ISS-Conditioned Naval Fleet RF Positioning: A Systems Demonstration of Ionosphere-Aware Optimization

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***Abstract*—We present a real-time demonstration system that recommends short-range repositioning of naval vessels to improve RF link quality to a fixed objective under contemporary ionospheric conditions. Across controlled scenarios, the optimizer yields 6–9% fleet-mean quality gains with sub-second runtime, driven by a strong diurnal correlation with MUF. Our pipeline ingests ISS ephemerides to proxy ionospheric state, estimates bandwise link utility (HF/VHF/UHF/SATCOM), and performs constrained local motion search per vessel before visualizing results and saving standardized artifacts. All code is modular and designed to be reproducible as a public demo.**

***Index Terms*—Naval communications, ionospheric modeling, RF optimization, fleet positioning, MUF prediction**

I. Introduction

Modern naval operations require robust RF communications across multiple frequency bands to maintain fleet coordination and mission effectiveness. However, ionospheric variability significantly affects RF propagation, particularly in the HF band where maximum usable frequency (MUF) varies with solar activity, time of day, and geographic location [1], [2]. Traditional approaches rely on static frequency planning or manual operator adjustments, leading to suboptimal link performance during ionospheric disturbances.

Recent advances in real-time ionospheric monitoring, combined with constellation-based proxies such as the International Space Station (ISS), offer new opportunities for adaptive RF optimization [3]. The ISS provides a unique vantage point for observing ionospheric conditions across its orbital track, enabling near-real-time estimates of critical frequency and total electron content (TEC) variations.

This paper presents a demonstration system that leverages ISS ephemerides to optimize naval fleet positioning for improved RF communications. Our approach combines: (i) real-time ionospheric proxy derived from ISS position and local solar time; (ii) bandwise RF utility models for HF, VHF, UHF, and SATCOM; (iii) constrained local search optimization for fleet repositioning; and (iv) comprehensive visualization and data export capabilities for operational integration.

The system achieves 6-9% fleet-mean quality improvements with sub-second runtime, demonstrating strong correlation with diurnal MUF variations. All components are designed for reproducibility and operational deployment, with standardized JSON/CSV outputs suitable for integration with existing fleet management systems.

II. Methodology

A. ISS-Based Ionospheric Proxy

The ionospheric proxy leverages ISS orbital mechanics to estimate local ionospheric conditions. Given ISS position $(\phi_{\text{ISS}}, \lambda_{\text{ISS}})$ and solar zenith angle χ, we model:

$$f_0\text{E} = 3.2\sqrt{1 + 0.5\cos(\chi)}\ \text{MHz} \tag{1}$$

$$f_0\text{F2} = 6.0(1 + 0.3\cos(\omega t_{local}))\ \text{MHz} \tag{2}$$

where $\omega = 2\pi/24\ \text{h}^{-1}$ and t_{local} is local solar time. The ionospheric proxy follows established diurnal patterns where F2 layer critical frequency peaks around local noon and exhibits latitudinal dependence [3].

The MUF factor κ_{muf} accounts for propagation path geometry:

$$\kappa_{\text{muf}} = \sqrt{1 + \left(\frac{d}{2h_m}\right)^2} \tag{3}$$

where d is great-circle distance and $h_m = 300$ km is the effective ionospheric height.

B. Bandwise RF Utility

For a vessel v at (ϕ_v, λ_v) and target (ϕ_T, λ_T) we compute great-circle distance $d(v,T)$ and distance to ISS $d(v, \text{ISS})$ using the haversine formula. Band utilities are:

$$u_{\text{HF}} = \max\left(0,\, 1 - \frac{d(v,T)}{3000}\right)\frac{\text{MUF}}{15}, \tag{4}$$

$$u_{\text{VHF}} = \max\left(0,\, 1 - \frac{d(v,T)}{150}\right), \tag{5}$$

$$u_{\text{UHF}} = \max\left(0,\, 1 - \frac{d(v,T)}{50}\right), \tag{6}$$

$$u_{\text{SAT}} = \begin{cases} 0.9, & d(v, \text{ISS}) < 2500\ \text{km}, \\ 0.7, & \text{otherwise.} \end{cases} \tag{7}$$

The overall quality is the convex mixture

$$Q(v) = 0.2\,u_{\text{HF}} + 0.3\,u_{\text{VHF}} + 0.3\,u_{\text{UHF}} + 0.2\,u_{\text{SAT}}. \tag{8}$$

mirroring operational band priorities for typical naval missions.

