An Open Logistics Interconnection model for the Physical Internet

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** Abstract:** Computer networks have been interconnected through the last decades with huge advantage into a worldwide Digital Internet. Unlike their digital counterparts, logistics networks remain highly fragmented, still mostly dedicated to a company or a specific market. The recently introduced Physical Internet concept proposes to remedy this situation by interconnecting logistics services on a global scale. The implementation and deployment of the Digital Internet has profited extensively from a structured and a standardized approach to interconnect networks. Indeed, the layered structuring of digital services and protocols associated to both the Open System Interconnection (OSI) model and the TCP/IP model has been instrumental in shaping the Digital Internet. This paper proposes, describes and illustrates a seven-layer Open Logistics Interconnection (OLI) model to enable interconnecting logistics services within the Physical Internet. It describes each proposed layer and the way logistic services are organized within and across these layers.

**Keywords:** Open Logistics Interconnection, Physical Internet, Open System Interconnection, Abstraction layers, Logistics services, Protocol suite.

1. INTRODUCTION

Most networks, be they water networks, electrical networks, digital networks or logistics networks, share common properties even though they may have huge intrinsic differences. Logistics networks encompass distribution networks, production networks and supply networks. Among networks, digital networks have reached an impressive level of interconnection. Indeed digital networks, heterogeneous in terms of technologies and manufacturers, have been merged into a unified network of networks, namely the Digital Internet. Logistics networks, despite a very old history, were mostly local networks until recently when the development of efficient transportation means drastically change the scale and the magnitude of such networks that now cover the world. Yet logistics networks remain highly fragmented, mainly dedicated to a company or a specific market, as promoted by the supply chain concept and vertical coordination (Heskett 1973). Even the rise of third-party logistics (3PL) did not really change that fact (Carbone and Stone 2005).

There is a noticeable exception: the 20ft and 40ft intermodal containers. These containers allow companies to ship from and to almost anywhere in the world, regardless of the operator and the transportation means (Levinson 2006). This system, while mainly maritime, has experienced an exponential growth in the past sixty years from nearly no container in 1950 to more than 27 millions in 2010 (World Shipping Council 2011). However actual logistics networks, both inland and across oceans, still overlap each other and are still poorly connected to each other.

Exploiting the Digital Internet metaphor, the Physical Internet has been recently proposed by Montreuil (2009, 2011) to enable the worldwide interconnection of logistics networks and services so as to increase by an order of magnitude the efficiency and sustainability of logistics. This paper proposes an Open Logistics Interconnection (OLI) model, similar to the seven-layer Open Systems Interconnection model of the Digital Internet, to structure the interconnected logistics services so as to ease the conceptualization, the implementation and the deployment of the Physical Internet.

The paper is structured as follows. Section two points out the drawbacks resulting from dedicated networks and then describes the Physical Internet interconnecting logistics networks so as to eliminate these drawbacks. Section three describes the main digital interconnection model and the TCP/IP pragmatic approach. Section four introduces the Open Logistics Interconnection model, documenting and illustrating its service layers. Finally, section five provides conclusive remarks and avenues for further research.

2. TOWARDS INTERCONNECTED LOGISTICS NETWORKS

2.1 Current logistics organization: a lack of interconnection

This paper deals with logistics networks. These are built upon transportation systems (trucks, railroads...), facilities (warehouses, hubs...) and information systems (ERP, TMS and WMS) to supply or distribute freight from shippers to their customers. They generically provide a collection of
specific operations: distribution or supply and related services among assets.

Current logistics networks are mostly fragmented, each dedicated to a specific organization, such as a car manufacturer, a retail chain or a postal service. At the transportation level, means are dedicated to specific logistics networks even if they share the infrastructure (road, railway, etc.). The main exception is container ships that aggregate containers from many customers and operators. At the distribution and supply levels, the dominant paradigm focuses on vertical coordination with the well-known supply chain concept (Heskett 1977). In order to emphasize this current fragmentation of logistics networks, Fig. 1 illustrates two company-specific logistics networks (plain and dashed) between the company’s plants (square) and warehouses (triangles) and their customers’ delivery points (circles). These networks, even though they physically overlap each other, are completely disconnected.

