Review of SC-104 Integrity WG Concepts

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Integrity Monitoring for High Precision Applications

- Objectives of the WG:
  - Review of Integrity Augmentation Monitoring Systems and Integrity Requirements
  - Definion of a roadmap for Integrity Monitoring Systems Messages and Protocols development
  - Generalised Architecture for Integrity Monitoring
  - Basic Integrity Monitoring Messages definition

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High Precision and Integrity needs

	Accuracy	Availability	Integrity	Continuity
Aviation 	++ (depending on flight mode en-route/approach)	+++	+++/++++ (depending on flight phases, e.g. CATI-CAT III)	+++
Rail 	++ (depending on the operation phase)	++ (integration with odometers)	++++ (at system level)	++++ (at system level)
Automotive 	**+++ (aided by INS)**	**+++**	**++++ (Autonomous Driving)**	**++++**
Geodesy/Surveying 	+++++	++++	++ (costs for missed surveying)	++
Maritime 	++ (depending on navigation mode en-route/approach)	+++	+++	+++

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Integrity Definitions

- **Integrity**: Ability of a system to provide timely warnings when the system should not be used for navigation
- **Alert Limit**: The alert limit for a given parameter measurement is the error tolerance not to be exceeded without an alert
- **Time to Alert (TTA)**: The maximum allowable time elapsed from the onset of the navigation system being out of tolerance until the equipment enunciates the alert
- **Protection Level (PL)**: Statistical bound error computed so as to guarantee that the probability of the absolute position error exceeding said number is smaller than or equal to the target integrity risk
- **Integrity Risk**: Probability of an undetected, threatening navigation system problem occurring in a fixed period of time

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Integrity Background

- **Misleading Information (MI)** occurs when the true navigation error exceeds an appropriate Alert Limit (Position Error-PE>AL)
- **Hazardous Misleading Information (HMI)** is said to happen for a given operation when the true navigation error exceed the Alert Limit and **no timely warning is provided** (PE>AL & PL<AL)

$$P(|x - \hat{x}| > AL \wedge No \quad Alert) \leq IR$$

- Integrity requirements is usually expressed in terms of **probability of HMIs during a predefined operational time interval** (e.g. 150 s for the Aviation Precision Approach, 1 hour in railway applications)
- **RTK**: requires Ambiguity Fixing Validation Monitoring

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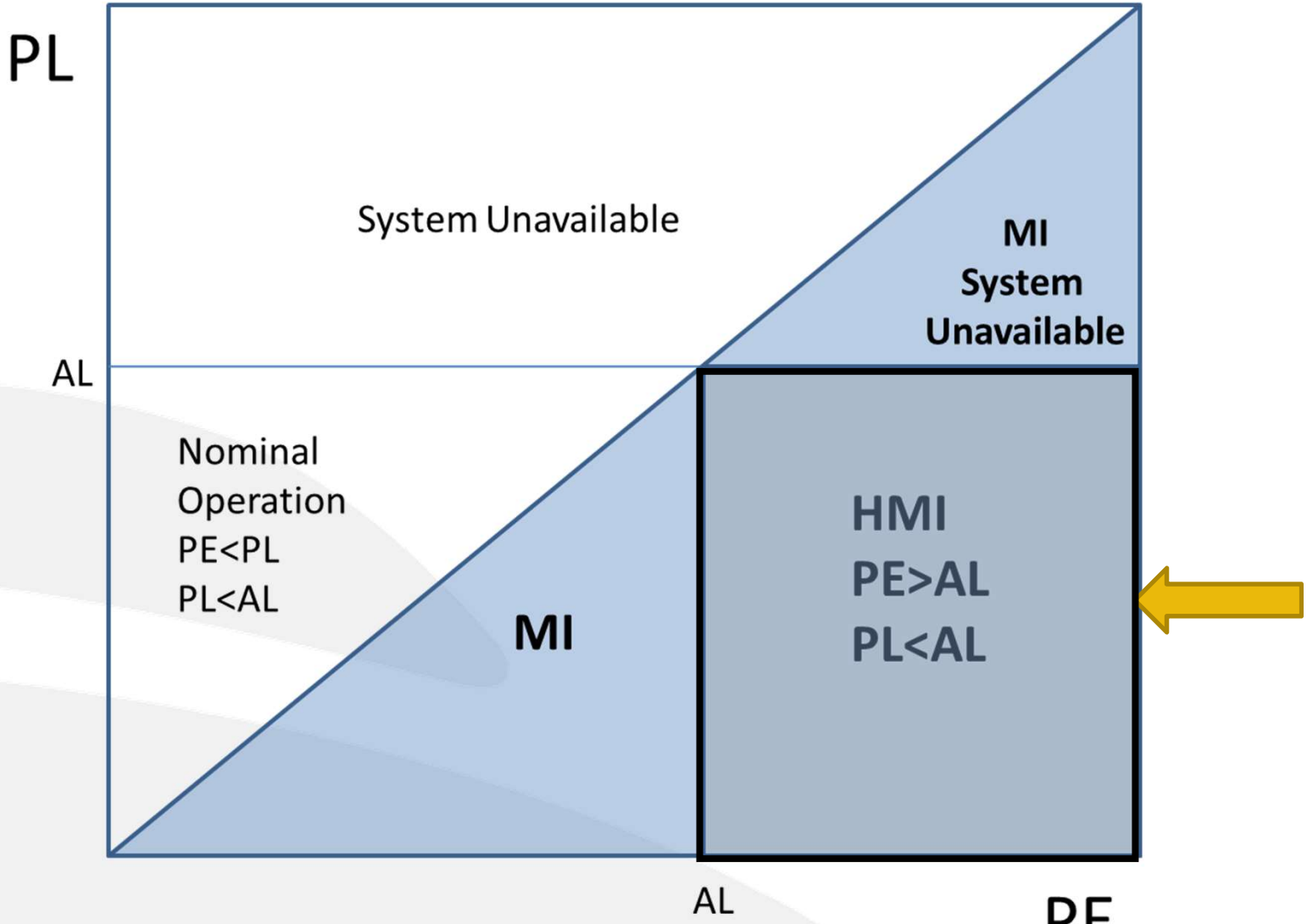
The Stanford Plot representation



