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Review

Intelligent logistics systems in E-commerce and transportation

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Abstract: Smart coordination of production, logistics, transport and governance aims to move, store, supply and use physical objects throughout the world in a manner that is economically, environmentally and socially efficient, secure and sustainable. To achieve this, intelligent Logistics Systems (iLS) are needed, providing for transparency and interoperability in Society 5.0's smart environments by Augmented Logistics (AL) services. iLS are high-quality Autonomous Systems (AS), represented by intelligent agents that can easily take part in and learn from their environments. Smart logistics entities, such as smart facilities, vehicles, intermodal containers and distribution hubs represent the infrastructure of the Physical Internet (PhI). In this article the role of iLS in e-commerce and transportation is discussed. New behavioural, communication and knowledge models of iLS and their AL services in relation to the PhI OSI model are presented.

Keywords: internet of things; smart production; smart logistics; smart business models; sustainability

1. Introduction

In this article the next generation of intelligent Transportation Systems, namely iLS in e-commerce and transport applications is addressed. First the state of technology in e-business and logistics is discussed, followed by a literature review to present the state of practice and research. In the sequel a novel iLS concept is presented, introducing a systematic approach to iLS design, addressing all of the distinguishing properties of the latest technological revolution. Its application is illustrated by a use case. By its discussion the most important properties of this solution and the impact on related smart environments are highlighted. In the contributions the distinguishing characteristics of this research are emphasized and its results are summarized. In the conclusion an overview of the past and an outlook on the future researches in this field are given.

1.1. State of technology

On the verge of a major paradigm shift from digitized and automated Society 4.0 to intelligent and autonomous Society 5.0 the next technological revolution is taking place.

For quite some time IT professionals have been seeking methods and tools to integrate business information systems amongst each other. At first, their aim was to enable their cooperation by e-business middleware–the so called "business connectors". As their partnerships spread, their information systems needed to be orchestrated, to finally achieve excellence in supply chain management, mainly by increasing transparency and by facilitating automated supply chain operations. Eventually, extended partnerships along supply chains have been achieved by the introduction of the Supply Chain Operating Network (SCON) [1] concept. However, their developers nowadays are confronted with numerous compatibility, scalability, transparency and sustainability limitations of contemporary e-commerce and Transport Management Systems.

Modern vertical PaaS (e.g., Elemica (http://www.elemica.com)) and horizontal SaaS (e.g., Salesforce (http://www.salesforce.com)) supply chain integrations through Web interfaces and cloud-based delivery models can offer a good enough solution in most contemporary business cases [2]. The same goes for smart city applications, where the city infrastructure and services are integrated by using Internet of Things (IoT) technology to be managed and made available through Web services and mobile apps (e.g., SmartAppCity (https://www.smartappcity.com/en/)).

On the other side, the agent based delivery model through intelligent Web and eXtended Reality interfaces offers greater flexibility in terms of transparency, scalability, interoperability and maintainability. Since these are the key properties of smart and sustainable logistics, they have become the next hot topic on the research agenda.

1.2. Literature review

In the past few years the aforementioned issues have been addressed from the perspective of smart production and logistics as well as smart governance by designing iLS for mutual cooperation, automatic cohesion, and integration of tracking and tracing technologies. In smart production and logistics environments their integrations with existing and newly developed Transport Management Systems, warehouse management and e-commerce applications has been investigated [3].

Smart city logistics has been extensively investigated to render economically, ecologically and socially excellent solutions that would disburden the city traffic while enabling efficient mobility and delivery of goods. In the course of this the main constraints and supporting technologies have been extensively investigated [4, 5]. Intelligent sensor networks have been identified as key traffic information source technology [6]. Big Data and data mining have been identified as key technologies for managing journeys, delivery trucks, toll collection, public transport, road safety and shared traffic information [7]. The use of intelligent traffic control, co-modality and modular containers has been investigated to provide for faster and more efficient transport of people and goods in urban areas [8]. In response to the increasing e-business market, last mile delivery [9] has been investigated in association with the management of urban consolidation centres [10, 11] supporting them. Hereby, the important role of the PhI in last mile parcel delivery has been highlighted.

Several authors have published researches that combine the IoT and Big Data technologies with e-commerce applications to form sustainable iLS solutions for smart communities and cross-border cooperation [12, 13]. Many have proposed to use hybrid agent based systems, integrating intelligent distribution centres within e-commerce application environments [14–16]. They also investigated the indicators influencing organisational efficiency in smart logistics ecological chains [17, 18]. By the introduction of intelligent agents technology, Big Data analytics and artificial intelligence methods, local, regional as well as cross border optimization of logistics networks are being strived for [12, 13, 15, 17, 19, 20].

