^{3} and plotted onto the map. The accuracy of the location data was confirmed with the drivers of the cars and when plotted against a map, was accurate. Other commands, such as remote unlocking of doors, were also tested and were successfully received by the sensors and the drivers verified that the correct operations were performed. In Figure 6.12, the results of tracking an asset are shown. This figure shows the current position of the asset, which is indicated by the red dot with the sensor ID number above it (top left). Previous positions, indicated by blue outlined beige squares are also shown (primarily in the bottom left).

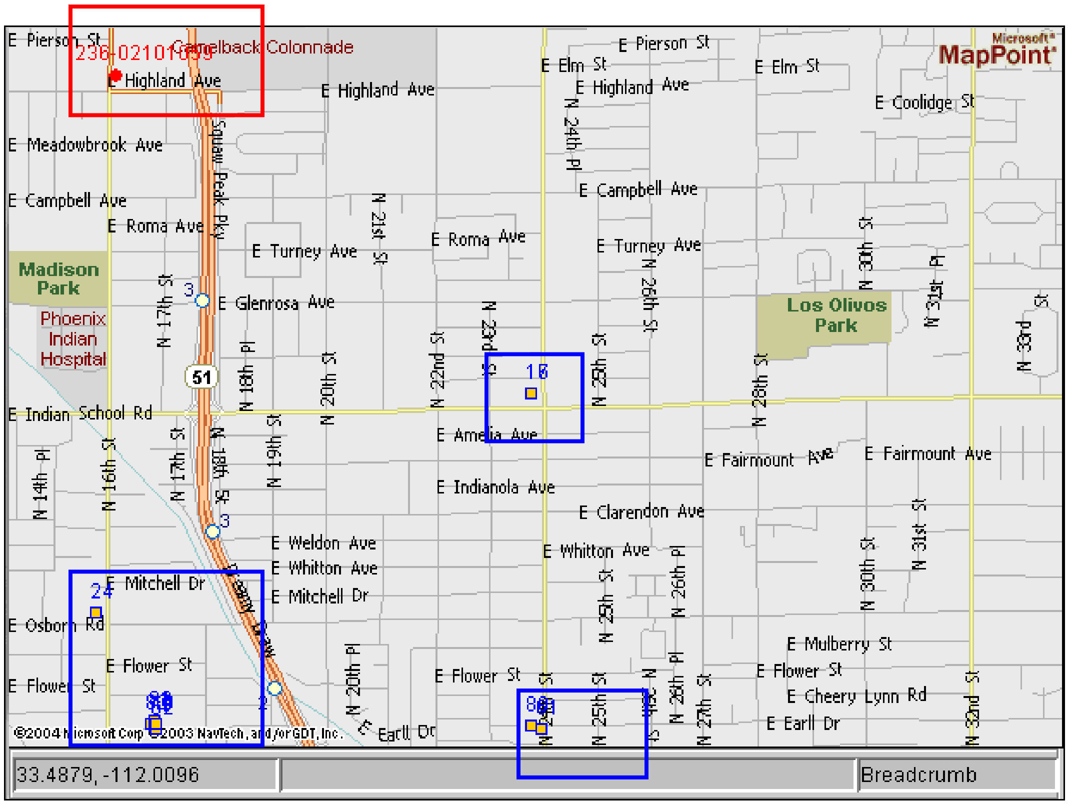


Figure 6.12: Tracking an Asset

The total time necessary to complete all the steps in paging an asset was also monitored during the course of tests. Paging an asset consists of the following steps:

1) A user issuing a page for a selected asset by selecting the desired operation through the Web Client.

2) The server receiving the page and relaying it onto the Aeris.Net AS server.
3) The Aeris.Net AS server then communicating with the Asset-Link sensor onboard the asset using MicroBurst.
4) The sensor performing the necessary operations and sending an acknowledgement message to the Aeris.Net DS server indicating the success or failure of the operation.
5) The Aeris.Net DS server relays the message to the server for decoding and storage.

