ENGINEERING THE WORLD'S LARGEST DGPS NETWORK

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Abstract

Key words: US Coast Guard, DGPS, nationwide network

This paper describes the United States Coast Guard's efforts to implement the world's largest ground-based Global Positioning System (GPS) augmentation service, Nationwide DGPS (NDGPS). NDGPS is being implemented to meet all surface transportation navigation requirements for the US. These applications demand a high level of robustness and reliability. This paper describes how the Coast Guard is meeting these challenges through system design, equipment configuration and command and control functions. This includes a thorough description of how the Coast Guard ensures the integrity of the system and broadcast corrections on a continuous basis. We also give some direct experience in the challenges of "beating swords into plowshares" through the conversion of the United States Air Force (USAF) Ground Wave Emergency Network (GWEN) into the NDGPS inland infrastructure.

Introduction

Integrating an obsolete radiobeacon system with an outdated USAF ground wave network coupled with state of the art GPS reference station, integrity monitoring, networking and leading edge computer equipment to build a nationwide Differential GPS system is a monumental task faced by US Coast Guard engineers. To meet not only the traditional maritime requirements shared by other nations but to cover all of a nation twice over and provide service for non-traditional DGPS applications as well adds to the complexity.

Differential Global Positioning Service (DGPS) is a land-based system that receives and processes signals from orbiting GPS satellites, calculates corrections from known positions and broadcasts these corrections via a Medium Frequency (MF) Transmitter to DGPS users in the Broadcast Site's coverage area.

The United States Department of Transportation (DOT) is coordinating the implementation of a network of DGPS broadcast sites across the continental United States, Alaska, Hawaii and Puerto Rico. Several Federal and state agencies, including the Federal Railroad Administration (FRA), Federal Highway Administration (FHWA) and the United States Coast Guard (USCG), are involved in the effort to install the NDGPS Broadcast Sites. When completed, this nationwide broadcast network will consist of over 126 sites and provide a standardized signal for DGPS service throughout the United States. Planned uses of the NDGPS network include positive train control, precision farming, smart vehicles, snow plow management, accurate waterway dredging and improved emergency response, an expansion of traditional uses which include harbor/harbor approach navigation, vessel tracking and buoy positioning.

The US NDGPS network design is based on the USCG's DGPS maritime service that began initial operation in 1996 with service coverage of major harbors and the nation's coasts. A major component of the NDGPS implementation plan is the reuse of USAF GWEN facilities as DGPS Broadcast Sites. This reuse of equipment, either in its current location or moved to new sites, reduces the cost of implementing NDGPS coverage.

System Requirements

The primary purpose of the marine DGPS network is to provide reliable position accuracy of better than 10 meters (2 drms) when navigating in harbor and harbor approach areas (up to 20 miles offshore) of the continental US, Puerto Rico, and selected portions of Alaska and Hawaii [1].

The initial requirement is for NDGPS to provide single coverage throughout the continental United States. The ultimate goal is to provide dual terrestrial coverage throughout the contiguous 48 states and single coverage in Alaska, Hawaii and Puerto Rico.

Each Broadcast Site is required to be on-air and monitored real-time by a centralized Control Station 99.7% of the time. Coupled with the expected double coverage planned throughout the continental US, this equates to a signal availability of 99.9%. Availability represents the percentage of time that the DGPS signal is usable.

The USCG DGPS system provides the user with broadcast messages as defined by the Radio Technical

Commission for Maritime Services [2] and utilizes Reference Station Integrity Monitor (RSIM) [3] messages for intra-system communication.

In order to verify site/system availability, each Broadcast Site sends RSIM Messages 15 (MF broadcast signal strength, signal to noise ratio and message error ratio) and 18 (position error) from the online Integrity Monitor and RSIM Message 24 (transmitter operational status) from the transmitter to its parent Control Station through a real-time X.25 communications network connection. USCG has a requirement to monitor and store these messages. With the expected termination of GPS Selective Availability (S/A) and the proposed additional civil frequencies in future GPS satellites, requirements of the US DGPS system are expected to change drastically.

Broadcast Site

As of February 2000 the Coast Guard has 62 operational DGPS broadcast sites throughout the United States. The original maritime DGPS network sites are located along US coasts and the Great Lakes. An agreement with US Army Corps of Engineers (ACOE) [4] expanded this maritime network to include major inland waterways such as the Mississippi River. Initially the USCG placed DGPS equipment at pre-existing marine radiobeacon sites and modulated the MF signal broadcast at these sites. As the use of DGPS expanded and the requirement for a nationwide system developed, the DOT decided to model the NDGPS system on the existing USCG maritime system. Currently, nine sites have been built in the interior part of the United States as part of the nationwide expansion.

