HBPR Based QoS Routing in LEO Satellites

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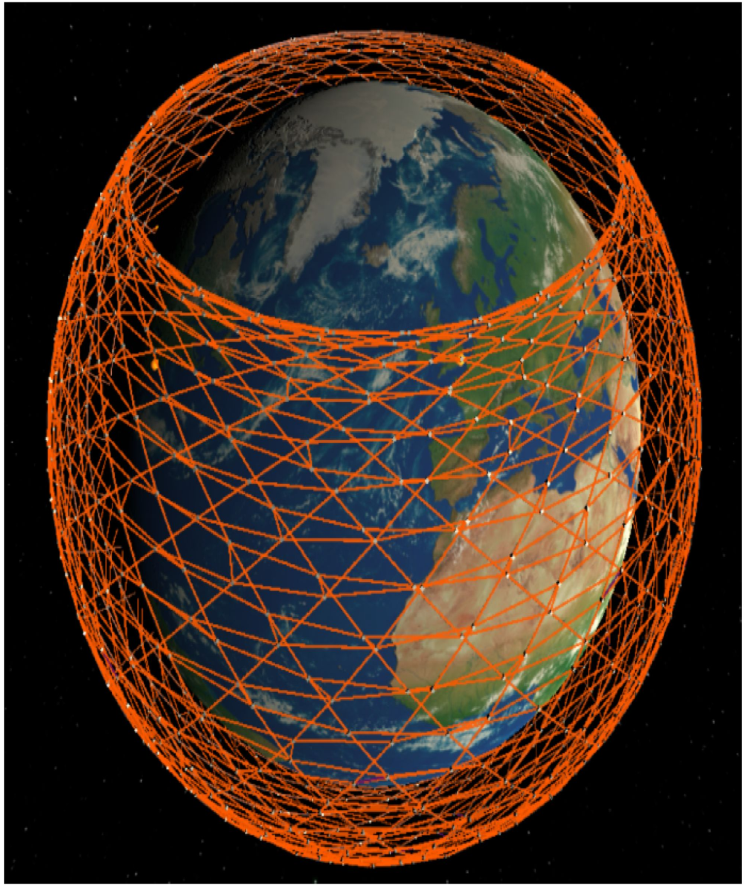
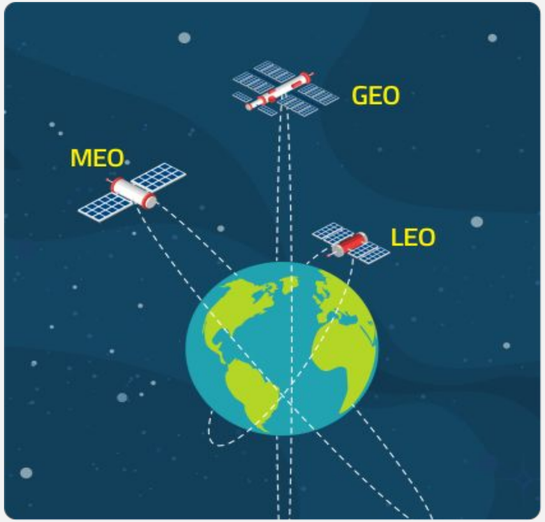