An integral smart production and logistics solution has also been proposed by a patent application CN102708474A. The envisaged IoT-based intelligent logistics system comprises a real-time logistics tracking service system, a logistics management platform subsystem, a transportation scheduling and monitoring subsystem, a warehouse management subsystem and an e-commerce platform subsystem. It promises saving manpower cost and time by integrating it with an e-commerce platform and is characterized by transparency of the information exchange.

From the perspective of information system safety and data security several issues have been highlighted–starting with data mining technologies [21] on logistics Big Data as well as advanced security analysis and transaction supervision to assure the security, control, and operating efficiency of transaction supervision [13].

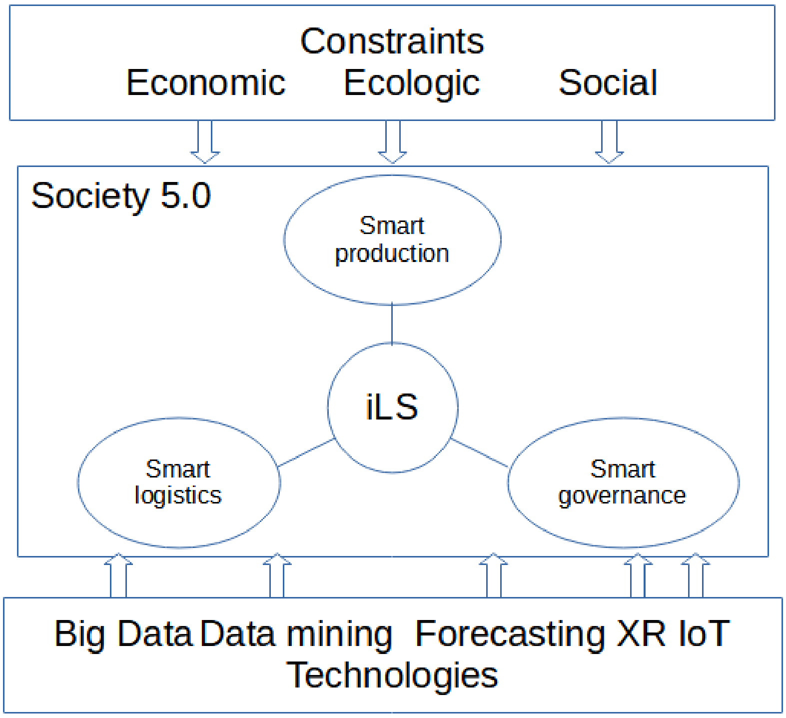

Figure 1. iLS in Society 5.0.

While the majority of the listed research works address different aspects of iLS design, only the patent application integrates IoT technologies with existing tracking and tracing technologies, like RFID and GPS, and a warehouse management, transport management and e-commerce platform to provide for an integral solution. Although at first sight it seems reasonable, to provide for a standard off-the-shelf AL framework, integrating new methods and technologies into such a solution may become increasingly difficult over time.

The problem with most of the listed solutions lies in the fact that they are proprietary, adapting themselves to existing technological solutions that are enabling on one and limiting on the other side. The common denominator of these solutions is that they don't imply the PhI as infrastructure. Hence, iLS can't unleash their full potential, since there is no reference to provide for interoperability of the proposed state of the art solutions. As with the mentioned e-commerce solutions, interoperability is also the key property of smart city solutions, and will be crucial when integrating the smart environments of Society 5.0.

1.3. Background

The formerly reviewed state of the art researches feature all Society 5.0s "smart" business models–smart production, smart logistics, smart governance–as well as most of its characteristic technologies–Big Data, Data Mining, Forecasting, Digital Twins and some form of eXtended Reality (Figure 1). iLS represent a central part of its information infrastructure combining the individual solutions into an ecosystem of independent but interrelated actors. As such, they represent a platform for their cooperation.

The background of this research relates to all aspects of the researches from the literature review. First, the concept of a logistics platform and service quality between the echelons of a supply chain was established [22]. Then a supply network was modelled as an overlay network on which autonomous agents perform supply chain operations [23]. A simulation study has shown that a network like this regulates itself considering its service quality [24]. Then an agent based e-commerce application was defined and evaluated to perform in correspondence with the simulation model [25]. By using a Bayesian model the service quality was confirmed to be the distinguishing property of choice in automated supply chain ordering processes [26].

The aforementioned research outcomes were joined by the concept of a SCON, being formerly investigated in [2]. The Intelligent Transportation Unit (iTU) [27] and intelligent agent concepts were joined in a iLS logistics framework, based on the PhI, as introduced in [1]. While the behaviours of intelligent agents, forming this adaptable, self-regulating network have already been modelled in [28], its data model remained to be defined. To be usable by the different entities and their iLS forming this network, it would have to be distributed, shared and communicable.

The distinguishing property of the researches listed in the literature review and the research presented here is the proposition of using the PhI as infrastructure. This is important to assure some form of an Open Logistics Interconnection Model [29] and allow for interoperability of the different methods and technologies used in designing modern iLS.

