

SURVEY OF LOCATION TECHNOLOGIES
TO SUPPORT MOBILE 9-1-1

Survey Conducted for State of California Department of General Services
Telecommunications Division, Sacramento, California and for the Association of Public
Safety Communications Officials (APCO)

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© By

C.J. DRISCOLL & ASSOCIATES

2066 Dorado Drive
Rancho Palos Verdes, CA 90732
Telephone: (310) 832-8834
Fax: (310) 832-3468

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C.J. DRISCOLL & ASSOCIATES

C.J. Driscoll & Associates, based in Rancho Palos Verdes, California, provides consulting services on automatic vehicle location and mobile communications to fleets and industry suppliers. Clients include major cellular operating companies, Fortune 100 electronics manufacturers, venture capital start-up companies and government agencies.

Clement Driscoll, principal of C.J. Driscoll & Associates, has over 15 years of experience in the fields of navigation, radiolocation and mobile communications. Mr. Driscoll formerly directed the marketing of PacTel Teletrac's fleet vehicle location system. He also served as Product Line Manager for Magnavox's commercial GPS and satellite communication products. Mr. Driscoll has conducted numerous proprietary studies for client companies and has written articles on vehicle location and mobile communications for publications including *Automotive Fleet*, *GPS World* and *Communications* magazines.

INTRODUCTION

Purpose of the Study

The purpose of this study is to identify location technologies which could be deployed to provide 9-1-1 response organizations with the capability to locate a caller using a wireless phone to request emergency assistance. Presently, wireless 9-1-1 calls do not have caller location information, precluding the intelligent routing of the call to the proper response agency. Many wireless callers are not aware of their location and the emergency situation adds to their disorientation. This lack of information extends the call interrogation process and delays the dispatch of the appropriate response agency.

Scope of the Study

This report identifies location systems and technologies which could be applied to mobile 9-1-1. The author believes that the systems covered in this study are representative of the state of the technology, though it is unlikely that all systems capable of locating mobile 9-1-1 callers have been covered. The study only covers systems developed by U.S. suppliers.

As the purpose of this study is to address the feasibility of automatically locating mobile 9-1-1 callers using cellular, PCS or ESMR networks, the study does not attempt to cover systems which utilize a vehicle mounted or handheld device other than a mobile phone to request police or medical assistance. However, it is appropriate to note that a number of companies are expected to offer systems in configurations other than mobile phones for requesting emergency assistance. It is anticipated that a number of vehicle-mounted systems will use GPS for location.

Organization

This report is divided into two sections. The first section covers systems which compute the location of the caller using signals transmitted over the network on which the call was placed. A number of these systems require an overlay to the wireless network. Other systems require a modification to the software or hardware in the phone. This section also covers several companies which have radiolocation technologies that could be applied to locating mobile 9-1-1 callers, but which are not currently developing a system targeted at this application.

The second section covers location systems which rely on an external network or infrastructure to compute location. These systems either use an existing network or infrastructure to compute location or compute position based on a proprietary network of antennas deployed around a metropolitan area. These systems require either that a

receiver module be embedded in the wireless phone or that an external module be interfaced to the phone. Some of these systems use the Global Positioning System (GPS) to compute location and one system makes use of the existing commercial FM radio infrastructure.

TERMINOLOGY

AVM: Acronym for Automatic Vehicle Monitoring. Systems such as AirTouch Teletrac which operate in the 902-928 MHz band and offer subscription-based vehicle location and data messaging services in metropolitan areas. See p. 55 for further explanation.

CDMA: Acronym for Code Division Multiple Access. Wireless voice transmissions are encoded and spread across a broad band of spectrum. Each transmission is assigned a unique code and only be identified and retrieved by the designated receiver. This allows more calls to occupy the same space in a communications channel. Qualcomm, Inc. is a primary developer of CDMA technology for use in wireless networks. CDMA modulation is expected to become one of the standards for digital cellular and Personal Communications Services (PCS) networks.

CDPD: CDPD is an acronym for Cellular Digital Packet Data, which is a system for transmitting data files over idle channels of existing cellular voice networks. A consortium of cellular operating companies will implement this service on their networks beginning in 1994.

DOA: Stands for Direction of Arrival. Location systems based on this technology generally use multiple array antennas, which allow for calculation of the angle of arrival of signals from wireless phones. The location of the transmitting device is the intersection point of lines of position based on DOA measurements at a minimum of two base stations.

ESMR: Acronym for Enhanced Specialized Mobile Radio. These are digital subscription-based two-way radio networks. These digital networks, being deployed by companies such as Nextel Communications, will be targeted at both commercial fleet and consumer markets and will compete with cellular and PCS.

GPS: Stands for Global Positioning System. This is a satellite navigation system deployed by the U.S. military, but widely used for commercial and civil applications. The GPS constellation consists of 24 satellites (21 primary satellites and 3 spares) in six orbital planes at an altitude of 10,900 nautical miles above the earth. The GPS satellites continuously transmit precisely timed signals which include information that enables GPS receivers to accurately determine the satellite's position in orbit. Since the signals travel at the speed of light, the amount of time that elapses from transmission to receipt of the satellite signal is easily converted by the receiver to the range or distance to the satellite. Range measurements to four or more satellites are generally needed for a receiver to compute location, but three satellites are sufficient if the altitude of the receiver above sea level is fairly constant. For security reasons, GPS accuracy is intentionally degraded by the U.S. government to 100 meters (95% probability). Average accuracy is actually about 50 meters.

ISM: Acronym for Industrial, Scientific, Medical band. The 902-928 MHz frequency band is often referred to as the ISM band, as the Federal Communications Commission authorizes certain types of equipment in these categories (including welding, sealing, diathermy, etc.) to operate in this band. This band is also shared by Automatic Vehicle Monitoring (AVM) systems, government users, automatic vehicle identification systems, unlicensed users employing low-powered spread spectrum equipment (Part 15 of FCC rules) and amateur users.

IVHS: Stands for Intelligent Vehicle Highway Systems. This is a government sponsored initiative to encourage technology developments to improve the flow of traffic on U.S. roads and highways. IVHS technologies include Automatic Traffic Information Systems to advise drivers of traffic congestion and alternate routes, Automatic Traffic Management Systems for improved municipal traffic flow management and other technologies. It is hoped that these technologies will reduce traffic delays, reduce pollution and increase safety.

MTSO: Short for Mobile Telephone Switching Office. This is the central computerized switch that controls the cellular network.

Multipath: Reception of a signal taking more than one path, one of them being a path directly from the transmitter, the others being paths caused by signal reflections from objects.

PCS: Acronym for Personal Communications Services. This refers to wireless digital services which will let users make calls using low cost, lightweight pocket phones. PCS systems will be based on microcells, typically spaced every few blocks. Many PCS networks will operate in the 1.8 GHz band.

Spread Spectrum: A method of transmission in which the transmitted signal is spread over a much wider bandwidth than it would occupy with normal modulation.

TDOA: Acronym for Time-Difference-of-Arrival. This technique is widely used in radiolocation systems. It involves measuring the differences between the arrival times of the signal at different receivers (base stations). The path that would be followed by a vehicle traveling in a manner that maintains a constant time-of-arrival difference between any pair of base station receivers is a hyperbola. The transmitter (e.g. cellular phone) is located at the point of intersection of three hyperbolas based on time of arrival difference measurements at three base stations.

EXECUTIVE SUMMARY

SUMMARY OF LOCATION SYSTEMS AND TECHNOLOGIES FOR MOBILE 9-1-1

Network-based Location Systems

- **KSI, Inc.** has developed and patented the Direction Finding Localization System (DFLS) which computes the location of a wireless phone by measuring the angle of arrival of control or voice channel transmissions from the phone. KSI claims to measure angle of arrival at base stations with typical accuracy of .3 degrees, resulting in location accuracy of approximately 150 ft. Estimated cost to deploy DFLS is \$30,000 per site for a basic system and \$3-5 million per network. The company is working on an Enhanced Direction Finding System (EDFS) with a target cost of less than \$30,000 per site.
- **Associated Communications Corporation** has developed a cellular location system which computes the location of the caller using Time-Difference-of-Arrival (TDOA) measurements on control channel transmissions from the phone. The company claims typical accuracy of 500 ft. or better, based on tests and demonstrations conducted on a Rochester, New York cellular network. This patented system will be ready for commercial deployment within 18 months through alliances with wireless network operators.
- **Engineering Research Associates (ERA)**, a subsidiary of E-Systems, has developed and patented the E-CAPS system which computes the location of a wireless phone using a combination of phase-based direction finding and TDOA techniques. ERA claims that location accuracy of E-CAPS is approximately 100 meters. E-CAPS performance will be evaluated in a Federal Highway Administration sponsored operational test to be conducted in Washington, D.C., beginning in October, 1994.
- **TrackMobile, Inc.** has patented a technique for computing the location of a cellular caller using signal strength measurements of control channel transmissions from A and B side cellular base stations. The signal strength measurements are transmitted from the phone to TrackMobile's Help Express Service Center where the caller's location is computed and passed to the responsible PSAP. The company reports typical location accuracy of 500 ft. A portable radio direction finding device is used in close range of the phone to determine its exact location. The TrackMobile system requires a modification to the software in the wireless phone, but no modification to the network.
- **U.S. West New Vector Group** is currently testing a system for locating a caller using a wireless network. The system uses Time-of-Arrival multilateration techniques to compute location. Simulation tests indicate a theoretical accuracy of 100 ft. Field tests of the system are currently underway. This system requires the addition of an

integrated circuit and software in the phone (estimated cost of \$3) and a network overlay which may be achievable at a cost of \$1/2 million for a typical network.

