

Lt.Col. Semih DÜZGÜNSIVACI

Evolution of Navigation Technologies

From Celestial Navigation to Resilient PNT Systems

1 Celestial Navigation
Ancient Times – 1500 AD



- Stars and the Sun
- Natural observation

Position estimation using celestial references.

2 Instrument-Based Navigation
12th – 18th Century



- Magnetic compass
- Sextant
- Marine chronometer

Accurate bearing, latitude and longitude determination.

3 Electronic Navigation
20th Century



- Radio navigation (e.g., LORAN, Decca)
- Radar systems

Electronic positioning and navigation support.

4 Satellite Navigation
1990s – Today



- GPS
- Multi-GNSS (Galileo, GLONASS, BeiDou, etc.)

Global, precise and continuous positioning.

5 Future Navigation
Resilient PNT Systems



- Terrestrial PNT
- Quantum PNT
- Pulsed Laser PNT
- AI-assisted navigation
- GNSS-denied operations
- Multi-sensor fusion

Assured navigation in all environments.

Prehistory (> 3000 BC) → Classical Era (500 BC – 1500 AD) → 12th – 18th Century → Early 20th Century (1920s – 1930s) → Late 20th Century (1990s) → 21st Century (Today and Beyond)


SPACE
ENABLES
A SAFER
TOMORROW
ANYWHERE
ANYTIME
A MORE SECURE WORLD
GNSS
Global Navigation Satellite System
POSITIONING
Determines precise location on Earth
NAVIGATION
Provides direction and guidance
TIMING
Delivers precise time reference
0100101
0101100
0100101

SPACE
SOVEREIGNTY
STABILITY
GLOBAL
RESILIENCE

GLOBAL GNSS CONSTELLATIONS

POSITIONING
NAVIGATION
TIMING
A MORE RESILIENT
TOMORROW

GPS
USA



GLONASS
Russia



Galileo
European Union



BeiDou
China



QZSS
Japan



NavIC
India



GNSS Vulnerabilities



Weak Signal Characteristics

Faint signal arrival.
Low power output.
Vulnerable at reception.



Environmental & Terrain Effects

Terrain masking. Urban canyons.
Atmospheric attenuation.
Degrades accuracy.



Space Dependency

Single point of dependency.
Long orbital pathways.
Vulnerable link.

