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# Next Generation Differential GPS Architecture

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# Next Generation Differential GPS Architecture

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Mr. David Wolfe is the Senior Engineer & Project Manger for the Nationwide & Maritime Differential GPS and Short Range Aids to Navigation projects at C2CEN, the US Coast Guard's primary engineering facility for land-based navigation systems. He is an active member of the Radio Technical Commission for Maritime Services (RTCM) Special Committee 104 (SC-104) for Maritime Differential GPS; International Electro technical Commission (IEC), Technical Committee 80, working group 4A for GNSS and DGNSS receiver standards; and the International Association of Lighthouse Administrations (IALA) radio navigation committee. He earned his BSEE from Drexel University in 1990. Mr. Wolfe is a member of the Institute of Navigation council as Marine Representative.

Mr. Mike Parsons is a 23-year veteran of Coast Guard radio navigation systems support and engineering. He is currently assigned to the land-based systems hardware engineering section at the Coast Guard Command and Control Engineering Center in Portsmouth, VA.

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Mr. Kendall Ferguson is a graduate of George Mason University with a B.S. in Computer Science. He has over 20 years experience in GPS Software development, real-time operating system use & development, and real-time software development. During his employment in DoD related contracting, Mr. Ferguson expertise was a key member in the development of the real-time, safety critical, launch control systems of the Tomahawk & Harpoon missile systems. While employed at Ashtech (1988-1992), he was responsible for the development of Ashtech's GPS post-processing software, support software, and other innovative GPS software. At The XYZs of GPS, Inc., Mr. Ferguson leads the development of the company's real-time GPS capabilities and other GPS software. Currently, he is the XYZs lead engineer on the NDGPS Architecture Modernization and the FHWA/USCG High Accuracy-NDGPS projects.

Mr. Michael Albright is a graduate of Bridgewater College with a B.S in Computer Science. His past experiences at Datatel Inc. include GUI, database, and network application development. He is currently a software engineering consultant and has provided these services to The XYZs' of GPS, Inc. for the past three years.

## ABSTRACT

The United States Coast Guard is engaged in a project to re-capitalize Reference Station (RS) and Integrity Monitor (IM) equipment used in the Nationwide Differential Global Position System (NDGPS). The Coast Guard in partnership with industry is developing a new software application to run on an open

architecture platform as a replacement for legacy equipment. Present commercially available off-the-shelf Differential Global Positioning System (DGPS) RS and IM equipment lacks the open architecture required to support long term goals and future system improvements. The utility of the proposed new hardware architecture and software application is impressive - nearly every aspect of performance and supportability significantly exceeds that of the legacy archetecture. The flexibility of the new hardware and software architectures complement each other to offer promising possibilities for the future. For example, the new hardware architecture uses Ethernet for internal and external site equipment communications. Each Local Area Network (LAN) will be equiped with a router and two 24 port switches. Various levels of password protection are provided to manage security both locally and remotely. While the new software application directly supports the legacy RS-232/422 interfaces to devices such as GPS receivers, a system design goal includes the ability to directly address each device from NCS. With the use of TCP/IP to RS-232/422 port server devices, the system can meet these forward reaching goals while supporting legacy equipment. New system capabilities include remote software management, remote hardware configuration management, and flexible options for management of licenses.

The new configurable RS and IM architecture is a PC-based emulation of legacy reference station and integrity monitor equipment. It supports fluid growth and exploitation of new signals, formats, and technology as they become available, while remaining backward compatible with legacy architecture and user equipment. Examples of new capabilities include enhanced data management & anomaly analysis, universal "On Change" Reference Station Integrity Monitor (RSIM) message scheduling, improved satellite clock handling, additional observation interval modes, and Range Rate Correction monitoring in the IM. Engineering initiatives under development such as implementation of pre-broadcast integrity are also presented.

This paper details challenges and goals that drove software and hardware design approaches destined to become the backbone of the Next Generation Differential GPS Architecture. Functional differences between legacy and next generation operation are explored. The new DGPS system architecture Will allow the USCG radiobeacon system to continue to deliver and improve navigation and positioning services to our nation and its territories.