Fig. 1. Overlapping yet disconnected logistics networks

The disconnection of logistics networks results in a huge number of crisscrossing logistics links in actual operations, causing all-around conflicts in terms of efficiency and service. For example, cost economies associated with full truck or train loads are conflicting with excessive levels of stock resulting from full load shipments. As the emphasis in past decades was put on stock, average loads of trucks are low and empty trip frequency remains high despite efforts from transportation companies. For instance in Europe, 25% of trips are empty and non-empty trucks use 56% of the weight capacity (EuroStat 2007). This inefficiency leads to a dead-end in term of logistics sustainability. Montreuil (2009, 2011) provide a number of other important inefficiency and unsustainability symptoms.

2.2 The Physical Internet

As the current logistics organization is at the source of the problem by multiplying disconnected flows and inefficiencies, reinventing logistics organization can be a key to the solution. Having this in mind a new logistics organization was recently proposed by Montreuil (2009, 2011): the Physical Internet.

The aim of the Physical Internet (PI) is to universally interconnect logistics networks through world-standard modular containers, interfaces and protocols in order to improve the worldwide efficiency and sustainability of logistics. Basically, the idea is to do in the physical world what was done in the digital world by the Digital Internet. As described by Montreuil (2009, 2011), this universal interconnection has numerous radical impacts on logistics structuring, operations and performance as well as on the business models of Physical Internet users (retailers, distributors, manufacturers, etc.) and providers (transporters, 3PL, etc.). Fig. 2 illustrates through its contrast with Fig. 1 the impact on the design and typology of logistics networks.

Fig. 2. A topology of interconnected logistics networks

The huge potential of interconnecting logistics networks into a Physical Internet was recently confirmed analytically by a continuous approximation model (Ballot et al. 2011). For example, costs were divided by 1.5 to 2.5 and travelled distances divided by two to five depending on hypotheses, making it possible to reduce by four the CO₂ emissions induced by logistics.

2.3 How to define logistics interconnectivity’s components?

Achieving universal logistics interconnection is a demanding endeavour. Logistics networks combine physical objects and digital information. This requires the interconnection approach to combine both the digital and physical facets. The following section describes the types of models exploited in the Digital Internet to enable universal interconnection, providing a basis for the introduction in section four of the proposed model for the Physical Internet.

3. THE DIGITAL INTERCONNECTION MODELS

Interoperability of products and services was always a central problem in the field of Information and Communication Technology, in order to address the lack of inter-system interoperability. There are two main approaches for dealing with digital network interconnection, respectively expressed through the seven-layer Open Systems Interconnection (OSI) model and the implemented TCP/IP model, also known as the Four or Five-Layer Internet Model and the TCP/IP protocol suite according to authors. TCP/IP stands for the main protocol suite in the Internet that is the Transmission Control Protocol/Internet Protocol suite.

3.1 The Open Systems Interconnection model

The Open Systems Interconnection model was introduced by both the International Standards Organization in 1984 and the ITU-T as standard X.200 with a second edition in 1994 (ISO/IEC 1994). The most important OSI Reference Model concept is networking layers. As illustrated in Fig. 3, the OSI
Each layer of the OSI model has a specific purpose:

- The physical layer defines electrical and physical specifications for devices. In particular, it defines the relationship between a device and a transmission medium, such as a copper or optical cable.
- The link layer has the function and procedural means to transfer data between network entities and to detect and possibly correct errors that may occur in the physical layer.
- The network layer provides the functional and procedural means of transferring variable length data sequences from a source host on one network to a destination host on a different network, while maintaining the quality of service requested by the transport layer. It performs network routing functions.
- The transport layer provides transparent transfer of data between end users, providing reliable data transfer services to the upper layers. It controls the reliability of a given link through flow control, segmentation/desegmentation, and error control.
- The session layer controls the dialogues between computers. It establishes the connections between the local and remote application.
- The presentation layer establishes context between application-layer entities. It provides independence from data representation by translating application and network formats. It transforms data into the form that the application accepts. It formats and encrypts data to be sent across a network.
- The highest application layer is closest to the end user. It identifies communicating partners, determines resource availability, and synchronizes communication.

