THE PRESIDENT'S
NATIONAL SECURITY TELECOMMUNICATIONS
ADVISORY COMMITTEE

NSTAC Report to the President on Commercial Communications Reliance on the Global Positioning System (GPS)

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EXECUTIVE SUMMARY

The President's National Security Telecommunications Advisory Committee (NSTAC) performed an evaluation in response to a White House request for commercial communications industry findings on the commercial communications infrastructure's reliance on the Global Positioning System (GPS). To gain current perspectives on the industry-wide use of GPS, the NSTAC solicited information from its members, other providers within the industry, and several external subject matter experts. Specifically, the NSTAC requested information on: (1) company and industry segment use of and reliance on GPS signals; (2) impacts to networks and operations that would result from loss or degradation of GPS signals; and (3) specific strategies implemented or planned to mitigate the impact of any GPS signal loss or degradation.

A broad cross-section of the commercial communications industry submitted feedback, including responses from individual companies in the telecommunications, computer software/services, and aerospace and defense sectors, and from industry trade associations. As a result of the evaluation, the NSTAC developed several findings and a recommendation for White House review and consideration.

This evaluation focuses narrowly on the commercial communications industry's use of and reliance on GPS, in accordance with White House direction to tailor the effort to enable a quick response. The NSTAC notes that reliance on GPS signals in military, maritime, aviation, and other civil environments varies widely depending on the specific use and application. GPS-based precision-guided munitions, maritime harbor approach and constricted waterway navigation, and aviation approach and landing are examples of critical applications with varying positioning, navigation, and timing (PNT) requirements supported by GPS. While instructive in understanding overall GPS deployment trends and vulnerabilities, non-commercial information was not evaluated or integrated into the NSTAC's findings, as that area was deemed to be outside the scope of this effort. The NSTAC looks forward to ongoing engagement with the White House staff and offers its continued support to national security telecommunications policy development and program planning.

Study Findings and Recommendation

The U.S. Government's commitment to provide and maintain civil space-based PNT services, such as GPS, free of direct user fees for civil, commercial, and scientific uses has encouraged the rapid adoption of GPS-based solutions throughout the commercial communications industry. In today's environment, GPS supports a broad range of commercial communications industry functions and applications; the primary use of GPS in each industry segment is in support of the networks' precise timing and synchronization requirements. Companies have selected and widely implemented GPS-based solutions primarily because GPS provides an inexpensive, globally-available, and highly reliable Stratum 1-quality reference source. As the commercial communications network infrastructure continues to evolve toward a high-speed all-digital environment, accurate timing and synchronization functions that support the infrastructure are becoming more critical.

Another important use of GPS is support to wireless location-based services, including support of wireless Enhanced 911 (E911) Phase II requirements. As the overall market for GPS-based devices and services continues to grow, the commercial communications industry is likely to identify and utilize additional uses of GPS to increase productivity, service delivery, and the number of available end-user applications.

Because of the fundamental role that GPS plays in supporting the commercial communications infrastructure, industry employs a range of strategies to mitigate the impact of GPS loss or disruption. To protect critical functions such as network timing and synchronization, companies proactively employ multiple layers of backup capabilities, mitigation strategies, and contingency plans to ensure protection against a wide range of potential GPS outage or disruption scenarios. At critical nodes in the infrastructure, redundant Stratum 1-level sources are deployed and protected automatically by secondary and tertiary backup capabilities and alternate timing sources. All major carriers adhere to extremely rigorous industry-standard requirements for network timing synchronization.

Technological, economic, and regulatory considerations necessarily factor into individual company decisions on how to mitigate the potential impact of GPS loss. Companies must consider available equipment types and cost, the required level of quality and precision, the failure or disruption tolerance of the underlying service/application, the desired level of redundancy, and the likelihood of GPS disruption and potential impact. As a result, while backup solutions and processes are universally implemented within the industry, specific implementations vary widely both within a particular industry segment, and across industry segments.

Because automatic backup capabilities and other safeguarding/mitigation strategies are widely available and implemented, short-term loss or disruption of GPS will have minimal impact on the commercial communications infrastructure and its operations. One important exception is that short-term loss or disruption of GPS signals will affect the ability to determine accurate location information for wireless E911 purposes.

The specific consequences of medium- to long-term loss or disruption of GPS will vary based on a number of factors, including the specific function or application being supported by GPS, the duration of the loss/disruption, the geographic size of the affected region, and the availability and implementation of effective backup capabilities and contingency plans. Feedback from the study generally indicates that the wireline network infrastructure, including wireline components of wireless, satellite, cable, and broadcast networks, will sustain operation automatically for approximately 30 days. Network performance would be closely monitored, as it is still possible for performance to be impacted during this time period. For other components, the impact of long-term GPS loss varies. For example, in the wireless network environment, the ability to hand calls off between code division multiple access-based cell sites will begin to be affected after 24 hours. In the satellite, cable, and broadcast network environments, service-specific impacts unique to those environments could occur (e.g., experiencing delay in the time to acquire satellite lock, reverting to the manual recording of radio frequency signal leakage by cable network operators, experiencing In Band On Channel/Hybrid Definition radio transmission degradation in the broadcast environment).

In the extremely unlikely event of a complete and catastrophic loss of GPS over an extended period of time (e.g., more than one month) and affecting a large geographic area (e.g., nationwide, continental, global), overall impact is more difficult to ascertain. Because of the diverse and highly distributed implementations of GPS-based solutions across the industry, any impact likely would be experienced in the form of a gradual degradation of network performance, with little potential for cascading network failures. Additional backup capabilities, processes, and mitigation approaches can and will be used to sustain network operation beyond this period; however, mitigation of an extended and complete loss of GPS would require costly reconfiguration of the network to redistribute alternative timing sources. Such a reconfiguration would require a cooperative effort between carriers.

The NSTAC also emphasizes that commercial communications networks do not operate in a vacuum, and service providers and network operators will take immediate corrective actions in response to any size event, particularly a large-scale catastrophic event with the potential to degrade the network. Even before all automatic means of backup are exhausted, companies will have already executed contingency plans and performed manual reconfigurations and network timing adjustments as required to maintain network operation.

Overall, industry members surveyed believe that their companies have taken measures to safeguard against those disruptions to the GPS signal that are likely to be encountered; however, to date, no industry or Government exercise has sought to replicate the impact of a long-term or permanent GPS outage simultaneously on all industries. The NSTAC recommends that the President direct the Department of Homeland Security and the Department of Defense to include various GPS outage scenarios in future planned disaster recovery exercises in coordination with the commercial communications industry.

1.0 BACKGROUND AND PURPOSE

In response to a January 2003 request from the Director, National Security Space Architect, the President's National Security Telecommunications Advisory Committee (NSTAC) reviewed and assessed policies, practices, and procedures for the application of infrastructure protection measures to commercial satellite communications systems used for national security and emergency preparedness communications. Specifically, the NSTAC reviewed applicable documentation addressing vulnerabilities in the commercial satellite infrastructure and identified potential policy changes that would bring the infrastructure into conformance with a standard for mitigating those vulnerabilities. As a part of its review, the NSTAC also considered Global Positioning System (GPS) timing capabilities and developed initial findings and a recommendation for further study of GPS-related issues. The results of this effort were published in the *NSTAC Satellite Task Force Report*, March 2004.

At the 2007 NSTAC Meeting, Ms. Frances Fragos Townsend, Assistant to the President for Homeland Security and Counterterrorism, requested that the NSTAC begin a scoping effort to further evaluate the commercial communications infrastructure's reliance on GPS.
Ms. Townsend called for the NSTAC to present its findings and recommendations for White House evaluation.

In response to this request, the NSTAC formed a working group comprised of industry and Government representatives to review findings from the March 2004 study and examine the commercial communications reliance on GPS, as well as the possible impacts that loss or disruption of GPS could have on the commercial communications industry, including its reliance on GPS for synchronizing local timing clocks. This response presents the NSTAC's findings for White House review and consideration.