## INTRODUCTION

The U.S. Coast Guard is part of a team implementing the world's largest ground-based GPS augmentation service [1]. The original mission of the DGPS service was to provide coverage for all harbor and harbor approach waterways throughout the Unites States [2] [3] [13]. To meet this requirement, the maritime DGPS broadcast network was built. The Maritime DGPS system provides differential corrections along the Atlantic, Pacific, Gulf Coasts, Great lakes, Hawaii, Puerto Rico and the southern Coast of Alaska. An agreement with the U.S. Army Corps of Engineers expanded Maritime DGPS coverage to the inland river system. As the numbers of DGPS users increased, so did demand for coverage. Later a team made up of Federal Highway Administration (FHWA), Federal Railroad Administration (FRA), US Coast Guard (USCG), and other agencies was assembled to sponsor implementation of a Nationwide DGPS (NDGPS) system so as to expand traditional coastal services to the interior of our nation. The Coast Guard was designated as the primary agency responsible for system maintenance and engineering. The NDGPS expansion primarily includes building additional broadcast sites and development of a Nationwide Control Station (NCS).

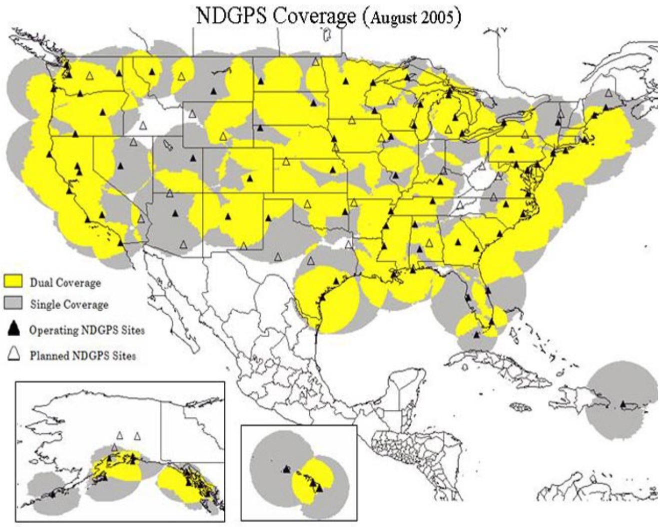

**Figure 1**

The 87 broadcast sites currently contained in the NDGPS system provide nearly 100% system wide coverage (Figure 1). Beacon site equipment configurations differentiated by transmitter type:

- (V1): Southern Avionics Corp. (SAC) transmitter with battery backup
- (V2): SAC transmitter with a generator backup
- (V3): RCA transmitter with generator backup

There are two operational Control Stations (CS) located in Alexandria, VA & Petaluma, CA. plus a support & engineering baseline located at C2CEN in Portsmouth, VA. Each CS has the ability to manage up to 200 remote broadcast sites and provides 45 days of performance data storage. Coast Guard personnel operate these Control

Stations continuously, tracking performance and responding to equipment and communications casualties.

In addition to supporting safety of life navigation, the NDGPS system participates in other infrastructure projects. All NDGPS sites provide GPS measurements to the National Geodetic Survey's (NGS) network of Continuous Operating Reference Stations (CORS) used for precise positioning and to the National Oceanic & Atmospheric Administration's (NOAA) Forecast Systems Laboratory (FSL) where these data are used to drive national weather prediction models [1] [6]. Several NDGPS sites have stable concrete High Accuracy Monuments (HAM) allowing data sent to NGS to be monitored for tectonic plate movement [1].

C2CEN's NDGPS Integrated Product Team (IPT) is working diligently to increase NDGPS system performance and value. This paper presents those efforts.

## NEXT GENERATION ARCHITECTURE

The next generation DGPS architecture was designed to ensure that replacement hardware and software would support continuous improvement geared toward users with ever escalating performance needs while maintaining traditional services. The architecture is designed so that future, higher performance safety-of-life navigation applications can be introduced in stages. To achieve this, the engineering team has adopted flexible system architecture as a design goal.

The engineering team invited industry, academia, and fellow government agencies to participate in several symposia where participants sifted through "best practices" to chart a course for the next generation project [12]. Among the participating government, industry, and academic leaders there was basic agreement that Ground Based Augmentation Systems (GBAS) provide a robust means of data delivery for differential GPS.

System level requirements for the next generation DGPS architecture are based on the US Coast Guard DGPS Broadcast Standard [3], the RTCM SC-104 standard [7] [8], and the Federal Navigation Plan [2]. They include the following:

- The design must be easily evolved into a higher accuracy positioning system
- The architecture should be compatible with new mission requirements as they emerge
- No aspect of legacy system performance may be compromised
- Hardware and software should be Commercial Off The Shelf (COTS) products
- Non-RTCM devices should have native HTML interfaces accessible via the WAN
- Devices must support remote operation, configuration, and diagnostics
- Devices must support remote firmware/software patches and upgrades
- The identification of techniques to eliminate Hazardous or Misleading Information (HMI)
- Data Capture during communications outages
- Increase operator casualty recovery options
- GPS antenna performance improvements
- Lower overall acquisition and support costs

These requirements are intended to maximize performance while reducing recurring support cost and are expected to allow efficient remote management of broadcast sites with minimum technician call-out.

