GPS III System Operations Concepts

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ABSTRACT

Over the past three years, the Lockheed Martin GPS III team has analyzed potential operational concepts for the Air Force. The completed tasks support the government's objective of a *"realizable and operationally feasible"* US Strategic Command (USSTRATCOM) and Air Force Space Command (AFSPC) concept of operations. This paper provides an overview of the operational improvements for the command and control of satellites, the provision of safe, precise navigation and timing services to end-users.

The GPS III system changes existing operational paradigms. Improved operator capabilities are enabled by a new high-speed uplink/downlink and crosslink communication architecture. Continuous connectivity allows operators a *"contact one satellite – contact all satellites"* concept enabling near-real-time navigation updates and telemetry monitoring. This paper describes potential improvements for the following operations:

- **Constellation Monitoring,**
- **Command and Control,**
- **Navigation Upload Monitoring,**
- **Global Service Monitoring,**
- **Global Service Prediction,**
- **Civilian Navigation (CNAV) Messaging, and**
- **Anomaly Detection and Resolution.**

This paper also describes future operational improvements as GPS applications continue to proliferate and the need for an improved infrastructure to effectively manage all the systems that affect GPS service grows.

The views expressed in this paper are those of the authors and do not reflect the official policy or position of the GPS Joint Program Office (JPO), Air Force Space Command (AFSPC), the United States Air Force, the Department of Defense, or the US Government.

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INTRODUCTION

The Global Positioning System (GPS) is the world's premier satellite-based Position, Velocity, and Timing (PVT) information system. GPS is comprised of three segments:

- the Space Segment,
- the User Segment, and
- the Control Segment.

Figure 1 illustrates the high-level interfaces between the segments.

Space Segment

The Space Segment (SS) is comprised of all operational GPS satellite vehicles (SV) in orbit. The SVs accept uplinked commands and uploads from the Control Segment; downlink telemetry to the Control Segment; crosslink commands, uploads, and telemetry within the Space Segment; and downlink ranging codes and navigation data to the User Segment.

User Segment

The User Segment (US) is comprised of anyone with a properly equipped GPS receiver set. Traditionally, the User Segment interaction with GPS has been via passive reception of ranging codes and navigation data from the Space Segment. This paper will discuss some of the ways the GPS will evolve to offer more active interfaces for the user.

Control Segment

The Control Segment (CS) provides for the command, control, communications, and monitoring of the GPS space segment. The CS is comprised of the Operational Control

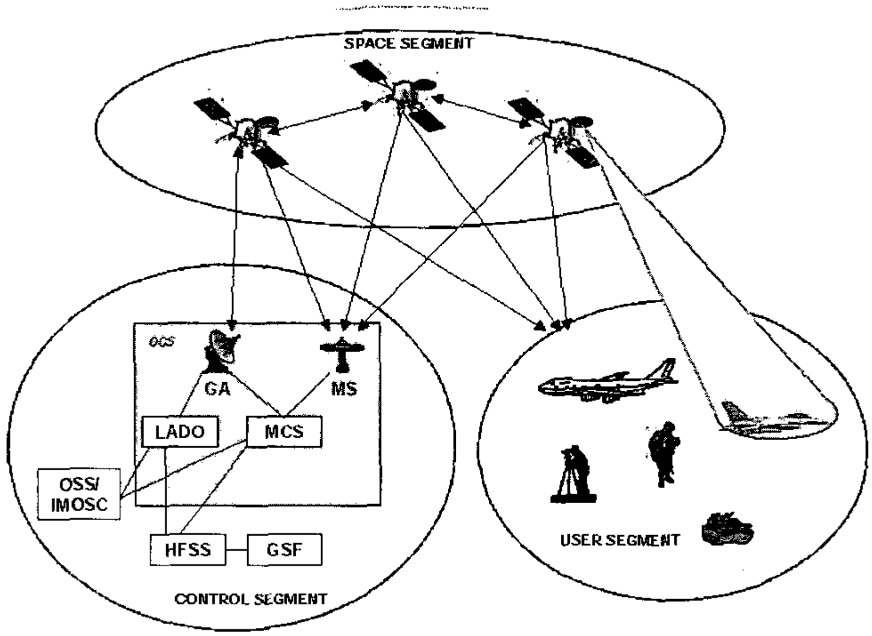

Fig. 1. Overview of GPS Segments

System (OCS), the Operational Support System-Integrated Mission Operations Support Center (OSS-IMOSC), the High Fidelity System Simulator (HFSS), and the GPS Support Facility (GSF). The OCS is further decomposed into additional elements including the Master Control Station (MCS); the Launch, Anomaly Resolution, and Disposal Operations (LADO) facility; the Ground Antenna (GA) network; and the Monitor Station (MS) network. The MCS and LADO have alternate locations to ensure system survivability. These elements, referred to as the AMCS and ALADO, respectively, provide the Air Force with additional operational flexibility.

