Wireless Location Positioning based on Signal Propagation Data

By
Jim McGeough
President & CEO
Digital Earth Systems, Inc

Abstract

The United States regulation known as the FCC E-911 Mandate[(1)], was passed in 1996, requiring that all wireless service operators provide an emergency 911 caller's cell phone location to the Public Service Answering Point (PSAP) to within 100 meters 67% of the time. This regulation sparked immediate interest in the development of wireless location technology among commercial providers.

The initial deadline for the commencement of implementation was the 1st of October 2001 and no major carrier met the deadline. The FCC granted temporary waivers and extensions of time however, non-compliant phone companies have received severe fines (AT&T fined $2.2 million in May 2002) and the FCC is now increasing the pressure for compliance.

The essential difficulty for the wireless phone companies is that the current *time-measurement* location technologies (based on triangulation) have marginal accuracy and require an investment of billions of dollars, and the wireless phone industry does not have this capital to invest. Another concern is that this financial hurdle has the potential to set back the urgently needed enhanced public safety and stall much needed revenue generation from premium location-based services. And such delays can do further damage to a fragile but essential sector of our economy.

However, the multi-billion dollar industry projections for location-based services have motivated alternate approaches to what is considered as the Holy Grail for wireless operators. Statistical modeling experts in the world's leading universities have turned their attention to location positioning and this paper describes a statistical location estimation software product based on a wireless propagation prediction model. This mathematical approach is more accurate, more robust and less costly than time-measurement approach, and can be implemented immediately.

Such a software solution is compliant with network standards and can save the wireless industry millions of dollars, enabling the immediate launch of enhanced public safety, compelling data services and increased ARPU (Average Revenue Per User) for the operators.

Introduction

In 1996, with the rising use of cell phones, the US Federal Communications Commission (www.fcc.gov) introduced regulations requiring wireless service providers to locate wireless phone users for emergency situations. The FCC regulation, known as the FCC E-911 Mandate[1], applies to all cell phones, and the regulation requires that all wireless service operators provide an emergency 911 caller's cell phone location to the Public Service Answering Point (PSAP) to within 100 meters 67% of the time. This mandate sparked immediate interest in the development of wireless location technology among commercial providers.

A number of different location technologies have been developed, using both Global Positioning Satellites (GPS) and cell tower based radio transmission (Rf) technologies and some have even undergone field trials with varying claims and degrees of success. These technologies are based on the micro-measurement of transmission *time* for wireless signals to travel through space and require the widespread deployment of specialized hardware units and network overlays. Although the FCC Mandate deadline of the 1st of October 2001 has already passed, the phone companies have not yet implemented these location systems and the evaluation and testing of these complex technologies is still underway.

Location Based Applications

While FCC regulations and emergency assistance applications are driving much of the current location technology development, the ability to determine the location of users within a wireless system also has significant commercial applications. For example, Location-Based Services (LBS) for wireless navigation, public services, city administration, traffic, personal entertainment and a host of business applications for mobile government and enterprise workers.

The prospects for location services are very exciting and promising, not only for wireless networks but for the next generation wireless broadband networks as well. According to the April 2000 Strategis Group report *'European Wireless Location Services'*, Mobile Location and Information Services are forecast to be worth US$81.9 billion by 2005"[2, 3, 4, 5]. Operators estimate total revenue from applications with a location element to be 8-10% of total revenues for operator. Location-based games are already taking off in Europe with the same viral growth potential to match Small Message Service (SMS). Location-based Service (LBS) applications are evolving in the following market segments:

- E-911 Emergency Location
- Personal Child Security
- Asset Tracking and People Finder
- Fleet Management
- Telematics
- Driving Directions
- Wireless Gaming
- Location Based Billing
- Information Directory Service
- Push/Pull Advertising
- Electronic House Arrest
- Enterprise Applications
- Field Force Effectiveness
- Mobile Worker management

Location Technologies

The location of mobile radios first appeared in military systems developed during the Second World War. The idea was simple: to find people in distress, or detect and eliminate people causing distress. During the Vietnam conflict the US Department of Defense launched a series of Global Positioning Satellites (GPS) to support military operations. In 1990, during the Gulf Crisis, the signal from GPS satellites was made available to the private sector so that commercial applications could be developed. More recently, a number of commercial GPS systems have been developed to provide location information to mobile users, with applications for fleet management, navigation, military targeting, and emergency assistance.

