IPIC 2024
10th International Physical Internet Conference
May 29-31, 2024 | Savannah, GA USA

Directional Routing for the Physical Internet:

A Sector-Based Approach with Dynamic Adjustment

Georgia Tech

Supply Chain and Logistics Institute

Physical Internet Center

Destinational Routing

Direct Destination Routing Overview

Ships goods directly to their destination

using the shortest or most direct path

possibly through intermediate hubs without altering the end goal

Characteristics:

- **Consistent Destination Focus**: Paths are fixed from the start, targeting the final destination
- **Efficiency via Hubs:** Utilizes intermediate hubs to enhance efficiency without deviation.
- **Optimization Goals:** Prioritizes minimizing distance or travel time.

Less flexibility in responding to in-transit changes or optimizing for cost when conditions vary

To address the limitations of destination routing, we propose directional routing as a flexible approach that dynamically adjusts to real-time conditions, optimizing efficiency, cost, and sustainability within the Physical Internet network

Directional Routing

Core Mechanism

Utilizes real-time data and intermediate decision points to dynamically optimize goods transportation based on current network conditions.

Key Characteristics:

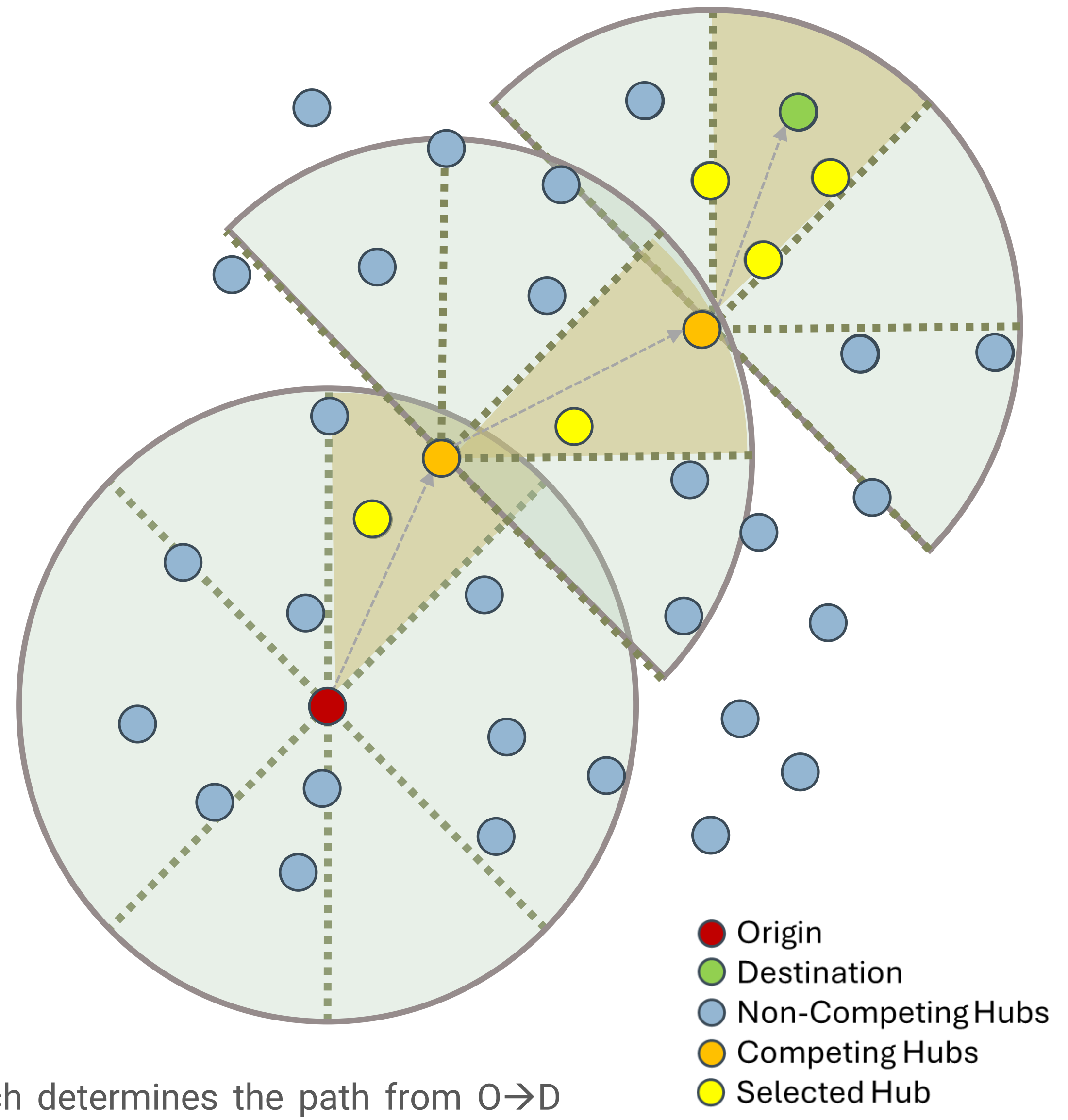
- **Adaptive Route Selection**: Adjusts routes based on congestion, costs, and resource availability.
- **Enhanced Flexibility:** Boosts logistics flexibility significantly.
- **Complexity:** Requires advanced decision-making and systems integration.

