



**CSRIC V**  
**WORKING GROUP 4: COMMUNICATIONS INFRASTRUCTURE**  
**RESILIENCY**  
**SUBGROUP B: NETWORK TIMING SINGLE SOURCE RISK REDUCTION**  
**FINAL REPORT**

**December 2016**

**TABLE OF CONTENTS**

<b><u>SECTION</u></b>	<b><u>PAGE</u></b>
<b>CSRIC STRUCTURE .....</b>	<b>V</b>
<b>1.0 RESULTS IN BRIEF .....</b>	<b>1-1</b>
<b>1.1 EXECUTIVE SUMMARY.....</b>	<b>1-1</b>
<b>1.2 OBJECTIVE .....</b>	<b>1-1</b>
<b>1.3 INTRODUCTION.....</b>	<b>1-1</b>
<b>1.4 WORKING GROUP 4B MEMBERSHIP .....</b>	<b>1-2</b>
<b>2.0 ANALYSIS, FINDINGS, AND RECOMMENDATIONS .....</b>	<b>2-1</b>
<b>2.1 MODERN COMMUNICATIONS NETWORKS REQUIRE PRECISE TIME AND FREQUENCY STANDARDS TO OPERATE EFFICIENTLY .....</b>	<b>2-1</b>
<b>2.2 A WIDE RANGE OF TIME AND FREQUENCY STANDARDS, WITH VARYING PRECISION AND STABILITY, ARE DEPLOYED IN COMMUNICATIONS NETWORKS.....</b>	<b>2-1</b>
<b>2.3 RNSS RECEIVERS (INCLUDING GPS) ARE THE MOST-DEPLOYED SOURCE OF PRECISE FREQUENCY CONTROL AND ABSOLUTE TIME DISTRIBUTION....</b>	<b>2-3</b>
<b>2.4 EACH SEGMENT OF AN RNSS IS SUBJECT TO SPECIFIC THREATS THAT COULD DENY PRECISE TIME SIGNALS TO SOME OR ALL NETWORK TIMING USERS.....</b>	<b>2-3</b>
<b>2.5 SPACE SEGMENT.....</b>	<b>2-3</b>
<b>2.6 USER SEGMENT .....</b>	<b>2-4</b>
<b>2.7 GROUND SEGMENT .....</b>	<b>2-5</b>
<b>3.0 OPTIONS .....</b>	<b>3-1</b>
<b>4.0 FINDINGS AND RECOMMENDATIONS .....</b>	<b>4-1</b>
<b>5.0 CONCLUSION.....</b>	<b>5-1</b>
<b>APPENDIX A ACRONYMS .....</b>	<b>1</b>
<b>APPENDIX B GLOSSARY .....</b>	<b>1</b>

**LIST OF FIGURES**

<b><u>FIGURE</u></b>	<b><u>PAGE</u></b>
<b>2-1. Geographical Locations of GPS Ground Segment Components [Source: GPS.gov] .....</b>	<b>2-5</b>

**LIST OF TABLES**

<b><u>TABLE</u></b>	<b><u>PAGE</u></b>
<b>V-1. Communications Security, Reliability, and Interoperability Council (CSRIC) V .....</b>	<b>V</b>
<b>1-1. CSRIC Working Group 4B Team Members.....</b>	<b>1-2</b>
<b>2-1. Frequency Standards by Stratum (All Values Typical) .....</b>	<b>2-2</b>
<b>2-2. Time Holdover for Unassisted Oscillators.....</b>	<b>2-2</b>
<b>2-3. Annual Probability, Impact, Geographic Scope, and Recovery Time for Threats Identified to the Space Segment.....</b>	<b>2-4</b>
<b>2-4. Annual Probability, Impact, Geographic Scope, and Recovery Time for Threats Identified to the User Segment.....</b>	<b>2-4</b>
<b>4-1. Availability of Identified Options.....</b>	<b>4-1</b>