Jamming

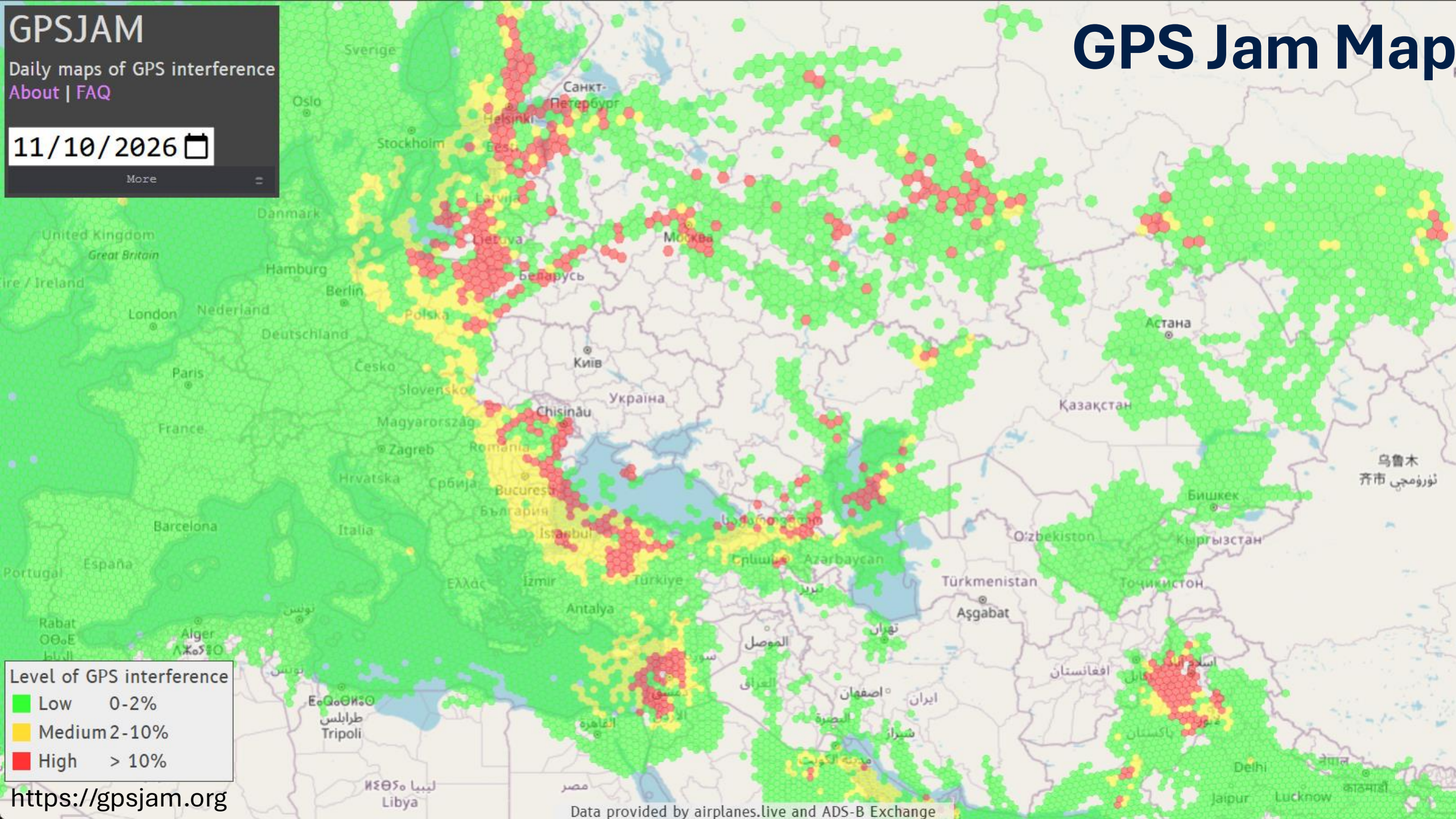


Signal Denial.
Low-power interference.
Loss of PNT services.

Spoofing



Fake Position reporting.
Misleading guidance.
Undetectable deviation.


GPSJAM
Daily maps of GPS interference
About | FAQ
11/10/2026
More
GPS Jam Map
Level of GPS interference
Low 0-2%
Medium 2-10%
High > 10%
https://gpsjam.org
Data provided by airplanes.live and ADS-B Exchange

Terrestrial Navigation Systems

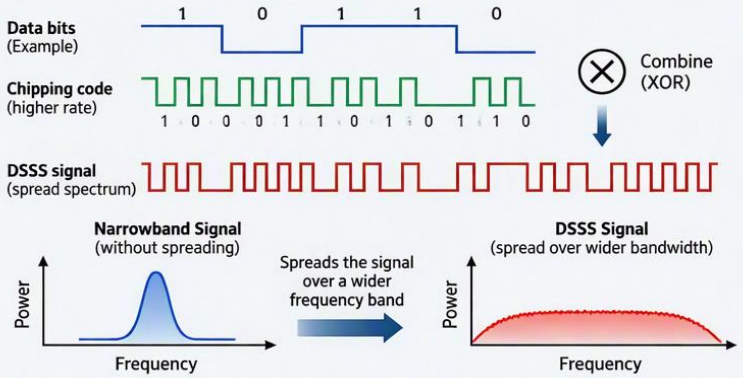

Terrestrial Navigation System
Positioning through a network of ground stations
Position Determined
Ground Station 1
(Known Position)
Ground Station 2
(Known Position)
Ground Station 3
(Known Position)
High accuracy
Independent of satellites
Reliable ground infrastructure