2.0 APPROACH AND SCOPE

The study approach and scope for this effort are briefly discussed below.

2.1 Approach

Representatives of NSTAC member companies, subject matter experts (SME) from non-NSTAC commercial communications companies, trade associations, Government participants, and GPS technical experts contributed to this effort. To gain a broad understanding of the use of and reliance on GPS within the commercial communications industry, the NSTAC invited SMEs from the Government, private sector, and academia to present briefings. The NSTAC also reviewed previous studies, including the March 2004 *NSTAC Satellite Task Force Report* findings on GPS vulnerabilities in the commercial satellite infrastructure and the findings and recommendations of the August 2001 *Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System*, prepared by the Volpe National Transportation Systems Center. Appendix A provides a list of working group members, Government personnel, and other participants.

To gain current perspectives on the industry-wide use of GPS, the NSTAC solicited information from its members as well as representatives of the Department of Homeland Security (DHS) National Coordinating Center-administered Telecommunications Information Sharing and Analysis Center. Specifically, the NSTAC requested information on: (1) company and industry segment use of and reliance on GPS timing and precision location signals; (2) impacts to networks and operations that would result from loss or degradation of GPS signals; and (3) specific mitigation strategies implemented or planned to minimize the impact of any GPS signal loss or degradation.[1]

A broad cross-section of the commercial communications industry submitted feedback, including responses from individual companies in the telecommunications, computer software/services, and aerospace and defense industry sectors, and from industry trade associations. The NSTAC presents its findings in this document and looks forward to continued engagement with the White House staff to support ongoing national security telecommunications policy development and program planning.

2.2 Scope

This study focuses narrowly on the commercial communications industry's use of and reliance on GPS, in accordance with White House direction to tailor the effort to enable a quick response. Deliberations with SMEs and evaluation of previous studies included information involving GPS uses and applications to military, maritime, aviation, and other civil environments. While instructive in understanding overall GPS deployment trends and vulnerabilities, non-commercial information was not evaluated or integrated into the NSTAC's findings, as that area was deemed to be outside the scope of this effort.

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[1] Within the commercial communications industry, the term "mitigation" often refers to **reactive** approaches or strategies applied after an event has occurred. Reflecting the industry responses collected for the study, this report uses the term more broadly to encompass both reactive approaches as well as **proactive**, or preventative, safeguarding strategies.

In soliciting information and perspectives from commercial communications industry representatives and the larger SME community, the NSTAC specifically requested that data submitted for the analysis be non-proprietary and unclassified. The findings documented in this response are generally applicable across all industry segments and represent NSTAC member company consensus. However, it is important to note that the study analysis revealed significant variance in the use of and reliance on GPS across industry segments and across companies within each industry segment. Feedback from individual companies likewise indicated that a wide variety of strategies, techniques, and implementation approaches are applied to mitigate the impacts of GPS loss or disruption, reflecting company-specific business case and risk assessment determinations.

3.0 COMMERCIAL COMMUNICATIONS RELIANCE ON GPS

This section describes the commercial communications reliance on GPS. **Section 3.1** discusses the use of and reliance on GPS, including applications and dependencies specific to the wireline, wireless, satellite, cable, broadcast, and corporate/enterprise network environments. **Section 3.2** generally characterizes the impact of loss or disruption of GPS for each network environment. **Section 3.3** identifies associated strategies, employed or planned by industry, to mitigate GPS-related impacts.

3.1 Use of GPS

GPS is a U.S. Government-owned utility that provides users with positioning, navigation, and timing (PNT) services. The U.S. Air Force operates the space and control segments, consisting respectively of the GPS satellite constellation and the worldwide control stations that maintain the satellite orbits and adjust the satellite clocks. The user employs GPS receiver equipment to receive signals from the satellites and calculate the user's location. Using the signals to measure the distances to at least four satellites simultaneously, a GPS receiver can determine three-dimensional position (latitude, longitude, and altitude) while synchronizing its clock with the GPS precise time standard.[2] The GPS constellation, illustrated in **Figure 1**, consists of a minimum of 24 satellites in one of six medium-earth orbits, approximately 20,000 kilometers above the earth's surface.[3]

The U.S. Department of Defense (DOD) began development in the 1970s of what would become the GPS system. However, the first U.S. pronouncement regarding civil use of GPS came in 1983 following the downing of Korean Airlines Flight 007. The Soviet Union shot down the airplane after it strayed over Soviet territory; afterwards, President Reagan announced that GPS would be made available for international civil use once the system became operational.

The first major success of GPS came in 1990-1991, during Operation Desert Storm. DOD's needs during the crisis sparked a surge in the GPS market, which had barely existed just a few years prior to the war. Desert Storm provided a showcase for all the military uses of GPS—from helping soldiers navigate across the desert to vastly improving targeting capabilities of artillery and bomber units. Following the war, GPS device sales to non-DOD customers surged, and U.S. commercial GPS manufacturers continue to produce new and cheaper receivers that are used across numerous industries and infrastructures.[4]

On December 8, 2004, the President established a new national *U.S. Space-based Positioning, Navigation, and Timing Policy* containing guidance and implementation actions for space-based PNT programs, augmentations, and activities for U.S. national and homeland security, civil, scientific, and commercial purposes.[5] In the policy, the U.S. Government pledged to provide on a continuous, worldwide basis, civil space-based PNT services free of direct user fees for civil,

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[2] To synchronize its clock, a GPS receiver requires signals from only one satellite in the constellation.

[3] Currently, there are 29 operational satellites and one experimental satellite in orbit.

[4] Pace, Scott, et. al. *The Global Positioning System: Assessing National Policies*, 1995.

[5] Available at the National Space-Based Positioning, Navigation, and Timing (PNT) Executive Committee Web site, http://pnt.gov/policy/

commercial, and scientific uses. The policy also established an Executive Committee that is charged in part with ensuring that efforts to deny hostile use of any space-based PNT services will not unduly disrupt civil and commercial access to civil PNT services outside an area of military operations, or for homeland security purposes.

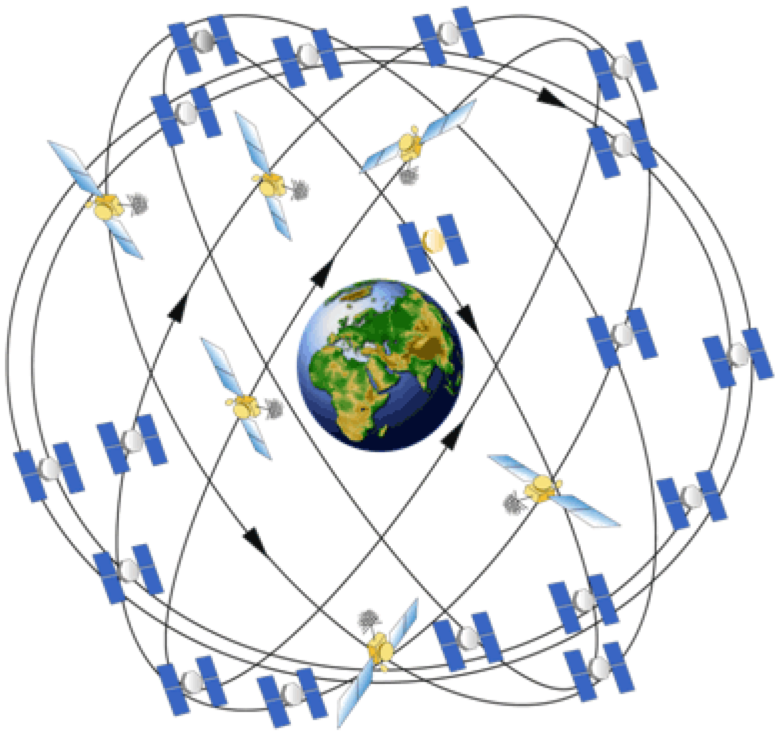

Figure 1. GPS Constellation[6]

