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CHAIRE INTERNET PHYSIQUE

Routing and network-slicing-based protocols for the Physical Internet network

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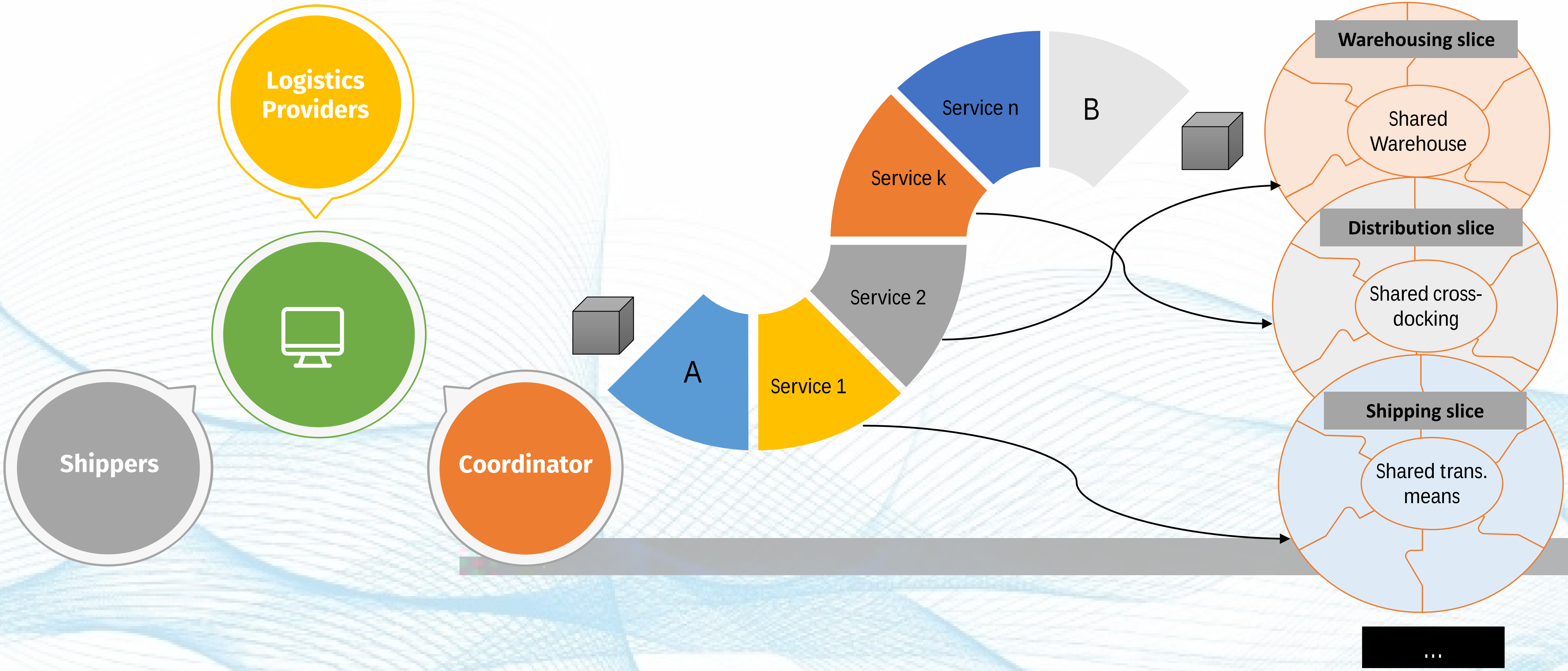
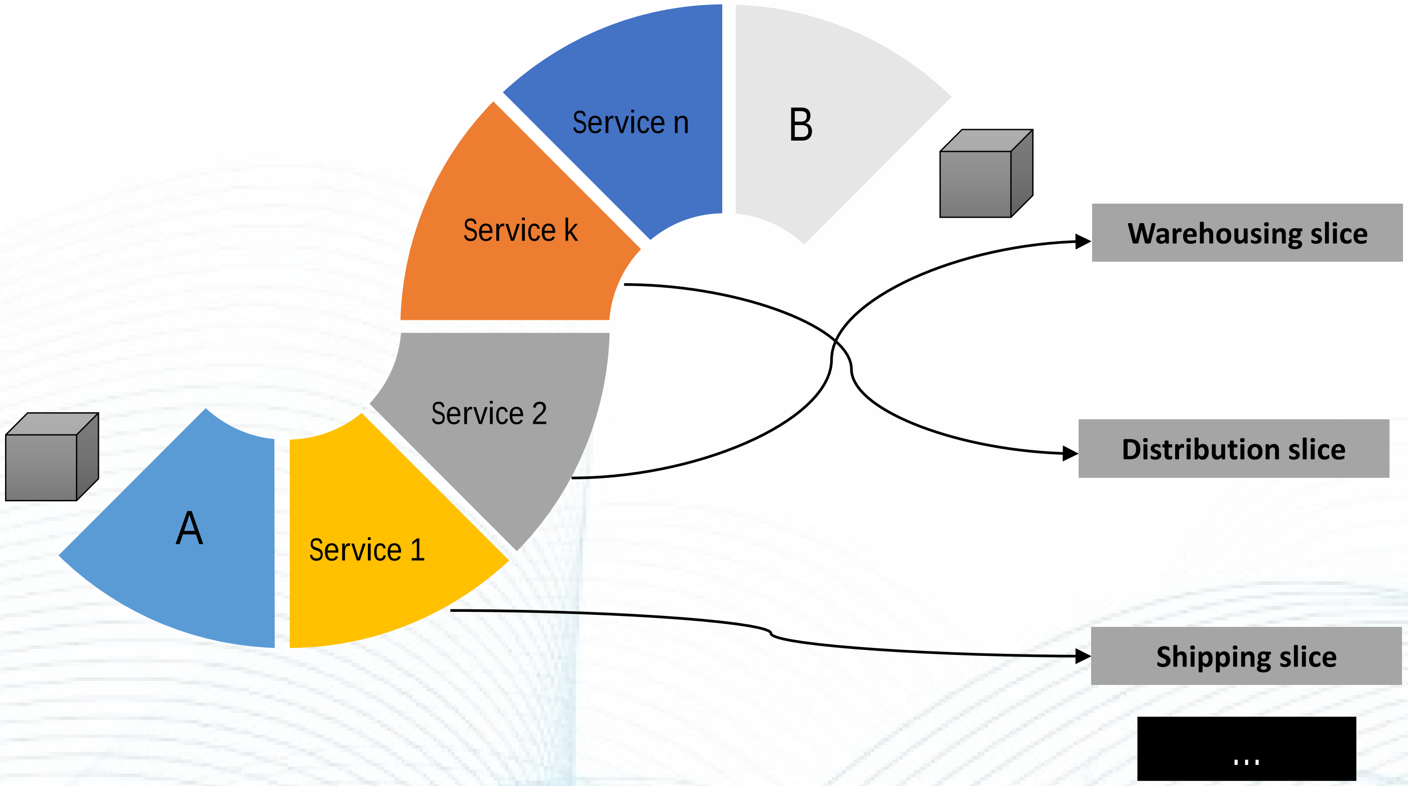
Context