RESISTANCE TO ELECTRONIC WARFARE



DSSS (Direct Sequence Spread Spectrum)

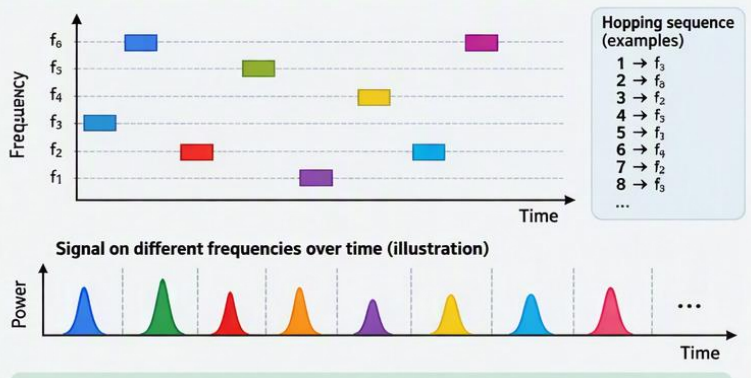
Data is combined with a high-rate chipping code, spreading the signal across a wider frequency band.



Result: Lower power spectral density, more resistant to interference, jamming and spoofing.

FHSS (Frequency Hopping Spread Spectrum)

The carrier frequency rapidly switches (hops) among many distinct frequencies according to a pseudo-random sequence known to both transmitter and receiver.

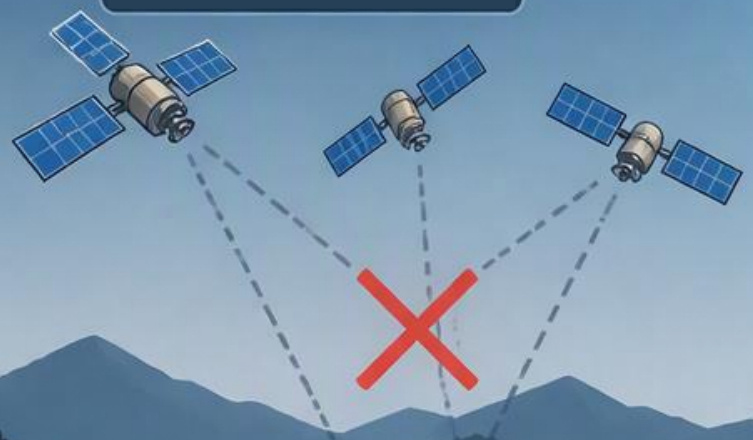


Result: The signal "hops" among many frequencies, making it difficult for a jammer to follow and effectively disrupt the communication.

MORE THAN POSITIONING

Provides precise time synchronization—independently of GNSS—
with a very low drift on a weekly basis.

GNSS



GNSS UNAVAILABLE
(Jamming, Spoofing, Outage)

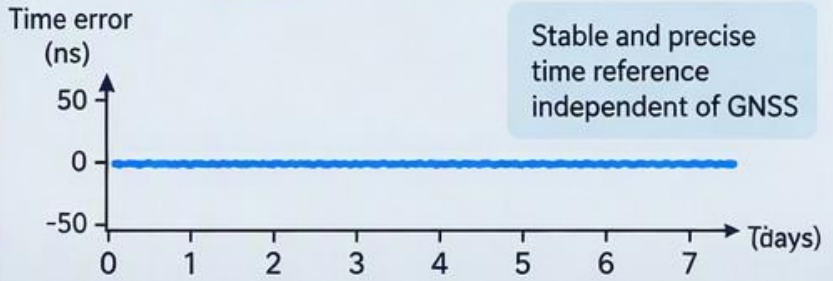
TERRESTRIAL NAVIGATION SIGNALS
(Positioning + Time Synchronization)