Although DOD controls and maintains the GPS, and makes the service available to U.S. and allied armed forces, there is also a large civilian component in the user community. The Department of Transportation is responsible for overseeing all civil uses of GPS, which has become integral to navigation for aviation, ground, and maritime operations. Emergency responders depend upon GPS for location and timing capabilities in their life-saving missions. Banking, mobile phone operations, and the control of power grids are facilitated by the accurate timing provided by GPS. Farmers, surveyors, and geologists use the free and open GPS signals to pinpoint locations.[7]

Commercial communications companies have selected and widely implemented GPS-based network timing and synchronization solutions primarily because GPS provides an inexpensive, globally-available, highly reliable, and extremely accurate reference timing source. The U.S. Government's commitment to provide and maintain civil space-based PNT services, such as GPS, has also encouraged rapid adoption of GPS throughout the commercial communications industry. The use of GPS-disciplined oscillators (GPSDO), implemented extensively throughout

[6] Source: National Space-Based PNT Executive Committee, http://www.pnt.gov

[7] http://www.gps.gov

the industry, is a cost-effective solution able to meet the various stringent network performance requirements for time and frequency. The use of and reliance on GPS in the wireline, wireless, satellite, cable, broadcast, and enterprise network environments are further described below.

Wireline Network Environment. GPS signals in the wireline network environment are fundamentally used as a primary reference timing source for a diverse range of telecommunications network equipment, including wireline switching offices, Synchronous Optical NETwork (SONET) and Synchronous Digital Hierarchy (SDH) nodes, multiplexer and demultiplexer equipment, digital cross connects, and customer premise equipment (e.g., private branch exchanges [PBX]). GPS is also used as a reference timing source for other industry segment wireline-connected network elements, including mobile switching centers (MSC), satellite network control and earth station equipment, and other core cable network and broadcast network elements.

In addition to provision of a primary time reference, GPS signals also are used to support essential network time, frequency, and phase synchronization functions. Digital telecommunications networks require highly reliable precision frequency and timing information to maintain data integrity and guarantee the delivery of high quality services. Timing impairments, or "slips," can cause impacts to service quality such as increased noise or "pops" during voice calls, loss of picture content during facsimile transmission, inefficient retransmission of data packets, and video content "drop out" and "freeze frame" occurrences. More severe impacts resulting from timing and synchronization impairments include dropped calls/connections, the inability to initiate/receive calls and establish/maintain connections, the loss of circuit or transmission path integrity, and eventual network element isolation and/or placement in an "out of service" condition. As the commercial communications network infrastructure continues to evolve toward a high-speed all-digital environment, accurate timing and synchronization functions that support the infrastructure are becoming more critical.[8]

In characterizing their use of and reliance on GPS, companies across industry segments (e.g., wireless, satellite, cable, and broadcast) note the associated wireline network reliance on GPS as a potential factor in their own reliance on GPS. Network interconnections (e.g., network interface points) and leased lines used to connect internal network elements are examples of underlying wireline components whose operation may have a dependence on GPS.

Wireless Network Environment. GPS is used to provide the highly accurate timing source required to synchronize mobile phones to the cellular network and to synchronize cellular network elements to one another. Radio carrier frequencies must also be synchronized precisely in order to prevent co-channel interference (i.e., cross talk) and other radio frequency (RF) interference problems. For code division multiple access- (CDMA) based networks in particular, precise frequency synchronization is required to support handoff of calls between cell sites.

Another important use of GPS in the cellular network environment is in support of location-based services, including support of Enhanced 911 (E911) Phase II requirements. To comply with the Federal Communications Commission's (FCC) wireless E911 requirements,

[8] National Communications System, "Telecommunications Network Time Synchronization," NCS Technical Information Bulletin 99-4, April 1999.

wireless carriers require accurate positioning information to provide the precise locations of wireless network callers so that police, fire, and emergency rescue personnel can be dispatched quickly.[9]

GPS also provides Time-of-Day information to support several cellular network functions including setting clock time on mobile devices and accurately time stamping billing records and data packets for network and service performance measurement. Feedback from industry also identified internal company use of wireless network services (e.g., use of cellular and paging services by company employees and contractors) as a potential peripheral reliance on GPS. Internal communications may be disrupted if these wireless network services become unavailable due to loss of GPS.

Satellite Network Environment. In the satellite industry, use of GPS signals is fundamental in providing timing reference and synchronization across satellite constellations and satellite network elements. In addition to timing synchronization, satellite network operators use GPS signals broadly in support of telemetry, tracking, and control (TT&C) time tracking and ranging operations as well as frequency referencing for many applications. Most land earth stations (LES) use GPS as a primary means to set the internal station frequency standard and clocks, and central satellite control systems use GPS as a master clock timing reference. Fixed satellite-based communications terminals also use GPS for geo-location and a timing reference. GPS capabilities enable terminals to quickly locate and acquire a satellite. Terminals may also use GPS to synchronize the terrestrial communications equipment with which they interface, providing consistent data flow throughout the link. Some satellite terminals that use complex spread spectrum waveforms rely heavily on GPS for system synchronization.

Cable Network Environment. The cable television industry also relies on GPS time signals as a primary timing reference for several network infrastructure components, including Building Integrated Timing Supply (BITS) clocks, Network Time Protocol (NTP) server deployments, Data Over Cable Service Interface Specification (DOCSIS) timing interface servers, and interconnecting or supporting wireline and wireless network elements (e.g., time-division multiplexing [TDM] circuits, T1 emulation circuits, microwave radio links). NTP servers are used by cable operators in support of the following: synchronization across cable system equipment such as servers, routers, switches, and terminal equipment (e.g., cable modems); time stamps in simple network management protocol tables and local logging for error and event correlation; set-top boxes, which use time information for use in electronic program guides, reliable content recording, and in processing Emergency Alert messages; and service applications such as video-on-demand (VOD) and Ad Insertion systems. Additionally, pursuant to FCC regulations, cable operators routinely monitor their systems for RF signal egress or "leakage," using signal leakage detection equipment that utilizes GPS location signals to automate the process of locating and repairing signal leaks.

[9] Under Phase II, the FCC requires wireless carriers, within six months of a valid request by a Public Safety Answering Point (PSAP), to begin providing the latitude and longitude of a caller, typically within 50 to 300 meters. The FCC requires carriers using GPS-enabled handsets to locate callers within 150 meters 95 percent of the time and within 50 meters about 67 percent of the time. In September 2007, the FCC voted to require wireless operators to meet E911 requirements at a local level, specifically the jurisdictional areas of individual 911 PSAPs, expanding upon the previous statewide or multi-state level requirement. Carriers must meet location accuracy targets by September 11, 2012.

Broadcast Network Environment. GPS-based systems are widely employed by broadcast radio and television (TV) stations. GPS provides precise timing and phasing references for equipment throughout the broadcast production and transmission chain. GPS is used as frequency reference for both analog and digital television transmitters. This is particularly important in the proper implementation of "Precision Off-Set," which is used to ensure that a digital TV (DTV) transmitter will not interfere with an analog transmitter operating on the same channel. In addition, single frequency TV networks recently have been approved for use by the FCC and are just beginning to be deployed in the U.S. This technology, called Distributed Transmission, relies heavily on GPS to ensure that all the transmitters in the network remain synchronized.

GPS is used to support the proper synchronization of digital radio transmitters. The U.S. In-Band-On-Channel (IBOC) digital transmission technology, also known as Hybrid Digital (HD) radio, overlays digital carriers onto an FM station's analog signal and relies on precise timing to ensure that the digital signal does not degrade those analog transmissions.

In both radio and TV production studios, GPS is used as the reference for the master clock system, which ensures that all the clocks in the studio increment their second hands simultaneously and remain locked to the same time. GPS is also used to derive master timing reference signals, which are required in a broadcast production system to keep audio and video in synchronization, to ensure that automation systems are time-aligned, and to meet the various requirements for broadcast standards compliance.

