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Hyperconnected Urban Logistic Service Networks: Bidding-Based Design Framework

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Joint work with

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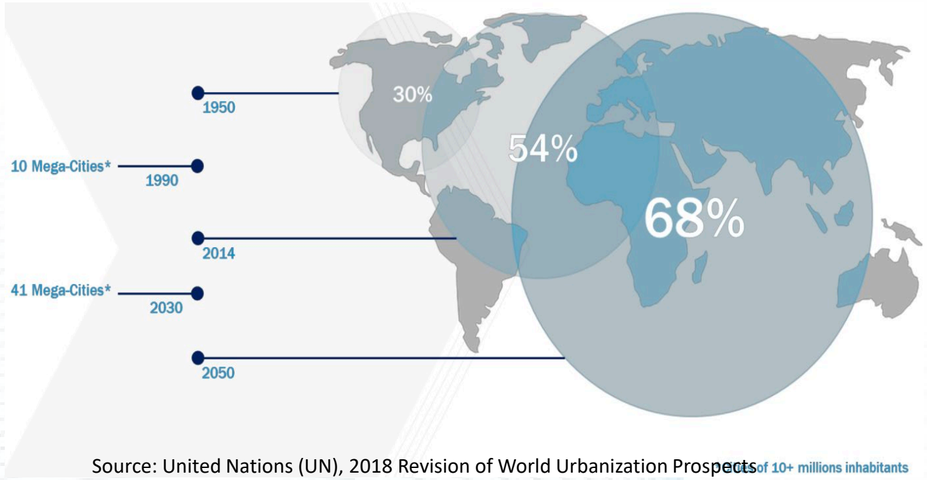
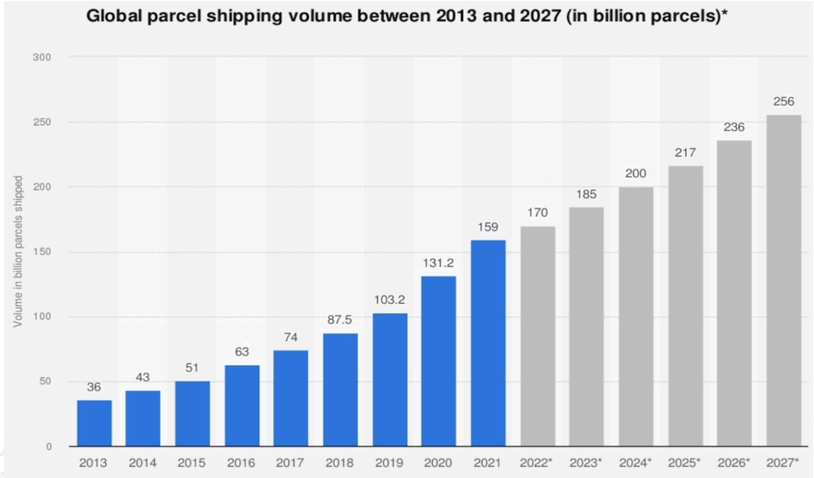
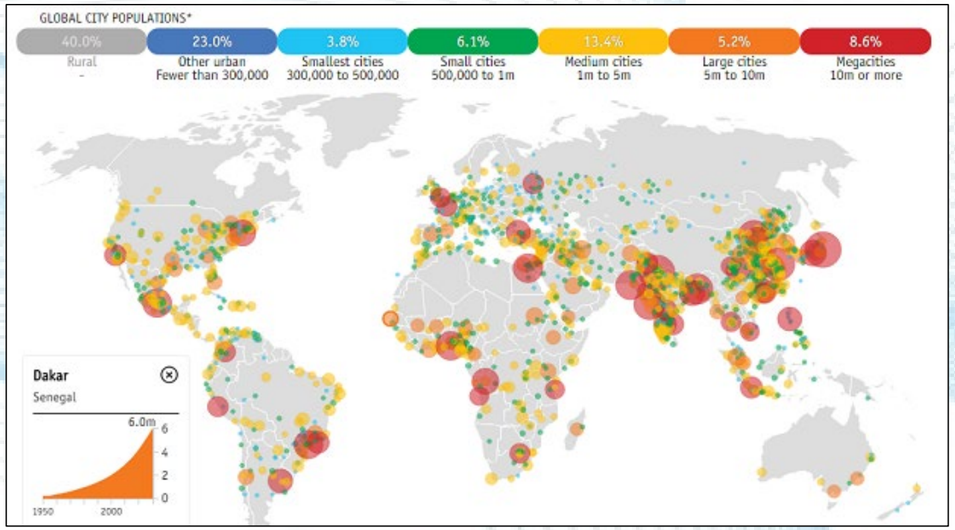
Motivation: Challenges in urban cities

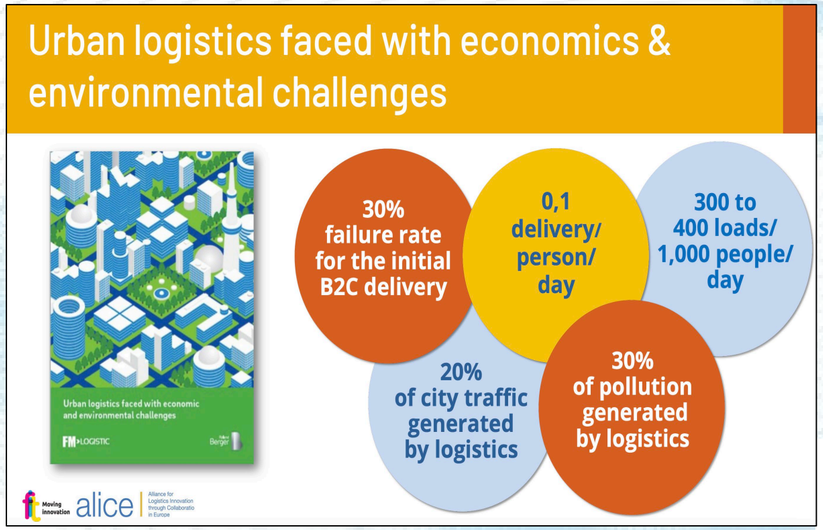


Source: United Nations (UN), 2018 Revision of World Urbanization Prospects

Source: Statista (Sep 2022)







