Using auctions to allocate parcel logistic services in Hyperconnected city logistics

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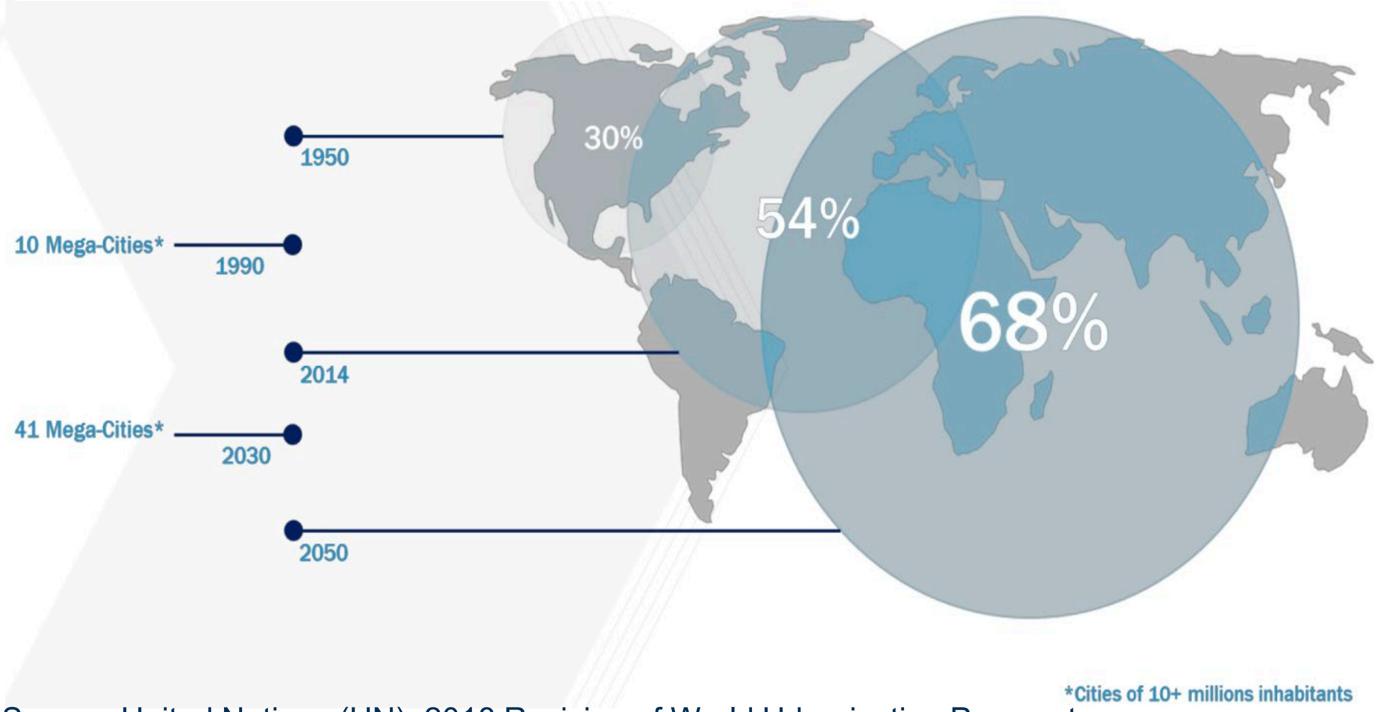
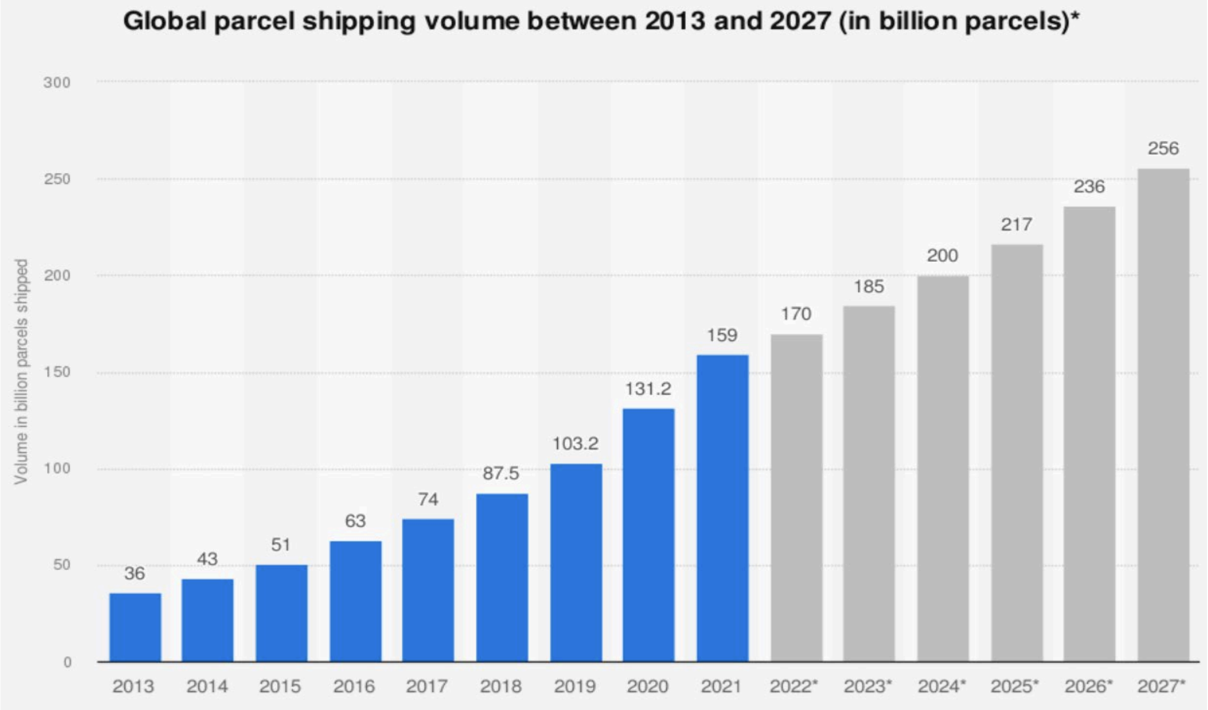
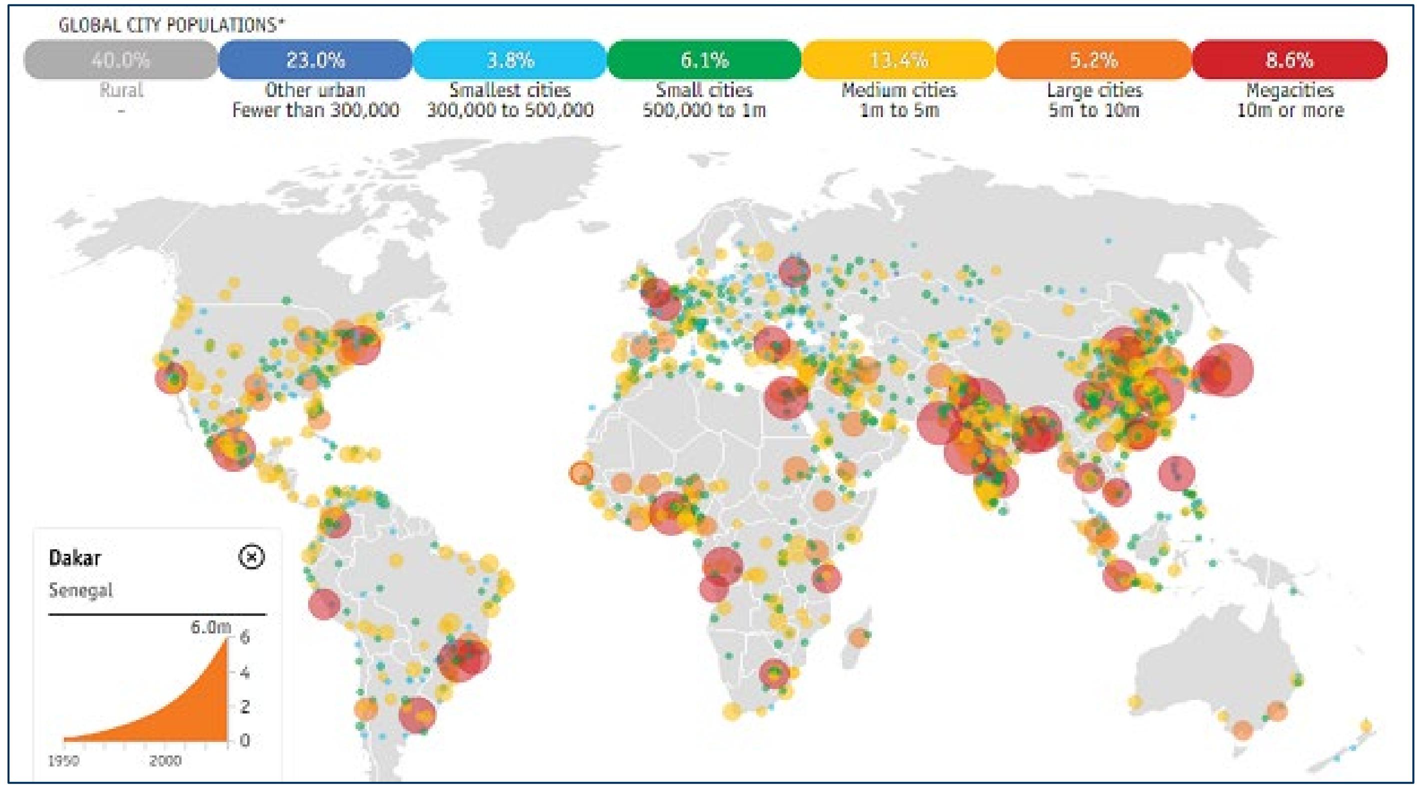
Problem Motivation: Challenges in Urban Cities

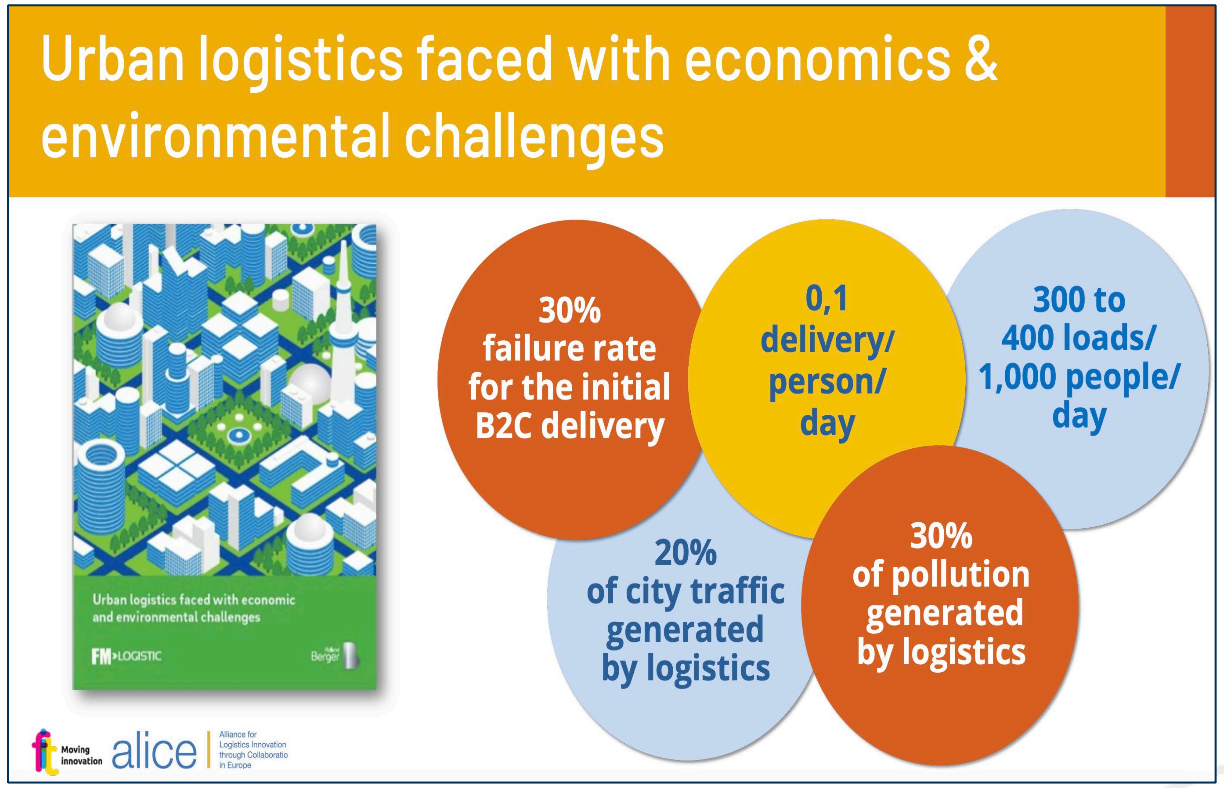


Source: United Nations (UN), 2018 Revision of World Urbanization Prospects

Source: Statista (Sep 2022)



