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Resilience of Satellite Systems to Support Autonomous Military Operations

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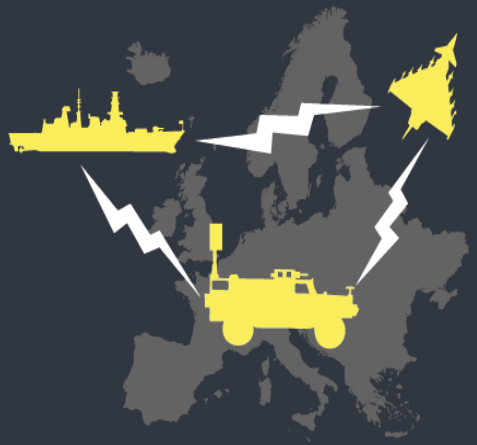


ASSOCIATION OF OLD CROWS

AOC Europe

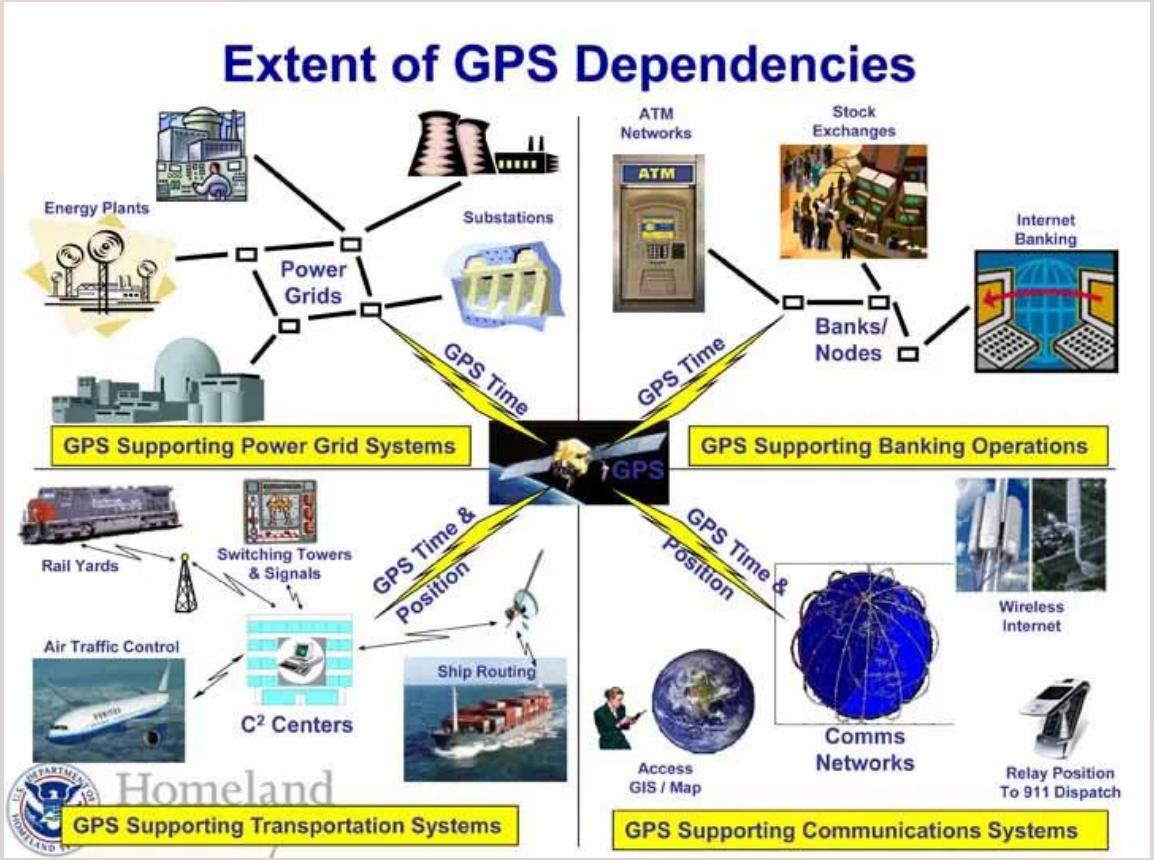
Liverpool, UK

11-13 October 2021

Overview to my talk today…..

If access to Global Navigation Satellite Systems (GNSS) suffered an extended interruption then all important references to position, navigation and timing (PNT) would be lost for maritime, aviation, electricity supply, financial markets, supply chains, communications, and defence operations. A State's economy would instantly suffer severe adverse effects and autonomous military operations would be on extended hold.

It is important therefore to incorporate ***resilience*** *into PNT systems*



……this illustration adds significance to the scope of PNT and insight into the systems that would be affected by its loss!