The measured times for 28 pages, from the moment the user issues the command to the moment that the server receives the results back from the Aeris.Net DS server, are shown in Figure 6.13. These pages were sent to two assets; one asset traveling between Calgary and Edmonton at highway speeds while the second asset was in Fort Lauderdale, Florida and stationary. The pages were sent equally distributed through a 24 hour period. The average time for roundtrip of a page was found to be 9.25s, with a maximum time of 16s, which was reached by only one of the pages. The standard deviation was 2s. The majority of the message travel time is spent between Steps 3-5 with the time taking by Steps 1 and 2 on the order of tenths of seconds.

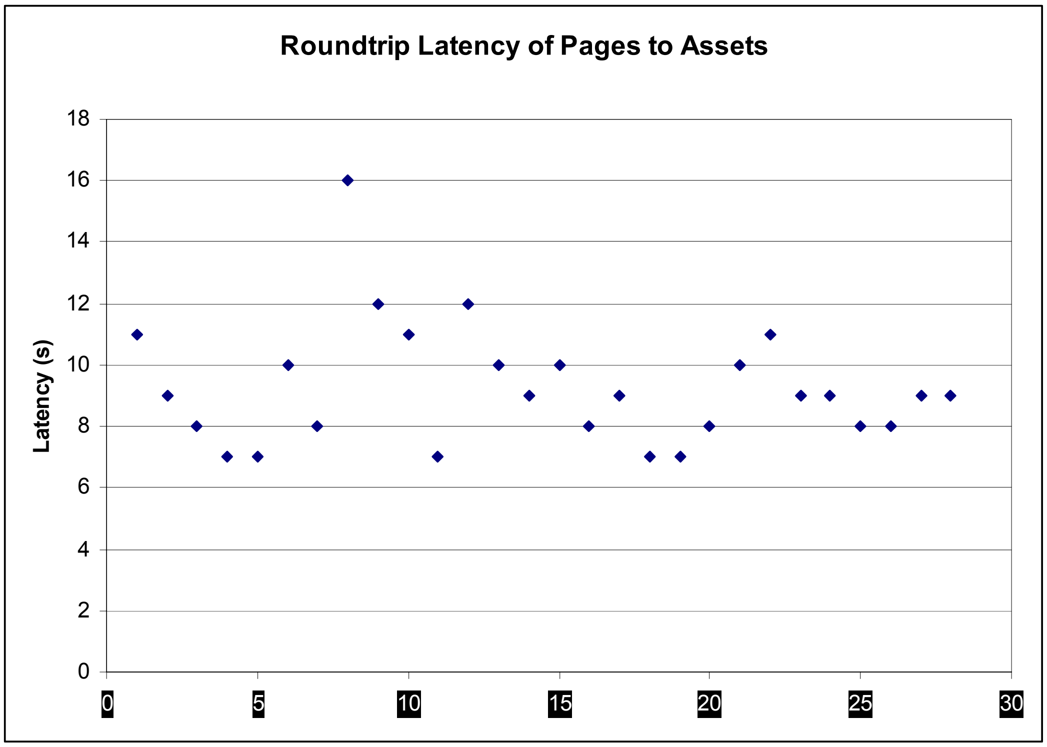


Figure 6.13: Roundtrip Latency of Pages to Assets

6.4 System Testing

System testing was conducted to quantify the computing requirements of an implemented MAMS such as ***i*VCAMS^3** and the limit to the number of assets and users it can support.

6.4.1 Single-Client Performance

The first set of tests were performed with only one client accessing ***i*VCAMS^3**. Of interest was the memory usage at the server, initialization time of the Data Module and typical response times for client queries. Memory usage was measured by Window's PerfMon utility, while built-in timing functions were used in ***i*VCAMS^3** to provide time measurements. In the following table, performance and resource usage metrics are reported for ***i*VCAMS**^{3} displaying the Calgary street network, which consists of 50,319 individual vector features taking 8.06 MB of hard drive space.

The Web Client was tested with Microsoft's Internet Explorer browser, as well as the Mozilla browser, an open-source browser heavily based on Netscape. These two browsers are used by the vast majority of Internet users. The JVM used for both the client and server modules of ***i*VCAMS**^{3} was version 1.4 of the Sun JVM. Table 6.1 lists the results of this test.

