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An Information Framework for Internet of Things Services in Physical Internet

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ABSTRACT The physical Internet (PI, or π) concept was developed to address the current unsustainability problem of logistics systems. The key physical elements in the PI include π-containers, π-nodes, and π-movers. The π-containers designed to be world-standard, smart, green, and modular are moved, handled, and stored throughout an open global logistic infrastructure. Meanwhile, the π-nodes and π-movers including physical systems and vehicles are designed to exploit as best as possible the characteristics of π-containers to facilitate material handling processes. Thus, the logistics industry vision is a key player poised to benefit from the Internet of Things (IoT) revolution since millions of π-containers with contained shipments being moved, tracked, and stored by a variety of the π-nodes and π-movers each day. This paper proposes first an information framework enabling IoT of the PI infrastructure and then a service-oriented architecture for the IoT applied for providing the IoT logistics services for the PI. A case study utilizing the architecture is presented to illustrate an efficient management service of logistics operations in the PI.

INDEX TERMS Internet of Things (IoT), physical Internet, wireless sensor network, RFID, M2M, service-oriented architecture (SOA), 3D layout.

I. INTRODUCTION

The current logistics system is still recognized to be unsustainable in terms of economy, environment and society despite several innovative logistics paradigms accompanying projects have been proposed and undertaken to reverse the situation. The intelligent logistics exploiting the intelligence concepts thanks to the integration of advanced information and communication technology (ICT) to improve the overall efficiency significantly in terms of security, physical flow management, automation of processes. One of key factors of such logistics vision is intelligent freight-transportation system that uses the latest technologies, infrastructure, and services as well as the operations, planning and control methods to efficiently transporting freight [1]. Such system is an effective solution to the significant transportation-related issues such as congestion, energy consumption, and environment. Simple Links[1] is an alternative framework of intelligent logistics. The project conducted by the consumer good forum aims to create, manage and analyze digital links between items and their containers as a dynamic hierarchy, then to infer item-level tracking and monitoring information for any item based on searching the hierarchy for the best available track, monitor and prediction data at a given time. The objective of project is enabled by an underlying principle that make items and their containers communicate together to share information all along the logistics links by using low cost identification technology (i.e., QR code). The primary demonstration results of the project imply the positive impact of project since it supports both ecological and economical value end-to-end. To reduce the environment damage caused by inefficient ways of logistics activities, the Intelligent Cargo project (iCargo) project[2] funded by European Union is expected to provide a potential solution. Relying heavily on ICT, the iCargo is capable of self-identification, context detection, service access, status monitoring and registering, independent behavior and autonomous decision making. Thus, the end-to-end visibility of shipment flow is improved by a cargo tracking system [2]–[4] capturing the real time

[1] Simple Links project introduction,https://www.theconsumergoodsforum.com/wp-content/uploads/2018/02/CGF-Simple_Links_White_Paper-1.pdf

[2] iCargo project, https://ec.europa.eu/digital-single-market/en/news/intelligent-cargo-more-efficient-greener-logistics

information relating to the location, time and status of the vehicles and carried iCargo. In this way, the logistics processes such as asset management, routing path of freight can be optimized to avoid empty trucks or congestion. Another logistics visions termed as green logistics indicates methods that employ advanced technologies and innovated equipments to tackle the environment issues such as greenhouse gas (GHG) emissions, noise and accidents mainly caused by inefficient logistics operations [5]. To make the global logistics green, the environment aspect is concerned as the top priority in all logistics operations, in particular, transportation, warehousing and inventory operations [6]. These three activities are conducted in a series of researches and investigated in Operation Research (OR) models. For example, to minimize the GHG emissions by the transportation, the operation is performed by optimizing four significant choices, namely, mode choice (i.e., plane, ship, truck, rail, barge or pipelines), usage of inter-modal transport (i.e., types of containers), equipment choice (i.e., type and size of transportation unit) and fuel choice (e.g., gasoline, bio-fuels, electric, etc.). As the optimal selection of these handling equipments is set off, the minimum emission is obtained, thus the environment sustainability is resulted in.