**CSRIC STRUCTURE**

**Table V-1. Communications Security, Reliability, and Interoperability Council (CSRIC) V Working Groups**

<b>Communications Security, Reliability, and Interoperability Council (CSRIC) V Working Groups</b>			
<p><b>Working Group 1</b></p> <p><b>Evolving 911 Services</b></p> <p><b>Co-Chairs:</b> Susan Sherwood &amp; Jeff Cohen</p> <p><b>FCC Liaisons:</b> Tim May &amp; John Healy</p>	<p><b>Working Group 2</b></p> <p><b>Wireless Emergency Alert</b></p> <p><b>Co-Chairs:</b> Francisco Sánchez &amp; Farrokh Khatibi</p> <p><b>FCC Liaisons:</b> Chris Anderson, James Wiley &amp; Gregory Cooke</p>	<p><b>Working Group 3</b></p> <p><b>Emergency Alert System</b></p> <p><b>Co-Chairs:</b> Steven Johnson &amp; Kelly Williams</p> <p><b>FCC Liaison:</b> Gregory Cooke</p>	<p><b>Working Group 4A</b></p> <p><b>Communications Infrastructure Resiliency</b></p> <p><b>Co-Chairs:</b> Kent Bressie &amp; Catherine Creese</p> <p><b>FCC Liaison:</b> Jerry Stanshine &amp; Michael Connelly</p>
<p><b>Working Group 4B</b></p> <p><b>Network Timing Single Source Risk Reduction</b></p> <p><b>Chair:</b> Jennifer Manner</p> <p><b>FCC Liaison:</b> Emil Cherian</p>	<p><b>Working Group 5</b></p> <p><b>Cybersecurity Information Sharing</b></p> <p><b>Co-Chairs:</b> Rod Rasmussen, Christopher Boyer, Brian Allen</p> <p><b>FCC Liaisons:</b> Greg Intoccia &amp; Vern Mosely</p>	<p><b>Working Group 6</b></p> <p><b>Secure Hardware &amp; Software</b></p> <p><b>Co-Chairs:</b> Brian Scarpelli &amp; Joel Molinoff</p> <p><b>FCC Liaisons:</b> Steven McKinnon &amp; Emily Talaga</p>	<p><b>Working Group 7</b></p> <p><b>Cybersecurity Workforce</b></p> <p><b>Co-Chairs:</b> Bill Boni &amp; Drew Morin</p> <p><b>FCC Liaison:</b> Erika Olsen</p>
<p><b>Working Group 8</b></p> <p><b>Priority Services</b></p> <p><b>Co-Chairs:</b> William Reidway &amp; Thomas Anderson</p> <p><b>FCC Liaisons:</b> Tim Perrier &amp; Ken Burnley</p>	<p><b>Working Group 9</b></p> <p><b>Wi-Fi Security</b></p> <p><b>Chair:</b> Brian Daly</p> <p><b>FCC Liaisons:</b> Peter Shroyer &amp; Kurian Jacob</p>	<p><b>Working Group 10</b></p> <p><b>Legacy Systems Risk Reduction</b></p> <p><b>Co-Chairs:</b> John Kimmins &amp; Danny McPherson</p> <p><b>FCC Liaison:</b> Steven McKinnon</p>	

## 1.0 RESULTS IN BRIEF

### 1.1 EXECUTIVE SUMMARY

Synchronized network timing (frequency, phase, and time) is a crucial element of communications network management. For call handoffs to take place between cell sites or for time-division multiplexing, components of a communications network need to be aligned to a trusted, precise network timing source. Various business processes require a precise and traceable source of civil time. The U.S. communications sector relies heavily on the Global Positioning System (GPS) to provide network time. GPS is a widely available, extremely precise timing source that is used across multiple infrastructure sectors. However, given the high dependence of the communications sector on GPS, the Federal Communications Commission (Commission) is interested in identifying ways to increase the resilience of communications networks by exploring complementary or backup solutions that could be employed to offer similar time precision as GPS in the event that GPS signals are lost. These solutions also need to be completely independent of GPS to significantly reduce any risk. This report addresses the problems associated with relying on GPS solutions, the ideal technical characteristics for systems to backup or supplement GPS, and our recommendations for possible backup solutions by the communications industry and others reliant on communications network timing sources.

### 1.2 OBJECTIVE

- Provide a report on options on acquiring and implementing backup precision timing solutions that are independent of GPS. Submission of WG4B Report 1 on Options – June 2016 (completed).
- Provide a report on recommendations on acquiring and implementing backup precision timing solutions that are independent of GPS. Submission of Final WG4B Report – December 2016 (completed).

### 1.3 INTRODUCTION

For call handoffs to take place between cell sites or for time-division multiplexing, components of a communications network need to be aligned to a trusted, precise network timing source. The communications sector relies heavily on GPS to provide network time. GPS is a widely available, extremely precise timing source that is used across multiple infrastructure sectors. However, given the high dependence of the U.S. communications sector on GPS, the Commission is interested in identifying ways to increase the resilience of communications networks by exploring complementary or backup solutions that could be employed to offer similar time precision as GPS in the event that GPS signals are lost. These solutions also need to be completely independent of GPS to truly reduce risk.

Working Group 4B of the Fifth Communications Security, Reliability, and Interoperability Council (CSRIC V) has identified the following as possible reasons why the current network timing system may fail temporarily or for a longer period of time.

- Solar flares or other disturbances
- Space weather phenomena
- RF interference episodes
- Failure of upstream time sources whether deliberate or accidental
- Accidental or deliberate jamming
- Spoofing

Working Group 4B has identified the key characteristics that are required to provide an adequate backup to RNSS solutions for network timing. These characteristics include:

- Redundancy
- Independence from RNSS
- Increased reliability
- Appropriate level of accuracy for the application

Finally, taking into account these key characteristics, Working Group 4B identified the 12 options listed in Section 3.0.

Working Group 4B examined the options and evaluated which ones are available today and those that may be available in the future.

#### 1.4 WORKING GROUP 4B MEMBERSHIP

<b>Table 1-1. CSRIC Working Group 4B Team Members</b>	
<b>Name</b>	<b>Organization</b>
Jennifer A. Manner (Chair)	EchoStar
Jodi Goldberg	EchoStar
Emil Cherian	Federal Communications Commission/Public Safety and Homeland Security Bureau
Bill Ryan	US Department of Homeland Security
Katy Ross	Iridium (Wiley Rein)
Ahmad Armand	T-Mobile
Joan Vaughn	T-Mobile
Chris Oberg	Verizon
Rob Seastrom	Time Warner Cable
Sameer Vuyyuru	TCS
Dennis Coleman	CenturyLink
Lee Cosart	Microsemi (ATIS)
Greg Turetzky	Intel (ATIS)
Trey Fogarty	NENA
Bill Check	NCTA
Walter Rausch	Sprint
David Overdorf	AT&T
Bill Shvodian	NextNav
Ethan Lucarelli	Inmarsat