Enterprise Network and Corporate Operations Environment. Feedback from the commercial communications industry also identifies use of and reliance on GPS signals to support company-internal enterprise network operation as well as corporate operation functions. For example, one company cites use of GPS timing via NTP servers for synchronization of all device timing (e.g., timing for switches, routers, servers, and desktops) on its global corporate network. Multiple GPS receivers feed timing data to distributed NTP servers, which synchronize their clocks to the GPS-provided time reference on a periodic basis. Network and computing resources then access the NTP servers for timing. The company also cites use of GPS timing to synchronize its internal SONET infrastructure. Regarding corporate operations, several companies cite extensive use of communications services (e.g., cellular and paging services, satellite phone service, use of personal communications devices such as Blackberry® devices) by employees and/or contractors while performing their jobs. Availability of these communications services may be impacted by a GPS loss or disruption. GPS equipment vendors also utilize the GPS signal during product development, testing, and production.

In support of workforce and resource management functions, GPS signals are used across the industry by field operations staff to more effectively coordinate service and maintenance activities. For example, in support of the cable industry's field service, plant maintenance, and auditing activities, company vehicles may utilize GPS signals as a part of intelligent automated vehicle fleet management systems. Another cited example of use of GPS positioning data is a disaster recovery and employee location mapping capability used by the company in the event of a regional incident. GPS location information is also used by some companies to support industry functions such as fiber locating operations (or "call before you dig" operations) and other field test and measurement functions. As the overall market for GPS-based devices and services continues to grow, the commercial communications industry is likely to identify and utilize additional uses of GPS to increase productivity, service delivery, and the number of available end-user applications. **Table 1** lists some examples of the commercial communications industry's uses of and reliance on GPS signals.

Table 1. Examples of GPS Use and Reliance

Network Environment	Application/Use
Wireline	• Time/frequency reference source (e.g., central offices [CO], SONET, TDM circuits, digital access and cross-connect (DAC) systems, termination equipment, voice switches) • Network timing/synchronization • Workforce and Resource Management
Wireless	• Time/frequency reference source (e.g., wireline elements, MSCs, cell sites, HLR/VLRs, mobile devices) • Network timing/synchronization (network element-to-network element, mobile phone-to network, RF carrier frequency sync) • CDMA mobile unit handoff • E911 Phase II and location-based services • Time-of-Day functions (clocks on mobile units, timestamp for billing and performance measurement) • Workforce and Resource Management
Satellite	• Time/frequency reference source (e.g., satellite network ground segment elements, land earth stations, TDM circuits, satellite terminals) • Network/Application timing and synchronization • TT&C time tracking and ranging operations • Workforce and Resource Management
Cable	• Time/frequency reference source (e.g., switches, routers, NTP server deployments, DOCSIS timing interface servers, cable modems, set-top boxes) • Network timing and synchronization • Set-top box use (electronic program guides, content recording, alert message processing) • Service applications (VOD, Ad Insertion systems) • RF signal leakage detection • Workforce and Resource Management
Broadcast	• Time/frequency reference source (e.g., broadcast production/distribution facilities, digital TV "Precision Off-Set") • Network timing and synchronization (e.g., DTV, IBOC/HD radio) • Broadcast audio/video synchronization • Time alignment for Automation systems • Per occasion Applications (e.g., remote broadcasting) • Workforce and Resource Management
Enterprise/ Corporate Operations	• Timing/frequency reference source • Network and device timing and synchronization (SONET, servers, routers, switches, desktops) • Fiber locating • Workforce and resource management • Development and production of GPS equipment and devices

Key findings regarding the commercial communications industry's use of and reliance on GPS are:

- The U.S. Government's commitment to provide and maintain civil space-based PNT services, such as GPS, free of direct user fees for civil, commercial, and scientific uses has encouraged rapid adoption of GPS throughout the commercial communications industry.
- GPS supports a broad range of commercial communications industry functions and applications in many commercial communications industry segments (e.g., wireline, wireless, satellite, cable, and broadcast network environments).
- The primary use of GPS in the commercial communications industry and across all commercial communications industry segments is the support of precision timing and network synchronization functions.
- Another important use of GPS signals is support to location-based services, including support of wireless E911 Phase II requirements.
- As the commercial communications network infrastructure continues to evolve toward a high-speed all-digital environment, accurate timing and synchronization functions that support the infrastructure are becoming more critical.
- As the overall market for GPS-based devices and services continues to grow, the commercial communications industry is likely to identify and utilize additional uses of GPS to increase productivity, service delivery, and the number of available end-user applications.

3.2 Impact of Loss or Disruption of GPS

In its 2004 study, the NSTAC found that "impacts of a loss of GPS could be seen across all aspects of the telecommunications industry … on wireline and wireless networks …[and] fiber optic and broadband transmission systems; radio, television, and cable broadcast systems; and satellite systems – all of which use GPS to some extent for synchronizing local timing clocks." Industry submissions in this GPS study generally confirm this finding and further substantiate specific impacts of GPS loss or disruption within each industry segment.

Generally, feedback indicates that short-term loss or disruption of the GPS signals for timing will have minimal impact on the commercial communications infrastructure and its operations. One important exception is that short-term loss or disruption of GPS signals will affect the ability to determine accurate location information for wireless E911 purposes. The impact of medium- to long-term loss or disruption of GPS will vary based on a number of factors, including the specific function or application being supported by GPS, the duration of the loss/disruption, the geographic size of the affected region, and the availability and implementation of effective backup capabilities and contingency plans.

Specific impacts of GPS loss in the wireline, wireless, satellite, cable, broadcast, and enterprise network environments are described below. Additional details on strategies for mitigating the impacts of GPS loss are presented in **Section 3.3**.

Wireline Network Environment. In the case of a short-term complete GPS loss or a long-term localized GPS loss, carriers indicate that the impact on wireline network operation is minimal due to the availability and use of backup systems and processes, alternative timing sources, and effective business continuity planning.[10] The most commonly-cited potential impact in the wireline network environment is the eventual loss of network timing and synchronization as a result of a long-term complete loss or disruption of the GPS timing signal across an extended area. Wireline carrier feedback indicates that wireline network infrastructure (e.g., circuit switches) will sustain operation automatically for approximately 30 days. Network performance would be closely monitored, as it is still possible for performance to be impacted during this 30-day window. Secondary and tertiary backup capabilities and other mitigation processes can and will be used to sustain network operation beyond this period. Carriers also note that mitigation of an extended and complete loss of GPS beyond this period would require costly reconfiguration of the network to redistribute alternative timing sources. Such a reconfiguration would require a cooperative effort between carriers. It should be noted that such an event, resulting in complete loss of GPS for an extended time and over a large geographic area, has never occurred.[11] Additionally, no industry or Government exercises have sought to replicate the impact of a long-term or permanent GPS outage simultaneously on all industries.

CO timing signal generator (TSG) systems provide a common source for frequency and phase alignment of all network elements operating in the CO building. This synchronization is essential for interoperability of digital transmission networks. The TSG receives timing from a highly accurate GPS primary reference source (PRS), cesium PRS, or Stratum 1-traceable timing delivered via an interoffice facility. These timing systems provide a robust, simple-to-administer, and trouble-free network of clocks of known quality and performance characteristics. Reliable clocks ensure that network synchronization provides the necessary level of performance demanded by a growing digital network.

The hierarchy of clock requirements is grouped into four stratum levels, as defined by the American National Standards Institute (ANSI) T1.101 standard.[12] The standard defines the minimum performance requirements for telecommunications network synchronization and timing requirements for each stratum level, as shown in **Table 2**.

[10] The term "complete GPS loss" refers to the inability to receive any GPS signals at all locations. The term "localized GPS loss" refers to the inability to receive any GPS signals within a limited geographical area (e.g., campus, city, region). These terms are in contrast to the term "partial GPS loss" which refers to the inability to receive signals from some, but not all, GPS satellites. According to industry feedback, partial GPS loss has no appreciable impact on network operations and services.