Protocols Proposed:

- Cardinal Sector-Based Routing (CSBR)
- Density-Adjusted Dynamic Sector Routing (DADSR)

Cardinal Sector-Based Routing (CSBR)

- Each tier in the Physical Internet, ranging from unit zones to continents, is further subdivided into eight sectors based on cardinal directions
- Avoid defining a single sector that spans from the origin to the destination because this approach would necessitate involving too many hub



Sector-based approach determines the path from O→D by identifying the sector in which the destination lies relative to the origin

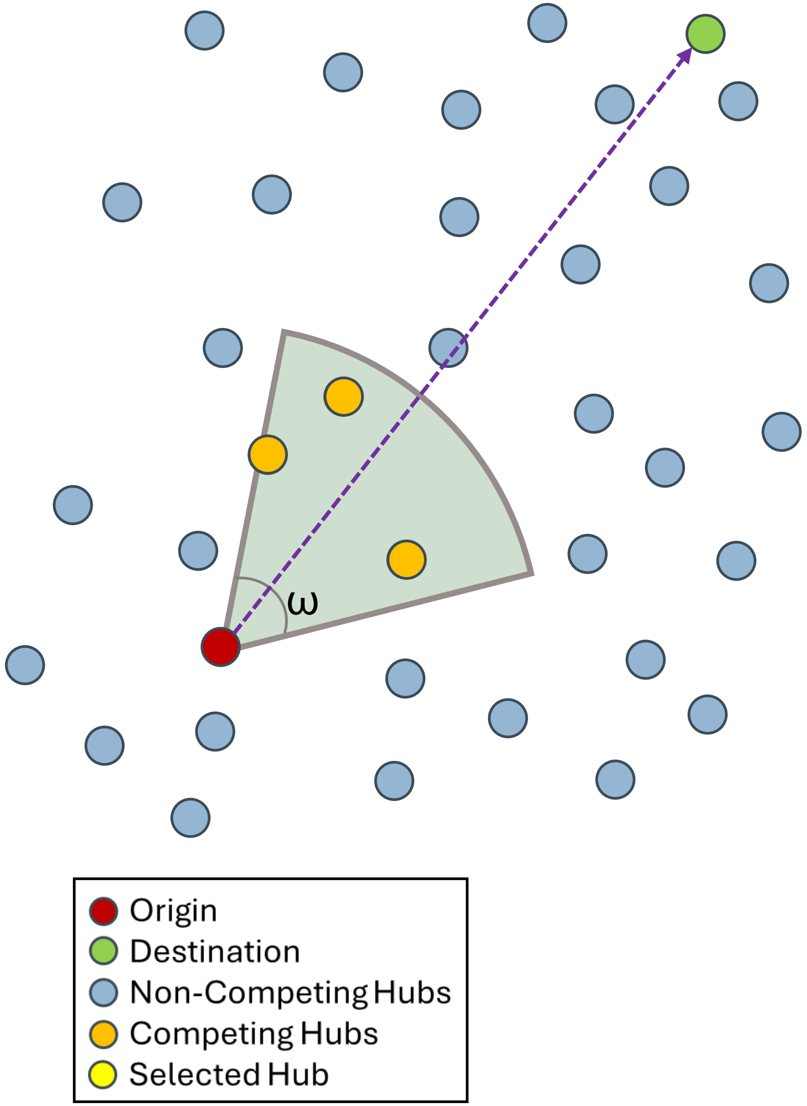
Density-Adjusted Dynamic Sector Routing (DADSR)

