Vehicle and Item Tracking Systems

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This paper describes the architecture of a GPS based vehicle locating system that is able to point the position of a certain vehicle on the map and also perform reverse geocoding to provide the actual address where the vehicle is placed at a given moment in time or live. I describe a client/server architecture for this system also providing a "caching" method for faster reverse geocoding response times.
Keywords: *GPS, GIS, GPRS, Mobile, Client-Server*

1 Introduction

Today's business is an ever changing environment and asks for improved software solutions to solve some issues that other times were impossible to create. For a company working with a large number of vehicles the management of the entire fleet is a difficult task and requires lots of manpower that otherwise could be employed with something more productive. Also, the control of the fleet through the analysis of the routes used by the drivers is difficult in a non-software environment because of the time needed and because it cannot be done in real-time to avoid any unpleasant results.

By logistics we can understand anything that moves freight on land, sea, and air - a service that can present the position of a shipment is very important because it enables the person responsible to tell the receiving partner that there might be delay of the shipment thus avoiding any unwanted bad feedback.

Public emergency services are a special case when it comes to locating and determining the state of a vehicle in the fleet. An emergency service must provide fast and reliable services because there are lives depending on the arrival of an emergency vehicle at the scene of a call. Emergency services need to be able to send the closest proper vehicle for the job to the scene and thus avoiding the need to place a radio call to all the vehicles and hope that the one that answers the call is the closest. This is a problem because when it comes to costs, it is a bad solution.

In these harsh economic times, when low costs are of the essence, the ability to track a vehicle to prevent it taking a longer route, or a slower route, to prevent the driver of the vehicle driving in an inefficient manner makes for lower costs of maintenance and for larger profits.

Since 2000 when the US government stopped jamming the signals of the global positioning system (GPS) satellites and thus making it available for civilian purposes, the accuracy of the location went to 5-10 meters. With this "liberalization" came the surge of GPS based PocketPC's, GPS navigation devices and software for this growing market.

Location systems have been around for longer that the publicly available GPS system, since 1996 more precisely, when the FCC (Federal Communication Commission) mandated all wireless carriers to offer a 911 service with the ability to pinpoint the position of callers making an emergency call [1].

The object of this paper is to present the methods of designing and implementing a vehicle tracking system using a PDA and a web server. The web server has to be able to perform reverse geocoding actions and also it has to be able to do this in a short amount of time. For these purposes I have presented a data caching method for an efficient way of retrieving data from the spatial database.

2 Previous work

As presented in [2], the features and functionalities needed by a fleet monitoring application should be comprised of two main components: monitoring fleet and

management optimization.
Monitoring fleet requirements:

- real time vehicle position;
- real time reading of al vehicles' km;
- car fleet management effectively coordinate routes;
- the possibility of monitoring the driver by the operator Dispatcher / Logistics Department;
- informing the driver of the path to follow, in case of an unknown area;
- increasing the safety of the car and driver.

Management objectives are linked with business process and actors, from customers to employers, focused on efficiency and optimal solution and flow:

- control and optimize routes traveled by vehicle fleet;
- improve services offered to customers by scheduling with precision arrival at an address, the operations of loading - unloading, periods of delivery / intervention, quality of goods by checking status (on / off) of the refrigeration plant or other kind of food throughout the transport
- eliminate unnecessary standing;
- remove trips made in personal interest;
- reduce theft of fuel and cargo;
- obtain statistical data for the logistic a sales department;
- number of visits to a client (or all clients)
- reducing travel expenses (daily allowance, accommodation)
- reducing the cost of repairs and spare parts
- control and optimize routes traveled by vehicles
- monitoring the event of a crash, by checking the correctness of the allegations of the driver (if he brakes on time, speed of movement, place of accident)

Another very important use is presented in [3].A vehicle tracking system, which can efficiently monitor and control the vehicles, is emerging in many ITS/IVHS-related areas. GIS and GPS technology linked with means of wireless communication are essential to the system determining the vehicle location. It is required to have a technique to handle the huge amount of spatial data entailed in a digital road map in order to trace the accurate position within a reasonable time.