Each of the DGPS broadcast sites has the same basic design – an equipment rack with the electronic equipment and MF transmitter located within a special shelter or building and reference masts, antenna coupler and broadcast antenna located near the shelter. Figure 1 shows the standard configuration of the Maritime DGPS Broadcast equipment.

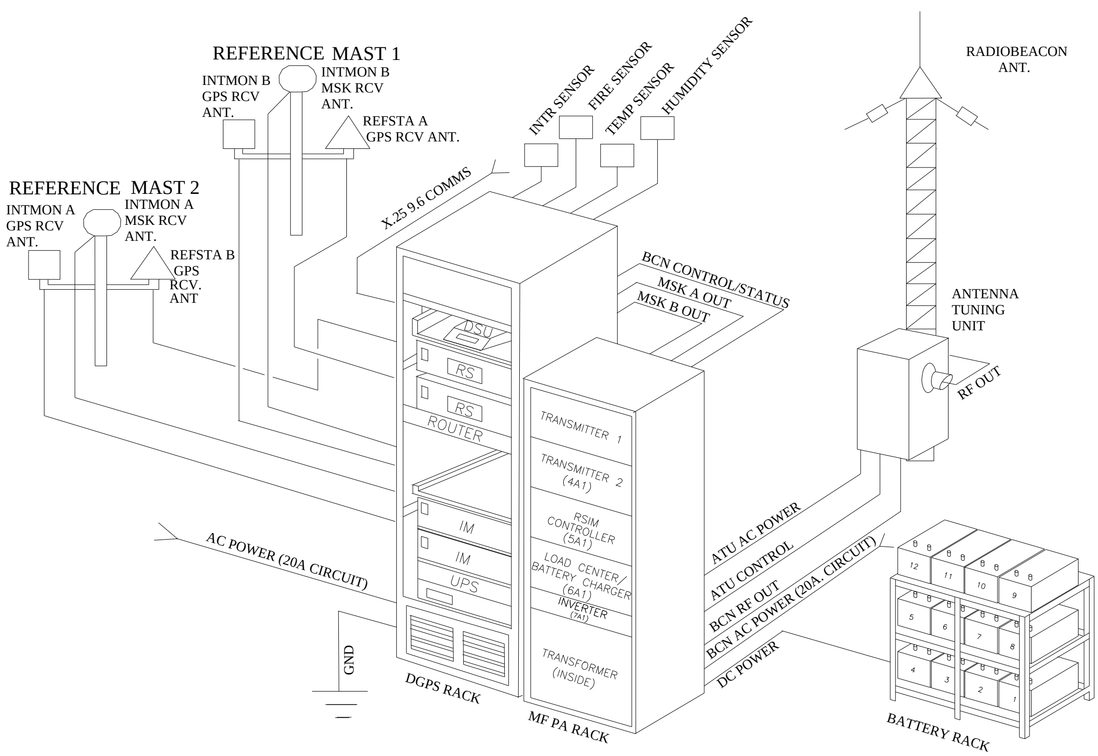

FIGURE 1: EQUIPMENT LAYOUT AT A MARITIME DGPS SITE

The USCG uses two ASHTECH, Inc. dual-frequency, 12 channel Z-12R™ DGPS Reference Stations. Each Reference Station consists of a GPS reference receiver and a minimum-shift keying (MSK) modulator. The Reference Station computes corrections for GPS satellite signals and outputs these corrections in an MSK format to an MF transmitter at an authorized frequency. The authorized US frequency ranges from 285 – 325 kHz in 500 Hz increments, but the USCG's system currently uses 1 kHz increments.

Two TRIMBLE NAVIGATION, Ltd. 12 channel, L1 frequency 4000IM™ MSK Integrity Monitors provide the required integrity for the differential corrections broadcast. As the name implies, the Integrity Monitor monitors the integrity, or accuracy, of the DGPS Broadcast information and provides the Reference Station and Control Station feedback on this accuracy. Both Integrity Monitors monitor the MSK signal from the broadcast antenna, but each Integrity Monitor only provides feedback to its respective Reference Station, i.e. Integrity Monitor A is directly wired to Reference Station A. The Integrity Monitor identifies the corrections from the individual Reference Station by the Reference Station ID number encoded into the broadcast.

All USCG Broadcast Sites are unmanned and are not usually located near a Coast Guard facility; therefore the Coast Guard's design incorporates redundant Reference Stations and Integrity Monitors. Although both Reference Stations provide signal inputs to an MF transmitter, only one set of corrections is broadcast at a time. If the primary Reference Station fails, the MF transmitter will automatically switch to the secondary Reference Station and continue to broadcast corrections allowing the faulty Reference Station to be repaired or replaced. Since each Integrity Monitor is directly connected to its dedicated Reference Station, the Control Station must take action to switch to the secondary Integrity Monitor if the primary Integrity Monitor fails.