The current constellation of GPS satellites consists of several different models, or "block" types, each with increased capability and additional features designed to improve end user service and system operations and maintainability. The Block II and IIA satellites were built by Rockwell International and were launched between 1989 and 1997. The Block IIR satellites were built by General Electric (now Lockheed Martin) and are in the process of being launched for constellation sustainment. The first Block IIR was launched in 1997 and eight are now currently in service. As many as eight IIR satellites will be upgraded to include the new military code (M-code) and a second civilian signal, and will be redesignated IIR-Modernized, or Block IIR-M. The Block IIF satellites are scheduled for first launch in 2006. The Block IIF will have all the capabilities of the IIR-M and will add a third civilian safety-of-life signal on L5.

In May 2000, the Air Force announced plans to pursue the next generation of GPS, designated GPS III. GPS III will provide improvements to the Space Segment and Control Segment to *"assure reliable and secure delivery of enhanced position, velocity, and timing signals to serve the evolving needs of military and civil users. GPS III will look at the entire GPS Architecture to achieve long-term GPS performance goals while managing long-term total ownership costs [1]."*

The first formal GPS III work came under the System Architecture and Requirements Definition (SARD) phase from October 2000 to October 2001. As one of the two competitively selected contractors for the SARD phase, Lockheed Martin conducted extensive GPS mission analysis to develop some preliminary operations concepts. Then from April 2002 to November 2002, the Lockheed Martin team participated in the Requirements Analysis Study, and worked shoulder-to-shoulder with United States Strategic Command (USSTRATCOM) and Air Force Space Command (AFSPC) to mature and document GPS III Systems Operations Concepts.

As part of the GPS III effort, Lockheed Martin has developed and refined an extensive set of engineering tools used to document and visualize these emerging operations concepts. Software simulators allow both developers and customers to quickly assess various operations techniques and to show traceability to architecture components and requirements. Control Segment operations are the epicenter for GPS service delivery, so new tools and software applications have been prototyped to illustrate various concepts. The Integrated GPS Simulator (I-GPSS), used to evaluate accuracy availability, dilutions of precision, and satellite outage probabilities, is just one example of the types of tools developed to hone these evolving operations concepts [2].

OVERVIEW OF CURRENT GPS OPERATIONS

The term *"GPS operations"* can be interpreted on a number of different levels depending on one's perspective. For the purposes of this paper, *"GPS operations"* will be loosely split into two categories: AFSPC operations, and L-band user operations.

AFSPC Operations

This category describes the viewpoint of the men and women within theAFSPC charged with the daily operations of the GPS Space and Control Segments. These operations are conducted 24 hours a day, seven days a week by personnel from the 2nd Space Operations Squadron (2 SOPS) and its reserve component, 19 SOPS, at Schriever Air Force Base (SAFB) near Colorado Springs, Colorado. Each operations flight is composed of a Flight Commander, a Flight Chief, and five system "specialists." The Satellite Vehicle Operator (SVO) is responsible for monitoring satellite telemetry to assess the health and safety of the various subsystems. The Payload System Operator (PSO) is responsible for monitoring the L-band signal and assessing current navigation performance via range measurements taken from the monitor station network. The Ground System Operator (GSO) monitors all the communications circuits between the MCS and the GA and MS networks. Two Satellite System Operators (SSO) are responsible for establishing S-band contacts between the GA and SV and transmitting all required commands and uploads. These seven-member operations flights are composed of enlisted and commissioned Air Force space operators with technical support from in-house analysis shops and a variety of contractors [3].

Operations within 2 SOPS and 19 SOPS have evolved over the years to take advantage of innovative techniques, tactics, and procedures designed to streamline operator actions without sacrificing checks and balances to ensure satellite safety and mission effectiveness. Nevertheless, limitations within the current architecture necessarily dictate that many operator activities are manually executed. A significant amount of the operators' time is spent establishing unique S-band contacts between a single GA and a single satellite in order to accomplish the required support activities. These satellite support activities include telemetry monitoring, configuration commanding, and navigation data uploads. 2 SOPS and 19 SOPS may conduct anywhere from 60-100 satellite contacts in a 24-hour period. Daily averages are typically 70 supports per day. Scheduling and executing these contacts is a significant operational burden.