3 Item location systems

In the short period of time since technology has presented us with ways of locating and tracking items, there have been several technologies that have approached the issue of tracking items as precisely as possible. Some consist of complicated architectures comprising of privately owned radio networks that cover cities and were used for the location of public emergency services at the time when the GPRS data transfer standard was not yet set up. The system is presented in the figure 1.

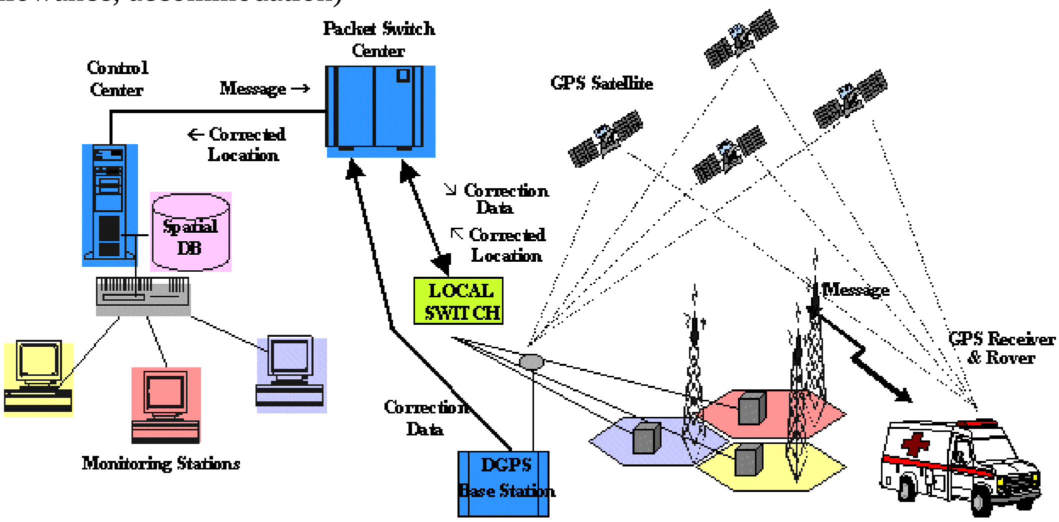

Fig. 1. The system

As presented in Figure 1, the early GPS tracking systems were very cumbersome and technically complicated. They involved a GPS receiver mounted on the vehicle that needs tracking, a network of radio receivers which would forward the information from the vehicle to a local switch, which would then send the information to a control center. The most economically inefficient component of this system was the need for radio receivers. These were the only solution before the introduction of the GPRS system that we have today.

The components in the early days of GPS tracking are still used today in vehicle locating systems, although they are rather different. In today's technological environment we can simplify the data transfer problem by using GSM/GPRS, a much easier and more cost-effective solution. This technology is widely available and covers most of the roads in a country making it the best solution for tracking vehicles on land. The architecture for a system using a GSM/GPRS data transfer solution should in most cases as presented in figure 2.

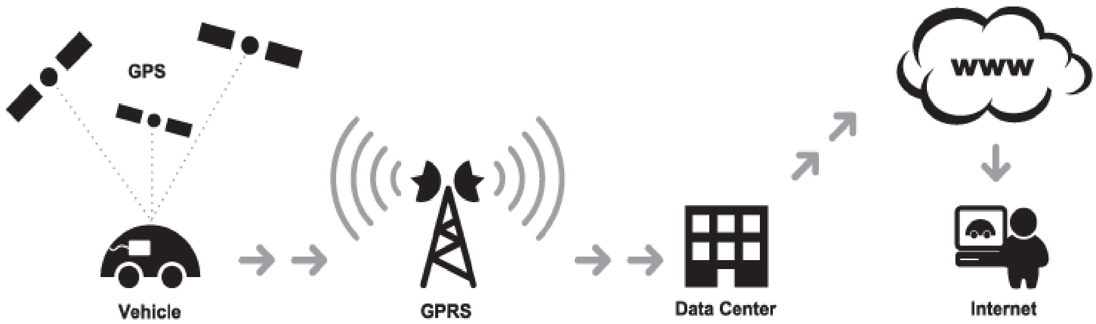

Fig. 2. The architecture for a system using a GSM/GPRS data transfer solution

In figure 2 you may notice the simpler way of approaching the data transfer problem by using the GPRS networks for data transfer between the vehicle and the data center. This solution would have been impossible to be implemented before GPRS, and was, for a long time not cost-effective and prevented companies from using it. The chain of the components is much shorter and thus less prone to problems. Since the only component that is now entrusted with transferring the information from the vehicle to the data center is the GPRS network – which is reliable and has a wide coverage – the information arrives faster and is much more economical to setup.