In April 1997 the Coast Guard entered into a contract with Southern Avionics Corporation (SAC) to replace all of the existing radiobeacon MF transmitters and antenna couplers. The SAC transmitter has two transmitter drawers (Side A and Side B). The Reference Station's MSK Output is directly connected to the respective sides, for example Reference Station A is connected to Transmitter Side A.

An RSIM Control Drawer monitors operation of the on-line transmitter side and automatically switches to the stand-by transmitter side if the Radio Frequency (RF) output power falls below a specified threshold or during other user defined fault conditions. The RSIM Control Drawer allows for remote control and monitoring of the transmitter by the Control Stations via standard RSIM messages. The RSIM Control Drawer also allows for the monitoring of the Broadcast Site environmental and control alarms (humidity, fire, intrusion, power loss, generator status, etc.).

The SAC transmitter carrier operating power is adjustable from 50 to 1000 Watts, with most of the USCG DGPS sites falling between 250 and 1000 Watts. Additional functionality includes the ability to operate up to 22 hours at 85% of maximum power level (850 Watts) on DC back-up power using a bank of twelve 12-volt, 200 amp-hour batteries and the ability to re-charge these batteries when AC power is restored.

The Reference Stations' GPS antennas and the Integrity Monitors' GPS and MSK antennas are located on two reference masts located at the site. The location for these masts is carefully reviewed prior to installation to ensure that multipath and masking problems are minimized. To reduce the effects of multipath the masts are placed at least 75 feet apart. To further reduce the effects of multipath one mast has GPS antennas for Reference Station A and Integrity Monitor B while the other mast has the GPS antennas for Reference Station B and Integrity Monitor A.

There are four different types of MF broadcast antennas used at US DGPS broadcast sites. The first is a VALCOM 74-foot whip antenna with a loaded coil and top-loading element (TLE). This antenna was originally used at marine radiobeacon sites and has been replaced wherever possible because of its inefficiency (less than 3%) and tendency to break down at power levels greater than 500 Watts in high salt environments. The VALCOM whip is in use only at sites where there is not enough property or where historical concerns (e.g., the broadcast site is co-located with a historic lighthouse) prevent the installation of a larger and more efficient antenna.

The second and most commonly used antenna type is a guyed ROHN tower in 90-foot, 120-foot and 150-foot heights, each with three TLEs. The efficiencies of these towers range from 6-8% for the 90-foot tower to 20% for the 150-foot tower with bandwidths of approximately 3 kHz.

The third antenna type is the Longwire and is most common at sites along the Mississippi River. The efficiency of this antenna type is approximately 13%.

USCG RF engineers are currently researching efficiency and bandwidth characteristics of these three antennas in an attempt to improve system performance.

The remaining antenna type is located at converted USAF GWEN sites. This antenna is 299 feet tall and has twelve TLEs. With an efficiency of approximately 55% and a bandwidth between 30 and 80 kHz, it is significantly better than any other antenna currently in the Coast Guard's inventory. The GWEN antenna efficiency translates into an expanded coverage area at the same power, reducing the number of required sites, an important factor in designing a system to ensure nationwide coverage. Consequently, the GWEN antenna design has been selected as the standard for all future NDGPS sites. Figure 2 shows the standard configuration of the GWEN DGPS Broadcast equipment.

In addition to re-use of the larger highly efficient antenna, the USCG is evaluating the re-use of the GWEN RCA MSK-5SS 5,000 Watt transmitter. The RCA MSK-5SS was originally a continuous wave 5,000 Watt AM transmitter that the Air Force modified for Low Frequency Pulse Operations. The Coast Guard has converted the RCA back into continuous wave operations in the 285 -325 kHz band and removed two of the Power Amplifier (PA) cards for a maximum output power of 2,500 Watts. The two removed PA cards are being used as spares since the age of the RCA transmitters has created a scarcity of spare parts.