Commercial Location technology systems fall into two broad categories; GPS and non-GPS. There are a variety of stand-alone GPS systems on the market for personal navigation applications[6, 7, 8] but these systems do not work indoors and do not integrate with the phone company infrastructure and therefore do not support the E-911 mandate. Assisted GPS (AGPS) solutions[9, 10, 11] specific to mobile phone applications have been announced and are currently being evaluated by wireless operators for use in rural areas where cell coverage may not be available. AGPS technologies have demonstrated good results but customers must be prepared to purchase a special new GPS phone or new GPS attachment.

Several radio network-based systems, which accurately measure the time difference (TDOA or EOTD) or time of arrival (TOA) of wireless radio transmissions [12, 13, 14,15] have been developed and tested with good results. Time measurement systems depend on network overlays of additional radio transmissions, which require expensive atomic clocks and special location measurement hardware integrated into the cell site Base Stations. Due to high implementation costs, these solutions are limited to test implementations. Much of the TOA infrastructure must be built up-front in order to deliver location services to wireless subscribers and some carrier's have received quotes of US$10,000 to $30,000 per cell tower site. With more than 104,000 cell site base stations in the US, the infrastructure cost for E-OTD or TOA solutions in the US could reach US$3 billion. Wireless operators have been reluctant to implement such costly technology.

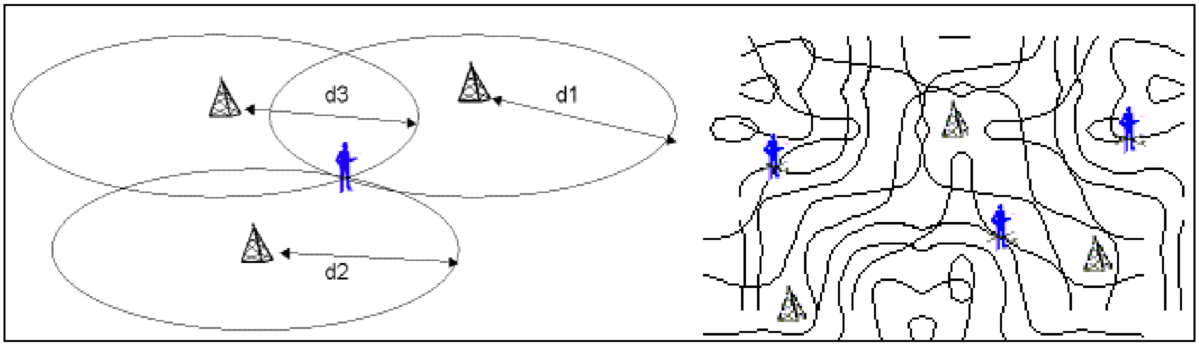
Signal Level Based Solutions

A more cost effective solution for location positioning is one that can be based on existing radio signal data measurement from a series of base stations to a mobile device. The advantage of this approach is that only existing wireless signal data is analysed, so no new hardware (network or handset) is required. However, significant signal level variations and multipath effects have proved a major obstacle to many developers. Adaptive schemes based on the use of on fuzzy logic, hidden Markov models, and pattern recognition [17] methods have been proposed and tested however, these schemes have not been efficient or cost effective for deployment on a nationwide basis.

More recently, Digital Earth Systems researchers, working with statistical modelling experts, have successfully completed field trials of signal-data based location positioning. This technology has being commercialised as GeoMode™; an economical, accurate and simple to install 100% software solution for wireless location estimation using freely available signal data. GeoMode™ does not require any costly network transmitters or cell site add-ons and is therefore less costly and less complex to implement and manage.

GeoMode™ And How It Works

In an ideal free-space environment, signal propagation contours are represented as perfect circles around base stations and the location of a mobile device is the unique intersection point of three circles as shown in the left diagram below.



In the real world however, practical propagation conditions, especially in urban areas where buildings and urban canyons are far from free-space propagation, and signal propagation contours are significantly distorted as indicated in the right diagram above. This problem has promoted the development of various approaches to location positioning with varied results.

Most location positioning technologies have been developed by engineers familiar with geometry and consequently, the majority of proposed solutions are geometric in nature. For example, Time Of Arrival (TOA / TDOA) or Enhanced Observed Time Difference (EOTD) solutions are nothing more than simple triangulation. The geometric solutions work well in ideal conditions. However, if the signal propagation environment differs from ideal conditions, the distance measurements are inaccurate at best, incompatible at worst.