## 2.0 ANALYSIS, FINDINGS, AND RECOMMENDATIONS

### 2.1 MODERN COMMUNICATIONS NETWORKS REQUIRE PRECISE TIME AND FREQUENCY STANDARDS TO OPERATE EFFICIENTLY

Many modern communications networks, whether wired or wireless, operate in synchronous mode. In a synchronous network, specific events must begin or end at a precise—and precisely-agreed-upon—time. For instance, transmissions in many networks must be synchronized to ensure that a receiver will be ready to process each unit of data, called a “frame,” when it arrives at an intermediate or final destination. When timing sync is lost, a frame “slip” can occur. A slip occurs when data from one frame arrives in a time slot assigned to an earlier or later frame by the receiving equipment. Frame slips cause a transient reduction in the apparent carrying capacity of a network link, degrading performance for end users. For some real-time services like voice and video, frame slips can result in audible or visual artifacts such as loud clicks or annoying pixilation. In order to maintain long-term framing synchronization, network equipment must keep track of both the oscillation rate and phase of some frequency standard. The former sets the length of an interval such as a second or a frame space, while the latter ensures that the edges of intervals in different (possibly widely separated) equipment lineup within tolerances.

Like their wireline counterparts, modern wireless networks require precise timing synchronization to prevent frame slips between cellular base stations and mobile devices. Additionally, however, these networks require precise timing-derived frequency standards. Stable frequency standards ensure that station transmitters operate in compliance with their license or assignment parameters and in accordance with a carrier’s network engineering plans. Frequency stability is maintained by disciplining a frequency standard to produce exactly the required number of oscillations during a specified time period (e.g., 25 000 000 oscillations in 1 second).

In addition to the *relative* timing precision required to maintain framing alignment and base station frequency, all networks require some degree of *absolute* time synchronization. Often referred to as “civil time,” absolute time is time in its ordinary sense: an agreed-upon time of day, established precisely by some civil or military authority. Within communications networks, accurate absolute time supports critical authentication, authorization, and accounting mechanisms, as well as various logging, monitoring, and alerting functions. In the United States, the statutory ultimate providers of authoritative civil time are the National Institute of Standards and Technology and the United States Naval Observatory, who coordinate with national laboratories of other countries via the International Earth Rotation and Reference Systems Service to create global time and reference frame standards.

### 2.2 A WIDE RANGE OF TIME AND FREQUENCY STANDARDS, WITH VARYING PRECISION AND STABILITY, ARE DEPLOYED IN COMMUNICATIONS NETWORKS

Network operators use a variety of time and frequency references to maintain network synchronization at different geographic scales. References are categorized based on their frequency stability and holdover time (that is, their ability to maintain accuracy in the absence of an external discipline source). Standards for these values are published by the Telecommunications Industry Association as American National Standards.<sup>1</sup> References under this standard are categorized into five strata, numbered 0 through 5, with decreasing stability and holdover times. (Note that these strata *do not* correspond with the distance-to-reference strata used in the Network Time Protocol.<sup>2</sup>)

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<sup>1</sup> <http://www.tiaonline.org>

<sup>2</sup> <http://www.ntp.org>



Generally speaking, the lower the stratum of a reference, the more accurate it will be, but the more costly it will be to deploy and maintain. Typical networks may have a very small number (perhaps only 1–3) of Stratum 1 references, with possibly tens of thousands of Stratum 4 references. In a network-based control model, references at lower strata must control or “discipline” the operation of references at higher strata, relying on intermediate (e.g., within a single facility) communications links to locally distribute precisely timed control signals.

The required accuracy of a frequency reference at a given stratum is expressed as a dimensionless ratio between the frequency of an ideal oscillator operating at the target frequency and a real-world reference operating as designed. Indirectly, this figure expresses how often an uncorrected source at a given stratum could be expected to produce a slip. Similarly, “holdover time” represents an estimate of how long a reference at a given stratum can be relied upon before a *first* slip will occur. It is important to note, however, that as longer times pass without access to a lower-stratum source, oscillators may drift further from their expected frequency, resulting in more and more frequent slips.

To minimize the chance of network slips or de-tunings, network operators must deploy complex control systems that allow local reference clocks in each facility to maintain close synchronicity with the lowest stratum of clocks deployed throughout the rest of an operator’s network, with the clocks of interconnecting networks, and, ultimately, with those of some civil authority. The cost of frequency standards and the complexity of the required synchronization and control networks are therefore key drivers of technology selection in the network synchronization space.

<b>Table 2-1. Frequency Standards by Stratum (All Values Typical)</b>			
<b>Stratum</b>	<b>Frequency Standard</b>	<b>Accuracy</b>	<b>~ Holdover</b>
0	Average of many cesium beam and hydrogen maser clocks, periodically calibrated with Cs or Rb Fountain references (NIST, USNO, “National Primary Reference Clock”)	NA	NA
1	Single Cs beam clock (Telecom “Grand Master”)	$1 \times 10^{-11}$	72 days
2	Rb-vapor-cell-disciplined crystal oscillator	$1.6 \times 10^{-8}$	7 days
3	Oven-controlled quartz oscillator	$4.6 \times 10^{-6}$	6 minutes
4	No or low-quality local oscillator; slave to Stratum 2 or 3	$32 \times 10^{-6}$	NA

**Table 2-2** shows the ability of various classes of oscillators to maintain time in holdover. The column labeled “Requirement” shows the maximum amount of daily frequency drift for a particular oscillator. The column labeled “Hold 1.5 μs” shows the time 1.5 μs is maintained based on the “Requirement” figure. In the case of the Stratum 1 cesium beam clock, the 17.4 day figure is based on a cesium clock accuracy figure of 1 part in  $10^{12}$ .