Problems arose when trying to use the standard maritime SAC automatic tuning unit (ATU) with the GWEN antenna for DGPS broadcasts. The GWEN antenna was designed for operating frequencies of 150 to 175 kHz. A side effect is that it is resonant near the DGPS operating frequency of 285 kHz to 325 kHz. Thus, the antenna

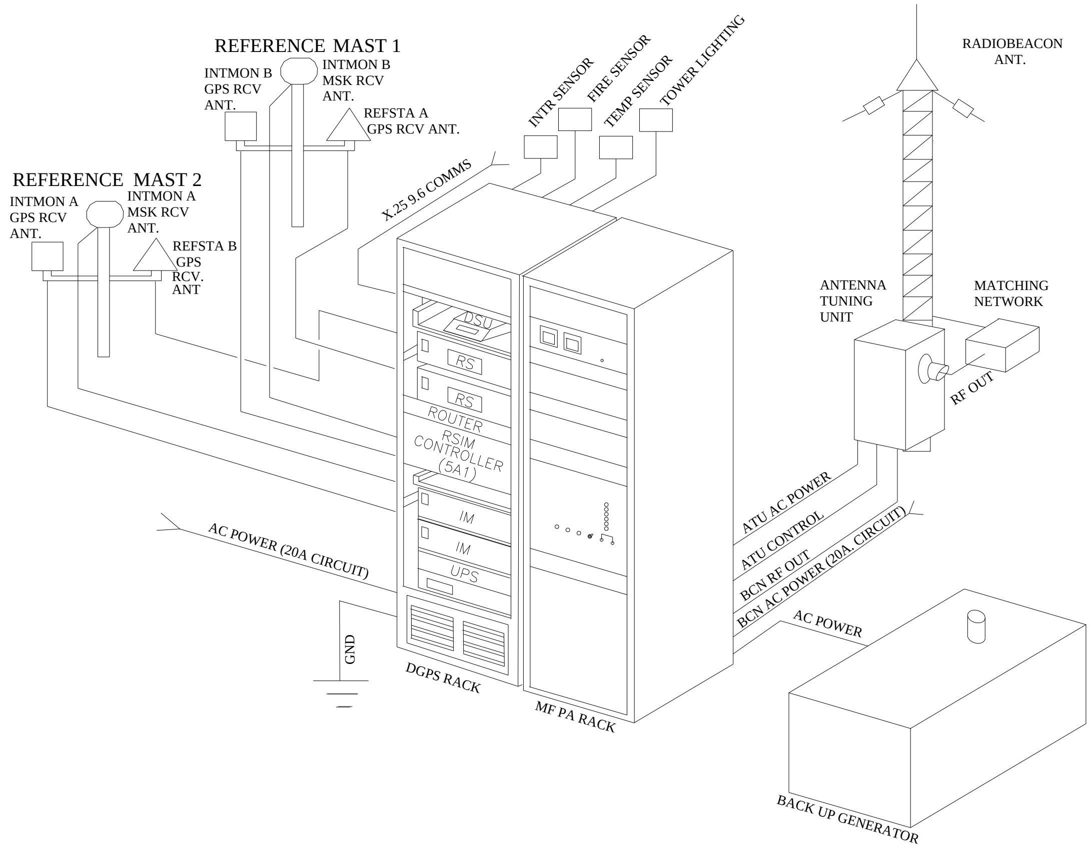

FIGURE 2: EQUIPMENT LAYOUT AT A GWEN SITE

is either outside the tuning range of the SAC ATU or just within tuning range but does not allow for the full range of the variable tuning circuit. During the first few site conversions when the TLEs had already been installed, Coast Guard RF engineers determined that installing a matching network between the ATU and the antenna was the most cost-effective way to solve this problem. At new installations the engineers also redesigned the TLE lengths enabling the SAC ATU to use its entire tuning range, eliminating the need for the matching network.

Additional modifications were needed to bring the RCA transmitter into compliance with DGPS requirements including the addition of a switch to allow for the transfer between Reference Stations and the creation of a separate RSIM control draw to perform the same functions as the SAC. During the modification process, each RCA transmitter undergoes a two-week refurbishment prior to installation at the NDGPS site. This is expected to extend its operational life by ten years.

A GWEN Site configuration also includes fenced shelters for emergency power generator and transmitter equipment. The 25,000-Watt generator with fuel for up to eleven days of operation provides site backup power capability in the event of commercial power failure.

Expansion Efforts

One of the Coast Guard’s original reasons for providing a DGPS correction was to enhance the ability of Coast Guard Buoy Tenders to set and service Aids to Navigation. Positioning buoys using the DGPS signal has resulted in considerable operating cost and time efficiencies and improved accuracy when compared to the previous method of using horizontal sextant angles. As more DGPS Broadcast Sites are installed, more users rely on this highly accurate positioning system and the demand for even more sites continues.