Agenda Overview



01

Introduction

Satellite Communication

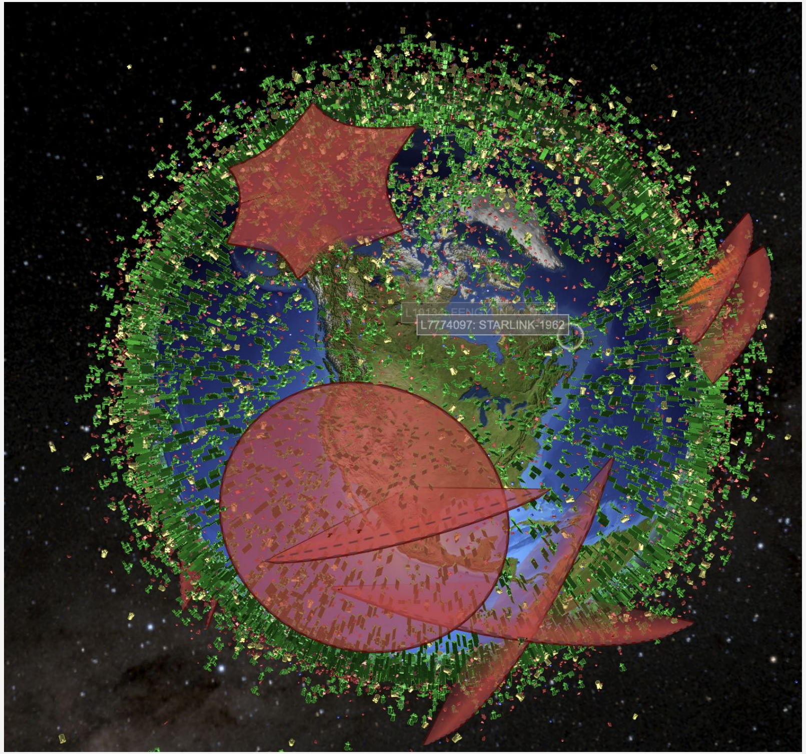
- Satellite communication is the transmission of information using artificial satellites in space. The major types of satellites are classified based on their altitude.
- LEO,MEO,GEO,SSO,GTO But in this problem Statement, Our main focus will be on LEO..

Why prefer LEO satellite?

How LEO contributes to global connectivity?

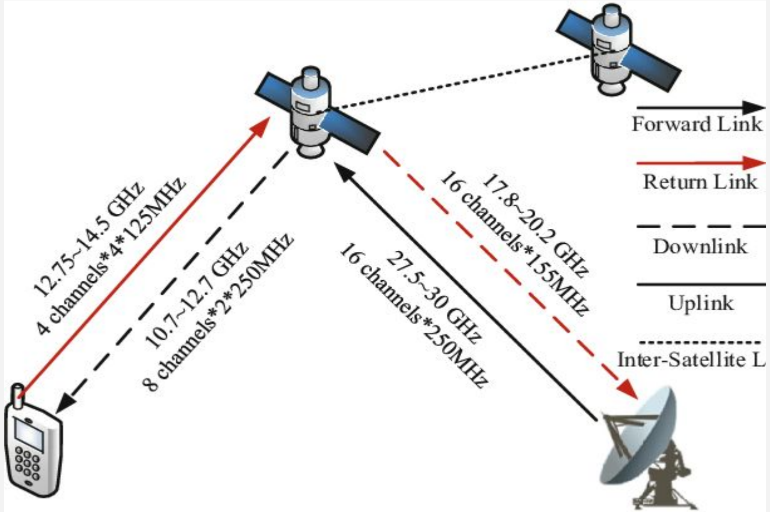
How does LEO satellite Communication Work?

LEO Satellites



How does LEO Satellite communication Works?

- User sends the request via user terminal.
- Signals are transmitted and received to the nearest satellite in the range which then relays the signal to a ground station for further transmission.
- Ground station/earth station fetched the data and send it back to the satellite.
- Satellite sends the data back to user terminal, completing the request.
- As satellite moves out of range, the data is handed over to the next satellite that is coming into the range.
- This handover process ensures continuous communication without interruption, even as the user moves/the satellite moves.

