Version 7.7

Environment Sensing Capabilities of the iPosi GNSS Receiver

Containment Loss applied to 3.5 GHz

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GLOSSARY

DISA	Defense Systems Information Agency
DA	Dispatchable Address for E911 services
FCC	Federal Communications Commission
FSS	Fixed Satellite Service: land to satellite up/down link station
GNSS	Global Navigation by Satellite System
G_{NSS}	GNSS terminal antenna gain (dBic)
IaaS	Infrastructure as a Service
NEAD	National Emergency Address Database
NIST	National Institute of Standards and Technology
Small Cell	Low power device performing Cell Tower functions (here assumed indoors)
AWGN	Additive White Gaussian Noise
RINEX	Receiver Independent Navigation Exchange (GNSS ephemeris data)
VCTXO	Voltage and Temperature Controlled Oscillator
MAC address	Media Access Control address

1 INTRODUCTION

This document is in response to the FCC request for Environmental Sensing Capability Proposals issued December 12 2015 as DA 15-1426 with reference to GN Docket No.15-319. This response is a proposal for iPosi to become an ESC operator for Category 'A' CBSD devices.

2 Background

iPosi Inc. is a technology company which is developing reference designs to embed into Small Cells / Wi-Fi access points to endow them with location, sync, and RF loss profiling capabilities deep indoors.

iPosi Assisted GPS/GNSS (A-GNSS) receivers can acquire indoor signals as low as -175dBm. These receivers can recover position and time from signals 100,000 times (i.e. 50 dB for L1 and greater with L5) weaker[1] than those observed in open sky conditions. In practical terms, this means they can operate in the basement of a 2-story concrete building.

This combination hardware/software solution inexpensively embeds into CBSDs. It produces requisite 3D location for each CBSD station as part of its Deployment Parameters, and lowers the cost of LTE GPS-grade synchronization. Station location is a key compliance factor for FCC Part 96 shared operation. Within the same cloud-assisted embedded architecture there is another equally important role: to accurately sense the local radio environment with satellite signals, and thus, provide accurate radio signal loss measurements in different directions. As GNSS satellites pass over an indoor CBSD, iPosi *measures* and records their received power levels at various azimuths and elevations – over time these passes fill out a containment profile.

The essence of the loss profiling is that the CBSD antenna will be collocated with the GNSS antenna. The RF power loss through building materials received by the GNSS antenna is, by symmetry, the same as the power loss through the antenna as a transmitter. Since the RF loss for any given building material is higher at higher frequencies (c.f. section 7), the *measured* (incoming) loss at L1 or L5 (1.575 GHz and 1.176 GHz respectively) will serve a lower bound for the (outbound) loss at 3.5 GHz -- or any frequency above L5.

These measured path losses are summarized in a table and pushed to a SAS to generate a license for the CBSD by taking into account Free-Space losses *together* with measured environmental containment losses.

By its very nature this new ESC paradigm avoids the need to know the whereabouts of federal assets, and therefore, "does not store, retain, transmit, or disclose operational information on the movement or position of any federal system or any information that reveals other operational information of any federal system that is not required to effectively operate the ESC by Part 96".

[1] ICD-GPS-200C p46 specifies minimum received power for the L1 CA signal to be -128.5 dBm into a 3 dBi linearly polarized antenna. This is equivalent to -128.5 dBm into a 0 dBic antenna. For L5, the received power is 4 dB greater than L1. A dipole can provide more gain at the horizon.

Ultimately, CBSD synchronization to GPS time could serve as an additional dimension to mitigate CBSD-to-legacy interference as well as protect sensitive CBSD receivers from incoming radar pulsed power (obviously blackout intervals must be dithered to avoid location of naval assets – however this is not an issue for maritime radar).

Furthermore, the iPosi loss-sensing will be a complementary approach to spectrum sharing when there is significant path-loss in the directions to the incumbents. When building losses so warrant, GAA users will be able to coexist with Naval Radar in coastal areas much less restrictive than the present exclusion zones. As an example, consider Table 1 below:

Protection distance with the added building loss using free space (d^2)

	ref d(Km)	0	5	10	15	20	30	40	<-Attenuation dB
	5	5.0	2.8	1.6	0.9	0.5	0.2	0.1	
	10	10.0	5.6	3.2	1.8	1.0	0.3	0.1	
Normal outdoor	**15**	15.1	8.5	4.8	2.7	1.5	0.5	0.2	
protection	**20**	20.1	11.3	6.3	3.6	2.0	0.6	0.2	
distance ref	**30**	30.1	16.9	9.5	5.4	3.0	1.0	0.3	<-Km
d(Km)->	**40**	40.1	22.6	12.7	7.1	4.0	1.3	0.4	
	5	50.2	28.2	15.9	8.9	[illegible]	1.6	0.5	
	75	75.3	42.3	23.8	13.4	[illegible]	2.4	0.8	
	100	100.3	56.4	31.7	17.8	10.0	3.2	1.0	

Table 1. Free-Space versus Containment and Free-Space exclusion distances

If under Free-Space (only) assumptions one needs a 40 km standoff distance to safeguard naval radar, then with 20 dB building loss (i.e. containment) one will only need 4 km with Free-Space from the building to achieve the same I/N ratio.

Thus, assuming moderate 15-30 dB building RF losses, one can unlock a lot of spectrum for a lot of users far closer to the coast on a continuous basis (although clearly, only buildings with RF containment near 50 dB will allow CBSDs to operate at near full-power close to shore).

This ESC method is also applicable to simultaneously protecting C Band satellite earth stations (FSSs) also envisioned by the Commission for spectrum sharing in its subsequent Docket 12-354 proceedings using bands outside the initial 3.55-3.7 GHz sub-band. Likewise, this method is also applicable to guarding against harmful interference due to close PAL-to-PAL or GAA-to-PAL stations operating nearby. This improves spectrum re-use intelligently as new CBSD installations occur, and in this context, has the advantage that no new infrastructure will be required beyond that described in [4].

The characteristics of the iPosi embedded chip-scale receiver are: position to better than 20 m (typically) inside buildings located in dense urban settings, and synchronization to within 100-250 ns of GPS time, as well as the

ability to detect up to 50 dB of RF loss relative to unobstructed GNSS signals with an accuracy[2] of ~ +/- 1 dB using L1 and L5 signals.

For the reader's convenience, the following describes the sections addressing specific operator requirements.