In the sequel, the concept of iLS featuring AL over PhI and the iLS-ontology, as their data management and information interchange model of choice, will be presented. Their important role in designing future smart logistics applications will be elaborately discussed.

2. AL over PhI

Since the PhI [30] is considered the result of a technology transfer of the Internet into the transportation domain, it is possible to make some assumptions that enable their comparison. Representing a logistics and transportation infrastructure of smart logistics entities to build their supply networks on, it relies on its acceptance and utilization to fully unleash its potential. Hence, apart from its OSI model, providing for interoperability and operational transparency, the development of appropriate AL services shall be crucial for its acceptance.

To successfully integrate AL services into the PhI, its four basic OSI-layers (Figure 2) needed to be defined [1]. In order to provide for AL services at PhI nodes, iLS should be aligned with them and the associated PhI OSI model. They shall provide for their physical, operational and transactional interoperability. By iLS intelligent entities in the PhI will not only communicate with or on behalf of persons, but rather with each other to automate supply chain processes by their interactions, thus facilitating their fully autonomous behaviour. Eventually, PhI service quality shall be manageable by introducing similar quality assurance mechanisms, as they already exist in the Internet, into the PhI.

In this article the iLS are introduced as PhI node's IT frameworks to build their AL services on. Since their operations are founded on the Monitor-Analyse-Plan-Execute loop over a shared Knowledge (MAPE-K) these operations represent the cornerstones for their consideration. First, the iLS are presented for what they are and how they operate. Then, their services are aligned with the PhI OSI model. Eventually, as a central part of their consideration the iLS knowledge base in the form of an ontology is presented. The procedures involved are addressed by the descriptions of individual PhI entities and illustrated by a use case. In the following discussion a review of the presented concepts renders a conclusion to this study.

2.1. iLS

iLS [1] are high-quality AS, represented by intelligent agents that can easily take part in and learn from smart environments to allow their stakeholders to fulfil their goals in socially and environmentally conscious ways and still remain competitive. As such, they incorporate the characteristic "self-properties" that pertain to AS:

- *Self-management* incorporates integrated-logistics support mechanisms to allow for sustainability.
- *Self-configuration* allows for easy discovery, connectivity and collaboration between iLS.
- *Self-optimization* includes a knowledge base to allow iLS to learn from their experiences and improve their performance.
- *Self-healing* allows iLS to quickly adapt in the case of extraordinary events or incidents.
- *Self-protection* establishes protection mechanisms to prevent iLS to be exploited in harmful ways.

AL services represent interfaces to iLS functions that will allow companies, governments, academics and citizens, to easily surpass the challenges that will be imposed by the PhI as a fundamental background process connecting the physical and cyber worlds.

iLS shall build and maintain a multidisciplinary knowledge base for immediate use by iLS stakeholders. This should allow companies to prevail over the necessary data analysis skills required to exploit big data stored in their knowledge bases and their PhI overlay network more easily.

Interoperability, data mining and decentralization of functions will allow iLS to be used not just in smart logistics and production environments, but also within the governance of the emerging smart cities and communities [1].

2.2. PhI OSI model

Here, based on the previously defined iLS protocols [28], the associated AL services among intelligent agents across the PhI (Figure 2) are elaborated to form its OSI model.

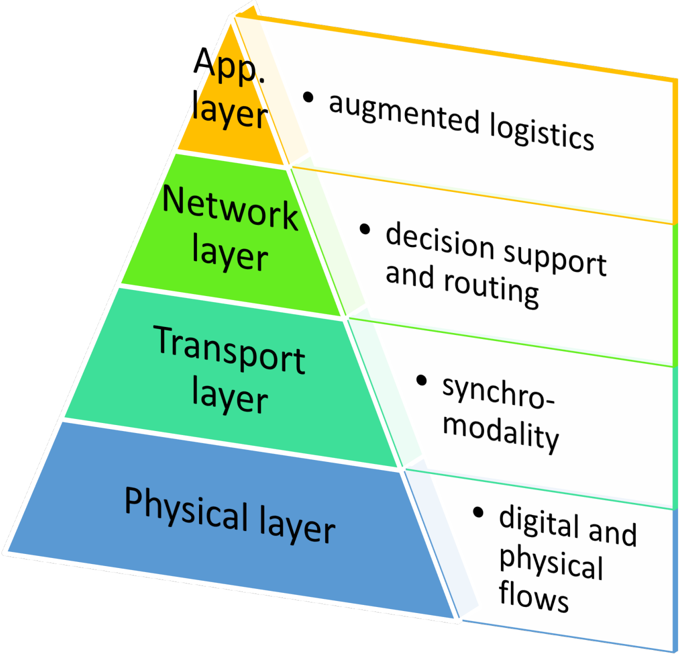

Figure 2. PhI OSI-layers [1].