- **Lockheed Sanders, Inc.** has developed a cellular location system which the company states is suitable for use in a high multipath urban environment. The system requires the installation of a receiver and processor at cell sites. A proprietary TDOA technique is used to compute the approximate location of the caller. A handheld device is used in close range to determine the exact location of the caller. The company expects the system to be ready for commercial deployment in 1995.
- **Lattice Corporation** is a start-up company which is designing a system for locating wireless network callers based on an overlay to the wireless network. The company reports that the system is designed to be low cost and to be effective in mitigating the effects of multipath propagation. At this time, the company does not wish to discuss the technique used to compute location except under non-disclosure. It is anticipated that the system will be available for commercial deployment in 1996.
- **Cartesia Corporation** will be testing a low cost system it has developed for locating wireless callers which receives and processes control channel transmissions installed at each network cell site. The system is not yet patented and the technique for computing location was not disclosed. The company will conduct field trials in the second half of 1994 to determine system accuracy.

Network-based Location Technologies

- **Qualcomm, Inc.** reports that its Code Division Multiple Access (CDMA) technology for wireless networks could be used to compute the location of the caller. The company reports that precise time is available at CDMA base stations, and the spread spectrum transmissions are very similar to GPS. However, when a CDMA phone approaches a base station it becomes difficult to obtain an adequate signal-to-noise ratio on neighboring base stations, as necessary for triangulation. Qualcomm reports that there are several possible solutions to this problem, but limited work has been done in this area to date, as there has been little customer interest.
- **ESL, Inc.**, a subsidiary of TRW, reports that based on the company's extensive experience in the development of radiolocation products, they believe there are enough mature technologies in the marketplace that a practical and affordable wireless 9-1-1 system is well within reach. For mobile 9-1-1 location, the company recommends the use of GPS embedded in the mobile phone along with a cellular-based location system incorporating direction finding and TDOA technology. ESL states that requiring that GPS receivers be installed in mobile phones will bring the cost of GPS receivers down to a few dollars per unit. A cellular-based location system based on DF and TDOA could achieve accuracies of 100-300 ft.

- **ArrayComm, Inc.** has developed a system for enhancing wireless network communication quality and capacity, using Spatial Division Multiple Access (SDMA) technology. The company reports that determining the direction of arrival of signals from a mobile phone is fundamental to their technology. The accurate bearing information would reportedly make it possible to compute the location of the caller with an accuracy of +/- 50 ft. in open areas and with a lesser degree of accuracy in dense urban environments.
- **OAR Corporation** indicates that their direction finding technology can be applied to locating mobile callers. The company reports that an antenna array, bearing processor and receiver could be installed at a cell site for \$10,000 or less, yielding bearing accuracy of approximately 3 degrees. In an urban environment, typical location accuracy would be within a city block.
- **Scientific Research Laboratories, Inc.** has developed a system called SpecTrack which is used to identify the location of interfering emitters in the cellular band and locations of high system usage. An antenna array and receiver/processor installed at cell sites yield a typical bearing accuracy of 3-5 degrees, resulting in location accuracy of approximately 500 ft. A vehicle-mounted radio direction finding unit is used to determine the exact location of the caller. The cost of base station equipment is estimated at \$7,500 per site.

Systems Based on External Location Network

- **Terrapin Corporation** is the developer of the PINS system, which computes the location of the caller by tracking signals from commercial FM radio stations. The patented PINS system measures the phase of the FM pilot tone from three or more stations and, based on these measurements, computes the range or distance to each transmitter. Location of the caller is computed by triangulation. Terrapin reports that typical system accuracy is 20-30 meters. Terrapin plans to have PINS chipsets embedded in wireless phones at an estimated cost of \$35 per phone. The company claims that FM signals provide a high level of in-building penetration.
- **NAVSYS Corporation** has developed the TIDGET Mayday System which computes the caller's location using a modified GPS receiver and modem interfaced to a mobile phone. The TIDGET receiver "takes a snapshot" of the captured GPS signals and transmits the data to the NAVSYS Operations Center where location is computed. The caller's location is passed to the responsible PSAP. Typical accuracy of the TIDGET Mayday System is 100 meters. NAVSYS expects TIDGET sensor prices to drop to under \$50 within one year for large quantity purchases.
- **Smith Advanced Technology, Inc.** offers the RALI system for mobile 9-1-1 location and related applications. RALI units incorporate a GPS receiver, microcontroller and software. The company reports that RALI units designed as a retrofit to existing cellular phones will be available in late 1994 at an estimated price of \$300. Smith

expects RALI units to be embedded in mobile phones within a year at an incremental cost of under \$100. The company also offers a RALI PSAP unit designed to integrate the RALI system into the PSAP's operations.

- **Galaxy Microsystems, Inc.** has developed a ground wave system which computes location based on transmissions from four towers located on the periphery of a metropolitan area. Galaxy receivers, which could be embedded in a wireless phone, compute location based on Time-Difference-of-Arrival (TDOA) measurements. System accuracy is reported to be 10 meters or better. Galaxy reports that the location network can be deployed around a metropolitan area for approximately \$200,000. It is projected that a Galaxy receiver chipset for installation in wireless phones could be made available in large quantities for \$15-\$25.
- **Automatic Vehicle Monitoring (AVM)** systems operating in the 902-928 MHz band can compute the location of users in system coverage areas with a typical accuracy of 100-150 feet or better. These systems use spread spectrum transmissions to network base stations and compute location at a network control center using Time-Difference-of-Arrival measurements. Transceivers are typically vehicle mounted, though some companies are working on portable configurations. Current transceiver prices are on the order of \$300. Current and prospective operators of AVM-band networks include AirTouch Teletrac, Pinpoint Communications, Inc., Southwestern Bell Mobile Systems and MobileVision, Inc. Only Teletrac has a commercially operational system today, with network coverage in six cities.

OBSERVATIONS AND CONCLUSIONS

- Based on this survey, it is clear that the technology exists to locate callers using wireless phones to request 9-1-1 emergency assistance. Effective location systems based on either an overlay to the wireless network or external radiolocation networks can be operational in the next 12-24 months if location system developers, wireless network operators and phone manufacturers are motivated to implement these systems.
- A number of companies have developed location systems based on an overlay to an existing wireless network. Most of these systems do not require a modification or add-on to the mobile phone and, therefore, could automatically locate callers using existing cellular phones.
- The best accuracy achievable with network-based location systems appears to be on the order of 100-300 ft., with degraded accuracy in dense urban environments. Most network-based systems do not work well indoors, as the strength of the transmitted signals used to compute location is reduced as the signals pass through the building's structure. Some suppliers plan to offer a handheld direction finding device to enable a responder to determine the exact location of the phone.
- The cost of network-based systems ranges from under \$10,000 per base station to \$30,000-\$40,000 per base station or more. The deployment cost for a metropolitan area will typically range from under \$1 million to \$5 million or more. Generally, higher cost systems claim a higher level of accuracy.
- Several suppliers offer systems capable of locating 9-1-1 callers which use signals from existing networks without requiring an investment in infrastructure or network overlays. These systems are based on the Global Positioning System (GPS), signals from commercial FM radio stations or currently available cellular transmissions. Some of these systems will reportedly add little or no cost to a basic wireless phone. These systems offer varying degrees of accuracy and in-building penetration.
- Mobile 9-1-1 systems based on GPS are currently in the form of external receivers interfaced to a mobile phone. In the future, some suppliers expect to have GPS receivers embedded in the phone. Industry sources project that if a high percentage of cellular phones were equipped with GPS, the price of GPS receivers would be reduced to a few dollars per phone. GPS generally provides position accuracy of 100 meters or better, but GPS signal shadowing can occur in dense urban environments and the signals are not available indoors. On the whole, GPS is well suited for in-vehicle 9-1-1 location, but it would need to be used in combination with other technologies to cover in-building emergency calls from portable cellular or PCS phones.

- Many of the systems which have been developed provide for location of a mobile caller, but not for passing location data and caller ID (ANI) through to the PSAP in a format compatible with existing PSAPs. Integration of wireless 9-1-1 location data into the PSAP in a standard format is a significant issue which should be dealt with in parallel with any implementation of location systems.

NETWORK-BASED LOCATION SYSTEMS

This section covers location systems which utilize the wireless communication network to compute the location of a mobile caller. Most systems covered require a modification to the network. Some systems require a modification to the phone. Systems developed (or in development) by the following companies are covered:

- KSI, Inc.
- Associated Communications Corporation
- Engineering Research Associates (E-Systems)
- TrackMobile
- U.S. West New Vector Group, Inc.
- Lockheed Sanders, Inc.
- Lattice Communications, Inc.
- Cartesia Corporation

Several other companies have technologies which could be enhanced to provide the capability to locate a 9-1-1 caller using a wireless network. Some of these technologies would require an overlay to the existing wireless network. A brief description of the location technology as it would be applied to locating mobile callers is included for the following companies:

- Qualcomm (CDMA)
- TRW (ESL)
- ArrayComm
- OAR Corporation
- Scientific Research Laboratories, Inc.

KSI, Inc.
7630 Little River Turnpike, #212
Annandale, VA 22003
Telephone: (703) 941-5749
Fax: (703) 941-5786

Company Background

KSI, Inc. is a small, privately-held company which was formed in 1986. The company has provided analytical, systems and software engineering support to the government and to commercial clients. In addition to the development of cellular location technology, KSI has designed and integrated sonar systems for the U.S. Navy and has also supported the Navy in the areas of advanced signal processing; detection, localization and tracking; analysis of acoustic and RF signal sources; tradeoff studies and parametric analyses; and data fusion and artificial intelligence.

Direction Finding Localization System

KSI began development of its Direction Finding Localization system (DFLS) in 1989. The system was designed to compute the location, speed and heading of users of wireless phones. A prototype DFLS has been operational since 1991.