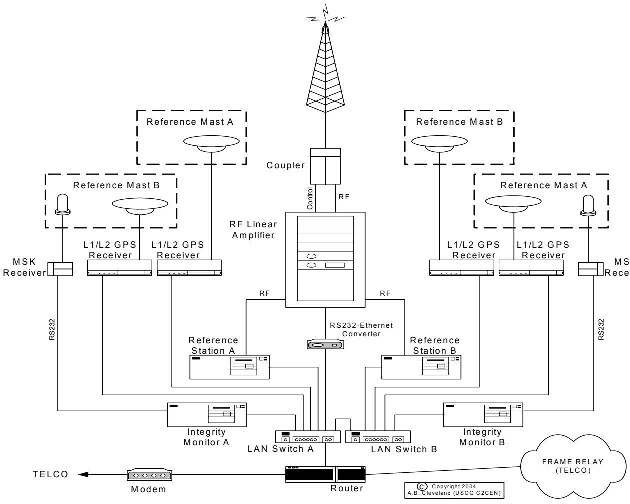

**Figure 2**

The next generation DGPS architecture (Figure 2) employs server grade personal computers, a new DGPS software application, OEM beacon receivers, and OEM geodetic GPS receivers communicating over an Ethernet. It has been tested in two configurations:

- Version 1.0: Legacy GPS receivers communicating with the DGPS application on serial RS-232 data channels
- Version 1.1: New geodetic grade OEM GPS and beacon receivers communicating with the DGPS application on an Ethernet Local Area Network (LAN)

With the exception of the serial comms used in Version 1.0, all internal and external broadcast site data channels are mapped through two 24 port Ethernet switches. The new system uses serial port servers to interface legacy equipment to the Ethernet. Version 1.1 testing was conducted using serial port servers to interface legacy MSK receivers to the new DGPS software application. The devices are reliable and simple to configure. Software licenses are managed using USB sentinel keys.

The vision for next generation DGPS extends well beyond simply replacing the RS and IM hardware. The project will modernize virtually every component of the system. Major initiatives include:

- Developing a robust DGPS software application
- Engineering an open architecture hardware platform
- Re-engineering comms networks
- Upgrading datalink components
- Continuing development of NCS

The discussion that follows is intended to outline specific features of the vision by detailing many of the issues confronted and the impact of subsequent design decisions on the operation. Potential system improvements, not yet funded, are presented in the Vision for the Future section.

## DGPS SOFTWARE APPLICATION

At the heart of the next generation DGPS architecture is a government/industry partnership between the DGPS IPT and The XYZs of GPS, Inc. to develop a commercially viable DGPS RS and IM software application [16][12]. Development was undertaken in two phases. Phase I focused on porting legacy RS and IM functions independently onto a PC platform. It used serial RS-232 data communication and honored all constraints imposed by legacy requirements. The Phase II effort expanded the architecture by adding TCP/IP communications, password protection, and a technician friendly Graphical User Interface (GUI). During each phase, engineering testing was conducted and completed with excellent results. Refinement of the new application continues as we move closer to deployment. Most of these refinements have centered on providing an NCS watch stander a clearer picture of anomalous conditions.

The new DGPS software application is modular [16] and is comprised of the components which follow:

- GPS Receiver Interface Module (GRIM): GRIM Interfaces with the GPS receiver and provides GPS observable data to the DGPS Processing Engine in both RS and IM configurations.
- Differential GPS Engine (DGPS_Eng): This module functions as either RS or IM producing RTCM SC-104 messages in its RS role or providing integrity monitoring (i.e., RSIM messages) in its IM role.
- XYZs MSK Modulator Program (XYZ_MM): This program obtains RTCM messages from the DGPS Engine and modulates them to excite the transmitter.
- Demodulating Receiver Interface Module (DRIM): DRIM interfaces with the MSK Demodulating Receiver providing demodulated RTCM messages to the DGPS Processing Engine in IM role.
- DGPS Monitor (DGPS_Mon): This module monitors the above modules providing broadcast site technicians with real time system performance information.

In the RS configuration, the software application uses all modules except DRIM. In the IM configuration, the application uses all modules except for XYZ_MM.