PRECISE TIME SYNCHRONIZATION



VERY LOW DRIFT
~10 nanoseconds
over a week



Stable and precise
time reference
independent of GNSS

SUPPORTS CRICKET SYSTEMS



MILITARY SYSTEMS
Mission synchronization,
network coordination



TELECOMMUNICATIONS
Network timing
(5G and beyond)



POWER GRIDS
Stable and synchronized
operations



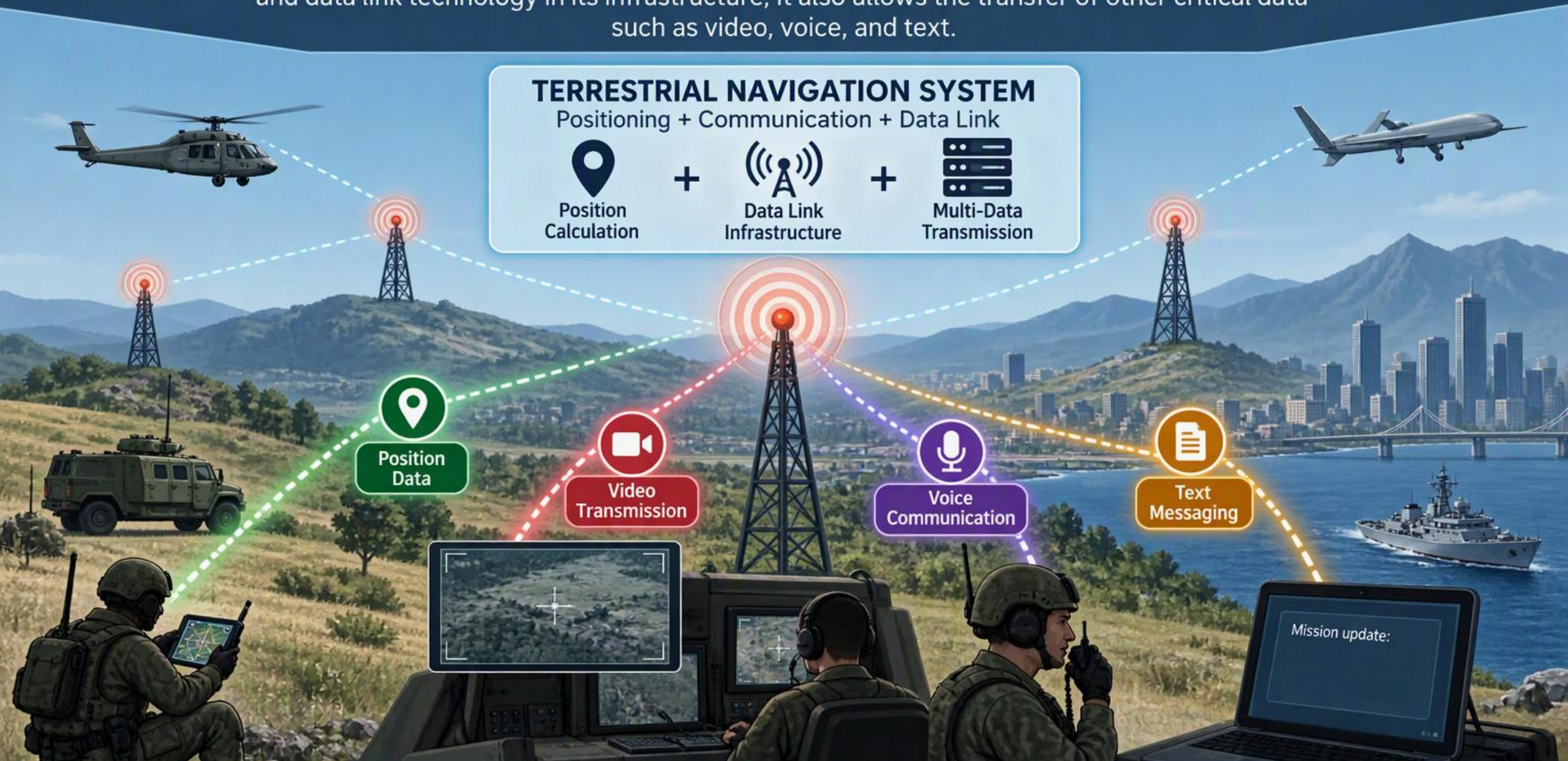
FINANCIAL INFRASTRUCTURES
Accurate time for
secure transactions