The DFLS system requires the installation of directionally sensitive receiving antennas, called Sensor Stations (SSs) which may be collocated at the wireless network antenna sites. SSs capture transmitted (control or voice) signals from wireless phones and process these signals to determine the angle of arrival. The directional information from the SS is relayed via a wired or wireless data link to a Central Station (CS) which processes the received data and computes the location of the caller. For 9-1-1 applications, DFLS can provide the caller's phone number and location to a Public Safety Answering Point (PSAP).

For 9-1-1 applications, DFLS can reportedly compute the caller's location in milliseconds before voice communication begins. KSI reports that the system is capable of computing the location of as many 9-1-1 callers as can access the communication network. The company reports that the system is compatible with wireless networks such as cellular, PCS and ESMR. The DFLS system was patented in 1988.

Target Applications

Intended applications for DFLS include emergency notification (9-1-1), roadside assistance, routing, and fleet management. The system can be used to gather probe information for traffic monitoring in support of IVHS Advanced Traffic Management Systems.

System Status

A demonstration DFLS system consisting of two SS units and one CS has been operational in the Annandale, Virginia, area since 1991. The company reports that a significant amount of field testing has been done tracking a company control group as well as thousands of targets of opportunity.

KSI reports that the DFLS system could be commercially deployed within one year, if sufficient funding is available.

Wireless Phone

DFLS does not require any modification to the wireless phone. Once deployed, the system will compute location of existing cellular phones as well as phones operated on future cellular and PCS networks.

System Accuracy

KSI claims typical location accuracy of 150 feet. This accuracy is based on the system's capability to compute bearing to the SS with an accuracy of 0.3 degrees. Accuracy achieved is impacted by the proximity of the phone to SS receivers, noise and the multipath environment. A higher level of accuracy can be obtained with bearing measurements from more than two sites.

Performance in Dense Urban Environments

Accuracy in dense urban environments may be degraded due to increased effects of multipath. Performance in dense urban environments can be improved through installation of additional SS units, which need not be located at network antenna sites.

In-Building Penetration and Vertical Resolution

DFSL will provide only limited in-building penetration due to the signal strength reduction caused by the structure. If a micro-cell is located in a building to support wireless communications within the building, the KSI system will identify the building from which the call was placed and, based on measurements from the microcell, may be able to determine from which floor a call was placed.

Projected Cost of Deployment

KSI estimates the cost of deployment for a basic system at approximately \$30,000 per SS, including one CS, which can generally cover a metropolitan area. The estimated cost to deploy DFLS on a wireless network in a major metropolitan area is \$3-5 million.

KSI is currently developing an Enhanced Direction Finding System (EDFS) which could be deployed at a cost of under \$30,000 per SS, depending on capabilities required, system complexity and the number of network sites.

Associated Communications Corporation

3 Bala Plaza East, Suite 502

Bala Cynwyd, PA 19004

Telephone: (610) 660-4910

Fax: (610) 660-4920

Company Background

Associated Communications Corporation commenced operations in November, 1979. The company has holdings in a number of communications companies and also actively operates communications businesses. Associated owns and operates cellular and microwave systems and has significant holdings in cable TV networks. The company is the majority owner of cellular networks in Buffalo, Rochester and Albany, New York and other locations. Associated has entered into a definitive merger agreement with Southwestern Bell with regard to these cellular properties which is expected to lead to the sale of these holdings later this year. The company owns 30% interest in Portatel del Sureste, S.A. de C.V., which provides cellular telephone service in five Mexican states. Associated, through a joint venture, has experimental licenses from the FCC to test Personal Communications Services technology in Los Angeles and Washington, D.C. and has purchased interest in an entity pursuing PCS licenses. Associated Communications Corporation is listed on the NASDAQ stock exchange.

Associated began development of its Cellular Location System in early 1992. The company currently has a staff of engineers (internal staff and consultants) dedicated to development and testing of the system.

Cellular Location System

Associated Communication Corporation's Cellular Location system computes the location, speed and heading of callers using wireless phones. The system is based on Time-Difference-of-Arrival (TDOA) measurements made on the reverse control channel transmissions from phone to cell site.

The Cellular Location System requires that equipment be installed at "coverage" cell sites, but not at "capacity" cell sites. (Capacity sites are sites that have been added to cover increases in network usage.) In a major city, typically about 2/3 of today's cellular network cell sites are "coverage" sites. Equipment installed at these sites includes an omnidirectional antenna (unless one is already in use) and a dedicated receiver which has a wider bandwidth, better timing and higher sensitivity than the cellular network receiver. To compute location the receiver measures the time of arrival of the center of energy (otherwise known as Group Delay) of the 100 millisecond control channel transmission. The data from the cell sites is passed to a digital signal processing system at a Central Site (typically at the MTSO) which computes location based on the intersection of isodelay

curves generated from the TDOA measurements. The caller's location is computed in real time after receipt of control channel transmissions.

On July 5, 1994, U.S. Patent #5,327,144 covering the Cellular Location System was issued to Associated RT, Inc., a subsidiary of Associated Communications Corporation.

Target Applications

Intended applications for the Cellular Location System include emergency notification (9-1-1) as well as a wide range of consumer and commercial fleet applications.

System Status

Associated's Cellular Location System was demonstrated over a six month period (late 1993/early 1994) in the Rochester, New York area, using the company's local cellular network. Demonstrations were conducted for other cellular operating companies and for national organizations seeking to market location-dependent services. Limited field testing was also done at that time, but test data has not been published.

Associated Communications estimates that in 18-24 months the location system can be commercially deployed and integrated into existing 9-1-1 operations. The company is actively pursuing partnerships and alliances to commercialize the location technology and to participate in further technology enhancement and development.

Wireless Phone

The Associated Communications system does not require any modification to cellular or other wireless phones. Once deployed the system will compute the location of existing users of the network as well as new users.

System Accuracy

Associated Communications claims typical system accuracy of 500 ft. RMS, under a variety of conditions, with its prototype Cellular Location System.

Accuracy in dense urban environments may be degraded due to multipath. However, some of the impact of multipath is offset by the fact that dense urban areas usually have more cell sites, making it possible obtain a more redundant solution.

In-Building Penetration and Vertical Resolution

Associated Communications reports that their location system works indoors, but accuracy is impacted by multipath and signal loss. The company indicates that it is very difficult to determine which floor of the building the caller is on with a cellular-based location system, as the location network is essentially on the horizontal plane.

Projected Cost of Deployment

Associated Communications declined to discuss system deployment costs in detail. However, they indicated that the cost will be less than the cost for Cellular Digital Packet Data (CDPD) network overlay, which is approximately \$40,000 - \$50,000 per cell site. CDPD requires a receiver, a transmitter and a linear amplifier while the Associated location system requires only a receiver and, in some cases, an antenna.

Engineering Research Associates

1595 Springhill Road
Vienna, VA 22182-2235
Telephone: (703) 734-8800
Fax: (703) 734-8862

Company Background

Engineering Research Associates (ERA) is a wholly-owned subsidiary of E-Systems. The company has been active for over 15 years in the engineering and production of communications and surveillance systems. ERA has developed over 25 Command, Control, Communications and Intelligence (C3I) systems for the U.S. government, for land, sea and tactical applications. ERA reports that each of these systems has included some form of geolocation, such as computing the location from which an intercepted signal originated.

ERA's annual sales total approximately \$50 million. The company has about 300 employees. ERA's parent company, E-Systems, reports annual sales of approximately \$2 billion.

E-CAPS (TM) Geolocation System

E-CAPS (CAPS stands for Cellular Auto Positioning System) is a geolocation system which computes the location, speed and heading of a caller using a cellular or PCS phone. The system tracks the reverse voice or control channel transmissions and computes location through a combination of techniques including phase-based direction finding and time difference of arrival (TDOA).

The E-CAPS Direction Finding System (DFS) is installed at approximately 1/3-1/4 of the network cell sites. Typical spacing between DFS units is approximately 4 miles. The DFS incorporates a receiver/processor, an 8-element array antenna and a GPS antenna. This unit computes the angle of arrival of the transmission from the phone. The data is time stamped and passed over the wireless carrier's T1 line to the Geolocation Control System (GCS). TDOA and triangulation calculations are made at the GCS, generally based on data from three or more DFS units. Typically, more than one GSC is required per cellular network.

Design of the E-CAPS system has been driven primarily by the requirements of the CAPITAL Project, an IVHS operational test to be conducted for the Federal Highway Administration (FHWA) which involves the collection and processing of wide area traffic surveillance data and the dissemination of the data to traffic monitoring sites and to in-vehicle devices. The FHWA awarded a contract for the CAPITAL IVHS operational test in August, 1993. CAPITAL Project team members also include Bell

Atlantic Mobile, Farradyne Systems, the Maryland State Highway Administration and the Virginia Department of Transportation.

The E-CAPS system is currently designed to operate on an analog cellular network. However, ERA reports the system can be modified to operate on a digital network with any modulation scheme.

Target Applications

Intended applications for E-CAPS include geolocation of probes for traffic surveillance and fleet management. ERA also expects E-CAPS to be used for consumer applications.

System Status

Development of the E-CAPS system began in January, 1993. System testing to date has included engineering field test of subsets of E-CAPS. ERA engineers will conduct tests of the complete location system before commencement of the CAPITAL IVHS operational test of E-CAPS. The operational test of E-CAPS was originally scheduled to begin in May, 1994, and is now scheduled to begin in October. The CAPITAL IVHS operational test will continue through January, 1995.

For the Capital Project, E-CAPS will be deployed on a limited number of Bell Atlantic cellular towers in the Washington, D.C. area. The system will be used to locate and monitor the progress along roadways of anonymous, cellular-equipped vehicles, randomly chosen for the purpose of collecting traffic data. Traffic data will be shown on digital map displays at remote sites including the Maryland State Highway Administration and the Virginia Department of Transportation. Incident and roadway status data will also be transmitted to equipment installed in vehicles operated by a local delivery company. The FHWA will evaluate the performance of E-CAPS in a report to be issued in the February-March, 1995, time frame.