In the legacy system, the RS and IM functions resided in proprietary GPS receiver hardware and firmware. Modifications required lengthy and costly development cycles. Once a change was approved for system wide implementation, then maintenance technicians were typically required to visit each remote broadcast site during installation. To facilitate remote management of the new software application, each module was engineered to be completely self-contained. Each executable file requires no external library or operating system file to run, other than those operating system files required by the operating system itself and those required to support the on-board PC hardware (such as device drivers). All code required by the application is contained within the executable file. Additionally, these executable files were engineered for compactness. The largest is DGPS_Eng.exe at 3.4 megabytes. Small application size combines with Ethernet mapping to make the application remotely upgradeable. A remote technician uses system networking facilities and “places” an upgrade file in the correct directory of the desired target PC, then performs a partial reset from NCS to populate it with the sites specific operating parameters.

As an example of performance improvements, the new DGPS software takes a slightly modified approach to managing observation intervals used to trigger certain alarm conditions. In the legacy equipment, a position error threshold of 10 meters, having an observation interval of 10 seconds, required that the threshold be exceeded for the entire 10-second observation interval, without interruption, in order for an alarm message to be sent to NCS. To illustrate this notion, we will describe an anomalous condition and describe how both the legacy and new systems would react. Picture a cluster of IM generated position fixes plotted on a chart. Because of an anomalous condition, the center of mass of these points is 12 meters from the origin of the plot; where the origin represents the known IM position. On that chart is painted a 10 meter circle to represent the maximum position error before an alarm is triggered. If one plots the instantaneous positions generated under this scenario, a cluster of points are plotted around the 12 meter center of mass. Some of these points would clearly fall outside of the 10 meter circle, while many would not. In the legacy implementation, those points that fall inside of the 10 meter circle cancel the possibility of an alarm message, when they occur within an observation interval. Thus, even if just one solution falls inside of the 10 meter solution error maximum over the observation interval, (and all the rest are outside) an alarm will not be generated. The new software application implements a "rolling window" average which compares the average solution over the observation interval against the alarm threshold and generates the alarm when the average exceeds the threshold. Clearly, if one is interested in more instantaneous information, one simply reduces the observation interval.

The new DGPS software application offers additional Range Rate Correction (RRC) management options tailored to optimize DGPS performance in a post Selective Availability (SA) environment [4] [5]. Studies have shown that small RRC values transmitted to the user over the datalink actually produce more noise in the user's position solution than would be present without the RRC corrections [14]. The new DGPS software application allows the service provider to force RRC to zero for any RRC less than a configured threshold. The DGPS IPT is recommending that operators force RRC to zero when they are below a 5cm/sec threshold. There are two conditions when RRC may rise above 5cm/sec:

- When a satellite is observed on the horizon through many more miles of troposphere
- When anomalous satellite activity is actually being detected and corrected by the RS

Service providers will now have the option of zeroing small RRC values, while still allowing beneficial larger RRC corrections to be sent.

The new DGPS software application contains an improved RS and IM clock handling process. The application tests all satellite clocks against each other seeking convergence in a process similar to Receiver Autonomous Integrity Monitoring. This enhanced clock testing ensures that an anomalous satellite does not cause an entire beacon site to become unavailable during an event. The application leverages the known (not necessarily static) RS and IM GPS antenna positions to be extremely precise when identifying suspect clock activity. With this approach system users should rarely see a DGPS beacon become unavailable during a satellite event.

Since it was envisioned that a broadcast site technician would never configure data channels manually, a software installer was developed to manage this complexity by automatically determining a site configuration based upon the technician's responses to a few simple installer questions:

- What is the router's IP address?
- Is this PC to be configured as an IM or an RS?
- Is this installation for Side A or B?

In the unlikely event that data channel mapping becomes corrupted, beyond the backup and restore facilities within the software itself, a technician would simply reinstall the application. This approach masks possible configuration complexities from the technician while maintaining complete flexibility.

Data management and anomaly analysis has been improved significantly. Phase II implemented a system of "ring buffers" within the software application. The new ring buffers capture all GPS and datalink data generated by the RS or IM in a daily file stored for a specified number of days. When a site experiences an anomaly, a control station operator can use the networking facilities of the system to retrieve data files built during this event. These data files can be locally replayed as if in real-time but at selected higher speeds to condense the analysis period. In addition to RSIM and RTCM messages regenerated at the time of an event, the new RS can be set.