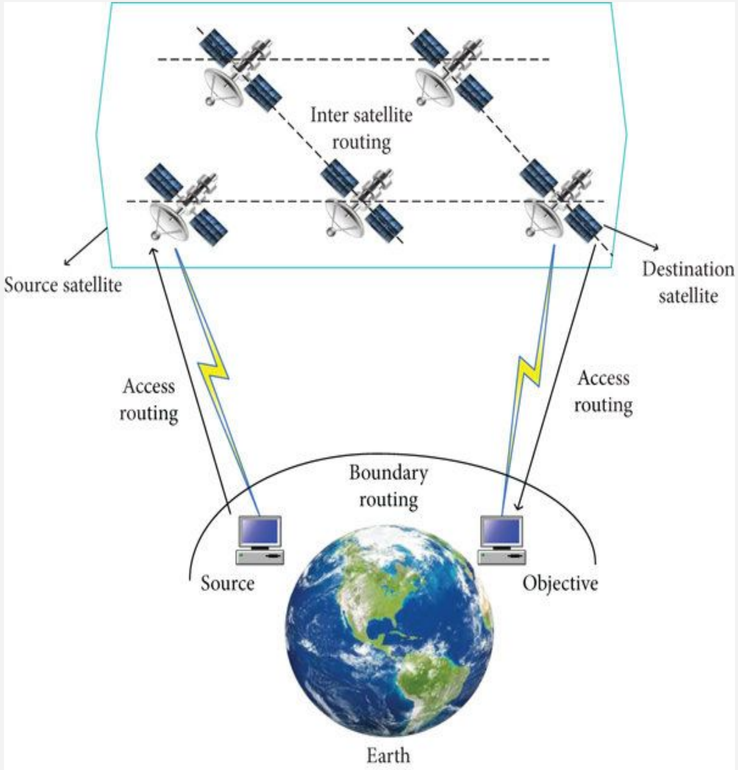


The Routing Problem

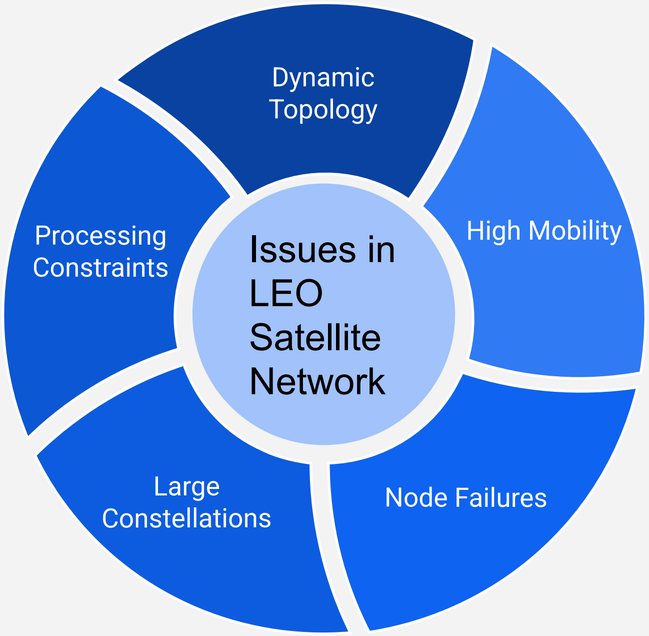
- **Routing** in satellite networks involves selecting the best paths for data to travel from a source node to a destination node. For LEO satellites, this becomes more complex due to their unique characteristics and large-scale deployment

Why do we need Routing?

→ Low Latency & Fast Communication
→ Network Scalability
→ Load Balancing
→ Fault Tolerance & Reliability
→ Security & Policy Enforcement
→ Quality of Service (QoS) Management



Issues in LEO Satellite Network



Quality of Service

- it refers to the ability of the network to manage and prioritize different types of data traffic—such as real-time communication, streaming media, transactional data, IoT transmissions, and bulk data transfer

→**Real-time Data:** Needs **low latency** and **high reliability** for smooth interaction.

→**Streaming Media:** Requires **high bandwidth** and **low packet loss** for seamless playback.

→**Transactional Data:** Demands **low latency** and **high security** for accurate processing.

→ **IoT & M2M:** Prefers **low power use** and **efficient bandwidth** for sensor communication.

→ **Bulk Data Transfer:** Focuses on **high throughput** and **data integrity** for large files.

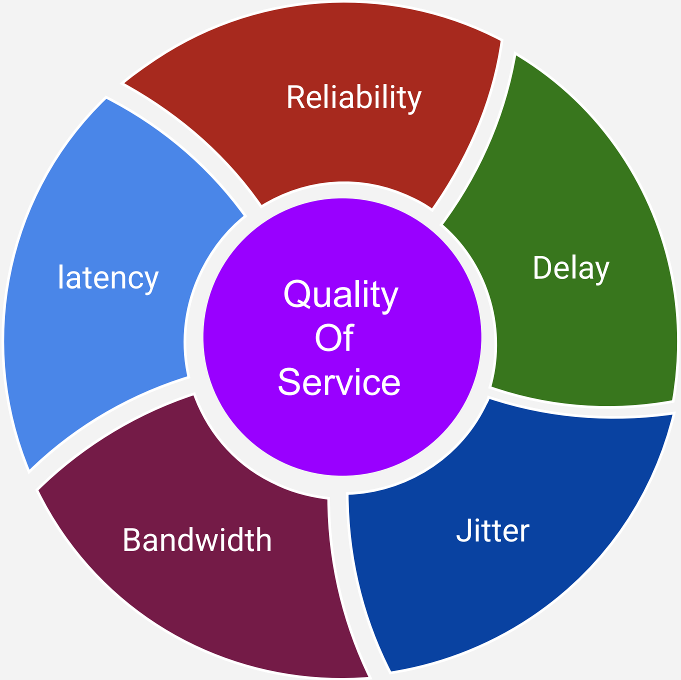
Quality of service(QoS)

What is QoS in LEO satellite networks?