Funding for the CAPITAL Project totals \$7.1 million, of which the Federal government will contribute \$5.5 million.

E-CAPS location technology is covered under U.S. patent #5317323 entitled Passive High Accuracy Geolocation System and Method. Another U.S. patent is pending.

ERA reports that E-CAPS will be available for commercial deployment in January, 1995. The system can be operational within approximately six months of receipt of order from a wireless network operator.

Wireless Phone

E-CAPS does not require any modification to the phone. Once deployed the system will compute the location of existing users of the network as well as new users.

System Accuracy

ERA states that location accuracy of E-CAPS is approximately 100 meters (95% probability). Multipath is a major error source, but filtering techniques are used to minimize its impact. The CAPITAL Project will provide operational test data to establish the operational accuracy of E-CAPS.

100 meter accuracy assumes the cellular signal is received by a minimum of 3 DSF units. Location can be computed if only 2 DSF units receive the signal, but accuracy may be degraded, depending on the location of the DSF units relative to the caller.

ERA reports that E-CAPS computes speed with an accuracy of +/- 5 MPH. Heading is also computed.

In-Building Penetration and Vertical Resolution

ERA reports that signal strength of radio signals is reduced as the signals pass through building walls. Since a minimum of 2 DSF-equipped cell sites must receive the signal to compute location, not all calls placed from indoor locations can be located. Indoors, multipath can also degrade system accuracy.

The E-CAPS system is not currently designed to compute altitude. This capability could be added in the future, but projected vertical accuracy will not make it possible to identify the floor from which a call is placed.

Projected Cost of Deployment

ERA is currently developing a pricing schedule for E-CAPS. System pricing depends on a number of factors including topography and the size of the area to be covered.

TrackMobile, Inc.
550 West B Street, Suite 250
San Diego, CA 92101-3537
Telephone: (619) 235-6085
Fax: (619) 235-0213

Company Background

TrackMobile, Inc. was incorporated in 1989 for the purpose of providing location-dependent services for consumer and commercial applications using the cellular network. TrackMobile services will be marketed under the name Help Express. To date, the company has focused primarily on developing technology, service specifications and business alliances. TrackMobile plans to commence commercial operations in a major city in the 1st quarter of 1995.

TrackMobile currently has under 10 employees and plans to expand its staff to 30 in the 1st quarter of 1995. Allstate Insurance company is a major investor in TrackMobile and the primary source of funding to date.

Cellular Location Technology

TrackMobile has developed location technology which uses existing cellular, PCS or SMR networks. The system is designed to compute location on either analog or digital networks. No modification to the network is required.

TrackMobile cellular phones are marketed under the name "Helpfon". The software in the phone is modified to transmit signal strength measurements of control channels from each cell site, including both A and B side cellular operators. The range to three or more cell sites is computed based on the signal-to-noise ratio of the received signals. The available signal strength is passed through the network to the Help Express Service Center where the caller's location is computed by triangulation. Speed and heading are also computed. TrackMobile holds several U.S. patents on its location technology.

Emergency messages transmitted from a Helpfon are received at the Help Express Service Center, which is housed at the National Dispatch Center in San Diego, CA. The nature of the emergency along with the identification and location of the caller are received by the TrackMobile dispatcher. Calls requiring 9-1-1 response are passed to one or more responsible 9-1-1 jurisdictions, based on the caller's location. TrackMobile field response team members (off-duty police officers) use portable direction finding devices to determine the exact location of the caller, in support of the responding law enforcement agency.

The TrackMobile system is designed to work with wireless networks including cellular, PCS and ESMR.

Target Applications

Intended applications for the TrackMobile Help Express service include location enhanced 9-1-1 response, stolen vehicle recovery, medical emergency response, roadside assistance, personal security response and street and address finding.

System Status

TrackMobile reports that work on the technology commenced in 1989. In the past 3 years over 400 field tests of the system have been conducted. It was reported that 75 audited field and product tests have been conducted by cellular phone manufacturers and cellular carriers.

The management of TrackMobile reported that the company is negotiating with a cellular operator for an ownership position in TrackMobile. The company also reported that it is close to closing a deal with a major cellular phone manufacturer to produce HelpFons which incorporate special software to support location.

TrackMobile plans to launch the Help Express service in a major U.S. city in the 1st quarter of 1995. The company plans to offer services in 30-50 of the largest MSA's within five years.

System Accuracy

TrackMobile reported that typical location accuracy is 500 feet. A reduced level of accuracy is obtained in marginal cellular coverage areas. A radio direction finding device, with a range of approximately two miles, is used to locate the precise location of the caller.

Performance in Dense Urban Environments

TrackMobile reports that it has done extensive algorithm development and testing to deal with multipath in urban environments. Averaging techniques are used to obtain the best possible accuracy in the operational environment.

In-Building Penetration and Vertical Resolution

The company reports that if a call is placed from inside a building, at a minimum the cell from which the call was placed is identified. The precise location of the caller, including the floor on which the caller is located, can be identified using the radio direction finding device.

Projected Cost

TrackMobile reports that the cost of a HelpFon will not be any greater than the cost of a standard cellular phone. Both mobile and portable phone configurations will be available, priced around \$200.

U.S. West New Vector Group

3350 161st Avenue S.E.

Bellevue, WA 98008

Telephone: (206) 562-5060

Fax: (206) 562-5640

Company Background

U.S. West New Vector Group, Inc. is a wholly-owned subsidiary of U.S. West, Inc. U.S. West New Vector Group owns and operates cellular networks in a number of cities including Seattle, Phoenix, Denver, Minneapolis and San Diego. Annual revenues of U.S. West, Inc. exceed \$10 billion.

U.S. West New Vector has been researching position determination technologies since 1991. The company has focused on development of systems which could address broad consumer markets and which would have a minimal impact on handset and network costs. The company reports that it has done development work on relatively coarse systems that define location as relatively large zones and also on highly accurate systems. For the past 9 months, New Vector has been conducting active technical research on a relatively high accuracy, low cost system suitable for a broad range of applications.

Cellular Location Technology

The location system being developed by New Vector uses Time-of-Arrival multilateration techniques to locate a caller. The system can operate in the cellular, ESMR or PCS bands. The system requires the installation of special equipment at more than 50% of the network cell sites. A modification to the wireless phone is also required, which will most likely consist of one integrated circuit and software. The IC can be embedded in a standard AMPs phone or a dual mode digital phone. The system is designed to compute location in the phone, though the system is also capable of computing location in the network. U.S. West has applied for a patent on the specific technique used to compute location.

Target Applications

Intended applications for the New Vector location technology include fleet management, emergency location services, fraud detection services, property tracking and recovery services and personal safety/security services.

System Status

U.S. West New Vector reports that extensive analysis and simulation of the system has shown that theoretical accuracy of 100 ft. is probable.

A field test program commenced this month (July, 1994) to address performance in stationary outdoor environments, indoor environments including high rise buildings and moving vehicle tests. New Vector reports that the system is being tested in the presence of moderate and severe multipath and GDOP (geometry of equipped cell sites). Wide area testing will be conducted. Field testing will continue through August, 1994.

U.S. West New Vector states that it will be willing to share details of its research and systems development with interested government agencies under non-disclosure beginning in September, 1994. The company reports that it is premature to estimate when the system will be available for commercial deployment.

System Accuracy

New Vector reports that empirical data on system accuracy will not be available until field test results are processed.

Cost

Based on the technology used, it is projected that the cost of the chip to be embedded in the phone will be approximately \$3. Based on available data regarding the New Vector system, it is estimated that the cost of the network equipment will be approximately \$1/2 million each for cities such as the primary U.S. West cellular markets.

In-Building Penetration and Vertical Resolution

New Vector reports that the location system is designed to provide maximum in-building penetration. In the New Vector system, transmission from cell sites will be at the legal limit of 500 watts ERP. The company claims that this provides a 20dB advantage over systems which rely on .6 watt transmission from a portable wireless phone. Field test data will be obtained in shopping malls, high rise buildings and other indoor locations.

New Vector has not conducted any tests to determine the capability of the system to resolve altitude.

Lockheed Sanders, Inc.

65 Spit Brook Road
M/S PTP02-C002
P.O. Box 868
Nashua, NH 03061-0868
Telephone: (603) 885-8055
Fax: (603) 885-8685

Company Background

Lockheed Sanders, Inc. is engaged in the development, manufacture and sale of advanced electronic systems and products in a broad range of markets. Major business areas include signals intelligence and communications jamming systems, information display systems, automated test systems and RF, microwave, millimeter wave, optical and acoustic systems. The company reports that it has some 40 years of transmitter location experience.

Lockheed Sanders, Inc. has approximately 4,500 employees. It is a wholly owned subsidiary of the Lockheed Corporation.

Cellular Location Systems

Lockheed Sanders, Inc. reports that it is developing a product line of equipment for determining the precise location of cellular phones in high multipath, urban environments. The network equipment consists of a receiver and processor contained within a standard chassis. The unit is designed to either stand alone or to interconnect to existing network equipment. A proprietary Time-Difference-of-Arrival (TDOA) technique is used to compute the approximate location of the caller.

The product line being developed includes a handheld device for use within buildings and at close range, which employs a proprietary direction finding technique.

Target Markets

Applications for the Lockheed Sanders system include mobile Enhanced 9-1-1, combating fraudulent cell phone use, fleet management, personal safety, location-based yellow pages and other location-dependent commercial and consumer services.

System Status

A prototype of the cellular location system has been developed. Field tests conducted to date have been on the company's proprietary base stations and not on an operational

cellular network. Lockheed Sanders reports that they are working on establishing relationships with cellular carriers. The company states that the system will be ready for customer field trial deployment by the end of 1994 and for commercial deployment in 1995.