Principle	DADSR adjusts sector orientation and width dynamically, focusing on the direct route from origin to destination and local hub density
Dynamic Sector Adjustment	Sectors start based on the direct route, then expand to include enough hubs for viable routes
Minimum Hub Inclusion	Ensures each sector has sufficient routing infrastructure
Maximum Angle Constraint	Limits sector size to prevent impractical dimensions
Network Density Awareness	Adapts to the varying density of large-scale networks, enhancing suitability for complex systems like the Physical Internet

Density-Adjusted Dynamic Sector Routing (DADSR)

Area Discovery Phase

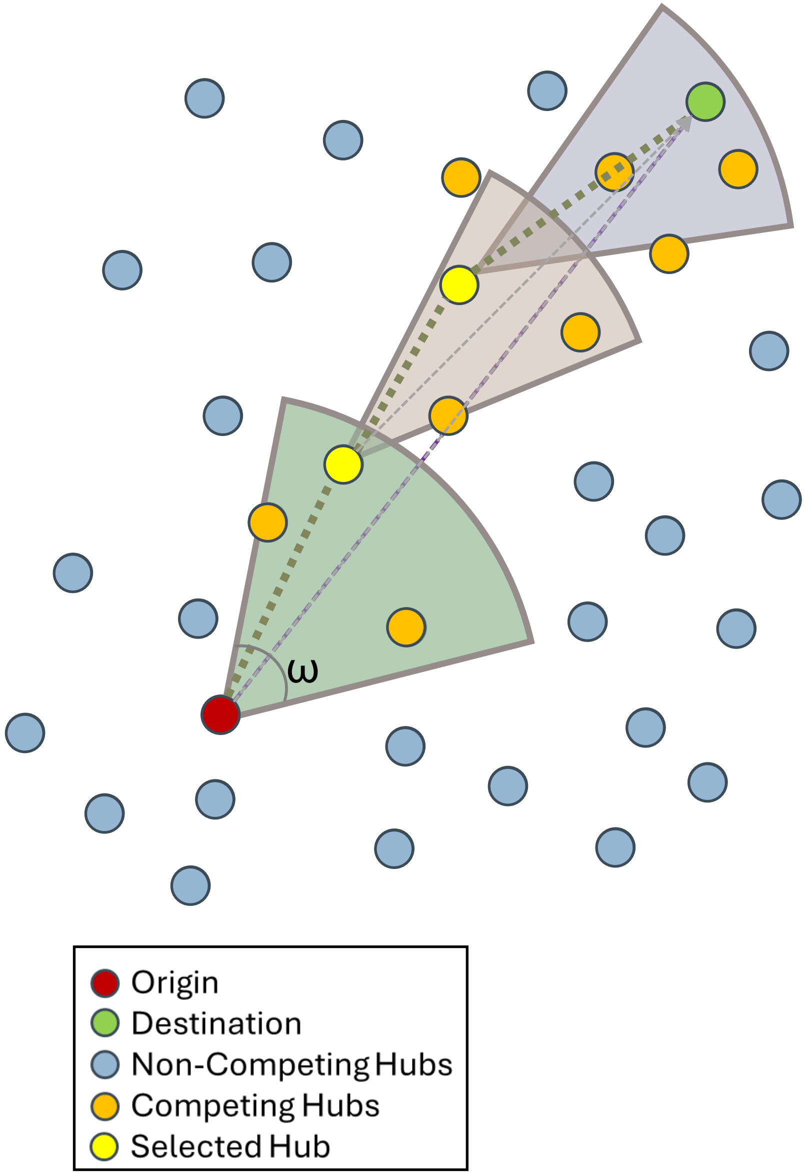
- **Calculate Bearing (θ):**
  - From O to D.
- **Dynamic Sector Formation**:
  - Set initial angular width (ω) based on minimum criteria, adjust dynamically based on network density.
- **Node Classification:**
  - Nodes within the active region ($x \in A$) are competitors; those outside ($x \notin A$) are non-competitors.
- **Central Path Definition:**
  - The direct route from the origin to destination centers the active region.