[11] While the examination of network impacts related to specific GPS vulnerabilities is outside the scope of this study, the NSTAC considered information on a range of threats and vulnerabilities, including unintentional disruption (e.g., solar bursts and ionospheric interference, RF interference sources, human factors) and intentional disruption (e.g., shutdown, jamming, spoofing, and meaconing [a system of receiving radio beacon signals and rebroadcasting them on the same frequency to confuse navigation]). In reviewing these vulnerabilities, participants generally characterized the potential for any long-term complete GPS loss as unlikely. Participants also agreed that the further study on GPS vulnerabilities, particularly potential space weather impacts, is necessary to better characterize likelihood of impact to the commercial communications infrastructure (See Associated Press, *Solar Bursts Could Threaten GPS,* April 5, 2007).

[12] American National Standards Institute, *T1.101-1999: Synchronization Interface Standards for Digital Networks.*

- Stratum 1 is the highest quality level in the clock hierarchy. Stratum 1 clocks are defined as autonomous sources, requiring no input from another source. In order to meet interface standards, all digital signals must be under the control of a clock or clocks traceable to a Stratum 1 source. Stratum 1-level timing sources, typically atomic oscillators (e.g., cesium beam) or GPSDOs, are specified to have a maximum "drift" of 1×10^{-11}. As shown in **Table 2**, T1 carrier cycle slips can be expected to occur only once every 72.3 days, worst case, if Stratum 1-quality clocks are used.

- Stratum 2 and lower-level clocks require input and adjustment from a higher stratum-level clock. Stratum 2 clocks are typically used as the master TSG oscillator at critical network sites. Stratum 2 TSG systems employ rubidium oscillators for extended holdover capability.

- Stratum 3E clocks are used as the master TSG oscillator at other locations in the network that are not Stratum 2 equipped. The Stratum 3E level was defined as a result of the widespread deployment of SONET transport and the associated need for enhanced phase filtering capabilities. Stratum 3 clocks are used in digital switches, DACs, and SONET network elements.

- Stratum 4 clocks are found in distribution facilities (e.g., channel banks) and end-user switching equipment (e.g., PBX).

It should be noted that every network element and every clock is effectively operating at the Stratum 1 level when the timing hierarchy is intact. The stratum level of subtending clocks only becomes a factor when the timing distribution chain is disrupted, and the holdover characteristics of the oscillators come into play.

Table 2. Stratum Clock Hierarchy and Timing Accuracy Requirements[13]

Stratum Levels	**Stratum 1**	**Stratum 2**	**Stratum 3E**	**Stratum 3**
Frequency accuracy, adjustment range	1×10^{-11}	1.6×10^{-8}	1×10^{-6}	4.6×10^{-6}
Frequency stability	NA	1×10^{-10}	1×10^{-8}	3.7×10^{-7}
Pull-in range	NA	1.6×10^{-8}	4.6×10^{-6}	4.6×10^{-6}
Time offset per day due to frequency instability	0.864 µs	8.64 µs	864 µs	32 ms
Interval between cycle slips	72.3 days	7.2 days	104 minutes	169 seconds

In the event of a complete loss of GPS signals, the wireline synchronization network is designed to fall back on internal network clocks, such as cesium PRS systems and rubidium and crystal oscillators, used for extended holdover capability. As Stratum 1-level clocks, cesium PRS

[13] Lombardi, Michael, NIST Time and Frequency Division, *Legal and Technical Measurement Requirements for Time and Frequency.*

systems are autonomous timing sources, equal in quality to a GPS-derived timing signal. Due to cost considerations, cesium PRS systems generally are only deployed at critical network sites.

For locations that receive their timing reference from a GPS PRS, extended loss of GPS would eventually cause the oscillator in the TSG to enter holdover status. Once in holdover, the oscillator in the TSG can maintain accurate frequency timing for a period dependent on the type of oscillator. For a Stratum 2 rubidium oscillator, network performance will be maintained for about thirty days. For a Stratum 3E crystal oscillator, network performance will be maintained for seven to ten days.[14] Once the holdover capability of the TSG oscillator is exceeded, these clocks would begin to "drift" away from a common frequency, and network elements would gradually lose synchronization with one another.

Service providers also cite the use of available external timing reference sources as a means to establish an accurate time reference (e.g., geographically diverse and redundant GPS-based devices, a backup precision timing reference source such as the LORAN-C signal, reconfiguration to "line time" off an interconnected network). Approaches to timing and synchronization backup (e.g., the types and order of secondary and tertiary backup sources employed) vary by service provider; however, all major carriers adhere to Telcordia standards for timing synchronization.[15]

As noted in the 2004 NSTAC study, a general approach in the public switched telephone network (PSTN) is to deploy a Stratum 1 timing source to every CO through a combination of cesium PRS systems, GPS-based solutions, and interoffice distribution of Stratum 1-traceable timing references.[16] Cost remains a primary factor in selecting a solution. For example, the cost of a cesium-based solution typically exceeds that of a GPS-based solution by about $20,000. Interoffice distribution of timing references is the least capital-intensive solution, but requires extensive planning and maintenance to ensure proper execution.

In summarizing impact to the wireline network, carrier feedback indicates that the wireline network infrastructure (e.g., circuit switches) will sustain operation automatically for approximately 30 days in the event of complete loss of GPS signals. Network performance would be closely monitored, as it is still possible for performance to be impacted during the 30-day window. Additional backup capabilities, processes, and mitigation approaches can and will be used to sustain network operation beyond this period. However, mitigation of an extended and complete loss of GPS would require costly reconfiguration of the network to redistribute alternative timing sources. Such a reconfiguration would require a cooperative effort between carriers.

[14] As noted in the 2004 NSTAC study, a Stratum 2 timing source referenced by a Stratum 1 timing source will maintain accuracy for up to one month. As shown in **Table 2**, a Stratum 2 source with no reference performing at the **minimum** ANSI T1.101 accuracy requirement (worst case) would result in an interval of about seven days between cycle slips. Similarly, at the minimum specified frequency accuracy for Stratum 3E clocks, the worst case interval between cycle slips is 104 minutes.

[15] Telcordia, Generic Requirements GR-253-CORE, *Synchronous Optical Network Transport Systems*, and GR-1244, *Clocks for the Synchronized Network,* among others.

[16] *NSTAC Satellite Task Force Report*, March 2004.

Wireless Network Environment. Long-term GPS timing signal loss or degradation could impair wireless network timing and synchronization. GPS is utilized in wireless network synchronization and provides a precise timing and frequency reference source for cell site radio controllers, MSCs (and interconnected wireline switching offices), and other wireless network elements. All of these network elements have backup internal and/or external timing sources, but if the GPS clock source is lost or disrupted, the internal timing sources will begin to drift from component synchronization at a rate based upon the class/type of clock implemented, and the timing error will build proportionally over time during which the reference source is unavailable. The error rate will build over time, and hard failures will manifest themselves randomly once the clocks drift outside of the system synchronization thresholds.

Wireless network operators report that the cell sites in an affected area likely would be the first cellular network elements to begin to drift, as their internal clocks typically guarantee only 24 hours of highly accurate holdover time. Beginning after 24 hours and as the timing of the cell sites drifts apart from one another (due to the lack of a common time reference), handoffs between cell sites would begin to fail, and cell sites would start to become isolated from the other cell sites in the network; however, in this scenario, cell sites would still be able to communicate with the MSC, and calls could still be originated from subscriber phones.

The wireline components of cellular networks can be expected to perform as discussed in the wireline network environment section above. For example, the lack of synchronization between MSCs would begin to result in "slips" on digital inter-office circuits/elements, eventually affecting circuit integrity between MSC locations and resulting in communication issues and data loss between network offices. It is likely that cellular telephone customers would initially experience temporary minor communication issues (e.g., pops, clicks, and data loss), which would worsen until the connection to the cell site was effectively out of service.