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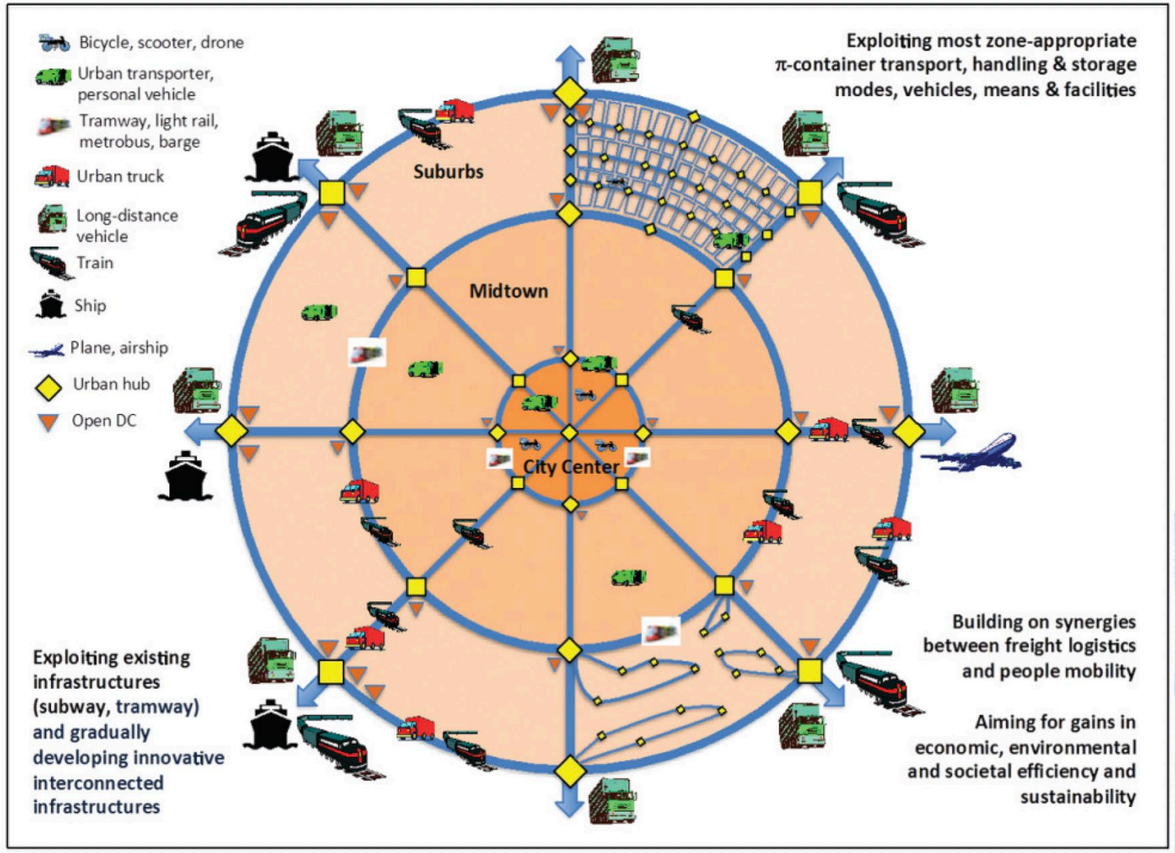
Hyperconnected City Logistics

Interconnect:

- Cities as nodes of the worldwide logistic web
- City logistic stakeholders into an open system via systems standardization
    - Coordination, Collaboration, Cooperation
- Multi-faceted activities of city logistics and urban planning
- Multiplicity of urban logistic centers
- City logistic networks into an urban web architecture



Source: Physical Internet Enabled Hyperconnected City Logistics (Crainic and Montreuil '16)

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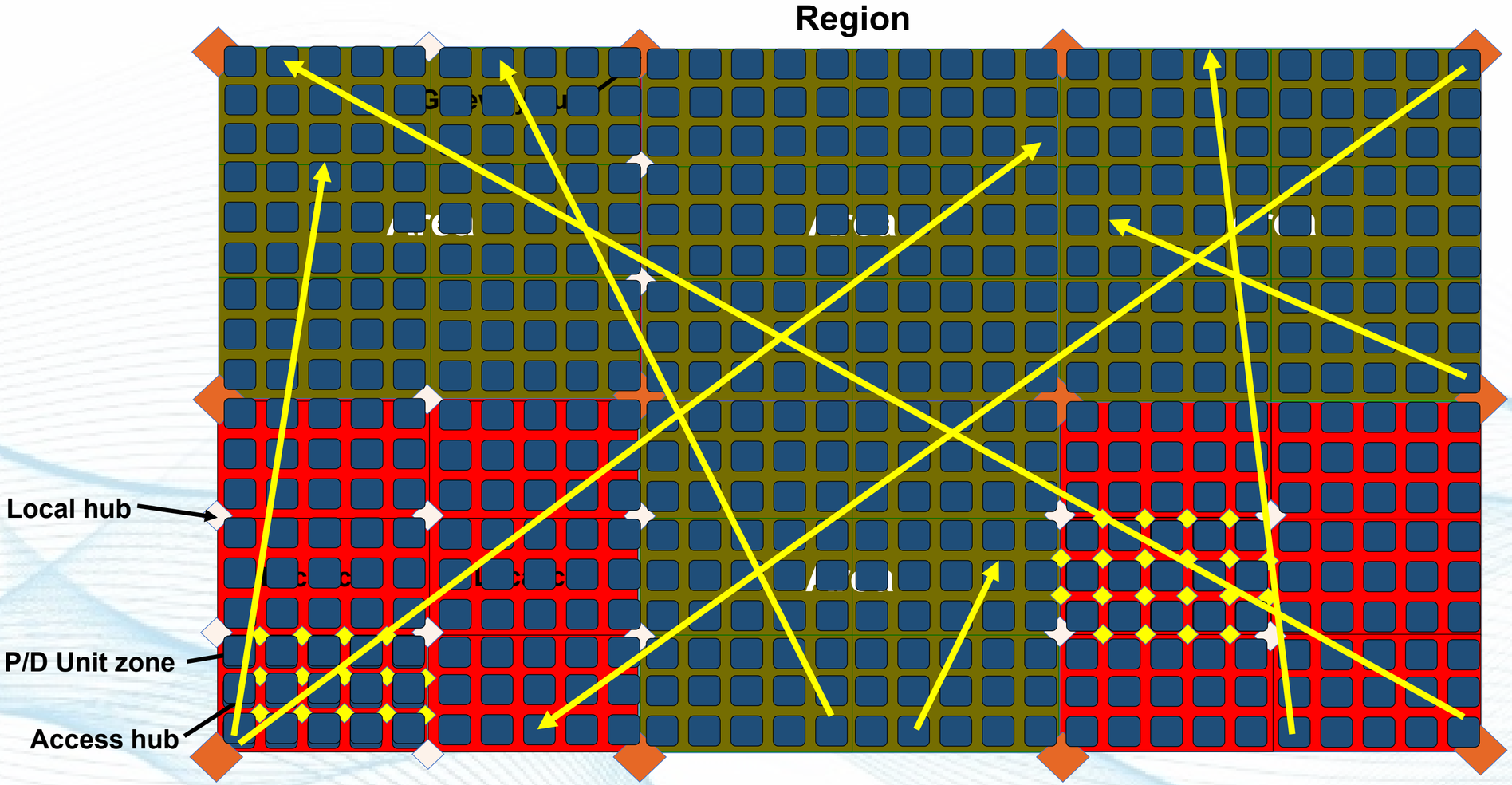
Hyperconnected Urban Logistic Network Topology