Density-Adjusted Dynamic Sector Routing (DADSR)

Node Selection and Object Forwarding Phase

- **Response from Competing Nodes:**
  - Competing logistics nodes provide information on their availability, capacity, and efficiency metrics.
- **Selection Criteria:**
  - The originating node selects the next hop based on a combination of factors such as distance to destination, node capacity, throughput efficiency, and sustainability considerations.
- **Dynamic Routing:**
  - The selection of logistics nodes for forwarding objects is dynamic, considering the current state of the logistics network and the specific requirements of the physical objects being transported.
- **Multi-objective function or scoring method for decision-making**



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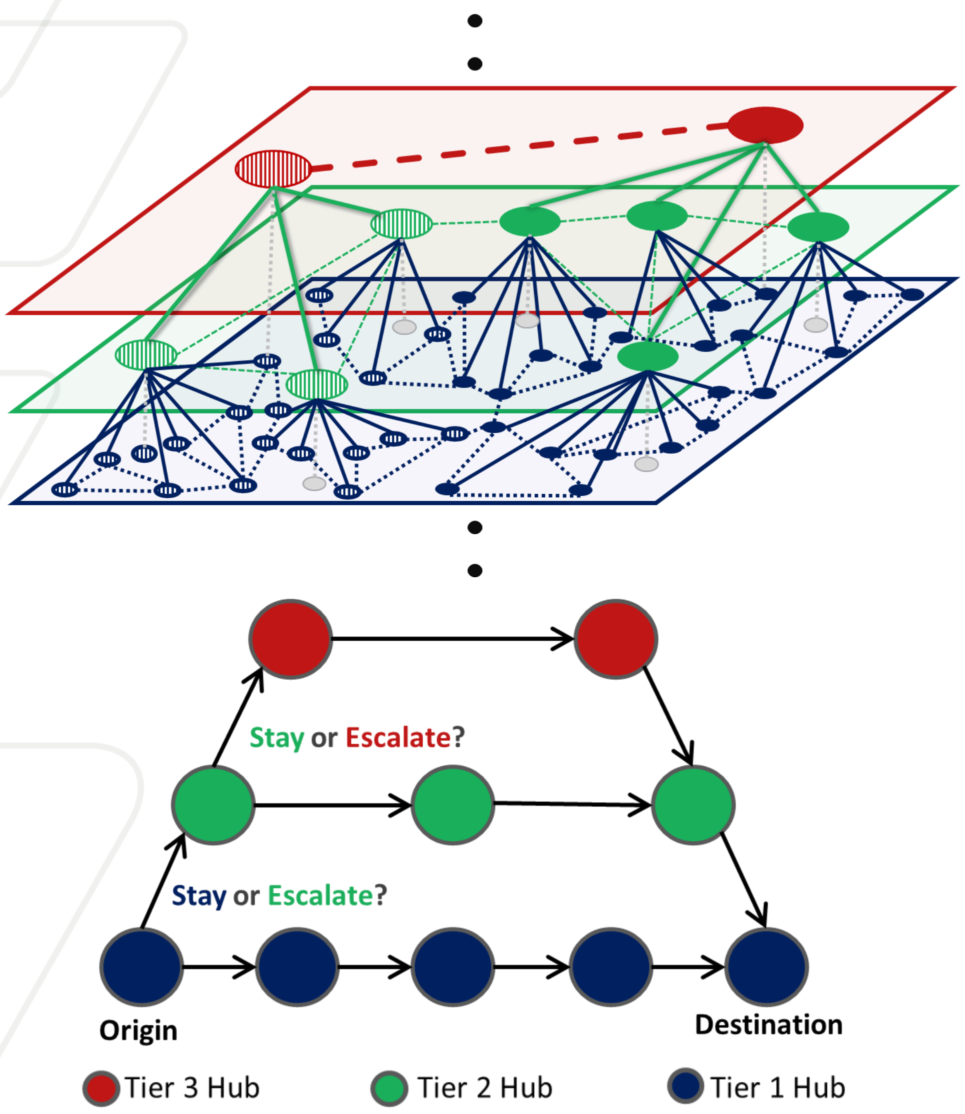
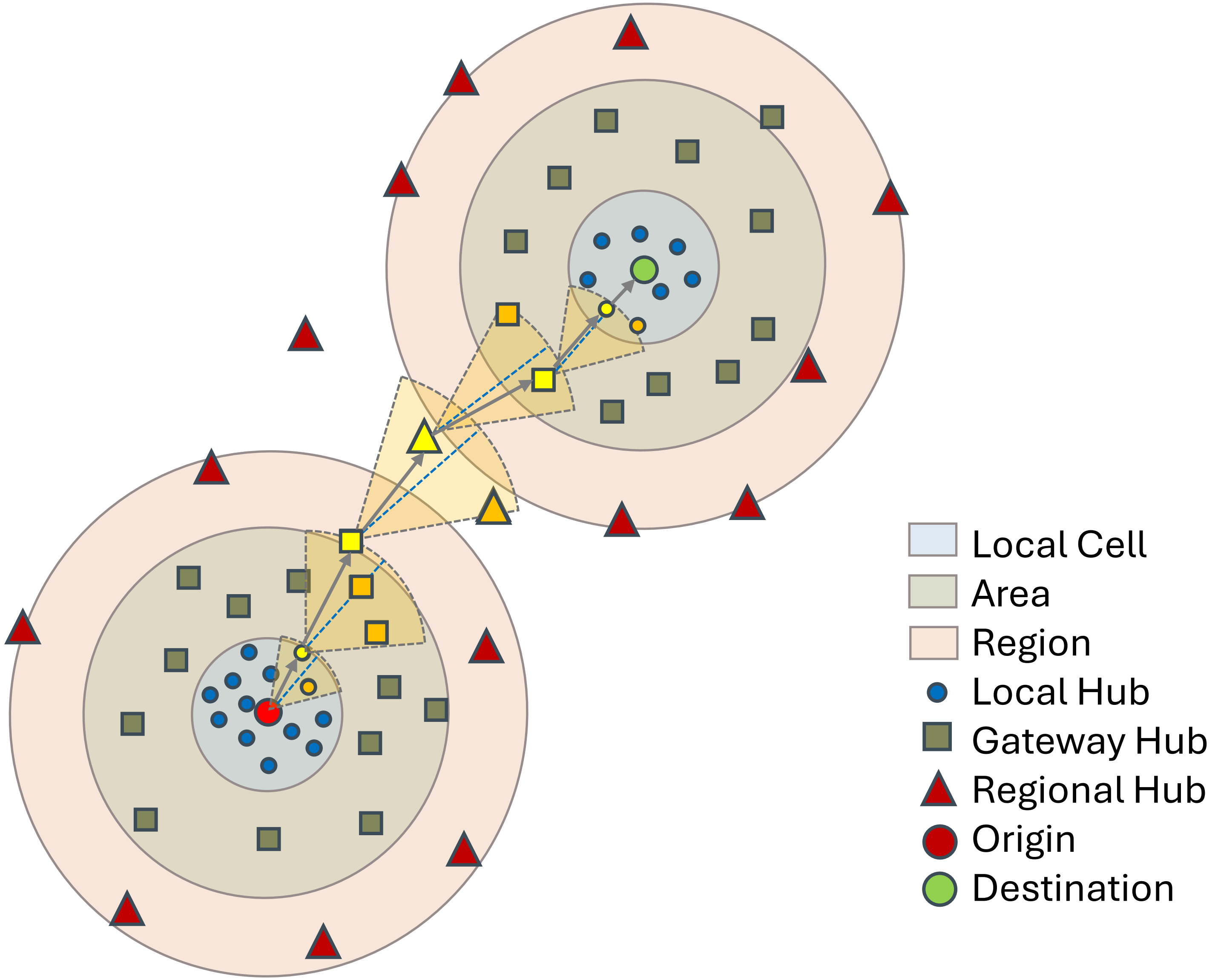
Dynamic Directional Routing in Multi-tier Mesh Network