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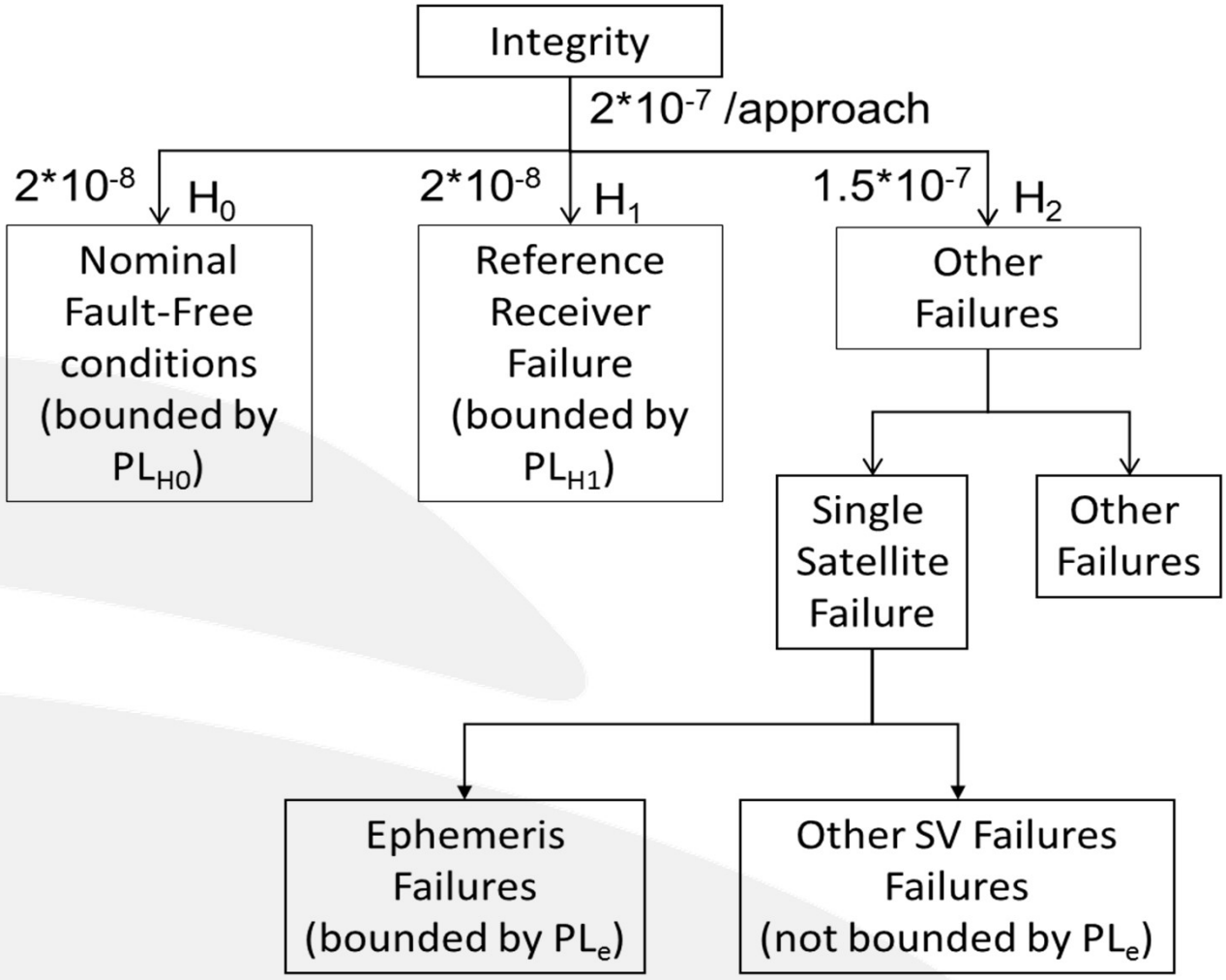
Fault Tree Analysis: Faults Aportionement



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Threat Model

	Nominal Fault	Partial Fault	Global Fault
Clock and Ephemeris	Correct estimation	Bad ephemeris	Erroneous EOPP, Ground System Failure
Ionosphere	Nominal	Scintillation	Solar Flare
Troposphere	Noninal	NA	NA
Signal Deformation	Nominal signal distorsions due to RF components and antenna	Satellite signal distorsion	NA
Code-Carrier Divergence	Different behaviour of Code and Carrier Measurements		NA
On Board Receiver Noise (Local Effects)	Nominal noise and Multipath	Excessive Multipath, or tracking faults	Multiple satellites tracking Faults and multipath or shadowing
Local Augmentation System Fault	Nominal Reference Stations	Single Fault on a Reference Station of Control Centre	Multiple Reference Stations, Communicationof Control Centre Fault
Global Augmentation System Fault	Nominal Augmentation Message generation	Missed single satellite Monitoring	Global Augmentation Fault
Communication System Fault (RS, Control Centre, user)	Nominal Latency and QoS	Excessive Latency or QoS	Communication System interruption

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Applications Requirements

Domain	Operation	Alert Limit (m)	TTA (s)	Integrity Risk
Maritime	Coastal	25	10 s	10^{-5}/3h
	Port	2.5	10 s	10^{-5}/3h
Rail	Start of Mission	3	NA	THR(*): 10^{-10}/h
	Normal Operation	12-100	NA	THR: 10^{-9}/h
Aviation	Category I Precision Approach	H 40, V 20	6 s	10^{-7}/150s
Automotive	Collision Avoidance	0.1	5 s	-
	Emergency Response	0.1-4	30 s	-
	Automated Vehicle Monitoring	0.2-30	5s-5 min	-
	Connected Vehicles	0.1	0.2	?