Urban city structured as a set of demand zones (mesh zones)
Origin-Destination (O-D) commodities with time requirements

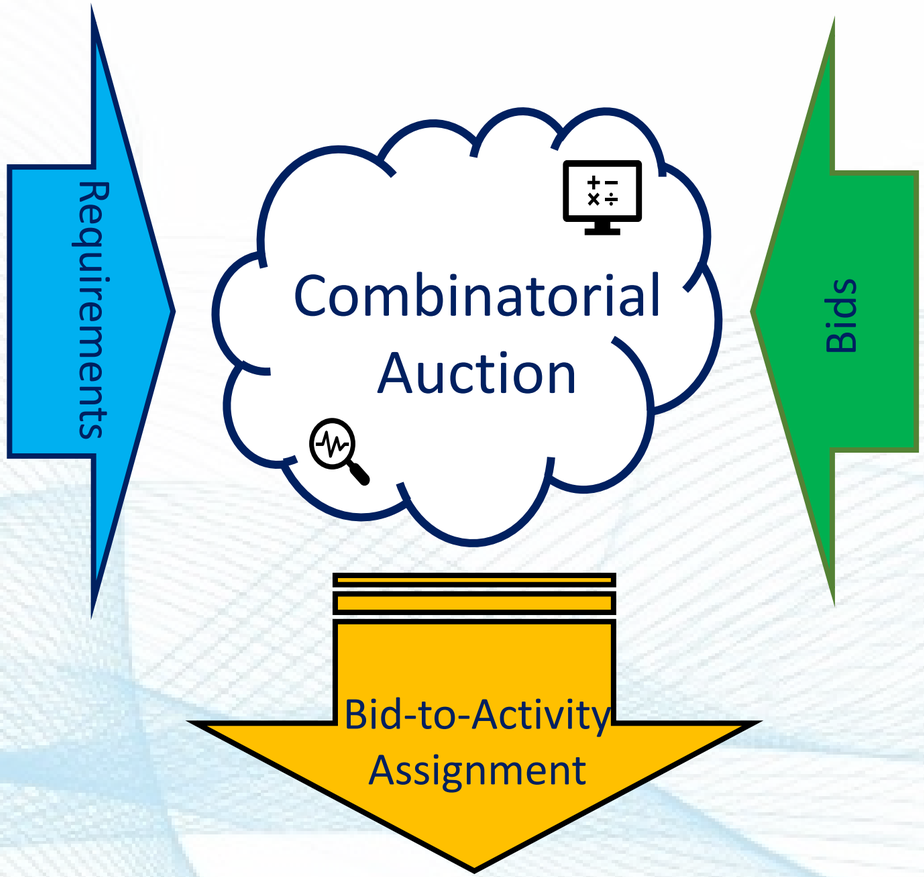
Representative literature on Hyperconnected Multi-tier mesh networks

[Montreuil et al. ’18]
[Hettle et al. ‘21]
[Grover et al. ‘23]

Problem Definition

Logistic Orchestrator

- Hyperconnected multi-tier network topology
  - O-D service guarantees (e.g., x-hour delivery)
- Multi-party coordination/orchestration via a **combinatorial auction**
  - **Allocation of logistic activities to LSPs**
  - Imposing **service level agreement (SLA) for each logistic activity**
  - Robust O-D service guarantees in min. cost



Logistic Service Providers (LSP)

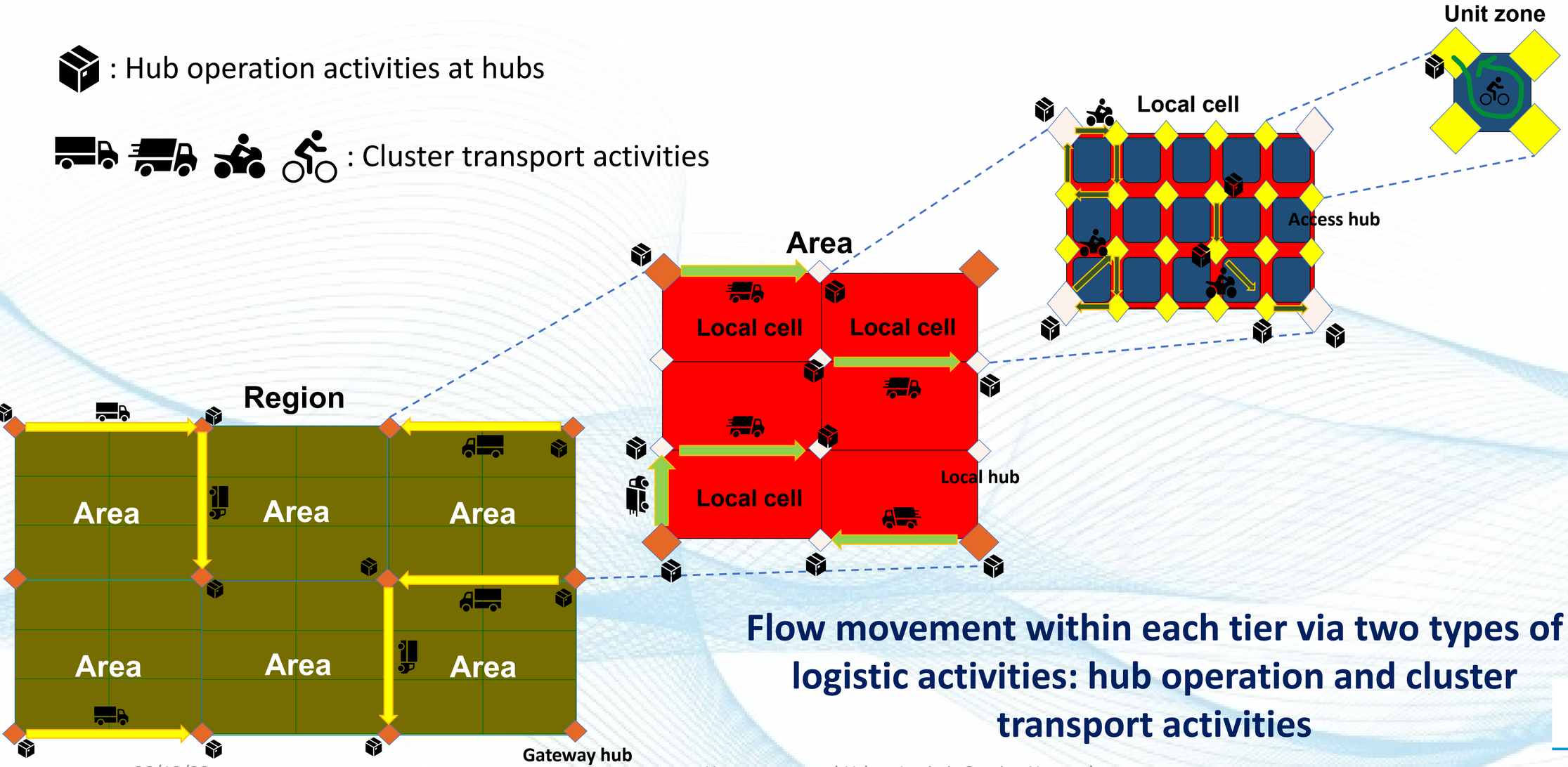
- Providing logistic services (transport/hub operation)
- Participating in the auction by **submitting bids** for logistic activities with bid prices
  - **Respecting the network topology and SLA**
  - Profit maximization