Who is responsible for designing QoS routing protocols in LEO networks?

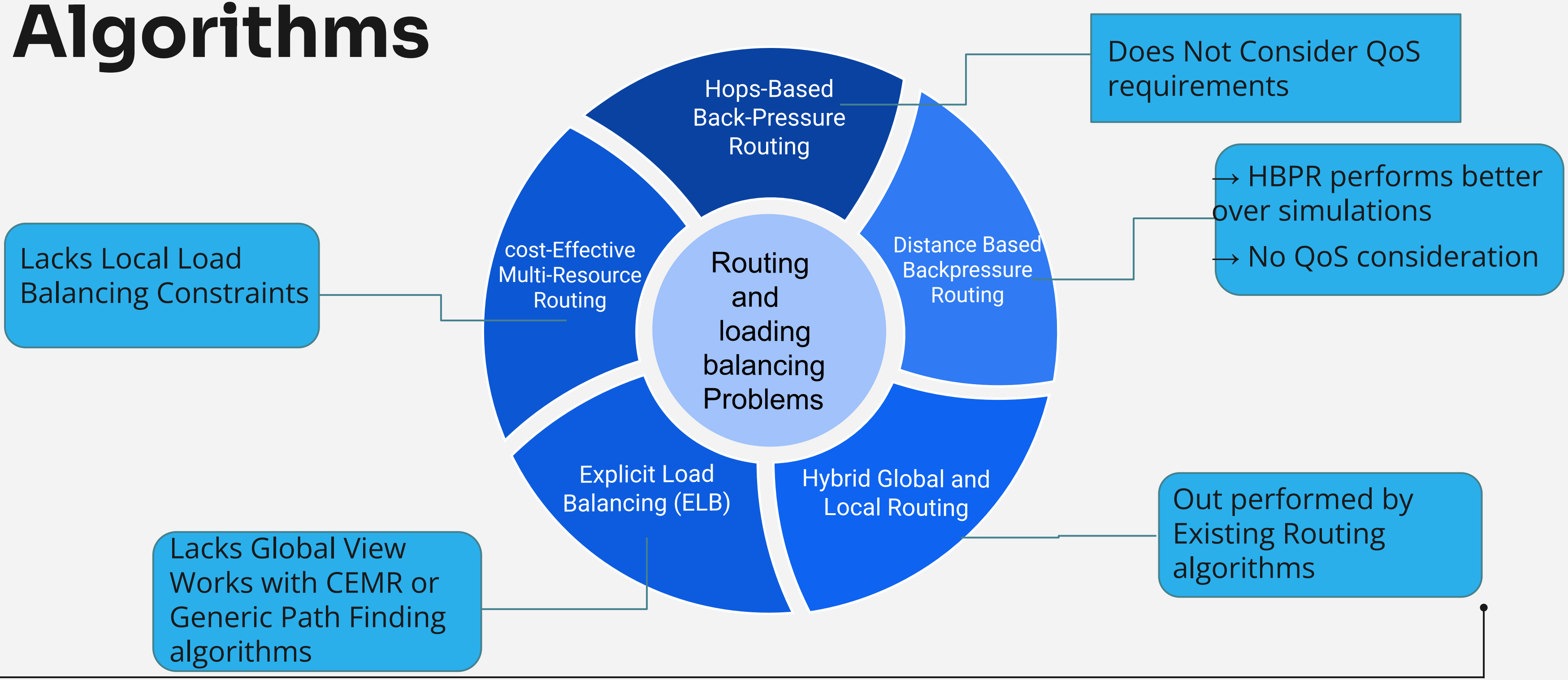
Why is multipath routing beneficial for QoS in LEO satellites?

Why is Quality of Service (QoS) crucial for reliable LEO satellite communication?