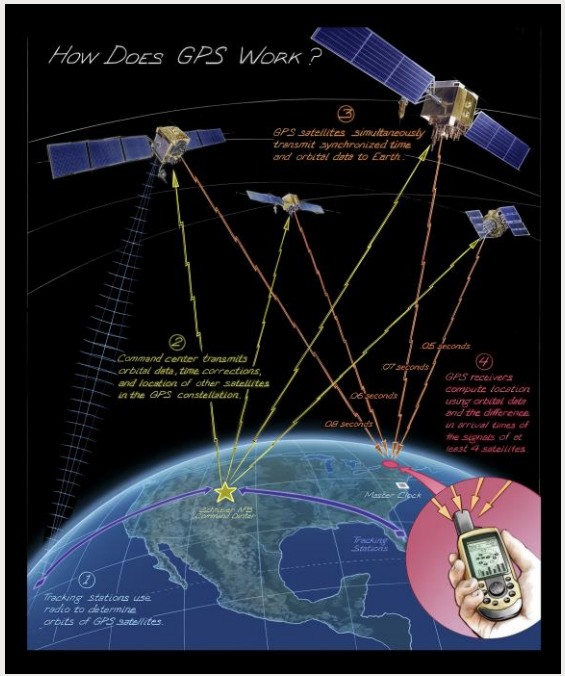
Reference US Homeland Security

……..but what is resilience (not fault tolerance)

Resilience of a critical system is the ability of a state/organisation to avoid, contain and mitigate the loss or interruption of/to a critical system.

Essentially, this means that critical systems that depend on PNT systems have the ability to continue operating at an acceptable effectiveness until full or partial PNT functionality is restored.

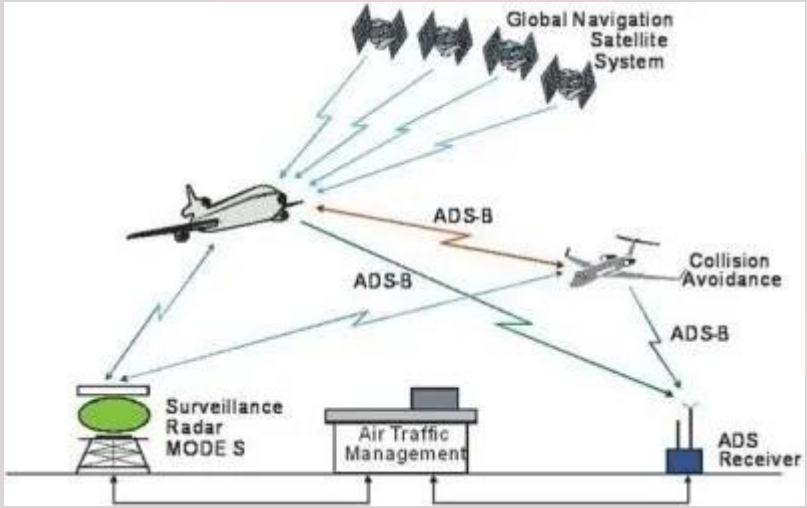
GPS…a brief overview

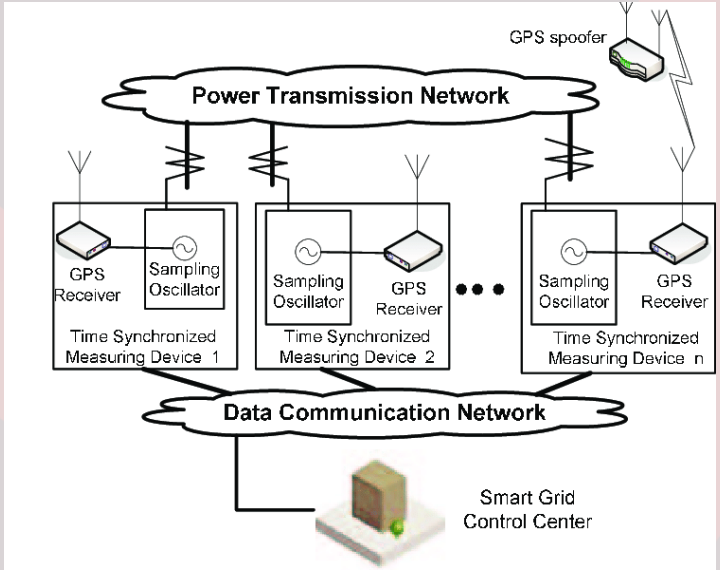


4 satellites for 3D positioning, signals very weak due to distance, GPS receivers use coded signals (L1 and L2) to distinguish from noise

