

Course Title: Research Methodology in Computer Science

Course Code: AI800

Weighting: 20%

Lecture: Dr. Mohammed Anbar

Hand-out Date: 28 June 2025

Hand-in Date: 12 July 2025

Hand-in Method: Online Submission via E-Learning.

Assignment Report: Literature Review Satellite Interference

Table of Contents:

- Summary of research papers
- Critical Analysis
- Synthesis of Literature and Opportunities
- Connection
- Conflict between the findings
- Synthesis Matrix for Literature Review
- References

Summary of research papers:

Paper 1: Frequency of Arrival-based Interference Localization Using a Single Satellite

This paper proposes a novel method for localizing intentional and unintentional RF interference sources by utilizing the frequency of arrival (FOA) to enhance interference detection and reduce dependency on multi-satellite systems. It's based on satellite motion to estimate the location of interference.

Methodology:

- 1-Satellite detects the signal in Ka-band and then transmits it to the ground gateway.
- 2-The gateway calculates the Doppler using the equations linking signal frequency to the emitter's location.
- 3-Calibration to use the correct system errors in frequency estimation.
- 4-Localization uses multiple locations related equations and the Earth surface constrain to solve the interference problem.

Results:

- 1- Accuracy increases
- 2- Higher satellite velocity

Conclusion:

FOA technique offers a highly accurate method of satellite communications.

Paper 2: Multiscale attention Networks for Satellite interference Detection

This paper proposes to develop a real-time robust interference detection system for satellite communications between LEO and GEO satellites overlapping frequency bands.

Methodology:

1-Model Innovation -DualAttWaveNet (bidirectional attention for time-frequency signal correlation.

2-uses wavelet loss to enforce multi-scale signal.

3-replace multi-head with single-head cross-attention.

Results:

Detect Satellite interference more accurately and faster.

Conclusion:

DualAttWaveNet provides high-accuracy and low-latency solutions for real-time satellite interface.

Paper 3: Coordinated Intra-and Inter-systems Interference Management in Integrated Satellite Terrestrial Networks

This Paper proposes a Coordinated Intra-and-Inter-system interference Management (CIIM) algorithm for Integrated Satellite-Terrestrial Networks (ISTNs) to address co-channel interference and interference between GEO and LEO.

The primary goal of this tech. It is to maximize downlink throughput while minimizing interference.

Methodology:

CIIM integrates inter-satellite handover for inter-system interference and user intra-system interference.

Result:

Higher handover thresholds reduce handover frequency but may cap throughput.

Conclusion:

Scalable, reduces unnecessary handover, and significantly improves backhaul capacity and system throughput.

Paper 4: Modeling and Analysis of Hybrid GEO-LEO Satellite Network

This paper proposes to develop an analytical model for hybrid GEO-LEO satellite networks and evaluate coverage performance under frequency sharing using stochastic geometry.

Hybrid Satellite modeling both sets (GEO and LEO) are modeled using Poisson Point Processes (PPPs).

Coverage probability derivation:

- 1- Biased-received-power (BRP) association policy
- 2- Satellite antenna gains
- 3- Nakagami-m fading and directional antenna assumptions.
- 4- Interference from both GEO and LEO satellites.

Methodology:

- 1- Stochastic geometry to model random satellite locations and user associations.
- 2- Laplace transforms used to analyze interference.
- 3- Monte Carlo simulations for validation.

Result:

Coverage improves in Hybrid networks.

Conclusion:

The model is scalable and can be used for evaluating satellite cooperation under spectrum sharing.

The result can guide the design and regulation of the future 6G NTN (Non-Terrestrial Network).

Paper 5: Modeling and Analysis of GEO Satellite Networks

This Paper proposes a novel framework for modeling and analyzing (GEO) networks using stochastic geometry, unlike (LEO) models.

This work accounts for the (GEO) satellites, which are stationary relative to Earth.

Methodology:

- 1- Satellite Distribution Modeling:
 - a- A(GEO) Satellites are modeled as a binomial point process (BPP) on the equatorial plane(2D) with terminals on Earth modeled in (3D).
 - b- The Poisson limit theorem is used to approximate (BPP) with Poisson point processes (PPP) for scalability.
- 2- Satellite Visibility: depends on terminal latitude.
- 3- Coverage Analysis:
 - a- A mathematical derivation of distance distributions from terminals to satellite.
 - b- Use of Nakagami-m fading to model channel characteristics. Laplace transform applied to analyze signal-to-interference-plus-noise ratio (SINR) and coverage probability.
 - c- Compared both BPP-based exact results and PPP-based approximations.