<b>Table 2-2. Time Holdover for Unassisted Oscillators</b>			
<b>Stratum</b>	<b>Frequency Standard</b>	<b>Requirement</b>	<b>Hold 1.5 μs</b>
1	Cesium beam clock	NA	17.4 days
2	Rb-vapor-cell-disciplined crystal oscillator	$1 \times 10^{-10}/\text{day}$	14.1 hours
3E	Enhanced oven-controlled quartz oscillator	$1.2 \times 10^{-8}/\text{day}$	1.3 hours
3	Oven-controlled quartz oscillator	$3.9 \times 10^{-7}/\text{day}$	13.6 minutes
4	Low-quality local oscillator	NA	NA

### 2.3 RNSS RECEIVERS (INCLUDING GPS) ARE THE MOST-DEPLOYED SOURCE OF PRECISE FREQUENCY CONTROL AND ABSOLUTE TIME DISTRIBUTION

As a result of the high cost of low-stratum frequency sources, and the challenges associated with traceable distribution of precise absolute time, most network operators work to minimize the number of low-stratum references required in their networks. High-quality “timing grade” RNSS receivers can, however, reduce the burdens associated with maintaining a large number of low-stratum references by providing a source of external “discipline” for an inherently-higher-stratum oscillator. For example, an oven-controlled quartz oscillator that would normally operate as, at best, a Stratum 3 reference can, if disciplined by a precise 1-pulse-per-second (1 PPS) RNSS output, operate as a Stratum 1 reference. With the global availability and high reliability of RNSS, generally, RNSS-based time and frequency sources have therefore become the overwhelming choice of network operators. While this has led to improved network performance and lower costs for consumers, such a great reliance on a single system of time and frequency distribution also introduces a critical vulnerability in global communications networks. In the case of the RNSS-disciplined quartz oscillator example above, a loss of RNSS-derived timing would lead to practically immediate time and frequency errors for attached equipment. Because the same loss of upstream discipline source would eventually have some effect on all but the most expensive (and consequently least-deployed) solutions, understanding the threats to RNSS availability is crucial to characterizing the need for an alternative time and frequency distribution source.

### 2.4 EACH SEGMENT OF AN RNSS IS SUBJECT TO SPECIFIC THREATS THAT COULD DENY PRECISE TIME SIGNALS TO SOME OR ALL NETWORK TIMING USERS

RNSS are characterized by three “segments”:

- A “space segment” consists of orbiting Satellite Vehicles (SVs) that broadcast precise time and ranging signals, along with other data required to calculate a navigation solution.
- A “user segment,” consisting of an RNSS receiver and special-purpose software or hardware. Most commonly, receivers acquire and track signals from multiple<sup>3</sup> satellites, analyzing their structure, timing, and possibly RF phase, and compute a position and time solution.
- A “ground segment” provides continuous monitoring of system health, distributes precise timing data to satellites from a national Primary Reference Clock, and precisely tracks satellite orbits to generate ephemeris (satellite almanac) data used by receivers to calculate their range from each satellite in view.

Each of these segments is subject to various threats that could limit or deny access to signals needed to maintain network synchronization. The sections below list some known vulnerabilities for RNSS operational segments and attempt to characterize their probability of occurrence, general impact, geographic scope, and time-to-recover.

### 2.5 SPACE SEGMENT

The space segment is the most commonly recognized aspect of an RNSS. Although on-orbit assets are generally highly reliable, RNSS space segment failures can and do occur. Most frequently, limitations on space segment availability or signal quality result from space weather events such as solar coronal mass

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<sup>3</sup> In some relevant circumstances, a fully-resolved “fix,” derived from multiple satellites, may not be required. For example, a network system could use the signals from a single, known-healthy satellite to maintain network synchronization within adequate parameters if certain correction parameters (e.g., for known satellite clock drift) could be distributed by other means, such as through a terrestrial telecommunications network.

ejections or geomagnetic storms. Less frequently, accidental or intentional RF jamming events in space (e.g., due to malfunctions in nearby or lower-altitude satellites) can limit space segment effectiveness across a broader area. Theoretically, a targeted, signal-specific attack could limit one or more satellite vehicles’ availability over its served area. Finally, a direct physical attack against a satellite vehicle is possible with existing air-launched ballistic missile technology. **Table 2-3** summarizes the Working Group’s view of the annual probability, impact, geographic scope, and recovery time for each of these threats. We note, however, that these estimates have been compiled without access to classified information that could materially alter the conclusions we reached.

<b>Table 2-3. Annual Probability, Impact, Geographic Scope, and Recovery Time for Threats Identified to the Space Segment</b>				
<b>Threat</b>	<b>Annual Likelihood of Occurrence</b>	<b>Impact</b>	<b>Geographic Scope</b>	<b>Recovery Time</b>
Direct impact of coronal mass ejection	Low	Catastrophic	Global	Years
Geomagnetic storm	Moderate	High	Global	Days
Electromagnetic pulse <sup>4</sup>	Very low	TBD	TBD	TBD
RF interference	Moderate	High	Localized	Days
RF jamming	Moderate	High	Localized	Hours – Days
SV attack	Very low	High	Localized, transient	Months – Years

## 2.6 USER SEGMENT

The user segment of RNSS systems, though functionally disaggregated from the operations of the space and ground segments, can be subject to specific failures or attacks as well. For example, user-segment equipment and firmware could be vulnerable to malware or physical attack. Given that it is much easier to get physically close to ground versus orbiting assets, RF jamming, PRN-code-specific jamming, spoofing (which is the intentional mimicking of the protocol in a rogue transmitter in order to send false position and timing information to the receiver), and physical attacks or damage are more likely for these targets.

