GLOBAL POSITIONING SYSTEM SERVICE

This document describes various aspects of the Global Positioning System (GPS). It provides only a "snapshot" of GPS service today, recognizing that technology is evolving and industry is introducing new services and capabilities at a rapid pace. This document is not intended to reflect a government position or endorse a particular terminal vendor or service. Rather, it is provided to offer broad industry information on GPS. We invite comments to ensure that the most current information is included in our analyses.

If you have comments regarding the information contained in this document, please contact the Public Safety Wireless Network (PSWN) Program Management Office (PMO) at 800-565-PSWN or access the PSWN Program Home Page at: www.pswn.gov.

Public safety agencies rely heavily on their land mobile radio (LMR) networks for communications and coordination within and among organizations. In the past few years, commercial services such as cellular, paging, and global positioning services (GPS) have provided powerful capabilities that complement existing public safety networks. It is important that public safety communities carefully evaluate, assess, and maintain current information on the expanding commercial wireless marketplace. This allows informed, objective assessments that will ultimately meet mission requirements.

The Start of Satellite Positioning

Satellite navigation has been used for many years by a variety of industries and government for communications and positioning. One of these satellite systems, Global Positioning System (GPS), provides precise satellite-based location and position information to civilian users. Developed by the Department of Defense (DoD), GPS' main goal was to serve military agencies, however GPS is used today by a variety of commercial users including civil aviation, trucking companies, construction firms, and mobile phone networks. This report describes GPS, discuses some of the key performance characteristics, provides sample costs, and discusses the benefits and limitations of GPS services to meet the needs of mobile customers.

What Is GPS Service?

GPS is a satellite-based navigation service that allows users to locate their position, and in some cases their moving velocity (for GPS, velocity refers to both direction and speed). Using a GPS terminal (GPS terminals are receive only – they do not transmit to other terminals or the GPS satellite), users can identify their three-dimensional position (latitude, longitude, and altitude), velocity, and time with precision and accuracy anywhere on Earth.

GPS navigation is accomplished using "triangulation" in which a user's GPS terminal receives signals from at least three GPS satellites. The satellites continuously transmit

information that includes both the satellite's position in relation to the Earth and the time. The terminal measures and compares the distance from the three satellites at a single point in time. An artist rendering of this process shown in Exhibit 1.

Three satellites are needed to derive position information; however, a fourth satellite is needed to derive velocity information. To do this, the fourth satellite compensates for the time difference between the terminals and the satellite system.

There are three basic types of GPS terminals: single processing, parallel processing, and differential GPS (DGPS). Single and parallel processing refers to a handset's ability to only process a single GPS satellite's transmission signal at one time (single processing) or multiple signals at one time (parallel processing). DGPS refers to GPS services that are complemented by a terrestrial signal to improve navigation information accuracy. These services are referenced throughout this document.

The GPS Constellation

GPS is a Department of Defense (DoD) launched and owned 24-satellite constellation. The satellites are maintained in a polar, middle earth orbit – 12,200 miles from earth – to provide navigation services on a global basis.

Important GPS service considerations and definitions are illustrated in Exhibit 2.

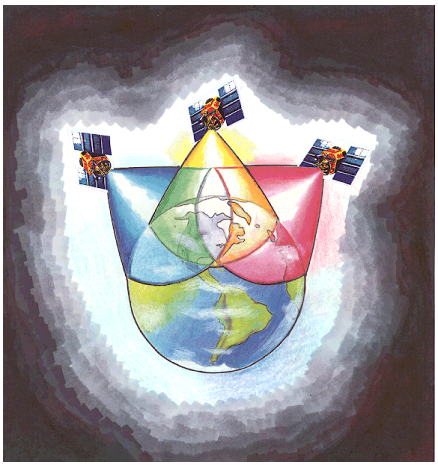

Exhibit 1
Rendering of the Coverage Provided by 3 of the 24 GPS Satellites

Availability	Identifies whether GPS service can be acquired by by the user
Coverage	Identifies whether GPS signals can reach users in a given area
Reliability	Identifies whether users can use GPS services during congestion or network disruption
Transmission Speed	Describes the end-to-end data speed, including positioning-determination time and transmission speed
Security	Describes the level of inherent security of the service and the capability to add security measures
Cost	Characterizes the costs typical of GPS terminals

Exhibit 2
Key GPS Technical Characteristics

Availability

GPS service is available to users, 24 hours a day, anywhere in the world. GPS provides two levels of service: Precise Positioning Service (PPS) for military use and Standard Positioning Service (SPS) for civilian use [1]. PPS is a highly accurate positioning, velocity, and timing service available only for national security organizations such as the U.S. military. SPS is a civilian service in which service accuracy is intentionally degraded by the DoD via intentional errors embedded in the signal. The DoD intentionally degrades SPS signal accuracy to protect national security interests.