One wireless service provider noted that even though the company's time reference is maintained with multiple high quality reference time sources, communication with network elements external to the company would also depend upon the ability of those external elements to maintain an accurate time reference. Another wireless service provider stated that, in the event of long-term loss or disruption of GPS, its wireline portion of the network would likely remain operational indefinitely due to redundant backup capabilities (i.e., external Stratum 1-quality timing source as a primary backup and rubidium-based oscillators as a secondary backup).

In addition to timing and data synchronization impacts, loss or degradation of GPS-based positioning information would critically impact wireless Phase II E911 and commercial location-based services. These services would immediately suffer from the inability to gather precise ranging measurements from satellites currently in the visible horizon during a GPS outage. Having fewer operational satellites in the GPS constellation or being out of the range of the receiving site would result in fewer possible location measurement points, making the determination of a highly accurate position estimate more difficult or impossible.[17] Strategies to mitigate the impact of loss of GPS-based location data are further discussed in **Section 3.3**.

[17] Reception of satellite signals from four satellites is needed to establish accurate position.

Other impacts of GPS loss in the wireless network environment include loss of Time-of-Day data that could affect billing and measurement systems' accuracy.

In summarizing the impact on wireless networks, carrier feedback indicates that the first network elements likely to be affected are cell sites, which will sustain operation for at least 24 hours. After this time period, the ability to hand calls off between cell sites will be affected, although calls can still be originated from subscriber phones as communications with the MSC will not be affected. Wireline network elements generally will sustain operation automatically for up to 30 days, although wireless carrier estimates of this time period varied from five days to beyond 30 days.

Satellite Network Environment. The 2004 NSTAC study noted that "most satellite operators use GPS timing for TT&C time tracking, ranging operations, and timing synchronization." Current study responses concur with previous the NSTAC findings. In the event of complete loss of GPS, one satellite network operator notes that its GPS receiver equipment is able to operate independently for several days. After this time period, available backup cesium-standard clocks and stable clock generators would be used as input timing reference to the GPS receiver equipment. This approach offers a long-term solution until GPS-based satellite timing is restored. The satellite network operator notes that it also is investigating the potential for its equipment to accept an external Inter-Range Instrumentation Group (IRIG-H) signal to use for synchronization via the National Institute of Standards and Technology (NIST) WWVB signal.[18]

Another satellite network operator notes that the absence of GPS does not cause an immediate threat to commercial satellite fleets' health; however, the capability to monitor and control satellite fleets would degrade gradually. Backup timing synchronization can be obtained from other sources such as NTP servers, but those servers may be dependent on GPS signals. Manual synchronization is also possible; however, it may prove unsustainable in the long term. One satellite service provider stated that failure of GPS "would be an inconvenience to the satellite control system" and would not result in loss of control.

LESs and satellite terminals are other satellite network elements whose operation may be impacted by GPS disruption. Most LESs use GPS to set the internal station frequency standard and clocks. They typically have atomic clocks for backup timing; however, one respondent noted that localized GPS anomalies may have to be resolved prior to backup initiation, resulting in a temporary outage. Some satellite user terminals require a GPS signal for location, spot beam designation and timing, while other user terminals may have access to platform navigation systems for timing. Other terminals do not require GPS or any external navigation system to function.

Another company response noted that satellite terminal designs are becoming increasingly dependent on GPS capabilities. When satellite terminals employ GPS receivers for geo-location, loss of GPS would impact the ability to quickly find, acquire, and track a satellite. Some fixed satellite-based communications terminals routinely use GPS to increase signal acquisition speed; a loss of the GPS signal would lengthen the acquisition time for an affected terminal.

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[18] National Institute of Standards and Technology, Time and Frequency Division, http://tf.nist.gov/timefreq/stations/wwvb.htm

The potential impact on fixed satellite-based communications terminal operation also can vary depending on terminal design and the underlying technology employed. For example, a simple frequency division multiple access terminal designed with a rubidium-based backup solution could operate almost indefinitely without GPS timing. However, satellite terminals that use more complex spread spectrum waveforms may be more dependent on accurate timing. A spread spectrum application that is not protected by an atomic frequency standard backup solution may suffer acquisition time degradation after only a few hours of GPS signal loss.

In summarizing feedback regarding the satellite network environment, network operators indicate that loss of GPS has minimal impact in the short term. Impacts of a long-term complete GPS loss will vary by company; backup capabilities and processes are available and will be used to mitigate potential impacts.

Cable Network Environment. The cable industry's wireline network infrastructure would be subject to the same wireline-associated impacts of GPS loss or disruption as previously described. The lack of GPS time signals for a prolonged time period would result in frame slips for TDM circuits, T1 emulation, and SONET systems, which would eventually impact the ability for these circuits and networks to carry traffic without some degradation. The lack of GPS time signals would also potentially result in inaccurate clocks on NTP servers used for synchronization across network equipment, set-top boxes, cable modems, and service applications. Potential impairments include inaccurate electronic program guide data, incorrect billing of digital voice calls, and prolonged debugging of network errors due to the lack of synchronized clocks. Should cellular communications become unavailable due to loss or disruption of GPS, cable operations (e.g., work force coordination and management) could be significantly impacted. The use of GPS signals in support of vehicle fleet management is in a nascent stage within the cable industry and impact on productively is likely minimal at this time; however, the loss of productivity may be greater in the future when cable operators have near real-time location information integrated into automated vehicle routing and dispatch systems.

Another associated cable industry impact of GPS loss or disruption is the inability of RF signal leakage detection equipment to automate the process of precisely locating the signal leak in a cable system. Manual recording of leakage locations can be used; however, that method is likely to be less accurate than the automated methods that utilize the GPS location signals, and may lengthen the time needed to repair the signal leak.

In summarizing feedback regarding the cable network environment, the cable network infrastructure dependent upon GPS time signals will sustain operation automatically for approximately 30 days in the event of complete loss of GPS signals. Beyond this period, some circuit termination equipment could be reconfigured to utilize the receive clock from the PSTN as a reference clock; however, this option may not be viable in the event of widespread GPS outage or degradation.[19]

Broadcast Network Environment. GPS is not critical to the operation of most broadcast systems. In the studio, most equipment components, including the master clock and timing reference

[19] Feedback from cable network operators also notes that the cable industry is deploying asynchronous links such as Gigabit Ethernet and will rely less on synchronous networks such as SONET in the future.

signal generators, have their own internal oscillators, which are very stable. If GPS fails, this equipment can be set to "manual" or will automatically revert to the internal oscillators and will be able to operate for some time without drifting off frequency. The same is fundamentally true for digital and analog television transmitters. While they rely on GPS for synchronization and frequency reference, they also have very stable internal oscillators that will take over in the event that GPS fails.

The areas for which GPS is critical are: (1) "Precision Off-Set" between analog and digital television transmitters (this area will no longer be critical after February 2009 when full service analog TV transmitters permanently stop broadcasting as required by law); (2) IBOC transmitters, which may interfere with companion analog FM signals; and (3) Distributed Transmission networks for television, in which the loss of a full-time frequency and time reference at the transmission sites will result in the transmitters creating interference with each other.

In general, through use of internal reference sources, these systems can "flywheel" through a loss of GPS synchronization for an extended period of time.[20] The severity and frequency of intermittent failures of the transmitted signals is directly proportional to the precision tolerance of the internal references. Eventually, system failure can occur due to a loss of synchronization; however, the amount of time to system failure is not easily predicted as it is dependent on the stability of the oscillators in each part of the overall transmission chain.

Enterprise Network and Corporate Operations Environment. GPS disruption may impact the commercial communications industry's enterprise network operation functions through loss of enterprise network timing synchronization. For example, one responder noted that, in the event of an extended GPS disruption or failure, the NTP servers, which provide timing for switches, routers, servers, and desktops, would eventually experience a time shift from true time. Long-term results could include network and service outages, discrepancies in security logs, invalidated public key infrastructure certificates and tokens, and SONET infrastructure failure. Corporate operations functions may also be impacted as industry employees and contractors lose the ability to communicate via paging, cellular, and personal communications (e.g., Blackberry® devices) services impacted by GPS disruption.