<b>Table 2-4. Annual Probability, Impact, Geographic Scope, and Recovery Time for Threats Identified to the User Segment</b>				
<b>Threat</b>	<b>Annual Probability of Occurrence</b>	<b>Impact</b>	<b>Geographic Scope</b>	<b>Recovery Time</b>
Receiver malware	Moderate	Moderate	Deployment dependent	Days – Weeks
RF interference	High	Moderate	Highly localized	Hours – Days
RF jamming	Moderate	High	Highly localized	Hours – Days
PRN code-specific jamming	Low	Moderate	Highly localized	Hours – Days
Antenna damage	High	Moderate	Site-specific	Hours – Days

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<sup>4</sup> The Working Group considered potential sources of EMP including natural (e.g., meteor explosions) and man-made (e.g., high-altitude nuclear detonations, explosive-pumped flux compression generators). The Working Group agreed that the impact of each type of EMP is sufficiently similar, and the likelihood of occurrence sufficiently low, that presenting our analysis of this risk source in an aggregate fashion is justified.

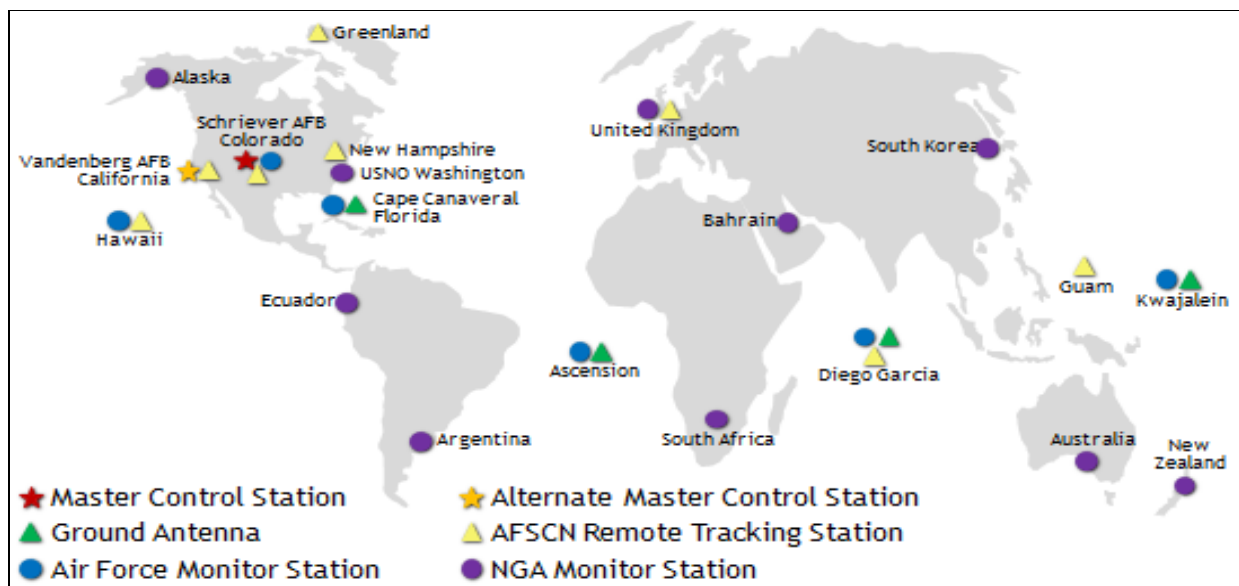
## 2.7 GROUND SEGMENT

The ground segment of RNSS systems also can be subject unexpected failures. These include failures of the wireless network and wireline network, human error on the part of its operators, and failure of satellite ground equipment (e.g., user terminals, gateway earth stations), or core clock systems at the United States Naval Observatory. Although the space segment has some independent holdover capabilities, medium- to long-term loss of even some ground segment capabilities could severely impact the quality or availability of RNSS signals-in-space.

According to GPS.gov, the official U.S. government website about the GPS and related topics,<sup>5</sup> the GPS ground segment consists of three main components:

- One Master Control Station (MCS) and one alternate MCS
- 16 monitor stations
- 12 ground antennas (four dedicated antennas and eight tracking stations from the Air Force Satellite Control Network)

The MCS is located at Schriever Air Force Base in Colorado. There is also an alternate MCS located at Vandenberg AFB in California. The MCS is the primary control segment of the GPS satellite constellation. To determine the precise locations of the GPS satellites, the MCS receives relevant information for the 16 monitor stations around the globe. The MCS also sends navigation commands to the satellites and safeguards the health and accuracy of the satellite constellation. The monitor stations around the globe track the GPS satellites as they fly over the monitor stations and also perform other measurements (e.g., atmospheric data). The monitor sites have very precise GPS receivers and are under control by the MCS. The 12 ground antennas are the communication link with the GPS constellation. There are four dedicated GPS ground antennas and, additionally, eight tracking stations of the Air Force Satellite Control Network (AFSCN) are capable of communicating with the GPS satellites. **Figure 2-1** shows the geographical location of the GPS ground segment components.