Sources: FRP and others

(*) THR: Tholerable Hazard Rate

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Application Specific Example: Automotive Integrity

- Autonomous Vehicle support
- Lane Keeping
- V2X and Cooperative ITS: Augmentation Service Provider and vehicle to vehicle messaging for High Integrity
- Sensor fusion: INS, LIDAR and High Precision mapping for improved Integrity and Reliability
- GNSS Manufacturers and Safety compliance
- Recent Releases: < 1 min lane-level accuracy for autonomous driving through PPP, LA and multi-delivery channels

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Integrity Monitoring Systems

- RAIM (Receiver Autonomous Integrity Monitoring): detecting faults through redundant GNSS measurements
- GBAS (Ground Based Augmentation System): Local Augmentation providing differential PR corrections and Integrity Monitoring for CAT I in the vicinity of an airport
- SBAS (Satellite Based Augmentation System): Wide Area Augementation providing corrections and Integrity messages
- ARAIM (Advanced RAIM): Global IM System able to meet LPV-200 requirements, multi-frequency, multi-constellation
- CRAIM (Carrier Phase RAIM): Integrity Monitoring for PPP
- Advanced Topics:
  - Sensor Fusion: GNSS/INS/IoT Integration
  - Integration of Different IM Systems (e.g. 2-Tiers, SBAS+LA)
- **Carrier Phase, RTK and Ambiguity Resolution IM**

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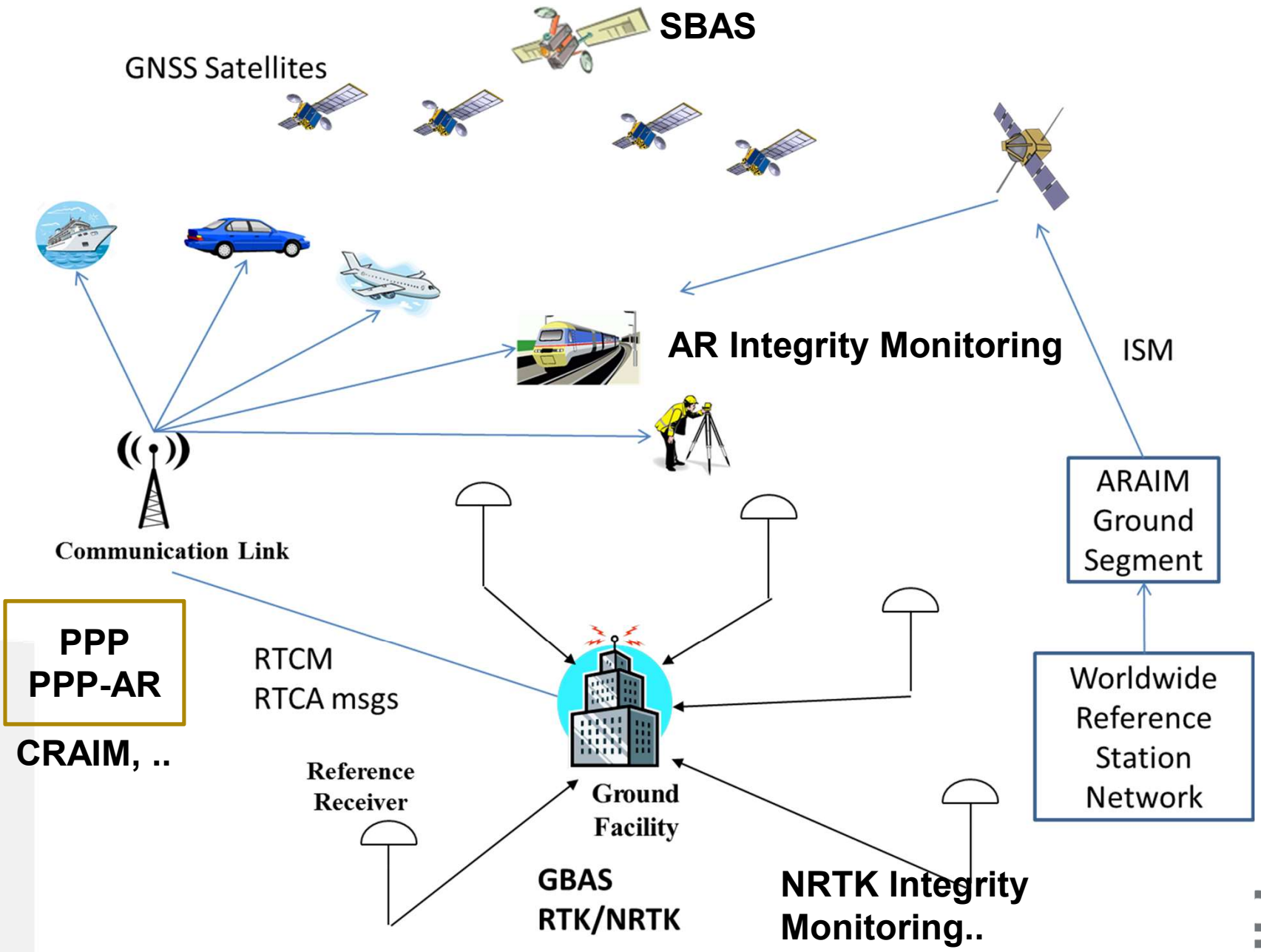
Augmentation Systems Overview