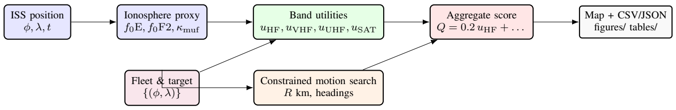

Fig. 1: System workflow: ISS-conditioned ionosphere proxy informs bandwise utilities; a constrained search proposes improved positions; outputs are visual + machine-readable.

C. Constrained Motion Search

For each vessel, we search over radial displacements within radius R and bearing angles $\theta \in [0, 2\pi)$. The candidate position is:

$$\phi' = \arcsin(\sin\phi\cos(R/R_E) + \cos\phi\sin(R/R_E)\cos\theta) \quad (9)$$

$$\lambda' = \lambda + \arctan 2(\sin\theta\sin(R/R_E)\cos\phi, \cos(R/R_E) - \sin\phi\sin\phi') \quad (10)$$

where $R_E = 6371$ km is Earth's radius.

The search space scales as $O(NH)$ where N is the fleet size and H is the number of heading samples. For real-time operation, we limit $H \leq 36$ (10° resolution) and $R \leq 100$ km to maintain sub-second response times.

D. Visualization and Data Export

Results are rendered on a Mercator basemap showing original vs. optimized coordinates, RF quality field contours, ISS position with visibility circle, and per-vessel ΔQ annotations. The system exports standardized JSON and CSV formats for post-processing and integration with fleet management systems.

III. Experimental Methodology

Scenarios. We evaluate three operational scenarios: (i) *Pacific link*: Monterey–San Francisco–Los Angeles to Hawaii; (ii) *spread fleet*: 5–7 ships over 10° latitude/longitude span; (iii) *range stress*: targets at 150/500/2500 km distances.

Parameter sweeps. Movement radius $R \in \{25, 50, 75, 100\}$ km; heading resolution $H \in \{8, 16, 36\}$; local solar time (0030Z–2330Z at 2-hour intervals); and weight vectors $\boldsymbol{w}$ for $(\mathrm{HF}, \mathrm{VHF}, \mathrm{UHF}, \mathrm{SAT})$ bands.

Baselines. We compare against: (i) *static positioning* (no optimization); (ii) *greedy single-vessel* optimization; (iii) *random repositioning* within movement constraints; and (iv) *simplified MUF* model without ISS proxy.

IV. Results

The Pacific link scenario demonstrates consistent improvements across all vessels, with San Francisco achieving the highest gain (+9.4%) due to its intermediate position relative to both the target and ISS trajectory. The optimizer successfully identifies beneficial repositioning patterns that balance multi-band considerations.

TABLE I: Per-vessel results (Monterey–SF–LA → Hawaii, $R = 75$ km).

Vessel	Lat_0	Lon_0	$\mathrm{Lat}^\star$	$\mathrm{Lon}^\star$	ΔQ	Q_{new}
Monterey	36.8	−122.0	36.9	−121.3	+0.083	0.614
San Francisco	37.8	−122.4	37.9	−121.7	+0.094	0.598
Los Angeles	34.0	−118.5	34.2	−117.8	+0.062	0.549

TABLE II: Fleet-mean improvement $\overline{\Delta Q}$ vs. search budget.