On the *physical layer* digital twins are formed for each of the logistics entities. They are assigned intelligent agents and joined in the iLS ontology (Figure 4). The most important property of entities on this layer is self-configuration – they need to establish and maintain their state (online, maintenance, offline, etc.) and status (e.g., location, temperature, pressure, stored/unloading/loading/transit/alert, etc.).

On the *transport layer* storage/deployment and routing operations take place. The most important property of entities on this layer is self-management–they need to manage their properties (Figure 5) like the changing states and status of storage, cross-docking and transportation facilities, as well as intelligent transport units (iTUs).

On the *network layer* routing decisions are made based on the relations among PhI- nodes (Figure 6). The most important property of entities on this layer is self-optimization–based on the status of the transport units and the availability of the neighbouring facilities, optimal routing decisions should be made to route transport units from sender to receiver in the fastest and safest manner. On this layer also self-healing actions need to be performed in case the states of the network nodes or the status of iTUs require them.

On the *application layer* AL interfaces need to be established among agents representing digital twins of logistics entities on one and legacy information systems on the other side. Based on the properties and relations of the nodes they represent, transactions, like orders, shipments, confirmations and other information telegrams are being formed and interchanged among intelligent agents as FIPA ACL messages in order to perform the specified operations on the PhI-network. Apart from this, the most important property of entities on this layer is self-protection–mainly data need to be protected in order to prevent their misuse. Hence, order and shipment data need to be accessible by authorized partners only, using appropriate signatures to authenticate themselves on the network. To protect shipments from tampering, they also need strong authentication methods to safeguard their promotion [1].

3. iLS ontology

By the use of the *iLS ontology* (Figure 3) digital twins are assigned to e-marketplace entities, PhI nodes and transport units. Here, their properties are stored and maintained in real time to provide for insight into the PhI-network status at all times.

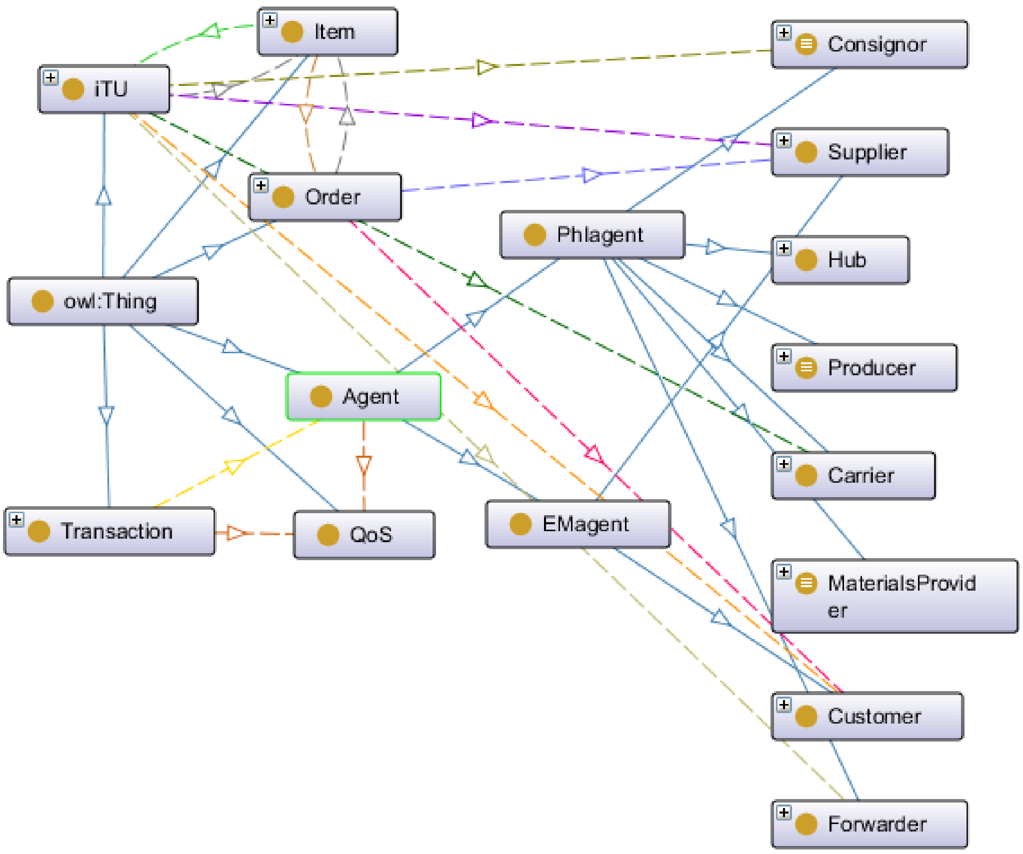

Figure 3. iLS ontology.