In contrast to geometric approaches, GeoMode uses statistical modelling based on a radio wave propagation prediction model, created from network parameters or empirical data, or a combination of both. This approach treats all signal properties as random variables, which are statistically dependent on the location of the transmitter, the receiver, and the propagation environment. Because of this dependency, an observation of the signal properties is actually a specific inference about the actual location of the observation.

In the geometric approaches (TOA, TDOA, EOTD), all the interest is in accurately measuring signal properties to the location (time or time difference). Whereas the GeoMode statistical modelling approach emphasizes propagation modelling, which describes the dependency of the measured signal on the location variable, i.e., the reasoning proceeds from the location to the signal properties. GeoMode solves the location problem as an inverse problem, which is the typical statistical approach in general.

In statistical terms, the GeoMode propagation model is a sampling distribution whose parameters we can estimate. In most propagation models, there are some parameters whose values cannot be derived from the underlying theory. These parameters are related to the location environment and there are no universally good values for them. Also, due to the complexity of radio wave propagation, there are no actual 'true' parameter values. So GeoMode maximizes the predictive accuracy using maximum likelihood parameters.

For this reason, the addition of empirical signal data to a network model, to obtain information about the parameters, enhances the accuracy of GeoMode to within 20-50 metres.

The advantages of the GeoMode statistical modelling approach include high accuracy, low cost, rapid deployment and simple to install. Also, the problem of incompatible measurements is not present in the statistical modelling approach, unlike the geometric one, because, no matter how unlikely the obtained measurement results are, they are always possible. Another advantage of the GeoMode approach is operational flexibility. For example, the only possibility of enhancing the accuracy of geometric based technologies is to increase the accuracy of the measurements, which is difficult as the geometric solutions already use atomic clocks capable of measuring time in nanoseconds! This is not the case with the statistical modelling approach; GeoMode accuracy can be enhanced anytime by either switching to a more suitable model for a particular environment or simply mapping additional data for the model.

In summary, the GeoMode™ system consists of two components:

- The first component is the GeoMode™ software that simply runs a statistical modelling algorithm on observed wireless signal data referenced to the relevant model for the coverage area. This software may be installed on a server at the wireless carrier's facility (in an SMLC) or at one of our GeoMode™ Location Service Data Centers. Additionally, a GeoMode software product is available for PalmOS and WinCE Personal Digital Assistants (PDAs). GeoMode™ software is fully independent of the network technology and is compatible with network vendor location specific products such as the Ericsson Mobile Positioning System™ (MPS), the Nokia mPosition Solution™ and commercial Location-based Services (LBS) middleware platforms. GeoMode software computes the X,Y location data, in any geographic coordinate system required, and either converts the X,Y location into a street address using reverse geo-coding software or passes the X,Y data to a requesting application. This location data, including a complete geographic display, can be provided to any Internet Location-Based Service application or Emergency Dispatch Center. GeoMode software can locate any wireless handset or communication device including legacy cell phones.

- The second component is a mathematical model. There are three types of models; a network model, or a data model, or a hybrid of both. The network model is based on network and base station data provided by the wireless carrier and the location of each base station and provides location positioning accurate to within 200 to 300 meters. The data model is created by mapping the wireless signal data in the coverage area and can provide location positioning accurate to within 17 meters. The hybrid model is a combination of both types of models; it is less costly than the pure data model and is more suitable for FCC E911 levels of location positioning accuracy; within 100 meters 67% of the time. GeoMode data models can be created by wireless network contractors or GeoMode Service Providers. The model density and specifications are based on the wireless environment and terrain features. Signal data mapping, which involves driving the network, will require from 3-10 man-hours per square kilometre depending on the level of accuracy required. Model maintenance is provided by GeoMode Professional Services or by the wireless carrier quality assurance staff. An advantage of the GeoMode model is that the accuracy of the location positioning system can always be enhanced by a simple low cost data mapping survey. The network and data models can also be synchronized to the wireless network maintenance database.

GeoMode^{TM} Model Data

The GeoMode location process can use a network model, or a data model, or a hybrid of both. Depending on the type of implementation selected, the model includes a combination of network and/or mapped signal data.