02
Related Work

Routing and loading Balancing Algorithms



Traditional Queue Length Back-Pressure Routing

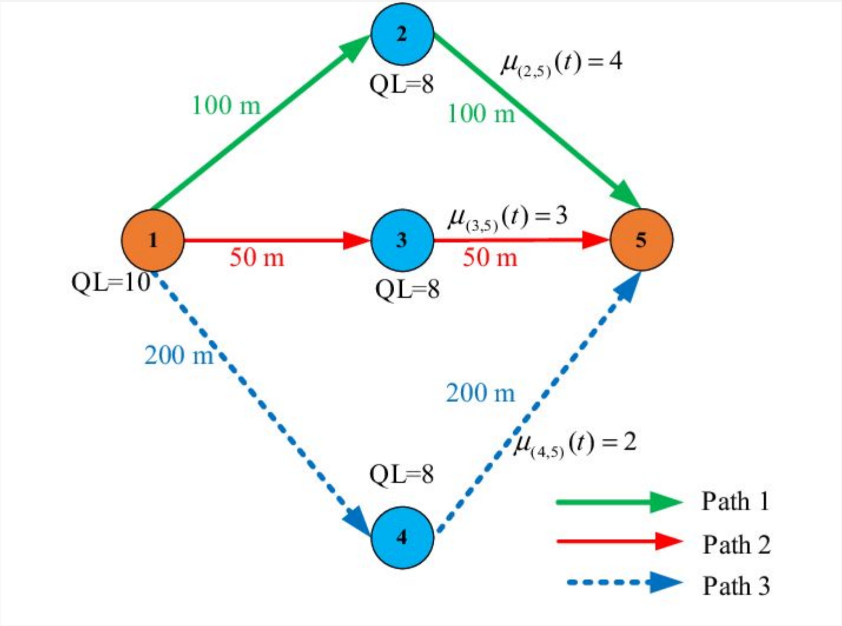
→ Criterion of queue backlog maximization

$$D_{ab}(t) = \max_{c:(a,b)}[P_a^C(t) - P_b^c(t)]$$

$$\text{Maximize}: \sum_{a=1}^{N}\sum_{b=1}^{N}\mu_{ab}(t)D_{ab}(t) \quad \text{s.t.}\ \mu_{ab}(t) \in \Gamma_s(t),$$

$\mu_{ab}(t)$ denotes the transmission rate of link (a, b).

→ BP routing is suitable for all kinds of multi-hop networks to maximize throughput.



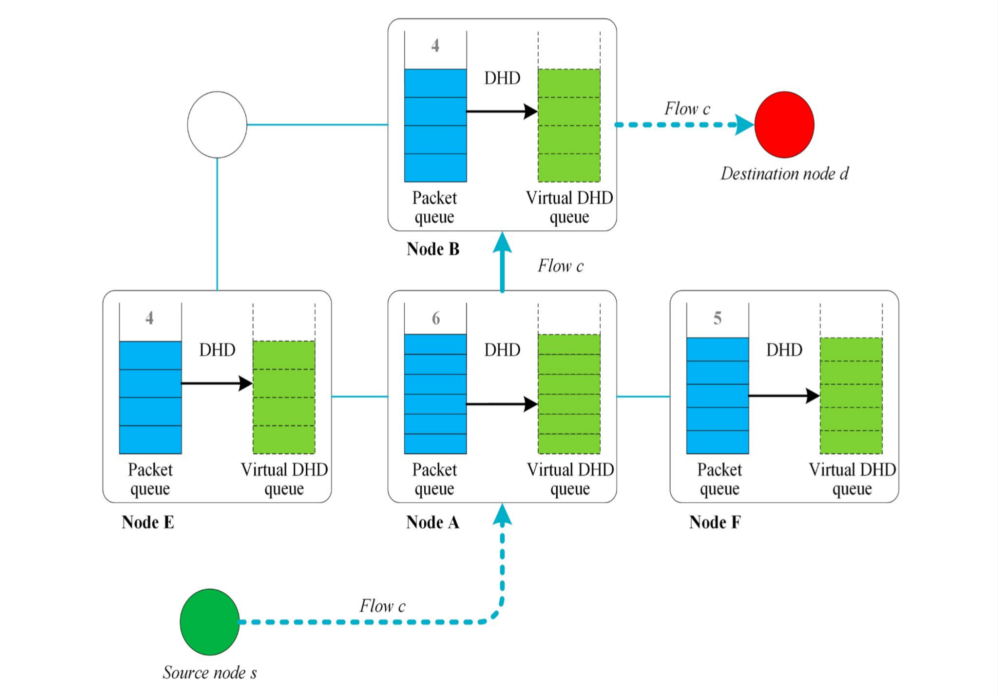
Distributed Hops Based Back-Pressure Routing