**Figure 2-1. Geographical Locations of GPS Ground Segment Components [Source: GPS.gov]**

<sup>5</sup> GPS.gov, <http://www.gps.gov/systems/gps/control/>

## 3.0 OPTIONS

In this section we provide different options for consideration on acquiring and implementing backup precision timing solutions. These solutions are based on the requirements identified in through WP4B's analysis and addressed in this report. These options were developed based on our analysis and outreach to third parties including the U.S. government, vendors and other experts.

### 1. Additional GPS Signals

**Description:** Add additional frequencies, such as the L2C and L5 frequencies, to GPS and augmentation satellites to transmit which provides an additional signal band option.

**Availability:** Both the L2C and L5 signals are available today to be transmitted from approximately 11 GPS satellites.

**Pros/Cons:** This may limit jamming episodes for a while, but over time will face jamming. In addition, this may help to guard against unintentional or intentional network problems. While this technology is only being developed, there is only limited commercial availability of equipment. These additional signals may help with jamming and interference events but not necessarily with space weather events.

### 2. Use of Alternative RNSS Systems

**Description:** Utilize other RNSS systems than GPS (e.g., Galileo, GLONASS).

**Availability:** Many of these systems are in use today.

**Pros/Cons:** This alternative could be subject to similar RF disturbances, such as space weather phenomena and jamming. However, it would provide a reliable alternative RNSS source for timing. RNSS systems operated by countries other than the US will likely provide civil time that is traceable. In addition, political considerations may limit the usefulness of this alternative for sensitive uses.

### 3. Use of LEO Satellite-Based Timing

**Description:** Satelles, Inc. offers a satellite-based network timing solution called Satelles Time & Location (STL), delivered over the Iridium<sup>®</sup> satellite constellation. The solution relies on a constellation of 66 Low-Earth-Orbiting (LEO) satellites to deliver timing signals anywhere on the Earth. STL can be deployed as an augmentation to GPS or in a standalone solution. In operation, STL bursts are transmitted once every 1.4 seconds on average. If the position is known, as in the case with a static cell tower, then precise time (<0.5  $\mu$ sec) can be calculated by processing a single burst. If the position is unknown, STL positioning is required first, which typically requires 2–5 minutes (from cold start). The precise time and frequency information derived from STL can be used to assist weak-signal GNSS acquisitions or as a GNSS-independent time solution. The STL signal is significantly more powerful than GNSS. The STL system can reliably decode the bursts and perform precise Doppler and range measurements at attenuations of up to 35 dB relative to unobstructed reception. This is sufficient to penetrate buildings and other occlusions, providing coverage in indoor and urban canyon environments. The STL location accuracy is estimated at between 30M and 50M.

**Availability:** STL was in development and test for the past 4 years and is now a commercially available service.

**Pros/Cons:** Because of the lower orbit of the Iridium constellation, the received signal strength of the STL solution is higher than that of GPS. Additionally, because it operates over a separate, U.S.-licensed satellite system, STL offers network diversity to GPS. The LEO orbit diversity and spot beam nature of STL also provides jamming and spoofing resilience that is not inherent in civil GNSS systems; however, as a space-based system, STL may have some susceptibility to space weather events.

#### 4. Commercial RF Distribution

**Description:** This approach uses a clock distribution over an RF mechanism on the ground and has accuracy down to the sub nanosecond level. It is a point-to-point based system.

**Availability:** This system is currently being tested and has limited use.

**Pros/Cons:** As a ground-based system, it is less subject to space weather phenomena (severity of sensitivity to space weather as well as range over ground depends on several factors including frequency). But it is still subject to intentional jamming. It is also a possible redundant system to protect against intentional/unintentional network problems.

#### 5. Antenna Pattern Optimization

**Description:** Use of directional antennas or the use of other forms of protection (e.g., terrain) to increase immunity to jamming sources located at the surface, including just raising the elevation angle cutoff to 15 degrees. Protects with phased array or antenna shielding for earth station.

**Availability:** This is available today commercially.

**Pros/Cons:** Added degree of protection to the GPS system against unintentional terrestrial interference. Still does not address space weather issue or network issues. Will not provide any additional immunity to jamming or spoofing attacks launched from an airborne or spaceborne platform. With the recent proliferation of consumer-grade drone technology, the barrier to entry for an airborne attack has been lowered to the point where a directional antenna's protection against intentional interference ought to be considered minimal.

#### 6. Navigational Message Authentication (NMA) on L2C

**Description:** Adds NMA to GPS L2C signals as a means to mitigate spoofing attacks on GPS devices using L2C.

**Availability:** Still under development.

**Pros/Cons:** Telecom sector use of NMA on L2C would require the deployment of additional receivers, or replacement of existing L1 receivers with a dual mode version supporting both L1 and L2C operation. NMA does not provide any mitigation of a jamming attack, nor does it address the issue of poor penetration of GPS signals into buildings. While NMA on L2C would not be immediately usable by current telecom receivers, the long-term application of NMA on GPS civilian signals may become an important defense against a spoofing attack. It is not for jamming but for spoofing and possible man-made mistakes. Still space vehicle-based, still susceptible to space weather phenomena (the frequency differential between L1 (1575 MHz) and L2 (1227 MHz) offers scant advantage against any difficulties that might be attributable to space weather events).

#### 7. Sync over Fiber

**Description:** Transporting very high precision time and phase synchronization over fiber using IEEE-1588v2 Precision Time Protocol (PTP) or a similar/derivative protocol. PTP packetizes

time and phase information for delivery over a packet-based network, such as Ethernet, which is, in turn, transported over fiber. PTP is susceptible to impairments due to packet delay variation and asymmetry in the forward versus reverse transmission paths. Further, there is a need to determine if PTP can be used to transport very high precision time and phase sync over the vast distances required to cover the continental United States.