Logistics Providers
Shippers
Coordinator
A
Service 1
Service 2
Service k
Service n
B
Warehousing slice
Shared Warehouse
Distribution slice
Shared cross-docking
Shipping slice
Shared trans. means
...

Context

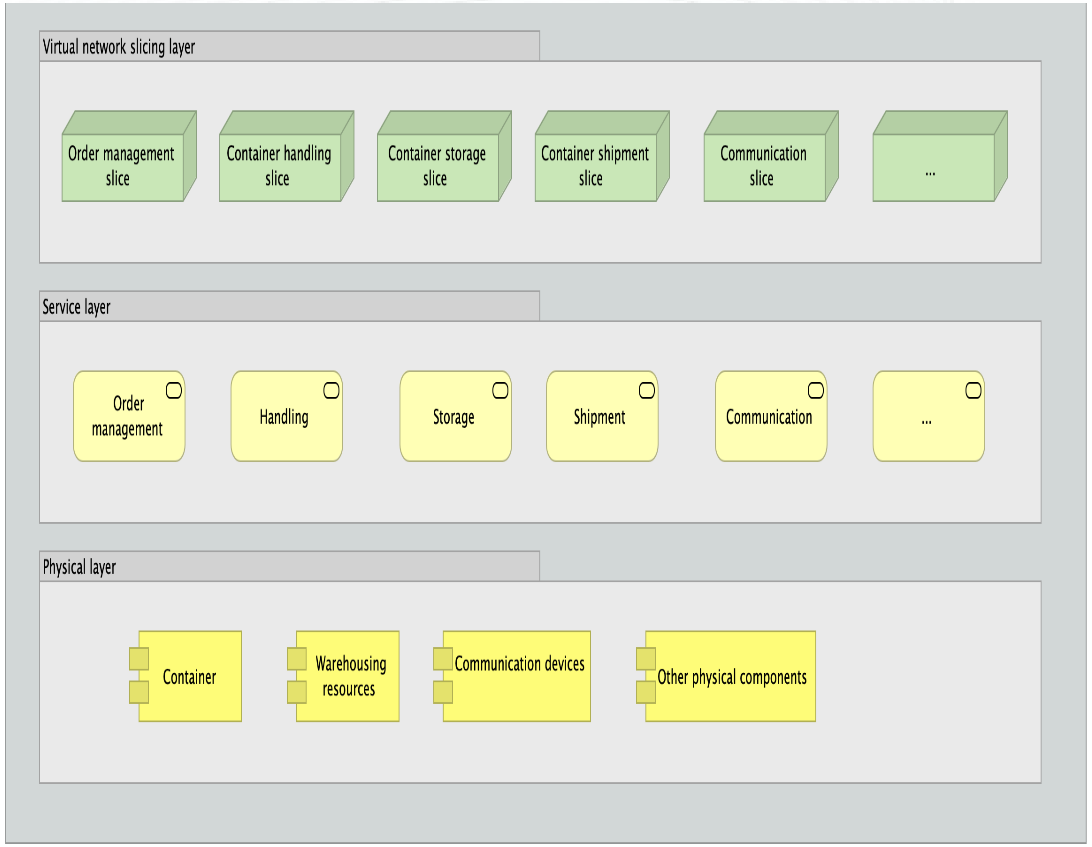


Containers or shipments have to be **allocated** to resources and delivered to customers while guaranteeing an end-to-end services, considering route-constraints (e.g., capacity, costs, lead time), and ever **changing** environments, i.e., **disruptions** (e.g., emergency or cancelled orders, hub unserviceability, transportation means unavailability).

Resources and **shipments** are considered to be able to compute decisions within a legal framework: they are supposed to **coordinate** with other entities in the network **about routes and loads allocation** based on **actual context** and **local knowledge** (known state of the system); **centralized** decision-making **can no longer** be **applied.**

Network-Slicing-Based Protocol

Network slicing allows the creation of **multiple virtual networks** with a **common physical infrastructure**, each optimized for **specific services** or user groups, aiming at providing customized and more efficient **end-to-end services** and **allocating the network cost** to the different deployed slices.



It is well-suited for use cases that require customized and more efficient **end-to-end services**

It involves the allocation of **dedicated resources** and the deployment of a wide range of services with **varying requirements**

It provides a high level of granularity, allowing coordinators to define and manage multiple network slices with distinct characteristics.

It requires a comprehensive management and orchestration framework to handle the lifecycle of network slices, including slice creation, configuration, monitoring, and scaling.