In 1996, the President assigned DOT as the responsible agency for all civilian GPS matters and to implement a national GPS augmentation for terrestrial transportation [5]. In January 1997, DOT formed the DGPS Policy and Implementation Team (PIT) to develop a nationwide differential system. Federal agencies that are members of the PIT include the Office of the Secretary of Transportation, Federal Highway Administration, Federal Railroad Administration and the US Coast Guard. After reviewing several options, the conversion of USAF GWEN sites into DGPS sites based upon the USCG standard design was determined to be the most efficient and cost effective method of providing nationwide differential coverage. After a successful GWEN to DGPS conversion site was established and tested at Appleton, Washington [6], the decision was made to expand the Coast Guard's DGPS network into a nationwide system.

GWEN was an emergency communications network within the continental United States built for the command and control of US strategic forces. It consists of a highly redundant network of sites hardened to withstand electromagnetic pulse and operated via Low Frequency ground wave signals. In the mid 1990's the NDGPS PIT learned of the USAF plans to decommission the GWEN system and received authorization to take control of the sites from the Air Force for use in the nationwide expansion. This program represents a large defense conversion to civil use and provides opportunities to utilize unneeded Air Force assets to reduce the cost of providing NDGPS coverage. Figure 3 shows the typical layout of a GWEN site.

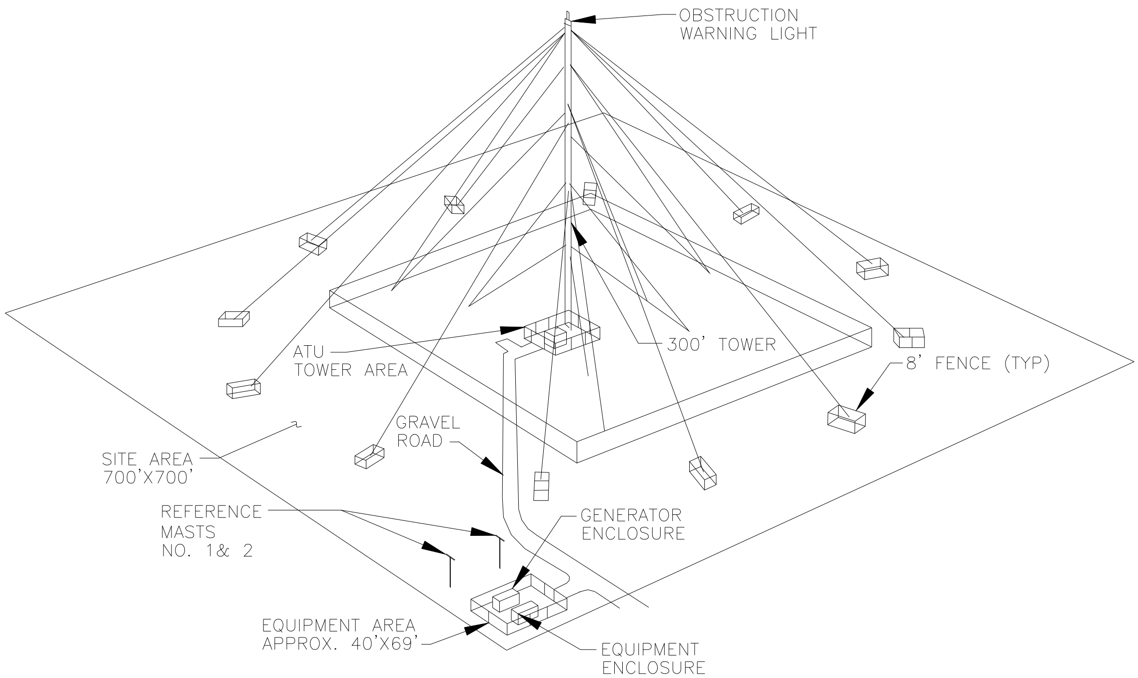

FIGURE 3. TYPICAL LAYOUT OF A GWEN SITE.

Each member of the NDGPS team is an important player in the success of the NDGPS expansion. The FRA is the sponsor of the NDGPS program, while the FHWA receives and redistributes all NDGPS funds appropriated by the US Congress. The FHWA also prepares the environmental impact statements for all new site construction. Because of its experience with the implementation of the maritime network, the USCG is tasked with the design, installation and operational control of each site. Local and state government agencies help with site selection, ensuring all local laws and regulations are met prior to the installation of new sites.

Site Selection

Approximately 45 of the current GWEN sites will be converted to NDGPS use at their current locations. If selected, the RCA transmitter with its increased output power coupled to a highly efficient antenna should result in service to a larger coverage area when compared to maritime DGPS sites, requiring fewer sites to be built. Several of these sites are located in the vicinity of maritime sites in the maritime network and once on-air will replace these lower power sites. This will improve overall performance (larger coverage area, stronger signal, less signal fluctuations due to weather) of the current maritime system and reduce operating and maintenance costs.