A typical *"day in the life"* of today's operations flight consists of 20-25 supports in an 8-hour shift. At the beginning of each support, the GSO manually verifies that communication lines between the MCS and the selected GA are up and functioning. The SSO runs a series of software scripts to establish a line-of-sight S-band contact between the selected GA and satellite. Once contact is made, the satellite telemetry stream is automatically parsed and displayed with the appropriate calibration parameters and units on a series of displays in the MCS. The SSO and SVO manually review up to 15 different computer displays to verify subsystem health and performance. Following the state-of-health, most supports include a data download (dump) of the Nuclear Detonation (NUDET) Detection System (NDS) payload for subsequent analysis. Once the NDS data dump is complete, the PSO runs a script to generate a new navigation upload to provide the most current ephemeris and clock predictions, constellation almanac, and other related parameters for L-band broadcast. The SSO transmits the navigation upload to the satellite, concluding the support requirements for a typical contact. The S-band connection is dropped and the GA returns to its pre-contact state. A typical support like the one described herein takes approximately 30-45 minutes.

Some support activities, such as satellite commanding or data dumps, are time critical and must be accomplished within a specific window. These constraints add some complexity to the contact scheduling process. A separate section within the 2 SOPS is responsible for planning a day's worth of contact activities, using software programs to ensure satellite support requirements are met within the allotted time. Unplanned constraints, however, such as the loss of communication to a remote GA site, often necessitate real-time shuffling of the contact schedule. This real-time shuffling is a manual process, often complicated by line-of-sight visibility times between a GA and the target satellite.

One of the overarching goals of the Lockheed Martin GPS III operations concept is to design a system that reduces the number of manual actions imposed on the operator. By limiting the amount of time MCS operators spend in the implementation of the system, we can transform those same

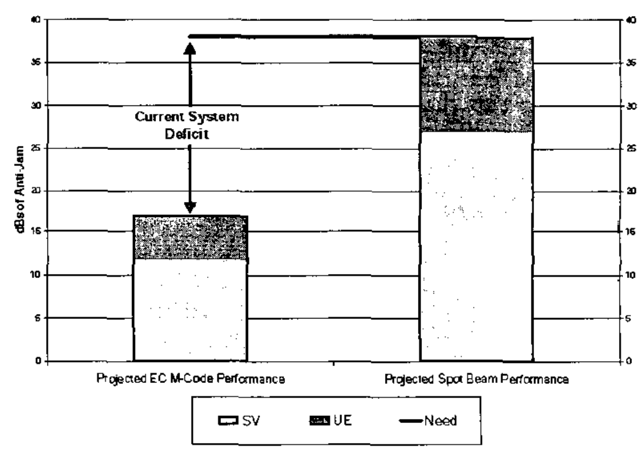

Fig. 2. GPS III Anti-Jam Improvements

operators into GPS mission managers. 2 SOPS and 19 SOPS can focus on the delivery of L-band services, concentrating on the quality of the signal and the accuracy of the positioning and timing product. The need for operations flight positions will remain, but the focus can shift to mission management and understanding how the actions of the OCS affect the end users of the system.

L-Band User Operations

This operations category describes the viewpoint of the individuals and systems that use the GPS broadcast information to accomplish a mission. This category includes users of both the Standard Positioning Service (SPS) and the Precise Positioning Service (PPS). During the SARD Study, Lockheed Martin examined over 270 user missions ranging

Table 1. GPS III Satellite Characteristics

Design Life	15 years
Orbit Altitude	10,898 nmi
Orbit Inclination	55°
Target Weight	3960 lbs
Launch Profile	Single or Dual Manifest
Launch Vehicle	EELV Atlas V or Delta IV
Payloads	Navigation, NDS
Broadcast Frequencies	L1, L2, L3, L4, L5, L6

from surveying to time transfer to delivering precision-guided munitions. The results of this analysis were used to help define the architecture that best meets the needs of these disparate missions.

Most L-band user operations have historically been passive in nature: GPS receiver equipment collects the broadcast ranging codes and messages for processing. The configuration of the broadcast has not been under user control. The modernization and GPS III programs, however, seek to change this paradigm and provide new taskable features, such as a high-power signal, in addition to the heritage service.