Accuracy

Lockheed Sanders states that the accuracy of the cellular location system is currently under field testing and verification. They report that the handheld unit determines a cellular phone's location without any residual ambiguity.

In-Building Penetration and Vertical Resolution

Lockheed Sanders reports that the use of the handheld direction finding device will enable 9-1-1 responders to identify the location of the phone inside a building. The determination of the floor on which the phone is located is planned as a future growth option.

Cost

The company states that is not in a position to disclose cellular location cost estimates at this time.

Lattice Communications

14205 SE 36th St., Suite 100
Bellevue, WA 98006
Telephone: (206) 649-1141
Fax: (206) 649-1199

Company Background

Lattice Communications was founded in 1993 for the purpose of developing a system for identifying the location of the caller using a wireless network. The founders of Lattice have business and technical experience in such fields as cellular communications, satellite communications, radar, and real time wide area networks. They have reportedly made technical contributions to companies such as Motorola, Cubic Defense Systems, TRW, PacTel Corporation and U.S. West.

Paul Norris, President and CEO of Lattice Corporation, co-founded two successful high-tech companies in the 1980's. One these companies, Quantum Medical Systems, developed medical diagnostic products and was sold to Siemens AG. Quantum Medical systems currently employs some 400 people. Norris also founded Seattle Silicon, now called Cascade Design Automation, which developed customer integrated circuit design technology and was sold to Oki Electric. Cascade's silicon and gallium arsenide design tools are currently used by Oki and other major communications equipment suppliers.

Location Technology

The location technology being developed by Lattice Corporation consists of an overlay to the wireless network. No modification to the phone will be required. Lattice reports that a key element of the system design is its ability to mitigate the effects of multipath propagation. The company does not wish to discuss the technique used to compute location in greater detail at this time except under non-disclosure. Lattice Communications holds U.S. patents on some of the techniques used in its system.

Target Applications

Intended applications for the Lattice system include 9-1-1 emergency notification, fraud interdiction, and other location-dependent commercial and consumer applications.

System Accuracy

Accuracy of the Lattice system is site and installation dependent. The company's investigations to date indicate that approximately 95% of measurements will be within a window of 300 ft. or less.

System Status

Lattice Communications estimates that the location system will be available for commercial deployment in 1996. The company will be seeking alliances with wireless operators in order to fund commercial deployment.

Performance in Dense Urban Environments

Lattice reports that the system is designed to operate in all wireless operating environments where communications are possible. Accuracy is somewhat degraded in dense urban environments.

In-Building Penetration and Vertical Resolution

Lattice states that the system's in-building penetration will be comparable to the wireless frequency being used. The company claims that a unique feature of its technology is that it will provide a measure of vertical resolution, depending on the environment and proximity to the base stations. Vertical resolution will be limited, however, due to typically unfavorable geometric conditions of a base stations located in a horizontal plane.

Projected Cost of Deployment

The cost to deploy the Lattice system will vary depending on the network equipment configuration at the cell site. Lattice feels it is premature to publicly discuss deployment costs, other than to say that system is designed to be relatively low cost.

Cartesia Corporation
3100 McKinnon
Suite 900 - LB 126
Dallas, TX 75201
Telephone: (214) 954-0022
Fax: (214) 871-1591

Company Background

Cartesia Corporation is a privately-held company which was formed in 1992. The company was formed for the purpose of applying advanced digital communications software and mapping technology to the needs of public agencies. The company's products are targeted at municipal and state agencies, law enforcement organizations and emergency service providers. The company's principal products are software packages which support the design of Emergency Service Network (ESN) boundaries, the maintenance of 9-1-1 Master Street Address Guide files and the mapping of 911 calls as they are received by calltakers.

In January, 1994, Trident Tracking Technology, Inc., which had been formed to develop cellular-based location technology, approached Cartesia Corporation with some preliminary software for computing the location of radiating sources using triangulation. Cartesia spent the next several months further developing the algorithms and integrating the location technology with the company's conventional PSAP mapped-ALI screen. In June, 1994, Cartesia Corporation entered into negotiations to acquire Trident Tracking Technology, Inc. The merger of the two companies is expected to be completed before the end of 1994.

Cartesia Corporation currently has 7 employees. The company is in the process of acquiring a 9-1-1 consulting company, which will increase the company's staff to approximately 20.

Cellular Location Technology

The Cartesia location system computes the location, speed and heading of callers using an overlay to the wireless network. The system tracks the control channel transmissions from the phone at 3 or more cell sites to compute the user's location.

Cartesia's location system hardware is installed at each network cell site. Data from each cell site is passed to the system processor located at the switch (MTSO), where the location of the caller is computed. The company's management declined to provide details concerning the equipment installed at the cell sites and the technique used to compute location. Cartesia Corporation has not yet filed for patents on the system.

The Cartesia system does not require any modification to the phone. The system is compatible with a wide range of wireless networks, including cellular, PCS and ESMR.

Target Applications

The Cartesia location system has been developed primarily to support E9-1-1 applications over wireless networks. Cartesia Corporation also intends to apply the technology for other commercial and consumer applications through alliances with wireless network operators. Intended applications include passive devices for tracking children, fleet vehicle location, monitoring the location of high value assets and cellular fraud detection.

System Status

In early 1994, Cartesia Corporation conducted a simulated test of a large number of 9-1-1 calls, based on cellular tower locations in Tarrant County, Texas. The company reported very positive simulation results.

Field testing of the Cartesia location system will commence this summer. Cartesia is negotiating with local cellular carriers to provide facilities for the testing. Cartesia reports that a local 9-1-1 district has received a public grant to conduct tests of wireless network caller location. Cartesia plans to provide test results in support of the work being done under this grant.

Cartesia's management stated that they expect to make an announcement in the 4th quarter of 1994 that the location system is ready for commercial deployment. The company plans to form alliances with cellular operating companies who will support deployment of the system.

System Accuracy

In field tests scheduled for the second half of 1994, Cartesia Corporation expects to demonstrate static test results of 70 ft. or better. (However, no field data has been obtained to date to confirm this level of accuracy.) System latency of approximately 5 seconds is anticipated in computing location, which will not affect static accuracy, but may impact dynamic performance.

Urban and In-Building Performance

Field tests will determine the accuracy obtainable in dense urban environments and inside buildings. Cartesia believes its system will handle multipath more effectively than most competing systems.

Vertical Resolution

The Cartesia system is reportedly designed to solve for altitude. The company expects test results to demonstrate vertical accuracy equivalent to the accuracy of each horizontal dimension. The company did not provide information on how this will be achieved.

Projected Cost of Deployment

Cartesia indicates that they have a very low cost design with an anticipated hardware cost of approximately \$5,000 per cell. The company reports that the only other cost item is the system processor and software located at the MTSO.

Qualcomm Incorporated

10555 Sorrento Valley Road

San Diego, CA 92121

Telephone: (619) 597-5025

Fax: (619) 587-8276

Company Background

Qualcomm Incorporated was formed in 1985. One of the company's principal business areas is the operation of the OmniTRACS system, which is the most widely used mobile communication and location system for the longhaul trucking industry. The other primary business area is the development and licensing of Code Division Multiple Access (CDMA) technology for wireless communications.

Position Determination with CDMA

Klein Gilhausen, Sr. VP of Qualcomm, wrote a white paper in approximately 1991 entitled CDMA Positioning Methods. This paper indicates that in wireless networks using Qualcomm's CDMA technology, transmissions from all cells are time synchronized using GPS satellite downlink signals to update rubidium clocks. Also, CDMA, like GPS, uses a direct sequence spread spectrum signal. The chip rates of the two systems are similar. The paper indicates that it is possible to compute position within a Qualcomm CDMA mobile phone if it is capable of receiving and tracking the pilot signals of three neighboring base stations and is provided with accurate location information of the base stations.

The "Near/Far Problem" is an issue using a CDMA network for positioning. According to Gilhausen's white paper, when a mobile unit comes close to a base station, it will become difficult to obtain an adequate signal-to-noise ratio on the neighboring base stations. The paper suggests several possible solutions to this problem including the use of one channel to support positioning or a technique using short pauses in transmission from cells to allow for timing measurements on neighboring cells. A copy of the Qualcomm white paper will be submitted to the sponsor of this study together with this report.

Status

Qualcomm reported that wireless network operators have not expressed much interest in location capability using CDMA, and, consequently, Qualcomm has not pursued development of the positioning technology beyond the analysis done in the white paper. It was indicated that Qualcomm is prepared to respond to the requirements of its customers in this area. The company reports that adding a positioning capability to CDMA would require some software work and might require a hardware change to the phone.

Accuracy

Qualcomm reports that without multipath, CDMA positioning would be accurate to within approximately 100 ft. It was stated, however, that multipath can cause a significant reduction in accuracy in a CDMA system or any other system. It was noted that Qualcomm's CDMA system can distinguish between a direct and a reflected signal path. The major problem with multipath occurs when there are no signals with a direct path.

ESL Incorporated
495 Java Drive
P.O. Box 3510
Sunnyvale, CA 94088-3510
Telephone: (408) 738-2888
Fax: (408) 743-6425

Company Background

ESL, Inc. is an operating unit of the Avionics & Surveillance Group of TRW, Inc. ESL has been active for over 25 years in designing and developing reconnaissance, surveillance, communications and imagery systems and in performing related analyses and studies. The company has some 20 years of experience in the development of radiolocation systems, primarily utilizing direction finding (DF) technology.

Positioning Technology

ESL does not have off-the-shelf capability to locate a 9-1-1 caller using a wireless phone. The company indicates that the problem of locating mobile caller is best solved through a combination of approaches which may involve the use of GPS, Interferometer Direction Finding and Time-Difference-of-Arrival (TDOA).