There are two types of entities in the iLS ontology: active and non-active (Figure 4). Active entities are subclasses of an Agent, representing the aforementioned intelligent agent, autonomously acting on behalf of its associated supply chain node. Non-active entities are Items, iTUs, Orders and Transactions, being handled by the PhI-network, as well as the Quality of Service (QoS) properties of Agents being achieved by their Transactions.

As new entities emerge, they are included into the PhI-network and are instantly visible to other entities. All changes are easily implemented by simply adding/extracting instances and assigning/changing their parameter values.

Since the users of the PhI-network are the Suppliers and Customers ordering Items on the E-marketplace, these classes of agents are introduced first. Every Order is fulfilled by promoting the ordered Item(s) through a supply chain between a Customer and a Supplier. A Supplier acts as a Consignor, shipping an iTU containing the ordered Item(s). They are transported through the network between a consignor (Supplier) and consignee (Customer).

In the iLS ontology two types of agents are intertwined–E-marketplace agents and PhI-agents–each having their own properties and relations. The Consignor agent represents their intersection since it relates to E-marketplace as well as PhI-agents likewise.

The fulfilment of a shipping Order is its entry point from the E-marketplace to the PhI, being the reconfigurable transportation network of PhI-agents facilitating the transfer of the shipped Items. The PhI-agents agents taking role in this process are a Consignor, a Carrier, a Forwarder and a Hub.

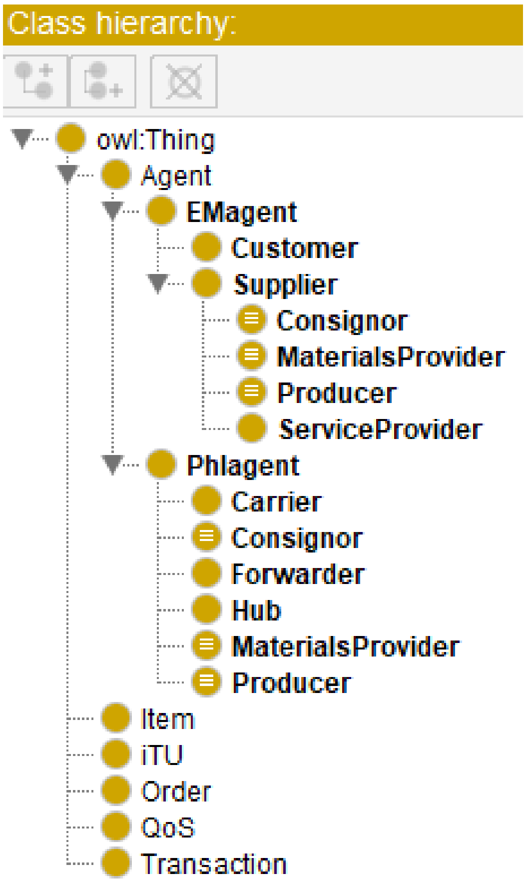

Figure 4. iLS entities.

A minimum number of required properties of the aforementioned iLS entities has been assembled in Figure 5. Every agent has a name and location. Location information is two-fold–an address as a string of characters and a Geo-location–for easier processing. It also has a creation time–the time when it was first initialized–as well as a maintenance time, interval and duration.

Every PhI-agent has a capacity being maintained as remaining capacity for load balancing purposes. Consignors can be attributed with a known consignor status (KC). In the same way PhI Hubs can be assigned their regulated agent (RA) status. The two statuses are used when determining the procedures and durations of their transactions handling [1]. Every PhI-agent is also assigned a state information–in maintenance, offline, or online. Every iTU is assigned a status information–damaged, loaded, stored, tampered, transported, or unloaded.

Every E-marketplace Order is assigned an Available-To-Promise parameter (ATP) being used to assess its timely fulfilment. It may comprise a number of Items, each attributed by a count and price as well as maximum price (MaxPrice) parameters for Supplier assessment [25]. Every Order may be fulfilled by a number of PhI Transactions taking place on the PhI-network. Transactions are attributed QoS values associated with their fulfilment. Every Agent inhibits the collective QoS value of all its Transactions for service quality assessment and load balancing.

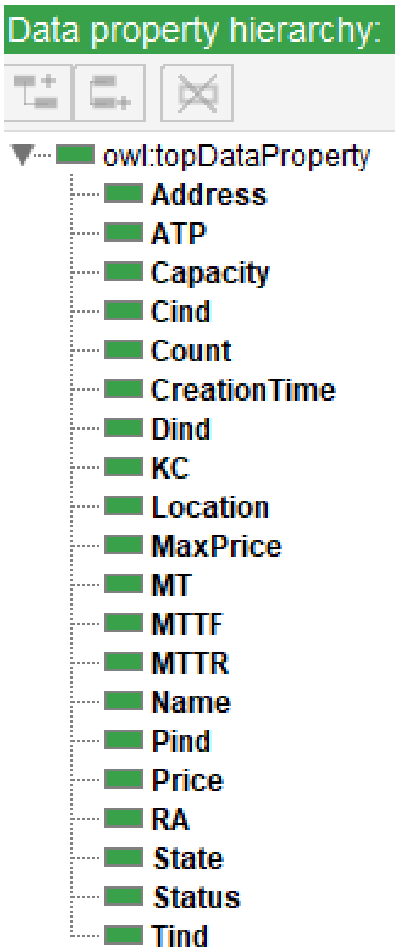

Figure 5. iLS Entity Properties.