Table 6.1: Single-Client Performance Metrics

Server-side memory usage	<36 MB of RAM total
Client-side memory usage	<33 MB of RAM total
Server-side initialization time	<20 seconds to build **MLSS** <11 seconds to retrieve street network attributes from database
Typical response times for client queries	16-40 ms, for all zoom levels
Typical data transmission size per query	5-10 KB at high zoom levels 20-40 KB at moderate zoom levels <400 KB at lowest allowable zoom level

It can be seen that the memory usage is quite low on the server side, consuming a total of 36MB and this value includes the memory used by the web server, the Calgary street network data, Data Module and server portion of the Application Module. The initialization time is also quick, taking roughly half a minute to complete. This initialization time also only occurs when ***i*VCAMS**^{3} is accessed for the first time and subsequent accesses do not have the initialization time at all. For the client side, the Web Client takes about 33MB of memory, which is acceptable for desktop, and laptop hardware. Response times are in the tens of milliseconds range, which is low enough to make ***i*VCAMS**^{3} feel responsive and is consistent even with changing zoom levels. The data size of each request at moderate zoom levels is small and can be handled by the commonly available wireless Internet networks. At the lowest possible zoom level, where more of the map is displayed on screen, the data bandwidth requirements become much higher. This would cause problems even on the fastest wired Internet connection. Restricting the ability of users to use such zoom levels is one way to avoid this problem, as is the use of raster maps that have consistent data sizes regardless of the zoom level.

6.4.2 System Limit Testing

To test the theoretical limits on the system, in terms of number of units and clients that can be supported, simulation testing was performed using several different computer systems acting as the Server. Simulation allowed for the precise control of variables, which is necessary to quantify the limits of **MAMSDev**.

In its development tools, Aeris.Net provided software that simulates the Aeris.Net AS and DS servers. This enables developers to create fully tested and compatible applications before using it with the real Aeris.Net MicroBurst network. The simulated server software is customizable and can be modified to send messages at a user-defined rate. In this way, we can simulate a different number of units by varying the frequency that messages are sent out by the simulated Aeris.Net server. We can then determine the limitations of the system in terms of the number of units and assets that it can support, by monitoring the CPU and network bandwidth usage using PerfMon. These monitored attributes are displayed in Figure 6.14. The test server consisted of an Intel Pentium III 933MHz system with 512MB of RAM and running the Microsoft Windows 2000 operating system. A different server on a private network was used for all simulation testing in order to minimize any unexpected external factors from affecting the simulation results. It was not possible to isolate the real server in the same way, as it was open to the Internet and performed important network management tasks.

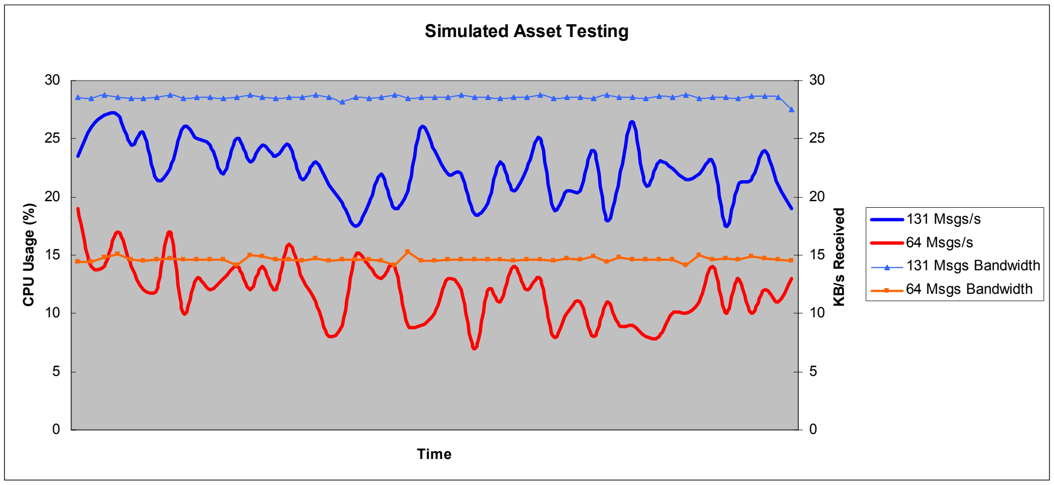


Figure 6.14: Graph of CPU and Network Usage at Two Message Loads

Using an assumption that an asset will send a message once every 30s, like in the snow plow system desired by Alberta Transportation in Section 3.3, 64 messages per second therefore approximate a fleet of about 1900 assets and 131 messages per second representing about 3900 assets. From the results of Figure 6.14, we can see that the CPU usage for even 3900 assets is not taxing the server, as it only ranges from 20% to 25%. For 1900 assets, the CPU usage is lower and ranges from 7% to 15%. As for network bandwidth usage, the simulation results shows that this should not be a major concern as the usage is 15KB/s and 29KB/s for 1900 and 3900 assets respectively and well within the limits of even home broadband Internet connections.