Optimized Service Networks

Logistic Activities in Hyperconnected Urban Logistic Network

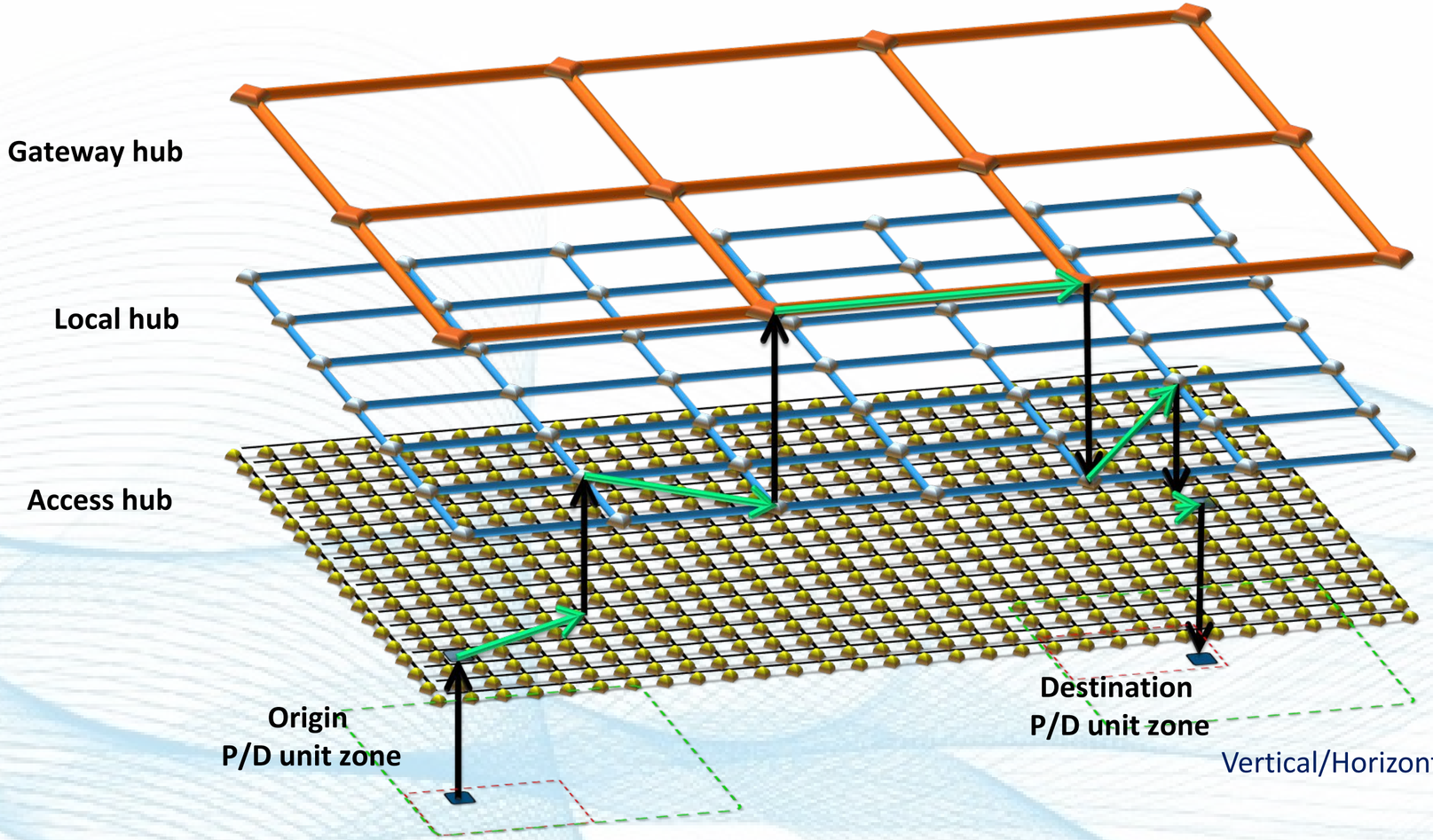
: Hub operation activities at hubs

: Cluster transport activities



Flow movement within each tier via two types of logistic activities: hub operation and cluster transport activities

Flow Movement Across the Proposed Networks



Vertical/Horizontal movements ⇒ Logistic activities

Origin-Destination flow movement across the networks through multiple planes via a set of logistic activities (cluster transport and hub operation activities)