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Simulation Setup

Baseline Static Routing Protocol (FixedRoute)

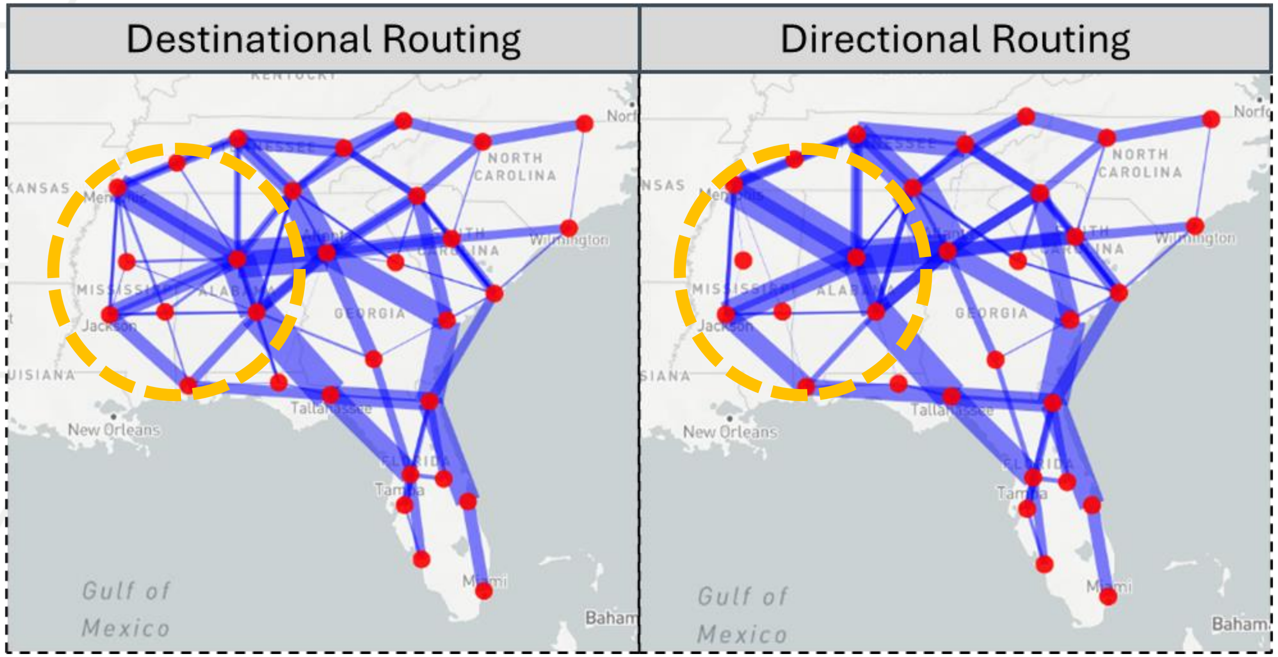
- Uses shortest path routing with a static network topology
- Manages trucks based on FIFO queuing system
- Pre-determined routing tables