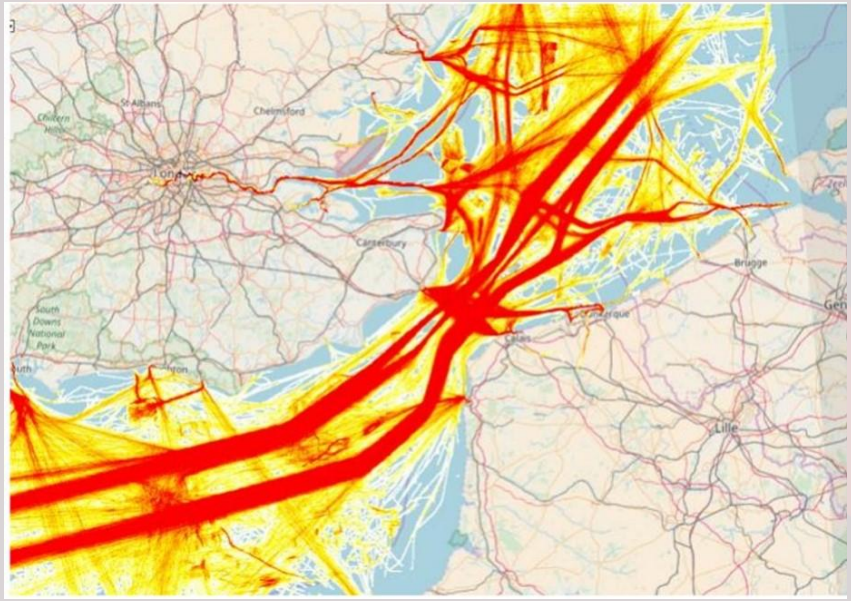
.....GPS Critical Infrastructure, example

Automatic Dependent Surveillance–Broadcast (ADS-B) & Smart Grid Control



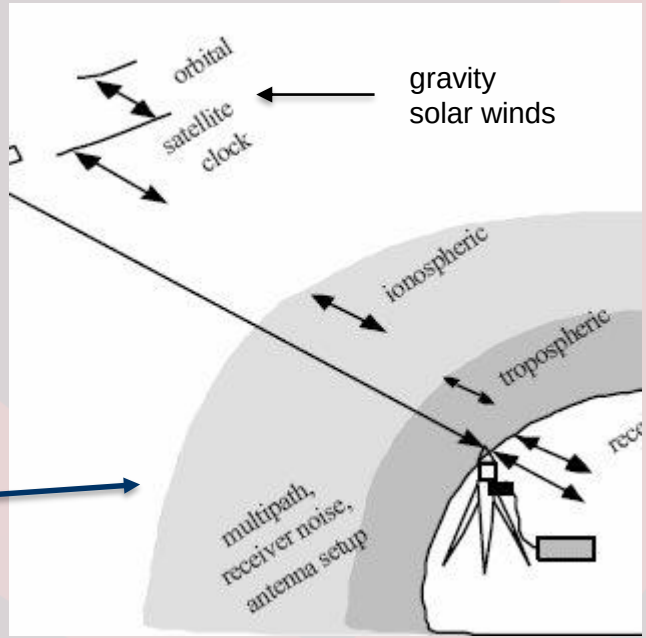


…ship density through the Dover Straight

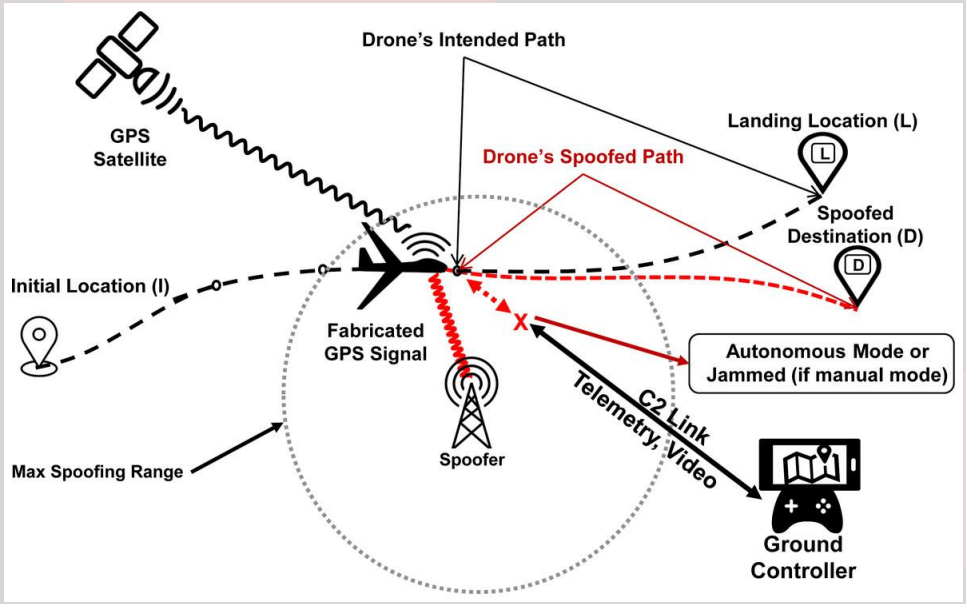


Real-world instances of Global Navigation Satellite System jamming and spoofing have been steadily increasing in recent years. Those incidents include hundreds of commercial ships being spoofed in the Black Sea and repeated GNSS jamming affecting commercial aviation in Norway.

……so, what can cause PNT error/failure?