For a long time, GPS/GPRS systems were a very good solution for locating every type of item, but with the appearance of RFID technologies, locating items inside buildings has become more exact and more useful.

The best example of where GPS tracking would not work is in a warehouse or hospitals. The accuracy provided by GPS is not sufficient for such a small scale. Consider all of the medical equipment, wheelchairs, gurneys and even patients that need to be tracked. GPS is not a practical or cost-effective solution.

For smaller areas, companies and healthcare organizations would likely use a network of RFID tags and readers to monitor the location of assets or inventory. A wireless LAN also would be more suitable. In such a system, each asset would be tagged with an RFID tag, and readers would be placed in strategic locations to be able to accurately read those tags within a matter of inches. A hospital worker would be able to find the exact room a wheelchair is located and retailers would be able to locate an item on any given shelf. [4]

The usage of RFID systems may also be used for POD (Proof of delivery) systems, implemented by the major parcel companies in the world to keep their clients informed about the location of a particular package they sent. RFID systems together with vehicle locating systems can provide a precise location and estimated time of delivery for a particular package. POD systems are more useful if they have implemented the use of task specific PDA's where the receiver of the package can sign either signing un the device for the delivery of the package or by inserting a present code into the device so that the package is marked as delivered.

POD systems are more useful in the case of "missed" deliveries, where the person who was supposed to receive the package, was not found. In this case, the delivery person can take a picture of the area and upload it to the server. In case the customer files a complaint that the delivery person hasn't delivered the package, the company has proof of the attempted delivery.

Interleaving a proof of delivery system with a vehicle locating system keeps the customers informed and happy.

4 Business implications

The importance of logistics to the business process is very hard to quantify, but it is obvious. Logistics are the basis of any company, be it a production company or a servicing company. Without the support of the logistics component of the supply chain, no company would be able to deploy its operations.

Having established the utmost of logistics in the supply chain we can discuss the importance of managing and supervising this component.

For a long time, the supervision and management of logistics was a rudimentary, time consuming and inefficient activity. This was not an asset for the logistics companies who were not able to provide their customers with valuable information about the location and time of delivery of their shipments. In today's business environment when information is a very valuable asset, the ability to provide the customers with real time information about the location and time of delivery of a shipment creates a business advantage.

Managing a large fleet of vehicles, can prove to be time consuming and inaccurate, since it is based on trust and honesty from the part of the drivers. This may not always be the best practice in a large company, where profit margin has to increase. Settling customer complaints because of delayed transports, or because of deteriorated contents may reduce the margin profit and create a bad reputation; also, large fleets prove to be expensive to run because of the negligence of the drivers which damage the vehicles, thus making them unusable for a period of time and expensive to repair.

Introducing a vehicle management system, makes the driver aware of the fact that he is tracked, and makes him more responsible, thus making a better image for the company.

The customer relations component of the business is best aided using a POD system, with the use of which the customers, sender and receiver, are kept informed about the status of the package. This system can be applied to large items also, not only to small packages (parcels, envelopes, etc.). Shipping companies use GPS trackers to monitor the position of a shipping container. Client companies may use hidden trackers to monitor themselves the position of a container and with the use of more sophisticated devices; they can monitor the temperature, the G-forces the container has suffered, the time of departure of a container, and many other parameters, which can prove useful in the case of a deteriorated shipment.