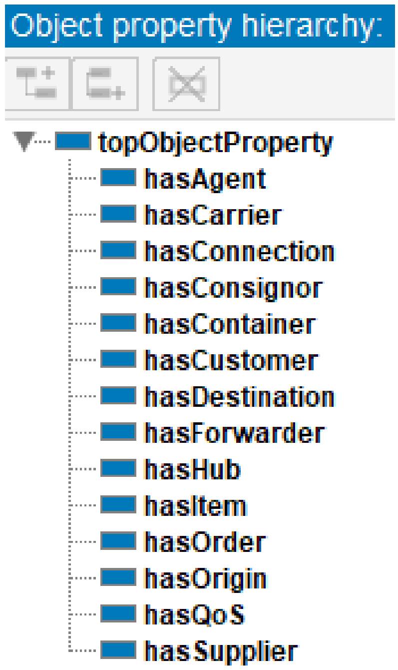

Figure 6. iLS entity relations.

Eventually, iLS ontology entities build associations that sensibly glue them together and establish the PhI network (Figure 6). Every Transaction has an associated Agent performing it (hasAgent). Every iTU has a consignor (hasConsignor), carrier (hasCarrier) and a forwarder (hasForwarder) handling it. It has an origin (hasOrigin), representing a Supplier and a destination (hasDestination), representing a Customer. It also has a collection of Items (hasItem) it comprises. In turn, every Item belongs to an Order (hasOrder) and is transported by an iTU (hasContainer). Every Order has a Supplier (hasSupplier) and a Customer (hasCustomer). A network of Hubs is formed by connections (hasConnection). Each Customer and Supplier may choose their Hubs through which they operate (hasHub). Finally, every Transaction and Agent have their QoS attributed (hasQoS) to intelligently perform supply chain operations on the network.

3.1. AL services

As indicated in [28], AL services are triggered by posting the appropriate FIPA ACL messages to respective iLS agents (e.g., a purchase requisition to the Customer agent). They are fulfilled autonomously on the PhI network as defined by their behaviours and communication protocols, referring to their ontology relations and properties to perform correctly. The iLS ontology is used to store and deliver all relevant information on the actors in the iLS framework–their knowledge base (Figure 7).

The *FIPA-contract-net* protocol [31] is used by e-marketplace and PhI agents to settle e-marketplace orders and perform PhI transactions utilizing the PhI network to transport an iTU from origin to destination. While the PhI infrastructure takes care of the core forwarding and routing process, the rooting decisions are made by PhI agents in real time, considering multiple factors (PhI node status, QoS parameters, capacities, etc.) that affect the safety and efficiency of order fulfilment. Hence, as indicated above, at each step additional monitoring and planning actions take place, affecting subsequent execution and control actions – MAPE-K loop.

Apart from moving the iTU through the network, PhI agents can also monitor the status and location of the shipments during transit. To make these inquiries, the *FIPA-query* interaction protocol [31] is used.

3.2. Service quality assessment

To provide for compatibility with the E-marketplace agents, the same QoS indicators ([25]) apply to PhI-agents as well. Their associated parameters (Figure 5) are: correctness (Cind), dependability (Dind), price (Pind) and timeliness (Tind).

Table 1. iLS Quality of Service Criteria.

Name	Description
Correctness (C)	"the ratio of correctly performed transactions."
Timeliness (T)	"the ratio of timely performed transactions."
Dependability (D)	"the mean of robustness plus availability."
Price (P)	"the ratio of price vs. maximum price."

While each Agent maintains its QoS indicators (Table 1), each Transaction is also assigned its own QoS value set that determines the service quality of its fulfilment. Based on their relative importance at each particular PhI node, appropriate weights (c, t, d, p) may be assigned to the QoS indicators:

$$QoS = \frac{c \times C + t \times T + d \times D + p \times P}{c + t + d + p} \tag{3.1}$$

By convention, all QoS indicators as well as their weights are in the interval (0,1). Their initial values are established with the initial configuration of each node and their gain [26] is recalculated with each transaction they perform.

3.3. Use case

Let us consider a working scenario based on the iLS ontology defined above. It consists of concrete actors–instances of E-marketplace and PhI Agents–fulfilling their functions on the PhI network through their iLS agents. Like the iLS ontology, it has been constructed using Stanford's Protégé tool [32].