GPS disruption may also impact equipment vendor corporate operations with the loss of capability to use GPS broadcast signals while developing and manufacturing company products. This would interfere with product development efforts and subsequently increase development costs, delay product manufacturing and delivery rates, and increase the risk to product operational reliability. The loss or degradation of GPS broadcast signals during development would affect the ability to completely evaluate and test operational system capabilities before production.

In summary, key findings regarding the impact of loss or disruption of GPS are:

- Generally, short-term loss or disruption of the GPS signals for timing will have minimal impact on the commercial communications infrastructure and its operations.

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[20] In an oscillator, the "flywheel effect" refers to the continuation of oscillations after removal of the control stimulus.

- Short-term loss or disruption of GPS signals will affect the ability to determine accurate location information for wireless E911 purposes.

- The impact of medium- to long-term loss or disruption of GPS will vary based on a number of factors, including the specific function or application being supported by GPS, the duration of the loss/disruption, the geographic size of the affected region, and the availability and implementation of effective backup capabilities and contingency plans. For example:

  – In the event of complete loss of GPS signals, wireline carrier feedback indicates that wireline network infrastructure (e.g., circuit switches) will sustain operation automatically for approximately 30 days. Network performance would be closely monitored, as it is still possible for performance to be impacted during the 30-day window. Additional backup capabilities, processes, and mitigation approaches can and will be used to sustain network operation beyond this period; however, mitigation of such an extended GPS loss would require costly reconfiguration of the network to redistribute alternative timing sources. Such a reconfiguration would require a cooperative effort between carriers.

  – In the event of complete loss of GPS signals, wireless carrier feedback indicates that the first network elements likely to be affected are cell sites, which will sustain operation for at least 24 hours. After this time period, the ability to hand calls off between cell sites will be affected, although communications with the MSC will not be affected. Wireline network elements generally will sustain operation automatically for up to 30 days, although wireless carrier estimates of this time period varied from five days to beyond 30 days.

  – Feedback from the satellite operators indicates that impacts of a long-term complete GPS loss will vary by company, and that backup capabilities and processes are available and will be used to mitigate potential impacts.

  – In the event of complete loss of GPS signals, feedback from the cable network operators indicates that the cable network infrastructure dependent upon GPS time signals will sustain operation automatically for approximately 30 days. Beyond this period, some circuit termination equipment could be reconfigured to utilize the receive clock from the PSTN as a reference clock; however, this option may not be viable in the event of widespread GPS outage or degradation.

  – Feedback from the broadcast industry indicates that GPS is not critical to the operation of most broadcast systems. Systems that may be affected by GPS loss include "Precision Off-Set" between analog and digital TV transmitters, HD Radio, and Distributed Transmission networks for television. For these systems, loss of GPS can be tolerated for "an extended period of time," although this time period is not easily predicted and requires further study.

- In the extremely unlikely event of a complete and catastrophic loss of GPS over an extended period of time (e.g., more than one month) and affecting a large geographic area (e.g., nationwide, continental, global), overall impact is more difficult to ascertain. Such an event has never occurred, and, to date, no industry or Government exercises have sought to replicate the impact of a long-term or permanent GPS outage simultaneously on all industries.

3.3 Mitigation Strategies

The commercial communications industry employs a range of strategies to mitigate the impact of loss or disruption of GPS. In all communications network environments, backup solutions are deployed at the most critical nodes to protect against the loss of a GPS-provided timing reference source. Generally, service providers and network operators select backup solutions and associated implementation approaches that are specifically designed to meet the requirements of the service/application. The selection of an alternative is also an economic and business case decision that must factor in available equipment types and cost, the required level of quality and precision, the failure or disruption tolerance of the underlying service/application, the desired level of redundancy, and the likelihood of impact. As a result, implementation of backup solutions vary widely both within a particular industry segment, and across industry segments. For example, at critical nodes (e.g., wireline COs, mobile switching centers, satellite control centers), redundant Stratum 1-level sources are often deployed and further protected by secondary and/or tertiary sources. For less critical applications (e.g., the time of day on a desktop computer, some NTP server applications), less accurate timing sources may be sufficient (e.g., internal quartz oscillators, internal central processing unit clocks in devices).

To protect commercial communications network elements, service providers, network operators, and vendors report a wide variety of safeguarding/mitigation approaches and contingency plans. Strategies cited to mitigate the impact of loss or disruption of GPS timing signals include:

- Use of external/internal precision cesium-based devices (e.g., beam clocks and oscillators);
- Use of external/internal rubidium-based devices;
- Use of quartz oscillators;
- Use of multiple geographically dispersed GPS receivers;
- Automatic fall-over to other timing sources in the event of primary failure (e.g., LORAN-C timing source);
- "Line timing" off other carriers' signals and "slaving" to the wireline carrier circuit blocking;
- Manual reconfiguration to receive clock timing from the PSTN;
- Manual reconfiguration to use ad hoc timing sources during an emergency;
- Use of other timing sources such as NTP servers or an IRIG source;

- Dependence on the internal free-running oscillator of the device; and
- Use of a combination of the above strategies.

Depending on the network service or application being protected, individual companies may choose to deploy primarily one type of strategy or a combination of strategies implemented in layers to provide secondary and tertiary levels of protection.

Wireless service providers cite use of terrestrial measurements as a secondary approach to locating wireless 911 callers in the event that GPS-provided location data is unavailable.[21] One service provider noted that terrestrial network measurements would be utilized until the mobile device can no longer communicate with more than one cell site. When the device is no longer able to communicate with more than one cell site, only network identification parameters and ranging measurements to the identified cell site would be utilized. Location determination solutions of this nature result are significantly less accurate than GPS-based measurements. Another wireless provider reported that no mitigation is available for E911 caller location information.

Responses from cellular service providers are also consistent with the NSTAC's previous examination of GPS and E911 geo-location. The 2004 report found that "wireless carriers typically use GPS assist technology as one means of providing the geo-location of a 911 caller. ... Different carriers use combinations of GPS and triangulation to determine the location of a wireless caller with pinpoint accuracy." The report also noted that without a properly functioning GPS system, cell site triangulation can be utilized to deliver location information, but in many areas of the country, the geographic arrangement of cell sites make the process of triangulation difficult, if not impractical. As a result, "the loss of GPS could leave 911 centers without the ability to automatically receive the location of wireless callers to 911, thereby endangering life and property. … [This impact] would be most severe in areas with low density of cell sites, particularly rural areas and highways. Unfortunately, these are areas in which emergency rescue personnel typically most need precise location information because they must cover large areas."

In other network environments, strategies to protect against loss of GPS positioning data generally entail manual measurement and recording. For example, cable operators can fall back to the manual recording of RF signal leakage locations, which will be less accurate than automated methods that utilize GPS signals, and will lengthen the repair time for the cable leakage, resulting in less technical staff productivity.

Regarding strategies to mitigate workforce management impacts of loss or disruption of GPS, company employees and contractors would fall back to use of other existing forms of communication (e.g., two-way radios, other carriers' services, email) should there be a GPS-related loss to primary communications modes. In the area of fleet vehicle management, one response noted that no effective alternatives exist to compensate for loss of location data as a

[21] The Network Reliability Interoperability Council, an FCC advisory committee comprised of commercial communications companies as well as public sector stakeholders has developed generic network reliability and security best practices, including practices regarding GPS location accuracy for E911 service. http://www.nric.org.

result of loss or degradation of GPS; however, the impact on current operations is characterized as minimal. As GPS is more fully integrated into automated vehicle routing and dispatch systems, it is anticipated that companies will put in place backup processes and systems to compensate for GPS signal loss or disruption.