Other L-band user operations are manual in nature. For example, users of the PPS must manually load cryptographic material on a periodic basis to ensure access to the encrypted portions of the broadcast. Once again, the modernization and GPS III programs seek to improve the security of the PPS while reducing L-band user burden. Key management and distribution will evolve to significantly enhance PPS flexibility.

GPS III NEED

Air Force Space Command has documented shortcomings of the Block II-era GPS architecture that limit military, civilian, and commercial effectiveness. These shortcomings include signal accuracy, signal availability (anti-jam), integrity, signal monitoring, constellation configuration responsiveness, and signal security [4, 5]. As the value of GPS increases, the need to reduce or eliminate these shortcomings increases. GPS III seeks to address this need, providing a transformational architecture that will allow both AFSPC and L-band user operations to evolve to a more responsive system with improved mission insight and better system performance.

GPS III ARCHITECTURE

The GPS III architecture preserves the same three segments that exist today: Space Segment, Control Segment, and User Segment. Unique attributes of each are highlighted herein.

Space Segment

The GPS III satellites will be designed to meet a 15-year operational life. Spacecraft size and weight are an important design consideration because the Air Force has set a requirement for dual manifest launch. Table 1 provides some of the characteristics of the GPS III satellite.

In order to provide the Air Force with the most flexible launch profile, the system will be designed to launch into any orbital plane at any time of year. This includes deploying into either a 3-plane or a 6-plane configuration.

Building on the success of the Block IIR program, Block III satellite processors will be reprogrammable to provide maximum flexibility over the operating life. These flexible processors include the navigation and NDS payloads as well as the spacecraft bus processor. The bus processor will perform redundancy management (REDMAN) functions to autonomously execute time-critical hardware configurations to protect the safety of users and the spacecraft.

Yet another carry-over from the Block IIR program will be a no-maintenance Electrical Power Subsystem (EPS). Earlier block models require periodic battery reconditioning, but the Block IIR and Block III batteries are designed so that this additional operational burden is eliminated.

There are at least five unique features of the Block III satellite that distinguish it from previous GPS block types:

- High-speed telemetry, tracking, and commanding (TT&C) uplink and downlink
- High-speed, directional crosslink
- High-power NAVWAR spot beam antenna
- Integrity functionality
- Reserved space for additional hosted payloads.

The high-speed TT&C link will provide significantly increased capacity over today's data rates. All Block III models will continue to carry the heritage S-band hardware to ensure backwards compatibility with the Air Force Satellite Control Network (AFSCN). Coupling the high-speed TT&C link with high-bandwidth directional crosslinks, the GPS III Space Segment will create a network in space, providing continuous connectivity to all satellites, all the time.

GPS III seeks to provide assured access to GPS services in a stressed (i.e., jammed) environment [5]. Through modeling using the GPS Interference and Navigation Tool (GIANT), we have shown that users achieve equivalent unjammed performance accuracies in the presence of a jamming threat with about 38 dB of anti-jam. These *"38 dBs of anti-jam"* are achieved through a combination of: 1) boosted signal power from the satellite; and 2) user equipment (UE) antenna and processing improvements.

Block III satellites will provide directed, higher power Military-Unique (MU) signals for up to two specific areas of operation (AOO) in response to (1), above. The satellites will use a NAVWAR spot beam antenna to boost the MU signals. The remaining *"dBs of anti-jam"* will come from planned UE improvements such as updated antennas, electronics, and tracking techniques. Figure 2 illustrates the current shortcomings of ECM-code and shows how GPS III meets the military requirements for anti-jam improvements.

Integrity is the ability of the system to provide timely warnings to enable a user to determine when the system should not be used to support the mission or phase of operations. Integrity ensures that the user is notified of signal errors that could be hazardous or economically harmful [5]. The Block III incorporates this integrity functionality to provide greater user assurance.

The Block III satellites will provide additional weight and power margin to support auxiliary payloads [6].

Control Segment

The GPS III Control Segment will be designed to gradually evolve from Block II-era operations to Block III-era operations. This transition is critical to the continuity of current GPS services.

At the highest level, the GPS III architecture retains many of the heritage architectural features: the OCS, OSS-IMOSC, HFSS, and GSF all remain. Within the OCS, however, there are several GPS III-unique characteristics. Most notable will be the inclusion of the new high-speed ground antennas (HSGA). At least three HSGA sites, all located within the continental United States (CONUS), will be established. The CONUS location provides improved physical security and reduced maintenance and logistics costs. The MCS will maintain connectivity with all the existing GPS-dedicated S-band sites at Ascension Island, Diego Garcia, Kwajalein Atoll, and Cape Canaveral until the last Block II-era satellite is decommissioned. Air Force Satellite Control Network (AFSCN)-connectivity will be retained indefinitely for emergency backup, satellite launch and early orbit operations, anomaly resolution, and satellite disposal.