Network data - This is data about the network and base station locations:

- CELL ID Cell Identity
- LAC Location Area Code
- BSIC Base Station Identity Code
- BCCH Frequency Channel Number
- X Latitude (WGS84) of cell BS
- Y Longitude (WGS84) cell BS
- Max_Pwr Power used by BTS for transmission in BCCH channel (in dBm)
- Antenna Height above surroundings
- Antenna Alignment Direction of antenna in degrees (clockwise from North)
- Ant_Half_Power_beam_Width Half Power Beam width of antenna (in degrees)
  (This data Is not required for location process but can help is setting up application and mapping network parameters)

Handset-based signal data - This is data is specific to each phone that is logged on the network:

- CI_Serving Serving Cell ID
- LAC_Serving Location Area Code
- TA Timing Advance Serving (i*s not required*)
- RxLev_Serving Receive Level Server
- CI NBR1 Cell Neighbour 1
- RxLev_Nbor1 Receive Level Neighbour 1
- CI NBR2 Cell Neighbour 2
- RxLev_Nbor2 Receive Level Neighbour 2
- CI NBR3 Cell Neighbour 3
- RxLev_Nbor3 Receive Level Neighbour 3
- CI NBR4 etc.
- RxLev_Nbor4 etc.
- CI NBR4 etc.

GeoMode^{TM} Implementation

In wireless cellular networks, the signal data between all base stations and all recognized handsets is measured at sub-second intervals to facilitate handover between cells. GeoMode software processes this signal data and determines the exact location of the phone to high levels of accuracy. The signal data required is available to the network base station controller (BSC) or to the mobile stations (MS or handsets) from the base stations directly. Therefore, the configuration and location of the GeoMode server will vary depending on the network provider and the operator preferences. The use of existing signal data allows implementation to be either network-based or handset-based.

It is therefore possible to have location-based services made available from the wireless carrier or from an independent data center or private independent application service provider (ASP).

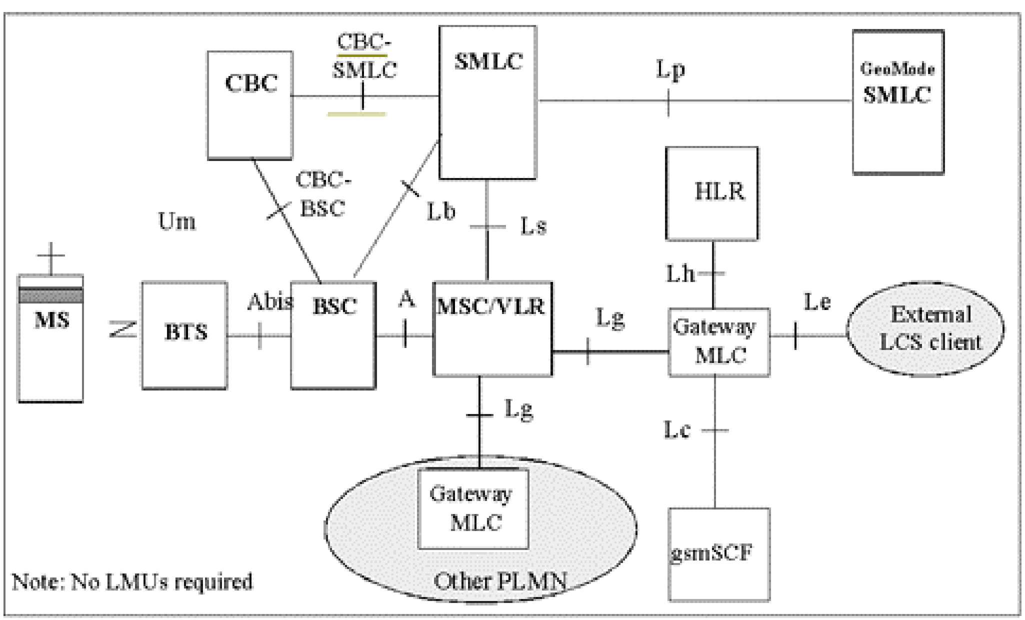
Network based Implementation (no modification to phones):

- GeoMode Serving Mobile Location Center (GeoMode SMLC) receives the signal data for subscriber handsets (MS) from the Base Station Controller (BSC) via a network interface
- GeoMode processes the location for that specific phone on request
- the specific phone location data (X,Y) is then passed either back to the MSC or direct to a commercial LBS application via the network external gateway / IP connection
- the MSC can route the X,Y data to any carrier application (E-911 or commercial).

Handset-based Implementation (WAP 1.2 compliant phones and GSM / GPRS modules):

- the handset / device (MS) collects the signal data specified above directly from the base station (BS). This data can be collected by any WAP 1.2 compliant device (most new phones) or on any standard GSM / GPRS module (for messaging or tracking devices)
- The BS data is sent to a GeoMode application server using SMS or Internet Protocol (IP)
- GeoMode Server processes the location for that specific phone as described above
- the specific phone location data (X,Y) is either passed back to the MSC via the network external gateway / IP connection or direct to a commercial application over IP.
- the MSC can route the X,Y data to any carrier application (E-911 or commercial).