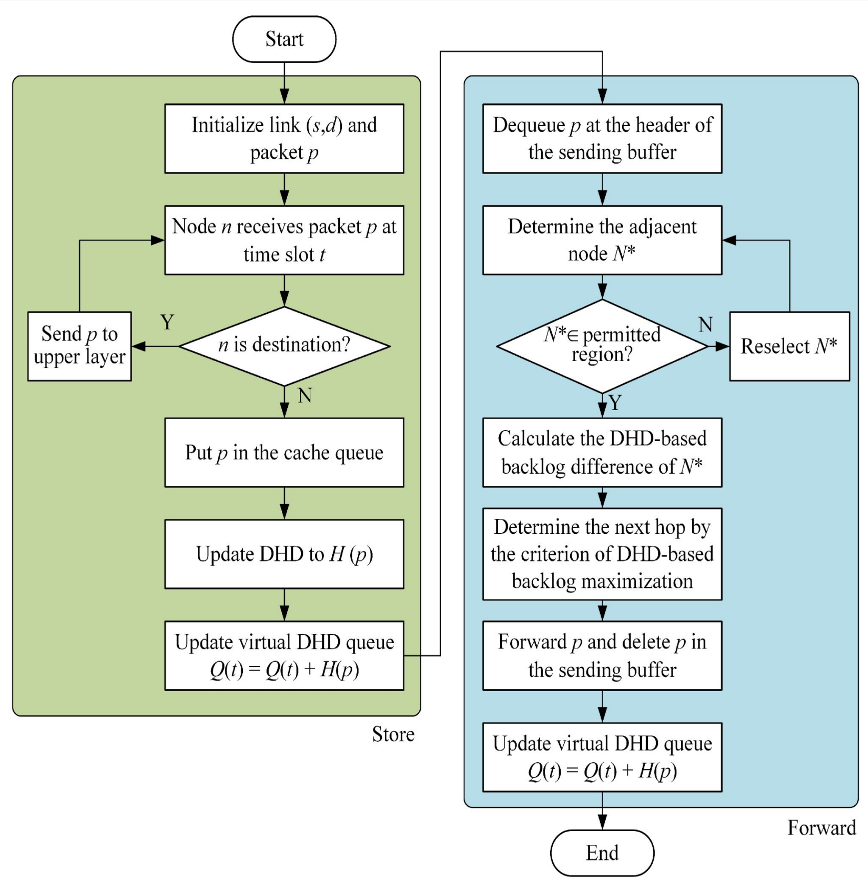
$$\hat{Q}_a^c = \sum_{p \in Q_a^c} H(p) = |Q_a^c(t)| \times H(p)$$