The monitor station network will be upgraded to measure and calibrate the high power NAVWAR spot beam. Additional L-band tracking sources will also be used by the MCS for expanded signal integrity monitoring.

The MCS itself will evolve to include new service level summary displays, improved telemetry trending and analysis capabilities, and operator-selectable automation levels. The MCS-to-AMCS connectivity infrastructure will be enhanced to provide better data synchronization for rapid deployment operations. There will be increased interaction with GPS information providers such as the US Coast Guard Navigation Center and the GPS Support Center.

Another architectural change in the Control Segment will be the continuing evolution of the interface between the PPS users and the MCS. This interface is currently in its infancy as the modernization and Selective Availability/Anti-Spoof Module (SAASM) programs introduce new taskable services. The GPS III spot beam will present additional complexity from a resource scheduling, loading, and deconfliction standpoint.

Table 2. GPS III Signal Improvements

	GPS II [7]			GPS III [6]			
	SPS		PPS	SPS*		PPS**	
Position Accuracy	Horiz	Vert	16 m SEP	Horiz	Vert	Horiz	Vert
(worst case threshold)	36 m	77 m		3.7 m	5.6 m	2.1 m	3.2 m
(global ave)	13 m	22 m	6 m	N/A***			

* Assumes "Good" UE and dual frequency
** Assumes "Best" UE and dual frequency
*** Global average not yet specified

The GPS Control Segment will act as the USSTRATCOM agent for evaluating spot beam requests, determining resource allocation, predicting service utility, assessing spot beam impact, executing the request, and evaluating spot beam performance.

In addition to these Block III-unique features, the new architecture will also continue to evolve some of the new modernization features like flexibility in the Military Navigation (MNAV) and Civilian Navigation (CNAV) messages. Continuous ground-to-space links will allow the Control Segment to rapidly configure and update these broadcast navigation messages.

User Segment

The objective of the GPS III program is to *"assure reliable and secure delivery of enhanced position, velocity, and timing signals to serve the evolving needs of military and civil users [1]."* The GPS III-unique features of most interest to users include improved signal performance, the new NAVWAR spot beam, flexible MNAV and CNAV messages, and the new integrity service. The GPS Joint Program Office serves as the lead integrator for these new capabilities.

Table 2 illustrates improvements of GPS III signal accuracy as compared to GPS II. The threshold values shown are for the worst-case location and assume 95% accuracy with service volume availability of 90% with the worst two satellites out. As shown, GPS III will provide significant user improvement.

The NAVWAR spot beam is a significant improvement to the User Segment architecture. Theater commanders will be given the ability to request higher signal power for their AOO. In order to achieve the anti-jam improvements shown earlier in Figure 2, PPS user equipment improvements are required. Coupled with the extra signal power from the spot beam antenna, users should be able to achieve benign-like tracking performance in a jammed environment.

The User Segment will also benefit from the new GPS III integrity service. This service provides signal performance and accuracy assurance.

The flexible MNAV and CNAV data message frames will reduce the length of time required to read the entire broadcast message. The age of data will be significantly reduced, improving positioning and timing accuracies. Furthermore, both messaging services can be expanded to include new message types as user requirements continue to evolve.

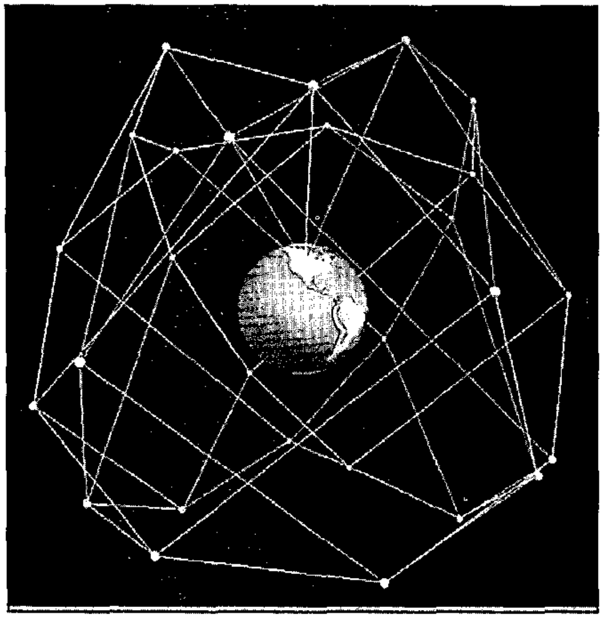

Fig. 3. Contact One-Contact All Concept

Collectively, the GPS III-unique features of the Space, Control, and User Segments enumerated above realize the vision of a rapid-response, real-time system focused on service delivery.