5. Client/ server architecture

The architecture of the locating system presented in this paper, and any vehicle locating system for that matter, consists of a GPS receiver connected to a GSM phone capable of sending position data to a server where it is stored in a database along with other information about the vehicle in question. Also in the system I included a web server that acts also as a server for receiving the data from the vehicles and as a web server that shows the data in a browser for the user to see. The web server has access to

a spatial database that stores the spatial data about the name and geographical details of the streets.
As smart phones and Pocket PC's have started being fitted with GPS receivers, they have become the cheapest and easiest way of receiving the GPS signal from the satellites and sending it to a server. This is also the simplest form of acquiring data in the vehicle, but there are special designed devices that allow the acquisition of data about the state of the vehicle (fuel level, engine rotations, sudden deceleration, door activity, instant fuel consumption, etc.) and the transfer to a server where it is stored for display and analysis.
The device fitted to the vehicles in my case is a Pocket PC running Windows Mobile 5.0 connected via Bluetooth to a mobile phone. The Pocket PC is running the GPS acquisition application designed in such a way that it stores positions and other GPS data whenever there isn't an internet connection so that no data is lost if the vehicle is out of GSM coverage. I chose this solution because it was the easiest way of solving the problem of data acquisition, but also because these days we can use a Pocket PC for navigation exactly because of their ability to receive GPS signals.
The web server is designed with two components: one that allows the vehicles to send their data, and one that displays the data to the user on a map for later analysis. The web server has access to a spatial database where I store information about the streets and the geographical information about them (latitude and longitude of the points that make up the line).
Since we are dealing with large amounts of spatial data, a spatial database engine was preferred to a usual relational engine. The spatial database engine keeps the same qualities of a relational database engine but adds data types and functions for the manipulation of spatial data.
The improvement in the processing power and the graphic memory of the desktop computers, coupled with the increased Internet accessibility and connectivity has supported the prolific adoption of digital mapping technologies by broad sectors of society.
The presentation layer of the application, relies on Internet, digital mapping technologies, because of their ease of use and accuracy. The system uses the mapping capabilities of Google Maps. The usage of Google Maps on Romania's territory is vague and incomplete many times. Using the vector graphics capabilities of Google Maps, I was able to plot spatial data onto a predefined map so that the road network was represented completely and informatively. This is not a critical requirement, since the software is able to return the position of a vehicle in relation to a spatial reference in the database. The plotting of the road network into a visible map, gives the user a better experience.

6 Spatial information

A geographic information system (GIS), or geographical information system captures, stores, analyzes, manages, and presents data that is linked to location. Technically, GIS is geographic information systems which includes mapping software and its application with remote sensing, land surveying, aerial photography, mathematics, photogrammetric, geography, and tools that can be implemented with GIS software. Still, many refer to "geographic information system" as GIS even though it doesn't cover all tools connected to topology.
In the strictest sense, the term describes any information system that integrates, stores, edits, analyzes, shares, and displays geographic information. In a more generic sense, GIS applications are tools that allow users to create interactive queries (user created searches), analyze spatial information, edit data, maps, and present the results of all these operations. Geographic information science is the science underlying the geographic concepts, applications and systems, taught in degree and GIS Certificate programs at many universities.
In simplest terms, GIS is the merging of graphic map entities and databases.

Consumer users would likely be familiar with applications for finding driving directions, like a GPS program on their hand-held device. GPS (Global Positioning System) is the real time location component that uses satellites to show your current position, "where am I now" on your device.

Once designed a client/server architecture, I needed a way of storing and processing the spatial data that was acquired from the vehicle. I had to have in mind also that the locating part of the application has to use WGS-84 data, which is an international standard for storing geospatial data and information about it. The database would have to store information about streets and roads in geospatial format and provide geospatial and other information also.

The obvious solution was to use a spatial database engine that can store and process OpenGIS standard information.

The biggest issue when dealing with spatial data is the need for indexing spatial data. Since spatial data is multidimensional, indexing it is different than normal integer or numeric types. Spatial data consists of points, lines, polygons, polylines and so on, that cannot be indexed in a relational database way. There are many ways of indexing spatial data: Grid (spatial index), Z-order (curve), Quadtree, Octree, UB-tree, R-tree: Typically the preferred method for indexing spatial data. Objects (shapes, lines and points) are grouped using the minimum bounding rectangle (MBR). Objects are added to an MBR within the index that will lead to the smallest increase in its size. [5]

R-trees are tree data structures that are similar to B-trees, but are used for spatial access methods i.e., for indexing multi-dimensional information; for example, the (X, Y) coordinates of geographical data. A common real-world usage for an R-tree might be: "Find all museums within 2 miles (3.2 km) of my current location".