The new DGPS software application allows RSIM [8] feedback messages to be sent to NCS "on change". When scheduled, any RSIM feedback message containing a satellite flag will be sent to both RS and NCS. In the legacy system, RSIM feedback message scheduling is only allowed from RS to IM. Having flagged feedback messages captured in the NCS database greatly enhances operator understanding of broadcast site behavior. In addition, the new DGPS software application offers universal "On Change" RSIM [8] message scheduling. The control station operator is allowed to schedule RSIM messages traditionally used by the NCS to configure the RS and IM to return to the NCS when a parameter is changed on a site using the GUI. Since these "On Change" messages are also triggered when NCS is the origin of a configuration change, these response messages provide an additional positive confirmation in response to the NCS configuration change commands.

The new DGPS software application institutes the RSIM defined full and partial RS and IM resets in the context of a software/PC base architecture controlling receiver and modulation devices:

- A partial reset closes and restarts the DGPS application, then reloads locally stored operating parameters
- A full reset closes the DGPS application, restarts the computer and receivers, and auto-starts the DGPS application loading it with operating parameters received from the NCS database

If NCS is not available, the RS or IM will load the locally saved last known good parameters received from NCS. During resets, the legacy RS produced a mark tone after a reset before RTCM messages began to flow out over the datalink. This prevented the transmitter from automatically switching to the standby RS and IM during the restart process. In the new application, the Digital Signal Processor (DSP) contained in the RS computer will shut down briefly during a full reset. This was deemed beneficial because it causes the transmitter to switch to the standby RS seeking to make the site available before correction age expires in user equipment. The transmitter will not switch sides during a partial reset. In the event that a device (such as a server) stops responding, there are remote power managers installed in the equipment racks. These power managers allow the NCS watch stander to cycle power on any single device in the system remotely. Every effort was made to ensure that the operator has sufficient options available to recover a malfunctioning device without a site visit.

In a DGPS reference station, the UDRE is defined as a one-sigma estimate of the uncertainty in the pseudo range correction. The intended purpose of the UDRE contained in DGPS corrections is to give the user an indication of how much impact, as estimated by RS, that multipath, signal-to-noise ratio, and other non-specific factors had on the generation of a particular correction value [7]. The new application uses the relationship between smoothed and unsmoothed code data to calculate the UDRE. If a GPS receiver does not provide smoothed code data to the application (e.g., legacy 4000IM), the new software is capable of producing its own and restoring the usefulness of the UDRE data to the user.

As the various DGPS software application's modules launch, data channel parameters are loaded from a locally stored file. To remotely "remap" the architecture of a broadcast site, a technician simply uses the system networking facilities to retrieve the sites *.ini files, makes desired changes, and places the files back in their original locations. As an example, to have all four DGPS_Eng iterations (RS-A, RS-B, IM-A, and IM-B) use observations provided by the GPS receiver normally mapped to IM-B, a technician would modify the target IP addresses contained in each server's *.ini files, return them to each device, and perform a full reset. All four devices would then use observables generated by IM-B's GPS receiver. The new DGPS software application offers tremendous flexibility to service providers while requiring no change to the legacy control station or the legacy network architecture.

There are many improvements contained in the new DGPS software application. Each was engineered to improve DGPS performance from within while not requiring new hardware. This approach ensured that enhancements would not only operate seamlessly, but also improve performance for legacy users [8].

## HARDWARE ARCHITECTURE

As stated earlier the Next Generation Differential GPS Architecture's hardware platform was configured in two ways:

- (Version 1.0) Legacy GPS receivers communicate using serial RS-232 protocol;
- (Version 1.1) Next generation geodetic GPS receivers communicate using TCP/IP protocol.

This approach increases the DGPS IPT's options for fielding the new architecture across the entire system, since funding can be unpredictable. Examples of configurations that could be considered are: replacement of Side A, but not Side B equipment; replacement of RS, but not IM equipment; replacement of DGPS function without new GPS receivers; etc. Virtually any blended configuration will work seamlessly.

Next generation GPS receiver hardware requirements were set at levels consistent with commercially available geodetic OEM devices. Currently the system requires dual frequency code and carrier measurements from the DoD GPS constellation of satellites. The architectural design has been kept as general as possible so that observations from other radio navigation sources, such as the European Galileo, could be introduced if desired. The new GPS receiver must support Ethernet TCP/IP communication and be remotely configurable. An HTML interface that facilitates remote operation and diagnostics is considered highly desirable.

The new hardware platform employs server grade OEM computers packaged in one "U" rack mount enclosure. Under the heaviest system requirements load tested so far, processor usage stayed under 7 percent [16]. The RS and IM are fabricated from the same PC configuration; they will be shipped with the required Digital Signal Processor pre-installed. In the event of a PC casualty, the service technician will simply replace it and reinstall the software application. A full reset will load all operating parameters from NCS. This approach greatly reduces maintenance technician training requirements.