Supposed we have a supplier of pharmaceuticals (e.g., Lek Ljubljana) who would like to deliver the ordered item (e.g., Item1) to one of his customers (e.g., Mariborske lekarne). Apart from the obvious customer-supplier relation it also acts as a consignor who ships the packaged item (Item1) in a container (e.g., iTU1) through its supply network. This operation involves the following steps (Figure 7):

1) The Consignor (e.g., Lek) assigns a carrier (e.g., Intereuropa) to transport its shipment from its location to the customer's location (e.g., Intereuropa Maribor Hub);

2) The shipment container (e.g., iTU1) is assigned the first available cargo transporter (e.g., forwarder IE101) between the two locations;

3) The two mentioned cargo hubs (e.g., Intereuropa Ljubljana and Maribor) serve as intermediate storage locations for all outgoing/incoming shipments of Lek/Mariborske lekarne;

4) Upon arrival the shipped item (e.g., Item1) is extracted from its container (e.g., iTU1) and stored at the customer's location.

Of course, the delivery needs to be agreed upon beforehand (Figure 7) in some previous correspondence between the two supplier and customer agents. As described in [28], each move through the supply network represents a PhI transaction (Figure 7). Their fulfilment is subjected to QoS monitoring, which helps to maintain the health of the supply network. Every supply chain operation refers to designated E-commerce and PhI agents who maintain their QoS, to be checked in their future correspondence.

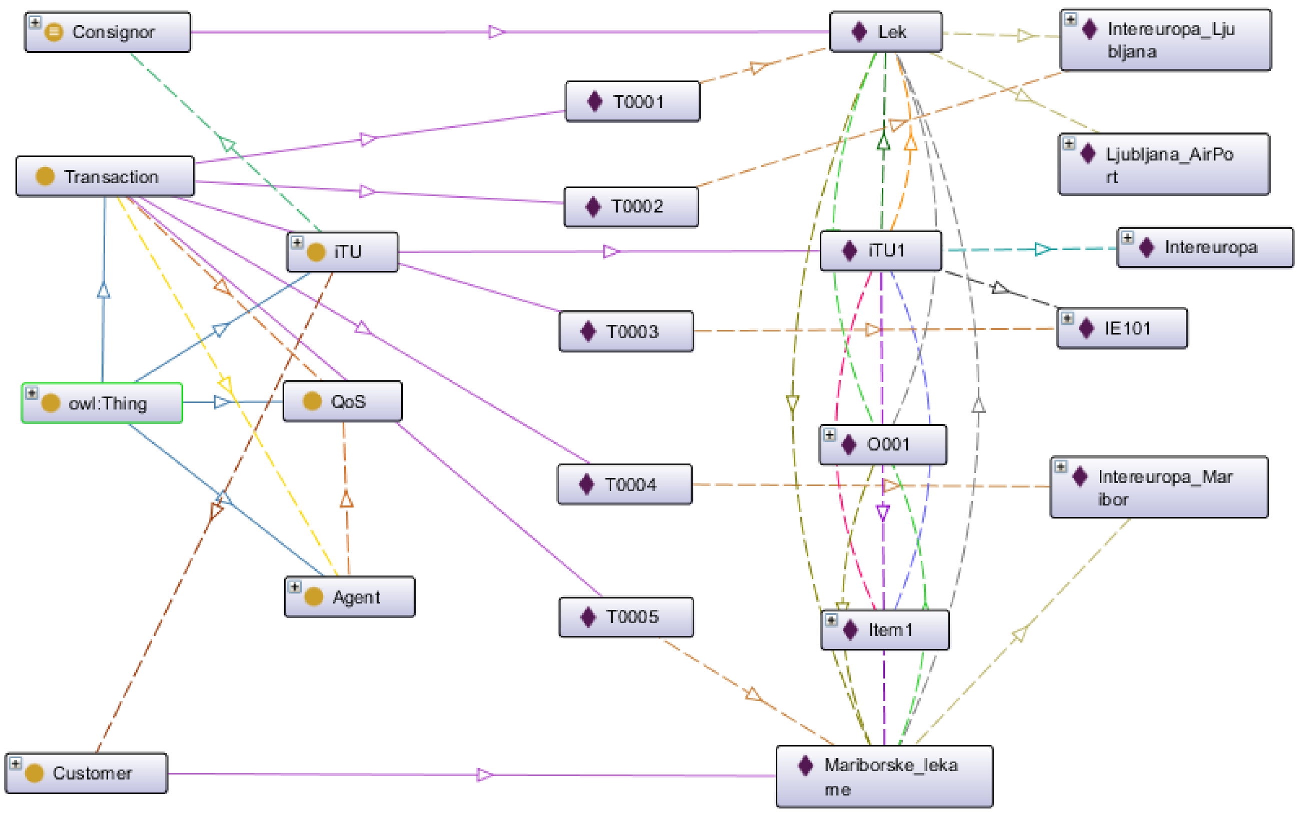

Figure 7. Order fulfilment and iTU Transfer Scenario.