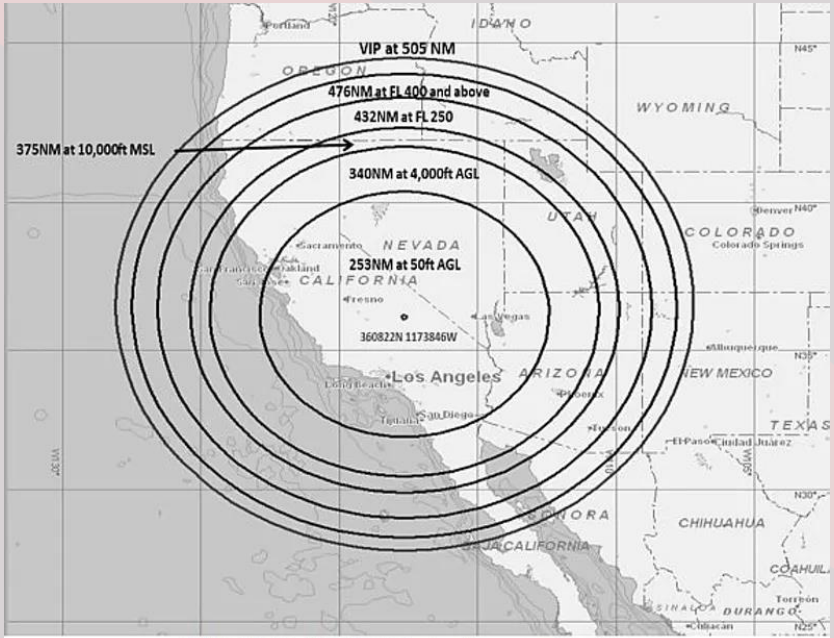
…….PNT Spoofing



There are two ways of spoofing:

- *Rebroadcasting GNSS signals recorded at another place or time (so-called meaconing)*
- *Generating and transmitting modified satellite signals*