Responses to ESC operator requirements[3]:

Table 2. ESC Operator Requirements

Requirements of ESC	**Section addressed**
A description of the methods (*e.g.*, interfaces, protocols) that will be used by the ESC to communicate with the SAS	Section 6.1 & 6.2
Description of sensing methodology (infrastructure based); storage of info re: federal assets	Section 2 & 3 & 6.3
Method to verify that all sensors can communicate with the ESC in a timely and secure manner	Section 3

Table 3. SAS and ESC Operator Requirements

Requirements common to SAS and ESC operators	**Section addressed**
A detailed description of the scope of the functions that the SAS and/or ESC would perform	Section 2 & 4
ESC operator possesses sufficient technical expertise to operate an SAS and/or ESC	Section 9

[2] Power levels can be post-corrected for environmental effects / satellite power issues by the iPosi reference station network.
[3] Page 7 & 8 SAS ESC Procedures PN (DA-15-1426)

The prospective SAS Administrator or ESC operator must demonstrate that it is financially capable of operating an SAS and/or ESC for a five-year term	Section 10
A description of how data will be securely communicated between the SAS and its associated ESC and how quickly and reliably these communications will be accomplished	Section 6.2 & 3
Technical diagrams showing the architecture of the SAS and/or ESC and a detailed description of how each function operates and how each function interacts with the other functions	Section 3,4, & 5
A description of the propagation model and any other assumptions that the prospective SAS Administrator or ESC operator proposes to use to model operations and facilitate coordination in the band	Section 5.1
A description of the methods that will be used to update software and firmware and to expeditiously identify and address security vulnerabilities	Section 3
An affirmation that the prospective SAS Administrator and/or ESC operator (and its respective SAS and/or ESC) will comply with all of the applicable rules as well as applicable enforcement mechanisms and procedures	Section 11

3 Architecture

The diagram below explains the architecture behind the iPosi solution. First, the embedded iPosi receiver uses the host processor to acquire the signals with the aiding information (timing and traditional GNSS aiding) sent via an iPosi server.

After acquiring signals, the iPosi server will function as an autonomous GNSS receiver, but will offload measurements back to a regional server to be post-processed for an optimal final position.

Once enough measurements have been obtained, and once the post-processed position is of good enough quality, the position is locked in, and the GNSS receiver continues to function in time-only mode (if GNSS sync is required).

Even after a final position is calculated, the iPosi GNSS receiver will continue to collect satellite data (preferentially in the direction of incumbents), and after a sufficient period (perhaps a few weeks), the CBSD's loss profile table (to be described later) will be sent to the SAS to obtain a GAA license.

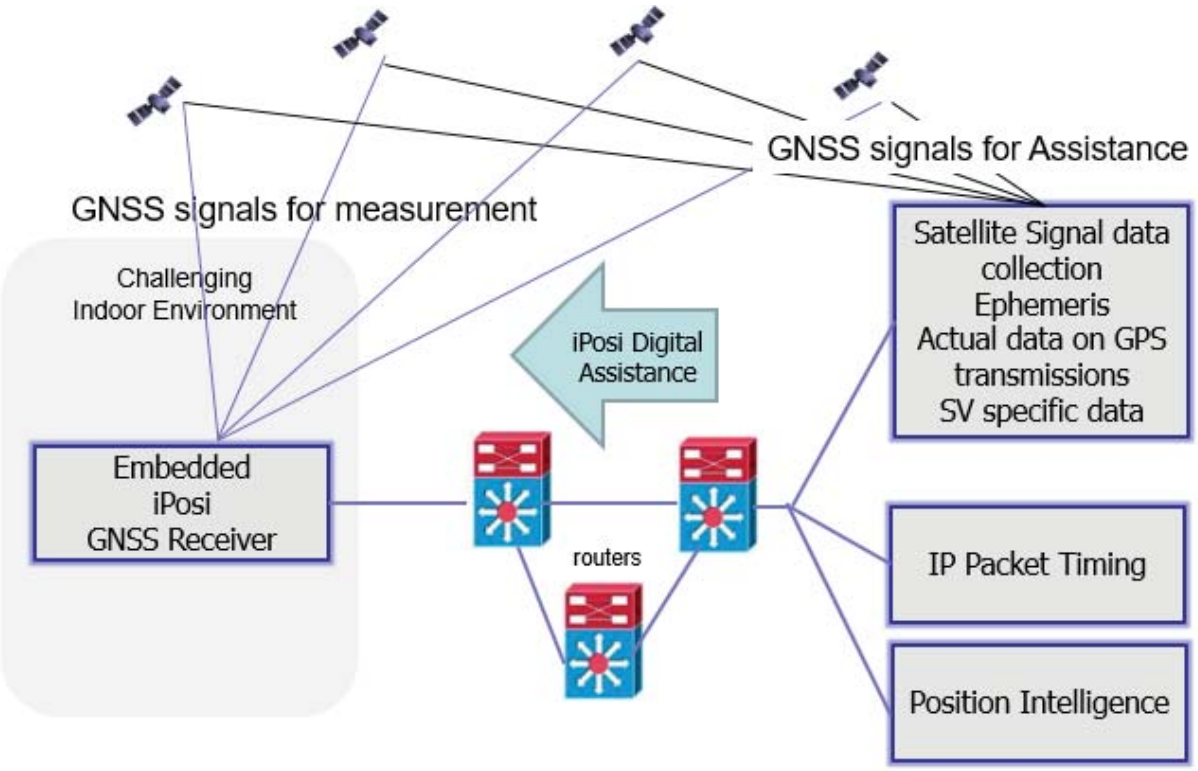

Figure 1. iPosi Assistance

Within the embedded receiver, the only new hardware necessary is the iPosi co-designed RF /digital ASIC which will connect to the local oscillator (VCTCXO) and the GNSS antenna (c.f. Figure 2).

NB Referring to Figure 2, the GNSS antenna (L1 & L5) on the right, would typically be very closely located (i.e. above or below) the CBSD antenna depicted on the left. Both their gain patterns will be carefully characterized; they will also be installed level to the ground.

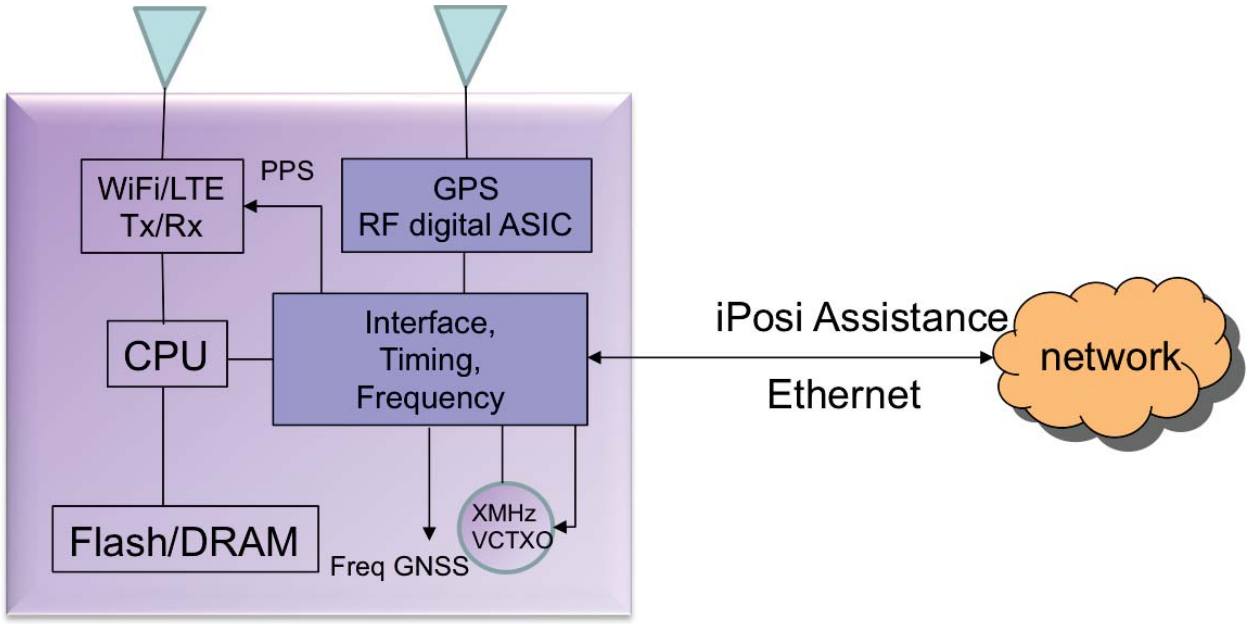

Figure 2. Embedded Client Architecture

The iPosi packet-timing assistance provides the CBSD with fine-time aiding for initial acquisition of GNSS signals. After initial acquisition, network packet-timing is shut-off, but the iPosi network will still send a continuous but low-bandwidth data stream to help in the continual tracking of the GNSS signals.