There is a second proposal for sync over fiber that may develop in the future. ITU-T standard J.211 describes a two-way protocol transported over the physical layer that includes a mechanism to correct for transport delay and asymmetry. It is not packet based and thus is not impaired by delay variation. This technology could be adapted to fiber transport using telecom industry standard Wave Division Multiplexing (WDM) technology.

**Availability:** Early in development process.

**Pros/Cons:** Early experiments show feasibility, after calibrating out asymmetry, of precision time transfer through a US commercial optical telecom network; time stability in the 10's of nanoseconds over measurements lasting several months has been shown. It is, however, experimental at this point. No commercial services exist at the present time. In order to function at maximum accuracy, PTP and similar protocols require a dedicated wavelength ( $\lambda$ ) in the optical transport network. MPLS and similar virtual networking technologies do not isolate PTP traffic from jitter caused by other traffic on the network, nor do they guarantee a symmetric path.

## 8. eLORAN

**Description:** There is the development of a new eLORAN type system in the United States for delivering very high-precision time and phase sync.

**Availability:** Under development.

**Pros/Cons:** This type of signal is very long wavelength, very high powered, would be very difficult to jam, and penetrates buildings well. eLORAN could begin limited operations in the United States in about 1 year and could be fully operational nationwide within several years. It is worth noting that some European nations are presently using eLORAN as a back up to GPS for position, navigation, and timing.

## 9. Sync Distribution via other RF Spectrum

**Description:** A very high-precision timing reference similar to the National Institute of Standards and Technology's time signal radio station WWVB that would operate in RF spectrum. Such a solution has been discussed in ATIS COAST SYNC and could operate below 1 GHz.

**Availability:** Still needs to be developed.

**Pros/Cons:** Sub-1 GHz RF spectrum signals penetrate buildings very well, and a timing source in that spectrum could be a viable back up to GPS for timing references. This proposal would require development to determine how best to provide the accuracies required for telecom needs. Propagation characteristics (distance/range, reliability) are highly variable, depending on frequency. Systems that are deployed primarily to meet the needs of another constituency (navigation upon waterways for instance) may not cover the entire United States.

## 10. Sync Distribution via Terrestrial Beacons

**Description:** An example of a Terrestrial Beacon System (TBS) is the NextNav Metropolitan Beacon System (MBS) operating between 920 and 928 MHz in the USA, which provides the

signals for NextNav's recently announced Timing as a Service (TaaS). NextNav's TaaS provides high-precision timing and frequency in GPS-challenged areas, such as Indoors and Urban Canyons and as a backup to GPS in other areas. The TaaS system can deliver very precise time and frequency synchronization. The received TBS signals from multiple terrestrial transmitters (30 W EIRP) is significantly more powerful than space-based GPS signals and provides for geographic redundancy of the signal. The signaling for TBS positioning has been standardized, in 3GPP, and the technology also enables 3D indoor location for "Mission Critical" location.

**Availability:** A GPS-based with Rubidium back-up system is deployed in select metro areas today, with capability for build to suit and expanded coverage coming soon. A totally GPS-independent system is currently under design.

**Pros/Cons:** As a ground based system, TBS is insensitive to space weather phenomena. The sub-1 GHz signals penetrate buildings well, enabling deep indoor time and frequency coverage. The high-power TBS signals are more difficult to jam than GPS, and multiple beacon overlap provides geographic redundancy mitigating a single beacon being jammed. Signal encryption and authentication protect against spoofing.

## 11. Hybrid DME (Distance Measurement Equipment)

**Description:** Combine an RNSS timing receiver with DME to provide a technological diverse timing solution and also to increase the accuracy of timing to the network. Aviation based.

**Availability:** Needs to be developed.

**Pros/Cons:** Aviation DME measures slant range by timing the propagation delay of VHF or UHF signals. In these frequency bands, propagation is limited to line of sight — not a problem when flying in an aircraft at 35,000 feet, but a likely deal-breaker for ground-based stations that are not extremely near an equipped airport.



## 4.0 FINDINGS AND RECOMMENDATIONS

We examined the options and have broken down our conclusions into two categories: those that are available today and those that may be available in the future. Our analysis is based on a review of the following factors:

- What is the benefit of the option?
- Is the option accurate?
- Is there a subscription or equipment cost associated with the option?
- What is the time frame for availability?
- What vulnerabilities does the option present?
- Is the option reliable?
- What is the coverage (global or scalable)?

**Table 4-1** captures our analysis:

<b>Table 4-1. Availability of Identified Options</b>							
<b>Option</b>	<b>Benefit</b>	<b>Accurate</b>	<b>Cost</b>	<b>Availability</b>	<b>Vulnerability</b>	<b>Reliable</b>	<b>Coverage</b>
1	Frequency diversity	X	Equipment	Now	Jamming	X	Global
2	Frequency diversity	X	Equipment	Now	Jamming, politics	X	Global
3	Frequency and system diversity	X	Subscription and equipment	Now	Jamming, space debris	X	Global
4	Purely terrestrial	X	Subscription and equipment	Now	Terrestrial	X	Scalable
5	Purely terrestrial	X	Equipment	Limited	Terrestrial	X	Scalable
6	Limits spoofing and purely terrestrial	X	Subscription and equipment	Limited	Terrestrial	X	Global
7	Purely terrestrial and non-RF	X	Subscription and equipment	Under development	Terrestrial	X	Scalable
8	Terrestrial based and difficult to jam	X	Subscription and equipment	Under development	Not as effective as GPS	X	Scalable
9	Purely terrestrial	X	Subscription and equipment	Under development	Jamming	X	Scalable