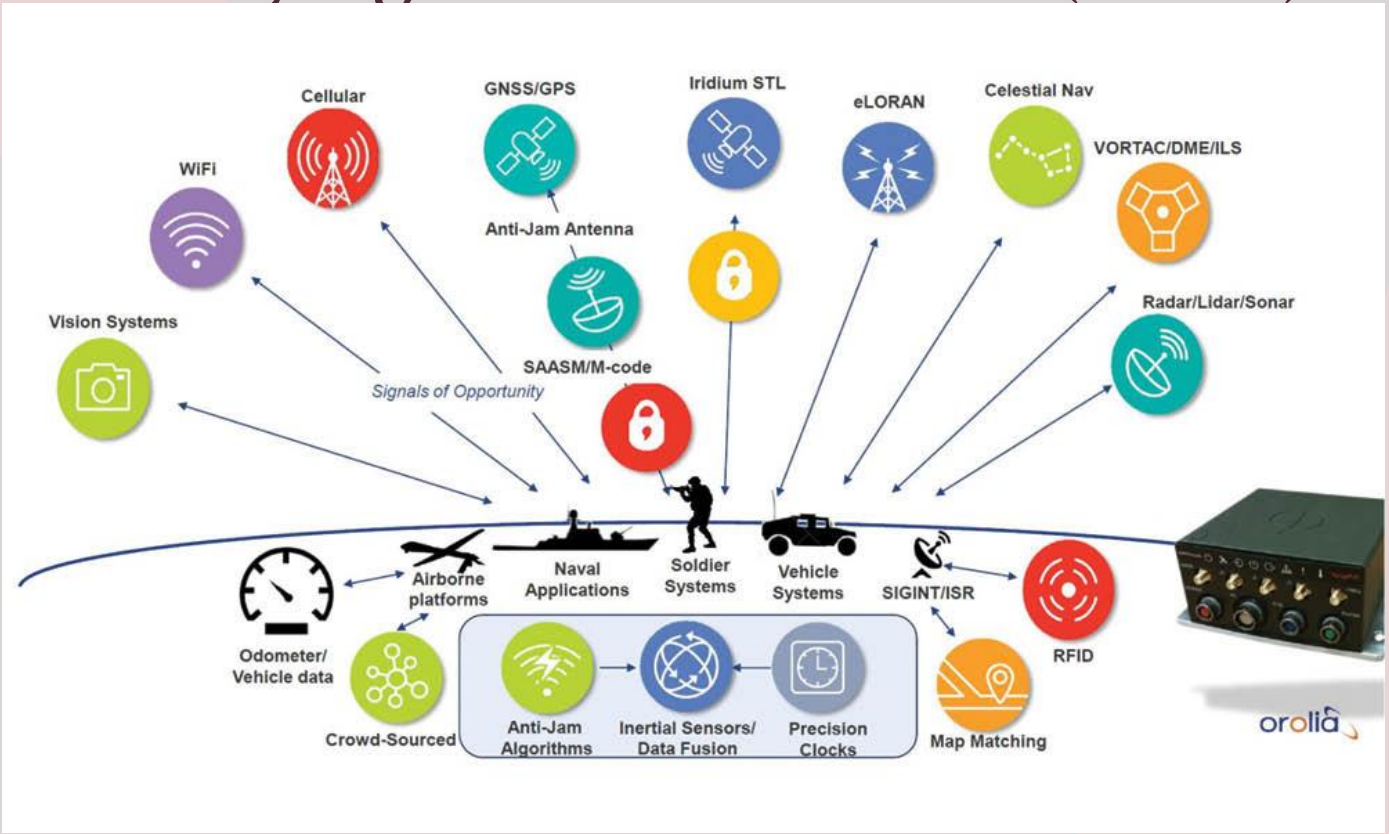
……..PNT Jamming



CHLK 16-08 GPS Interference Testing

The U.S. military is conducting tests of a wide-area GPS jammer with the potential to knock-out signals from Global Positioning System satellite navigation in California from beyond the Oregon border to well into Mexico during testing periods.

……identifying PNT alternatives (APNT)



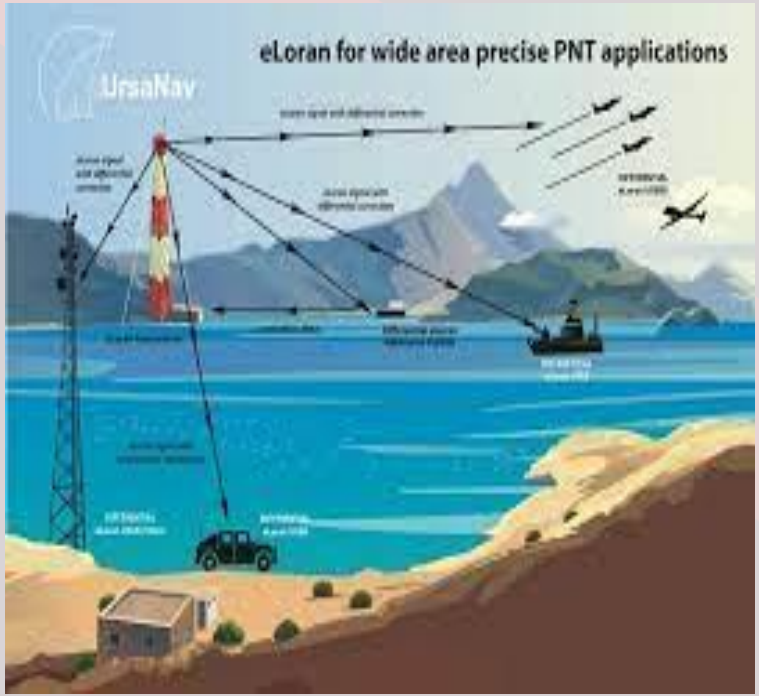
Technology	Capability	Status
eLoran	Can provide resilient PNT and data cross-sector over large geographic areas. Proven as a technical solution.	Future subject to cross-sector support from governments, regional agreements and/or viability of commercial operation.
R-mode	Maritime-only PNT and data within areas of cooperating infrastructure.	Feasibility of 24/7 capability to be established (depends on mitigation of debilitating skywave interference). Requires modified infrastructure, new standards and regulatory agreements.
Radar Absolute Positioning	Littoral coverage for 5nm to 10nm possible, depending on options (shore infrastructure of active responders or passive coastal feature mapping).	Basic feasibility demonstrated with active modified racons. Agreement needed for modification or replacement of existing radars and racons.
Signals of Opportunity	Digital television (DVB-T) with 8MHz bandwidth offers capability for positioning independent of GNSS (with similar accuracy) but range is limited to littoral navigation. AM broadcast is ideal with 100s km range, if available.	Opportunistic radio positioning feasible within a Software Defined Radio (SDR) incorporating other capabilities (e.g. R mode) AM is being switched off in many parts of the world.
Bathymetric Navigation	Bathymetric profile from multi-beam sonar is matched to a database to determine position.	Used by naval applications. Reliable positioning requires up-to-date database and is limited for shifting or less contoured seabed profiles.
Low Earth Orbit (LEO) Communication Satellites	Ranging and Doppler measurements available for all phases of voyage. Few details on capability.	Many LEO satellites available. Boeing established positioning systems with its Iridium satellites. Recent interest has been reported from Apple.
Onboard systems	Inertial system Bathymetric Quantum, geo-magnetic, gravity gradiometry	Available, but limited duration backup Military use, needs detailed surveys Long-term development required; but efficacy uncertain.