This 'background' assistance data-feed will have a built-in heartbeat. It will serve to keep the iPosi server continually informed of the CBSD's state of operation. *Without reception of heartbeat from the iPosi server, the CBSD will stop broadcasting* (after a previously configured period of time has elapsed).

One last feature of the system architecture, is that the GNSS receiver can be shut-down, but the CBSD can coast on its internal oscillator while new GNSS firmware/SW is uploaded (because of new features, or to patch security vulnerabilities) -- without compromising CBSD operation. As with all data, the new build or patch will use a strong salted hash code for authentication.

4 Description of Use of iPosi-enabled CBSD

4.1 General

A CBSD equipped with iPosi sensing capability will typically be installed in the interior of a building – i.e. in a room *without* an outside window. The CBSD antenna and the GNSS receiver antenna will be collocated as closely as possible and installed level to the ground, at a known height above the ground; the gain pattern of the GNSS antenna will be well characterized, as will that of the 3.5 GHz CBSD antenna.

The receiver will typically self-survey for a period of time, after which its data will be securely offloaded to a regional iPosi peering server to compute its post-processed position to satisfy the requirements in CFR 96.39(c).

Within a week, the receiver will have observed multiple (non-repeating) satellite passes, and the azimuthal loss patterns will be known with tiles of roughly 10-degree accuracy.

Within a month, a dense coverage of 3x3 degrees can be established (except for the GNSS coverage hole c.f. Appendix A). This grid can then be uploaded to the SAS to obtain a license (c.f. section 5 Models for SAS).

If the RF containment of the CBSD does not warrant a license (at any usable power) from a SAS, due to proximity to the coast (or to other non-naval incumbents), the iPosi regional server would relay messages from the SAS to switch off during naval operations and act on a Grant Suspended message.

4.2 Naval incumbent

The same install as the 'general' procedure (described above) except that upon the post-processing procedure revealing that the CBSD is near a coastal area, the iPosi post-processing server checks to see that no GNSS hole (c.f. Appendix A) is present facing the coastal area (i.e. north-facing for continental US). If the iPosi server determines it can (over a few weeks) build a complete loss-profile in the direction of the coast, the server will instruct the CBSD to favor acquiring/tracking satellites in the direction of the coast.

For the north-facing GNSS hole, the iPosi server will interpolate that area (i.e. the rows for that elevation angle) using the minimal loss recorded at that elevation. Non-traversed pixels outside of the 'hole' will be interpolated using the values of their neighbors. There will only be a handful of these after a month of surveying (please see Appendix A, Figure 5).

After the iPosi server has gathered sufficient GNSS data to build a profile, the loss profile scaled to 3.5 GHz including the antenna, is submitted to a SAS. A license will be granted if there is sufficient containment.

As mentioned above, if containment does not warrant a GAA license (at any power), the iPosi server will act as relay to the SAS's commands to switch on/off.

4.3 FSS incumbent

The same install as the 'general' procedure. Note that it is assumed the SAS knows the gain pattern of any FSS antenna for all azimuths and elevations.

It is our understanding that the locations of FSS assets can be made available to ESC operators. With this knowledge, the iPosi server could determine if there is any proximity to these, and if so, determine the directions (azimuth and elevation) of GNSS satellites to favor, in order to build an accurate loss profile in the direction of the FSS incumbent(s). Ultimately, however, the SAS would have to know the details of the FSS's gain pattern.

4.4 PAL incumbent

We understand that there may need to be some “out-of-band” messages to help inform the CBSD where stationary PALs are located, or at least their direction relative to the CBSD. This would help the CBSD preferentially search in the direction of any incumbents and obtain a license a little faster.

In particular, it is assumed that the PAL could schedule a test period (at a time which minimizes the effects of possible interference) during which the CBSD will transmit at its Maximum Transmit power. This could be a test to perform in order to transition the CBSD from Granted to Transmission state. The SAS would mediate this test period.

4.5 GAA to GAA Sharing

If the other GAA is also an iPosi-enabled CBSD, it is expected the SAS will apply models using the Free-Space distance between the two receivers as well as both their containment losses (c.f. section 5).

5 Model to be used by SAS

The SAS will be given a table of azimuth and elevation loss parameters in dB.

The format is: [#rows, #cols] unsigned short, unsigned short, then actual table value.

For instance, if #rows=10 & #cols = 4, the azimuth will be divided in 360/#rows = 36 degrees and the elevations will go from 0 to 40, in 40/#cols = 10 degrees

Table (unsigned byte)[#row][#cols]:

Table 4. SAS Loss Table

dB	0^0-36^0 azimuth	36^0-72^0 azimuth	72^0-108^0 azimuth	108^0-144^0 azimuth	144^0 - 180^0 azimuth	180^0 - 216^0 azimuth	216^0 - 252^0 azimuth	252^0 - 288^0 azimuth	288^0 - 324^0 azimuth	324^0 - 360^0 azimuth
30^0-40^0 elev	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
20^0-30^0 elev	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
10^0-20^0 elev	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
0^0-10^0 elev	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX

Aside from the SAS table, the CBSD will transmit a 3x3 matrix **A** (IEEE float) to transform between WGS84 and East North Up local coordinates.

A will be sent as a series of 9 floats: A_{11}, A_{12}, A_{13}, A_{21}, A_{22}, A_{23}, A_{31}, A_{32}, A_{33}

Thus, for each incumbent to be protected, the SAS computes the WGS84 vector from incumbent to CBSD:

$\mathbf{P}(\text{incumbent})_{WGS84} - \mathbf{P}(\text{CBSD})_{WGS84} = \mathbf{dX}_{WGS84}$

$(dE, dN, dU) = dX_{ENU} = \mathbf{A}\ dX_{WGS84}$

Whereupon, (in local coordinates), the angle to the incumbent is

$\text{azimuth} = \tan2^{-1}(dN, dE) * \frac{180}{\pi} = \alpha$ [degrees]

which determines the index into the column of the table $index_{col}$ = floor(α / #cols).

The elevation is determined by

$\text{elevation} = \tan2^{-1}(\ dU, (dE * dE\ +\ dN * dN)^{1/2}) * \frac{180}{\pi} = \beta$ [degrees]

which determines the index into the row of the table $index_{row}$ = floor(β / #rows).

Finally, the minimum loss from the CBSD to the incumbent is [dB]:

$$Loss\ [dB] = 20 * log10(d) + 20 * log10(f) + 20 * log10\left(\frac{4\pi}{c}\right) + T[index_{row}, index_{col}]$$

Where f is the frequency [Hz] of the signal to be protected (e.g. 3.5 GHz) and d = |dX| is the Euclidean norm of the vector dX. The inverse square law is conservative but appropriate for nearby PALs.