$$\hat{\omega}_{ab}^c(t) = \max_c \left[\hat{Q}_a^c(t) - \hat{Q}_b^c(t)\right]$$

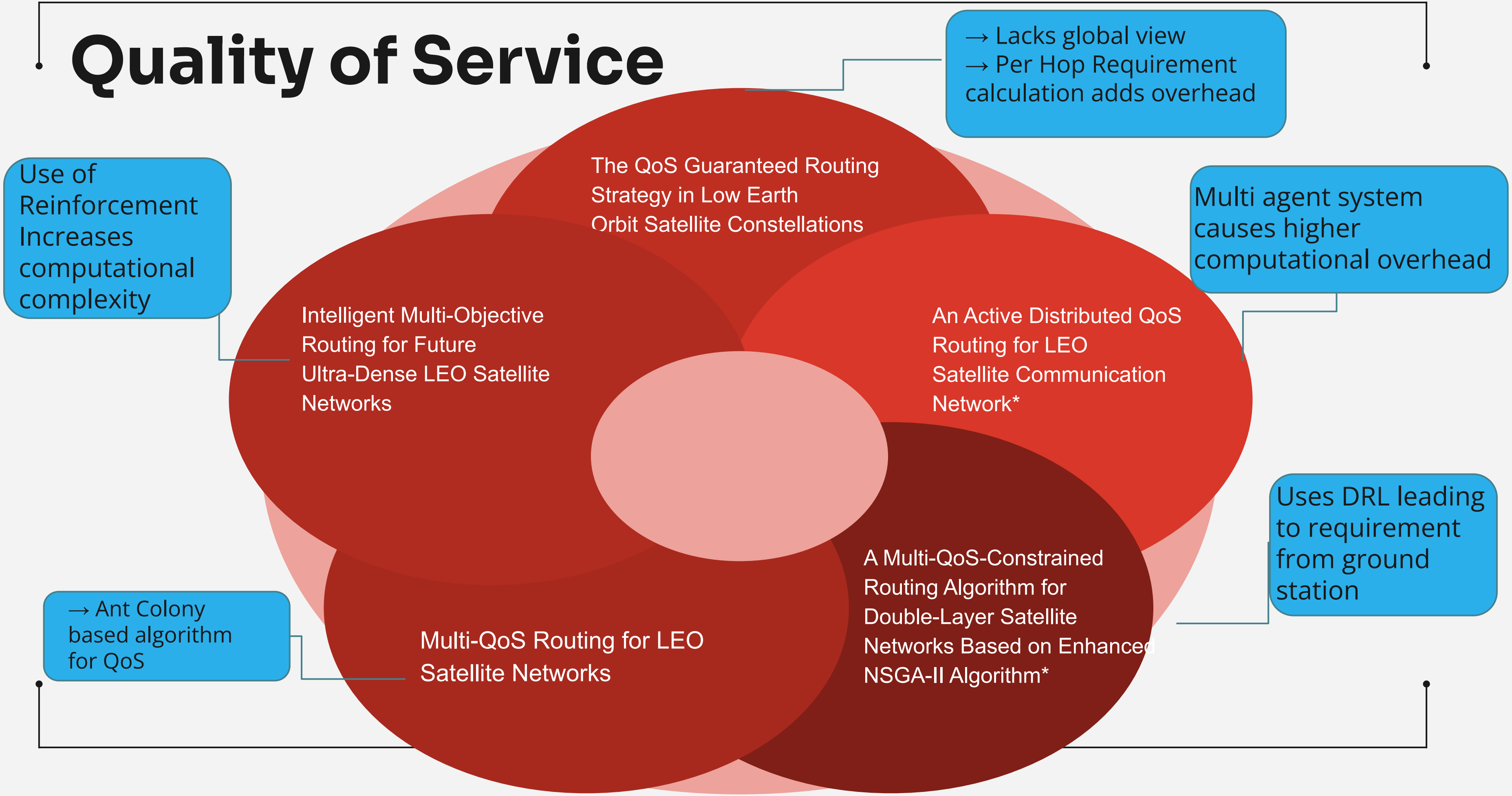
$$Maximize : \sum_{a=1}^{N} \sum_{b=1}^{N} \mu_{ab}(t)\tilde{\omega}_{ab}^c(t)$$

$$\text{s.t.} \quad \mu_{ab}(t) \in \Gamma_s(t)$$




Start
Initialize link (s,d) and packet p
Node n receives packet p at time slot t
n is destination?
Y
Send p to upper layer
N
Put p in the cache queue
Update DHD to H (p)
Update virtual DHD queue Q(t) = Q(t) + H(p)
Store
Dequeue p at the header of the sending buffer
Determine the adjacent node N*
N*∈ permitted region?
N
Reselect N*
Y
Calculate the DHD-based backlog difference of N*
Determine the next hop by the criterion of DHD-based backlog maximization
Forward p and delete p in the sending buffer
Update virtual DHD queue Q(t) = Q(t) + H(p)
Forward
End

Quality of Service



03
Gap Identification And Motivation

03 Gap Identification And Motivation

- Fewer works which Integrated QoS with the Load Balancing and Routing.
- Current QoS algorithms proposed depends on RL increasing the computational complexity.
- Only three routing algorithms have taken QoS into account in load balancing and Routing
  ie : ELB , HGLR, CEMR
- All variations of Back Pressure Routing including Hops Based did not take QoS into account.

04
Problem Statement

04 Problem Statement

→ Existing **routing, load balancing, and QoS protocols** operate in isolation, leading to inefficiencies.

→ **Routing algorithms** may cause congestion due to static path selection.

→ **Load balancing techniques** often neglect **QoS constraints** (latency, jitter, packet loss).