The data structure splits space with hierarchically nested, and possibly overlapping, minimum bounding rectangles (MBRs, otherwise known as bounding boxes, i.e. "rectangle", what the "R" in R-tree stands for).

Each node of an R-tree has a variable number of entries (up to some pre-defined maximum). Each entry within a non-leaf node stores two pieces of data: a way of identifying a child node, and the bounding box of all entries within this child node.

The insertion and deletion algorithms use the bounding boxes from the nodes to ensure that "nearby" elements are placed in the same leaf node (in particular, a new element will go into the leaf node that requires the least enlargement in its bounding box).Each entry within a leaf node stores two pieces of information; a way of identifying the actual data element (which, alternatively, may be placed directly in the node), and the bounding box of the data element.

Similarly, the searching algorithms (for example; intersection, containment, nearest) use the bounding boxes to decide whether or not to search inside a child node. In this way, most of the nodes in the tree are never "touched" during a search. Like B-trees, this makes R-trees suitable for databases, where nodes can be paged to memory when needed.

Different algorithms can be used to split nodes when they become too full, resulting in the *quadratic* and *linear* R-tree sub-types.

R-trees do not historically guarantee good worst-case performance, but generally perform well with real-world data. However, a new algorithm was published in 2004 that defines the Priority R-Tree, which claims to be as efficient as the currently most efficient methods and is at the same time worst-case optimal.

Reverse geocoding is the process of finding an address, toponym or another type of resource for a given lat/lng pair [6]. This permits the identification of nearby street addresses, places, and/or areal subdivisions such as neighborhoods, county, state, or country. Combined with geocoding and routing services, reverse geocoding is a critical component of mobile location-based services and Enhanced 911 to convert a coordinate obtained by GPS to a readable street address which is easier to understand by the end user.

Reverse geocoding can be carried out systematically by services which process a coordinate similarly to the geocoding process. For example, when a GPS coordinate is entered the street address is interpolated from a range assigned to the road segment in a reference dataset that the point is nearest to. If the user provides a coordinate near the midpoint of a segment that starts with address 1 and ends with 100, the returned street address will be somewhere near 50. This approach to reverse geocoding does not return actual addresses, only estimates of what should be there based on the predetermined range. Alternatively, coordinates for reverse geocoding can also be selected on an interactive map, or extracted from static maps by georeferencing them in a GIS with predefined spatial layers to determine the coordinates of a displayed point. Many of the same limitations of geocoding are similar with reverse geocoding. The accuracy and timeliness of the reference layer used to reverse geocode a coordinate will have a significant impact on the accuracy of the results.
Reverse geocoding services have typically not been public due to the need for extensive computing resources and currently updated and large databases. However, public reverse geocoding services are becoming increasingly available through APIs and other web services as well as mobile phone applications. These services require manual input of a coordinate, capture from a GPS, or selection of a point on an interactive map; to look up a street address or neighboring places. Examples of these services include the GeoNames reverse geocoding web service which has tools to identify nearest street address, place names, Wikipedia articles, country, county subdivisions, neighborhoods, and other location data from a coordinate. GeoNames uses the United States Census Bureau's tiger line data set as the reference layer for reverse geocoding. Google has also published a reverse geocoding API which can be adapted for online reverse geocoding tools, which uses the same street reference layer as Google maps.