The remaining sites required to complete the NDGPS system will be constructed using relocated GWEN equipment or entirely new antennas and transmitters based upon the GWEN design. Exactly how many sites are needed has not been determined. Selection of sites is based on public safety requirements that require dual coverage. After this, sites will be built to fill in appropriate coverage gaps and as required by the expanding user base until complete nationwide coverage is achieved.

Once the PIT has decided on a location for a new NDGPS site, usually a specific town or city, a standard site selection guide is sent to a local State or Federal agency representative to be used to help locate possible sites. The local representative looks for potential sites within a 30-50-mile radius of the location based upon criteria outlined in the selection guide. The selection guide includes criteria on the required property size (11.2 acres), environmental concerns, the availability of power and telephone service and the presence of any tall objects that could mask the GPS antennas. Upon completion of this stage of the review, the number of potential sites has usually been narrowed down to one or two and the results are sent to USCG Command and Control Engineering Center (C2CEN). C2CEN sends a representative to visit these few sites for a final survey before deciding where the site will be installed.

Despite these procedures, the selected site(s) often has one or two associated problems. For example, at a planned site in Ohio a 600-foot metal bridge is located only a few hundred feet away from the broadcast antenna. Even using computer modeling, the effects to the coverage area will not be known until after installation is completed. At the Annapolis, Maryland GWEN site, a problem arose because of an 855-foot tall television tower located 980 feet to the southwest of the site. The television tower partially turned the broadcast antenna into a directional array. The predicted radiation pattern had a significant gain to the northeast of the site and at certain frequencies in the DGPS spectrum, there were several orthogonal dB losses when compared to the main lobe. In California, the Essex NDGPS site is also the home to an endangered tortoise. Consequently, special training has to be given to the maintenance crews to limit the impact to the tortoise and its habitat.

The initial determination of NDGPS site placement has been based upon the signal strength predictions using Millington's method. An analysis conducted by the United States Coast Guard Academy (USCGA) [7] shows a marked difference between these predicted signal strengths and observed signal strengths especially over rough terrain encountered in the Western US. The USCGA is in the process of developing a new model based upon the terrain's slope over which the signal must travel. This new method appears to have a direct correlation in the differences observed between the predicted and actual signal strengths. This effort, in addition to readings taken from operational sites, will help to ensure that complete coverage of the US is achieved.

Another concern in site selection is the effects of skywave interference on the DGPS signal. There has been anecdotal evidence of distant DGPS sites interfering with users' reception of the signal from a local site [8]. As the number of sites increases the probability of receiving destructive interference from another site also increases. C2CEN and the USCGA are beginning to study these affects and determine ways to mitigate the problem. One potential result of this study is the that the USCG may assign frequencies at 500 Hz increments as opposed to the 1 kHz increments currently used.

The largest area requiring construction of new sites is in Alaska where there are no GWEN sites. The estimated cost of installing an NDGPS site in Alaska is in excess of $1 million (US) per site. With 15 sites planned in Alaska, the PIT is searching for ways to reduce this cost. One idea is to broadcast the DGPS signal using a diplexer onto a pre-existing broadcast antenna, such as the LORAN-C stations positioned throughout the US. With an expected cost saving of over $500,000 (US) per site, this implementation would drastically reduce the price to achieve DGPS coverage in Alaska. The engineering aspects of this proposal are discussed later in the paper.

Communications Network

All communications between Broadcast Site equipment (Reference Station, Integrity Monitor and Transmitter) and the Control Station is performed via an X.25 Packet Switching Network, a Router and Data Servicing Unit (DSU). Communications is established from the Control Station application using dedicated virtual circuits with each piece of equipment. These virtual circuits are opened and remain open until communications with the Broadcast Site is explicitly terminated. Each Broadcast Site has a 9.6 kbps line providing service to the X.25 network. Each Control Station requires a single 56 kbps line; a second line is installed to ensure redundancy. The Control Station application initiates the calls after which two-way communication can occur. System implementation enforces the restriction that no more than one Control Station can establish/maintain a connection with a given Broadcast Site.

The Control Station router performs protocol translation making the application network-independent. The Control Station has a fast-Ethernet network, permitting interconnectivity between Server and Client machines. A 100 Base T connection provides fast updates between redundant server machines.

Control Station

System requirements specify that NDGPS Broadcast Sites be monitored and controlled on a continual basis from a central location and that these Control Stations have the capability to simultaneously monitor and control at least 200 sites. The control functions afford watchstanders the capability to change site parameters and disable sites, i.e., turn off corrections, as circumstances warrant. There are two operational Control Stations, USCG Navigation Center East (Alexandria, Virginia) and USCG Navigation Center West (Petaluma, California), and one Engineering site, USCG C2CEN (Portsmouth, Virginia). Each control suite has the capability to monitor and control the entire system. Additionally, the Control Station application, Nationwide Control Station (NCS), must provide online data storage for at least one year. Figure 4 shows the relationship between a Control Station and a Broadcast Site.