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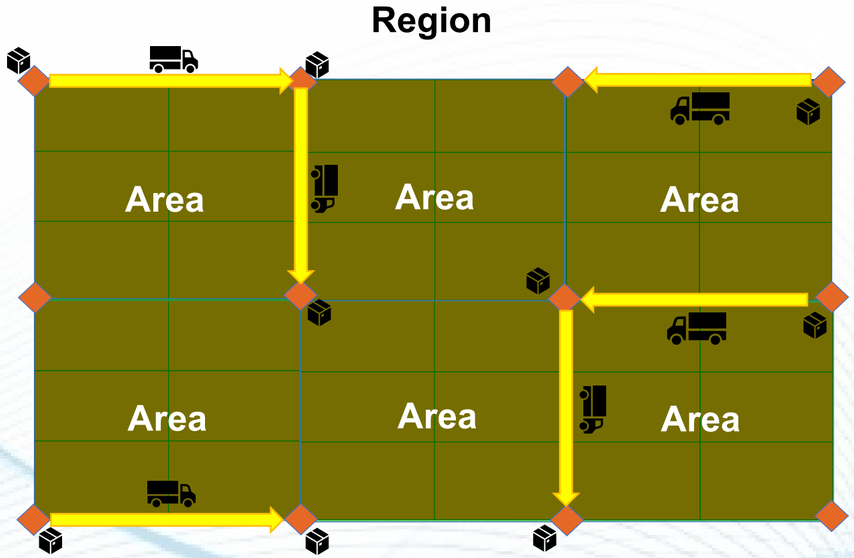
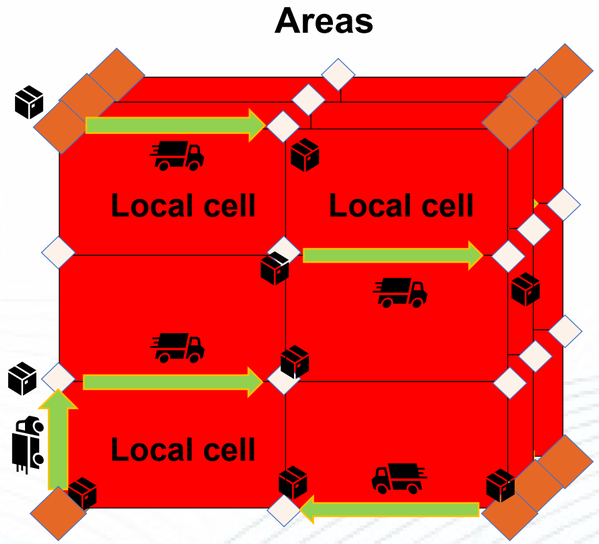
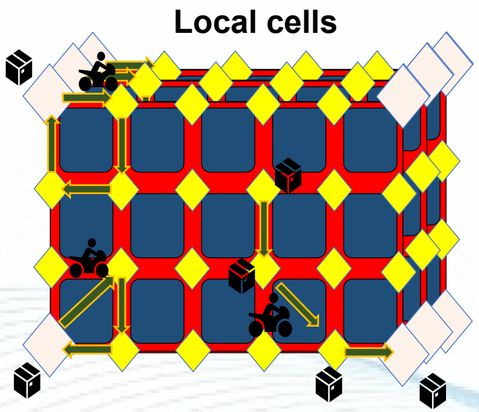
Service Level Agreement (SLA)

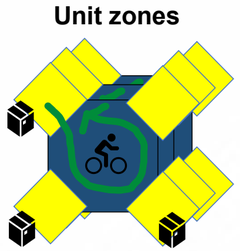
: Hub operation activities at hubs

: Cluster transport activities







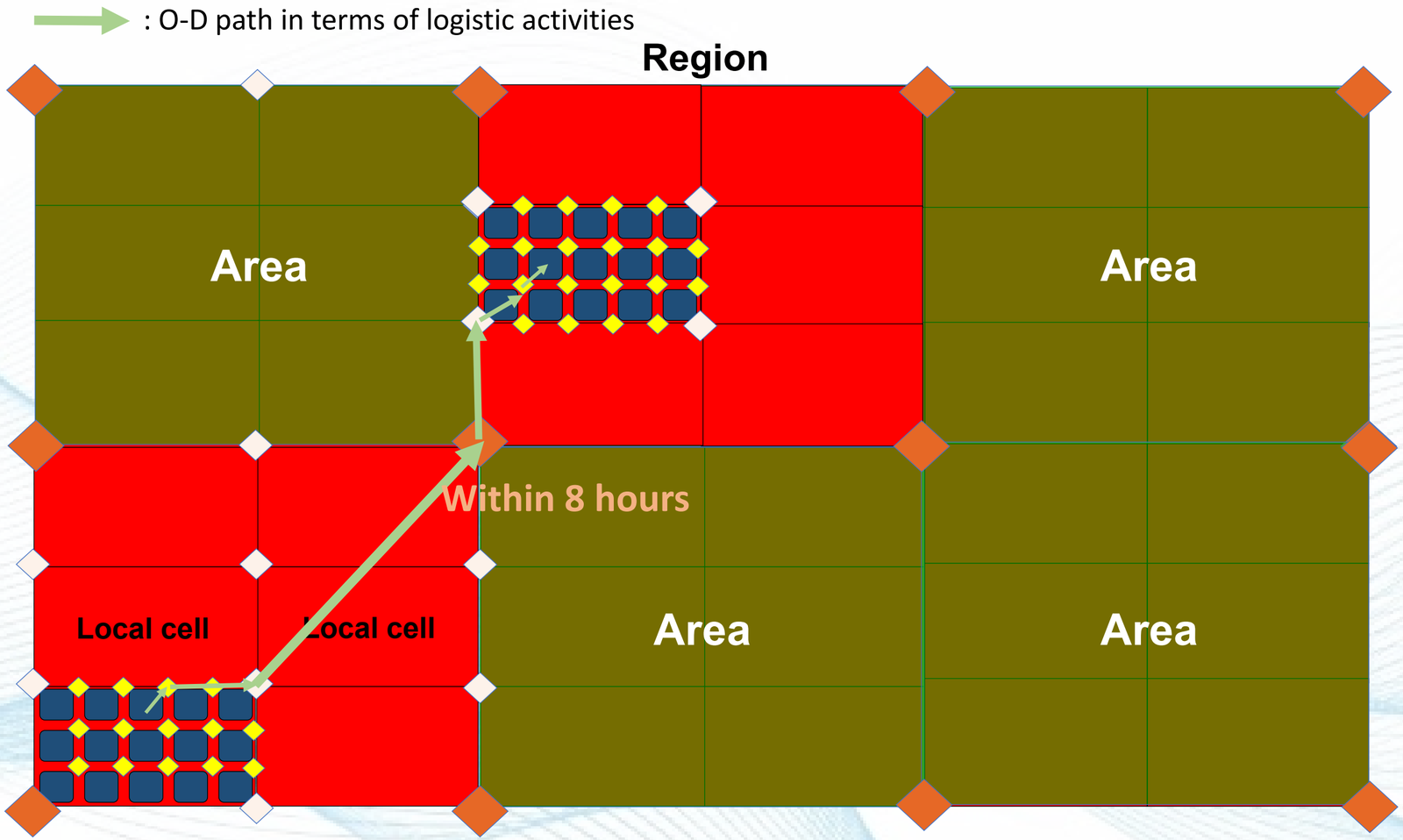


Set of logistic activities in each tier of hyperconnected multi-tier networks

- Movement of O-D commodities through multiple planes via a set of logistic activities
  - One path for each O-D commodity
- Robust O-D service guarantees
  - e.g., x-hour delivery from origin O to destination D at 99.9%

- **Robust time requirements (Service level agreement (SLA))** imposed on logistic activities
  - e.g., within 40 minutes for Area 1 transport activity at 99.9%
- Multiple SLA options for each logistic activity
  - More freedom for logistic service providers

SLA Options for Logistic Activities by Logistic Orchestrator



Example of the movement of O-D commodity

Going through 11 logistic activities

- 6 cluster transport and 5 hub operation activities

Many combinatorial choices

- Equally allocated
- Proportional to volume/distance
- …

⇒ Possibly too aggressive

⇒ High bid prices

Impact of SLA for activities on the overall cost

- Requiring approximation of the reaction of bidders (LSPs)