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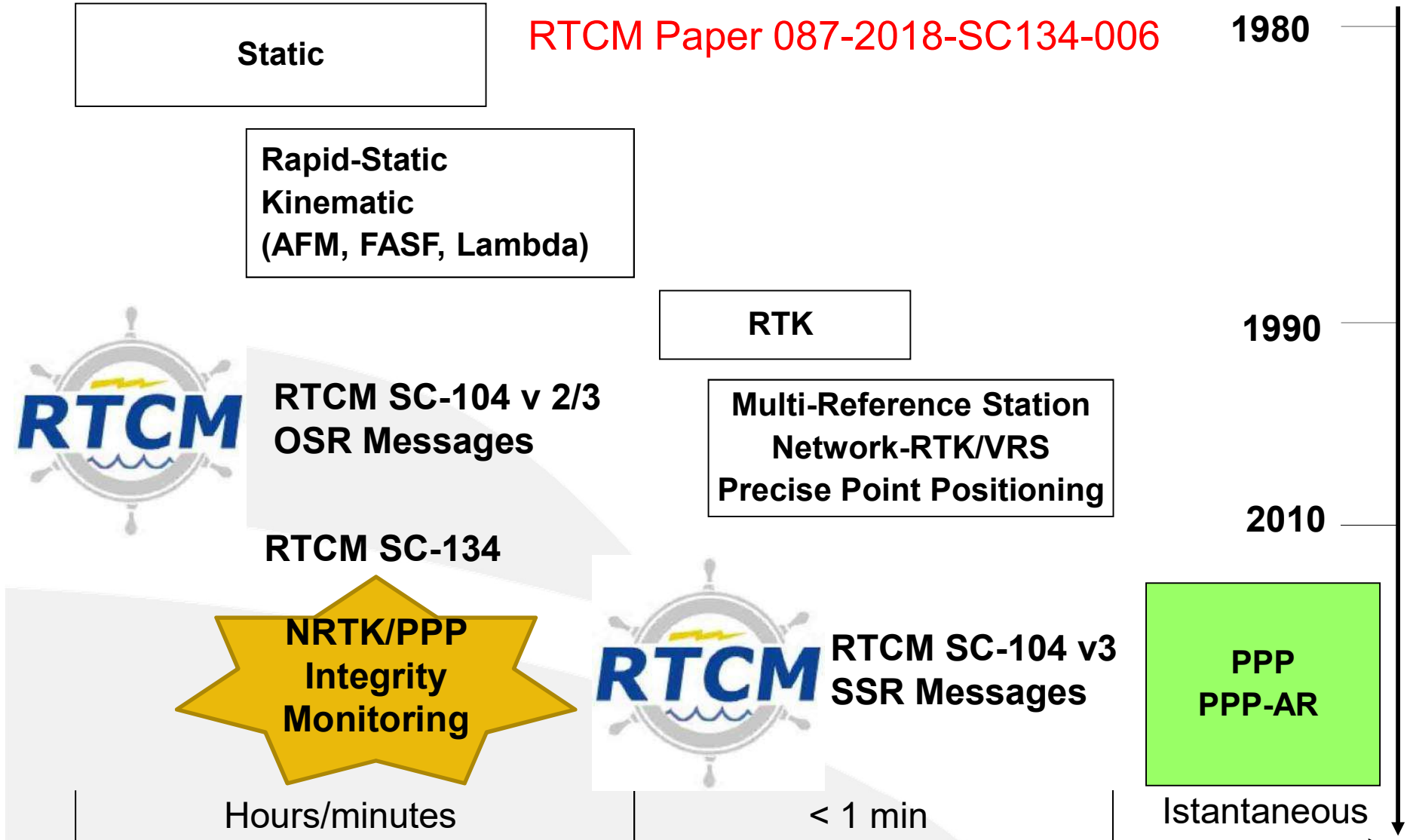
High Precision Systems Evolution



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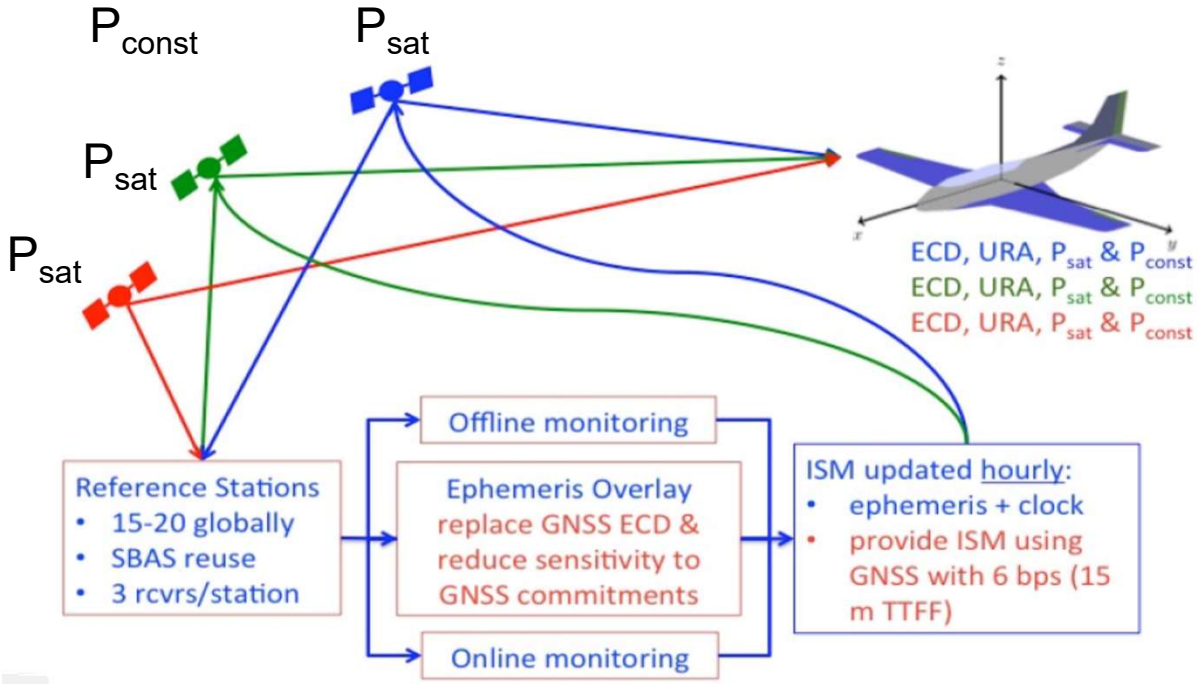
ARAIM Architecture