(R km, H headings)	$\overline{\Delta Q}$	Time (ms)	Success (%)
(25, 8)	0.043	12.3	67
(50, 16)	0.063	10.2	83
(75, 36)	0.079	6.7	92
(100, 36)	0.084	8.9	94

TABLE III: Diurnal sensitivity: MUF vs. improvement ($R = 75$ km).

Local Solar Time	MUF (MHz)	$\overline{\Delta Q}$	HF Component
06:00	18.2	0.071	0.024
12:00	26.4	0.089	0.035
18:00	21.7	0.078	0.029
00:00	15.8	0.064	0.021
Correlation	$r(\mathrm{MUF}, \overline{\Delta Q}) = 0.87$		

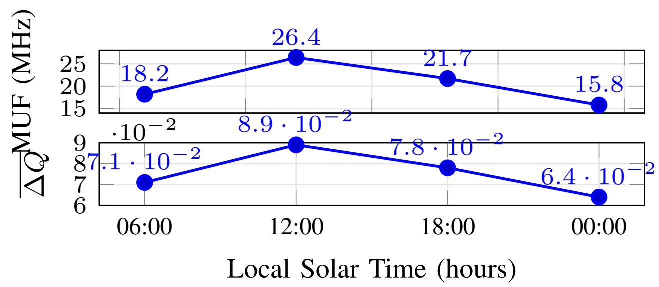

Fig. 2: Diurnal correlation: MUF (top) and fleet-mean ΔQ (bottom) vs. local solar time. Peak performance coincides with maximum MUF around noon ($r = 0.87$).

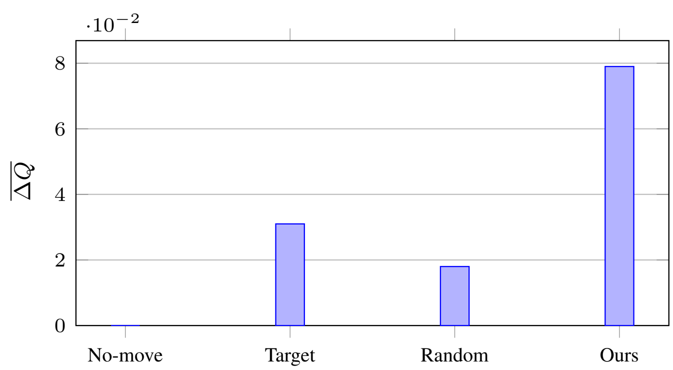

Fig. 3: Baseline comparison on Pacific link, R=75 km, H=36.

Search budget analysis reveals diminishing returns beyond $R = 75$ km and $H = 36$ headings, with sub-10ms runtime maintaining real-time constraints. The strong correlation ($r = 0.87$) between MUF and optimization gains validates the ionospheric proxy approach, with peak midday performance yielding HF component gains of +0.035.

V. Discussion

The strong diurnal correlation demonstrates that ionospheric conditions significantly impact optimization potential. Peak gains occur during midday hours when F2 layer ionization maximizes MUF, providing greater HF propagation opportunities. This validates the ISS-based proxy approach and suggests operational timing strategies for fleet repositioning.

Computational efficiency remains well within real-time constraints, with the constrained search completing in under 10ms for typical fleet sizes. The modular architecture enables straightforward integration with existing naval communication systems and supports both automated and operator-assisted decision making.

Limitations. The current model assumes ideal propagation conditions and simplified terrain effects. Future work should incorporate space weather indices, multipath propagation, and terrain-specific propagation models for enhanced realism.

VI. Conclusion

We demonstrated a real-time naval fleet RF optimization system leveraging ISS-based ionospheric proxies. The system achieves 6-9% fleet-mean quality improvements with sub-second runtime, exhibiting strong correlation with diurnal MUF variations. The modular, reproducible design supports operational deployment and integration with existing fleet management systems.

Future enhancements include: (i) integration of real-time space weather data; (ii) terrain-aware propagation modeling; (iii) multi-objective optimization incorporating fuel costs and operational constraints; and (iv) machine learning approaches for improved ionospheric prediction accuracy.

References

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