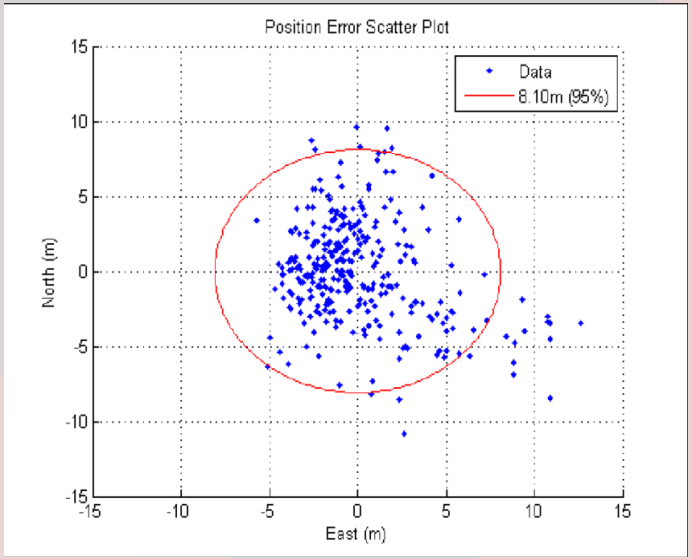
Resilient PNT for Maritime

Several alternative backup technologies could be considered complementary to GPS (GNSS) for future introduction into ships' Integrated Navigation Systems. They have varying capabilities, and different limitations and levels of maturity,

General Lighthouse Authorities of the U.K. and Ireland (GLA)

…….example APNT using eLoran





Scatter plot showing the performance of calibrated Loran when compared to Differential GPS. Loran was accurate to 8.1m (95%), Alan Grant (et al) Royal Institute of Navigation

Level 1	**Ensures recoverability after removal of the threat.** 1. Must verify that stored data from external inputs adheres to values and formats of established standards. 2. Must support full system recovery by manual means, making all memory clearable or resettable, enabling return to a proper working state, and returning the system to the defined performance after removal of the threat. 3. Must include the ability to securely reload or update firmware.
Level 2	**Provides a solution (possibly with unbounded** degradation) during threat.** Includes capabilities enumerated in Level 1 plus: 4. Must identify compromised PNT sources and prevent them from contributing to erroneous PNT solutions. 5. Must support automatic recovery of individual PNT sources and system, without disrupting system PNT output.
Level 3	**Provides a solution (with bounded degradation) during threat.** Includes capabilities enumerated in Levels 1 and 2 plus: 6. Must ensure that corrupted data from one PNT source cannot corrupt data from another PNT source. 7. Must cross-verify between PNT solutions from all PNT sources.
Level 4	**Provides a solution without degradation during threat.** Includes capabilities enumerated in Levels 1, 2 and 3 plus: 8. Must have diversity of PNT source technology to mitigate common mode threats.

The US Resilient PNT Conformance Framework is a step towards establishing standards for PNT system resilience. While test methodologies are still to come, users can start preparing now

Satellite Time and Location (STL) alternative to Space-Based PNT

denied GNSS environment.

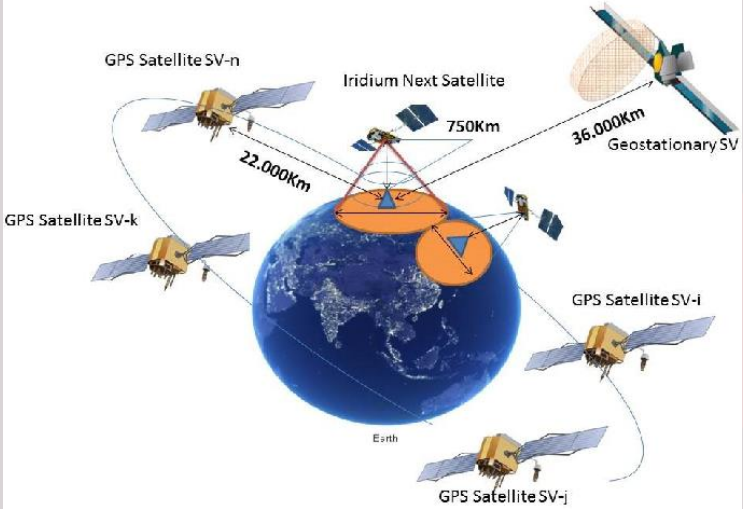


Fig. 2. Iridium LEO satellites, GPS and Geostationary Satellites orbits

	GNSS	STL
Timing accuracy to UTC	~20 ns	~200 ns
Positioning accuracy	~3 meters	30-50 meters
Time To First Fix	~100 seconds	Few seconds for 500 km ~10 minutes to converge
Anti-Spoof	GPS: only for military use Galileo: PRS – future	Yes, encrypted signal
Anti-Jam	Weak signal – easily jammed	Yes: 30 – 40 dB stronger
Coverage	Global Precision degrades at poles GLONASS – better at high Lat	Global Coverage increases at poles