This reduced accuracy, known as "selective availability", provides civilian users sufficient accuracy to track their location for applications such as vehicle location or hiking directions. Approximate GPS civilian selective availability accuracy is as follows:

- 100 meter horizontal accuracy
- 156 meter vertical accuracy
- 340 nanosecond time accuracy.

Additional accuracy for civilian users can be obtained through DGPS. DGPS uses a system of fixed, terrestrial transmitters that augment the GPS satellite signal. To do this, a DGPS terrestrial transmitter receives the satellite-generated SPS GPS signal, corrects the intentional error embedded in the signal using its own fixed location as a reference, and transmits error-correction information to subscribing users with DGPS-capable terminals. DGPS terminals then use the DGPS transmitted error-correction information to correct the received GPS signal. This provides users with accuracy to within 10 meters of actual location.

Coverage

GPS uses 24 satellites to provide service to users virtually anywhere on the globe. The GPS satellite system is designed to ensure that user terminals can receive signals from four satellites 95 percent of the time at any point on Earth [1].

More accurate DGPS service, however, is available only within the coverage area of the terrestrial DGPS transmitters broadcasting supplemental error-correction signals. The U.S. Coast Guard broadcasts DGPS signals along some coastal areas and waterways while subscription-based DGPS signal coverage depends on the service provider's broadcast area.

GPS radio signals can become degraded by moisture (such as rainfall, fog, or snowfall) or blocked by concrete, steel, or rock. As a result, positioning information can be difficult to obtain when the terminal is located in urban high-rise environments, dense vegetation, canyons, and inside buildings or automobiles. (An external antenna can be used for automobiles.) Users should match operations requirements of accuracy and GPS coverage to ensure that service is available when and where they need it.

Reliability

The GPS system consists of three components: the space segment, the control segment, and the user segment. User GPS terminals share the network infrastructure when making a position determination. However, unlike other commercial wireless services, GPS is not a two-way service (i.e., GPS terminals receive signals from satellites but do not transmit to the satellite). Thus, user congestion is not a concern as it is with other mobile wireless services like cellular telephony. If a terminal is unable to receive a signal from one of the needed satellites, it simply waits for the next transmission (seconds) to compute its exact location.

The GPS system components, however, are susceptible to system level service outages or individual satellite outages. Although rare, when a satellite malfunctions, the terminal may have to wait for an operational satellite to move into position overhead before calculating its position precisely again. Satellite outages will affect some GPS terminals more than others. Specifically, service outages will affect single-processing terminals; however, parallel multi-channel terminals can scan through up to 12 satellites simultaneously reducing the vulnerability to satellite outages. More detailed descriptions are presented later in this document.

Transmission Speed

Each satellite sends a basic data navigation message every 30 seconds. The average length of time it takes for the signal to propagate through the atmosphere and reach the terminal is approximately 70 milliseconds. This delay is unnoticeable to the user because a signal is waiting for position calculation as soon as the terminal is turned on.

Processing speed, on the other hand, can be noticeable if a terminal is unable to locate four

satellite signals quickly. GPS terminals (parallel multi-channel terminals) are available today that automatically scan for signals from up to 12 satellites simultaneously and use the four best signals to calculate its location – this reduces processing delay. Parallel multi-channel terminals are used for mission critical operations such as civil aviation that cannot tolerate positioning delay.

Privacy and Security

Because user terminals do not transmit any data to a satellite, a user's privacy is completely ensured. GPS signals are transmitted in the clear and can be received by any user with a GPS terminal.

User Equipment

The GPS user equipment consists only of a GPS terminal. GPS terminals are radio receivers that can be hand-held or installed on aircraft, ships, submarines, cars, and trucks. The terminals detect, decode, and process GPS satellite signaling information. Terminals vary in cost, size, ruggedness, output interface, accuracy, and their ability to overcome adverse signal conditions.

There are three types of GPS terminals, sequential single-channel units, parallel multi-channel units, and DGPS-ready units. Sequential units can only receive a timing signal from one satellite at a time using a single channel. Thus, they scan sequentially through all the possible satellites and risk losing signal lock as they switch channels. This slows down the positioning process and limits accuracy. Parallel multi-channel GPS terminals are capable of simultaneously receiving transmissions from between four and 12 satellites – improving service reliability and reducing processing time. DGPS-ready units allow users to take advantage of DGPS services to improve service precision.