To locate wireless 9-1-1 callers, ESL would install a computer at the mobile telephone switching office (MTSO) which would determine the location of the mobile phone based on the responses of ESL direction finding (DF) equipment located at cellular base stations. Using Interferometer DF, the direction of arrival of the signal would be computed from the measurements of phase differences between different antennas within the DF antenna array. In addition, ESL is currently investigating the use of a low cost implementation of time-difference-of-arrival (TDOA) radiolocation to further reduce the equipment requirements at the base stations. With TDOA, instead of requiring an antenna array with up to five antennas and a dual channel receiving system, a single antenna and a single receiver would be required at each DF site, significantly reducing the cost of the system.

Status

In R&D investigations conducted between 1991 and 1993, ESL developed and demonstrated a ground-based cellular intelligence collection system. The system included a military version of ESL's portable interferometer DF device. Collected data showed DF accuracy on the order of 1.5 degrees.

ESL states that while the company does not have an off-the-shelf system for 9-1-1, based on their experience alone they believe there are enough mature technologies available in the marketplace that a practical and affordable wireless 9-1-1 system is well within reach. The challenge is to configure a low cost system.

Accuracy

ESL reports that GPS accuracy can be as good as 30 ft. (This is true assuming differential corrections are applied.) Accuracy achievable with DOA (Direction of Arrival) or TDOA technology in relatively open areas is better than 100 ft. In dense downtown areas, outdoor accuracy can degrade to 300 ft. and higher.

In-Building Penetration and Vertical Resolution

ESL indicates that if a call from a wireless phone is made within a building, neither GPS, DOA or TDOA will provide good results. With the presently available technology, the best that can be achieved is to identify the building. The company suggests that it may be necessary to install a location sensor in every base station of an in-building PCS network. If a power level sensor and coarse direction finder are used, the in-building system should be relatively inexpensive.

Cost

ESL indicates that if GPS is mandated to be included within every wireless phone sold in the U.S., the estimated unit cost would be a few dollars per phone. The cost to develop a functional trial system using DOA/TDOA is estimated by ESL at several million dollars.

Wireless Phone Location Assessment

ESL's complete report assessing the issues related to wireless phone location will be submitted to the sponsors of this study.

ArrayComm, Inc.
3255 Scott Blvd., Bldg. 4
Santa Clara, CA 95054-9082
Telephone: (408) 982-9080
Fax: (408) 982-9082

Company Background

ArrayComm, Inc. is a privately-held company which was formed in April, 1992. The company was formed to develop and license Spatial Division Multiple Access (SDMA) technology for enhanced communications quality and capacity in wireless networks. The founders of ArrayComm have extensive experience in wireless communications with companies such as Motorola and Alcatel.

IntelliCell System

The ArrayComm IntelliCell system uses SDMA technology which relies on the use of multiple element antenna arrays to locate and track users. The multi-element antenna array is used to estimate the directions of arrival of multiple signals transmitted over the same frequency (same channel) and separates the individual signals. Fundamentally, it locates sources of electromagnetic energy. ArrayComm claims to be able to resolve the angle of arrival of signals transmitted from wireless phones to fractions of a degree in clean signal environments.

The ArrayComm system is reported to be compatible with all wireless analog and digital modulation formats.

In February, 1994, ArrayComm, Inc., Watkins-Johnson Company and Spectrian, Inc. received a matching grant award from the Advanced Research Projects Agency (ARPA) as part of a \$11.4 million effort to develop "smart antenna" technology based on ArrayComm's patented SDMA technology. The matching funds will be used to develop a beta test configuration to support productizing of the ArrayComm technology.

Target Applications

ArrayComm plans to license the IntelliCell SDMA-based system to manufacturers of wireless (cellular, PCS, ESMR) base station equipment who, in turn, will sell the equipment to wireless network operators. Wireless operators using the SDMA technology will define the applications for the mobile unit tracking capability inherent in the system. ArrayComm believes that mobile 9-1-1 location estimation is possible with the company's SDMA system installed in a wireless network.

System Status

ArrayComm has developed a cell site prototype employing the SDMA technology. The company reports that it has been successfully demonstrating simultaneous communication of three cellular phones on the same frequency using its technology. To date, computing the latitude and longitude of the caller has not been a requirement. ArrayComm states that this is easy to do with the accurate angle of arrival information that is already available with their system.

The company reports that the IntelliCell system is ready to be licensed. The company is currently working to develop license agreements with wireless base station manufacturers. If successful, the system could be deployed on a widespread basis within two years.

Wireless Phone

The ArrayComm system is compatible with existing cellular phones. No modification to the phone is required for communication or positioning with the SDMA technology.

System Accuracy

ArrayComm states that its system can provide for resolution of the caller's location with a typical accuracy of approximately +/- 50 meters in rural and suburban areas. The highest accuracy is obtained when the caller is close to the base stations used in the solution.

The ArrayComm system does not resolve the floor from which a call was placed.

Dense Urban Environments

Some degradation of accuracy occurs in dense urban environments. ArrayComm claims that the system is as accurate as the size of the radiator. In urban environments, the building itself often serves as the radiator of the radio signal. In a very dense urban environment such as downtown Manhattan, it may only be possible to resolve the source of radiation to a city block. ArrayComm believes this is also true of other wireless network location technologies.

Cost

ArrayComm states that the cost for cellular operators to deploy SDMA technology will be determined by the base station manufacturers to whom the technology is licensed.

OAR Corporation
10447 Roselle Street
San Diego, CA 92121-1532
Telephone: (619) 453-4014
Fax: (619) 546-8739

Company Background

OAR Corporation was founded in 1968. The company is a developer and manufacturer of direction finding, surveillance and spectrum management products and systems. The company's emitter tracking and location devices, portable direction finders and man-portable tactical systems are sold to law enforcement agencies, military and spectrum management users in the U.S. and abroad. The company recently completed delivery on an FAA contract for radio direction finders to track planes located between radar control coverage areas. OAR teamed with Hughes STX on this project.

OAR Corporation has approximately 50 employees.

Location Technology

OAR Corporation indicates that its direction finding technology can be applied to locating callers using a wireless network. The system would include an antenna array, bearing processor and receiver installed at cell sites.

For 9-1-1 applications, the company might also incorporate signal strength measurements to help resolve the range from the base station to the caller.

System Accuracy

OAR Corporation's current direction finding technology would allow for computing the direction of the caller with an accuracy of 3 degrees RMS. In an urban environment, typical positioning accuracy would be within a city block. When positioning is based on direction finding, accuracy is greater when the caller is close to the base station.

Cost

OAR Corporation estimates that the equipment cost for an antenna, processor and receiver for installation at a cell site would be approximately \$10,000. The company believes this cost can be reduced to around \$3,000.

Scientific Research Laboratories, Inc.

P.O. Box 2729

Santa Maria, CA 93455

Telephone: (805) 928-0133

Fax: (805) 925-2744

Company Background

Scientific Research Laboratories, Inc. (SRL) was incorporated in 1983. The company produces a total of 43 product configurations including antennas (137.5 - 950 MHz), low noise amplifiers, telemetry transmitters and receivers, video transmitters and receivers, radio direction finding equipment and field survey meters.

SRL has six employees and annual sales of approximately \$1 million.

SpecTrack

Scientific Research Labs (SRL) has developed the SpecTrack system which is a channelized spectrum management system designed to identify the location of interfering emitters in the cellular and ISM bands. The base station configuration installed at the cell site includes a scanned antenna array and a chassis housing a multi-channel phase coherent receiver and processor. The system identifies the angle of arrival of any emissions from a wireless phone with an accuracy of 3-5 degrees. The SpecTrack system also includes a mobile radio direction finding unit installed in response vehicles which provides the capability to home in on the mobile phone.

Target Markets

The SpecTrack system was developed to identify the location of interfering emitters which may be jamming cellular or ISM channels. The system is also designed for site surveys to identify locations where wireless phone usage is concentrated and new cell sites may be required. SRL states that the SpecTrack technology can be effectively applied to a system for locating wireless callers for 9-1-1 response.

System Status

The SpecTrack mobile radio direction finding unit has reportedly been in successful beta test for a two year period. Beta testing of the base station unit is scheduled for the fall of 1994.

Accuracy

The SpecTrac system calculates the angle of arrival of transmissions from wireless phones with an accuracy of 3-5 degrees. The system typically resolves the location of the caller with an accuracy of 500-1,000 ft. The vehicle-mounted radio direction finder, based on input of the transmission channel, homes in on the location of the caller.

Cost

SRL reports that the estimated cost of the fixed site base station unit is \$7,500. The price of the vehicle mounted DF unit is approximately \$1,900.

SYSTEMS BASED ON EXTERNAL RADIOLOCATION NETWORKS

This section of the report covers location systems which utilize a separate network to compute the location of a 9-1-1 caller using a wireless phone. Several suppliers use an existing radiolocation network, such as the Global Positioning System (GPS) or the existing commercial FM radio infrastructure, to compute location. Other companies plan to deploy radiolocation networks with coverage in major metropolitan areas which could compute the location of mobile 9-1-1 callers and pass this information to the PSAP.

Systems developed by the following companies are covered in this sections:

- Terrapin Corporation
- NAVSYS Corporation
- Smith Advanced Technology, Inc.
- Galaxy Microsystems, Inc.
- Automatic Vehicle Monitoring Systems
 - AirTouch Teletrac
 - Pinpoint Communications, Inc.
 - MobileVision

Terrapin Corporation
11958 Monarch Street
Garden Grove, CA 92641
Telephone: (714) 898-8200
Fax: (714) 895-7526

Company Background

Terrapin Corporation is a venture capital funded company which was formed in 1991. The company has developed and patented radiolocation technology which uses signals transmitted by commercial FM radio stations to compute location. The founders of the company have backgrounds in GPS receiver development, with companies such as Texas Instruments, and also have prior engineering experience with commercial FM networks. The Terrapin technology was developed on the premise that FM receiver technology is inherently low cost and FM signals will provide superior performance to GPS in urban environments and can be tracked indoors.