Source: ARAIM Working Group C

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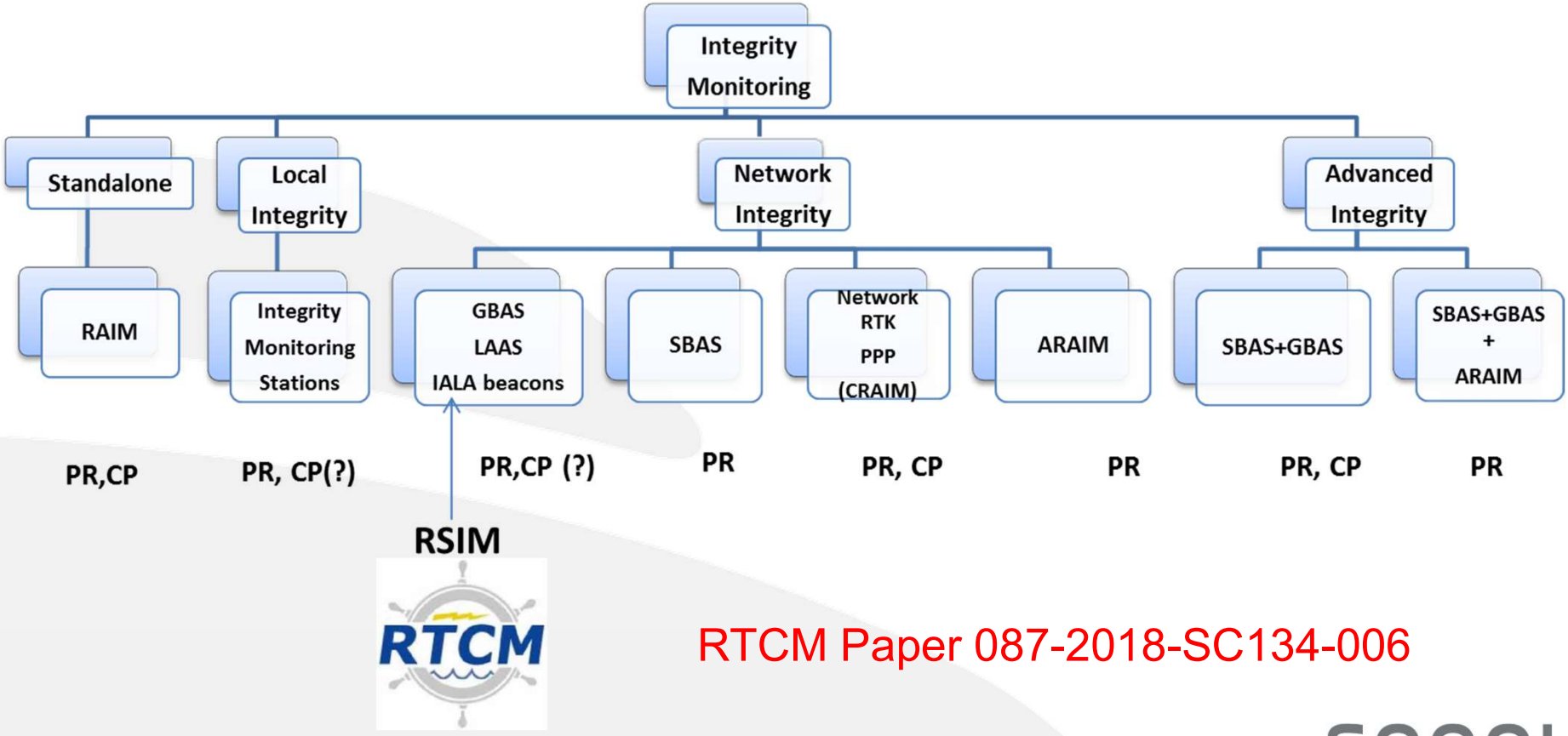
	Bit-Size	Scaling Factor	Coded Range
Constellation ID	3	N/A	[0 … 7]
Satellite ID	6	N/A	[0 … 63]
GNSS IOD Reference	10	N/A	[0 … 1023]
ISM ToA	11	60 sec	[0 … 1 day]
Sum	**30**		
Data	**Bit-Size**	**Scaling Factor**	**Coded Range (TBC)**
SAT_Health_Flag	1		[Use, Do Not Use]
Psat	4		[10-6 … 10-3] log-equidistant.
Pconst	4		[10-8 … 10-3] log-equidistant
Sigma_int	3	N/A. [Index=Value]	[0.30:0.10:0.70; 0.90; 1.10; 1.50] m
Bias_int	4	N/A. [Index=Value]	[0.30:0.05:.90, 1.10 1.30, 1.50, 1.70] m
Sigma_cont	3	N/A. [Index=Value]	[0.20; 0.25; 0.35; 0.40; 0.50, 0.60; 0.75; 1.00] m
Bias_cont	4	N/A. [Index=Value]	[0.30:0.05:.90, 1.10 1.30, 1.50, 1.70] m
Sum	**22**		