In the Next Generation Differential GPS hardware architecture, function of a device will no longer be determined by hardware. It will be determined by software [12]. This means that a broadcast site's architecture can be significantly changed by remotely updating the initialization files used during resets. Not only can device identities be changed, but also any new mapping of data channels could be accomplished remotely without need to visit the site.

The Next Generation Differential GPS Architecture transitions broadcast sites away from serial RS-232/RS-422 communications to an Ethernet LAN. An Ethernet LAN offers many benefits:

- Each CAT-5 cable supports many data channels
- Data channels operate at much higher rates
- All devices can interact with every other device
- All devices are accessible via the WAN
- All data channels are individually configurable

The wide area network will be remapped so that each broadcast site has ownership of an exclusive series of 255 IP addresses. Each broadcast site device will have a unique IP address. Not only will the system continue to use RTCM standard communications, but the new IP address mapping of broadcast sites will allow devices with native HTML interfaces to be accessed remotely.

Single points of failure were a significant design consideration. The team determined that migrating to Ethernet posed very little single point of failure risk, except in an earlier system architecture which used a single Ethernet switch per broadcast. The team determined that such architecture could potentially disable an entire broadcast site due to the single failure of the switch. As a result, the team decided to install separate Side A and Side B LAN switches. A jumper is used to connect the two LANs, preserving the configuration flexibility of a single switch without the single point of failure risk it poses. The WAN is routed through Switch A. The WAN is not considered to reside in the critical path to site availability, so loss of comms due to a single side switch failure was not deemed to pose a significant risk to the user.

The project calls for all GPS antennas to be upgraded, so Ohio University was contracted to conduct a study of commercially available antenna technology. All antennas tested performed extremely well, but the Trimble Zephyr was deemed to be the best fit for next generation DGPS architecture. Selection was based on high gain, excellent multipath rejection, phase center stability, and low elevation gain roll-off [15]. The Ohio University study is summarized in a paper to be published in the Institute of Navigation meeting minutes.

Remotely addressable power strips mounted in the equipment racks are used to perform “hard” resets. An RJ-45 cable connects each strip to the LAN. The devices have configurable static IP addresses and a remote GUI that opens across the WAN. A remote operator sees each outlet specifically labeled for its use (e.g., RS-A, RS-B, IM-A, IM-B, etc) and is given three options for each; ON, OFF, and RESET. If a device plugged into these strips becomes unresponsive, the remote operator can remotely cycle power and let it auto-start rather than calling for a technician to travel long distances to the site.

## INFRASTRUCTURE IMPROVEMENTS

NCS is used by watch standers to control, monitor, and analyze performance of NDGPS broadcast sites. NCS is a C2CEN product which is based on RTCM SC-104 Standard [8]. NCS’s development cycle is continuous. Major NCS modules include:

- NCS_Server: Located at each Control Station, provides real time system monitoring, manages network communications, and builds a database from RSIM message traffic
- NCS_Client: Used by a 24/7 live watch. Provides intuitive watch stander interface, system status information, and remote site configuration and control capability
- NCS_Availability: Tracks system availability by site, opens and closes availability events, evaluates impact of comms outages, and codes failure events for analysis
- NCS_Reporter: Suite of performance analysis tools. Tracks GPS correction quality, datalink performance, equipment failure trends, and allows ad hoc database queries

After initially fielding NCS, the DGPS IPT sought support from the project sponsor to continue support at development levels. As a result, NCS is evolving swiftly into a world class software application capable of efficient system wide command and control. NCS reduces impact of availability threats and has consistently lessened watch stander training requirements with each new revision.

The new hardware platform relies on a dedicate Frame Relay WAN to communicate with NCS providing the watch stander with real time broadcast site casualty and performance data [1]. Under the legacy architecture, the WAN was mapped with a single IP address per broadcast site. Devices appeared on serial ports of the router. In the Next Generation Differential GPS Architecture, the router serves as a gateway and each device has a unique IP address. New broadcast site IP addresses will follow the following scheme - 172.16.XXX.YYY, where XXX is a unique Site ID number and YYY is a number used system-wide to designate a particular device, such as RS-A computer, RS-A GPS receiver, IM-A computer, IM-A receiver, etc. There are a number of benefits to assigning IP addresses to each device:

- Software patches and upgrades can be installed remotely
- Native HTML interfaces will work seamlessly in the background over the WAN
- Comms outages are detected all the way to the device, not just to the router
- 9.6Kb serial comms are not fast enough to pass most dual-frequency GPS observations without compression, but Ethernet has room to spare

Remapping of the WAN offers an immediate increase in system performance and opens many avenues for future improvements.