Layering aims to ensure independence of each layer by defining services provided by a layer to the next higher layer, independent of how these services are performed (Zimmermann 1980). This is illustrated in Fig. 4. Layers perform a global service by exchanging with each other through standard protocols, regardless of how the contribution of each layer is achieved internally.

As can be seen in Table 1, the TCP/IP model differs structurally from the OSI model by its number of layers, with its highest layer, the application layer, grouping the three highest layers of the OSI model (Kurose & Ross, 2008). Indeed the session, presentation and application layers are not distinguished in the TCP/IP model. They have been grouped as in practice Internet applications have historically not respected the layering strictness at these three highest layers of the OSI model. The lowest four layers have mostly the same functions in both models, with the ISO model expressing them in a broader open system context while the TCP/IP expresses them in a strict Internet context.

The layering concept offers three key advantages from the Physical Internet perspective. First it offers a framework to split a complex task in smaller and simpler tasks. Second it provides an easy way to implement and change components as the interfaces remain unchanged and interoperability. Third it is a key for interoperability, exploiting the fact that a given (n+1)-layer can use services from very distinct lower n-layer instances as long as the (n+1)/n interface is the same.

4. AN OPEN LOGISTICS INTERCONNECTION MODEL

Digital networks are heterogeneous, yet only deal with data. Logistics networks are not only heterogeneous but also have to handle not only goods but also much information, already partially digitalized (legal, custom, etc.), and money, now widely digitalized counterpart for the physical exchange. To enable seamless universal interconnectivity within such a complex setting requires a standard approach like was done for the Digital Internet. This leads to proposing an Open Logistics Interconnection Model of the Physical Internet.

4.1 Layered structure of the OLI model

As the Physical Internet is at its conceptual infancy stage, it is proposed to use a seven-layer service structure in line with the OSI model, with the understanding that practice may lead to unify some layers as was done with the TCP/IP model.

Fig. 3. Open Systems Interconnect Reference Model, ISO 7498, Organization for International Standardization (ISO).

Fig. 4. Services description of OSI model in.
Adopting seven layers offers richer and more rigorous representation at this early conceptual stage.

The OLI model proposes the following seven layers: (1) physical, (2) link, (3) network, (4) routing, (5) shipping, (6) encapsulation, and (7) Logistics Web. Table 1 contrasts the layers of the OSI, TCP/IP, and OLI models.

### Table 1. Layers of the OSI, Internet and OLI models

<table>
<thead>
<tr>
<th>Layer</th>
<th>OSI model: Digital Internet</th>
<th>TCP/IP model: Digital Internet</th>
<th>OLI model: Physical Internet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Physical</td>
<td>Physical</td>
<td>Physical</td>
</tr>
<tr>
<td>2</td>
<td>Data Link</td>
<td>Data Link</td>
<td>Link</td>
</tr>
<tr>
<td>3</td>
<td>Network</td>
<td>Network</td>
<td>Network</td>
</tr>
<tr>
<td>4</td>
<td>Transport</td>
<td>Transport</td>
<td>Routing</td>
</tr>
<tr>
<td>5</td>
<td>Session</td>
<td>Session</td>
<td>Shipping</td>
</tr>
<tr>
<td>6</td>
<td>Presentation</td>
<td>Presentation</td>
<td>Encapsulation</td>
</tr>
<tr>
<td>7</td>
<td>Application</td>
<td>Application</td>
<td>Logistics Web</td>
</tr>
</tbody>
</table>

Table 1 makes clear the firm intention to have the OLI model adhere to the basic logic of the OSI model, while adapting it to the realities of the logistics world. Layer 1 is named identically in both models. Second, the data link OSI layer becomes a link OLI layer, emphasizing that links are both digital and physical in logistics. Network layer 3 and transport layer 4 are named the same in both OSI and OLI models. Layers 5 to 7 have names more in tune with the physical world, yet conceptually play similar roles.