Integrity Monitoring Systems Classification



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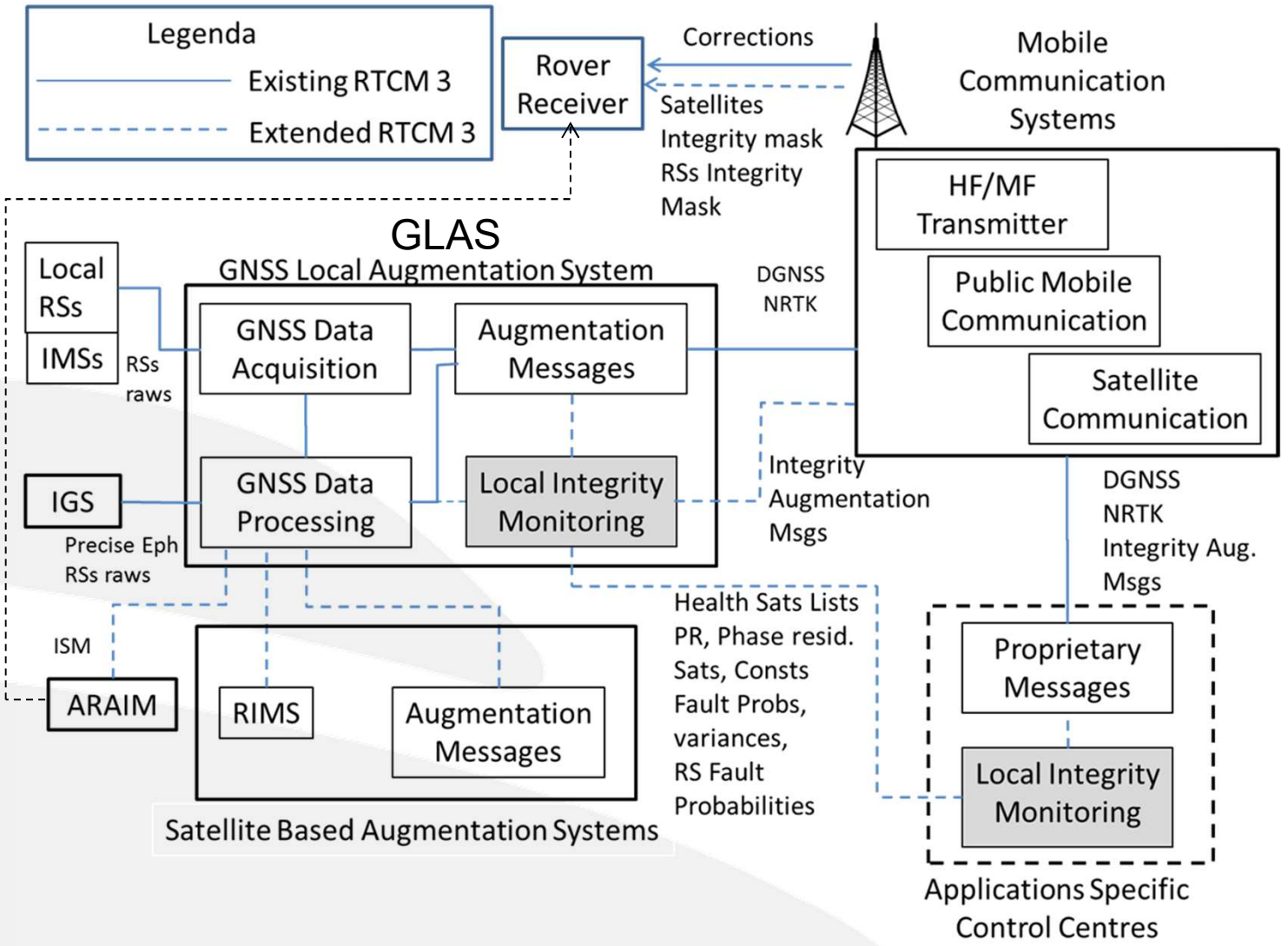
Generalised Architecture



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Integrity Systems Comparison

	Message contents	Standards/Architectures					
		RSIM	RTCM	SBAS RTCA	GBAS RTCA	IALA	ARAIM
IMS/RS to CS	PR Variances	√			√		
	CP Variances				√		
	PR Residuals	√					
	CP Residuals						
	GPS Satellite Health Status	√	√		√	√	
	Other Constellations Satellites Health	√			√	√	
	Multiple Frequencies differentiation				√		
CS to rover or ASSP	Probability of Satellite Fault						√
	Probability of Constellation Fault						√
	Probability of RS Fault						
	Sigma values/variances				√		√
	Bias Values				√		√
	RS/DGNSS Service Health					√	
	CP parameters				√		
	GPS Satellites Health		√	√		√	√
	Other Constellations Satellites Health		√	√	√	√	√
	Multiple Frequencies differentiation				√		

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ARAIM – Working Group C

	Parameter	Description	Value	Size (bits)
Data Header	ISM_WN	ISM Week Number	[0, 1, … 1023]	10
	ISM_TOW	ISM Time of Week (hours)	[0, 1, … 167]	8
	ANSP ID	Service Provider Identification	[0, 1, … 255]	8
	Criticality	Usable for Precise/Vertical?	[0, 1]	1
	Total Header = 27 bits			
Per Constellation Parameters	$Mask_i$	32 bits indicating whether an SV is valid for ARAIM (1) or not (0)	$[m_1, m_2, \ldots m_{32}]$	32
	$P_{const,i}$	Probability of constellation fault at a given time	$[10^{-8}, 10^{-5}, 10^{-4}, 10^{-3}]$	2
	$P_{sat,j}$	Probability of satellite fault at a given time	$[10^{-6}, 10^{-5}, 10^{-4}, 10^{-3}]$	2
	$\alpha_{URA,j}$	Multiplier of the URA for integrity	[1, 1.25, 1.5, 2, 2.5, 3, 5, 10]	3
	$\alpha_{URE,j}$	Multiplier of the URA for continuity & accuracy	[0.25, 0.5, 0.75, 1, 1.25, 1.5, 2, 4]	3
	$b_{nom,j}$	Nominal bias term in meters	[0.0:0.25: 2.5,, 3, 4, 5, 7.5, 10]	4
	Total Core = 46 bits x 4 Constellations = 184 bits			