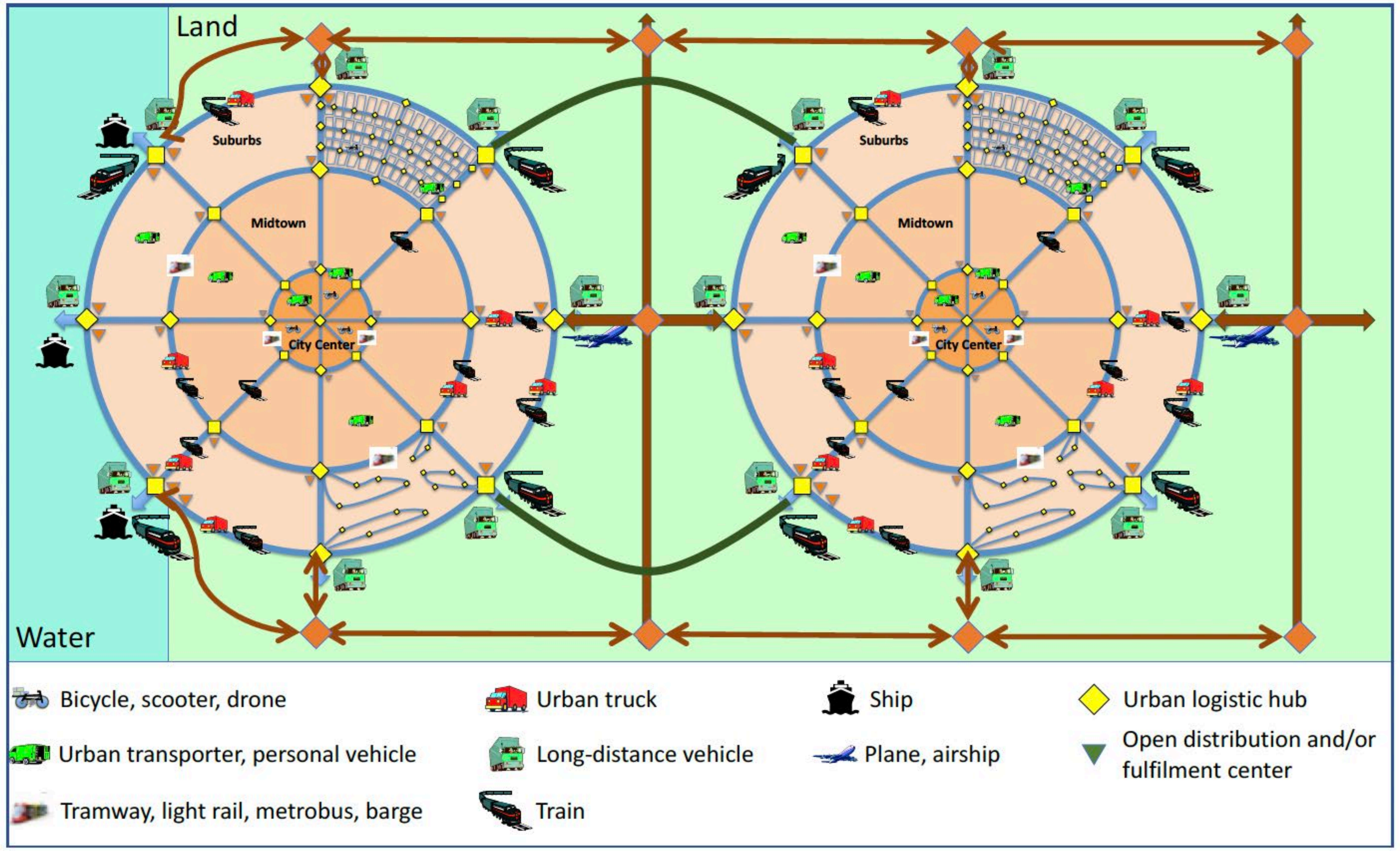




Hyperconnected City Logistics

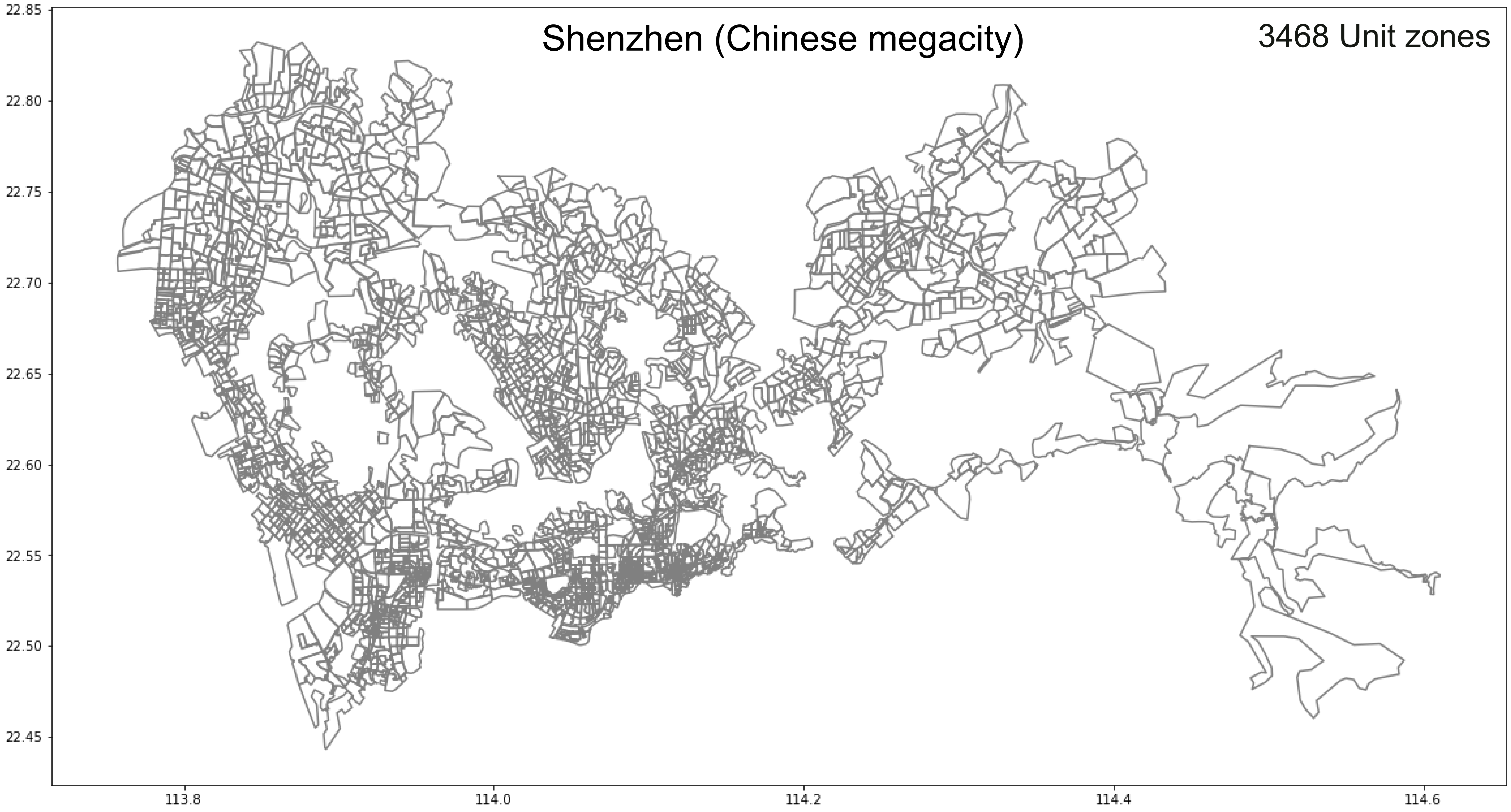
Interconnect:

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



Source: Hyperconnected city logistics: a conceptual framework (Crainic, Klibi, Montreuil '23)

Hyperconnected Urban Logistic Network



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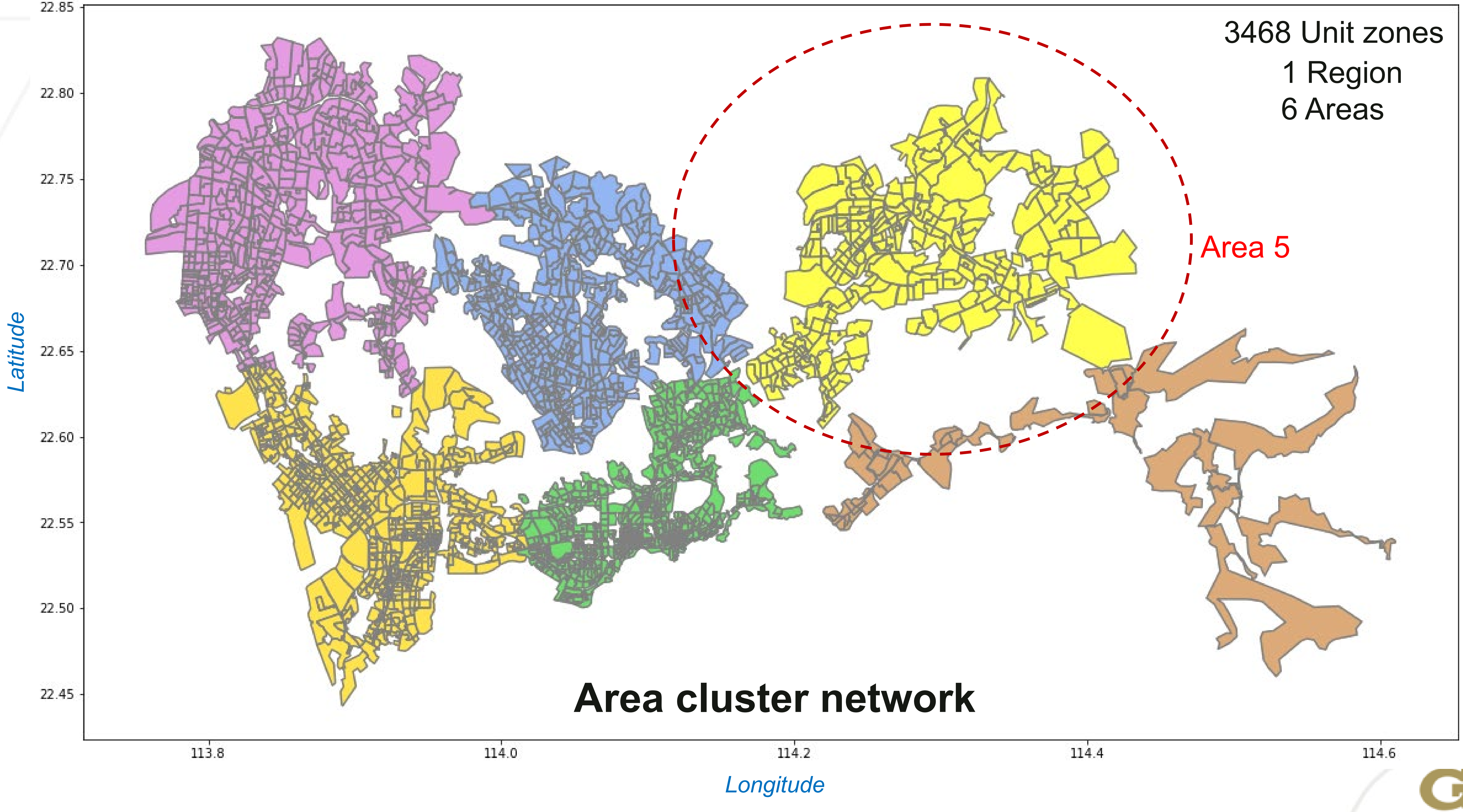
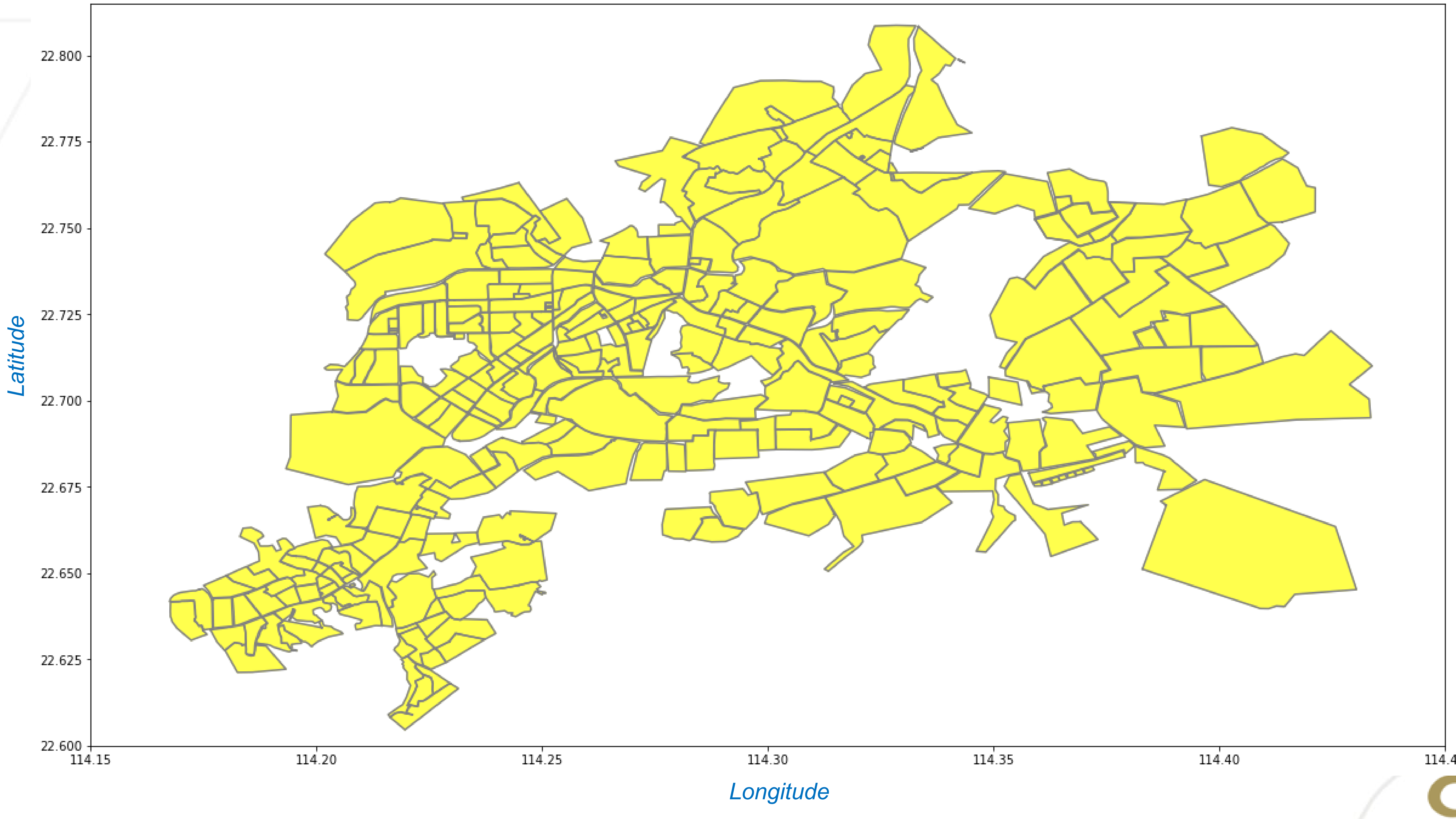
Hyperconnected Urban Logistic Network