As in the OSI model, a layer in the OLI model is a collection of similarly conceptual functions providing services to its upper layer and receiving services from its lower layer. In the OLI model, these services can be offered by software agents, automatons and equipment, or yet by humans (directly or through a software interface). They can be also encapsulated in organizations.

4.2 Proposed layers of the OLI model

This section introduces the essence of each layer in the OLI model. It does not provide details about each layer, nor does it so neither about the standard protocols and services that will have to elaborated and implemented. This will the object of future research projects within the Physical Internet Initiative. Here the purpose is to put in place the basic foundations.

The layered services of the OLI model provide a framework for exploiting the physical, digital, human and organizational means of the Physical Internet. The basic seven layers of the OLI model are described hereafter.

**Layer 7**

The physical layer deals with moving and operating physical elements of the Physical Internet. These include π-containers as well as a variety of Physical Internet means such as vehicles, carriers, conveyors, stores and sorters (Montreuil et al. 2010). This layer validates that the physical elements are operating according to specifications, that for example a π-conveyor indeed allows moving π-containers between its entry and exit points.

The physical layer insures the standardization of the physical interconnections of the Physical Internet. It defines the physical specifications for π-containers, such as structural or electrical specifications, as well as of π-means. Functionally and dimensionally, it notably specifies the layouts and relative positioning of entry and exit points, gripping mechanisms and interlocking mechanisms. It monitors the π-means, aiming to detect and correct their physical dysfunctions such as the loss of integrity of a π-container having been dropped, unsealed without client agreement, or whose temperature control is malfunctioning. Thus RFID technology is a current solution for the digital side of the Physical Layer.

**Layer 6**

The link layer focuses on the detection and possible corrections of unexpected events form the operations at the physical layer by checking consistency between physical operations and its digital mirror.

It notably allows to detect and to engage protection against, or correction of dysfunctions such as a road segment or a conveyor being blocked, a π-container lost while being sorted, breakdown of security tracking of π-container moving along the π-link, or yet the appearance of an unknown security-threatening π-container. This layer is especially essential to ensure hand-over of a π-container from an operator to another and to avoid error propagation through the physical network. For that purpose, some standards such as EPCIS (GS1, 2011) could be used to enable the link on the digital side.
Network layer

The network layer focuses on the interconnectivity, integrity and interoperability of networks within the Physical Internet. It provides the functional and procedural means for insuring that π-containers can be routed within a π-network and across π-networks while maintaining the equality of service requested by the routing layer. Indeed it provides the protocols for π-containers assignment to means (handlers, vehicles, etc.) across the networks of the Physical Internet, similarly as TCP in the Digital Internet. It engages the triple-level assignments of π-containers to π-means on π-links according to the route provided by the routing layer. It monitors the π-containers as they flow across the Physical Internet, identifies routing errors and engaging in minimizing their impact, and complementarily identifies punctual routing opportunities and reacts so as to take advantage of them.

This layer also defines the composition and decomposition of π-containers, the assignment and control of flows of π-containers across π-networks.

Routing layer

The routing layer provides the functional and procedural means for getting a set of π-containers from its source to its destination in an efficient and reliable manner. It enables and controls the efficient and reliable inter-node transport and handling services to the upper layers according to their environmental, economical and service priority specifications. Stated otherwise, it defines for a set of container their best path according to networks status.

It is at this layer that π-routing protocols are defined, put into action and controlled. It monitors the status and service capability, capacity and performance of all π-means within each π-network. It does the same at an aggregate network level. For example it monitors the current accessibility of a given π-network.