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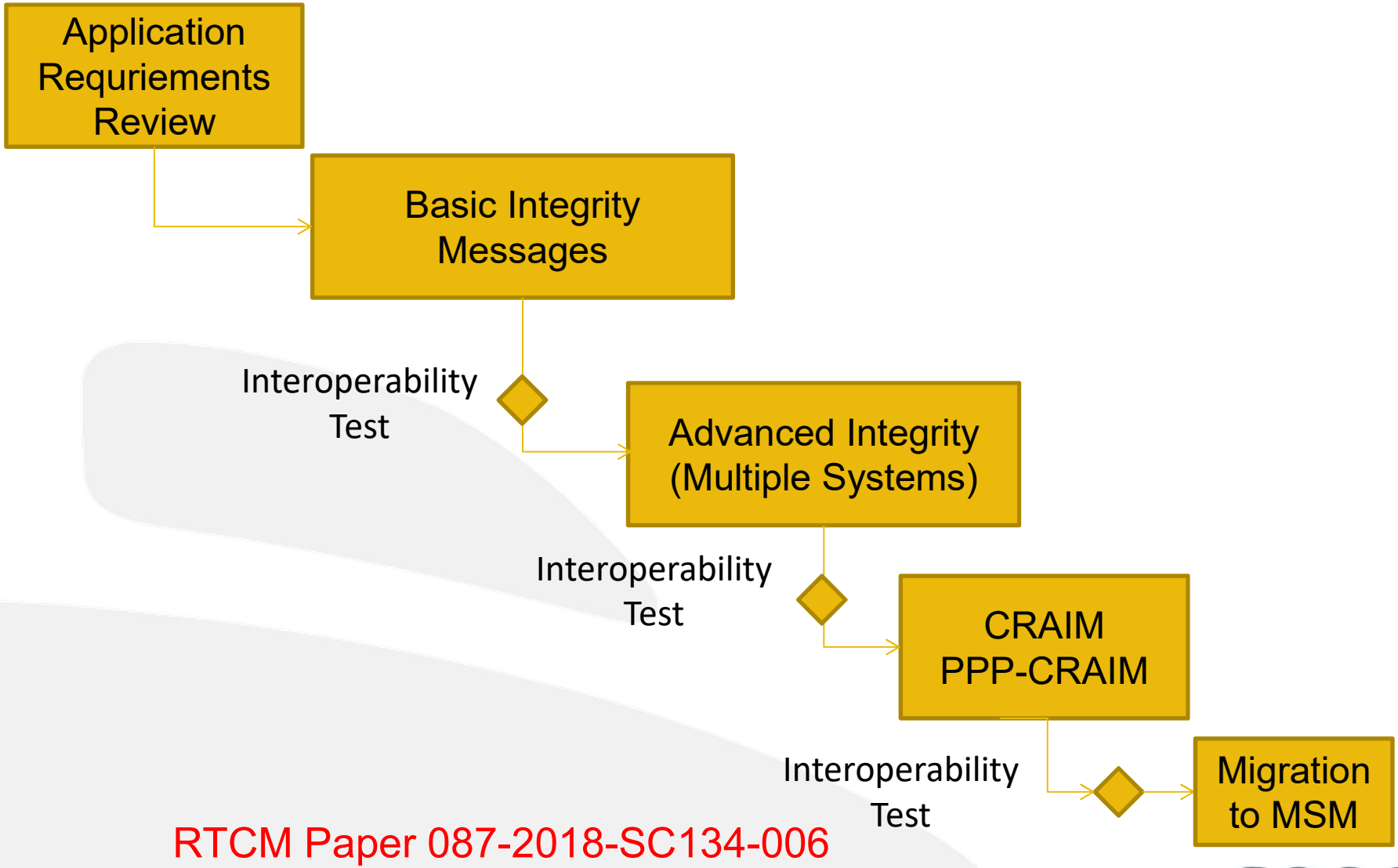
Integrity Messages development Roadmap



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Constelations and Satellite Integrity Data

Table 3.5-1 - Contents of the Message Header, Type 51: Constellations and Satellites Integrity data

DATA FIELD	DF NUMBER	DATA TYPE	NO. OF BITS
Message Number	DF002	uint12	12
GPS Epoch Time (TOW)	DF004	uint30	30
Constellation Health Mask	DF907	bit(24)	24
TOTAL			***66***

Table 3.5-2 – Contents of Constellation-Specific Portion of a Type 51 Message

DATA FIELD	DF NUMBER	DATA TYPE	NO. OF BITS
Satellites Mask	DF914	bit(32)	32
Pconst (Probability of Constellation Fault)	DF904	bit(2)	2
TOTAL			Nconst*34

Table 3.5-3 – Contents of Satellite-Specific Portion of a Type 51 Message

DATA FIELD	DF NUMBER	DATA TYPE	NO. OF BITS
Psat (Probability of Satellite Fault)	DF905	bit(2)	2
TOTAL			Nsat*2

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Proposed Type 52: Fast Constellation and Satellite Health Status

Table 3.5-4 - Contents of the Message Header, Type 52: Fast Constellation and Satellite Health Status

DATA FIELD	DF NUMBER	DATA TYPE	NO. OF BITS
Message Number	DF002	uint12	12
GPS Epoch Time (TOW)	DF004	uint30	30
Constellation Health Mask	DF907	bit(24)	24
TOTAL			***66***

Table 3.5-5 - Contents of the Constellation-Specific Portion of Type 52, for each satellite in the Constellation Mask

DATA FIELD	DF NUMBER	DATA TYPE	NO. OF BITS
Satellites Health Mask	DF908	bit(64)	64
TOTAL			***64***

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Type 52 Extensions for Multiple Integrity Monitoring Systems

DATA FIELD	DF NUMBER	DATA TYPE	NO. OF BITS
Satellites Mask	DF914	bit(32)	32
Pconst (Probability of Constellation Fault)	DF904	bit(2)	2
TOTAL			Nconst*34

Constellation Specific Contents

DATA FIELD	DF NUMBER	DATA TYPE	NO. OF BITS
Psat (Probability of Satellite Fault)	DF905	bit(2)	2
TOTAL			Nsat*2

Satellite Specific Contents

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Proposed Messages Type 53: Reference Station

Table 3.5-6 – Contents of Message Header, Type 53: Reference Station Specific Integrity data and measurements variances

DATA FIELD	DF NUMBER	DATA TYPE	NO. OF BITS
Message Number	DF002	uint12	12
Reference Station ID	DF003	uint12	12
GPS Epoch Time (TOW)	DF004	uint30	30
Constellation Mask	DF915	bit(12)	12
TOTAL			***66***