Area cluster network

Hyperconnected Urban Logistic Network



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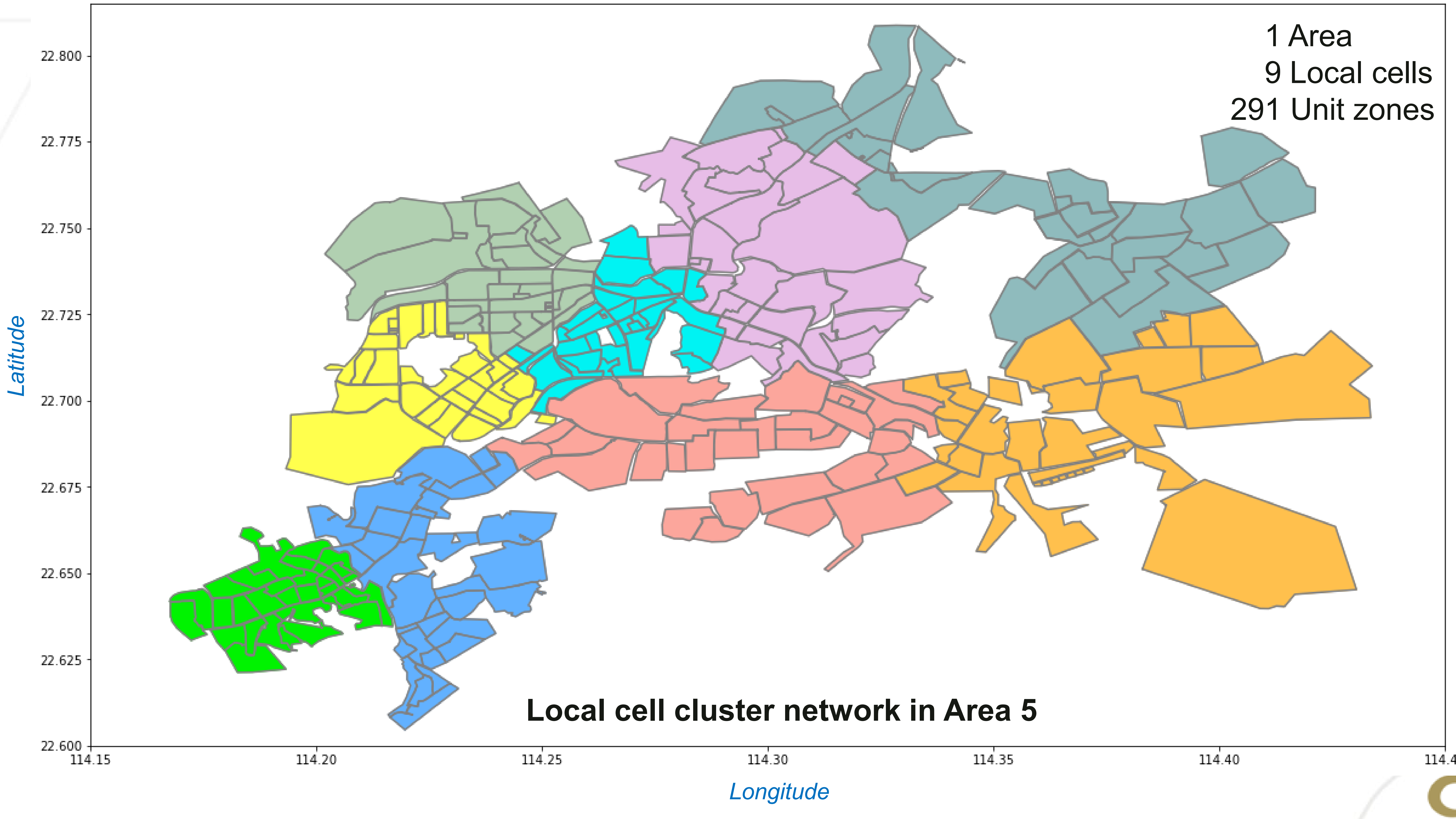
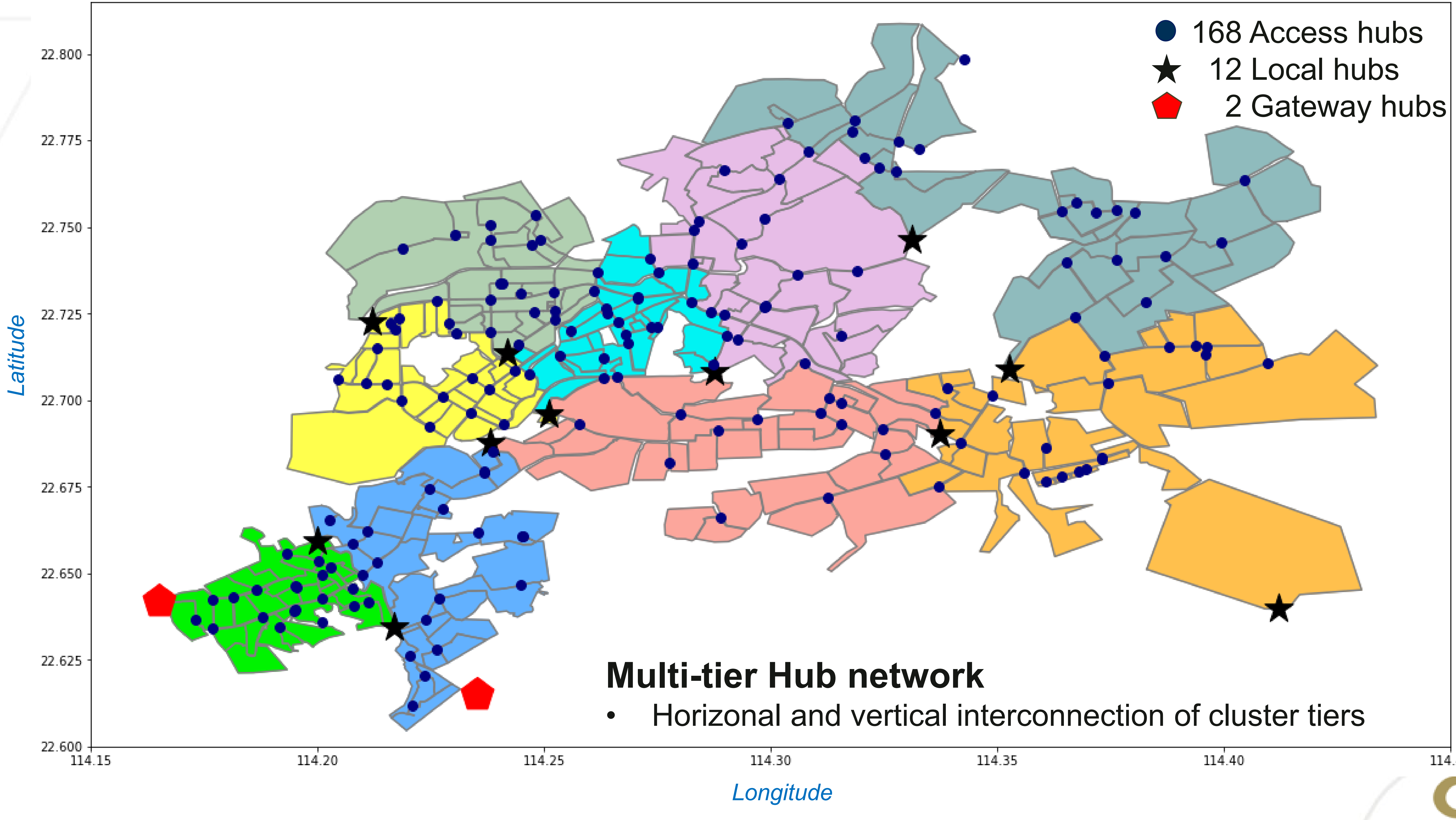
Hyperconnected Urban Logistic Network



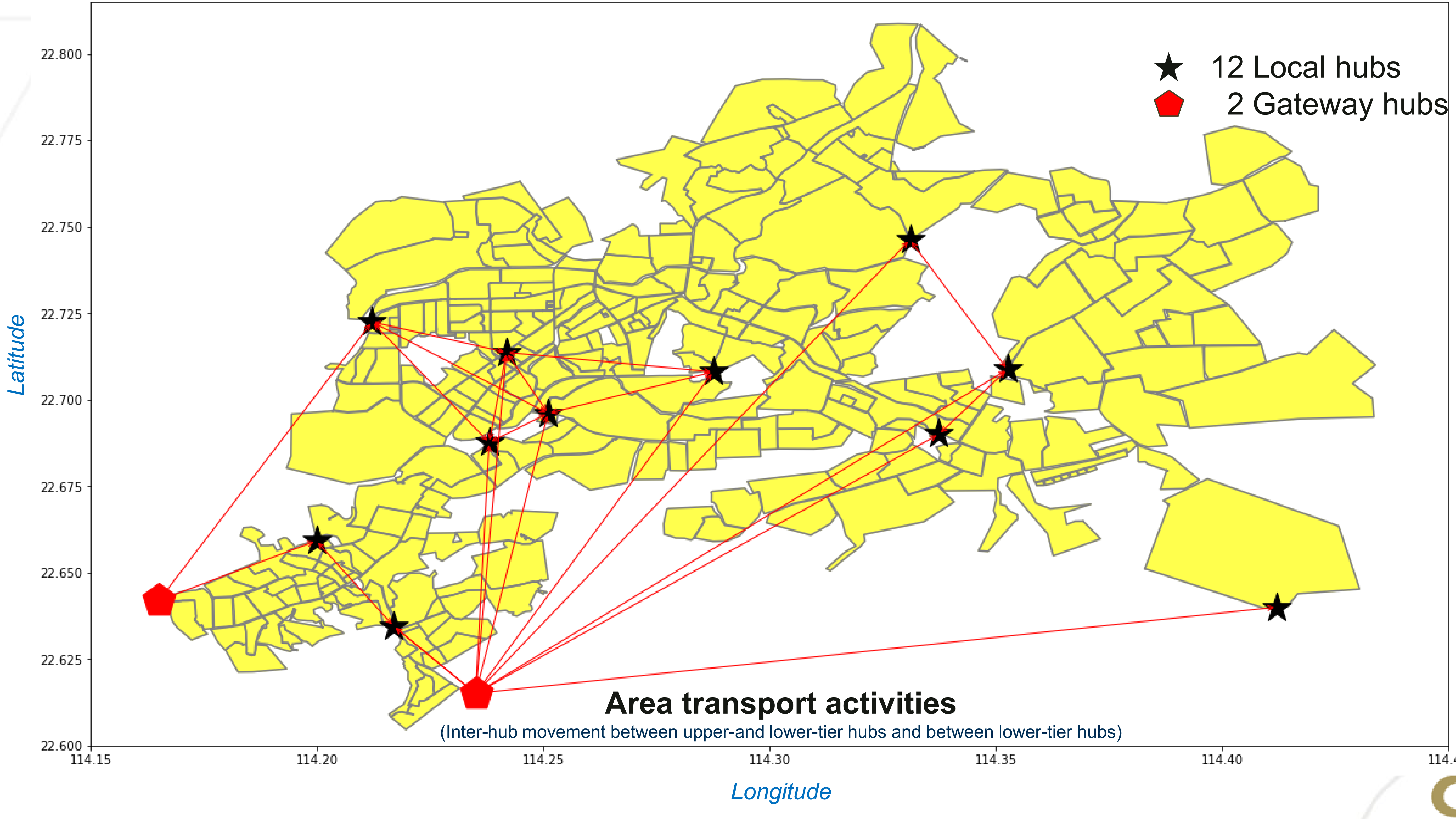
Hyperconnected Urban Logistic Network



Multi-tier Hub network

- Horizonal and vertical interconnection of cluster tiers

Hyperconnected Urban Logistic Network



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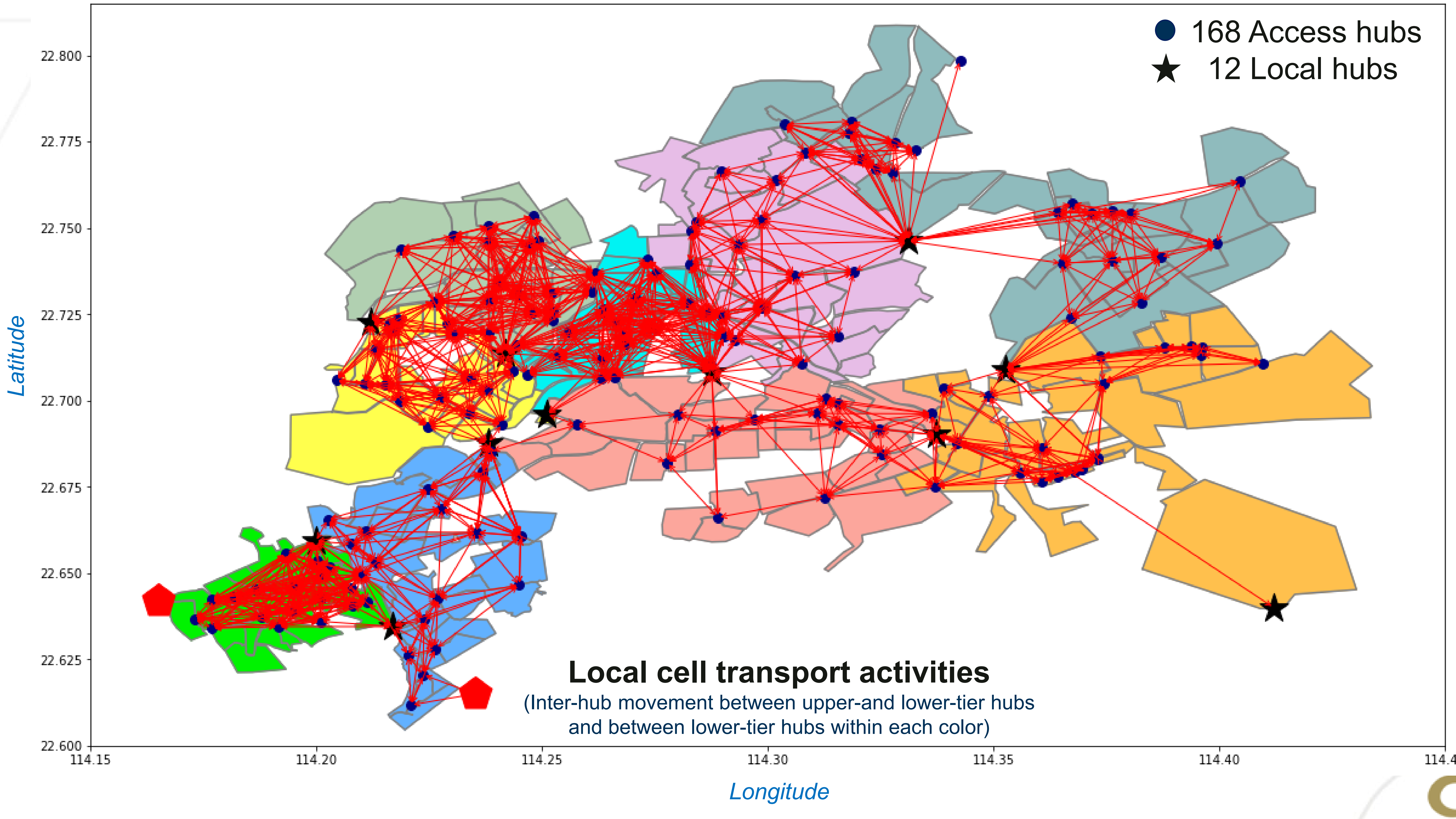
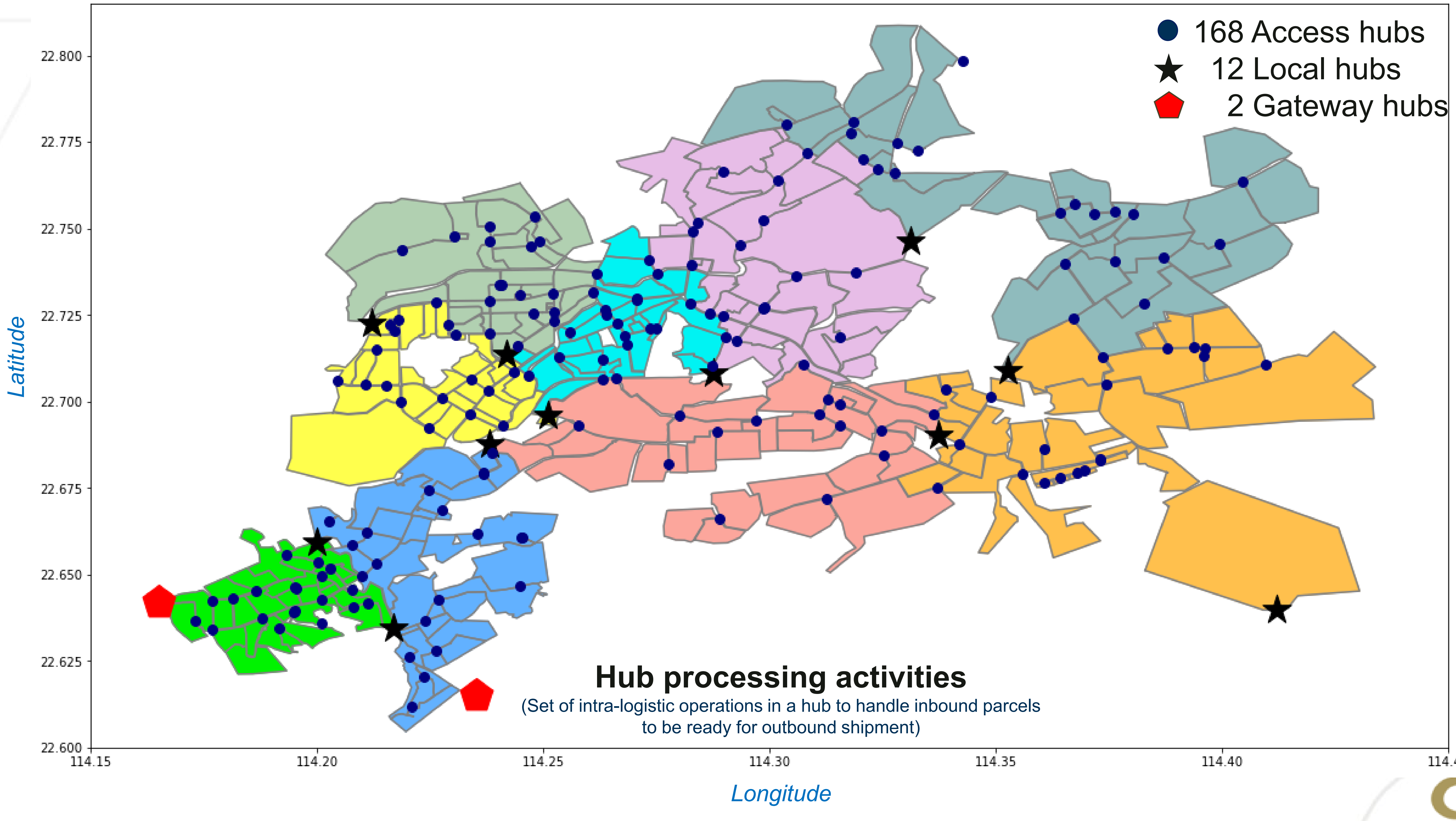
Hyperconnected Urban Logistic Network