NCS has been designed adhering to Object Oriented design principles. To implement the greatest degree of flexibility, the application incorporates data-driven dynamic design, maximizing the use of a relational database to ensure data integrity and robust processing

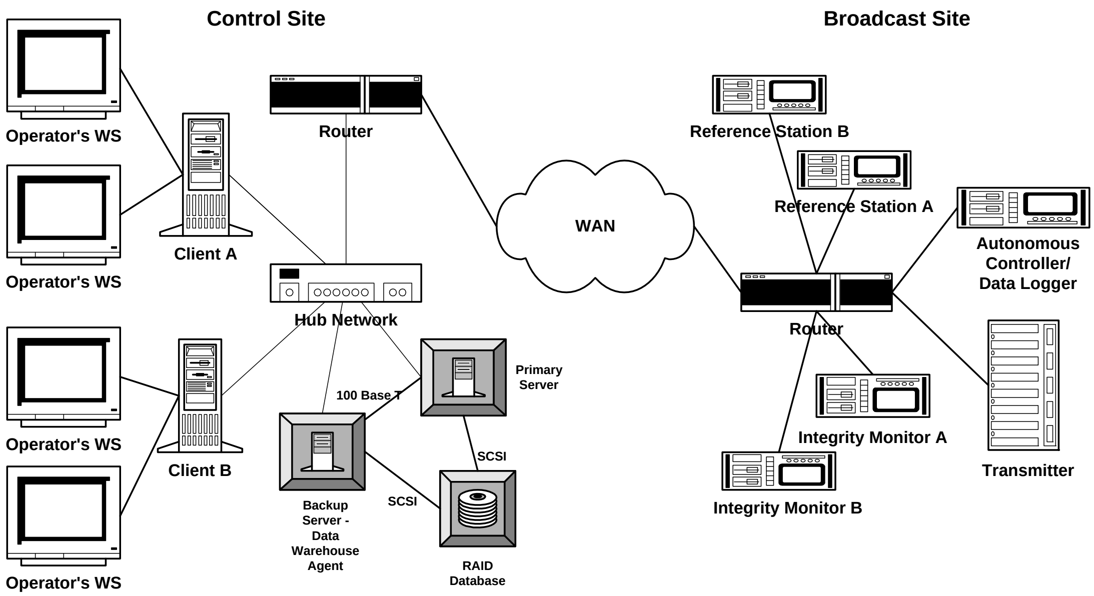

FIGURE 4. DGPS CONTROL STATION AND BROADCAST SITE CONFIGURATION

Implementing client-server architecture, NCS processing is easily allocated into the primary areas of its driving requirements to monitor and control. The Server portion of the application performs system Monitoring including all network communications and data storage. The Client, on the other hand, performs the Control functions, providing a user interface for watchstander-initiated changes and System Status and Information display.

This design minimizes and/or eliminates single points of failure and provides fault tolerant data storage. Features of note include mirrored servers, redundant power supplies and processors within each server, redundant SCSI buses, controllers and cables, and finally, Redundant Array of Inexpensive Disks (RAID) disk configuration.

An independent data warehouse agent running on the Backup Server to handle administrative/data-analysis tasks removes processor intensive operations from the Primary Server, minimizing operational impact on the system.

Engineering Efforts

USCG C2CEN has several projects underway to improve Broadcast Site performance. The first is an in-depth analysis of the entire RF network to identify ways to improve system performance and decrease the amount of off-air time. The maritime DGPS network is experiencing systemic problems with power fluctuations and high levels of reflected power automatically shutting down the transmitters. These problems are most likely caused by variations in the weather changing the antenna characteristics faster than the ATU can adjust.

The underlying problem is that antennas used in the maritime DGPS network are shorter electrically than ideal quarter wavelength antennas. These electrically short towers have higher currents and voltages and are more susceptible to corona effects, arc-overs and weather variations. The decision to use these antennas was an economical one, but they have created problems in meeting availability requirements. Numerous improvements to the system have already been made – improved ground planes, insulators, and addition of corona rings. The RF study will look at these and other areas in an effort to improve system-wide on-air availability

Another project will install an Autonomous Controller and Data Logger (ACDL) at each Broadcast Site. In the event of a communications loss with the Control Station, this commercial ACDL software program and computer will capture and log all USCG required RSIM messages, automatically respond to basic alarms and attempt to establish communications with the Control Station using an alternate network such as a dial-up modem. When the network connection is reestablished, the ACDL will send all data logged during the outage to the Control Station. The Coast Guard counts any time when there is a loss of communications between the Broadcast Site and Control Station against Broadcast Site availability since there is no logged data to show how the site performed during that time. Implementing ACDL will provide the capability to compute availability using the data captured during the communications loss. This will give a more accurate picture of Broadcast Site performance than is currently possible.