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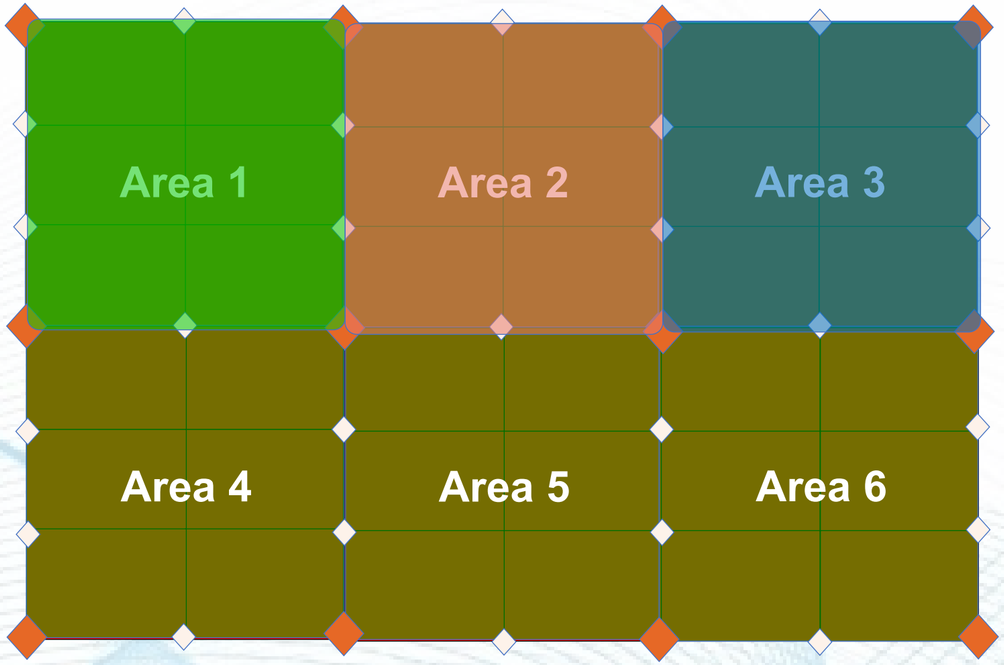
Bid Construction by Bidders (LSPs)

b_{ij}: Bidder i's bid j
p_{ij}: Bid price of bid j Bidder i
Format of bids: {Activity(ies), p_{ij}, SLA}

SLA options for cluster transport activities for Areas 1-6 = {40, 60, 90 mins}



Bidder 1

b_{11} : {Area 1, p_{11}, 40 mins}
b_{12} : {Area 2, p_{12}, 60 mins}
b_{13} : {Area 3, p_{13}, 90 mins}

Set of single bids

Bidder 2

b_{21} : { (Area 1, Area 2), p_{21}, {40 mins, 40 mins}}
b_{22} : { (Area 5, Area 6), p_{22}, {60 mins, 40 mins}}

Set of bundle bids → Economies of scope, Better resource utilization

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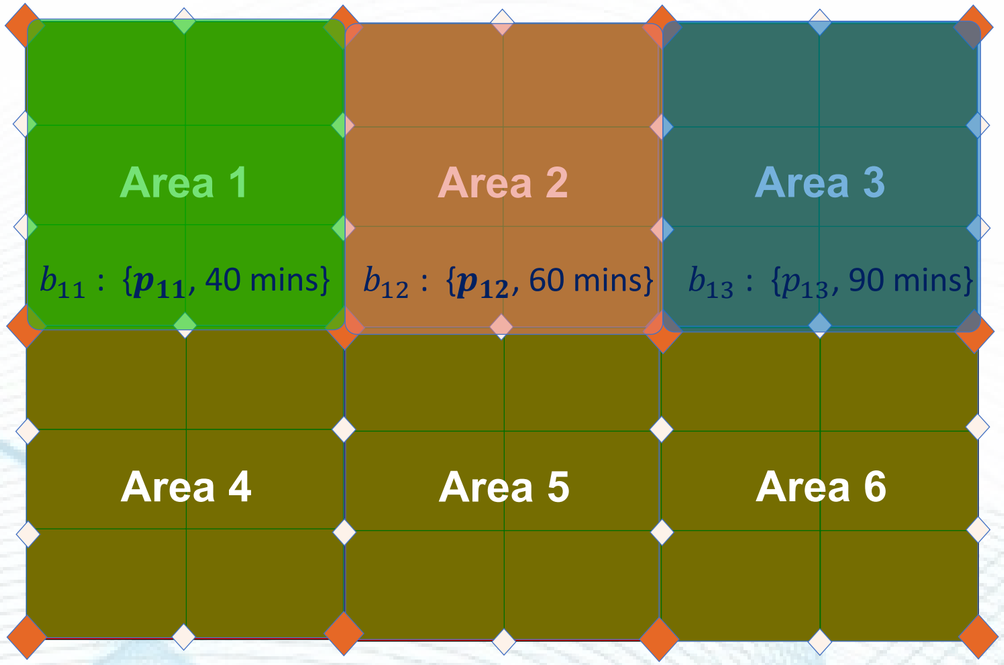
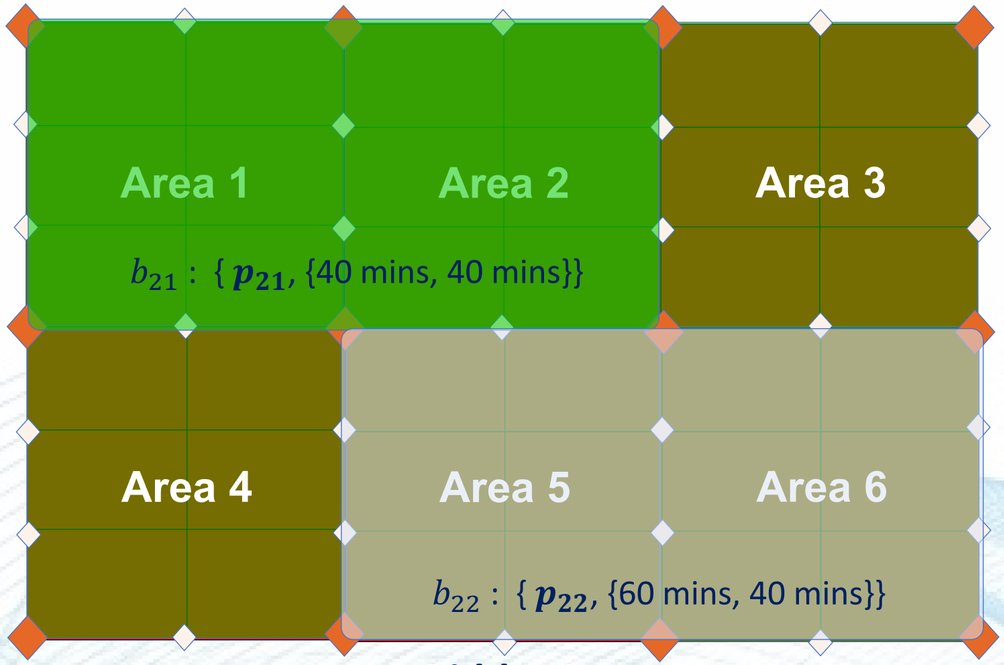
Bid Construction by Bidders (LSPs)