<b>Table 4-1. Availability of Identified Options</b>							
<b>Option</b>	<b>Benefit</b>	<b>Accurate</b>	<b>Cost</b>	<b>Availability</b>	<b>Vulnerability</b>	<b>Reliable</b>	<b>Coverage</b>
10	Purely terrestrial	X	Subscription and equipment	Limited	Jamming	X	Scalable
11	Purely terrestrial	X	Subscription and equipment	Under Developed	Jamming	X	Scalable

**Table 4-1** evaluates the following criteria for each of the 12 options:

- **Benefit:** The operational/technical benefit of the specific option in terms of providing an alternative to GPS for network timing. The benefits are characterized as purely terrestrial (meaning that the problems identified earlier in the report with satellite do not exist); non-RF (meaning that the jamming and interference concerns with RF-based services do not exist); limiting spoofing; frequency diversity; and system diversity.
- Whether the system is accurate in a manner similar to GPS network timing solutions.
- Where the cost for adding this system will be seen in terms of a new subscription or additional equipment costs. Because of the wide variety of uses, we were unable to quantify the actual cost per system.
- Whether the system is available now. For several of the options we looked at, they are only available on a limited basis or are not yet available.
- The most likely vulnerability of the system. These include being terrestrial, which means it is more likely subject to manmade and natural disasters, jamming, space debris, or even political climates for at least one of our proposed options.
- Whether the proposed system is reliable.
- The coverage of the system whether it is global or more localized and scalable.

As our analysis demonstrates, several appropriate options are emerging that could be utilized to provide additional reliability for network timing should GPS become unavailable or impaired. Some of these alternatives suffer from similar vulnerabilities as GPS, such as jamming. Others require additional approvals or suffer from geopolitical issues. In addition, other solutions are still being developed and need more work. In addition, all have some level of cost involved, but this often depends on the network and the need of the user.

Finally, we urge the FCC to collaborate with other federal agencies to consider the creation of national notification system for incidents of GPS jamming as a complement to any network timing solution. While not an overall solution, this would provide a notification system for users to be able to quickly react to GPS and other network timing outages. Notification would occur as soon as an outage happens. Afterwards, the cause of the outage would be investigated.

## 5.0 CONCLUSION

Network timing reliability has been well-served by GPS for several decades. However, as our networks become increasingly reliant on these technologies and as risks in this area continue to increase, it is critical that we carefully examine our options. As demonstrated herein, a number of options that can supplement or, if required, replace GPS service are increasingly becoming available. Each option must be carefully evaluated and considered in the context of the proposed usage to see which will have the best performance for that specific usage. We urge the Commission to encourage network operators to carefully examine and determine which solutions will best meet their needs but avoid having a single source solution.

## APPENDIX A ACRONYMS

**Table A-1** contains a list of the acronyms referenced within this report.

<b>Table A-1. Acronyms</b>	
<b>Acronym</b>	<b>Definition</b>
3GPP	3 <sup>rd</sup> Generation Partner Project
AFSCN	Air Force Satellite Control Network
ATIS	Alliance for Telecommunications Industry Solutions
CFR	Code of Federal Regulations
CMS	Commercial Mobile Service
CSRIC	Communications Security, Reliability and Interoperability Council
DME	Distance Measurement Equipment
eLORAN	Enhanced Long Range Navigation
EMP	Electromagnetic Pulse
FCC	Federal Communications Commission
GHz	Gigahertz
GPS	Global Positioning System
LEO	Low Earth Orbit
MBS	Metropolitan Beacon System
MCS	Master Control Station
MHz	Megahertz
NIST	National Institute of Standards and Technology
NMA	Navigational Message Authentication
PPS	Pulse Per Second
PRN	Pseudo Random Noise
PTP	Precision Time Protocol
RF	Radio Frequency
RNSS	Radionavigation Satellite Service
STL	Satellites Time & Location
SV	Satellite Vehicle
TaaS	Timing as a Service
TBD	To Be Determined
TBS	Terrestrial Beacon System
UHF	Ultra High Frequency
USNO	United States Naval Observatory
VHF	Very High Frequency
WDM	Wave Division Multiplexing
WG	Working Group
WG4B	(CSRIC V) Working Group 4B

## APPENDIX B GLOSSARY

**Table B-1** contains a list of the terms covered in this report.

<b>Table B-1. Glossary</b>	
<b>Term</b>	<b>Definition</b>
<b>3GPP</b>	The 3GPP is a collaboration agreement that was established in December 1998. The collaboration agreement brings together a number of telecommunications standards bodies that are known as “Organizational Partners”.
<b>Alliance for Telecommunications Industry Solutions (ATIS)</b>	A US-based organization that is committed to rapidly developing and promoting technical and operations standards for the communications and related information technologies industry worldwide using a pragmatic, flexible, and open approach. <a href="http://www.atis.org/">http://www.atis.org/</a>
<b>Global Positioning System (GPS)</b>	A satellite based Location Determination Technology (LDT).
<b>Working Group (WG)</b>	A group of people formed to discuss and develop a response to a particular issue. The response may result in a Standard, an Information Document, Technical Requirements Document, or Liaison.