Analogies across Hubs and Routers in the Physical and Digital Internet

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Imports & Exports
$16 Trillion

272 million containers delivered

Maritime Transport
> 10.6 million tons

Imports & Exports
~60% world's GDP

Still, very inefficient!!!

67 million empty containers delivered

23% of miles traveled empty

Average container load of 30-40% in laden trips
Problems and approaches

• Problems
  • Need for sharing data, events, information, of collaboration across agents
  • Need for synchromodality
  • Need for routing algorithms for logistics
  • Need for common semantics

• Approach
  • Start by defining a common, general model of operations in hubs
    • Inspired on digital internet
  • Leverage models as common semantics for creating new algorithms
Main features of a router

- Port 1
- Port 2
- Port N
- Port N+1
- Port N+2
- Port 2N
- Buffers
- Routing Logic
- Interconnection Matrix
- MTU
Digital internet structured as a hierarchical tree of Autonomous Systems (AS)

AS: “connected group of one or more IP prefixes run by one or more network operators which has a single and clearly defined routing policy”.

Different relations among ASs:
- Peering
- Customer
- Provider,…
Digital Internet: Routers

Internet Structure and types of router

AS X

Area A

Area B

Area C

AS Y

AS Border Router
Area Border Router
Core Router
Internal Router
Inter-AS Link
Inter-Area Link
Internal Link
Digital Internet: Routers

Operations

De-encapsulation

Encapsulation

Routing

Forwarding

a) Non-AS Border Router

Incoming Packets
Packet Reception
Layer 2 Controller
Packet Buffering
Routing
Outgoing Packet Interface Assignment
Outgoing Buffering
Layer 2 Controller
Outgoing Packets

b) AS Border Router

Incoming Packets
Packet Reception
Layer 2 Controller
Packet Buffering
Policy Enforcement
Routing
Outgoing Packet Interface Assignment
Outgoing Buffering
Layer 2 Controller
Outgoing Packets

Policy Enforcement
Mapping of the packet to the outgoing interface
Waits for the link to be available
Encapsulation

De-encapsulation

Encapsulation

Forwarding

De-encapsulation

Encapsulation

Forwarding

De-encapsulation

Encapsulation

Forwarding

De-encapsulation

Encapsulation

Forwarding
Physical Internet: Hubs

Main features of a hub

**Physical Internet**
- Transport Modes
- Inbound/Outbound docks
- Turnaround time
- Storage areas
- Package reallocation
- Decomposition/composition

**Digital Internet**
- Physical modes
- Ports
- Computational latency
- Buffers
- Package reallocation
- De-encapsulation/encapsulation
Physical Internet: Hubs

Types of hub

• Multiple taxonomies in the literature
  • Single dimension (size OR facilities OR services OR functional hierarchy)
  • Multiple dimensions (Higgins et al.): area of influence, scope of activities and variety of services

• Our proposal
  • Multiple dimensions: area of influence, variety of services, largest and smallest handling units, intermodality capabilities, warehousing capabilities

• Resulting categories:
  • Gateways
  • Large regional distribution hubs
  • Classification centers
Autonomous systems in the Physical Internet

- Autonomous Systems in the Physical Internet:
  - We identify ASs with single markets (SM), economic unions (EU) or countries for four reasons: no internal trade barriers, a common external tariff, and free factor and asset mobility.
  - These areas are governed by a clearly defined and common set of rules for all logistics agents operating within. Similarly, any goods coming from outside the AS have to go through a customs clearance, subject to tariffs, economical policies and agreements.
  - ASBRs: Gateways

- Within the AS
  - Areas and sub-Areas: regions with dense trade networks can be modeled as areas or sub-areas. ARs and CRs represented by large regional distribution hubs.
  - Local networks: metropolitan areas and last mile. Internal routers equivalent to classification centers.
Physical Internet: Hubs

Operations

- Proposed model for operations in any type of hub

Intra-AS goods

1. Docking
2. Cargo unload
3. Temporal storage & decomposition if required
4. Internal reallocation

Inter-AS goods

- Customs clearance

Outgoing cargo

- Temporal storage & composition if required
- Cargo Load
- Undocking

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• It’s the semantics!
  • Having a common model helps defining metrics and algorithms regardless of the type of hub.

The following metrics, $T_{av}$ and $T_s$, could be common for any hub:

\[
T_{av} = ETA + T_{dk} + \sum_{i=1}^{k} T_{u}^{i} + T_{dc},
\]

\[
T_{s} = T_{dk} + \sum_{i=1}^{n} T_{l}^{i} + \sum_{j=1}^{m} T_{u}^{j} + T_{udk},
\]

However, their inner parameters depend on the type of hub.
### Physical Internet: Hubs

#### Operations: practical cases

<table>
<thead>
<tr>
<th>Proposed Model</th>
<th>Seaport</th>
<th>Intermodal distribution centre</th>
<th>Cross-docking classification centre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Docking ($T_{dk}$)</td>
<td>Sea Traffic Management, Gate control Nautical services (pilotage, mooring, tugging)</td>
<td>Rail shunting operations</td>
<td>Vehicle reception</td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Cargo unload ($T_u$)</td>
<td>Terminal Cranes (STS, RTG, RMG, SC, etc.)</td>
<td>Cranes (RMG, reach stacker, etc.)</td>
<td>Forklifts</td>
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<td>Human force</td>
</tr>
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<td>Storage &amp; decomposition ($T_{dc}$)</td>
<td>Bulk, general cargo, ITUs handling Open air - yard /warehouse storage</td>
<td>ITU handling, Decomposition in smaller handling units (PI-container) Open air - yard, Incoming dock -reception area, warehouse facilities</td>
<td>Incoming dock -reception area</td>
</tr>
<tr>
<td>Customs clearance</td>
<td>Customs inspection and clearance</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Reallocation ($T_r$)</td>
<td>Cranes, Internal transport</td>
<td>Cranes, Internal transport, Conveying units, Forklifts</td>
<td>Forklifts, Conveying units</td>
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<td>Open air – yard, Outgoing dock – expedition area, warehouse facilities</td>
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<tr>
<td>Cargo load ($T_l$)</td>
<td>Terminal Cranes (STS, RTG, RMG, SC, etc.)</td>
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<td>Undocking ($T_{udk}$)</td>
<td>Sea Traffic Management, Gate control Nautical services (pilotage, mooring, tugging)</td>
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From Hubs to PI-Hubs

Discussion and Future Work

Digital Internet

- Pros
  - Negligible time in router. Routing depends on latency, bandwidth,… or other metrics measured in the links.
  - Packets can be replicated without cost
  - Routing per-hop, adaptable

- Cons
  - Routing cannot be planned in advance
  - Difficulties with QoS

Physical Internet

- Pros
  - Control and physical plane are detached
  - Possible to model parameters related to operations
  - Perform forecasting and resource reservation
  - Enabler of synchronomodality

- ToDos
  - Devise routing algorithms based on common semantics aimed at reducing costs, delivery time and emissions while providing flexibility and adaptability
Thanks for having us!

Any (easy) question?