Submitted bids for Area transport activities by Bidders 1 and 2



Bidder 1

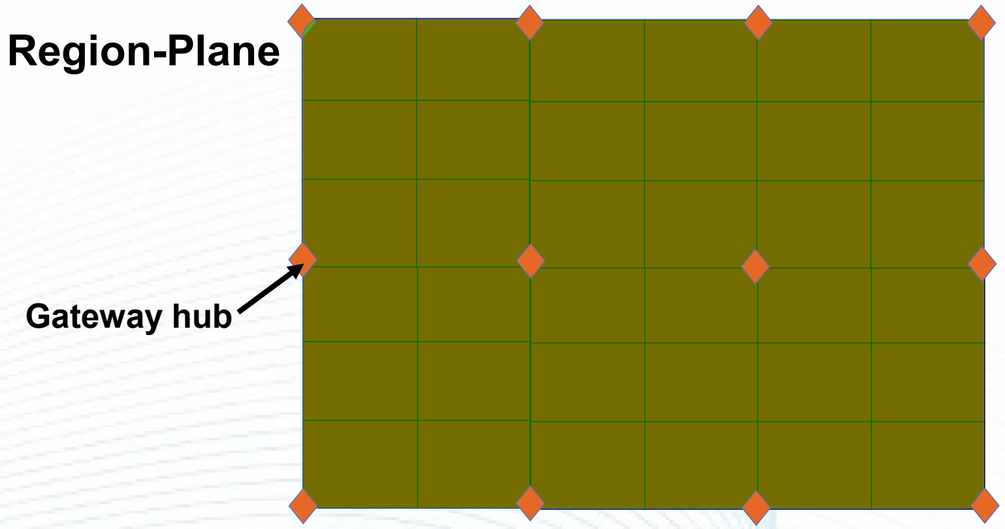


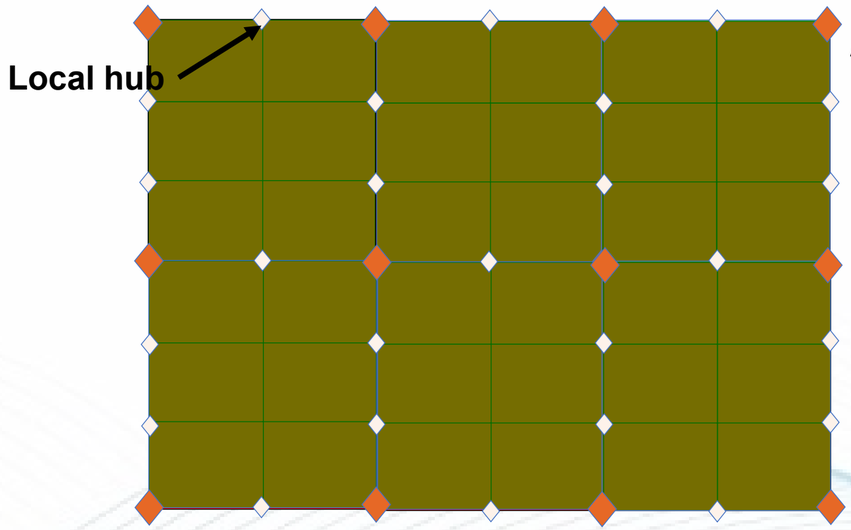
Bidder 2

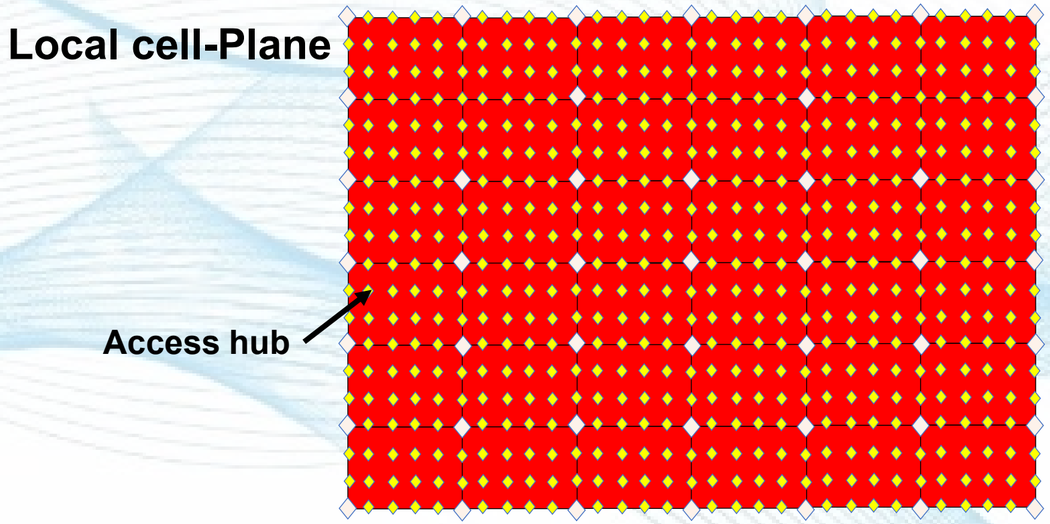
Bid Price (p) = Cost + Margin

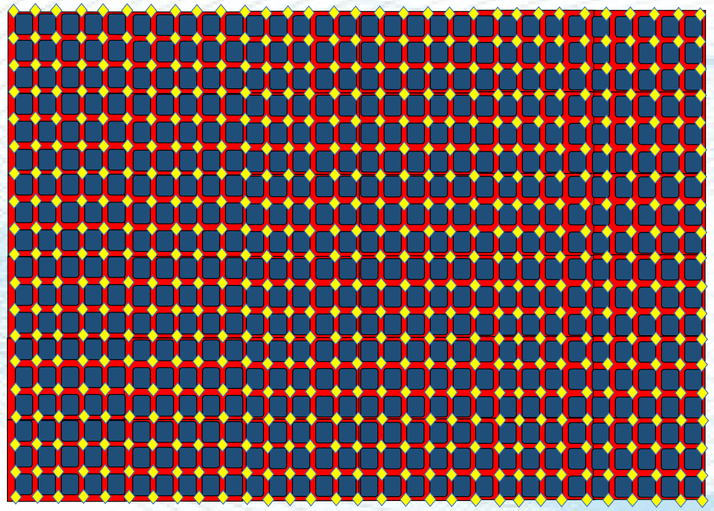
- Cost
  - Resource/Capacity
  - SLA
- Margin
  - Competition
  - Willingness to pay