3.4. Discussion

In terms of transparency, this iLS framework offers full transparency of the PhI network to its users. As in the Internet, they can establish short and long distance connections to their partners and monitor the fulfilment of their operations in real-time.

This adaptable framework also provides for scalability since SCON partners can join the PhI network, use its resources and leave it seamlessly. This is only a matter of iLS configuration and registration with the network. The interfaces and protocols are clear and simple, providing for interoperability and maintainability in the iLS based SCON framework.

In order to maintain a certain level of QoS within the PhI, its monitoring needs to be automated. From this point of view, the PhI nodes' QoS indicators collectively represent the network status. Based on their values, assignment and routing decisions are made to assure safety and efficiency of the PhI network. They may also be used to identify strong (mainstream) and weak (support) network nodes, which is important from the perspective of load balancing in the PhI network.

To provide for sustainability, integrated logistics mechanisms [33] should be in place. All iLS agents possess two intrinsic properties, indicating their availability as well as their up-time (Figure 5). Maintenance actions may be scheduled to be performed at certain nodes of the network in the prescribed intervals. During their maintenance, their status is offline and their assignments and flows are redirected by the PhI network layer in order to maintain network availability and flexibility. By doing so, one not only can make informed assignment and routing decisions to provide for network efficiency, but one can also predict the availability of network nodes. Typically, for the nodes certain utilization and/or maintenance intervals should not be exceeded. In cases of extraordinary situations like irregular node failures or (partial) network black-outs, the support nodes need to sustain network operation until recovery/maintenance actions are complete.

To provide for safety and security within the PhI network, automated authentication and authorization methods of consignors and their consignments should be used [27]. In addition, to assure confidentiality and traceability of items and/or transactions also the Blockchain mechanism can be used.

4. Contributions

To allow for smart production and logistics integration the agent based delivery model has been chosen in this research. Since in logistics the Internet of Things can be used to represent moving objects, these concepts could be combined.

To serve as a SCON, the appropriate data representation and interchange models for future smart production and logistics applications have been investigated. In this article the knowledge base of an agent based SCON platform for integrated e-commerce and supply chain management applications has been introduced. Based on an existing e-commerce ontology and the PhI OSI model an appropriate iLS ontology for smart logistics applications has been devised.

In contrast to existing PaaS and SaaS delivery models, using the agent based delivery model and ontology as knowledge base offers significant improvements in flexibility, maintainability and transparency of SCON. By using the iLS agent based framework, its stakeholders don't need to reveal any more information than they usually do in performing e-commerce and supply chain operations. Moreover, their operations are performed autonomously and transparently, using the PhI infrastructure and standard FIPA protocols.

In addition to the aforementioned benefits, also two key aspects in designing sustainable PhI applications have been considered and systematically addressed by this iLS framework – service quality as well as safety and security. By integrating the concept of QoS into the model, transaction data can be used for local, regional as well as global supply chain optimization. By design, iLS protocols also feature safety measures like state monitoring, load balancing, planned maintenance, etc. At the same time, data security is provided for by secure transaction channels, strong authentication of iLS agents and secure authorisation of iTUs, as described in [27].

This article features a review of iLS and their applications. The use of iLS in e-commerce and transportation are addressed by the presented agent based SCON framework model. By the layout of its design and the case study a proof of concept is given. Although still evolving, the presented iLS ontology at current stage already enables the representation of supply chain nodes and transport units in the semantic Web – for who they are, what they do and the ways they interact. Due to its transparency, interoperability, flexibility and scalability, it fulfils all predispositions of the iLS-based SCON data model.

5. Conclusions

Smart production, smart logistics, and smart governance (smart cities and communities) are iLS applications used in these smart environments to intelligently manage their resources and processes. In the perspective, they shall be integrated across the PhI by an ecosystem of cooperative intelligent production, transportation and governance systems–their iLS frameworks–and their associated AL services. Being spatially and temporally determined, these systems need to be aware of their perimeters during their operation. Only by this, the stimuli from their environment can be aligned with their actions. Hence, the need for a common knowledge base, presented here.

Besides connectivity, interoperability and QoS, iLS need to expose properties, native to autonomous systems: *self-configuration, self-management, self-healing and self-protection*. To achieve these goals, they need to utilize and maintain a knowledge base, as defined by the here described ontology, as well as utilize Artificial Intelligence methods in their operation. Intelligent Web, agent and eXtended Reality technologies are to be used to access, use and control them through their AL services.

Apart from their obvious use in smart production and logistics applications, intelligent agents and ontologies represent the foundations and building blocks for the transition from the digitized Society 4.0 to the smart and socially aware Society 5.0, also termed the Innovation Society. By the integration, foreseen by iLS, they may achieve their goals in an efficient, green and sustainable manner.

Conflict of interest

The author declare they have no conflict of interest.

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