Network-Slicing-Based Protocol

Disruption management & preference integration

1

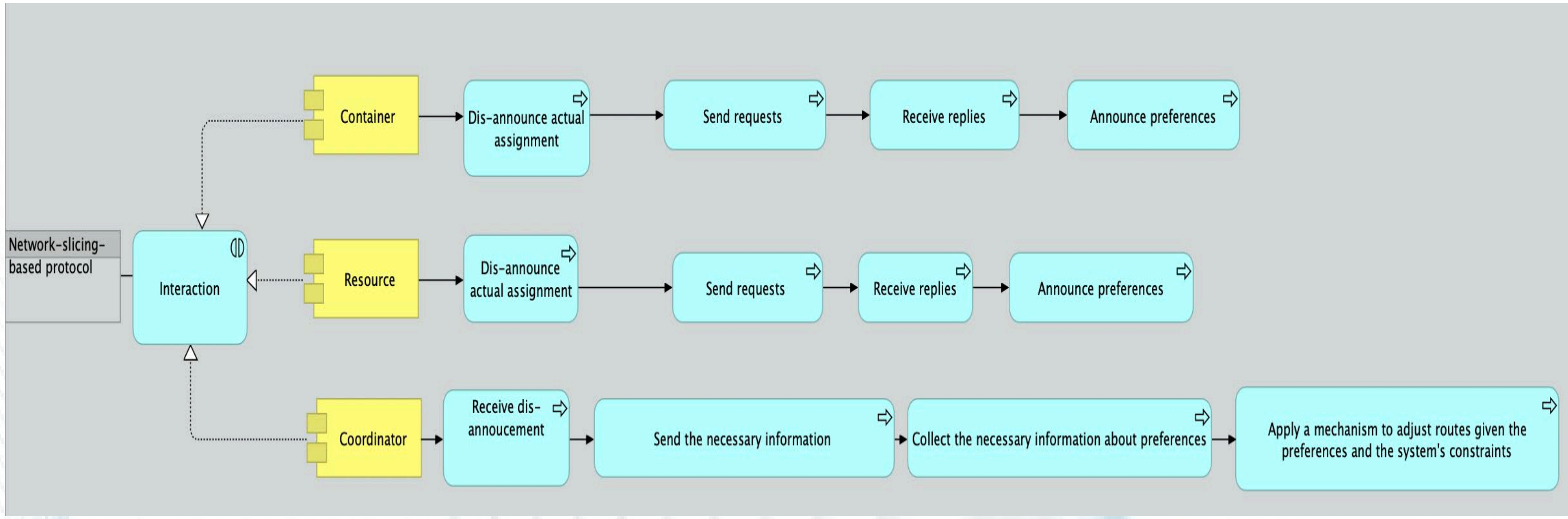
Slice creation

Based on the service layer requirements

2

Allocating resources in a slice

MCDM and assignment algorithms while minimizing logistics costs and CO_2 emission



Examples of reactive assignment algorithms designed to offer good-quality solutions with simple computational capabilities.

Algorithm 1 Assignment algorithm in normal scenarios

Assign each downstream location (i.e., destinations) to a hub ▷ using the clustering algorithm
Load orders into best-fit containers ▷ using containerization protocol described in Sarraj et al. (2014a)
$HubList \leftarrow$ List of hubs
$ContainerList \leftarrow$ List of containers
$VehicleList \leftarrow$ List of vehicles
$V_k \leftarrow$ Maximum volume capacity of vehicle k
$W_k \leftarrow$ Maximum weight capacity of vehicle k
for each $h \in HubList$ **do**
  for each $k \in VehicleList$ **do**
    $L^k \leftarrow$ New empty list of containers to be transported by k
    for each container p leaving h **do**
      $v \leftarrow$ Volume of container p
      $w \leftarrow$ Weight of container p
      if $V_k \geq v$ and $W_k \geq w$ **then**
        Append p to L^k
        $V_k \leftarrow V_k - v$
        $W_k \leftarrow W_k - w$
        $ContainerList \leftarrow$ removing container p from $ContainerList$
      end if
    end for state $L^k \leftarrow$construct and optimize the sequence of destinations to visit using neighborhood search operators ▷ refer to (Dumez et al., 2021)
  end for
end for
Return constructed routes with the corresponding total cost and arrival time

Algorithm 2 TOPSIS's steps

Acquire each alternative i and criterion j
Construct normalized decision matrix:
$r_{ij} \leftarrow \frac{x_{ij}}{\sqrt{\sum x_{ij}^2}}$ with r_{ij} and x_{ij} are original and normalized score of decision matrix resp.
Construct the weighted normalized decision matrix:
$v_{ij} \leftarrow w_i r_{ij}$ with w_i is the weight for j criterion
Determine the positive ideal and negative ideal solutions:
Positive ideal solution: $A^* \leftarrow \{v_1^*, ..., v_n^*\}$ with $v_j^* = \{max(v_{ij}), if j \in J; min(v_{ij}), if \in J'\}$ ▷ refer to (Hwang and Yoon, 1981; Behzadian et al., 2012) for further details
[redacted]