Bid-to-Activity Allocation



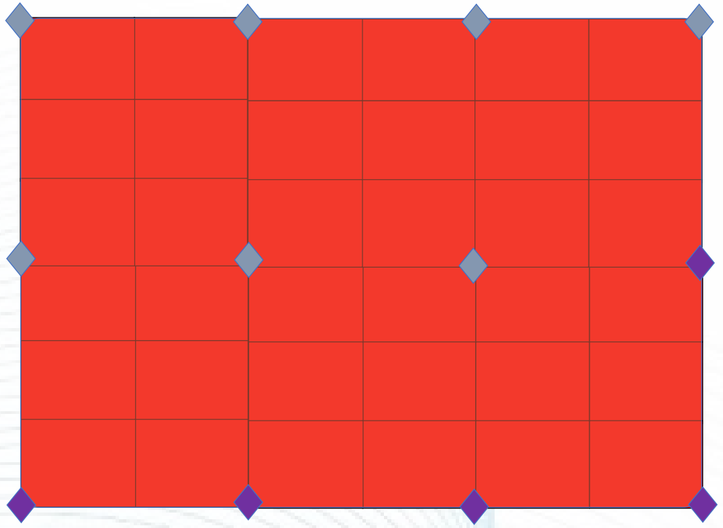


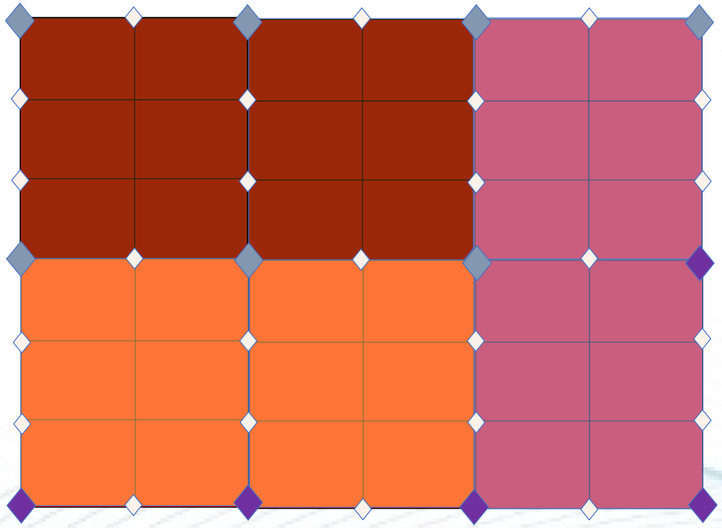




Bid-to-Activity Allocation ⇒ Optimized Service Network

Region-Plane

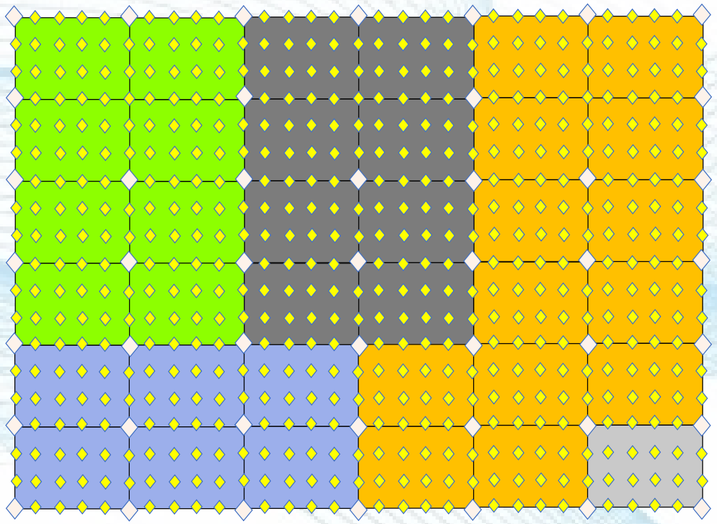


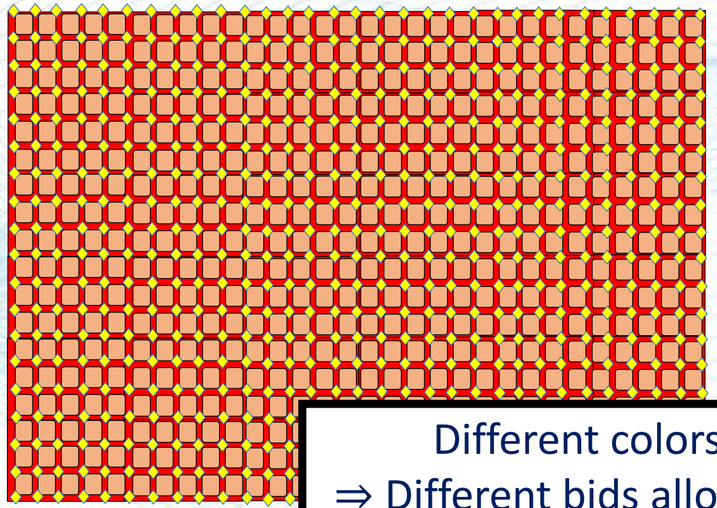


Area-Plane

Case where all local hubs are allocated to one LSP (one bundle bid)

Local cell-Plane





Unit zone-Plane

Case where all unit zone transport activities and access hub activities are allocated to one LSP (one bundle bid), respectively

Different colors
⇒ Different bids allocated

Research Questions/Avenues

We consider a **first-price sealed-bid reverse combinatorial auction** in which **the logistic orchestrator** allocates each logistic activity to some specific **bidder** such that **the O-D service guarantees are robustly guaranteed** while minimizing cost

1st Phase by Logistic Orchestrator

- Pre-auction stage
  - Bid definition/requirements
  - Network/Logistic activity Information
- **Service Level Agreement Offer Problem (SLAOP)**
- How to **determine a set of Service Level Agreement (SLA) options for each logistic activity**

2nd Phase by Bidders

- **Bid Construction Problem (BCP)**
- **Which bids to submit** when – under the uncertainty of other bidders' decisions and orchestrator's final decisions?
  - Profit Maximization

3rd Phase by Logistic Orchestrator

- **Winner Determination Problem (WDP)**
- **How to determine winning bids** for each logistic activity and **which SLA to assign** each logistic activity
  - Robust O-D service guarantees
  - Cost Minimization

Summary

Contributions:

- New notion of the service network design problem in line with Physical Internet initiatives
- Three-phased bidding-based design framework

Next steps:

- Optimization, Simulation, and Game theoretic techniques for each Phase
  - Approximation of reaction of other players
  - Capturing competition and uncertainty
  - Robust O-D service guarantees

Thank you!

Questions: skwon82@gatech.edu