C2CEN is in the process of creating a portable DGPS site. There are several reasons why a broadcast site can be off air for an extended period of time. Damage from severe weather, an earthquake or even extended maintenance can cause a site to fail to meet the 99.7% availability requirement (approximately 2 hours per month). In these cases, a portable DGPS site could be set up at or near the off-air site to provide a temporary signal until the main site is brought back on-line.

The proposed portable DGPS site would include a smaller suite of equipment (Reference Station, Integrity Monitor, communications equipment and GPS/MSK antennas), a small transmitter, ATU, a portable MF broadcast antenna and a generator. All of this equipment would be packaged together for easy transportation and set-up and stored so that it could be delivered anywhere in the US within 24 hours. The portable site may not provide the same coverage as the standard site but could provide DGPS corrections in an area where and when it is most needed.

Diplexing two separate signals onto a single antenna is a technique commonly used in broadcast engineering. It has been successfully implemented at the Savannah, Georgia DGPS site where a DGPS signal (319 kHz at 900 Watts) and a weather data and mariner information broadcast signal, called NAVTEX (518 kHz at 2500 Watts), are both radiated from the same antenna. An initial study on the feasibility of diplexing a DGPS signal onto a LORAN tower is underway. The typical design of LORAN Towers, 625 feet tall with twelve TLEs, would provide an estimated efficiency of over 70% at the DGPS frequencies. The location of the existing LORAN Stations in Alaska and throughout the continental US would decrease the required number of NDGPS sites to achieve the desired coverage, significantly reducing the cost. The enormous differences between the LORAN and DGPS signal powers (LORAN is a pulse-wave typically operating at over 400K Watts peak power and DGPS is a continuous wave signal operating at 1K Watt) might make the application impossible. Since both are safety of life navigation signals, there must be assurances that neither signal adversely affects the other.

Other Applications

Other US government agencies use the equipment at DGPS Broadcast Sites [9]. The National Geodetic Survey (NGS) uses a connection to both Reference Stations to poll data as part of NGS's Continuously Operating Reference Stations (CORS). This provides GPS carrier phase and code range measurements in support of 3-dimensional positioning activities throughout the United States. NGS posts the data on its Internet web-site (www.ngs.noaa.gov/CORS/) to enable post-processing of GPS data, providing positioning accuracies that approach a few centimeters both horizontally and vertically. This data is also used by the Coast Guard to adjust its own reference positions thereby improving its differential corrections accuracy.

The National Oceanographic and Atmospheric Association (NOAA) also utilizes Broadcast Site resources to augment its weather forecasting capabilities. NOAA has mounted the GPS Surface Observing System (GSOS) instrument package on one of the reference masts at each site. GSOS contains equipment to measure local pressure and temperature and a GPS antenna to measure the time delays between the L1 and L2 frequency reception to determine the water vapor present in the air. The data is transmitted to NOAA Forecast Laboratories where it is evaluated by the GPS Integrated Precipitable Water Vapor Observation System to improve weather forecasts.

Conclusion

The successful effort to configure legacy systems acquired by DOT and the USCG with DGPS reference and integrity equipment and modern computer, networking, and interface systems has shown that building a large cost effective NDGPS network is feasible. It also demonstrates the capability to achieve NDGPS coverage goals while maintaining the integrity and accuracy users expect from the traditional USCG maritime service.

Several challenges remain before the system can attain full operational capability scheduled for 2003 [10]. Aside from political issues dealing with US Congressional funding, these unique challenges include improvements in the existing GPS infrastructure, environmental issues associated with constructing new sites, and the sliding scale of technology. While meeting the stringent operational requirements and supplying the advertised DGPS MF signal, the USCG must implement a nationwide DGPS system that will be functional and supportable. At the same time, it must seamlessly integrate planned GPS improvements, the removal of S/A, and the evolving requirements for improved accuracy for the complete life cycle of the system.

As the user base increases with the advent of new applications and technology, C2CEN, USCG and DOT will continue to improve the NDGPS system to meet constantly changing public needs. Users of the DOT supplied DGPS MF correction signal can be confident of the integrity and accuracy of their DGPS position knowing the engineering successes that have led to this expanding US Nationwide Differential Positioning System.

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