In particular, the entries in the table T account for the gain pattern of the CBSD's transmissions at frequency f, and the GNSS antenna at L1 or L5 (1.575 GHz and 1.176 GHz respectively). They do not take into account the incumbent's antenna gain - except in the case described in section 4.5 where containment losses at either end are known (e.g. via another table uploaded by an iPosi-enabled CBSD). In that case, the computation is described below.

In the case where CBSDs 1 and 2 have a loss profile table, T_1 & T_2, the losses will be:

$$Loss = 20 * log10(d) + 20 * log10(f) + 20 * log10\left(\frac{4\pi}{c}\right) + T_{1[index1_{row}, index1_{col}]} + T_{2[index2_{row}, index2_{col}]}\ dB$$

In particular, $index2_{row}$ = ($index1_{row}$ + #columns / 2) % #columns since the azimuths will be 180 degrees apart.

It is the SAS's job to calculate the maximum power for a license, respecting the maximum I/N ratio tolerated by the incumbent.

There might be some circumstances under which the CBSD may be endowed with an after-market iPosi solution. In this case, it is possible the CBSD Operating Parameters (bandwidth, antenna make and model, insertion loss, etc.) may reside in the SAS but not in the iPosi solution. In such a case, the iPosi after-market functionality may entail pushing a containment table, which does **not** take into account the CBSD antenna gain. Such a table will be clearly labeled "environmental loss" only.

5.1 Model and Parameter Updates

During the loss-profile commissioning phase (i.e. after the CBSD has locked in its location and gone into time-keeping mode), the CBSD will push its measurements to the iPosi server where the power measurement will be corrected by iPosi reference receivers (which enjoy an RF feed from open sky antenna).

Upon being notified of the granting of a GAA license using the Loss Table, the iPosi server will send a copy-of-record of the Loss Table back to the CBSD.

The CBSD will still periodically send measurements to the iPosi server to continually refine the Loss Table. However, if at any time after a license is issued, the CBSD generates table entries which decrease by more than 3 dB with respect to the copy-of-record, then the CBSD will *immediately* push this new data to the iPosi server, which will post-correct these values and, if warranted[4], send the SAS a new Loss Table to confirm the CBSD's ability to retain its license (this could occur if a wall is knocked out in an adjacent room in order to install a window).

For entries in the table where no data exists (i.e. for pixels which have not been traversed by a satellite), but where neighboring pixels have been populated, the average of adjacent pixels will be used.

For pixels in the north facing hole (in North America), the minimum of any pixel for that table's row (i.e. entries for that elevation) will be used.

For entries where the receiver was functioning normally (i.e. when Doppler and Code phase for 3 or more satellites are consistent), but a given satellite was **not** acquired, a full containment loss of 50 to 56 dB (L1 or L5 and depending on the actual GNSS antenna) will be recorded for that given satellite.

If a GAA licensed CBSD experiences a power interruption, and the heartbeat is interrupted, the iPosi server will list its state as Registered. Upon being powered up again, the CBSD will attempt to validate its position using its previous location and copy-of-record of its Loss Table (as a 'fingerprint'). Only when there is high certainty that it has not been moved, will it re-enter service (and the SAS will be notified that the state returns to Transmission). If the CBSD can confirm that it has been moved from its original position, the iPosi server will make a Deregistration Request to the SAS; the CBSD will then go into the Deregistered state.

[4] The iPosi server will be able to post-correct in case of satellite power variations. Note that local GNSS jamming or severe weather effects will only *increase* losses. Higher than normal satellite transmit-power levels, or malicious spoofing would *decrease* losses.

Note that in most deployments we expect there to be 4, or more, networked iPosi-enabled CBSDs which can range off each other – further enhancing their position validation capability.

5.2 Aggregation model

It is assumed the SAS operator will develop and deploy sophisticated aggregation models which take path loss profiles into account – especially in the case of dense ocean-facing populations with respect to naval 3.5 GHz signals.

6 Protocols and Data flow

The iPosi architecture has a peering server in a local geographic region. All iPosi-enabled CBSDs will communicate to the iPosi server and this will be the connecting peer with the SAS. When, and if, licenses are granted, the iPosi peering server will contact the appropriate CBSD to relay its license and Operation Parameters.

The regional iPosi server will also connect to the National Emergency Address Database (NEAD) to cross-check E911 locations with Dispatchable Addresses.

The CBSD will be identified to the iPosi server and the SAS using its **MAC** address. Protocols and data integrity will be discussed separately below.

6.1 Encryption and data integrity

Data between CBSD and iPosi servers is sent over a secure socket layer (SSL); SSL certificates will also be used for the iPosi servers.

The CBSD will also use appropriate SHA-256 HASH codes to authenticate itself as being a legitimate iPosi-enabled device; likewise, the iPosi server will use HASH codes when replying to the CBSD so that it can authenticate data pushed to it by an iPosi server.

In particular, if the iPosi server contacts a SAS, and it determines that it will grant permission to a CBSD to operate at a certain power level and frequency, the Operation Parameters will be hashed along with a secret salt. The CBSD will then be able to authenticate (or not) the power level received from the iPosi server.

6.2 Protocols

Communication between the iPosi server and any SAS will be governed by the protocols and security measures put in place by the SAS.

As per Wireless Innovation Forum Technical Reports [3], data pushed and pulled to and from a SAS will be via HTTP (RFC 2616, 7230,7540), and data sent will be JavaScript Object Notation (JSON) formatted.

The CBSD Position, Loss Profile Table, and the Local Coordinate conversion matrix will be pushed to a SAS, with an authentication hash-code using a pre-agreed upon secret salt. **The authentication data will always be in the last field**.

Table 5. Data pushed to SAS

Field	**Field description**
01:23:45:67:89:ab	CBSD identifier (MAC address)
Data	(Position, Local Coordinate Matrix, Table Loss)
0xb6c767960c983bc59a85180bd83f1b64…….	Authentication hash over **Data** using shared secret salt

The actual calls will look something like:

POST $BASE_URL/esc?start=LossTable {CBSD pushes its Loss Table which factors CBSD antenna gain **and** environmental losses}

POST $BASE_URL/esc?start=LocalCoords {CBSD pushes its 3x3 transformation matrix from ECEF to ENU}

POST $BASE_URL/esc?start=Position {CBSD pushes its location in ECEF WGS84 coordinates}

GET $BASE_URL/sas_admin?start=Directions {it is hoped an out-of-band message could be sent by the SAS to alert the CBSD in commissioning phase to the local azimuths of incumbents; **this is an aspirational GET message**}

POST $BASE_URL/esc?start=EnvLossOnly {CBSD pushes Loss Table for building and environment **only**, this mode may apply for after-market cases}

6.3 Sequence Diagrams for data flow

The following sequence diagram illustrates only the data flow germane to operations as an ESC (more granular interactions are not relevant to these discussions). The following numbered events pertain to Figure 3.

Please see crucial notes following Figure 3.

1) CBSD is installed in the field and connects to iPosi server and starts drawing iPosi assistance in order to establish its location. Within 1-24 hrs. enough data will be accumulated for an accurate 3D position.
2) The iPosi server sends CBSD registration information to the SAS; CBSD is in Registration Pending state.