The Medium Frequency (MF) datalink engineering team is in the process of fielding many improvements [11]:

- A new Antenna Tuning Unit able to compensate for environmental changes at a site

- An RSIM SC-104 standard compliant Remote Transmitter Control Interface (RTCI)
- An improved minimum maintenance industrial battery backup system
- Upgraded and ruggedized transmitter output stage PCBs;
- Improved Lightning and Icing protection.

The MF datalink offers robust correction delivery to users in virtually any environment. It is quickly becoming one of the most stable and reliable means of ensuring steadfastly available service to safety of life navigation users.

Virtually every facet of the NDGPS system is being upgraded or improved. All improvements have been designed to ensure no impact on legacy users, while, at the same time, positioning NDGPS to offer improvements in pos/nav services and capabilities.

## VISION FOR THE FUTURE

The Next Generation Differential GPS Architecture has been designed to fulfill legacy requirements while serving as a launch point for innovation. Some of the enhancements presented here should be viewed as long-term investments, while others will be more immediate.

As additional augmentations emerged to meet specific safety requirements of other transportation sectors, these new systems began benchmarking against the older, established systems such as DGPS. This healthy process resulted in the emergence of new system performance paradigms. A paradigm that the Next Generation Differential GPS Architecture team has embraced is the concept of preventing Hazardous or Misleading Information (HMI) from reaching a user. A concern in the legacy NDGPS architecture is that in order to detect an out of tolerance correction, an out of tolerance correction must be sent over the datalink. This means that users likely received the out of tolerance correction as well as the IM. Development is underway on an enhancement called Pre-Broadcast Integrity. Pre-Broadcast Integrity will check RTCM corrections, over the LAN, before they reach the 200 baud data link. In this way the IM gets to evaluate the correctors ahead of time and report to the RS any corrector which should be edited. The Next Generation Differential GPS Architecture is capable of providing at least 5 Hz Pre-Broadcast Integrity checking in the IM without causing any datalink latency. The RS will maintain a pool of 1 Hz correction sets which are fed to the 200 baud modulator as needed. Some valid corrections will be discarded, this is true; but a collateral benefit is that IM integrity checking is stepped up to 5 Hz or faster, thus reducing time-to-alarm. The engineering team is optimistic about the benefits of Pre-Broadcast Integrity. Software coding is underway and a draft supplement to the RTCM SC-104 standard is being finalized.

The legacy broadcast site architecture does not capture or hold any performance data at the site, so during a communications outage, the information that would normally pass to the control station is simply lost [1]. This does not impact site availability, but it does leave gaps in the NCS database. The next generation DGPS architecture allows for the addition of an Autonomous Control Data Logger (ACDL). ACDL will serve two functions:

- Autonomous Control: Initiate basic casualty recover procedures at a broadcast site in the event of equipment casualty during comms outage
- Data Logger: Capture and store all RSIM message traffic normally sent to the Control Station during a comms outage

While DGPS broadcast sites are not dependent on communication with the NCS for user availability, ACDL will ensure that data used to drive operations, maintenance, and engineering projects accurately reflects system performance.

The NDGPS system currently has fielded 348 RS and IM units exchanging RSIM messages with NCS 24 hours a day, 7 days a week generating hundreds of thousands of RSIM messages each month. The current storage capability of NCS is 45 days. After that the data are archived. Before data are archived, an operator can produce any number reports (e.g. availability) or performance plots (e.g. MSK Signal strength). Furthermore he has several powerful tools to process ad hoc queries. After archiving, the data are inaccessible to the operator. Data warehouse development is underway. This will expand availability of performance data from 45 days to 13 months. There are significant challenges associated with the massive volume of data produced by the system, but several promising options are being evaluated by C2CEN.

NDGPS has nearly achieved its goal of 100% continental US coverage and is actively pursuing a strategy to achieve 100% redundant coverage RSIM [1] [12]. The Coast Guard Academy has developed coverage prediction software used by Navigation Center personnel to predict coverage and communicate it to users. The DGPS IPT would like to continue to develop this coverage prediction software so that it is being updated dynamically by NCS to provide real time visual depiction of actual system coverage. Using this information, the watch stander could then remotely raise or lower beacon signal output to fill any coverage gaps that appear as a result of adverse weather or equipment casualty. The software currently exists as a prediction model and the MF datalink team is finalizing work on a remote transmitter control interface which incorporates remote output level control. A convergence of these technologies may allow real time management of NDGPS system coverage.