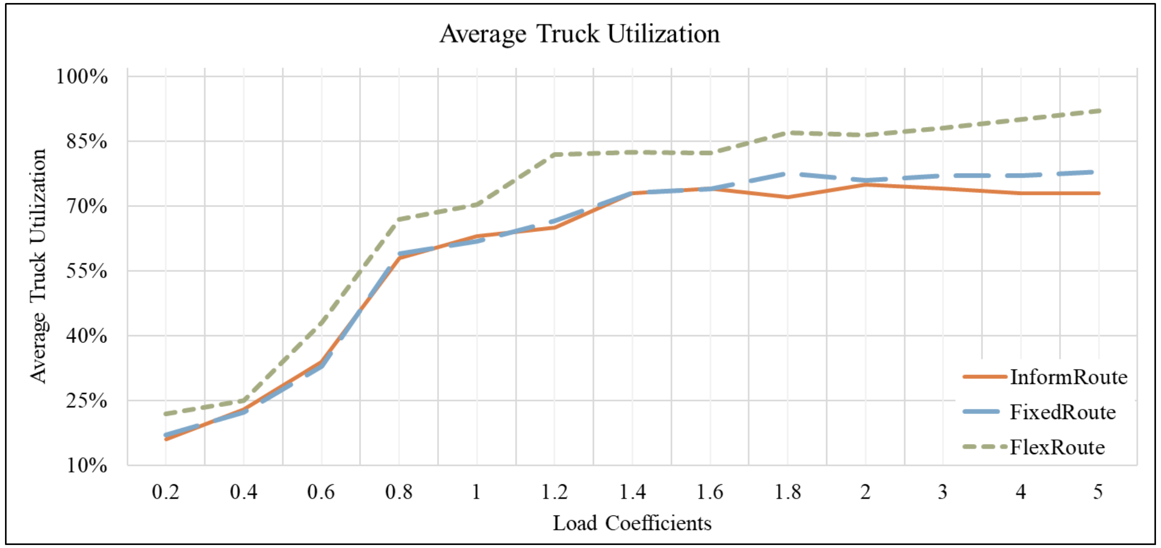
Dynamic Routing Protocols

I. ***InformRoute : Enhances route decision-making based on real-time traffic and node status***
   - Collects and utilizes data about neighboring node delays.
   - Predicts and adjusts for queuing times at nodes, modifying route weights accordingly.

II. ***FlexRoute : Maximizes load consolidation and routing flexibility***
   - Evaluates slack time for each container to determine feasible route deviations
   - Uses information of containers at neighboring nodes and their respective destinations
   - Chooses paths that potentially increase truck utilization by consolidating loads

Dynamic Directional Routing of Finished Vehicles in Southeast US





LOAD CONSOLIDATION

Capable of consolidating loads based on the current capacity and potential efficiencies in directional paths

HUB UTILIZATION

Uses information from hubs to determine congestion levels and waiting times

DYNAMIC ROUTES

Path selection is flexible and can change based on real-time data

INCREASED RESILIENCE

More adaptable to unforeseen circumstances, such as hub closures or delays

REDUCTION IN TOTAL MILES

10%

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Thank you for your attention!

For further information or questions, please contact
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