RTCM Paper 090-2018-SC134-009

Key Issues for RTCM SC-134 and Proposed Globalstar Contributions

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Motivation

- **Recommend key areas of focus for SC-134 to support high-integrity vehicle applications**
  - **Additions to existing message content**
  - **Development of flexible protection level equations**
- **Make use of experience gained in RTCA development of SBAS and GBAS**
- **These are areas where Globalstar intends to contribute to the work of SC-134.**

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Additional RTCM Message Content

- **To support high-integrity applications, the following additional information is needed by users:**
  - **Overbounding error standard deviations (not just "best estimates")**
  - **Bounding error biases**
  - **Prior fault probabilities (of GNSS ranging sources and augmentation systems)**
  - **Emergency "do not use" messages to meet short times-to-alert (TTAs)**

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Bounding Standard Deviations ("Sigmas")

- **Range error standard deviations that bound actual errors (when applied in a Gaussian distribution) are needed to calculate high-integrity error bounds (protection levels) by users.**
  - **Ideally sent along with "best estimates" of standard deviations for each error source for which the augmentation system is responsible.**
  - **Separate broadcast of prior failure probabilities helps define required bounding probabilities.**

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Bounding Error Biases

- **Bounds on residual error biases that may remain after correction/monitoring should also be broadcast.**
  - **Avoids the need to conservatively overbound bias errors with a larger overbounding sigma (as must be done in SBAS and GBAS).**
  - **As with sigma, preferable to broadcast both bounding and "best estimate" biases**

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Prior Fault Probabilities

- **Rather than building fixed (assumed) prior fault probabilities into standards, these should be broadcast so that they can be modified as needed.**
- **Prior fault probabilities (P_f) include:**
  - **Single-satellite fault probabilities for each supported GNSS constellation (P_{sat})**
  - **Constellation (correlated) fault probabilities for each supported GNSS constellation (P_{const})**
  - **Fault probabilities for PPP/correction parameters provided by augmentation system (P_{aug})**

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Prior Fault Probabilities (cont'd.)

- **Broadcast prior fault probabilities represent limits at which bounding error standard deviations and biases apply.**

- **Broadcast prior fault probabilities adjust "*K*-values" in user protection level equations:**
  - **Lower prior fault probability → higher P_{MD} allowed at user → lower K_{MD} required in user protection level equation → smaller protection level (all else being equal)**

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Prior Fault Probabilities: Two Definitions

- **Failure *Onset* Probability (probability of transition from "nominal" to "failed" state per unit time)**
  - **Poisson approx.: not valid at beginning and end of SV life**

$$P_{F,onset} \cong \frac{number\ of\ observed\ fault\ events}{total\ observation\ time}$$

$$MTBF \cong \frac{1}{P_{F,onset}} \equiv \text{Mean Time Between Failures}$$

- **Failure *State* Probability (long term average probability of being in fault state)**
  - **exponential queuing approximation**

$$P_{F,state} \cong \frac{MTTR}{MTBF + MTTR}$$

$$MTTR \equiv \text{Mean Time To Repair (following failure onset)}$$

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Emergency "Do Not Use" Messages

- **When sudden, hazardous faults are detected by augmentation system, a simple and rapid means to notify users (before the next scheduled message update) is needed.**
- **In SBAS/WAAS, this capability is included within the "Fast Correction" messages.**
  - **Four identical consecutive messages inflate UDRE or set UDRE to "do not use" for one or more satellites**
  - **This is outside the normal message sequence**
  - **Multiple messages sent to assure correct reception within users' time to alert**

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Protection Level Equations

- **Protection level equations translate range-domain error bounds and fault probabilities (after corrections from augmentation system) into position-domain error bounds at the desired integrity probability.**
  - **Based on user's own GNSS satellite geometry**
  - **Based on user's own models for local errors and fault modes**

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Aviation Protection Level Equations

- ***Under nominal conditions (H_0)*:**

$$VPL_{H0} = K_{ffmd}\sqrt{\sum_{i=1}^{N} s_{i,vert}^2 \sigma_i^2}$$

Bounding range error variance

Extrapolation to H0 integrity risk probability (for Gaussian dist.)

Geometric conversion: range to vertical position

- ***Under specific faulted condition (H_f)*:**

$$VPL_f = \left|B_{f,vert}\right| + K_{md,f}\ \sigma_{vert,f}$$

Vertical position error std. dev. under faulted condition

Error bias caused by faulted condition (converted to vertical position error)

Extrapolation to faulted integrity risk, incorporating prior probability (for Gaussian dist.)

- **The maximum protection level across all nominal and faulted conditions is applied by the user.**
  - **Multiple different fault-condition protection levels may exist.**
  - **Faulted conditions without computed protection levels must be bounded by the maximum protection level.**

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Augmented Protection Level Equations

- **Approach suggested for dual-frequency SBAS in [Walter, *et al*, ION GNSS 2010]:**

- **Nominal (H_0) case:**

$$VPL_0 = K_{v,PA}\sqrt{\sum_{i=1}^{N} S_{3,i}^2 \sigma_{ff,i}^2} + \sum_{i=1}^{N} \left| S_{3,i} b_i \right|$$

Gaussian multiplier to achieve required P(HMI) (user-specific)

Bounding error sigma and bias (from RTCM broadcast; valid to broadcast prior fault prob.)

- **Faulted (H_{f_k}) case (multiple fault scenarios *k*):**

$$VPL_1 = K_{v,md}\sqrt{\sum_{i=1}^{N} S_{3,i}^2 \sigma_{ff,i}^2} + \sum_{i=1}^{N} \left| S_{3,i} b_i \right| + \max_i \left| S_{3,i} B_i \right|$$

Gaussian multiplier to achieve required P(HMI) (user-specific; incorporating prior fault prob.)

Worst-case error bias on SV i due to fault mode k

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SC-134 Protection Level Equations

- **Objective for SC-134 should be to develop a standardized format for protection level calculations that can be used by many different implementations:**
  - **Standalone GNSS (e.g., ARAIM or other user-specific integrity approaches)**
    - **ARAIM "solution-separation" PL concept**
  - **Augmented GNSS (WADGNSS, PPP, LADGNSS)**
  - **User filtering of GNSS inputs (e.g., via Extended Kalman Filter, or EKF)**
  - **Fusion with non-GNSS sensors**
- **Broadcast integrity information supports protection-level calculations while having each user take responsibility for his application of it.**

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Summary

- **This presentation proposes specific components of SC-134 work plan:**
  - **Additional integrity-related information in RTCM messages**
  - **Development of a flexible framework for user protection level calculations**
- **Protection-level development would be based upon the information provided in updated message types**
- **Protection-level development would support many different user implementations**

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