Algorithm 3 Assignment algorithm with transshipment

Assign each downstream location (i.e., destinations) to a hub ▷ using the clustering algorithm
Load orders into best-fit containers based on q^{a*} ▷ using containerization protocol described in Sarraj et al. (2014a)
Assign each container to a hub ▷ using the clustering algorithm
[redacted]
      $L^k \leftarrow$ New empty list of containers to be transported by k
      $L^k_{pq} \leftarrow$ New empty list of hubs to be visited for pickup and delivery by k
      $index_{h'} \leftarrow$ index of the hub(s) where *orders*will be picked from, and
      orders will delivered to, if applicable $HubListPK$
      for each container p leaving h **do**
        $v^* \leftarrow$ Volume of container p
        $w^* \leftarrow$ Weight of container p
        if $V_k \geq v^*$ and $W_k \geq w^*$ **then**
          Append p to L^k
          Append $index_{h'}$ to L^k_{pq}
          $V_k \leftarrow V_k - v^*$
          $W_k \leftarrow W_k - w^*$
          $ContainerList \leftarrow$ removing container p from $ContainerList$
        end if
      end for
    end for state $L^k \leftarrow$ construct and optimize the sequence of hubs and destinations to visit
    using neighborhood search operators ▷ refer to (Dumez et al., 2021)
end for
Return constructed routes with the corresponding total cost and arrival time

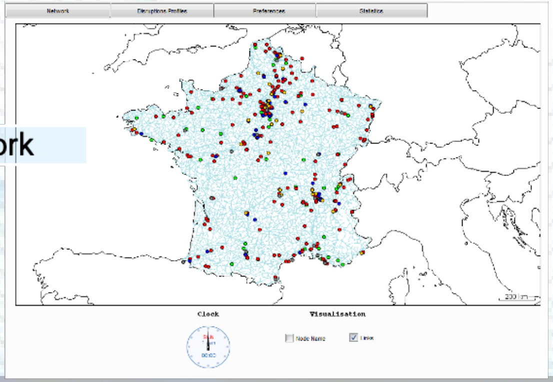
Experiments

Using a muli agent simulation, and data from major French retail chains Carrefour and Casino and their 106 largest suppliers,

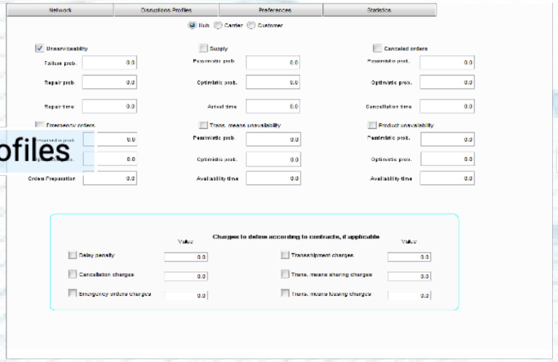
Assessing the performance of the protocols

- 303 plants, 57 warehouses, and 58 distribution centers across France.
- Three products: liquids, groceries, and personal and home care.
- 2,582,692 full pallets are routed.
- 211,167 orders of 702 different products, accounting for approximately 20% of French FMCG market share for the considered product families.