GPS III OPERATIONS CONCEPTS

As described earlier, defining operations concepts for the *GPS III* architecture requires presenting the perspectives of two distinct groups: the AFSPC operators charged with operating and maintaining the Space and Control Segments, and the end-users of the GPS service. The remainder of this paper will present a summary of the work the Lockheed Martin team has completed to date in researching, analyzing, and documenting these concepts.

AFSPC OPERATIONS

The high-speed uplinks, downlinks, and crosslinks revolutionize GPS satellite operations. Once a sufficient number of Block III satellites are on-orbit, the MCS will communicate with the Space Segment via one or more HSGA. A single HSGA will establish line-of-sight contact with a single Block III satellite as it rises over the horizon. This satellite will act as the conduit for all uplinked and downlinked information. Tied to the rest of the Block III constellation via the high-speed crosslinks, the MCS will be able to *"contact one satellite, contact all satellites,"* as shown in Figure 3. There will be at least three HSGAs to provide redundancy and enable a *"make before break"* operations concept – a new line-of-sight contact will be established with a rising SV before the existing contact is broken with an SV that is setting out of view. Automated planning software within the MCS will schedule these HSGA contacts to ensure continuous connectivity.

Constellation Monitoring

MCS personnel will have an ever-present TT&C link, providing continuous, real-time insight to telemetry from every SV. In today's operational environment, SV telemetry analysis is isolated to one or two contacts, totaling 45-90 minutes daily. In the GPS III era, there will be a continuous stream of telemetry. As incoming SV telemetry is received by the MCS, software routines will evaluate the telemetry, comparing it to the expected values contained within a series of vehicle-specific telemetry databases. These databases will contain not only expected values, but also the associated behavior characteristics for each telemetry point. Since MCS software routines will evaluate telemetry, identify out-of-limits conditions, and resolve minor discrepancies, screen-by-screen state-of-health assessments will no longer be required. Consequently, operator workload will be greatly reduced, because only critical alarms will be elevated for response.

In addition to the continuous SV telemetry, the constellation is also monitored via the network of Air Force and NIMA monitor stations that continuously feed data back to the MCS. The MCS L-band monitoring software will report any anomalous behavior to the operations flight, again reducing overall operator workload. Data from Air Force, NIMA, and potentially other sites feed into the Kalman filter and are used to update estimates for the ephemeris and clock states. These states are then used as the basis for the predictions that appear in the broadcast navigation messages.

Command and Control

The omnipresent TT&C link can also be used for command and control of the entire constellation. The *"contact one, contact all"* paradigm eliminates the restrictions imposed by line-of-sight visibility with a ground antenna. Now satellite configuration and data dumps can be performed at any point in time, ensuring that satellite support requirements are met, regardless of any constraining time windows.

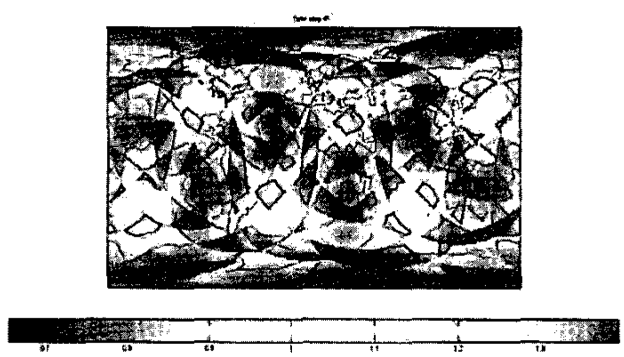

Fig. 4. Example Service Monitoring Display

Personnel within the MCS will maintain a Vehicle Support Requirements (VSR) database that defines all activities that must be performed to ensure proper SV bus and mission operations. This VSR database will contain a listing of each activity, how often the activity should be performed, how long the activity takes to complete, etc. The VSR database then serves as the primary input to the MCS automated scheduling function, Schedule Control. Once the initial database is populated with requirements, it need only be reviewed periodically (e.g., quarterly or even annually) to validate the support activities listed.