Result:

- 1- Latitude impact.
- 2- Trade-off in Satellite count.
- 3- On-Orbit Positioning.
- 4- Approximation Accuracy

Paper 6: Resource Allocation and Interference Coordination Strategies in Heterogeneous Dual-Layer Satellite Networks

This paper proposes to enhance service efficiency and manage co-channel interference in a heterogeneous dual-layer satellite by integrating LEO and GEO with mobile edge computing in the network caching and SDN.

Methodology:

- 1- System Architecture: combines LEO and GEO satellites with edge/cloud computing and SDN for scheduling and transmission coordination.
- 2- Optimization Model
- 3- Solution Approach: decompose the problem into three parts:
 - a- User side
 - b- Service side
 - c- Network side

Result:

1-EPFD constraint considers Equivalent power flux density (EPFD) to regulate interference from LEO and GEO satellites.

2- Interface coordination: EPFD constraints effectively limit LEO-GEO interference, preserving GEO Priority while allowing spectrum reuse.

3-Performance Gain: The Proposed strategy is significant and reduces co-channel interference.

Critical Analysis:

The reviewed studies collectively demonstrate significant progress in addressing interference challenges in GEO satellite communications, and particularly in the context of increasing spectrum congestion and the emergence of hybrid GEO-LEO.

Each contribution offers a unique perspective, ranging from the physical layer interference localization to advanced AI-based detection and network-level resource coordination.

Synthesis of Literature and Opportunities		
Challenges	Strengths	Gaps
Precise localization	Doppler-based modeling (Kalantari)	Multipath and multi-resource resistance
Real-Time detection	Deep learning (Yang)	Power/computation tradeoffs in satellite
Cross-orbit coordination	Recourse sharing models (ISTN, Li)	Lack of interoperability standards across operators
System-Level Planning	Stochastic modeling (Jung)	Real-time adaptability
Regulatory enforcement	Angular separation strategy	Underutilizes orbital slot, lacks dynamic resource optimization

Connection:

The reviewed studies demonstrate a clear convergence in addressing the escalating challenge of Radio Frequency interference (RFI) in GEO satellite communications, particularly as orbital congestion and cross-orbit interactions intensify.

Conflict between the Findings:

The studies align on the need to address interference in the GEO satellite system; several important conflicts and contradictions emerge. Particularly regarding implementation trade-offs, performance scalability, and regulatory assumptions.

Synthesis Matrix for Literature Review:

Author	Year	Interference type	Methodology	Key Findings	Conflict
Kalantari	2016	Unknown RF interference in GEO	FOA+ Doppler localization	Sub-km accuracy in localizing single-source interference	Accuracy depends on ideal Doppler shifts and lacks multi-source handling
Yang	2025	Persistent + transient RFI (GEO/NGSO)	DualAttWaveNet(deep learning with wavelet attention)	Achieved ~97% accuracy in RFI detection under noise	High computational demand; less feasible for real-time onboard deployment
ISTN Coordination	2023	Co-channel interference (GEO-LEO)	Simulation of beam overlap coordinated handover	Reduced inter-orbit interference by 65% with spatial multiplexing	Assumes perfect cooperation among operators, which is rare in real-world deployments
Jung	2024	Aggregate interference from LEO to GEO	Stochastic geometry + SINR modeling	Identified SINR thresholds and density effects in dual-orbit setups	Limited to statistical insight; lacks real-time feedback mechanisms
Angel Separation	2023	Adjust-slot interference in GEO	Analytical angular exclusivity model	2.5 angular separation reduces interference by 40%	Conservative; reduces orbital/spectral capacity significantly
Li	2025	GEO-LEO cross-layer beam interference	ADMM-based distributed optimization	Improved throughput by 35% using edge-aware resource allocation	Requires accurate real-time channel knowledge; latency-sensitive

References:

- Kalantari, E., al.(2016). Frequency of Arrival-Based Interference Localization Using a Single Satellite. arXiv:1608.00350.
- Yang, J., et al. (2025). DualAttWaveNet: Multiscale Attention Network for Satellite Interference Detection. arXiv:2504.17187.
- Zhang, C., et al.(2023). Coordinated Intra-and Inter-System Interference Management in ISTNs. arXiv:2312.07936.
- Jung, H., et al.(2024). Modeling and Analysis of Hybrid GEO-LEO Satellite Networks. arXiv:2410.14902.
- Li, X., et al.(2025). Resource Allocation and Interference Coordination in Heterogeneous Dual-Layer Satellite Networks. Sensors, 25(4), 1005.
- Exclusive Angular Separation Strategy. (2023). arXiv:2312.15924