TRANSPORTATION
Safe and reliable
operations

DATA LINK CAPABILITY

A Terrestrial Navigation System does not only calculate positions ; thanks to the smart communication and data link technology in its infrastructure, it also allows the transfer of other critical data such as video, voice, and text.



BROAD PLATFORM SUPPORT

An architecture that can be integrated into many different military platforms, including unmanned aerial vehicles (UAV/UCAV), missiles, unmanned ground vehicles (UGV), and unmanned surface vessels (USV).

UAV / UCAV



- Reconnaissance
- Surveillance
- Mission data transfer

MISSILES



- Guidance and control
- Telemetry
- Mission updates

TERRESTRIAL NAVIGATION SYSTEM

UGV



- Navigation
- Command and control
- Video, voice and data

USV



- Navigation
- Remote operation
- Sensor data transfer

RAPID DEPLOYABILITY & COST EFFECTIVENESS
OF TERRESTRIAL NAVIGATION SYSTEMS

A resilient, adaptable and economically efficient alternative to space-based positioning.



CONTINUOUS NAVIGATION
EVEN IF GNSS IS DENIED

QUICK SETUP
Minutes, not months

SMALL TEAMS
Low manpower requirement

COST EFFECTIVE
A fraction of orbital costs

HIGH RESILIENCE
Rapid replacement capability



1 **TRANSPORT**
Lightweight and modular

2 **DEPLOY**
Set up in minutes

3 **OPERATE**
Continuous navigation support

MINIMAL DOWNTIME
Restore navigation support with minimal delay.

LOWER INFRASTRUCTURE COSTS
Significantly less expensive than launching or maintaining orbital assets.

FIELD REPLACEMENT
If a unit is destroyed or compromised, a new transmitter can be rapidly erected on-site.

HIGHLY ADAPTABLE
Designed for field mobility and diverse operational environments.