The second simulation test aimed to determine the maximum number of clients that could be supported by the Web Client. A client simulator application was written to try to mimic the behavior of a real human user while using the system. Several simulations were run, with the number of simulated clients varied and important performance attributes from the server logged.

The client computers were connected to the server over a Fast Ethernet local network, to eliminate any influence in the results due to network speeds. The Calgary street network dataset, consisting of 50,319 individual vector features, was used for the simulation. A summary of the monitored attributes is presented in Table 6.2 and these attributes were:

- Memory usage – the amount of memory used by the System on the server.
- CPU usage – the percentage of the server's processing time used by the System on servicing requests from users.
- Responses per second – the number of responses handled per second.
- Average Response Time – the average time needed to service a request.
- 90th Percentile Response Time – the threshold response time where 90% of all responses were serviced.
- 1s Percentile Response Time (s) – the percentage of responses which were serviced within 1s or less. The value of 1s was chosen because it represented a time period where a user would still find the system responsive.
- Average Bandwidth Usage – the amount of network bandwidth being used by the server per second

Table 6.2: Summary of the Server Attributes with Simulated Users

Number of Users	Memory Usage (MB)	% CPU Usage	Responses per second	Avg. Response Time (s)	90th Percentile Response Time (s)	1s Percent Rank	Avg. Bandwidth Usage (KB/s)
20	70.3	5.3	0.421	0.262	0.746	94.2%	22.6
35	70.5	8.7	0.749	0.250	0.750	95.0%	36.7
50	72.6	12.4	1.115	0.306	0.829	92.7%	51.9
70	75.8	17.8	1.561	0.455	1.031	89.5%	73.7
90	85.2	25.6	1.935	0.948	1.817	83.8%	91.3

From the results presented in the table, it can be seen that the system is capable of scaling with increasing number of users. Memory usage remains low even up to 90 users and only increases at a slow rate with more users. Between 70 and 90 users, the stress on the server starts to increase at a faster rate. CPU usage increases at a nearly constant rate between 20 and 70 users but this rate grows faster between 70 and 90 users. This is also reflected in the attributes that deal with response times, which show a noticeable degradation in performance as well. This reason for this behavior is currently unknown.

In summary, supporting even a large asset fleet does not require significant CPU or networking resources. Therefore, much of the CPU and networking bandwidth can be allocated to the client side. This is important since the Web Client is more demanding of CPU usage and network bandwidth. The server that was used, despite being more than three years old, was able to support an asset fleet of thousands and up to 90 users. With modern servers that are many times more powerful, ***i*****VCAMS**^{3} would be capable of working in extremely large real-world operations supporting thousands of assets and hundreds of simultaneous users.

i**VCAMS**^{3} was able to solve the problems posed in Section 2.3. It monitored a vehicle's location plus additional attributes important for safety and security. The combined data is sent back using a wireless network for timely availability to users and ***i*VCAMS**^{3} can automatically contact users when key events occur. Users are able to make decisions using built-in tools, which can be sent immediately to the vehicle. Such decisions are automatically updated into databases, so that the current status of a vehicle is always up-to-date when other users view it.

Chapter 7

Conclusions and Recommendations

The focus of this thesis has been on creating a new development platform that will aid in the deployment of Mobile Asset Management Systems. Numerous software and hardware technologies were investigated in the course of the thesis and those found to be most useful for creating the platform or for MAMS in general were selected. A fully complete platform, known as **MAMSDev** was then developed and is capable of addressing all the important concerns in MAMS, including asset data acquisition, transmission and handling and analysis as well as unique capabilities for user access to asset data. **MAMSDev** was used as a basis for the development of a prototype MAMS known as ***i*VCAMS^3**. This system was built based on the requirements of industrial partners and tested in the field with actual vehicles equipped with onboard remote sensors over several regions of North America.