Schedule Control software within the MCS will produce a dynamic queue of time-tagged satellite support activities. These activities will be sequenced to ensure that all support requirements are successfully completed in accordance with the rules defined in the VSR. Each activity will be automatically initiated at the designated time with any exceptions reported to the operations flight. The operations flight can invoke manual mode at any time, but the system is designed to give operators the freedom to automate as much of the routine schedule as they desire, providing flexibility in training and transition concepts.

Upload Monitoring

The MCS processes monitor station ranging data and uses a Kalman filter to update satellite orbit and timing parameter estimates every 15 minutes. The current GPS operations concept involves using these Kalman filter estimates to make a prediction of satellite ephemeris and timing information approximately once per day. This prediction is formatted into an upload, transmitted to the satellite, and broadcast as the navigation message. Uploads are SV-specific and must be uploaded via a line-of-sight S-band contact with the target SV.

The GPS III Control Segment will not be limited to uploading each SV only once per day. Using the HSGA and high-speed directional crosslinks, the MCS will be able to uplink Kalman filter estimates more frequently, significantly reducing the constellation-wide age of data (AOD) from today's average of 12.5 hours. This reduced AOD will translate into improved timing and positioning accuracy.

Global Service Monitoring

The Block II-era Control Segment has limited tools in the following areas:

1. Viewing the current constellation performance
2. Assessing the impact of potential outages or actions
3. Utilizing the external inputs or requests to improve the quality of service.

The GPS III Control Segment will improve the operations toolbox in all of these areas. Displays of current system performance (and, notably, areas of weak performance) will be available in near real-time. An example of a global service monitoring display showing dilution of precision (DOP) metrics is given in Figure 4.

To help the operations flight be more aware of the global impact of either improvements or outages, displays will be provided that show the results of "what if" scenarios and provide pre-commitment information on the adverse or positive impacts of a course of action or failure. For example, the global service impact of setting a satellite unhealthy for maintenance at a particular time will be available. This can then be compared with other maintenance times to limit the impact in specific regions or areas.

The GPS III Control Segment will also benefit from increased interaction capabilities with both civil and military communities. This will eventually allow both an increase in information flow out of the OCS (e.g., service predictions and status changes) as well as an increase in information flow into the OCS (e.g., CNAV messaging inputs).

Global Service Prediction

In addition to reporting real-time performance, the MCS will also be equipped with software tools to perform service prediction. These products will be tailored to specific user need, taking into account differences in user equipment, operational environment, and services used (positioning vs. time transfer, SPS vs. PPS).

CNAV Messaging

The Civilian Navigation (CNAV) message provides a flexible data frame with Forward Error Correction (FEC) and a transmission rate of 25 bits per second. Within each 300-bit CNAV message is a 6-bit message identifier. At present, only message types 1-7 have been defined [8]. As civilian applications grow and new message types are defined, the GPS III capability to rapidly uplink and transmit CNAV messages may be exploited. This can be valuable for navigation service notifications including rapid notification of constellation health and configuration changes. MCS operators will be given an interface to add CNAV messages either manually or automatically based on pre-defined rules. A similar capability for military navigation (MNAV) messages will exist for MCS operators and authorized users.

Anomaly Detection and Resolution

Anomalies are unplanned events that may or may not affect system performance. Anomalies can affect one or more of the three GPS segments simultaneously. A major role of the on-duty operations flight is to detect anomalies as soon as they occur, protect L-band users from any affects, configure the affected component(s) to a "safe" condition, and resolve the anomaly.

The current Block II-era GPS architecture has developed an extensive set of techniques, tactics, and procedures for anomaly detection and resolution. Historical lessons learned will be carried forward and applied to the Block III system. For example, on-board satellite redundancy management – the ability for the spacecraft processor to detect out-of-limit conditions and autonomously resolve them – will be an inherent design feature for all future block types.

From an AFSPC operator perspective, anomaly detection will be significantly improved by virtue of the streaming, real-time telemetry input from all GPS III satellites. When the MCS telemetry analysis scripts detect an out-of-limits condition, automated software routines will assess the situation to determine the proper course of action. If the procedure requires operator intervention, an alarm will be sent to the appropriate operator position(s). On-line, hypertext-linked documentation and training material will further facilitate the anomaly investigation and proper resolution.