https://www.youtube.com/watch?v=0eG8U7wNDz8&t=1s

TUALCOM

FROM REGIONAL TO NATO SCALE

BUILDING SECURITY THROUGH COLLECTIVE DEFENSE

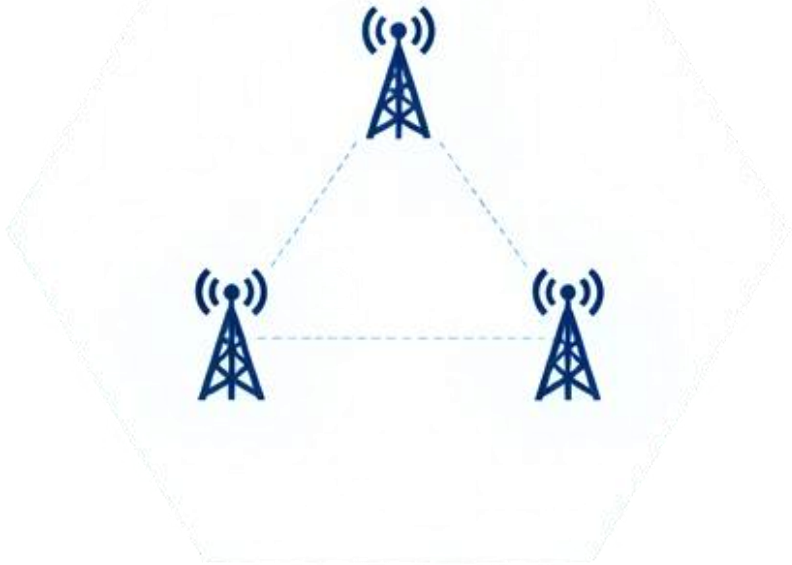
Hierarchical Evolution of Cooperation



Roadmap for Scaling Terrestrial Navigation Networks

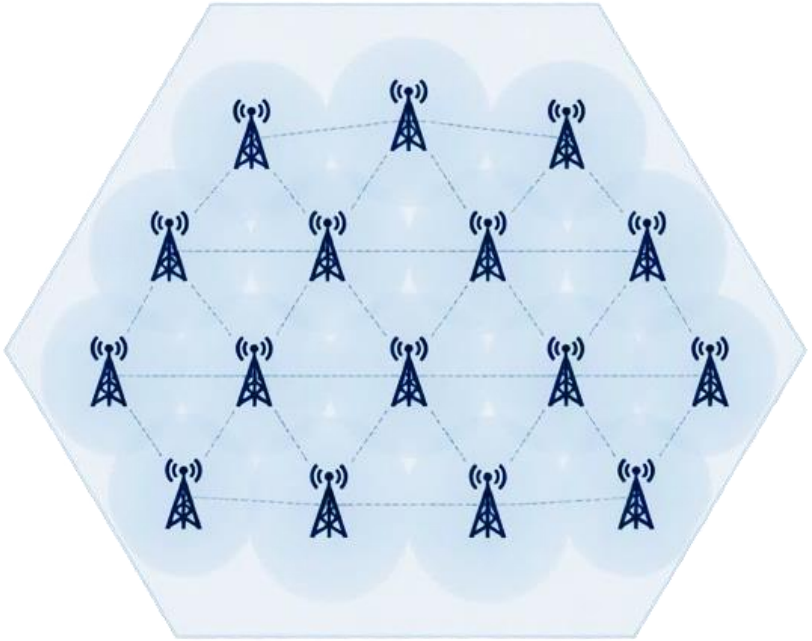
Phase-1

Establishment of Regional Terrestrial Navigation Systems

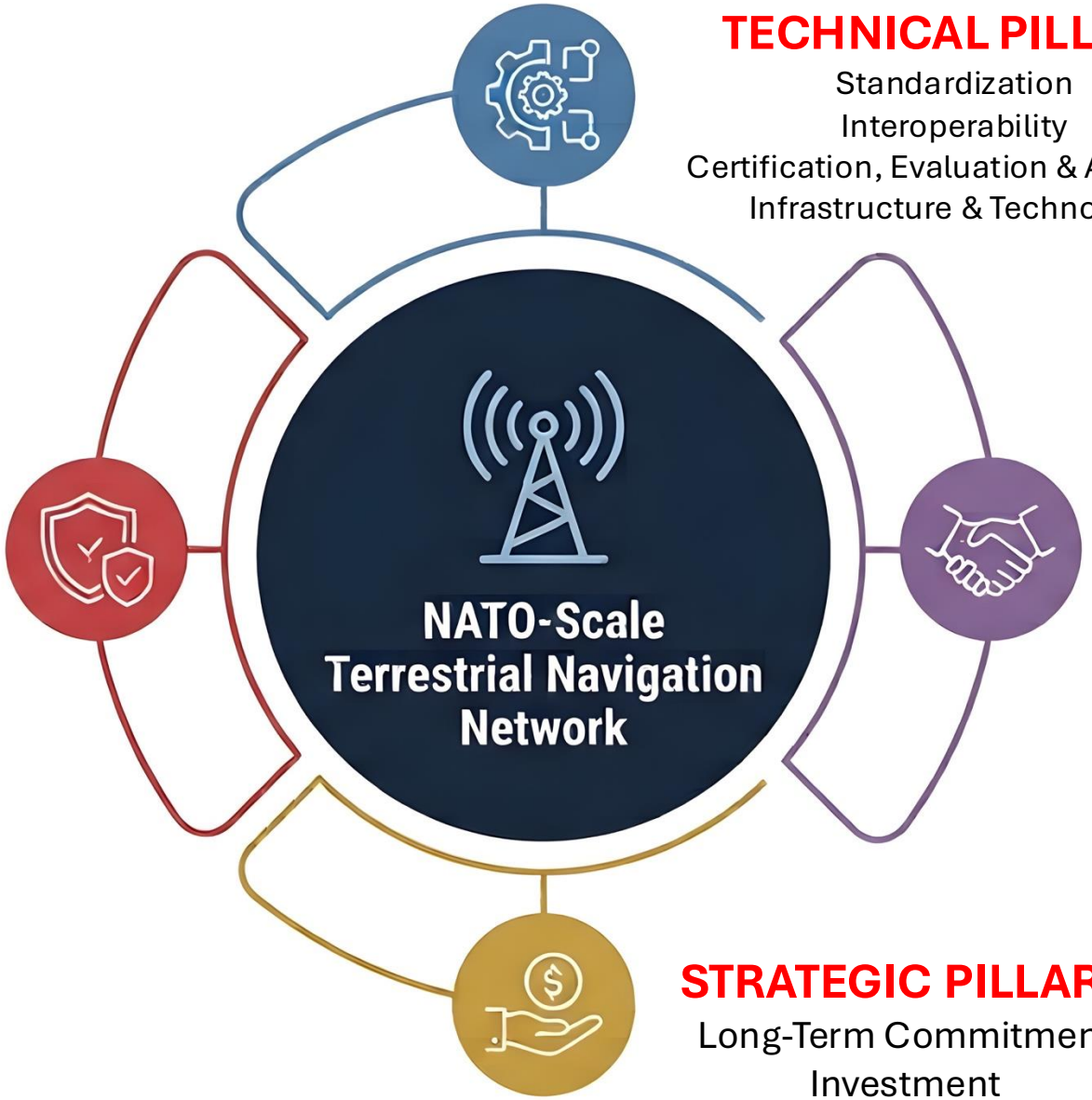


Phase-2

Enlarging the Covering Area



Key Pillars of a Scalable Terrestrial Navigation Network



TECHNICAL PILLARS

Standardization
Interoperability
Certification, Evaluation & Adoption
Infrastructure & Technology

SECURITY PILLARS

Cyber Protection