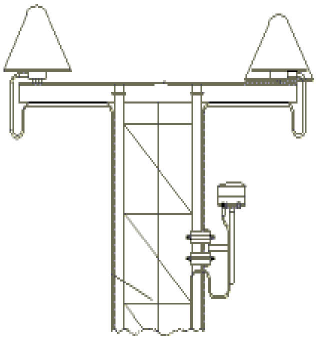

**Figure 3**

The Trimble Zephyr was selected as the Next Generation DGPS Architecture GPS antenna. Each broadcast site has four GPS antennas. These antennas are mounted at the top of two masts that have a 60" cross member attached. There is a GPS antenna mounted at each end of the cross member (see figure 3). The multipath environment can definitely be improved should there be a need to do so to meet more demanding pos/nav specifications. This could, for example, be accomplished by removing the cross member and centering a single GPS at the top of each tower. Possibly increasing the height of the mast would be helpful. In this configuration, a zero insertion loss antenna sharing device would be used to provide antennas to all four GPS receivers. These actions, and possibly others, could improve the site's multipath environment and could possibly reduce the total number of GPS antennas supported in the system.

The Next Generation Differential GPS Architecture can transmit data from an external source on the datalink. This is done by scheduling RTCM 60, 61, 62, and 63 messages defined in the RTCM SC-104 standard as reserved for LORAN. Transmission priorities of these messages are configurable. These messages are also compatible with compression algorithms that may potentially increase information content while reducing the required communication bandwidth. Virtually any type of data such as LORAN Additional Secondary Factors, GPS observables, or IONO/TROPO models can be transmitted regionally or nationally using these

The NDGPS system discussed so far provides real-time positioning accuracies at the meter level. The horizontal components are possibly accurate to 1 m. (95%), whereas the vertical component is possibly accurate to 2 m. (95%). These numbers represent typical accuracy; more correctly, accuracy is a function of the user's distance from the reference station. These accuracies are substantially better than the system requirement. To some extent this is a result of several factors:

- Better GPS receivers and antennas
- The continuing emphasis on integrity and availability
- Overall system improvements

As a reminder these accuracy levels have been achieved using basic L1 C/A code pseudoranges. There has not been a systematic effort to eliminate reference station multipath, eliminate atmospheric delay differences between reference stations and users; or eliminate orbital error. The reduction of these errors would, obviously, improve the accuracy of the current system.

If the current accuracy exceeds current system requirements what is the motivation for seeking more accuracy? The answer has two parts:

- Ever since S/A was terminated, in the year 2000, there has been spare bandwidth, and bandwidth is precious
- More accuracy can enable new applications which hold the promise to save lives

It seems natural to explore whether or not the bandwidth which has been freed up can carry added data for bringing about accuracy improvements which would enable important applications.

Accuracy improvements can be achieved by eliminating reference station multipath, improving user multipath, improving GPS broadcast orbits or having the reference station broadcast precise orbits, and/or having the reference station broadcast modeling information with respect to atmospheric delays to the user. Multipath improvements require no new bandwidth; the broadcasting of precise orbits would take just 1-2 bytes per second. These changes obviously would yield some amount of accuracy improvement. Broadcasting atmospheric modeling data, on the other hand, would require greater bandwidth and lead to greater accuracy gains. This is being investigated.

The discussion above concerns how to better use legacy facilities. Another avenue under exploration concerns the possibility of adding bandwidth and broadcasting correspondingly more data to the user. In this case one might send the data types discussed in the last paragraph to the user but also send dual code and carrier measurements. One could imagine sending satellite radio navigation data if there was enough bandwidth and benefit. It has been demonstrated in two recent FHWA activities that the above engineering steps could yield decimeter level positioning for users 100 – 200 km., or even more distant, from such a reference station.

## SUMMARY AND CONCLUSION

The next generation DGPS architecture will be installed throughout the system within the next two years, but that truly is just the beginning. Every component of the NDGPS system from control station; to communications networks; to the broadcast site GPS, datalink, and infrastructure subsystems is undergoing significant upgrade and will remain the focus of continuous improvement initiatives. All of the many projects mentioned in this paper are converging rapidly as they seek to embrace new technology in an effort to provide the greatest value, availability, and accuracy to system users. As performance upgrades are implemented, NDGPS will continue to enhance national infrastructure by remaining an important pillar of the federal government's strategy to save lives through deployment of safety-of-life navigation systems.

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The purpose of this paper is to present initiatives and propose new ideas for exploration. It is not intended to reflect USCG direction or policy. Use of company names, trademarks, or copywrited material is not an endorsement of any product or service.

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