A dynamic routing protocol with payments for the Physical Internet: A simulation with learning agents

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Introduction: need for dynamism

- The Physical Internet aims to route loads dynamically over a logistic network.
- Each time a Load arrives at a Node, a decision must be quickly taken to jointly select the Next node, the Carrier, and the price for this new segment.
- Hence the need for a Digital Internet like protocol. Something fast and reliable.
- This poster presents what we believe is the first PI dynamic routing protocol taking payments into account. It also present an environment to test the new protocol.

Protocol: Presentation

Because the freight transport market is highly competitive, we can use a game theoretic approach to design our protocol: the key component is an auction (see Auction).

It involves three agents: Shippers to generate Loads, Carriers to transport them, and Nodes to materialize the network and make the routing decisions.

Each time a Load and a Carrier are waiting at a load, an auction is run. Note that the case when we have a single carrier bidding should be rare in the context of a Few-To-Many market.

Protocol: Auction

Generate:
- Reserve Price for Shippers by answering: “How much am I ready to pay to get this loads from this node to its destination?” \( R \)
- Bids for Carriers by answering: “What is the minimum price I am ready to be paid to transport the load to each of this next node?” \( b_i \) for each carrier \( i \) and each node \( l \)
- Penalties for Nodes by answering: “What is the expected price to deliver the load after reaching a next node?” (sort of DI Administrative Distance) \( w_l \)

Select \((i^*, l^*) = \text{argmin}(w_l + b_l)\) and \( B = \min_i (w_l + b_i^*)\).
Carrier \( i^* \) must transport load to node \( l^* \) and is paid \( B - w_{l^*} \).

The auction is IR, IC, BB, and almost always AE (in a Few-To-Many market).

Simulation: Network

We make a simulation of the Western European freight transport market using the ETIS+ database.

We aggregate volumes of 11 regions to 11 single nodes (Bremen, Dresden, Madrid, Marseille, Milan, Naples, Paris, Rotterdam, Saarbrücken, Salzburg, and Warsaw) and generate flows according to the real data.

Regions for each node and Main cross-region flows. Legend: total tonnages (imports + exports, excluding internal transports)

Simulation: Agents

Carriers try to bid in a profitable manner to offset the following costs:
\[
C(t) = \text{OnTheRoad}(t) \times \text{RoadC} + \text{FarFromHomeC}(t)
\]
where
\[
\text{FarFromHomeC}(t) = \text{NotAtHome}(t) \times \text{DriversC} + \text{AdminC}(t)
\]
RoadC and DriversC are constant for each carrier and AdminCosts(t) is an exponential function doubling the total cost in 10 days.

Shippers bid high to make sure Reserve Prices are not involved.

Nodes charge zero and then we increase this price.

Simulation: Carriers’ bids

We simulate Carriers using Reinforcement Learning. To increase the learning speed and avoid to relearn the model for each new agent, we use a centralized learning TD3 structure for all carriers.

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