EW Protection
Physical Security

ORGANIZATIONAL PILLARS

Cooperation
Governance & Coordination
Legal & Sovereign Frameworks

STRATEGIC PILLARS

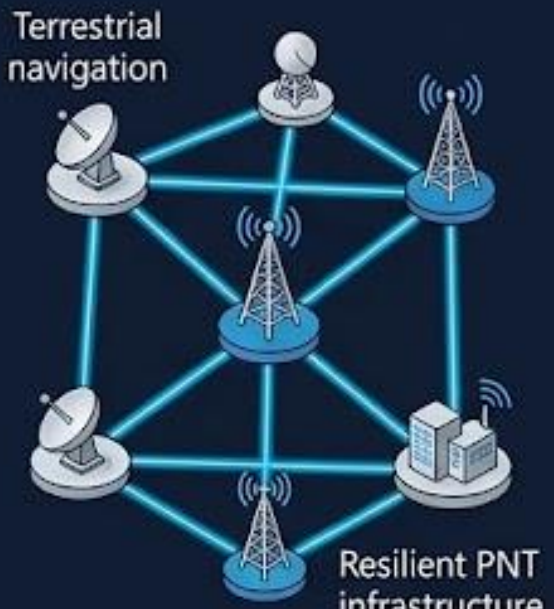
Long-Term Commitment
Investment

Jamming

Spoofing

Signal Denial





‘Conclusion’

GNSS Alone Is Not Enough

Increasing threats and operational limitations require complementary navigation capabilities.

Terrestrial Navigation Offers Resilience

Reliable positioning and timing services in GNSS-denied environments.

Cooperation Is Essential

Common standards, interoperability, and international collaboration are key to future navigation ecosystems.

Together, we are stronger!



Q&A