GPS terminals can interface with computers to download data, interconnect with modems, and provide on-screen and computer mapping features. Some GPS terminals provide terminal-based displays for positioning information and can overlay position information on a mapping system. Some even provide the capability to output location information to a computer through a modem. For example, vehicular GPS terminals can be connected to an on-board wireless data device such as an LMR radio or cellular transceiver to send the real-time vehicle location data to a dispatcher or computer-aided dispatch station.

Key factors when purchasing GPS terminals include functionality, device ruggedness, ease of use, battery life, storage capability, display quality, warranty, DGPS capability, and cost. Two representative GPS terminals are pictured in Exhibit 3.

Garmin GPS 38

Eagle View Gimbal-Mount

Exhibit 3
Examples of GPS Terminals

GPS from a Network Level Perspective

Within the GPS space segment, the satellites are positioned so that six to nine satellites will be in view at nearly all times to any user on the globe. However, for position determination, only four separate satellites are required to calculate a user's longitude, latitude, altitude, and velocity.

The GPS control segment is responsible for monitoring and operating the GPS. It consists of a master control station located in Colorado, with five monitor stations and four ground antennas located throughout the world as illustrated in Exhibit 4. The monitor stations continuously track all GPS satellites in view and collect ranging data from the satellite broadcasts. The ranging information is transmitted to the master control station, which computes precise satellite orbits and updates each satellite's navigational message. The updated information is transmitted to each satellite via the ground antennas. New navigation information, calculated from the monitored data, can be uploaded to the satellites several times per day.

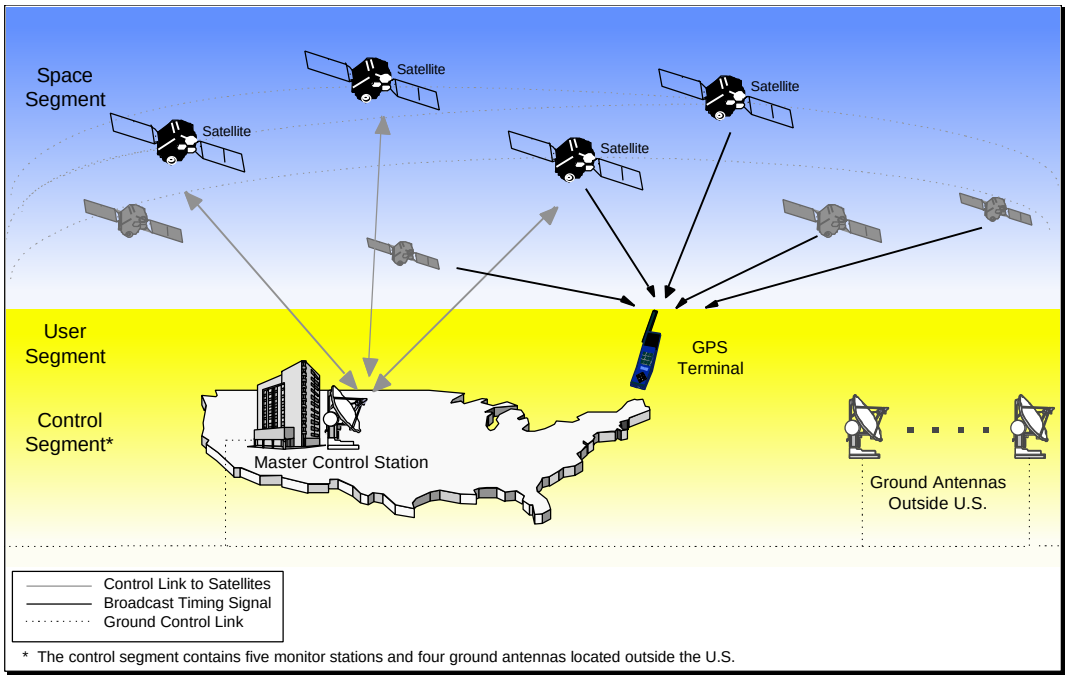

Exhibit 4
GPS Architecture

GPS Costs

Unlike other commercial services, GPS users receive the GPS service for free; however, DGPS users need to pay a yearly subscription, typical costs are $75 - $600 per year. Users do need to buy the terminal; terminals are available from over 150 different vendors. Low-end sequential single-channel terminals cost between $150 and $300. High-end parallel multi-channel GPS terminals with DGPS capability can cost as much as $1000. Exhibit 5 lists the costs and capabilities of a sample set of SPS-capable GPS terminals. Additional terminal features, such as built-in advanced mapping features, computer controllability, and external antennas are available at additional cost on high-end units.