Hyperconnected Urban Logistic Network



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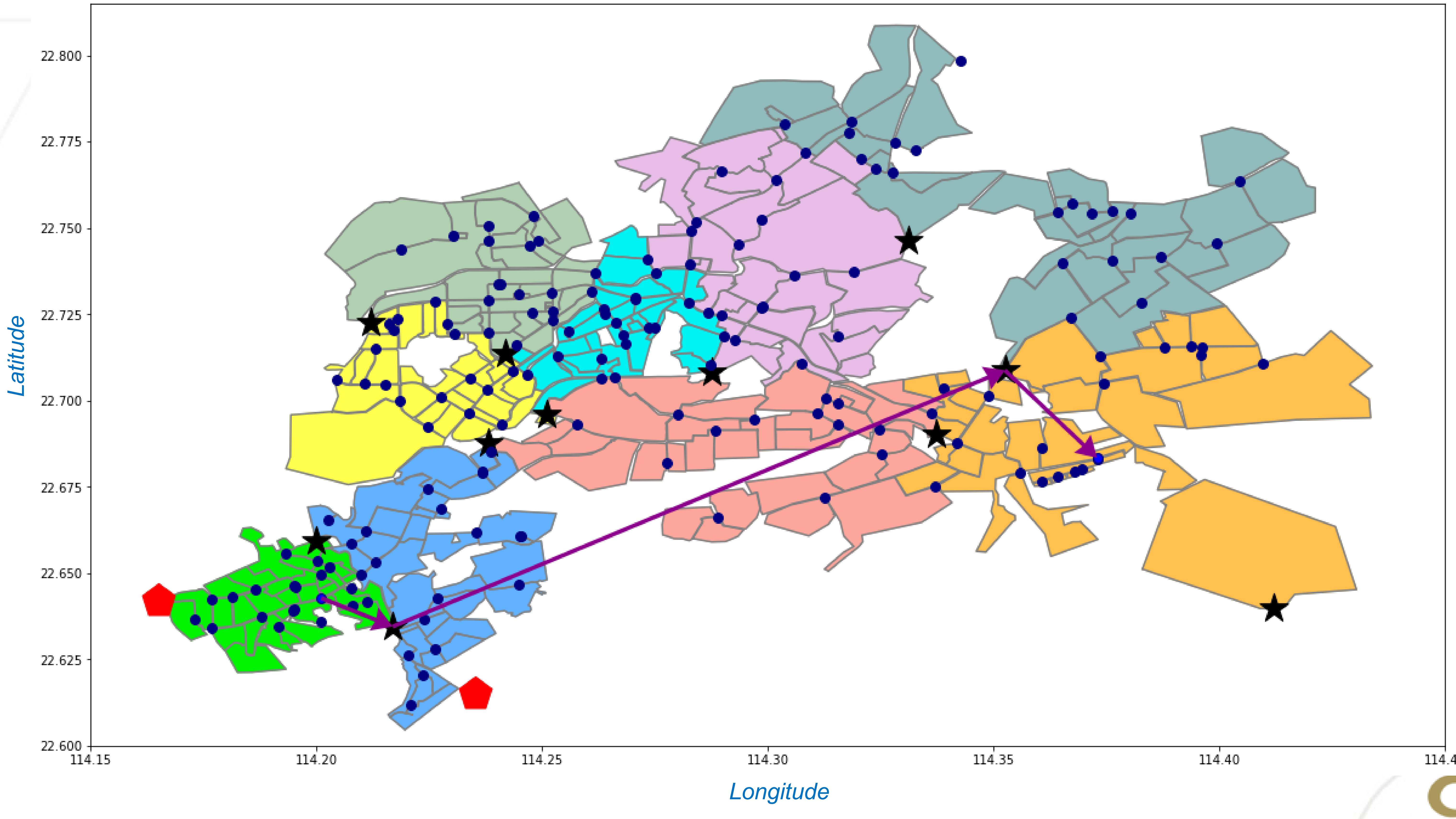
Hyperconnected Urban Logistic Network



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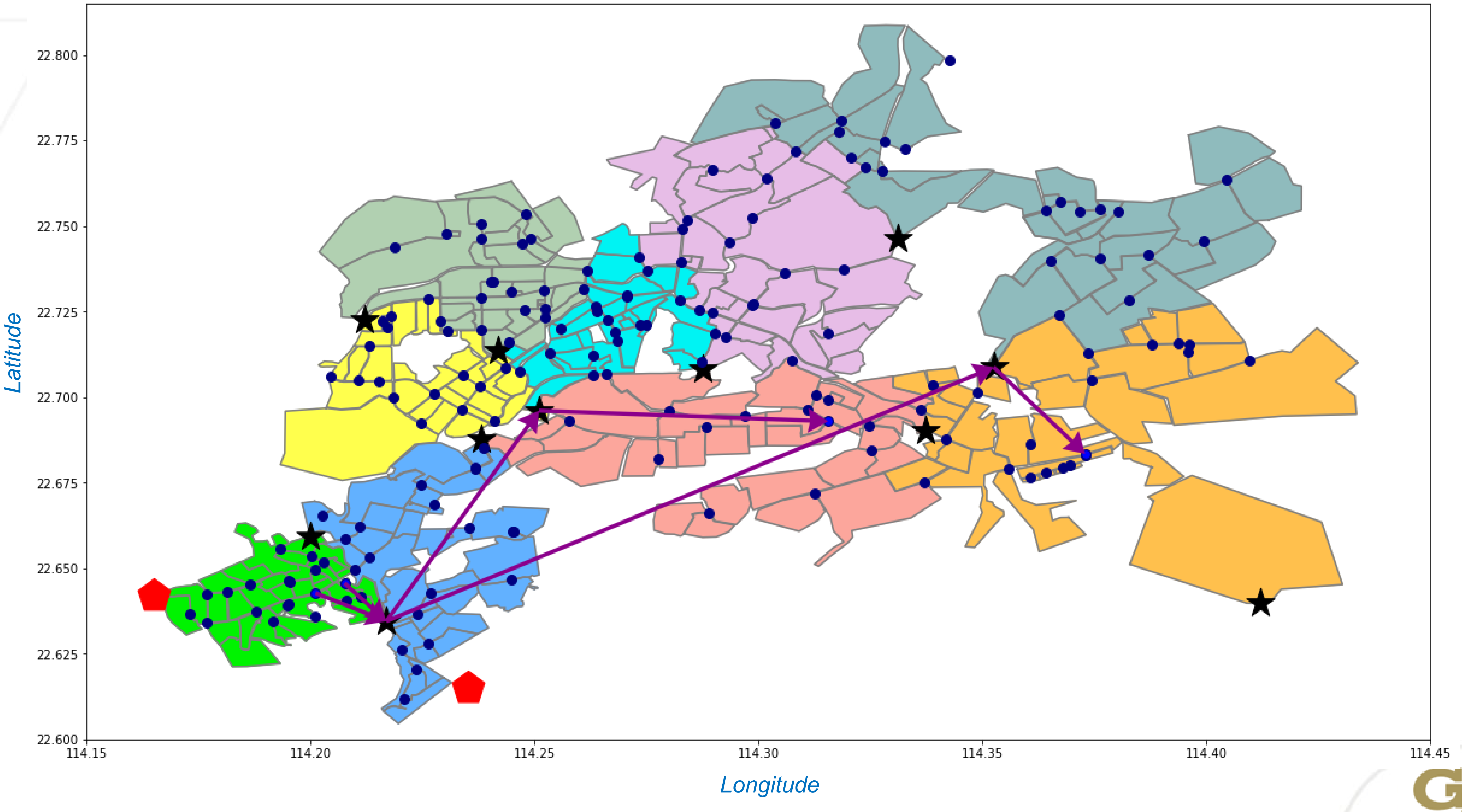

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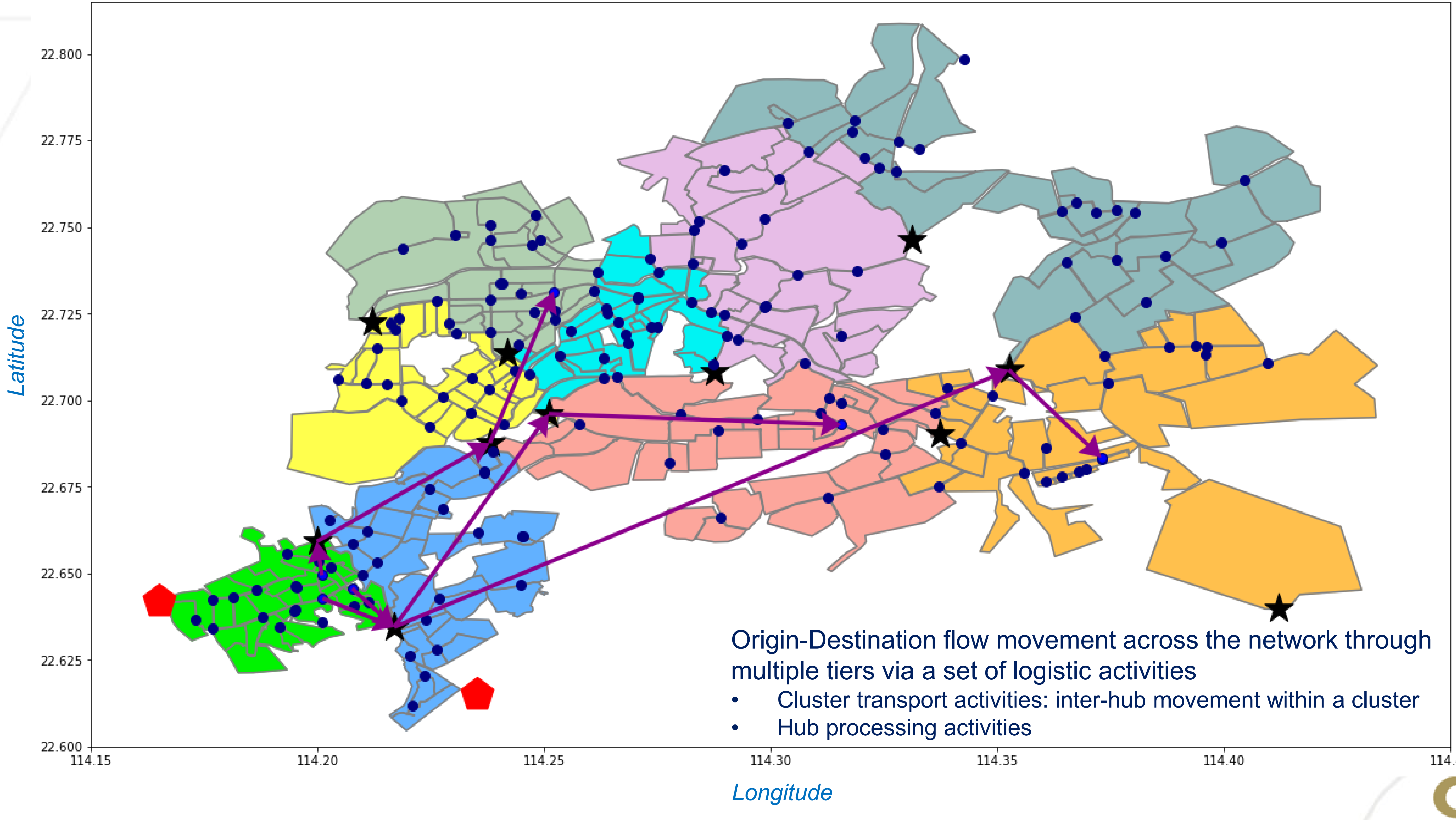
Hyperconnected Urban Logistic Network



Origin-Destination flow movement across the network through multiple tiers via a set of logistic activities

- Cluster transport activities: inter-hub movement within a cluster
- Hub processing activities