Terrapin Corporation is affiliated with KOR Electronics, a supplier of radar simulation and electronic countermeasure equipment. The two companies have approximately 50 employees, mostly engineering and technical support staff.

Terrapin PINS System

The Terrapin system is referred to as PINS, which stands for Position, Information and Navigation System. The PINS system computes location by measuring the phase of the pilot tone sine wave broadcast by commercial FM transmitters. PINS algorithms convert phase measurements on signals from three or more stations to range measurements, and location is computed by triangulation.

For wireless 9-1-1 applications, a PINS receiver module is interfaced to the phone or embedded in the phone. The phase measurement data will be transmitted over the wireless network to a processor at the PSAP or other site where location will be computed. This will minimize receiver cost. For some other applications, location will be computed in the phone.

The Terrapin system requires installation of a Fixed Observer in each metropolitan area. The Fixed Observer computes phase and frequency drift corrections for each station, effectively synchronizing the transmissions off-line. The corrections are transmitted to users over an FM subcarrier or other suitable broadcast medium.

Terrapin believes that a major advantage of the PINS system is its use of the existing infrastructure of some 4,000 commercial FM radio transmitters operating in the U.S., many of which broadcast at a power level of 50,000 watts or more. According to

Terrapin, use of commercial FM transmissions eliminates the need for network infrastructure and provides for good urban and in-building performance.

Target Applications

Intended applications for the Terrapin PINS system include mobile 9-1-1, roadside assistance, stolen vehicle recovery, routing travellers to their destination, fleet management and electronic monitoring of probationed and parolled prisoners.

System Status

The Terrapin system has been in development since 1991 and live system demonstrations have been conducted since 1992. The current receiver test hardware configuration is PC-based. The first PINS receiver product, a single printed circuit board in an enclosure, is scheduled to be available in September. Terrapin management reports that within the next six months the company will complete the development of a PINS receiver in the form of a low cost chipset suitable for incorporation into wireless phones.

Terrapin is currently establishing alliances with wireless network operators and other potential partners who will work with Terrapin to commercialize the PINS technology for targeted applications. Terrapin is also seeking alliances with major cellular phone manufacturers who will incorporate the PINS location technology into their phones. The Terrapin system will be commercially available in a number of major cities, beginning in 1995.

System Accuracy

Terrapin states that the accuracy of the PINS system, for mobile 9-1-1 applications, will typically be 20-30 meters, depending on the multipath environment. PINS receiver configurations will vary somewhat depending on the performance and cost level required for the application.

Performance in Dense Urban Environments

Terrapin Corporation claims that the system performs well in urban environments since the FM signals tracked by PINS are relatively low in frequency and not subject to shadowing from tall buildings and foliage. PINS algorithms are designed to optimize performance in high multipath environments.

In-Building Penetration and Vertical Resolution

Terrapin believes its radiolocation system has better in-building penetration than competing systems due to the use of relatively low frequency FM signals and due to the high power levels of commercial FM broadcast stations. Terrapin claims that signals from three or more FM stations can be received in most buildings and that location accuracy of 20-30 meters can generally be obtained.

The PINS system does not currently compute altitude. However, Terrapin is investigating ways to compute altitude using microcell repeaters.

Cost

Terrapin estimates that by sharing the processor in the wireless phone, PINS chipsets can be supplied to cellular phone manufacturers and other partners for approximately \$35 per chipset. Terrapin plans to license PINS technology to wireless phone manufacturers.

The cost to deploy redundant Fixed Observers in major metropolitan areas is estimated at \$25,000 per city.

NAVSYS Corporation
14960 Woodcarver Road
Colorado Springs, CO 80921
Telephone: (719) 481-4877
Fax: (719) 481-4908

Company Background

NAVSYS Corporation, which was founded in 1986, is a privately-held research and development company that incorporates GPS technology into customer products. The company's activities are focused in the following areas:

Innovative Research: conducts basic and applied research in GPS-related areas under contract to government and industrial clients, emphasizing conceptual research and systems prototyping under Small Business Innovative Research (SBIR) and similar R&D contracts.

Technology Licensing: NAVSYS develops and patents GPS technology for license and transfer to companies serving commercial markets. The emphasis is on technology transfer for low end, low cost high volume markets such as weather balloons and vehicle tracking systems.

Special-Purpose Equipment: NAVSYS designs and manufacturers small quantities of special purpose, high end systems, equipment and software, including GPS signal generators, GPS translator test equipment and precision range.

NAVSYS Corporation has 24 employees and annual revenues of approximately \$2 million.

TIDGET Mayday System

The TIDGET is low cost GPS sensor, developed and patented by NAVSYS, which is designed to "take a snapshot" of the raw sampled data from GPS satellite transmissions. The TIDGET does not include the Digital Signal Processor and microcomputer included in standard GPS receivers which, according to NAVSYS, significantly reduces the cost. The TIDGET receiver is embedded in the GPS antenna module which is mounted in a suitable location on (or inside) the vehicle for maximum visibility of the sky. The current configuration of the TIDGET is designed for vehicular, rather than portable applications. However, NAVSYS reports that the company is currently developing a portable TIDGET configuration for downed pilot and other emergency applications under an ARPA contract.

The TIDGET sensor is integrated with the Mayday terminal installed in the vehicle which provides a two-way data link between the vehicle and the Operations Center. A modem

for communication over the selected communication network (cellular, PCS, ESMR or other) is included in the Mayday terminal.

NAVSYS reports that the TIDGET is able to turn on, capture and transmit satellite data in less than one second. Computation of location at the Operations Center also requires less than one second. With a 9600 baud modem, or faster, the process of locating the caller typically requires no more than 3 seconds.

The TIDGET does not process the GPS data, but rather transmits it over a communication link (cellular, PCS, ESMR or other) to the Operations Center, where the data is processed and location computed. The Operations Center also places priorities on calls, routes calls for assistance to the appropriate agency and notifies the motorist of the action taken and the anticipated response time. The initial Operations Center will be located in Denver, Colorado. A single Operations Center can cover a large geographic area.

The TIDGET will be manufactured under license by companies such as Plessey.

Target Applications

Civil applications for the TIDGET include 9-1-1 (Mayday) and other personal location services. Government applications for the TIDGET include tracking weather sensors (radiosondes), drifting bouys carrying oceanographic sensors, sonobouys and wildlife tracking.

System Status

The TIDGET was initially developed by NAVSYS in 1990. In 1992, NAVSYS received experimental contracts for the TIDGET from the U.S. Air Force for tracking radiosondes and from the Royal Aircraft Establishment for tracking sonobouys.

NAVSYS Corporation will participate in an operational test of a vehicle Mayday service, sponsored by the Federal Highway Administration (FHWA). Along with NAVSYS, team members involved in the test include Enterprise, a multi-state IVHS research and implementation organization, Comnet Cellular, U.S. West, Cellular One, Environmental Systems Research Institute, the Colorado State Patrol and Castle Rock Consultants. The full-scale operational test, which will commence in mid-1995, will involve a minimum of 2,000 vehicles and will cover 12,000 square miles in Colorado. Each participating vehicle will be equipped with a TIDGET interfaced to a cellular phone. Among the primary purposes of the test is to implement and evaluate a low cost personal security system for obtaining roadside assistance via an automated system that provides the responding party with detailed information on the location and type of assistance required.

Plessey is licensed to manufacture the TIDGET. Production configurations of the TIDGET are expected to be available from Plessey in early 1995.

System Accuracy

The TIDGET Mayday System is designed to provide approximately 100 meter accuracy. NAVSYS reports that accuracy of up to 10 meters can be obtained if additional satellite data is transmitted and more time is allowed to compute location.

Performance in Dense Urban Environments

The TIDGET Mayday System is designed to compute location, in some cases, with as few as two visible satellites. NAVSYS states that this provides the capability to compute location in dense urban areas a higher percentage of the time than standard GPS receivers which require 3-4 visible satellites.

In-Building Penetration and Vertical Resolution

The GPS system does not provide for in-building penetration. An unobstructed view of the satellites is required.

Cost

NAVSYS states that the TIDGET currently costs less than \$100 per unit which is significantly less than the cost of a conventional GPS receiver. The company states that TIDGET sensor prices are projected to drop to less than \$50 within a year for large quantity purchases.

Smith Advanced Technology, Inc.

2009 Gallatin Street
Huntsville, AL 35801
Telephone: (205) 533-3822
Fax: (205) 534-7461

Company Background

Smith Advanced Technology, Inc. is a privately-held company which was formed in 1985. The company is primarily active in the development of software products and systems for government agencies and the military. Smith is involved in verification and validation of software for control of the Space Shuttle's main engine system. The company is also focusing its capabilities in artificial intelligence systems at reducing manpower requirements at traffic management centers. The company's annual sales were not disclosed.

Roving Automatic Location Identification System

The Roving Automatic Location Identification System (RALI), developed by Smith Advanced Technology, provides the PSAP call-taker with the location and call-back telephone number of the wireless caller. The system uses the same channel to transmit location and caller number (ANI) and for voice conversation between the caller and the PSAP. RALI uses the Global Positioning System (GPS) to compute the location of the caller.

The RALI in-vehicle unit consists of a GPS receiver, a microcontroller, software logic and appropriate telephone interfacing electronics. When 9-1-1 is dialed, the RALI unit responds to a request from the PSAP for current position, speed, direction and call-back telephone number. The protocol provides for privacy protection so that vehicle ID and location is only provided as authorized.

RALI offers a retrofit kit to accommodate the currently installed base of mobile telephones. The PSAP portion of the RALI system requires a 486DX or equivalent processor. The RALI system will operate on any wireless network.