Ericsson GSM GeoMode Diagram



(GSM 03.71 version 7.3.0 Release 1998)

GeoMode™ E-911 Field Trials

GeoMode™ software has been rigorously tested in Stockholm, Helsinki, Palo Alto, Indianapolis, New Orleans and New York. The benchmark for all testing is the FCC mandate, which requires that all wireless service providers have the ability to locate 911 emergency callers to within 100 meters at least 67 percent of the time.

Field Trials for FCC Mandate specification testing were conducted with The New York City Department of Information Technology & Telecommunications (DoITT) and a wireless carrier in New York City during 2002. The trials with the wireless carrier were held under non-disclosure agreements and the results of these trials will be published in due course. In the 2001 Field Trials, a pure data model was implemented independently from the carrier (Voicestream) and demonstrated location accuracy of within 17 meters 67% of the time and 57 meters for 95% of the time. GeoMode™ meets the USA Federal Communications Commission (FCC) Mandate for E-911 by a wide margin and will also provide enhanced emergency services for legacy phone handsets. The results below are from testing in Helsinki and New York City during 2001.

GeoMode Accuracy Specifications

Error Statistics	**Helsinki 2001 GeoMode 1**	**FCC E-911* GeoMode 2**	**NYC 2001 GeoMode 3**
Mean	279m	90m	12m
Median	237m	80m	9m
67%	320m	100m	17m
95%	620m	210m	57m
Maximum	1930m	540m	473m
Implementation	GM-N	GM-D / GM-H	GM-D
Network based	Yes	Yes	Yes
Handset based		Yes	Yes

Data Mapping**	Nil	Drive	Drive
Man Hrs / Sq. Km.		3	10
Man Hrs / 50 Sq. Km.		150	500
Man Hrs / 500 Sq. Km.		1,500	5,000
Cost / Man Hour		$20	$20
Cost / Sq. Km.		$60	$200
Cost / 50 Sq. Km.		$3,000	$10,000
Cost / 500 Sq. Km.		$30,000	$100,000
Cost / Average Cell***		$300	$1,000

* Data mapping estimated for FCC Mandate
** Costs estimated for data mapping only
*** Average cell size based on 1km radius

Premium LBS Applications

In addition to E-911 and LBS applications, GeoMode^{TM} is ideally suited to remote control applications such as vehicle telematics, public transit management, asset security, telemedicine or any other remote control function where location or change in location is also a factor.

In the automation control market, GeoMode^{TM} will support the combined communications and control functions location requirements for Asset & Vehicle Locator (AVL) applications. The AVL application consists of a GSM modem fitted with input/output capabilities, which can simultaneously send and receive data, and output this data via a full serial port. The AVL has multiple analogue I/O ports for direct remote control and monitoring functions. The cost of the GeoMode^{TM} approach to vehicle based LBS applications is projected to be considerably less than the combination of technologies typically required to provide this functionality today.

There are 300 digital cellular networks installed in nearly 142 countries, which gives GeoMode the unique ability to operate almost worldwide. AVL applications can provide instant information and control of any equipment or person to which it is attached. It can provide status reports whilst monitoring and controlling hundreds of operational functions from a remote base station anywhere on a cellular network.

By using only the coverage of GSM, GPRS or any digital cellular telephone network, GeoMode^{TM} based AVL applications can provide 24-hour World wide location, monitoring, tracking and remote control functions. This provides enormous potential and opportunity for use in a multitude of industrial, security, life sciences, commercial and personal monitoring and control applications. The ability to automatically locate and accurately establish the positioning of cellular phone or equipment anywhere in the world as well as exchange data, messages and voice communication and have remote control functions is of great importance in many business areas and mobile applications. All this is possible with a single technology.

The value of AVL, Vehicle based LBS and control applications equally apply to other types of equipment and property such as pleasure boats/yachts, long haul trucks, cargo/parcels, transport containers, remote patient tracking and monitoring and many types of dispatching and distribution systems. Latter developments now mean that a low cost personnel communication system can be implemented for use with police, security staff and other operators where personnel are at risk.