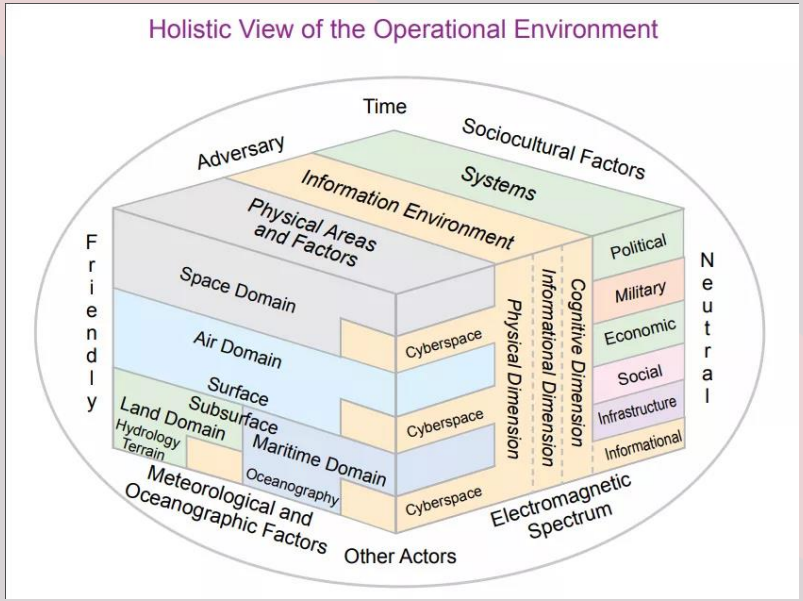
John Fischer, Orolia

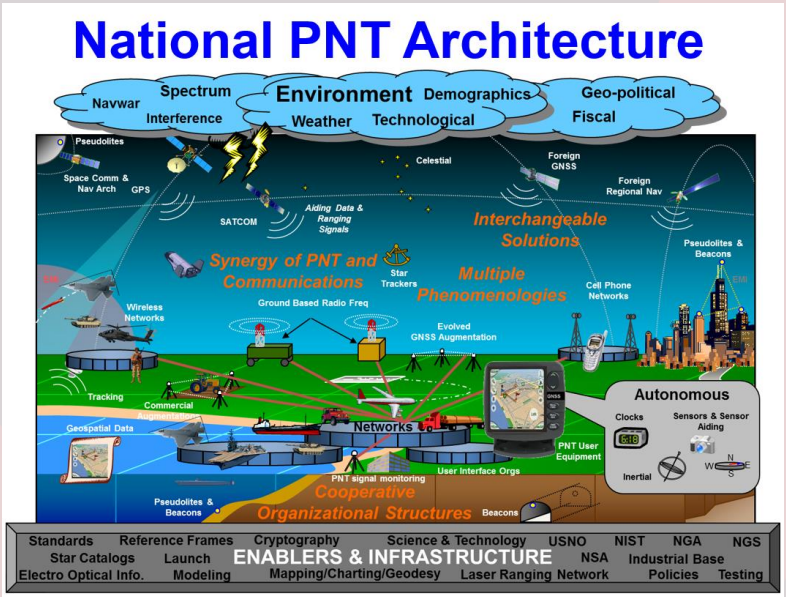
H. Benzerrouk, Q. Nguyen, F. Xiaoxing, A. Amrhar, A. V. Nebylov and R. Landry, "Alternative PNT based on Iridium Next LEO Satellites Doppler/INS Integrated Navigation System," 2019 26th Saint Petersburg International Conference on Integrated Navigation Systems (ICINS), 2019, pp. 1-10, doi: 10.23919/ICINS.2019.8769440.

…and now for the complexity of resilience

- *Widespread incorporation of PNT applications has changed the game for military, civil, commercial, and scientific applications of all kinds. We must consider controls to the PNT universe by adding resources in a structured manner to assure resilience under all conditions.*
- *A plethora of GNSS and PNT combinations now exists across the landscape. The military must be able to rely on the availability and characteristics of PNT sources that they use.*
- ***The plethora of PNT services on the battlefield introduces vulnerabilities and confusion that can undermine both situational awareness and command and control.*** *Therefore, a thorough understanding of PNT options and what each brings to the game is essential in order to be able to manage this resource through resilience options to benefit the warfighter.*