7 System configuration

As mentioned earlier, the server architecture has to be composed of a web server and a relational database engine with spatial capabilities. The solution that I opted for was the use of a Windows XP machine that has installed a SQL Server 2008 database and Apache and PHP 5 as a basis for the web interface.
The server hosting the Apache server has to be accessible from the Internet because this is the place where the GPS information will be relayed to and processed. The database engine can be stored on a different machine and thus making it inaccessible from the outside thus making the data safe. The machine hosting Apache can be running a version of UNIX so that the security of the information is not compromised.
The software system is composed of the following modules:

- Data acquiring and processing – provides a web interface to which the mobile unit sends its GPS information (latitude, longitude, speed, direction, time, date), processes it and stores it in the database;
- Information management – provides an efficient way of managing the vehicle related information (driver, last service, service intervals, etc.)
- Vehicle operation control – shows live tracking data and old tracking data; shows the vehicles on the map with related information (speed, distance covered, etc.); shows driving times; provides the fleet manager with information about running times, inappropriate use of the care, speeding, etc.
- Message management – sends the authorized personnel critical information about the vehicles position when a certain event occurs (i.e. exits a predefined area, goes over a speed limit etc).

The system is web based and designed using HTTP. The web server is running Apache with PHP 5.0. This solution makes the system accessible to any platform as long as it is able to run a web browser. The system can be accessed also via mobile devices making it easier and faster to take the right decisions based on the newest data available from the vehicles.

The systems' operations starts at the GPS/GPRS unit mounted in the vehicle. The GPS tracker sends the coordinates to the server, using HTTP transfer, where they are processed as follows: the information is split into specific values (latitude, longitude, speed, etc.) and stored into the database. Every time a vehicle sends it's position, the server checks if the position is within the boundaries set for this specific vehicle – if any – and if the vehicle has left the perimeter assigned, it will send a report to the person responsible with this information. Also alerts are sent when a vehicle goes over a speed limit specified for it.

For a hidden approach to the tracking device, it is advisable to use purpose designed tracking devices that can monitor a set of parameters such as the engine's RPM, deceleration forces, container temperature, weight on trailer axis, etc. The usage of such a device is suggested when the logistics manager only needs to track the progress of the vehicles but not the contents of the vehicles. For such a system, it is advisable the usage of a rugged PDA with barcode/RFID reader that is able to register every package on the server and if using a POD system, the confirmation of delivery.

The web interface designed for the manager, shows the vehicles on a live map that is updated at a specified time and shows the position of the vehicle on the map alongside with other related information (speed, distance covered since engine started, etc.). The interface also provides the fleet manager with the possibility to go through old records and compare tracks, and other parameters to make more efficient the vehicles' use.

Another feature of the system is that it provides reports that show the manager statistical data that can help him make decisions regarding the driver or the vehicle. Based on these reports, the manager can decide when to schedule a certain vehicle for service or he can detect a potential malfunction of a vehicle.

The usage of modern web technologies in the design of this system, means that data gathered from the vehicles can be forwarded to different companies or even customers who may be allowed to view part of the information related to a particular shipment. If a certain customer has a shipment that is a trucks full load, the transport company can provide the customer with a web interface that can present the customer with the current situation of the transport and the situation of the transport since the contract's start.

In many European countries, transport companies that use a vehicle locations system benefit from smaller insurance premiums, because the risk of theft is much reduced, and also the risk of paying unfounded damage insurance is smaller. Such a web based system can provide the insurance companies with vital data through the usage of Web services, without them being able to see all of the data, or the architecture behind the system. This way, the data processing at either ends of the transaction can be processed using different technologies, different programming languages.

A **Web service** (also **Webservice**) is defined by the W3C as "a software system designed to support interoperable machine-to-machine interaction over a network. It has an interface described in a machine-processable format (specifically Web Services Description Language WSDL). Other systems interact with the Web service in a manner prescribed by its description using SOAP-messages, typically conveyed using HTTP with an XML serialization in conjunction with other Web-related standards." Web services are frequently just Internet Application Programming Interfaces (API) that can be accessed over a network, such as the Internet, and executed on a remote system hosting the requested services. Other approaches with nearly the same functionality as web services are Object Management Group's (OMG) Common Object Request Broker Architecture (CORBA), Microsoft's