Target Applications

Applications for the RALI system include mobile 9-1-1, roadside assistance, fleet management, emergency notification for the hearing and speech impaired and other consumer and commercial applications.

System Status

Smith Advanced Technology reports that field testing of the RALI system commenced in early 1994. Field trials have been conducted in Atlanta, Las Vegas, Huntsville and Mobile, Alabama, and other locations. The company states that a Canadian wireline/cellular operator will install the RALI system at 9 PSAPs and will market the retrofit unit in a Canadian province beginning late this year.

Smith is establishing alliances with wireless and wireline operators in the U.S. who will market RALI for commercial and consumer applications. The company hopes to work with wireless phone manufacturers to have RALI units embedded in the phone.

The company plans to commence product delivery in late 1994.

System Accuracy

The accuracy of GPS is specified by the U.S. government as 100 meters. GPS performance can be degraded in dense urban environments by signal blockage from buildings, though Smith Advanced Technology claims that current GPS technology incorporated in the RALI system minimizes this problem. The company plans to offer low cost dead reckoning sensors as a future option.

In-Building Penetration and Vertical Resolution

The GPS system does not provide for in-building penetration. In portable phone applications, the system will save the last known position before the caller entered the building. If PCS base stations are installed inside buildings, the RALI system will receive/transmit the location of the building's base station or the base station on the individual floor.

Cost

The cost of the RALI mobile retrofit unit is approximately \$300. Smith Advanced Technology expects to have RALI units embedded within mobile phones. The RALI unit in the phone will consist of a GPS receiver and software which would run on the phone's processor. The company states that the cost of embedded RALI units will be driven by GPS receiver costs which, depending on volume, could be under \$100 in less than a year.

Galaxy Microsystems, Inc.

2127A Ringwood Avenue

San Jose, CA 95131

Telephone: (408) 894-7043

Fax: (408) 894-7045

Company Background

Galaxy Microsystems, Inc. was incorporated in 1985. The company has been primarily active in the design of radio frequency (RF) systems for the military, emphasizing the use of digital gallium arsenide technology. In 1989, Galaxy was awarded a contract by the U.S. Army for development of a spread spectrum radiolocation system for training applications. This system, based on low frequency transmissions from network towers, was successfully demonstrated to the Army in 1991. Despite a successful demonstration, DoD funds for system deployment were not available. Galaxy is currently seeking to commercialize this technology.

Galaxy has offices in San Jose, California, and Austin, Texas, and has a staff of approximately 15 employees.

Galaxy Position/Location System

The Galaxy Position/Location (P/L) System requires the installation of four towers on the periphery of a metropolitan coverage area. Four transmitters will cover an area of approximately 2,500 square miles. Additional transmitters can be added to increase the coverage area. The towers broadcast ground-wave signals in the LF band (180-450 KHz) using spread-spectrum Code Division Multiple Access (CDMA) modulation. Transmission power is typically 20-40 watts.

Galaxy receiver modules compute location based on Time-Difference-of-Arrival (TDOA) or phase difference of three received signals referenced to the fourth. The phase differences are used along with the known locations of the transmitters to calculate position.

A System Area Monitor is used to maintain transmitter alignment and to make transmitter phase and clock drift rate corrections as needed. When the error components of any signal exceed an established threshold, a control message is sent to the corresponding transmitter causing it to realign with the other signals.

Target Applications

Applications for the Galaxy P/L system include mobile 9-1-1 location and fleet management. The system is also targeted at the vehicle navigation market, based on the

capability of the system to compute accurate location within the vehicle. Other commercial and consumer applications are also targeted.

System Status

Following demonstration of the P/L system to the U.S. Army in 1991, a test system was installed in Austin, Texas. Field tests and demonstrations were conducted over a 9 month period. These tests were used to evaluate system software upgrades, including software to support tracking with signals from only three towers.

Galaxy reports that the next step, based on availability of funding, will be development of a pre-production configuration.

Accuracy

Galaxy reports that field tests demonstrated typical accuracies of 3-6 meters, relative to known benchmarks in the 80 square mile coverage area. Galaxy specifies overall system accuracy as 10 meters or better.

In-Building Penetration

Galaxy reports that the P/L system can be configured to transmit at somewhat higher frequencies which tests indicate result in better in-building penetration. The level of power transmission from the towers impacts the ability of the system to compute location indoors.

Cost

Galaxy reports that a network consisting of four towers and a System Area Monitor can be deployed at a cost of approximately \$200,000.

P/L receivers based on a single printed circuit board using standard components would be priced at approximately \$500. Incorporating a portion of the circuitry on an ASIC would reduce the price to about \$100. Galaxy indicates that with the volume that could be generated from integration of the P/L receiver into wireless phones, a P/L receiver in the form of a chipset would be forecasted to sell in the \$15-\$25 range.

Automatic Vehicle Monitoring Systems

In the 1970's, the Federal Communications Commission (FCC) established interim rules under which licenses to operate in the 902-928 MHz frequency band would be granted to companies for the operation of vehicle tracking systems in metropolitan areas. This band is shared with other licensed and unlicensed users. This band is referred to as the ISM (Industrial, Scientific, Medical) band or as the AVM (Automatic Vehicle Monitoring) band.

Several companies have obtained FCC license approval to operate vehicle tracking systems in this band, including the following:

- AirTouch Teletrac, Garden Grove, CA
- Pinpoint Communications, Inc., Dallas, TX
- Southwestern Bell Mobile Systems, Dallas, TX
- MobileVision, Boca Raton, FL

AVM-band systems have a number of common characteristics. All systems are based on a proprietary network of transmitting and receiving antennas deployed in and around a metropolitan area. In-vehicle transceivers, when activated by the pushing of an emergency button or other means, transmit a spread-spectrum code burst which is received by network antennas. Location is computed at a network control center based on Time-Difference-of-Arrival (TDOA) measurements. AVM-band systems offer data messaging in addition to vehicle location. One system, MobileVision, provides for voice communication as well as data.

For mobile 9-1-1 applications, an AVM-band transceiver could be interfaced to a wireless phone and programmed to have the unit automatically transmit when 9-1-1 is called. Location, computed at the AVM control center, along with caller identification, would be forwarded to the responsible PSAP. Interim FCC rules at this time generally limit the use of AVM systems to vehicular applications.

AVM-band systems typically cost several million dollars to deploy in a metropolitan area. The only company offering commercial services at this time is AirTouch Teletrac which has operational networks in six cities. Some other companies plan to deploy commercial networks in major cities in the near future.

The FCC is in the process of writing final rules covering AVM-band systems, which are expected to be issued this year.

Limited specific information on the Teletrac, Pinpoint and MobileVision systems follows. Southwestern Bell Mobile Systems reported that the company is not yet ready to provide details concerning its AVM system or deployment plans.

AirTouch Teletrac
7391 Lincoln Way
Garden Grove, CA 92641-1428
Telephone: (714) 897-0877
Fax: (714) 892-8637

Background and Status

AirTouch Teletrac, formerly known as PacTel Teletrac, has been commercially operational since 1990. Teletrac provides stolen vehicle location and roadside assistance services for consumer applications and also provides vehicle location and data communication services for metropolitan area fleets. Teletrac reports that nearly 1,000 fleets subscribe to its Fleet Director service, making it the largest U.S. supplier of vehicle location for metropolitan area fleets. Teletrac is currently operational in Los Angeles, Chicago, Detroit, Miami, Dallas and Houston. The company has not reported any specific plans to deploy the network in other cities at this time.

Teletrac is 51% owned by AirTouch Communications, Inc.

System Accuracy

Typical accuracy of the Teletrac system is 100-150 ft.

Cost

The price of Teletrac transceivers is currently around \$300. The company reports that in large volume, the next generation transceiver could be priced at \$100 or less. The company reports that low cost transceivers could be embedded inside wireless phones, FCC regulations permitting.

Consumer stolen vehicle recovery and roadside assistance services are currently priced at approximately \$12-\$18 per month, depending on the service plan.

Pinpoint Communications, Inc.

Park Central VII
12750 Merit Drive
Suite 800, L.B. 20
Dallas, TX 75251
Telephone: (214) 789-8900
Fax: (214) 789-8989

Background and Status

Pinpoint Communications, Inc. has developed the Array™ network which the company describes as an urban-based wireless data network which integrates high speed data communications with vehicle location. A series of field demonstrations of the system were conducted in the Washington, D.C. area in 1993. The company plans to conduct a six-month commercial test program in Dallas, Texas, beginning in early 1995. Pinpoint is attempting to raise funds to deploy the Array network in 40-50 largest U.S. metropolitan areas.

Pinpoint plans to commercialize the use of the Array network through alliances with applications enablers, systems integrators, value-added resellers, providers of user solutions and equipment manufacturers. Targeted applications include emergency notification, fleet management, vehicle security and other IVHS-related services for consumers.

Accuracy

Pinpoint reports that location accuracy is 20-300 ft., with typical accuracy of 50 ft. or better. The system achieves this accuracy through a patented technique for measuring Time-Difference-of-Arrival, very accurate synchronization of base station clocks and a dense base station infrastructure.

Cost

Pinpoint reports a target price of \$300 or less for vehicle-mounted transceivers.

MobileVision
1225 Broken Sound Parkway NW
Suite E
Boca Raton, FL 33487
Telephone: (407) 241-7375
Fax: (407) 241-7366

Background and Status

MobileVision was originally a joint development of METS and Ameritech. In 1992, METS took over development of the MobileVision system.

MobileVision, like other AVM-band systems, provides for vehicle location and data messaging. The system also provides for voice communications.

METS plans to deploy the MobileVision system initially in Chicago, Washington, D.C., Dallas and Los Angeles. Roll-out into these cities is contingent upon receipt of financing.

Targeted applications for MobileVision include fleet management, emergency notification, stolen vehicle recovery and other IVHS services.

Projected hardware and service cost information was not provided.