When compared to GPS AVL technologies, the GeoMode^{TM} technology will provide superior performance and accuracy in urban areas for less cost. However, the GPS may be more suitable in rural areas where the cell coverage may be sparse. A GPS location system also requires a clear line of sight and is therefore unreliable when moving in urban areas with high buildings, inside buildings, in mountainous terrain, and in any other enclosed or covered spaces.

GeoMode™ Wireless Communications

GeoMode offers the advantage of integrated positioning, location-based communication, monitoring and control functions on a single world standard wireless technology platform. GeoMode represents a very elegant and low cost approach to integrated automatic positioning, communication and control. This technology uses the existing network data to achieve location, real time tracking, status monitoring and control of a mobile unit and communication of this data to one or more remote base stations and other parties. This technology can monitor and control any number of units Worldwide in areas covered by digital cellular networks and is an ideal platform for mobile worker management applications.

GeoMode™ New Developments

The integration of GeoMode technology into asset / package and commercial shipping systems is another application area under development where smart labels contain all shipping and manifest data and these are tracked by a vehicle based GeoMode AVL connected via wireless technology to corporate and Internet based systems. Medical and Life Science applications are also possible with GeoMode technology, especially for patient monitoring such as GeoMedic (www.geomedic.com) that include location. Likewise, prisoner monitoring and electronic house arrest applications can be enabled with GeoMode.

The GeoMode technology is also suitable for low cost dedicated emergency phones and personal security devices for children, travellers and other people at who may be at risk. GeoMode™ Internet services can allow permission-based access to visually monitor the map location of family, private group or employee subscribers online.

Conclusion

All location techniques have their limitations and, in the real world, unsatisfactory performance will be experienced in varying propagation environments, no matter which technique is used. From an operational point of view, the benefit of the GeoMode approach is that a wireless location positioning solution can be implemented today which meets FCC mandate requirements and requires very little infrastructure investment. This approach enables wireless carriers to support existing premium data services and LBS applications, which currently depend on Global Positioning Satellites (GPS).

With GeoMode, improved performance can be continuously derived from stationary or mobile reference measurements and signal data mapping in the field. This ensures that the wireless carriers will be ready to support new and emerging premium revenue generating services that require accuracy better than the FCC mandate.

Wireless executives have stated that a solid business case is needed before they can invest in premium location based services. This is not the case with the most recent 'killer' technologies such as the Internet, e-Mail and SMS messaging, and recent history has shown the opposite, that when you make such low cost, easy-to-use and compelling technologies available, subscribers embrace it rapidly. The FCC Mandate has merely distracted wireless operators from the Holy Grail and wireless phone companies need to install low-cost location positioning immediately. Only then will the wireless services industry realize the bonanza of increasing ARPU, renewed shareholder confidence and rapid viral growth.

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Biographical information

Jim McGeough

E-mail: jmcgeough@digienet.com

Mr. McGeough is Founder and CEO of Digital Earth Systems Limited, a privately held software developer and consultancy. His responsibilities include the development and implementation of emerging wireless technologies in connection with the company's end-to-end Location-Based Services solution strategy. In this role, Jim directs, plans and implements development of the company's client requirements and technologies, the Digitalearth network of global partnerships, and corporate and business development.

Jim's career commenced in Australia, in the early 70s when, as a graduate surveyor, he and several technology pioneers developed some of the earliest software solutions for automated mapping applications.

Prior to founding Digital Earth Systems, Jim was a vice president of international operations for a major geo-technologies company and previously an executive consultant in the GIS industry. Jim has held a number of management positions in the software and consulting industry in Australia, New Zealand and the USA including Synercom (now part of Logica); Azimuth Consulting (now Silverline Technologies); Wang New Zealand (now Gen-i). His career has focused on the development of applications and services for utilities and local government clients with particular emphasis on location related technologies. More recently, Jim has provided strategic marketing, technical and business development counsel to client companies. His role at Digitalearth includes managing relationships with global partners and technology industry forums.

Jim has been a featured speaker at professional meetings and industry events Worldwide and is an active spokesperson on wireless location positioning issues. He has also published several articles and papers in numerous Industry trade publications and is a frequently utilized industry expert by many trade journalists. Jim's 2002 activities include speaking at the Pulver.Com LBS Summit and Chairman of the 2002 Wireless Positioning & LBS Conference.

A native of Ireland, Jim is currently based in Dublin, Ireland with offices in Washington DC where he is an active member of industry groups including the Geospatial Information Technology Association (GITA). As a veteran of the Geographic Information Systems industry, Jim leads a visionary group of strategic technology partners with skills in wireless based mobile computing and location services.

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