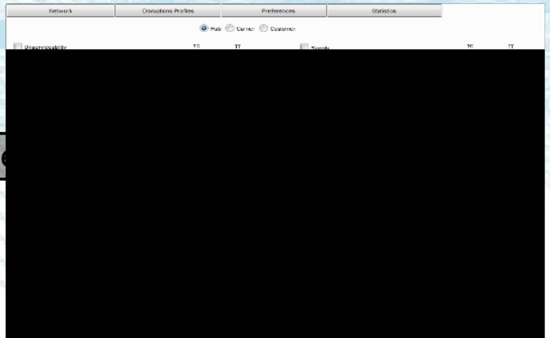
Network



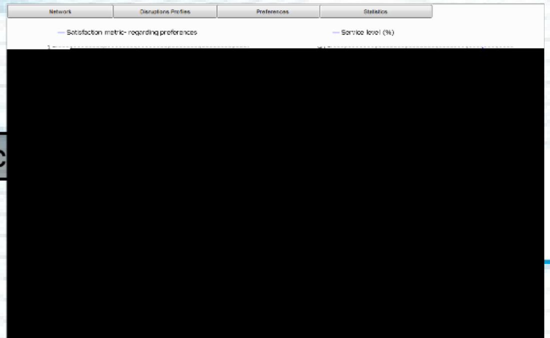
Disruption profiles



Preferenc



Statistic



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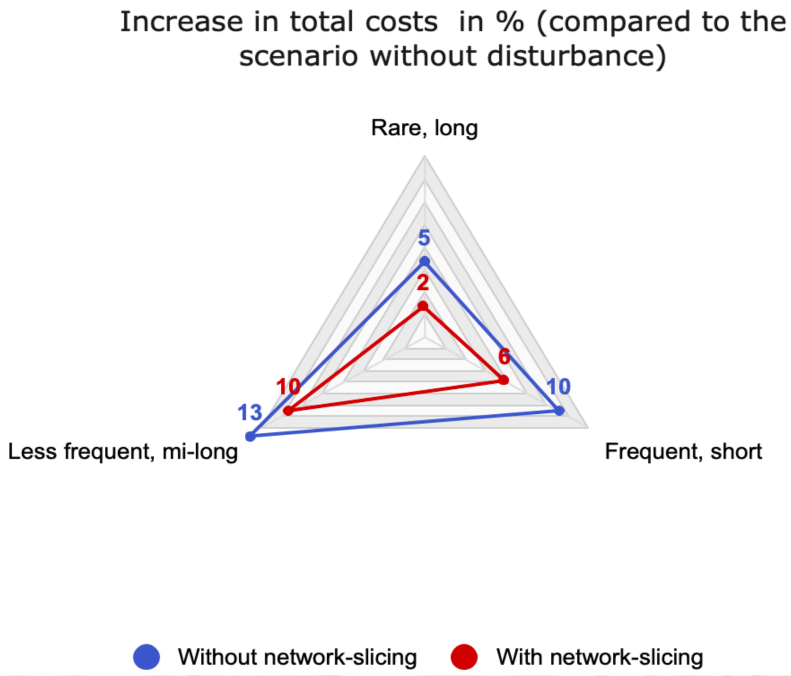
Experiments : Simplified Example

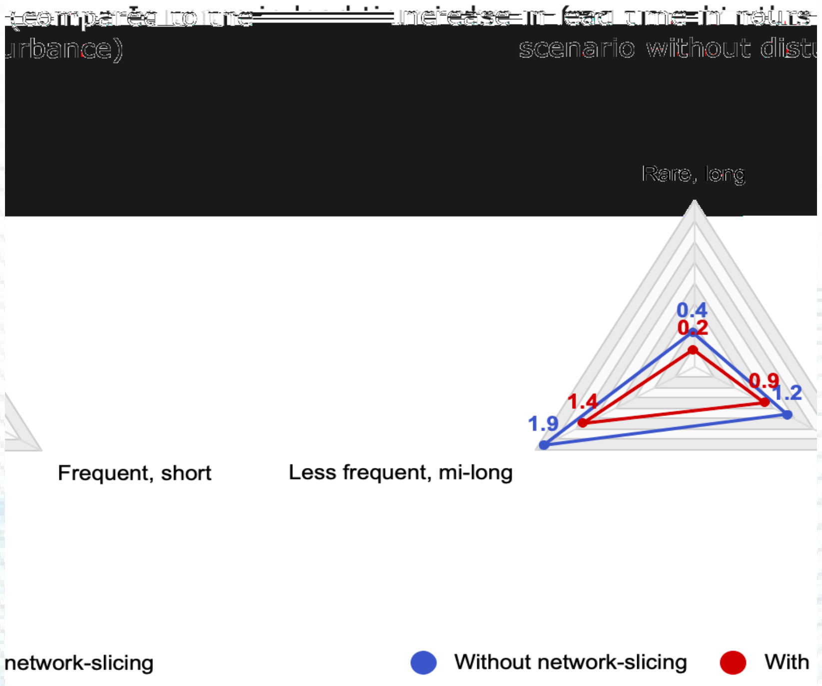
- A 7-day simulation, 10 plants, 10 warehouses, 10 carriers (trains and trucks), 1000 orders of 5 different products to ship, and only storing and shipping services.
- We evaluate the performance of the proposed protocols in absence and presence of disturbance, namely, hub resource breakdown.
- We evaluate the performance of the proposed protocols in presence of disturbance, namely, hub breakdown. We consider long, rare ; less frequent, mi-long and frequent, short disturbance profiles.