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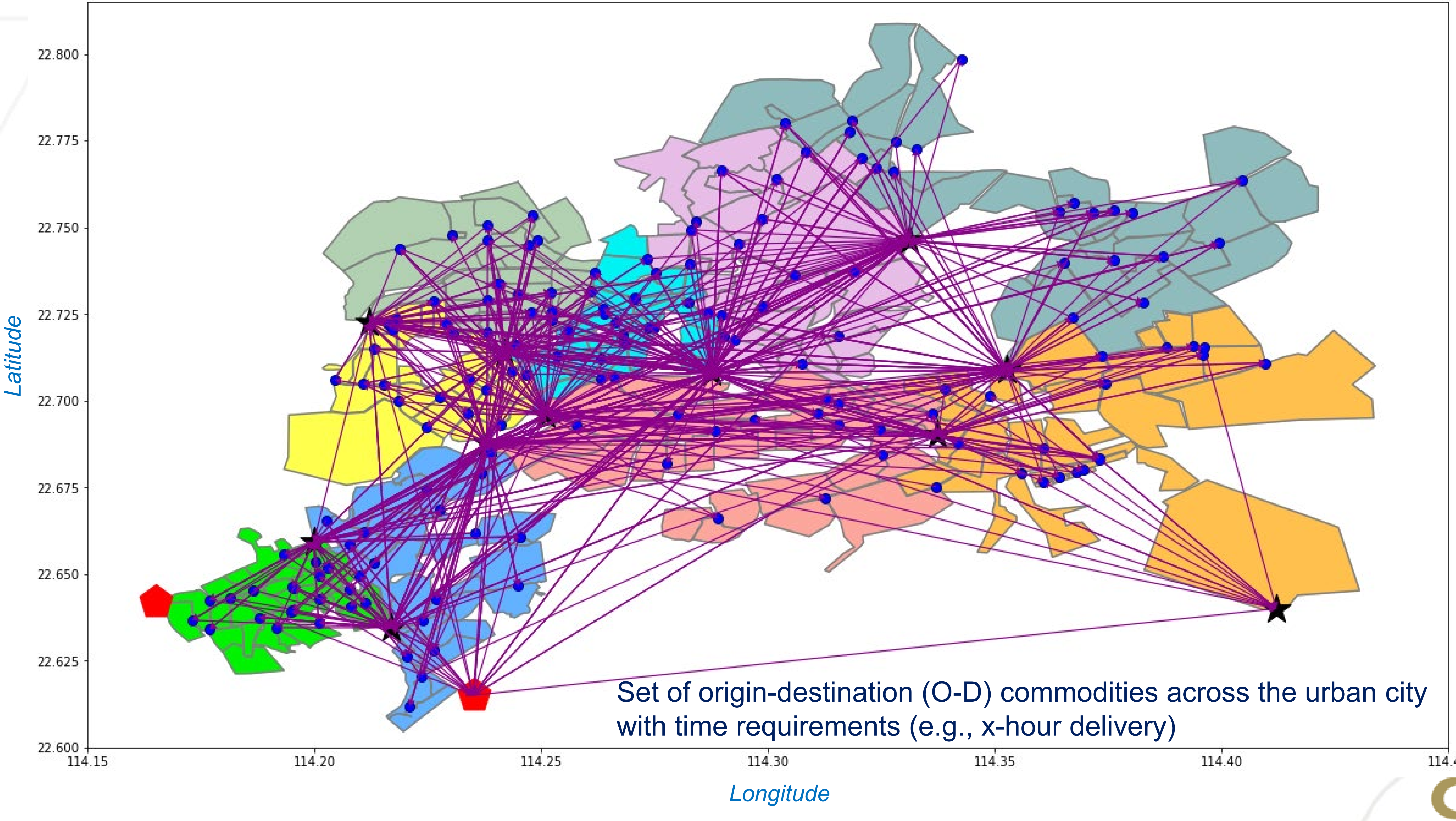
Hyperconnected Urban Logistic Network



Set of origin-destination (O-D) commodities across the urban city with time requirements (e.g., x-hour delivery)

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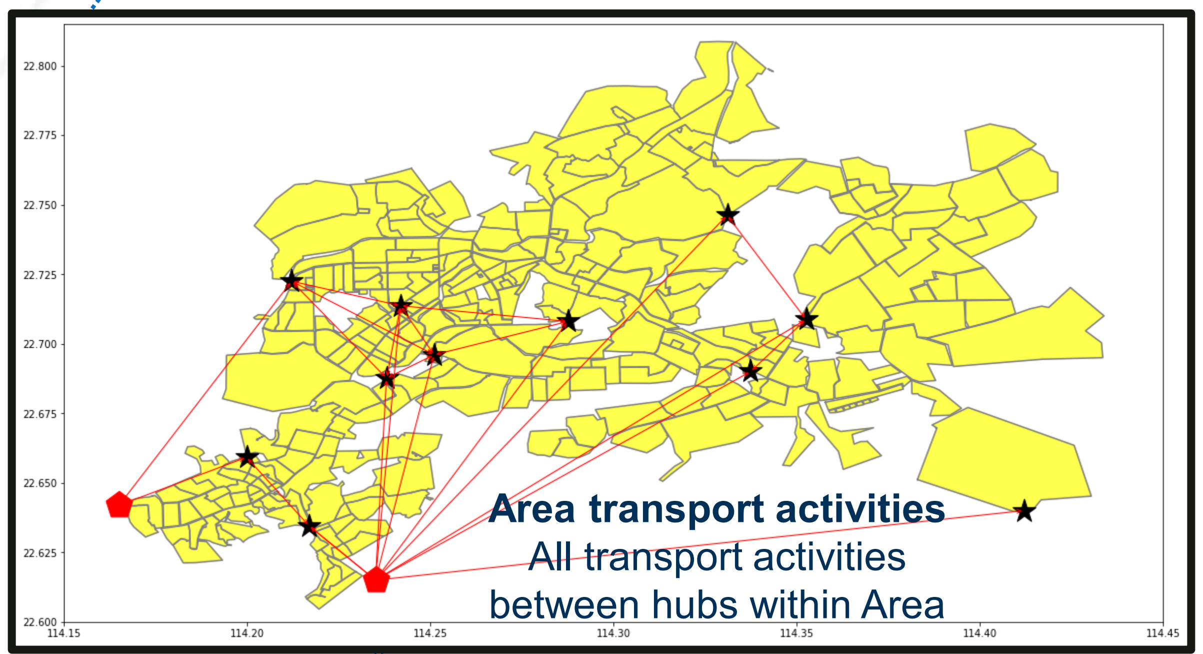
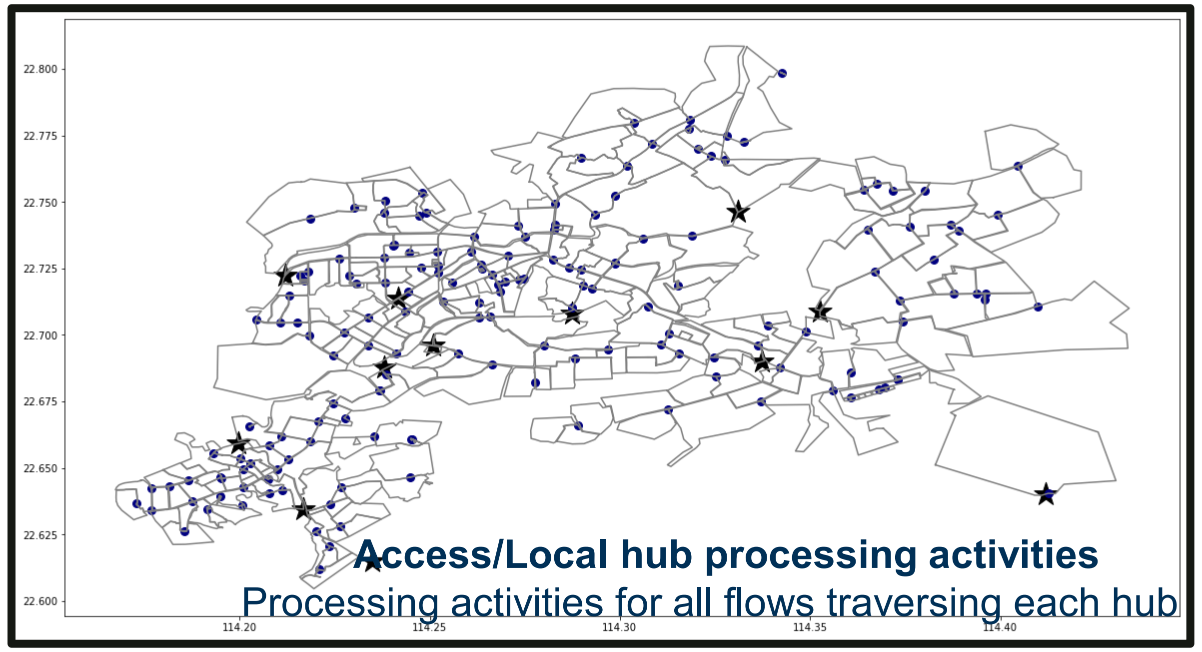
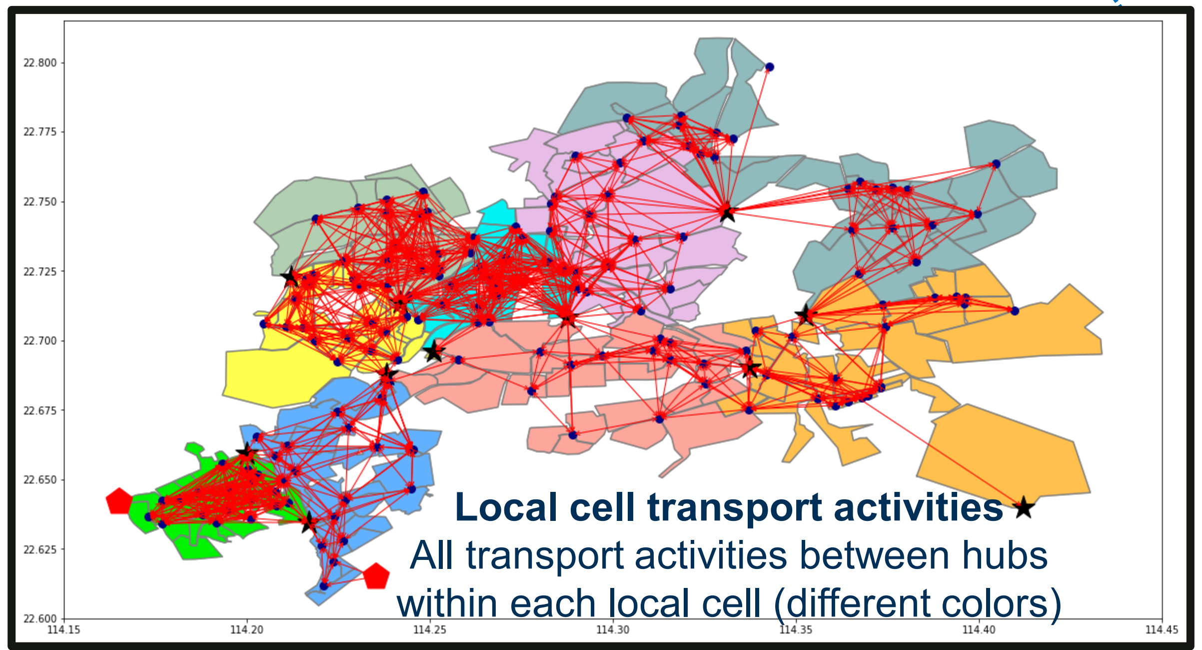
Logistic Orchestrator and Service Level Agreement

Urban Logistic Orchestrator

- Serving citywide O-D demand, ***robustly*** ensuring time service guarantees (e.g., 99.9% O-D service guarantees)
  - Predetermined O-D path in terms of logistic activities
- **Multi-party service network** by outsourcing each logistic activity through term contracts
- **Reliable Service Level Agreement (SLA)** for each activity
  - Reliable time requirements imposed (e.g., within 40 minutes for Area transport activity at 99.9%)







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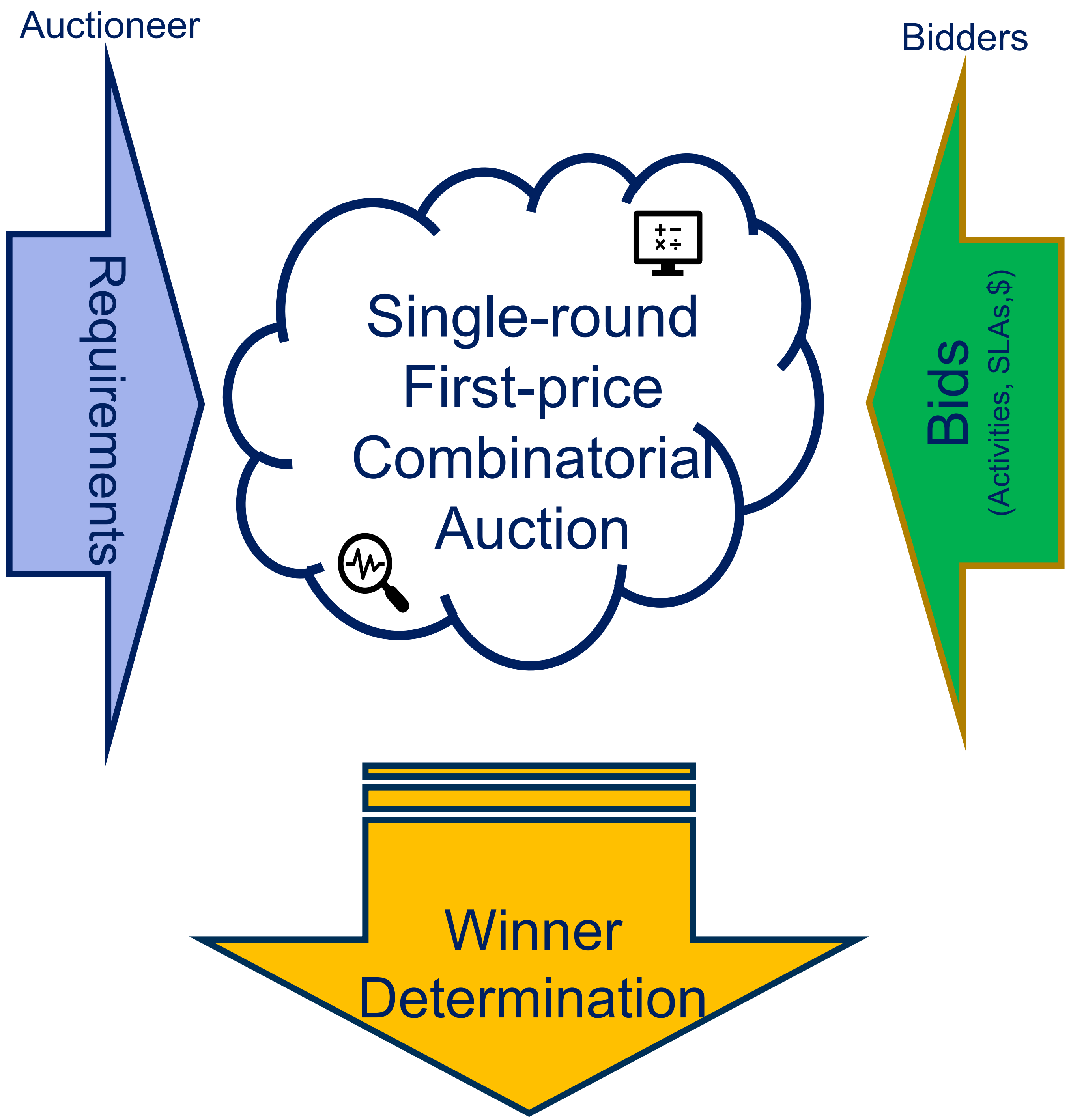
Combinatorial Auction for Logistic Activity Allocation

Logistic Orchestrator

- Hyperconnected multi-tier networks
  - O-D service guarantees (e.g., x-hour delivery)
- Auction/Bid requirements
  - **Demand patterns** for each logistic activity
  - **Multiple service level agreement (SLA) options** for each logistic activity
- Multi-party coordination/orchestration via a **combinatorial auction**
  - **Allocation of logistic activities to LSPs**
  - Profit maximization for the allocation process