Distributed Component Object Model (DCOM) or Sun Microsystems's Java/Remote Method Invocation (RMI).
In common usage the term refers to clients and servers that communicate over the Hypertext Transfer Protocol (HTTP) protocol used on the Web. Such services tend to fall into one of two camps: Big Web Services and RESTful Web Services. Such services are also referred to as web APIs.
"Big Web Services" use Extensible Markup Language (XML) messages that follow the Simple Object Access Protocol (SOAP) standard and have been popular with traditional enterprise. In such systems, there is often a machine-readable description of the operations offered by the service written in the Web Services Description Language (WSDL). The latter is not a requirement of a SOAP *endpoint*, but it is a prerequisite for automated client-side code generation in many Java and .NET SOAP frameworks (frameworks such as Spring, Apache Axis2 and Apache CXF being notable exceptions). Some industry organizations, such as the WS-I, mandate both SOAP and WSDL in their definition of a Web service.

8. Data caching method

It is obvious that when we have to handle large amounts of data regarding geographical objects (lines, polygons, points) we need a way to make the searching time shorter so that we can get query results in a fashionable time. Taking into consideration that a map contains hundreds of thousands of streets that translate into lines when talking about geospatial data, retrieving information about the position of a vehicle becomes time consuming and unreliable. The problem lies in the time needed to fetch information about the position of a point in relation to a line and thus retrieving the street on which a vehicle is located. I have considered that a distance of 5 meters between a point and a line is sufficient enough to get correct results. When trying to search through more than 300.000 spatial entries and performing spatial operations also, the time needed is longer that the time in which the map can refresh itself.
Many caching techniques have been developed over the time, but the object of this paper is not to present them. The most obvious solution is the use of an access table where I store the number of accesses that a certain street had over time. This eliminates make the system more precise and whenever a street is retrieved from the main table, it will only delete those records that have the least accesses. This method is also very useful because since it has the same structure as the main one, we can put spatial indexes on the geospatial information and so making searching even easier. The caching method works in the following way: when a street name is needed, the software first searches in the cache table for the closest street to the point in question (5 meters) and if it finds one, it increases the access counter for the respective street. If there was no street found, it then goes in the main table and searches for one. If it finds a street, it checks if there is place for it in the cache table, if not it deletes the row that has the smallest number of accesses, inserts it and sets the counter to 1. This process is repeated every time a street is needed.

9 Conclusions

In this paper, core issues have been described regarding GIS, GPS and wireless communication networks to be evolved during the development of the land vehicle tracking system. The implementation method has been also presented with client/server solution in spatial data processing, and a data-caching technique which is suitable for data retrievals in reasonable response time.
This paper proposes a GPS/GPRS vehicle tracking system that can be used by any company that needs a better way of controlling the costs of its vehicle fleet. Using the GPS system, a vehicle can be placed anywhere on the Earth's surface with a 10 meter precision and because most of the worlds roads have been recorded in geospatial data, we can not only place a vehicle on the map, but we can also fetch its exact position, in some cases to the street

number.

The GPRS solution provides an easy and reliable way of data transfer between the vehicle and the datacenter mostly because it covers a large surface of the road network. The costs of using a GPRS network have been decreasing and the constant development of new GSM modules that are smaller and smaller makes it the best choice.

The design of a software solution that can acquire data from vehicles and make sense of it is of the utmost importance in any company that has to manage large fleets of vehicles. The usage of a web based system is the obvious solution because the information can be sent over the Internet to any corner of the world and accessed on any platform as long as it is able to run a web browser.

Spatial databases make the tracking of a vehicle much easier with the spatial operations that can be performed on the geospatial data stored in the database.

Further development of this solution will consist in refining the caching algorithm and in the development of industry specific reports that can satisfy any fleet manager. The development of smaller and more precise GPS modules will enable the system to retrieve the position of the vehicle with greater accuracy.

Also further development will consist in applying routing algorithms on the geospatial database to provide the fleet managers with optimal routes for the drivers. The usage of classical path finding algorithms is taken into consideration, but considering the large network or roads Europe has, they could prove time consuming. The development of smart route finding algorithms, that are able to cache some parts of the map on the basis that many times, a major road is used between many cities. The route computation should only be performed at city level depending on the vehicle's location at a point and the position in regard to the closest major road exiting the city.

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