→ Existing **QoS-aware routing** lacks the capability of Load Balancing

→ A **unified algorithm** is needed to integrate **QoS, routing, and load balancing** for optimal network performance.

→ The proposed solution will dynamically adjust routing based on **Node congestion, delay constraints, and traffic distribution** to enhance efficiency and service quality.

05
Approach

05 Approach

Define QoS Metrics

- Prioritize **latency, jitter, packet loss, and throughput** in path selection.
- Introduce a **QoS-weighted backlog metric** to refine HB-BP decision-making.

QoS-Aware Backlog Calculation

- Modify the queue backlog equation to include **packet delay sensitivity**.
- Use a **weighted backlog**: $\hat{Q}_c^a = |Q_c^a(t)| \times H(p) + \alpha \times \text{QoS Factor}$
- where **α** adjusts the influence of QoS constraints.

Adaptive Path Selection

- Adjust **DHD (Destination-Hops-Delay) calculation** to factor in QoS needs.
- Prioritize routes with **lower congestion and better QoS scores**, not just hop count.

Approach

Continuous Monitoring & Optimization

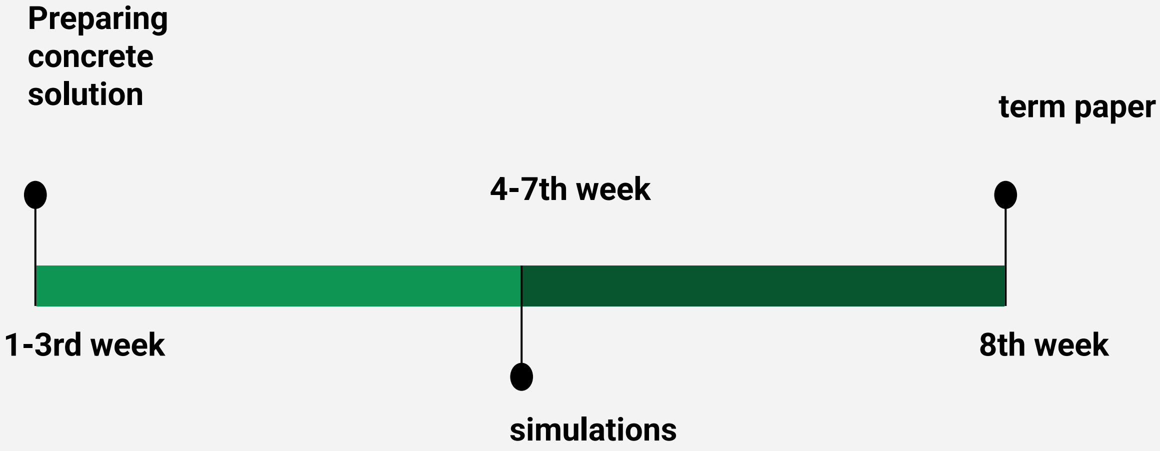
- Introduce a **feedback loop** to adjust backlog weights in real time.
- Predict congestion using **historical network state data** to optimize forwarding.

Simulation & Validation

- Test the QoS-enhanced HB-BP routing in **NS-3 or OMNeT++** with real-world satellite mobility models.
- Evaluate performance against **baseline HBPR routing without QoS integration**.

06
Timeline

06 Timeline of our project



07 Challenges

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Simulation Inconsistencies Across Platforms

- Existing research uses **different simulators (OMNeT++, NS2, NS3, OPNET)**, making it challenging to **standardize and port simulations into NS3**.
- Lack of publicly available simulations for some works complicates validation and benchmarking.

Trade-off Between Load Balancing and QoS

- HB-BP routing **spreads traffic evenly**, while QoS-aware routing may require **prioritizing specific paths**, leading to potential conflicts.

08
Conclusion

08 Conclusion

Problem Statement: Current routing solutions either optimize load balancing or QoS but fail to integrate both efficiently in a single framework.

Existing Work: HBPR routing balances load but lacks QoS integration; QoS-based routing exists but does not account for dynamic load balancing.

Gaps: No unified approach combining **QoS, routing, and load balancing**

Challenges: Selecting the right QoS algorithm for HB-BP, maintaining real-time QoS constraints, and standardizing simulations across different platforms, fragmented simulations across **OMNeT++, NS2, NS3, and OPNET** hinder validation.

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Thank you!