3) After 1-24 hrs., measurements are uploaded to the regional iPosi server for final post-processing of 3D position (this position is also submitted to NEAD).
4) The iPosi server then pushes position of CBSD, and local transformation matrix to SAS (CBSD is in Registered state). Note: The CBSD *could* seek a traditional license without Loss Table for interim operation.
5) The iPosi server contacts SAS to ask for a list of stationary (i.e. non-naval) incumbents in order to inform CBSD of azimuths to preferentially search. Near coastal areas, the CBSD will be instructed to preferentially search azimuths in the directions offshore.
6) The iPosi server communicates these directions/positions to the CBSD (which could be in Transmission state if a traditional license was sought and granted in 4).
7) CBSD periodically offloads data to iPosi server to build the Loss Table.
8) Once the iPosi server determines the table to be of high enough resolution, it contacts the SAS.
9) SAS grants or denies a GAA license (possibly at some power level lower than requested).
10) If a license is granted, the details of power & frequency are relayed & CBSD goes into Transmission state. If a traditional license (i.e. ignoring containment) is granted, CBSD also moves into Transmission state.
11) CBSD periodically uploads data to iPosi server to enhance Loss Profile, and monitor changes in local RF environment (or local GNSS signal abnormalities e.g. persistent low grade jamming).
12) Naval Radar ESC detects ships and notifies SAS which notifies the iPosi server.
13) If only a traditional license was granted, the CBSD ceases operations and goes to Granted state. If the CBSD was granted a license based on containment, the CBSD continues in the Transmission state.

Please see the data flow in the sequence diagram Figure 3 following the steps described above

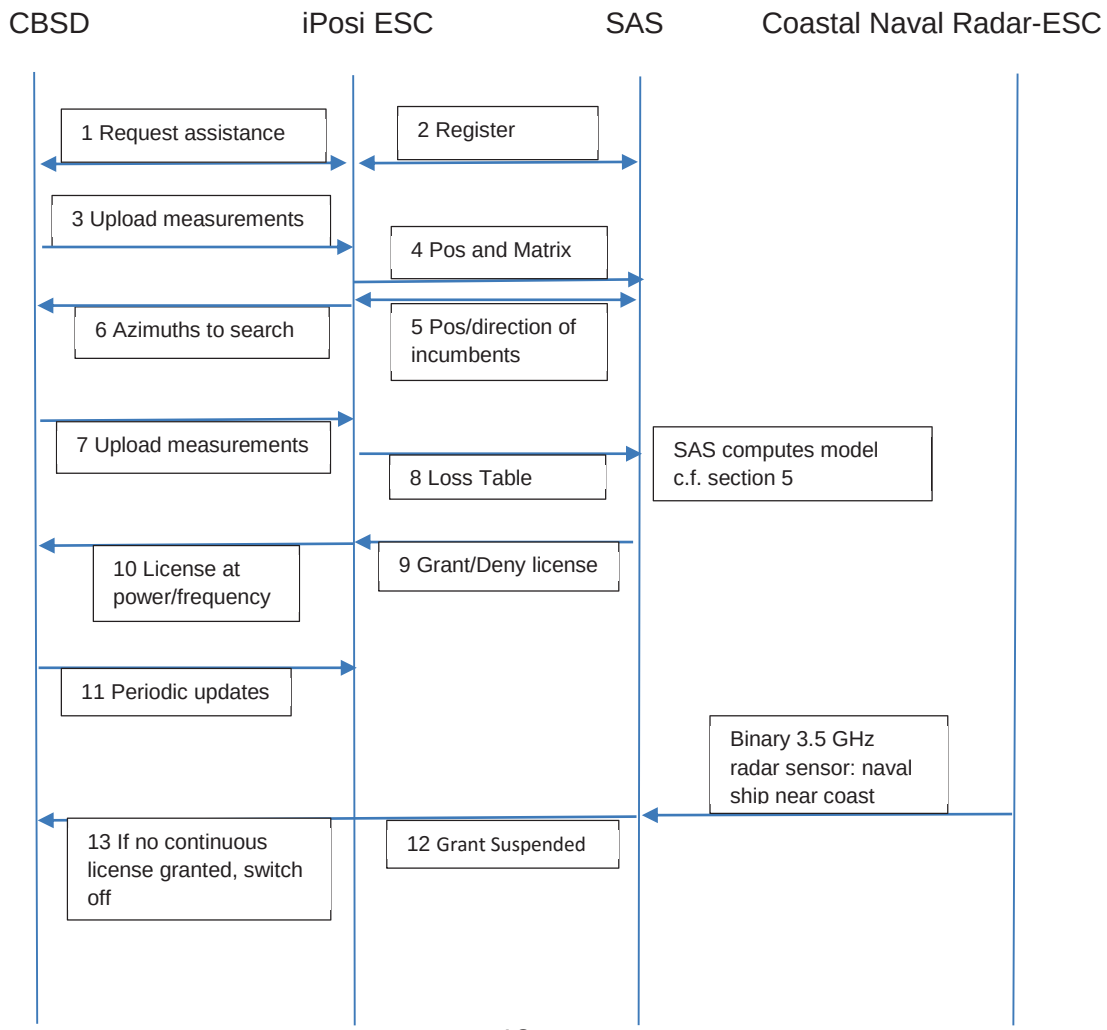

Figure 3. Data Flow

Two important points to be made:

1) Since the CBSD *could* be operating under a traditional license (e.g. while awaiting completion of Loss Table), the Grant Suspend messages (e.g. due to nearby navy traffic) will be obeyed, whereas if the CBSD is operating under a license generated using the Loss Table, the CBSD should be able to continue in Transmission state.

Therefore, we would suggest augmenting the Grant Request message (from iPosi server to SAS) to have a comment:

Protection Level "**Contained** Category A, GAA"

in order to alert the SAS of a forthcoming Loss Table (in fact, this could be the message which triggers a response regarding the local directions of the incumbents). Once the SAS has received the Loss Table and computed a permissible Maximum Transmit power, it could reply with a field in its Grant Response:

Operation Parameters "**Maximum Tx power given containment submitted UTC-Date**"

in order to confirm to the iPosi server and CBSD that the license does, in fact, take into account the Loss Table[5]. If and when a naval ship triggers a Grant Suspend message, the CBSD as licensed above would remain in Transmission state and add in its Heartbeat Response to its SAS:

Grant Suspension: false *{i.e. CBSD in Transmission state}*

Operation Parameters: "**Maximum Tx power given containment submitted UTC-Date**"

2) If a new incumbent were to become known to the SAS (e.g. a new cell tower PAL) which would be interfered with by the current CBSD's transmit power, it is assumed the SAS would then issue the iPosi server a Spectrum Revocation / Reassignment message. The iPosi server would relay this to the CBSD, but also send the SAS its most up-to-date Loss Table along with a Grant Request and wait for a new license (undoubtedly at a lower power than previously authorized).

7 NIST Material Loss Data

The table below shows the attenuation differences between some different materials at 3.5 GHz versus 1.5 GHz, c.f. [1]. In particular, the differences are always larger for almost all building materials, thus offering some conservative margin. Glass, however, offers an almost flat loss profile as shown below.

[5] If the granted license does ***not*** mention "**given containment submitted UTC-Date"**, then the CBSD must cease operation when the SAS issues a Grant Suspend message.