……& now the real complexity of PNT



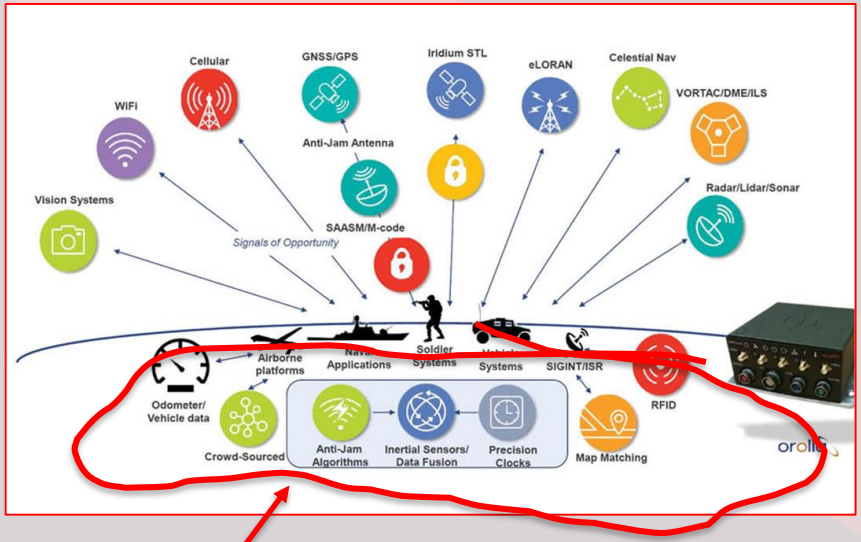


….with world-wide operations PNT interference will be difficult to spot & resilient solutions difficult to apply coherently, The result that C4I will become unstable leading to chaotic conditions !!!!!!!!

……..*modular open systems approach (MOSA)?*

- *To combine all of navigation sources in a structured combination*
- *Use smart receivers to be able to handle different signal types*
- *To use smart antenna to distinguish jamming signals*
- *To use machine intelligence to combine the best navigation sources*
- *To integrate the smart navigation system into the C4I system of systems (SoS) to provide homogenous operations using heterogenous system (a neat trick if you can achieve it!)*
- *Current NATO systems (MoD and DoD) **do not** have the level of SoS integration to support this concept.*

…….applying MOSA (DoD Solution)



Needs to be integrated across the network of systems (SoS)

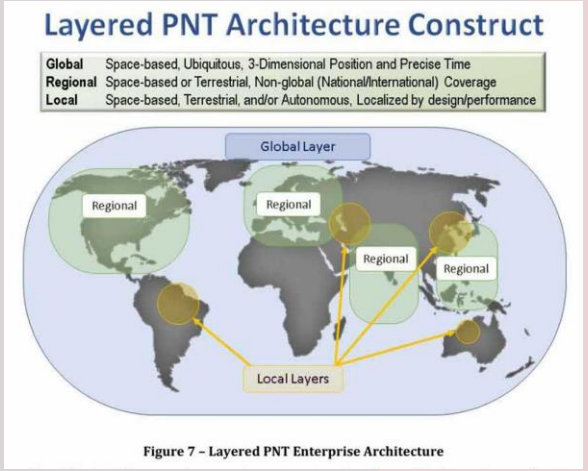
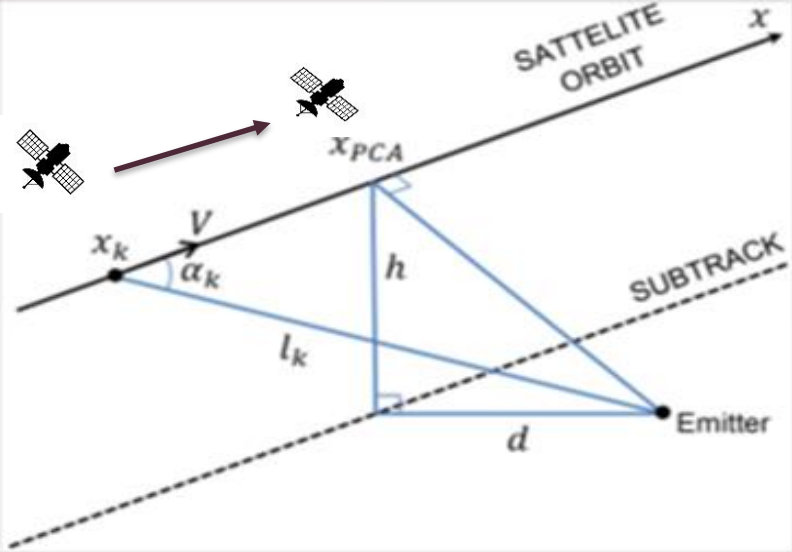


Figure 7 – Layered PNT Enterprise Architecture

The regional layer is defined by systems that service countries/continents. Regional sources can be in space or ground-based systems with characteristics different from satellites — eg, enhanced Loran (eLoran)

…..finding jammers and spoofing (Nav Sentinel)



Research being undertaken utilises a single cubesat (micro-satellite) using Doppler analysis to locate intentional/unintentional navigation interference. Satellites operate at LEO (400km – 500km) and can locate uncooperative emitters to within 1 km.

The Nav Sentinel advises the Smart C4I Nav System of the nav intruder to take action!

….. *Geomagnetic storm warning as solar flare expected to directly hit Earth on Monday 11/10/21*

The flare - officially known as a coronal mass ejection (CME) - was observed on Saturday on the side of the sun directly facing our planet and comes as we enter ***a period of increased solar activity****.*

http://news.sky.com/story/geomagnetic-storm-warning-as-solar-flare-expected-to-directly-hit-earth-today-12431243

CME events could severely interfere with GPS and hence PNT

Thank you for listening

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