Table 3.5-7 – Content of Type 53 message

DATA FIELD	DF NUMBER	DATA TYPE	NO. OF BITS
Prs (Probability of Reference Station Fault)	DF012	bit(2)	2
Satellites Mask	DF914	bit(32)	32
Reference Station Health	DF916	bit(2)	2
L1 Pseudorange standard deviation	DF906	uint8	8
L1 Phase standard deviation	DF910	uint8	8
L2 Pseudorange standard deviation	DF906	uint8	8
L2 Phase standard deviation	DF910	uint8	8
TOTAL			***68***

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Proposed Type 54: GBAS-like PRC

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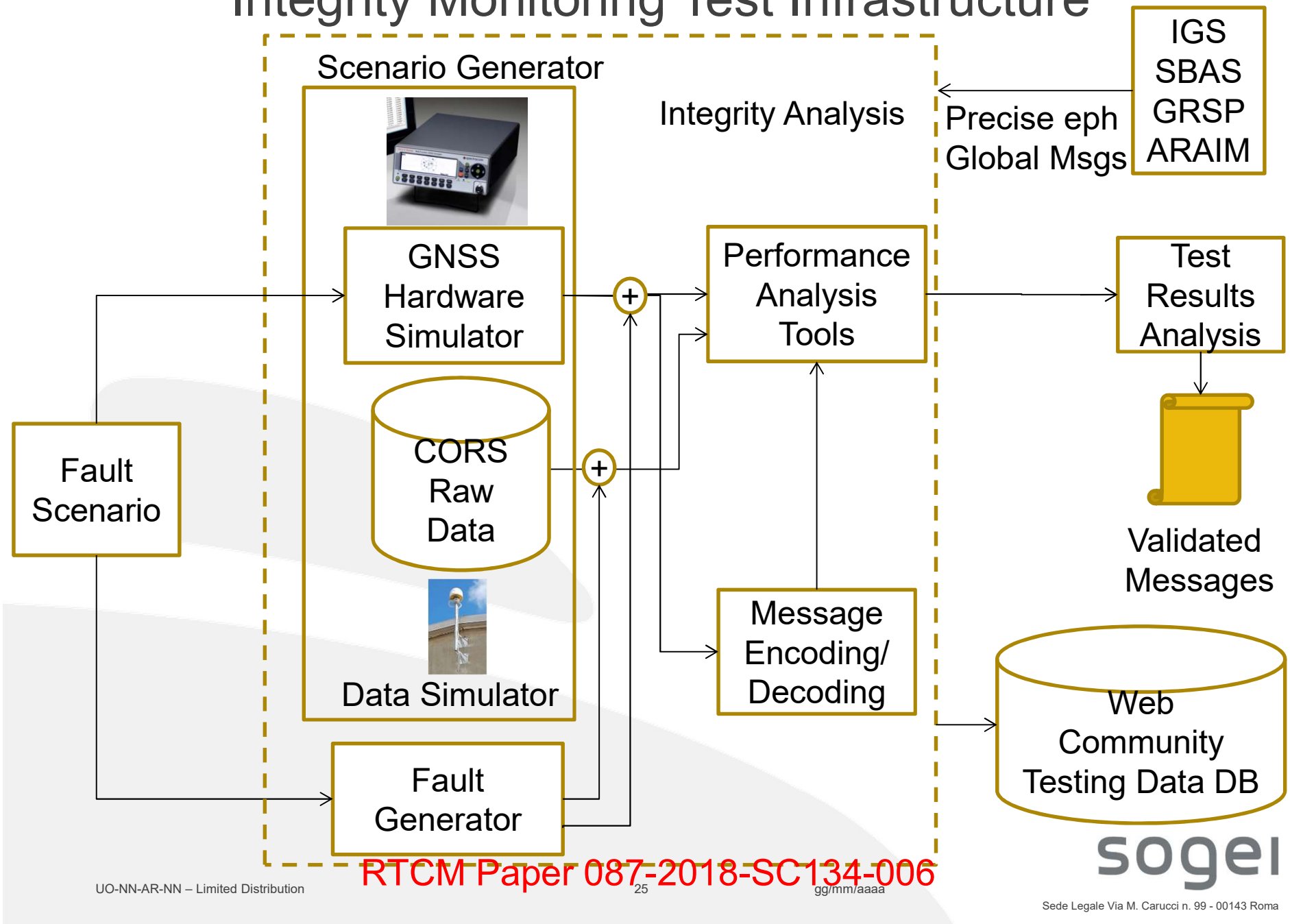
DATA FIELD	DF NUMBER	DATA TYPE	NO. OF BITS
Message Number	DF002	uint12	12
Reference Station ID	DF003	uint12	12
Network ID	DF059	uint8	8
Number of Reference Stations	DF223	uint7	7
GPS Epoch Time (TOW)	DF004	uint30	30
Number of common measurements	DF928	bit(5)	5
Synchronous GNSS Flag	DF005	bit(1)	1
TOTAL			***75***

DATA FIELD	DF NUMBER	DATA TYPE	NO. OF BITS
Ranging Source ID	DF920	bit(8)	8
IOD	DF071	uint8	8
PRC	DF922	int16	16
RRC	DF924	int16	16
σ_{pr_gnd}	DF907	uint8	8
B1 (note 1)	DF926	int8	8
B2	DF926	int8	8
..	DF926	int8	8
BnRS	DF926	int8	8
TOTAL			***56+8*nRS***

For each satellite

For each RS in the network

Integrity Monitoring Test Infrastructure



Interoperability Test-Bed Drivers

- Clear Safety Analysis and Fault Scenario definition by applications
- Use of Members GNSS Hardware signal simulators and Fault Generators
- Reuse of existing Performance Analysis Tools
- Test-Bed covering main application areas:
  - Rail
  - Aviation
  - Automotive
- Liason with existing specific Test-Beds
- Web Community Test Data Sharing DB
- Geographical distribution: Worldwide

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Keypoints for the SC-134

- Application specific Safety Requirements Review
- Architecture and Interfaces among Augmentation infrastructures, Application Providers and users
- Roadmap Definition: Current Augmentation Systems, Future Augmentation evolutions
- Distributed Test-Beds Setup by applications for Interoperability Test

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