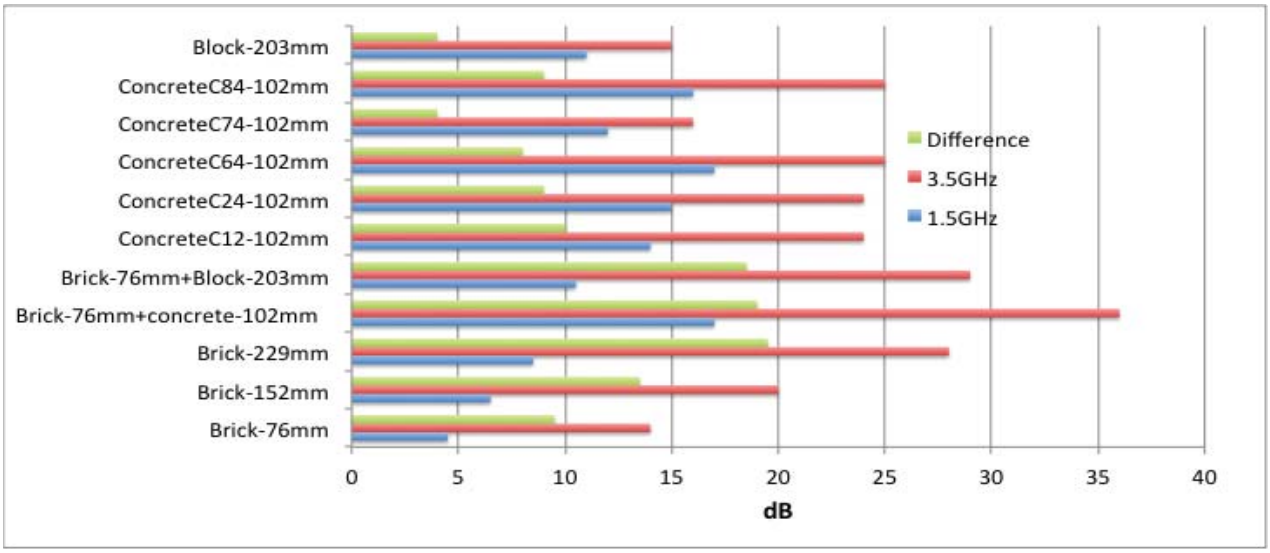

Figure 4. Table of selected material loss from NIST

Additionally, a study presented during the IEEE ICC in London 2015 [2] has looked at the RF losses through modern glass at different frequencies (c.f. Figure 5):

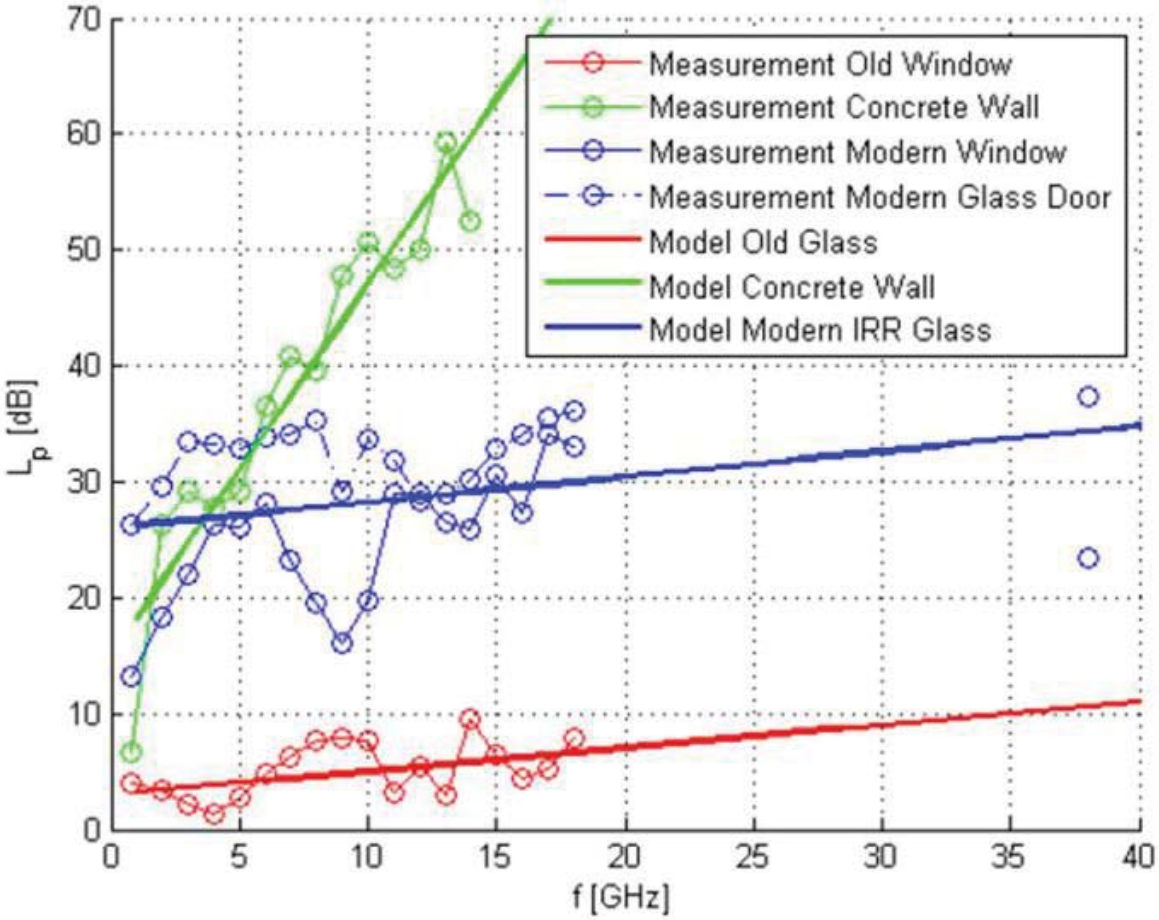

Figure 5. Measured attenuation over frequency for different façade elements

Note how this data shows more loss at 3.5 GHz than at 1.6 GHz for concrete and new building glass; old glass however, offers an almost flat response across frequencies.

8 Experimental Results

Efforts are underway with industry leaders to conduct a measurement campaign which validates the effectiveness of iPosi receivers as ESCs.

iPosi was selected to present at CableLabs' Innovation Showcase in February 2016, and as a result, we are collaborating with them to validate our technology using their test facilities. We expect to begin tabling results in May 2016. With the permission of our partners these results will be made public when final.

The efforts will start with the validation of losses through glass, concrete, and drywall in isolated rural settings. These efforts will then shift to urban settings. The emphasis being on looking at the composite of building materials in different architectural arrangements.

9 Technical Expertise

The technical qualifications of the iPosi employees can be found on the iPosi website: www.iposi.com

iPosi further relies on consultants within the University of Colorado who maintain extensive industry experience building and supporting carrier grade networks.

iPosi Inc. is also working with Virginia Tech Applied Research Corporation in support of DISA on clutter loss calibration. As stated by Virginia Tech staff, "This is for the purpose of using GPS signals to directly measure clutter – with the objective of refining clutter loss estimates used in analysis of AWS-3 early entry coordination requests (to improve spectrum sharing coexistence before DoD systems transition from the band)."

iPosi is actively working with industry partners to obtain RF Loss measurements in real-world buildings (at 1.575GHz) comparing these against 3.5 GHz measurements.