	SELECTED GPS TERMINALS						
Feature	**Garmin GPS 12XL**	**Eagle Explorer**	**Eagle AccuMap Sport**	**Eagle AccuMap 12**	**Eagle Expedition**	**Eagle View Gimbal Mount**	**Garmin GPS 38**
Approx Retail Cost	$250	$160	$500	$625	$200	$325	$230
Style	Handheld	Handheld	Handheld	Handheld	Handheld	Mobile	Handheld
Power	Batteries	Batteries/Auto 12V	Batteries/Auto 12V	Batteries/Auto 12V	Batteries/Auto 12V	Vehicle Power	Batteries/Auto 12V
External Ant Connection	Yes	No	Yes	Yes	No	Yes	No
Position Point Storage	500	750	1250	1250	750+	750	250
Number of Channels	12-channel	12-channel	5-channel	12-channel	12-channel	12-channel	8-channel
Computer Controllabilty	No	Yes	No	No	Yes	No	No
Built-in Software			Mapping	Mapping		Mapping	
DGPS Ready	Yes	Yes	Yes	Yes	No	Yes	Yes

Exhibit 5
Sample GPS Terminal Cost and Capabilities

GPS Considerations

Users must carefully consider their operational requirements and the services that may satisfy those requirements. Exhibit 6 describes some considerations in selecting GPS terminals and services. Remember that GPS terminal costs, service packages, and billing structures vary by manufacturer and type of features; DGPS services result in annual subscription costs. Before acquiring GPS services, potential users may choose to employ the checklist in Exhibit 6 to assist in determining whether GPS services meet their needs.

GPS Considerations

- **Cost—** GPS does not charge a usage fee. When a GPS terminal is purchased, users can use the service as often or as rarely as they need without incurring any additional costs. The large number of terminal manufacturers and models has reduced unit prices to as low as $150 for mass market applications.
- **Coverage —** Using a constellation of 24 satellites located over the globe, GPS terminals can provide positioning information on the ground, in the air, and over the water worldwide.
- **Mobility —** GPS terminals are available in handheld, battery operated, and vehicular models that are compact and lightweight - conducive to mobility.
- **Interface Capability —** Many terminals can interface with computers, communications devices, and associated software. Through built-in links to computers, terminals can download information to mapping software or modems, facilitating further processing of real-time or stored position data.
- **Line-of-Sight Requirement —** Because GPS terminals require seeing four satellites simultaneously to produce a measurement, its accuracy and reliability can be degraded by shadowing in urban areas, dense foliage, and canyons. Furthermore, moisture in the atmosphere such as during snowstorms and in dense fog can limit GPS accuracy unless custom capabilities are implemented to ensure accuracy.
- **Limited Civilian Accuracy —** The U.S. Government has limited the accuracy of GPS available to civilian users to about 100 meters. Applications that require greater accuracy will have to use DGPS receivers. However, DGPS is not available worldwide and varies widely in its cost and accuracy.

Exhibit 6
Benefits and Limitations of GPS Service

GPS CHECKLIST

- Do I need GPS service?
- Where do I need GPS service? Locally? Regionally? Nationally?
- Will GPS work in my operational environment?
- How much does the terminal cost?
- Is the terminal single-channel or multi-channel capable? How many channels can it scan in parallel?
- What accuracy is specified for this terminal?
- What power requirements does the terminal have?
- How much storage capacity is available?
- Are attachments available for in-vehicle use? Can an external antenna be used?
- Can the terminal be used with a personal computer in real-time mode? What additional software is required?
- What additional cables are necessary to link the terminal to a computer?
- What software is preprogrammed into the terminal?
- What internal mapping features or Geographic Information System capabilities does the terminal have?
- Is additional hardware or software required to use DGPS with this terminal?
- What type of service and pricing plans does the DGPS provider offer?
- What is the coverage area of the DGPS service provider?

Exhibit 7

User Checklist of Questions to Better Understand GPS Service

APPENDIX A
LIST OF ACRONYMS

DGPS	Differential Global Positioning System
DoD	Department of Defense
GPS	Global Positioning System
LMR	Land Mobile Radio
PMO	Program Management Office
PPS	Precise Positioning Service
PSWN	Public Safety Wireless Network
SPS	Standard Positioning Service

APPENDIX B
REFERENCES

1. Signals from four satellites visible 95 percent of the time on Earth.
Nakamura, Karen, "Feeling Lost? An Overview of Global Positioning Systems." (1997). Obtained from *WirelessNOW GlobalUpdate Listserve:* http://www.commnow.com

APPENDIX B
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