Key findings regarding mitigating the impact of the loss or disruption of GPS are:

- To protect critical functions such as network timing and synchronization, companies employ multiple layers of backup capabilities, mitigation strategies, and contingency plans to provide protection against GPS outages and disruptions.

- Technological, economic, and regulatory considerations necessarily factor into individual company decisions; therefore, specific mitigation strategies and backup capabilities will vary.

4.0 SUMMARY

In evaluating the commercial communications industry's use of and reliance on GPS, the NSTAC finds that:

- The U.S. Government's commitment to provide and maintain civil space-based PNT services, such as GPS, free of direct user fees for civil, commercial, and scientific uses has encouraged the rapid adoption of GPS-based solutions throughout the commercial communications industry.

- GPS supports a broad range of commercial communications industry functions and applications in many commercial communications industry segments (e.g., wireline, wireless, satellite, cable, and broadcast network environments).

- The primary use of GPS in the commercial communications industry and across all commercial communications industry segments is the support of precision timing and network synchronization functions.

- Another important use of GPS signals is support to location-based services, including support of wireless E911 Phase II requirements.

- As the commercial communications network infrastructure continues to evolve toward a high-speed all-digital environment, accurate timing and synchronization functions that support the infrastructure are becoming more critical.

- As the overall market for GPS-based devices and services continues to grow, the commercial communications industry is likely to identify and utilize additional uses of GPS to increase productivity, service delivery, and the number of available end-user applications.

- To protect critical functions such as network timing and synchronization, companies employ multiple layers of backup capabilities and other mitigation strategies to provide protection against GPS outages and disruptions.

- Technological, economic, and regulatory considerations necessarily factor into individual company decisions; therefore, specific mitigation strategies and backup capabilities will vary.

- Generally, short-term loss or disruption of the GPS signals for timing will have minimal impact on the commercial communications infrastructure and its operations.

- Short-term loss or disruption of GPS signals will affect the ability to determine accurate location information for wireless E911 purposes.

- The impact of medium- to long-term loss or disruption of GPS will vary based on a number of factors, including the specific function and application being supported by

GPS, the duration of the loss/disruption, the geographic size of the region being impacted, and the availability and implementation of effective backup capabilities. For example:

– In the event of complete loss of GPS signals, wireline carrier feedback indicates that wireline network infrastructure (e.g., circuit switches) will sustain operation automatically for approximately 30 days. Network performance would be closely monitored, as it is still possible for performance to be impacted during the 30-day window. Additional backup capabilities, processes, and mitigation approaches can and will be used to sustain network operation beyond this period; however, mitigation of such an extended GPS loss would require costly reconfiguration of the network to redistribute alternative timing sources. Such a reconfiguration would require a cooperative effort between carriers.

– In the event of complete loss of GPS signals, wireless carrier feedback indicates that the first network elements likely to be affected are cell sites which will sustain operation for at least 24 hours. After this time period, the ability to handoff calls between cell sites will be affected, although communications with the MSC will not be affected. Wireline network elements generally will sustain operation automatically for up to 30 days, although wireless carrier estimates of this time period varied from five days to beyond 30 days.

– Feedback from the satellite operators indicates that impacts of a long-term complete GPS loss will vary by company and that backup capabilities and processes are available and will be used to mitigate potential impacts.

– In the event of complete loss of GPS signals, feedback from the cable network operators indicates that the cable network infrastructure dependent upon GPS time signals will sustain operation automatically for approximately 30 days. Beyond this period, some circuit termination equipment could be reconfigured to utilize the receive clock from the PSTN as a reference clock; however, this option may not be viable in the event of widespread GPS outage or degradation.

– Feedback from the broadcast industry indicates that GPS is not critical to the operation of most broadcast systems. Systems that may be affected by GPS loss include "Precision Off-Set" between analog and digital TV transmitters, HD Radio, and Distributed Transmission networks for television. For these systems, loss of GPS can be tolerated for "an extended period of time" although this time period is not easily predicted and requires further study.

In the extremely unlikely event of a complete and catastrophic loss of GPS over an extended period of time (e.g., more than one month) and affecting a large geographic area (e.g., nationwide, continental, global), overall impact is more difficult to ascertain. Because of the diverse and highly distributed implementations of GPS-based solutions across the industry, any impact likely would be experienced in the form of a gradual degradation of network performance, with little potential for cascading network failures. The NSTAC also emphasizes that commercial communications networks do not operate in a vacuum, and service providers and network operators will take immediate corrective actions in response to any size event, particularly a large-scale catastrophic event with the potential to degrade the network. Even before all automatic means of backup are exhausted, companies will have already executed contingency plans and performed manual reconfigurations and network timing adjustments as required to maintain network operation.

Overall, industry members surveyed believe that their companies have taken measures to safeguard against those disruptions to the GPS signal that are likely to be encountered; however, to date, no industry or Government exercise has sought to replicate the impact of a long-term or permanent GPS outage simultaneously on all industries. The NSTAC recommends that the President direct the Department of Homeland Security and the Department of Defense to include various GPS outage scenarios in future planned disaster recovery exercises in coordination with the commercial communications industry.

APPENDIX A
WORKING GROUP MEMBERS, GOVERNMENT PERSONNEL, AND OTHER PARTICIPANTS

WORKING GROUP MEMBERS

Intelsat, Limited	Mr. Richard DalBello, Chair
The Boeing Company	Mr. Marc Johansen, Vice-Chair
Verizon Communications, Incorporated	Mr. James Bean, Vice-Chair
AT&T, Incorporated	Mr. Thomas Hughes
	Ms. Rosemary Leffler
Bank of America Corporation	Mr. Roger Callahan
The Boeing Company	Mr. William Patrick Reiner
	Mr. Robert Steele
Intelsat, Limited	Ms. Sallye Clark
	Mr. Sterling Winn
Lockheed Martin Corporation	Mr. Allen Dayton
National Cable & Telecommunications Association	Mr. Andy Scott
Qwest Communications International, Incorporated	Ms. Diana Gowen
	Mr. Thomas Snee
Science Applications International Corporation	Mr. Hank Kluepfel
Sprint Nextel Corporation	Mr. Lee Fitzsimmons
	Ms. Allison Growney
	Mr. John Stogoski
Raytheon Company	Mr. Bill Russ
Rockwell Collins, Incorporated	Mr. Ken Kato
Verizon Communications, Incorporated	Mr. Roger Higgins

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Department of Homeland Security, National Communications System	Mr. Dale Barr Mr. Kelvin Coleman
Department of Homeland Security, United States Coast Guard	Captain Curtis Dubay
National Space-Based Positioning, Navigation, and Timing Coordination Office	Mr. Robert Crane Mr. Michael Shaw

APPENDIX B
ACRONYM LIST

ACRONYMS

BITS	Building Integrated Timing Supply
CDMA	Code Division Multiple Access
CO	Central Office
DAC	Digital Access and Cross-Connect
DHS	Department of Homeland Security
DOCSIS	Data Over Cable Service Interface Specification
DOD	Department of Defense
DTV	Digital Television
E911	Enhanced 911
FCC	Federal Communications Commission
GPS	Global Positioning System
HD	Hybrid Digital
HLR	Home Location Register
IBOC	In Band On Channel
IRIG	Inter-Range Instrumentation Group
LES	Land Earth Station
MSC	Mobile Switching Center
NIST	National Institute of Standards and Technology
NSTAC	National Security Telecommunications Advisory Committee
NTP	Network Time Protocol
PBX	Private Branch Exchange
PNT	Positioning, Navigation, and Timing
PRS	Primary Reference Source
PSAP	Public Safety Answering Point
PSTN	Public Switched Telephone Network
RF	Radio Frequency
SDH	Synchronous Digital Hierarchy
SME	Subject Matter Expert
SONET	Synchronous Optical NETwork
TDM	Time-Division Multiplexing
TSG	Timing Signal Generator
TT&C	Telemetry, Tracking, and Control
VLR	Visitor Location Register
VOD	Video On Demand