Table 3. Reference User Equipment Error (UEE) Assumptions

UE Class	Reference UEE (rms)
Good	0.75 m
Better	0.4 m
Best	0.11 m

The GPS III MCS will also support a variety of external interfaces that will assist with anomaly detection and resolution. Connectivity to the FAA and US Coast Guard Navigation Center will ensure that SPS anomalies are rapidly characterized and reported. Inputs from other agencies such as terrestrial and space weather services will be used to help establish root cause. Many anomalies are related to the type of user equipment and location of use, and this information will be centrally pooled to provide the most complete set of anomaly symptoms. Furthermore, anomaly details will be archived; in the event of similar conditions in the future, previous methods of resolution will be rapidly available to assist the MCS operators.

Spot Beam Operations

Certainly the most unique GPS III operations concepts deal with the employment of the new NAVWAR spot beam service. The architecture is designed to provide all stakeholders with the requisite information to make decisions about when, where, and how to provide a high-power spot beam. The system provides the tools to determine need, benefit, and impact of use, and leverages the high-speed links to rapidly configure the NAVWAR antenna and monitor its performance.

L-BAND USER OPERATIONS

One of the cornerstones of the GPS III program is to preserve backwards compatibility with all existing GPS services. Ideally this means that L-band users will not have to worry about whether the L-band signal is coming from the oldest Block II satellite or the newest Block III in the constellation. The design, manufacture, test, and operation of the GPS III architecture will ensure that this requirement is met.

To only focus on backwards compatibility, however, is to miss a number of opportunities that GPS III brings to the L-band user. Some of those advantages, as well as any changes to L-band user operations concepts, are presented here.

Table 4. Terrestrial Service Volume Accuracy Requirements

	Good	Better	Best
Horizontal	3.7 m	2.7 m	2.1 m
Vertical	5.6 m	4.0 m	3.2 m
Time Transfer	13.3 ns	9.4 ns	7.5 ns

Better Accuracy

User accuracy metrics are a function of not only the GPS signal in space, but also the user equipment (UE). The GPS III Draft System Specification defines three classes of user equipment termed "Good," "Better," and "Best" as shown in Table 3 [6].

Using these assumptions, Table 4 provides the Block III threshold requirements for terrestrial service volume accuracy based on each of the three UE classes [6].

In order to take maximum advantage of GPS III accuracy, users should acquire and track in a dual frequency mode. More frequent uploads will lower the age of data, and flexible MNAV and CNAV messaging will provide more timely ephemeris and clock updates. As a result, user equipment should "read" the broadcast navigation message more frequently than just at the top of every hour.

Taskable Services

GPS III provides a new taskable service (spot beam) and significant enhancements to the modernized taskable services of flexible navigation messaging and cryptographic key management. Military users will be able to interact with the Control Segment to request specific GPS services. Once these services have been requested and implemented, the user equipment logic will need to determine things like when and how to look for the spot beam signal instead of the lower power earth-coverage signal.

EVOLVING OPERATIONS

GPS applications continue to proliferate, and AFSPC and L-band user operations continue to adapt accordingly. In addition to the GPS III-specific concepts presented in this paper, there are several other efforts underway that seek to transform GPS operations.

AFSPC has drafted a vision for an expanded operational infrastructure that will combine the existing architecture with additional expertise and information centers. This single "effects-based" center is tentatively called the GPS Operations Center (GOC) and will be manned by representatives from across the Department of Defense, Department of Transportation, and allied military forces [9]. The GPS III architecture design contains sufficient flexibility to seamlessly fit into the GOC concept, gradually evolving to provide expanded capabilities while preserving backwards compatibility.

As these concepts evolve, the focus remains on developing systems that give operators and users real-time access to the most important information used to make critical decisions. For the AFSPC operators, those decisions relate to satellite health, safety, and configuration. For L-band users, those decisions relate to how good the positioning and timing service is now and what its predicted performance will be in the future.

CONCLUSION

The GPS III system offers significant operational advantages to both the AFSPC operators of the Space and Control Segment as well as the L-band users within the User Segment. The *"contact one, contact all"* paradigm improves system responsiveness and flexibility. A number of GPS III features will translate into better positioning and timing performance for all users. The NAVWAR spot beam antenna provides the military with improved anti-jam to preserve their use of GPS in a hostile environment. Improved MCS displays and new software tools will transform satellite operators into GPS mission managers. Lockheed Martin will continue to work side-by-side with Air Force and civilian agencies to ensure that GPS operations in the future remain focused on the end user mission accomplishment.

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