Shipping layer

The shipping layer provides the functional and procedural means for enabling the efficient and reliable shipping of sets (corresponding to orders for instance) of π-containers from shippers to final recipients. It sets, manages and closes the shipment between the shipper and each recipient. It defines the type of service to be delivered (normal, express, etc.) and insures the management of receipt acknowledgements. It establishes and rules the procedures and protocols for monitoring, verifying, adjourning, terminating and diversion of shipments.

It gets shipping requests from the deployment layer and it requires transport services for its shipments from the transport layer.

Encapsulation layer

The deployment layer provides the functional and procedural means for efficiently encapsulates products of a user in uniquely identified π-containers before accessing the PI networks.

It allows linking product supply, realization, distribution and mobility taken at the upper Logistics Web level with their π-container deployment implications. It transposes decisions about moving and storing products into decisions about moving and storing π-containers. It proceeds first to encapsulation assignments of products within specific π-containers.

It monitors and validates the capabilities, capacities, prices and performances of π-nodes and π-means, in general of π-service providers, as well as the status of signed contracts and of deployed π-containers. At this layer reside certain current EDI operations.

Logistics Web layer

The Logistics Web layer is the interface between the Physical Internet and the users of logistics services. It provides the functional and procedural means enabling them to exploit the Physical Internet, indeed to take dynamic decisions about product supply, realization, distribution and mobility through an open and global Logistics Web enabled by the Physical Internet. Here, the term product is used as a generic expression encompassing materials, parts, modules, finished products, and so on. Such activities as the expression of needs, the programming of flows and the establishments of supply contracts are part of this layer.

It is within the Logistics Web layer that reside the vast majority of current software for supply chain management, logistics management, operations management and enterprise resource management.

4.3 Services between layers

The OLI model allows organizing the offered services on a layer per layer basis.

Fig. 6 illustrates this structuring by focusing on the inter-layer services involved in a client-supplier purchase order.
Complementary to the inter-layer service logic depicted in Fig. 6, logistics services are also laterally structured among actors within each layer. At the lowest physical layer, they for example structure the services associated with insuring a proper physical and digital loading of a π-container into a trailer. Within higher layers, they insure the physical, digital and operational handshaking necessary for defining and coordinating segments, routes and shipments.

The service layers get into play within each user of the Physical Internet and within each logistics service provider, through every node in the networks, so as to insure the efficient, robust and sustainable source-to-destination delivery, routing, deployment and monitoring of π-containers within the Physical Internet.

5. CONCLUSION

As a contribution towards the enabling of the Physical Internet, this paper has introduced the Open Logistics Interconnection (OLI) model. Similar to the Open Systems Interconnection (OSI) model, the OLI model exploits a seven-layer logistics service structuring.

The OSI model and its simplified TCP/IP model alternative have played and are still playing today a central role in shaping the Digital Internet. The OLI model aims to fulfil the same niche in logistics. Yet it is more complex and nuanced as the Physical Internet deals with physical objects, data, money and humans. At its highest layers, the OLI model deals with supply chain, realization, distribution and mobility decisions at the core of business competitiveness. At its lower layers, it deals with the interplay of complex handling, storage, transportation and tracking technologies. Overall it has to be applicable across industries, markets and regions at various levels of economic, technological and logistics maturity.

The paper opens a promising research avenue as it has merely scratched the surface of the OLI model specification. More in-depth layered service definitions are required. Standards and protocols must be proposed, assessed, experimented and validated within each layer and across layers. Even the current appellation of each layer and the number of layers are tentative and may be bound to adaptations based on further investigation. This has happened with the Digital Internet through the collaborative learning process associated with its several times scaled up implementation and exploitation. The paper offers a starting point, hopefully motivating numerous researchers to tackle these hugely important issues on the roadmap toward efficient and sustainable logistics across the world.

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