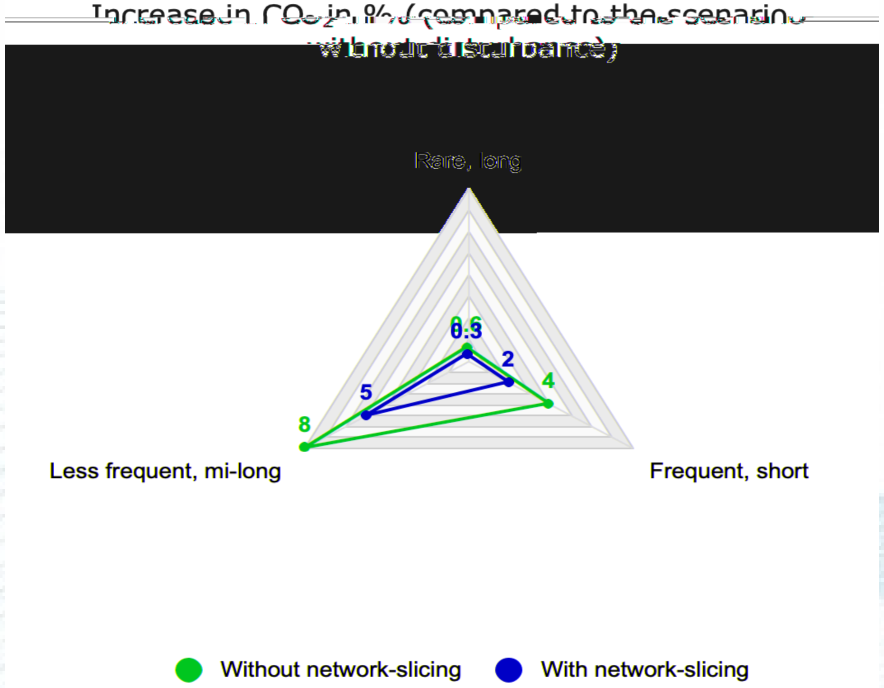
#	Breakdown prob.	Repair prob.	Average dur. (hour)	Lost capacity of PI	Description
1	1%	30%	3.1	3%	Rare, very long
2	10%	70%	1.4	13%	Less frequent, mi-long
3	20%	90%	1.1	18%	Frequent, short

- The performance is evaluated using three key performance indicators, namely, increase in total cost (i.e., transportation and storage), in lead time, and CO_2 emissions.
- Two scenarios are evaluated:
  - Without network-slicing: locally optimizing resources allocation.
  - With network-slicing: optimizing resources allocation for all slices.

Experiments







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Conclusions & Perspectives

- *A network slicing-based protocol for more efficient resource allocation and management and to guide individual self-interested decisions toward a system-wide common goal.*
- *A dynamic and reactive protocol to consider various contexts, such as disturbing events, route constraints, and PI actors' preferences and local knowledge of the system's state.*

- Future research should investigate the trade-offs in implementing logistics network slicing while considering decentralized protocol and managing disruptions.
- Investigate other classes of operational disruptions, but also tactical and strategic ones, along with reactive alternatives that have yet to be investigated.
- Generalize the scope to the case where multiple coordinators (i.e., platforms) provide communication and container delivery in and between several PI sub-networks.
- Generalize the scope to cover and compare on-demand and scheduled services;
- Capitalize on data collected, using the routing tables, to assist the disturbance management by using similarities and accurate predictions (e.g., reinforcement learning, transfer learning, or case and rule-based reasoning).