10 Financial model for ESC operation

The algorithms and architecture required to run the iPosi location and 24x7 synchronization services already requires a significant network and server infrastructure. Thus, the financial burden of augmenting the system with heartbeats and other messages is *de minimis* (although from an engineering standpoint, the extra functionality will require careful integration and testing).

iPosi offers a range of reference designs which CBSD manufacturers can embed into their receivers. The actual data services required to run and enable the GNSS part of the receivers -- as well as the communications with the SASs -- would be performed by iPosi.

The iPosi business model will be flexible, but consistent with existing Infrastructure as a Service (IaaS) providers, with lifetime (5-7 years) buy options. There will be a range of subscriptions options, but all pricing will build-in the operation of the iPosi network.

Regardless of business model, iPosi will contract with its customers using standard clauses to ensure that if iPosi were to become insolvent, the customer (CBSD OEM) could take over and run the data services so as to continue with the operation of its licensed CBSDs.

The licensing fees collected by iPosi will cover SAS access costs, running of the iPosi packet-timing network, and the continuous data feed required for GNSS assistance. However, we expect the cost associated with SAS access fees to be trivial compared to the cost of running the iPosi assistance network. As previously stated, we also expect the incremental cost of adding ESC capabilities and protocols to the iPosi assistance network to be relatively minor – more of a design cost than significant additional operating cost.

10.1 Ownership

iPosi and its designates retain ownership of its IP and software – whether it be hosted on a server, or embedded in a CBSD.

iPosi will own the GNSS receivers and network time-servers in its regional network (i.e. the physically racked equipment) and its ancillary cables and antennas. iPosi will lease rack and roof space on its collocation centers for its GNSS assistance network.

The actual GNSS hardware conforming to iPosi's reference design will be owned by the CBSD owner / manufacturer.

Lastly, the post-processing of the CBSD GNSS data would be done through two proven IaaS leaders for (geographical and business redundancy): AWS and Level3.

11 Affirmation of Compliance

iPosi affirms that it will comply with all applicable FCC directives, rules, enforcement mechanisms, and procedures as an ESC operator.

12 References

[1] NIST Construction Automation Program. Report No.3 Electromagnetic Signal Attenuation in Construction Materials by William C. Stone. October 1997, Building and Fire Research Laboratory, National Institute of Standards and Technology Gaithersburg, Maryland 20899

[2] Analysis of 38 GHz mmWave Propagation Characteristics of Urban Scenarios. Ignacio Rodriguez, Huan C. Nguyen1, Troels B. Sørensen1, Jan Elling, Jens Age Holm, Preben Mogensen, and Benny Vejlgaard. Presented at IEEE ICC 2015, London, UK.

[3] Drocella, E. F., J. C. Richards, R. L. Sole, F. Najmy, A. Lundy and P. M. McKenna, "3.5 GHz Exclusion Zone Analyses and Methodology," NTIA Technical Report TR-15- 517, U.S. Dept. of Commerce, Jun. 2015. http://www.its.bldrdoc.gov/publications/2815.aspx

[4] Using On-Shore Detected Radar Signal Power for Interference Protection of Off-Shore Radar Receivers. Frank H. Sanders, Edward F. Drocella, Robert L. Sole. NTIA Technical Report 16-521, March 2016

APPENDIX A GNSS Coverage at Different Latitudes

Satellites on non-polar orbits (e.g. GPS, GLONASS, Galileo, BeiDou, etc.) will have certain gaps in their sky plots, as will be described below. The size of the gaps is a function of the inclination of their orbital plane relative to the earth's axis of rotation and the latitude of the user.

At 28.43^0 latitude, the GPS-only coverage after 30 days can be contrasted with GPS + GLONASS coverage (c.f. Figure 6):

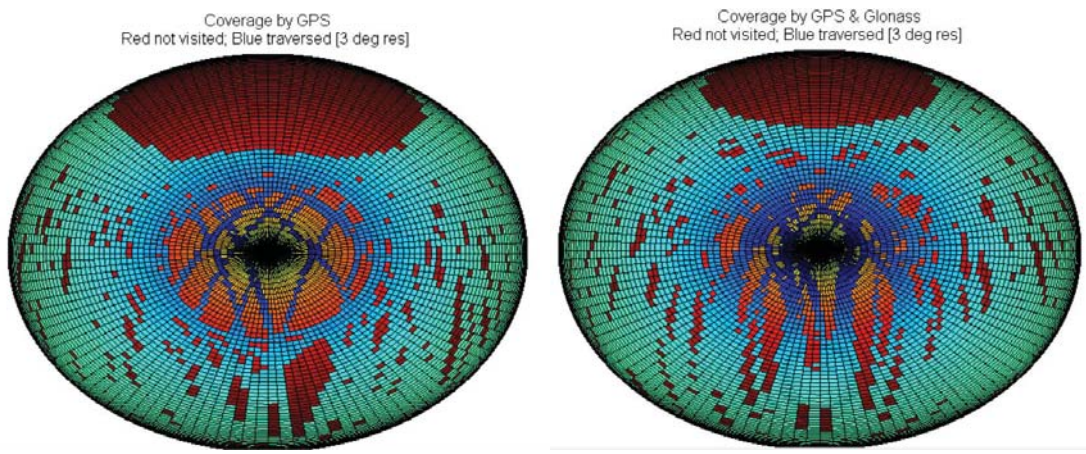

Figure 6. GNSS coverage

As can be seen above, the inclination of GNSS orbits leaves a gap in coverage on the northern face in the northern hemisphere. Among the GPS, Galileo, BeiDou, and GLONASS constellations (with inclinations of 55^0, 56^0, 55^0, and 65^0 respectively), it is GLONASS which has the smallest gaps in its sky plots. To illustrate this, we have some simulations generated from RINEX ephemeris data over simulated positions at different latitudes over a week. Pixels (of 3^0x3^0 spacing) in blue have been traversed, whereas pixels in red have not. Figure 7 shows the symmetric gap on the north or south faces at the equator for GPS & GLONASS (for clarity, this diagram would look the same if the domes were rotated 180^0 about their tops).

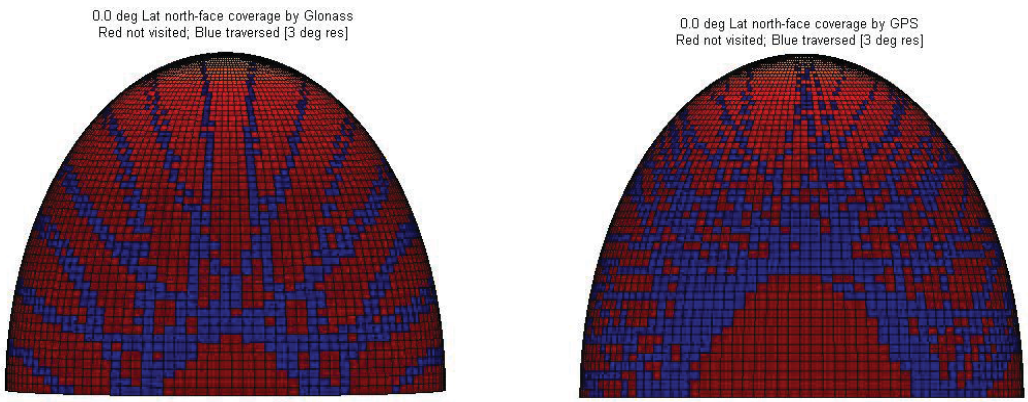

Figure 7. North or South facing gap in GLONASS and GPS at Equator

For locations off the equator, the symmetry is broken. If moving north, a larger gap opens on the north facing side than on the south facing side. This shown in Figure 8 for GPS only. The trend continues until around 18^0 latitude (just below the top of the Yucatan peninsula), where the south gap disappears, and there is ***only a north facing gap***. Finally, (for GPS) at around the latitude of Seattle (48^0 latitude) the bottom of the northern gap rises above a 0^0 mask angle (c.f. Figure 9)