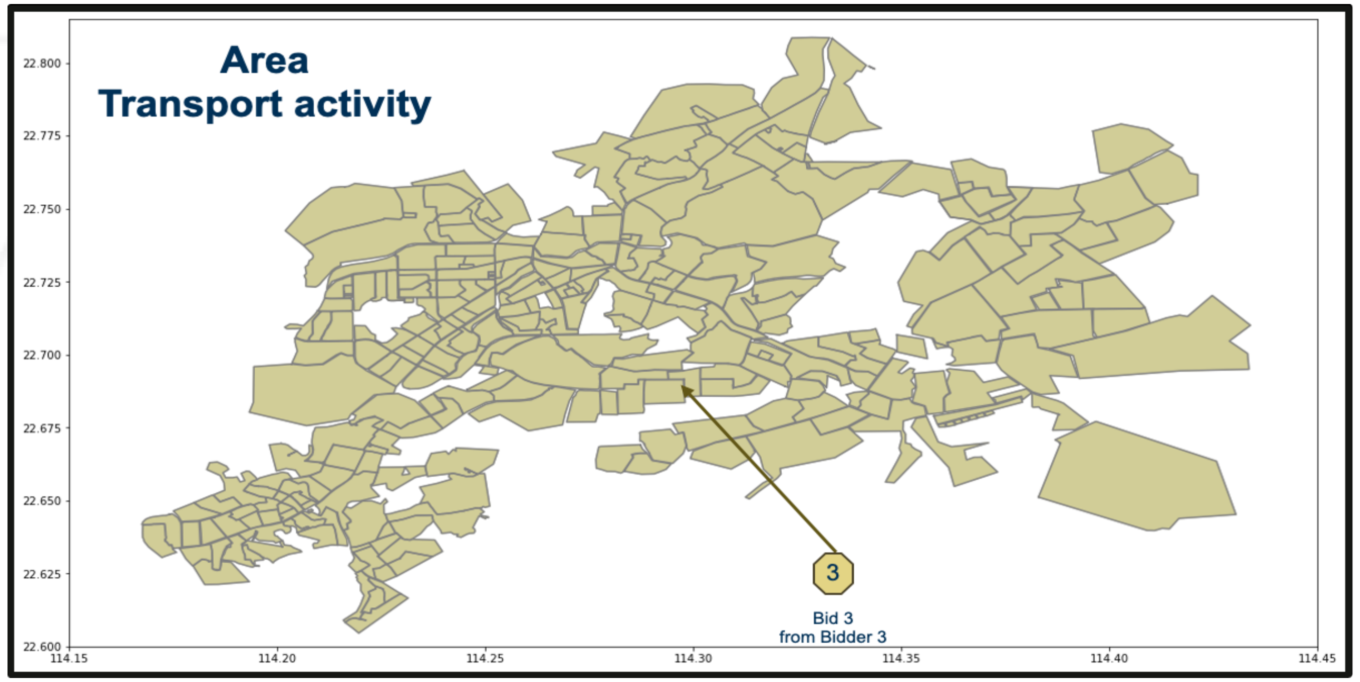


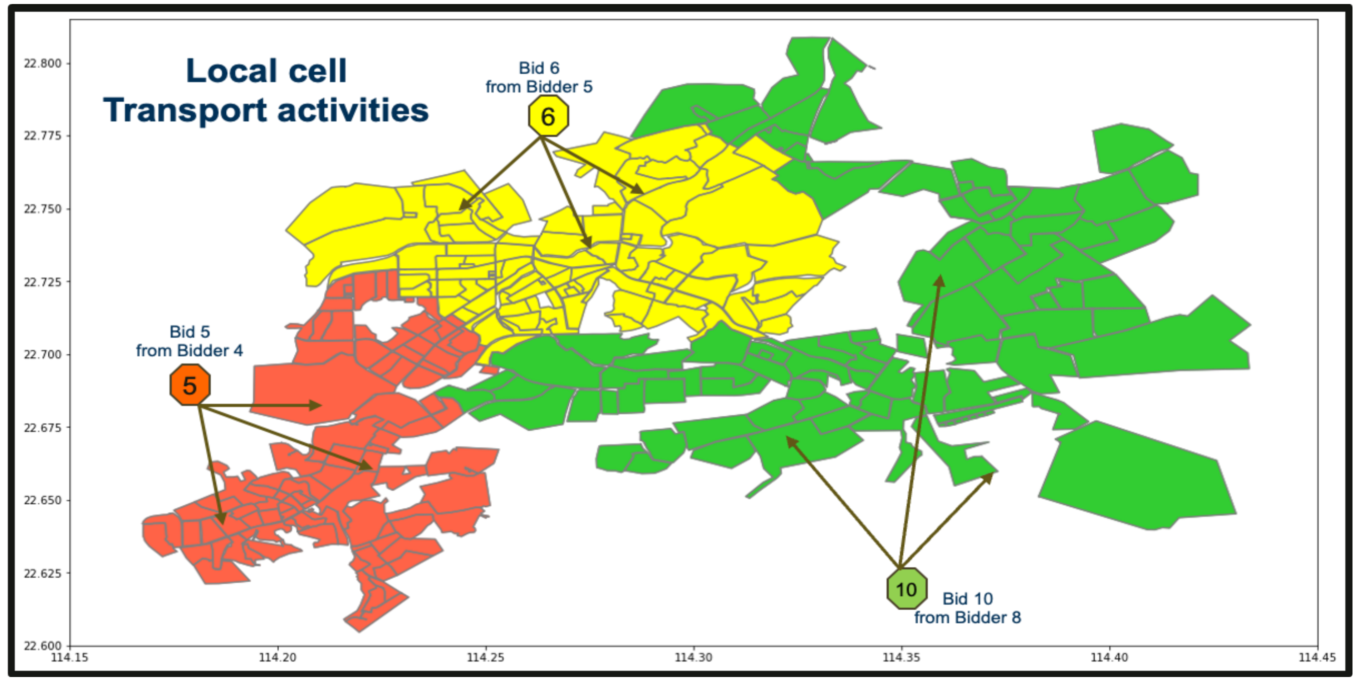
Logistic Service Providers (LSP)

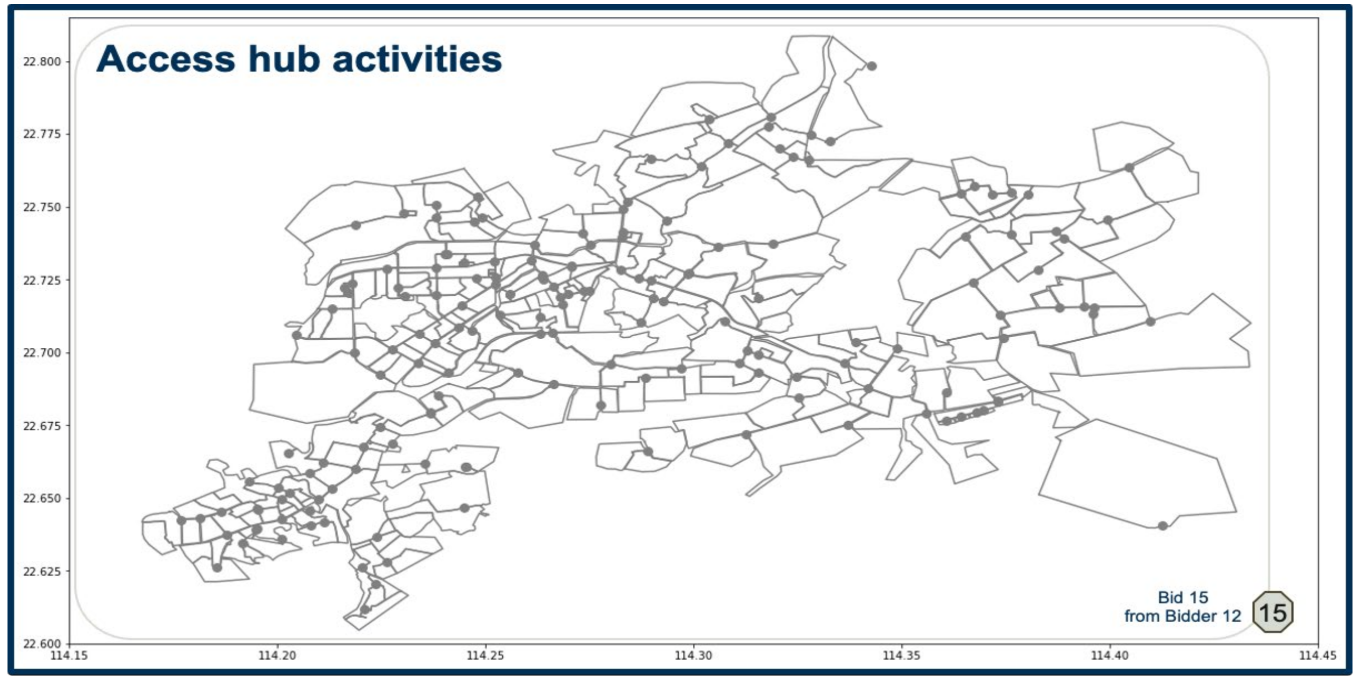
- Providing logistic services (transport/hub operation services)
- Participating in the auction by **submitting bids** for logistic activities and SLAs with bid prices
  - **Respecting auction and bid requirements (service level agreement for activities)**
  - Profit maximization

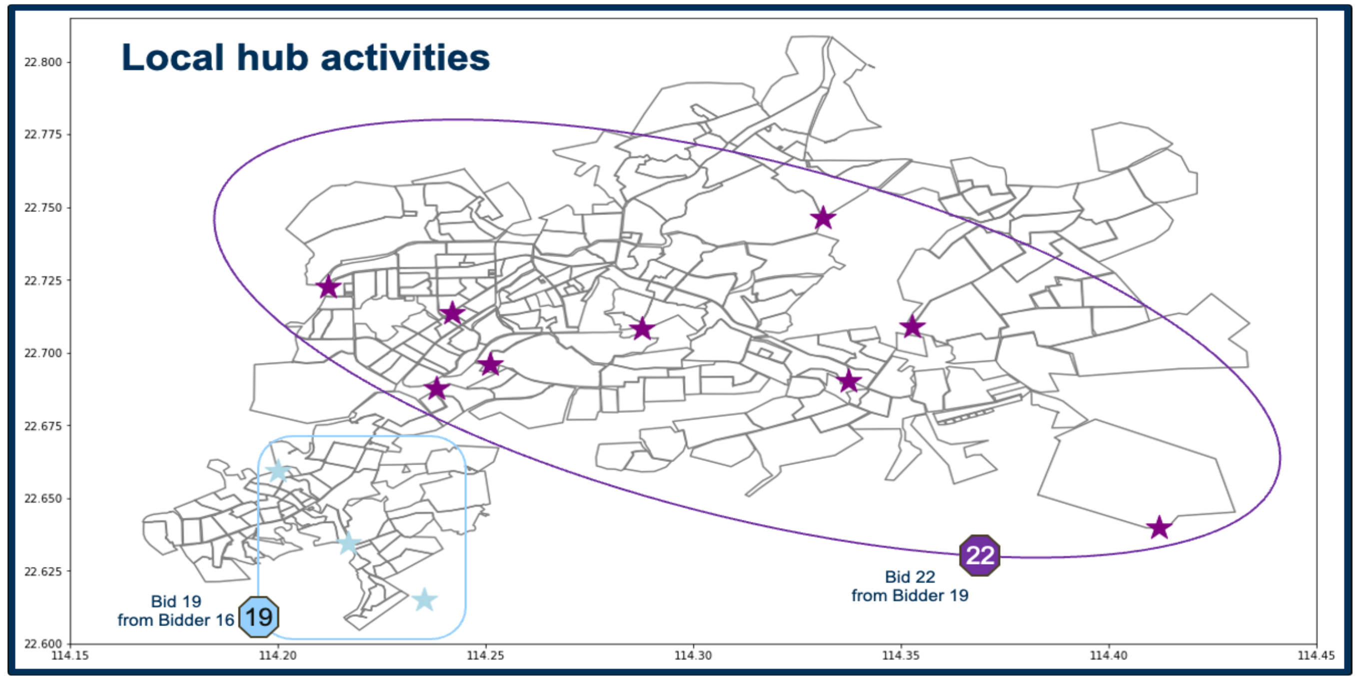
Optimized Multi-Party Service Network

Winner Determination Problem (WDP)