7.1 Conclusions

The major findings obtained and the tasks completed in the course of the thesis are as follows.

1) Creating a new Development Platform, called **MAMSDev** dedicated to MAMS is an extremely useful new approach to MAMS. It reduces the resources, time and cost needed to deploy a MAMS, enhancing the benefits of the MAMS.
2) The use of an object-oriented application framework was deemed the ideal

structure for a useful platform as it improves reusability.

3) MAMS requirements for software and hardware were determined and suitable, functional technologies were found for implementation into a platform.
4) A fully functional and complete platform called **MAMSDev** was created based on object-oriented application frameworks and Java for ease of reuse and extensibility. It features a modular design separating the important functions of a MAMS, that of communication, data management and user interaction into independent modules. This modularity enables developers the flexibility to use all or only certain capabilities of the Platform. **MAMSDev** is fully documented and manuals have been created to aid in the deployment of a MAMS based on it.
5) **MAMSDev** provides data management and storage capabilities through its Data Management module. The specific details of database structures and asset attributes that are monitored are abstracted, allowing developers to modify their data storage and handling methods to match their field operations with little impact to the rest of the MAMS.
6) **MAMSDev** enables remote access to assets and their data to users over the Internet using its Application Module. This is a great benefit because many field workers, who would benefit greatly from access to asset data, were unable to do so without being physically at the same location as the data. Access is simple, requiring only a modern Internet browser and the freely available Sun Java Runtime Environment. Two-way capabilities are possible, enabling users to control assets and opening up exciting new uses for MAMS.

7) A prototype system, called ***i*****VCAMS**^{3} was developed which utilizes all aspects of **MAMSDev** fully. It was designed in conjunction with input and requirements from industrial partners and was used to evaluate the usefulness of **MAMSDev** for MAMS development purposes. It also provides a guide for third-party developers for creating their own custom MAMS. ***i*****VCAMS**^{3} utilizes the CSI Asset-Link remote sensor and Aeris.Net MicroBurst wireless data network. The Asset-Link sensor integrates vehicle sensors with GPS and cellular communication with two-way capabilities to provide a complete asset monitoring and control system. MicroBurst is a low-bandwidth wireless data network that has coverage throughout North and Central America. **MAMSDev**'s Communication Module can receive messages and issue commands to the Asset-Link 200 by using the MicroBurst network.
8) Field-testing was conducted to ensure that the asset could send messages and locations back to the Office and that users could issue commands to the asset. Testing was completed successfully with vehicles in Calgary, Edmonton and locations in the USA. It was possible to monitor vehicles when they were stationary and in motion, even with vehicles traveling at highway speeds.
9) System testing was done to find the limits of the system in terms of maximum supported users and assets. This was done in simulation in order to have precise control of variables. The simulation results indicated that ***i*****VCAMS**^{3} could handle a fleet of up to 3900 assets and support simultaneous access for 90 users with an inexpensive system that at the time of testing was already three years old. Modern

servers would increase the limits significantly to the point where large real-world operations are possible.

7.2 Recommendations

While **MAMSDev** currently is fully functional, there are still areas that can be improved. New additions can also be added in the future to further enhance the value and usefulness of **MAMSDev**. These include:

1) Improved security – in the real world, system and data security is a critical issue. Future research should look ways of securing access to only authorized users and into encryption to protect asset and user data.
2) Enhanced scripting capabilities - **MAMSDev** can be improved with increased scripting capabilities to modify and customize more aspects of a MAMS built with **MAMSDev**. The existing scripting capabilities are beneficial, enabling modifications to be made without modifying and re-compiling the source code.
3) Keeping abreast of new technological developments – in order to remain a useful tool for developers, **MAMSDev** will need to be updated as new technologies for computing, location and other data acquisition and wireless communication become available.
4) More hardware and software testing – test with modern servers and enterprise level databases and web serving software in order to see how **MAMSDev** works with a computer system and software that a company would use. Testing with additional hardware could also determine what is bottlenecking performance that was found in Section 6.4.2.

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