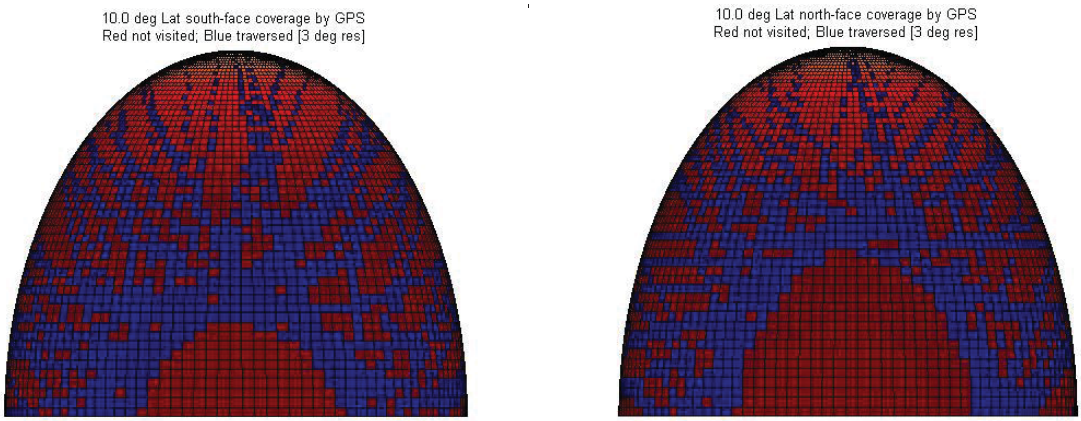

Figure 8. GPS-only South-facing gap smaller than North at $+10^0$ latitude (broken symmetry)

Thereafter the gap rises until it covers the top of the sky plot at the north-pole. The polar coverage for GPS and GLONASS is illustrated in Figure 10; this time the plot is viewed at 90^0 elevation.

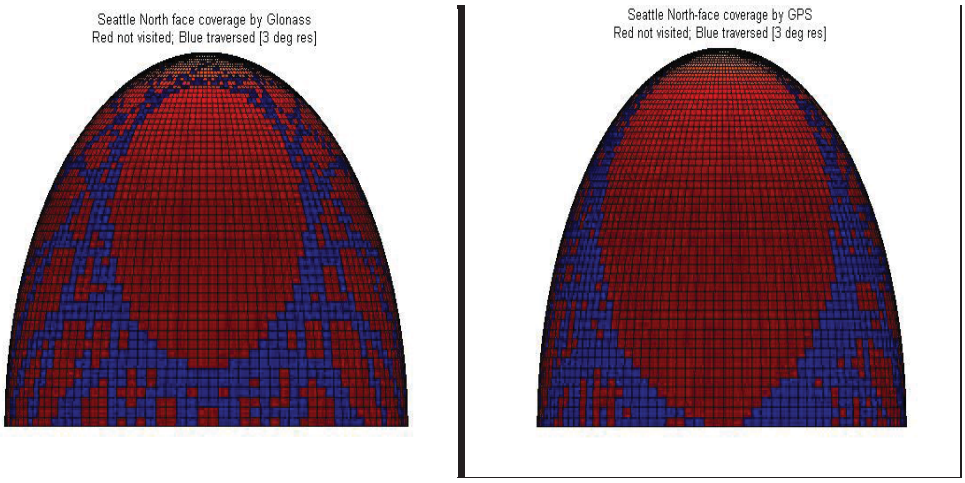

Figure 9. GLONASS and GPS north-face gap Seattle latitude

Thus it can be seen that for the latitudes below 48 degrees in the continental US, it is preferable to use GLONASS. This is illustrated in Figure 11, where a latitude of 33^0 was used (e.g. San Diego).

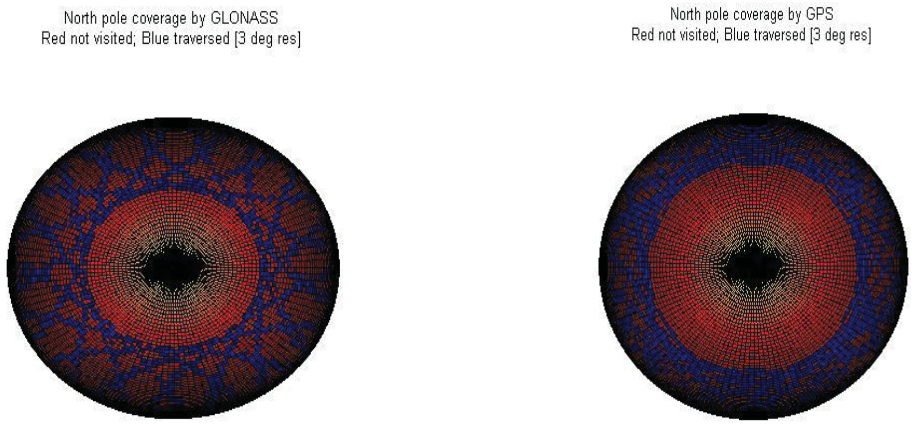

Figure 10. Polar coverage by GLONASS and GPS

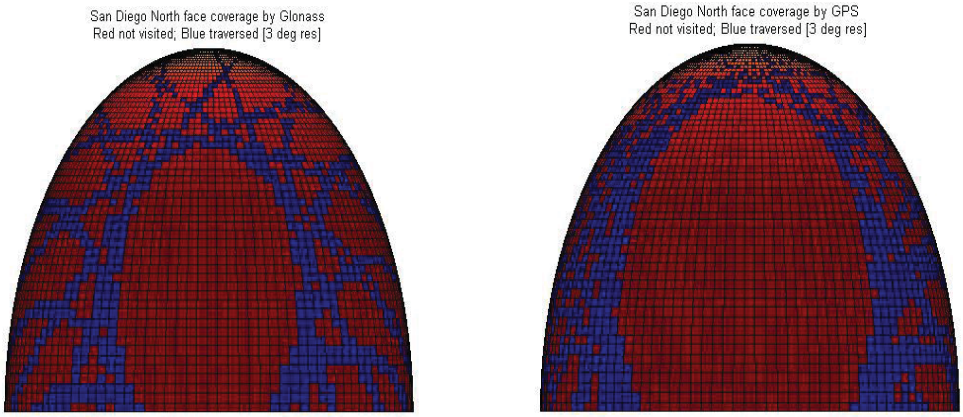

Figure 11. North facing San Diego coverage GLONASS & GPS

In summary, when between latitudes of 18^0 and 48.5^0, there is only a north-facing gap in the sky plot of GPS coverage; for GLONASS the corresponding values are 15^0 and 39^0. So augmenting the receiver's GPS coverage with GLONASS offers a way to reduce the north-facing gap for in-building containment for new spectrum. We note that GLONASS is specified to yield a received power of -131 dBm as compared to GPS' -128.5 dBm.