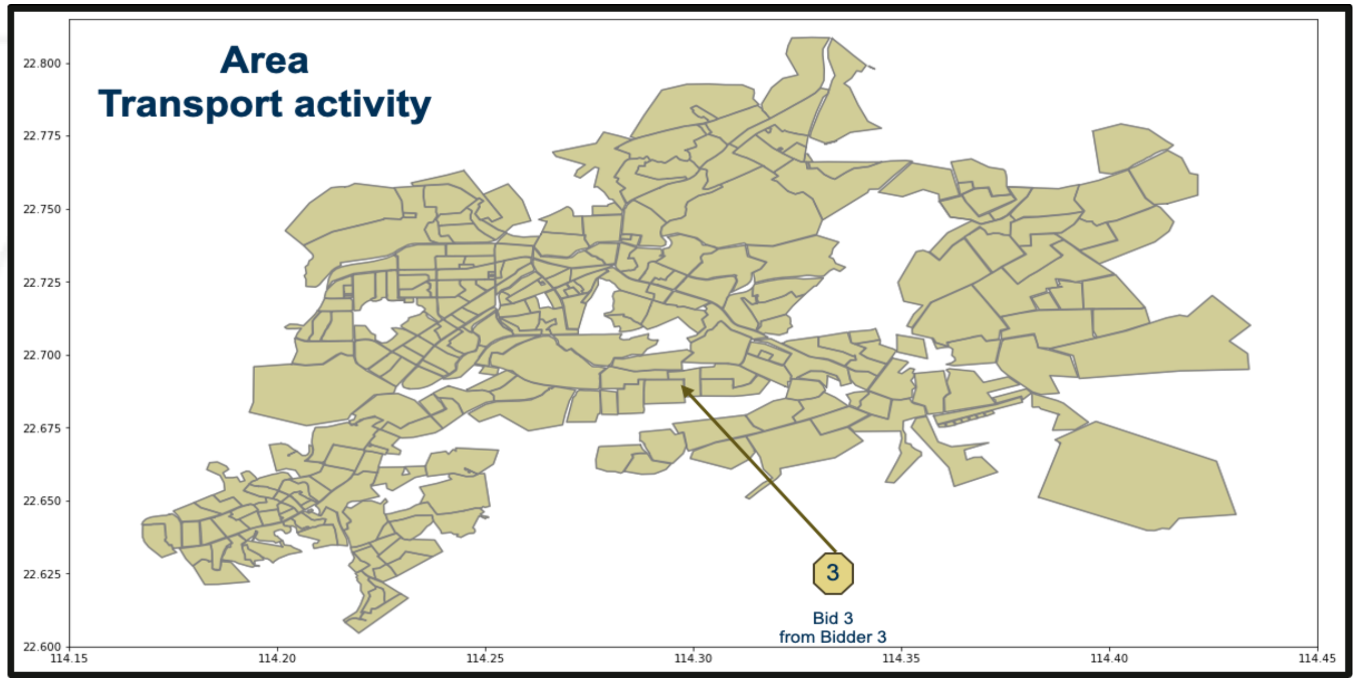


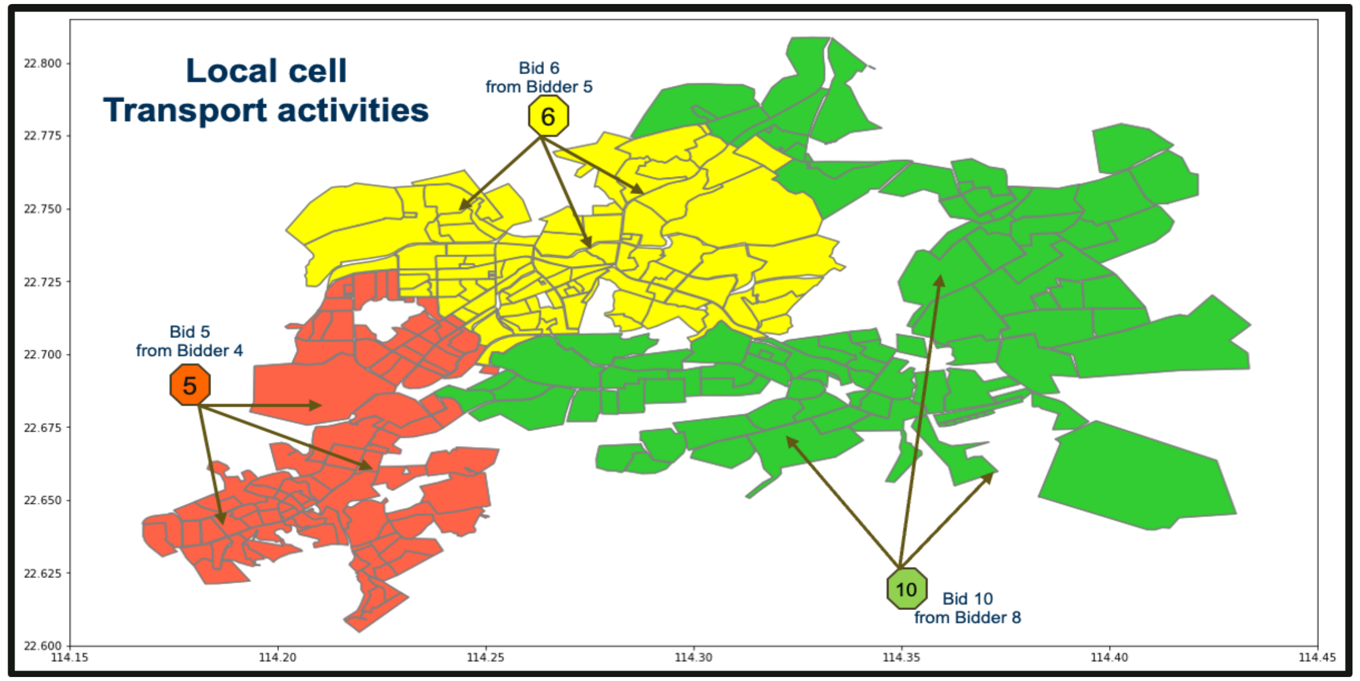
1. Network O-D &
Set of logistic activities &
SLA options

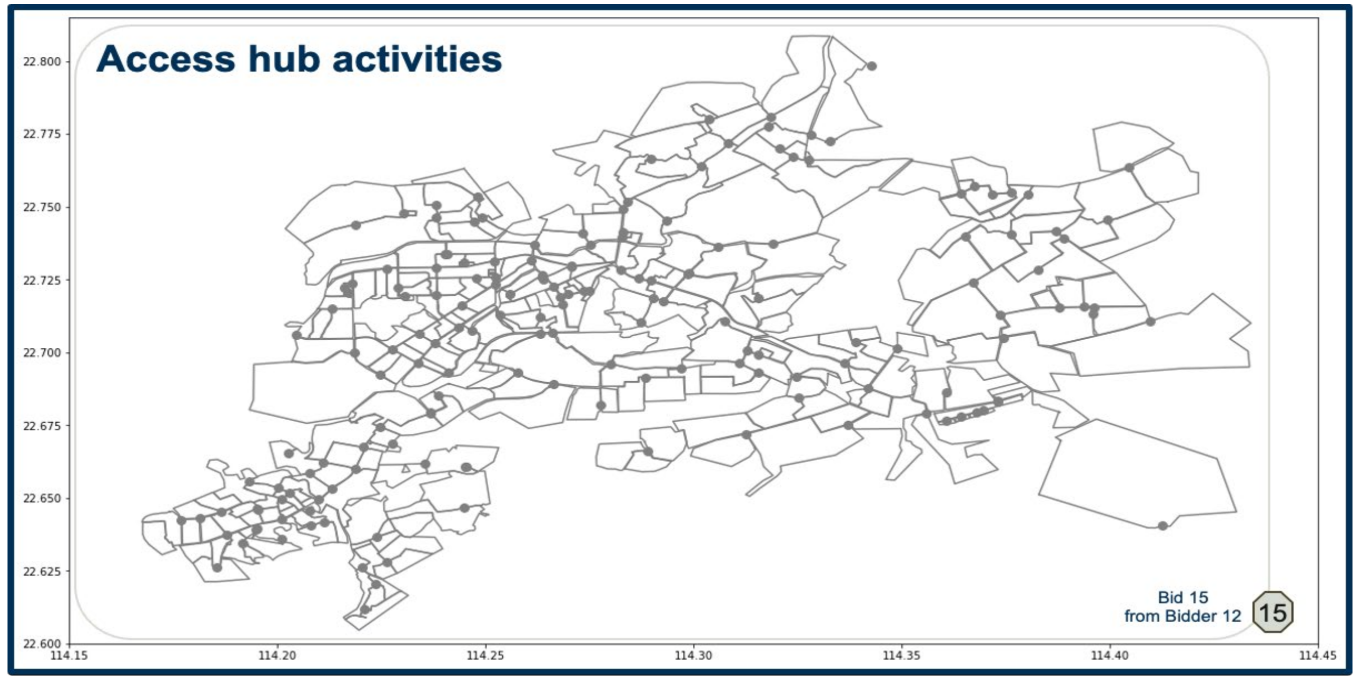
2. Bids submitted by bidders
(Activities, SLA, $)

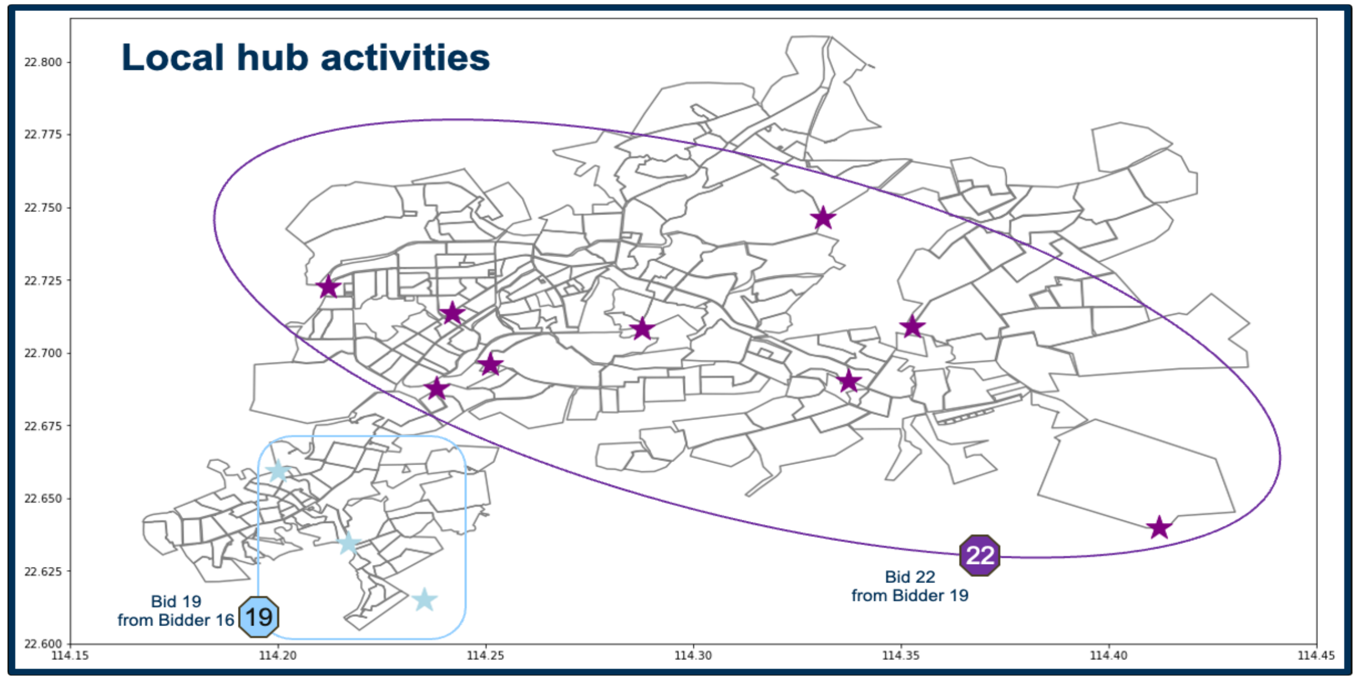
3. Selection of winning bids
⇒ O-D Service guarantees

Winner Determination Problem (WDP)









Will the set of winning bids still be able to robustly ensure O-D service guarantees after auction?

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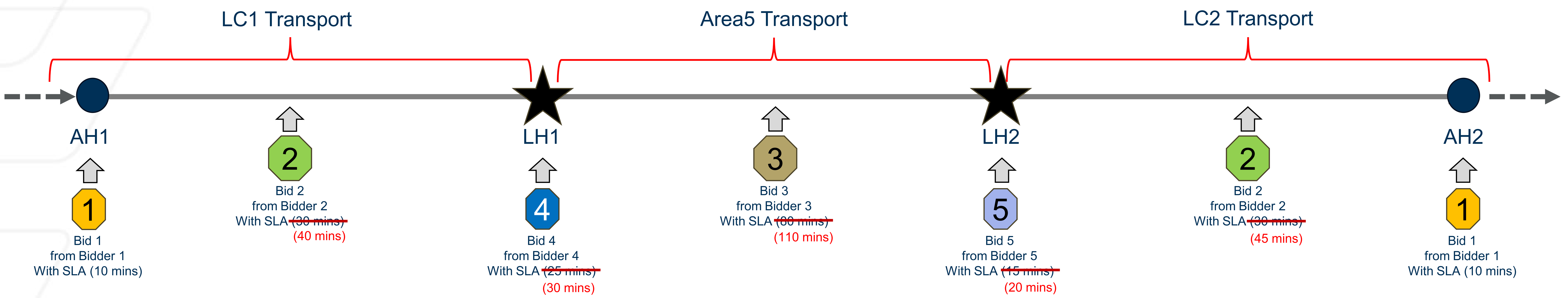
Associated Uncertainties in WDP

O-D Service guarantee τ_o: 4 hours



S_b: Claimed SLA of bid b at 99.9% reliability during auction → γ_b: Realized SLA of bid b after auction

- **Deterministic** SLAs: All SLAs are respected after auction ⇒ $\sum_b S_b \leq \tau_o$ (O-D Service satisfaction)
- **Uncertain** SLAs: Tactical Auctions ⇒ Information lag ⇒ Unexpected events (e.g., Demand ↑, requiring more resource)
  - Advanced bidders: $S_b \approx \gamma_b$
  - Naive bidders: $S_b < \gamma_b$

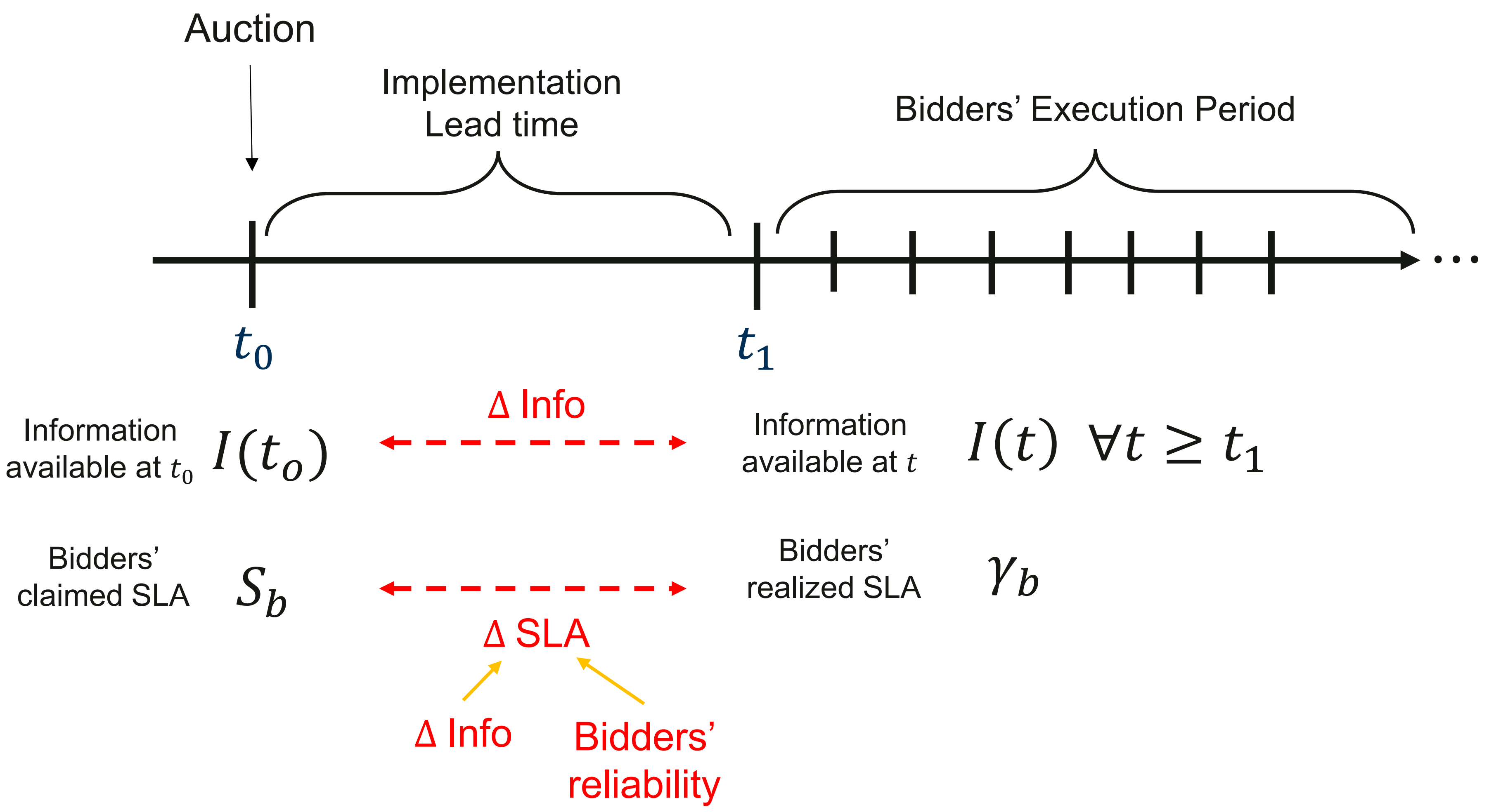
  ⇒ $\sum_b \gamma_b > \tau_o$ (O-D Service unsatisfaction)

Bidders' Reliability under Information Asymmetry ⇒ Uncertainty in SLA and O-D services ⇒ Profit ↓

Methodology Details for WDP

Aim: To design a ***robust*** multi-party service network with ***O-D guaranteed services*** while maximizing profit

- Uncertainty in SLAs ⇒ Uncertainty in O-D services
  1) Information lag induced by tactical auctions
     - Δ in information (Demand)
  2) Bidders' reliability (Historical on-time performance)



SLA Uncertainties
Modeling downside deviation in realized SLAs (γ) after auction through a discrete and finite set of scenarios (Ω)

→

Robustness in O-D Services
Chance constraints on desired probability of O-D service guarantees through scenario approximation

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Problem Formulation For WDP

Data:

- L: Set of logistic activities
- O: Set of O-D pairs
- τ_o: Expected revenue for O-D pair o
- L_o: Path for O-D pair o (Set of logistic activities)
- τ_o: Service guarantee for O-D pair o
- R: Set of participating bidders
- B_r: Set of bids from bidder r
- ρ_o: Desired probability level of service guarantee for O-D o
- Ω: Set of scenarios
- $\gamma^l_{rb\omega}$: Realized SLA of activity l in bid b from bidder r in scenario ω

Decisions:

- $x_{rb} \in \{0,1\}$: Selection of bids from bidder r
- $y_{o\omega} \in \{0,1\}$: Satisfaction of O-D service o in scenario ω
- $z_{o\omega} \in \mathbb{R}_+$: Violation amount of O-D service o in scenario ω

Expected Profit = Revenue – Cost

Select one bid for each logistic activity

Desired probability level of O-D service guarantees using chance constraints

Scenario-Based Approximation of O-D service guarantees

Case study: Instance Characteristic

- Area of a Chinese megacity with a subset of origin-destination flows
  - Approx. 15,000 parcels daily across the region between 36 origin-destination pairs

- Auction items: **21 Logistic activities** with **2 SLA options**
  - 7 Cluster transport activities
  - 14 Hub processing activities

- Decision makers
  - 1 Urban logistic orchestrator
  - 42 Logistic service providers (bidders)
    - 13 bidders interested in cluster services
    - 29 bidders interested in hub services

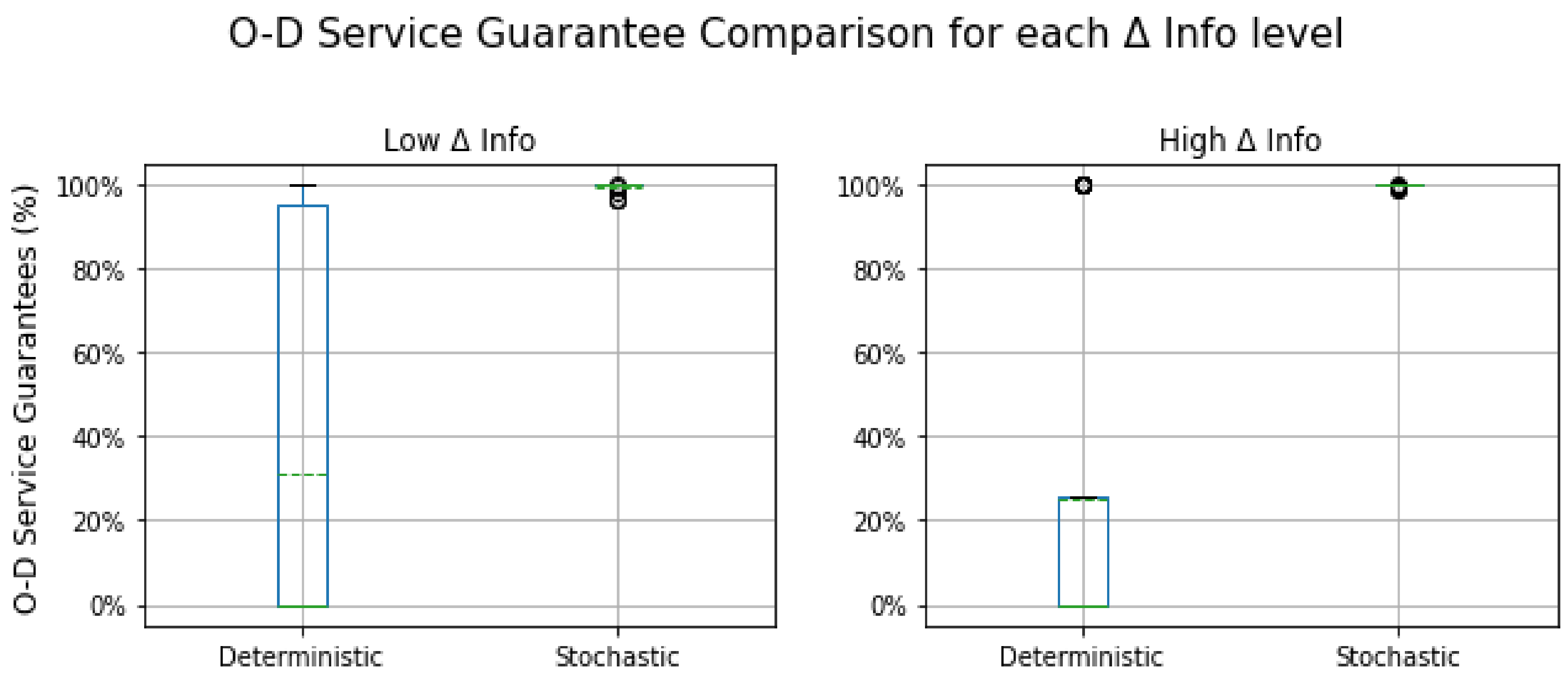
- Market Uncertainty Setting (SLA Uncertainty Matrix)
  - Bidders' reliability
  - Δ in information (Demand)

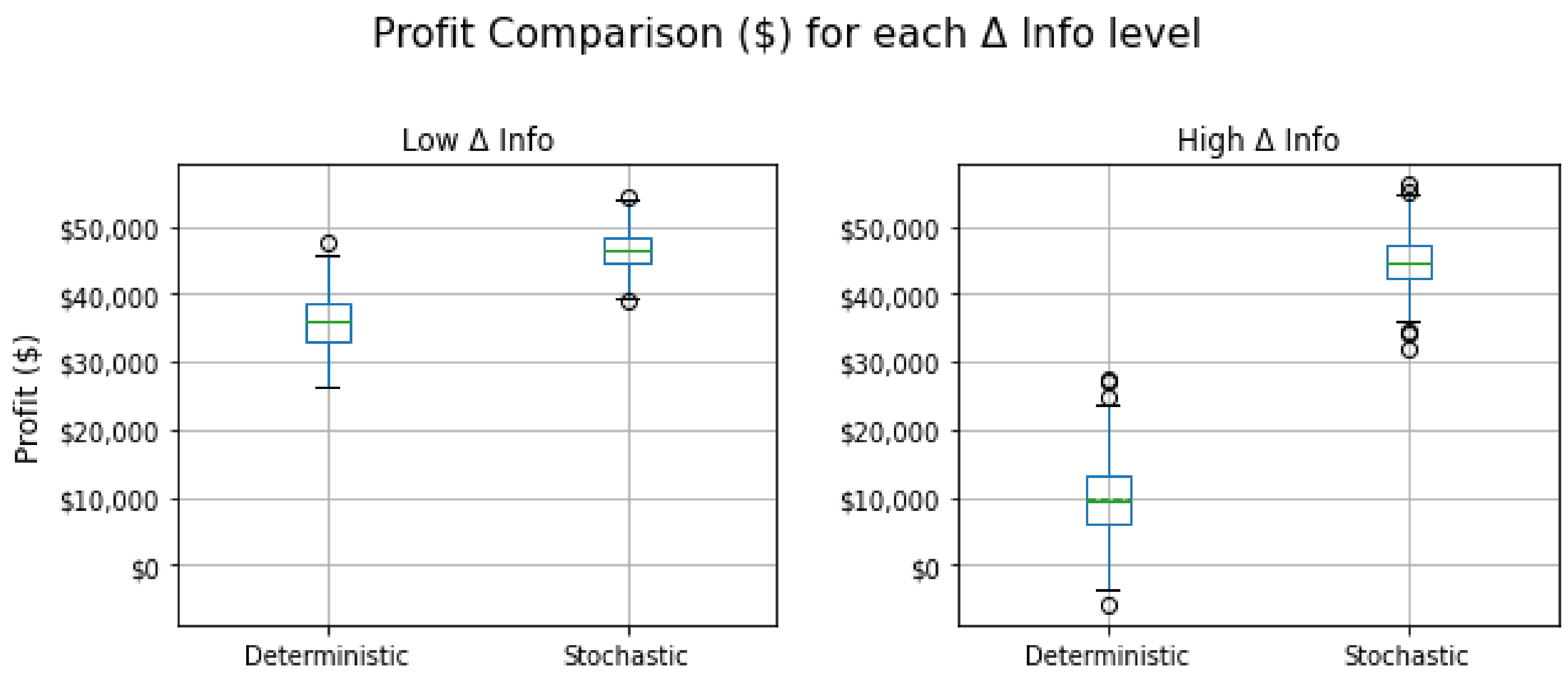
SLA Uncertainty Matrix

Bidders' reliability \ **Δ Information**	Low	High
High	Low downside deviation in SLA	Moderate downside deviation in SLA
Low	Moderate downside deviation in SLA	High downside deviation in SLA

Preliminary Results: Profit and O-D Service Levels

- 500 Simulation runs for each output (deterministic and stochastic opt. model) under two Δ Info settings
  - Realized SLAs of bidders





	Deterministic		Stochastic			
	Avg. O-D Service (%)	Avg. Profit ($)	Avg. O-D Service (%)	Δ O-D Service (%)	Avg. Profit ($)	Δ Profit (%)
Low Δ Info	31.32%	$35,855.2	99.65%	218%	$46,621.5	30.93%
High Δ Info	25.03%	$9,668.4	99.75%	298%	$44,723.6	362.3%

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Preliminary Results: Value of Hyperconnectivity

❑ Value of Hyperconnectivity ⇒ Benefit of Multi-stakeholder system

- What if we only allocate activities to limited # of bidders?
  - Imposing hard constraints on # of bidders to choose
- **Deterministic** model
  - Tendency to select large # of combinatorial bids from fewer # of bidders with low price and reliability
- **Stochastic** model
  - Tendency to select smaller # bids from many # of bidders with higher price and reliability to hedge against uncertainty in SLAs

Example of model behaviors

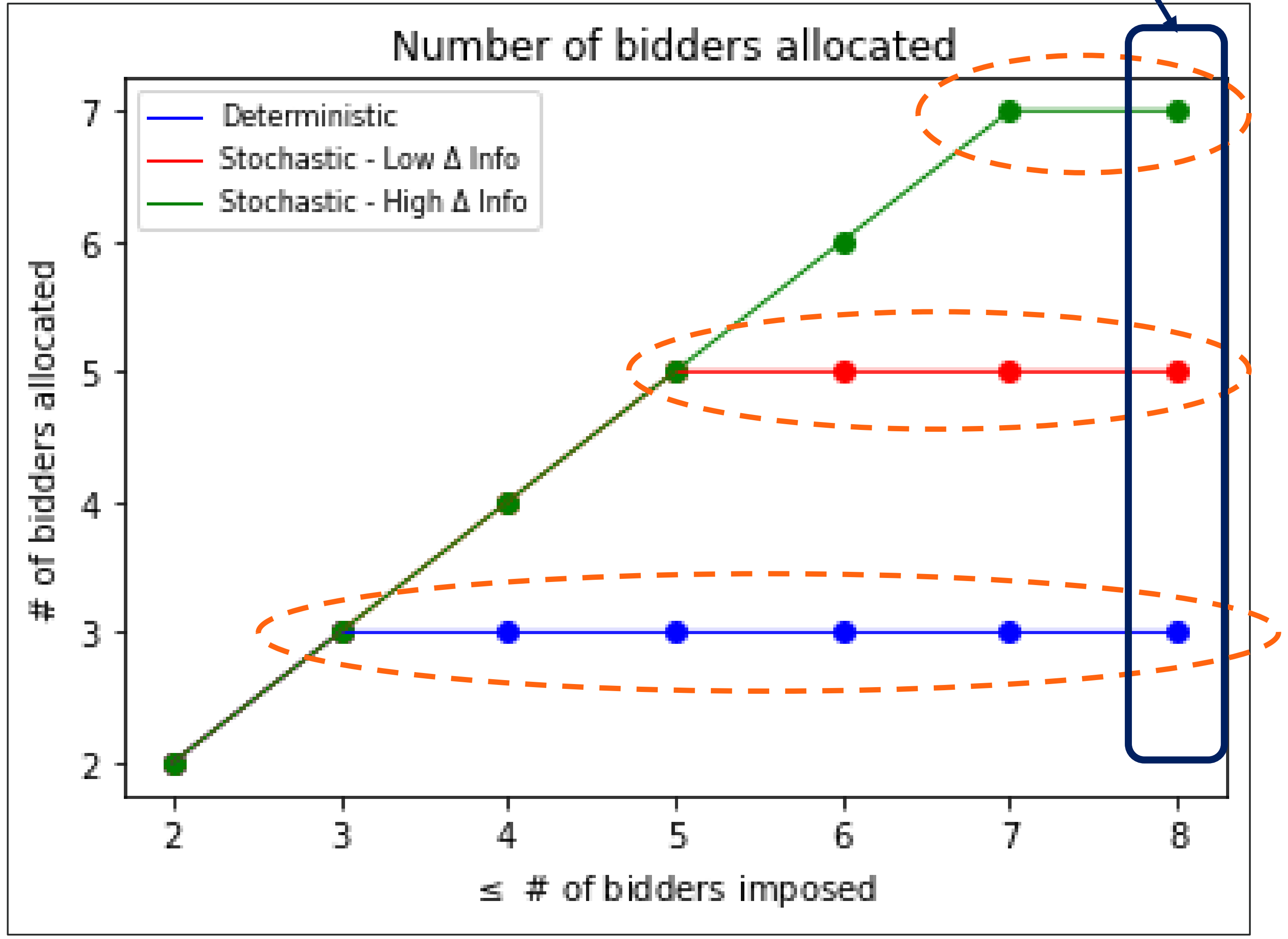
Bidder 1

(Allocated bidder)

Setting	Selected Bids
Deterministic	Bids 1, 4
Stoc – Low Δ	Bids 1
Stoc – High Δ	Bids 4

Activities associated with Bid 4 from Bidder 1 are covered by different bidders in stochastic settings

Optimal # of bidders to allocate



⇒ Additional set of constraints to the optimization model to restrict # of bidders to select

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Summary

Contributions

- Novel winner determination problem setting in line with hyperconnected city logistics
- Chance-constrained stochastic program formulation for winner determination problem

Future Research

- Incorporation of variability risk measures directly into the decision-making model
  - Chance constrained risk-averse stochastic programming
- Modeling regulation/enforcement that affects effectiveness in real-life operations

Thank you!

Questions: skwon82@gatech.edu