Recently, the Physical Internet (PI, or π) is an emerging paradigm that is strongly expected to achieve simultaneously the three dimensions of sustainability: economy, environment and society at global scale [7]. Conceptually, by taking the Digital Internet as a metaphor the PI is built towards an open global logistics system founded mainly on physical, digital, and operational inter-connectivity through a standard set of modular containers (π-containers), collaborative protocols (π-protocols), and smart interfaces (π-nodes, termed for container distribution centers) for increased efficiency and sustainability [8], [9]. Accordingly, the PI does not manipulate the physical goods directly but such π-containers that encapsulate the physical merchandise within them. These π-containers are world-standard, smart, green and modular contains. Particularly, they are characterized by modularity and standardization worldwide in terms of dimensions, functions and fixtures. In the existing logistics and supply chain the diversity of brands and types of products with various sizes and weights leads to a nearly infinite range of different sizes of carton boxes. Therefore, generating efficient unit loads from such a high variance of cases is complicated and leads to inefficient space utilization at the pallet level and as a consequence also on a truck level. To release such issues, the container standardization concept of the PI aims to determine a limited set of modular container dimensions subject to all specific requirements [10]. Thus, having a small number of such containers would make it much easier for goods to be rolled out of π-nodes and onto π-trucks and π-trains. In addition, as the open global logistics network, the PI allows all stakeholders share the infrastructure including the π-containers, π-nodes, and π-movers (denoted for material handling equipments) to maximize its operation efficiency. In addition, the modularity of these containers enables sets of smaller π-containers to be composed easily to generate composite π-containers, which are efficient unit loads throughout the PI network. In addition, the π-nodes and π-movers are designed and innovated to exploit as best as possible the standard and modular encapsulation. For example, the physical dimensions of π-movers such as π-pallets or π-trucks should be modular and can be adapted to fit any size of composite π-containers [11]. In this way, facilitation of logistics processes such as moving, storing, handling, transporting the unit loads enables the system to gain huge efficiency and sustainability. The work in [12] proved that container standardization increases the space utilization of trucks and material handling equipments. In the similar research, an evaluation of PI performance introduced in [13] indicated that transporting shipments in the PI network contributes to reduce the inventory cost and the total logistics system cost as compared with the traditional logistics system thanks to the consolidation facilitation of such standardized containers. Furthermore, such advantage characteristic of the PI would enable the PI network to achieve more sustainable environment since the shipment consolidation approach was proved to mitigate the carbon and energy waste effectively in the traditional logistics system [14], [15].

A project has been conducted by CELDi (Center for Excellence in Logistics and Distribution) to examine more comprehensive impact of the PI on the performance of existing logistics system in the U.S.A. The primary demonstration results declared in [9] imply various positive impacts of the PI on all three sustainable aspects. Concretely, if the PI was rolled out on 25% of flows in the U.S.A, its impact would represent a saving of 100 billion USD, a reduction of 200 million tonnes of CO^2 emissions, and a decrease of 75% in the turnover of long distance for vehicle drivers driving heavy goods. Another project led within CIRRELT (Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation) is to estimate the potential energy, environmental and financial gains for one industrial producer of manufactured goods exploiting an open distribution network. The simulation results from several scenarios introduced in [9] show the impact of PI with manifold gains including an increase in the fill rate of vehicles (e.g., trucks, trains, etc.), energy savings (saving millions of litres of Diesel per year), and a reduction of overall logistics cost.

The PI is a long-term vision for an end-to-end global logistics network, and several alliances like MHI[3] and ALICE[4] have already adopted and then promoted the PI conceptualizations and practices. They also has decided to declare the PI as the ultimate logistics goal and set up a comprehensive roadmap to realize the PI concept by 2050. To reach the full-fledged PI many factors need to be taken into account simultaneously, including physical objects such as

[3]MHI, the largest material handling logistics, and supply chain association in the U.S., has created a community of industry thought leaders called the U.S. Roadmap for Material Handling & Logistics. http://www.mhi.org/

[4]ALICE (Alliance for Logistics Innovation through Collaboration in Europe), http://www.etp-logistics.eu/

π-containers, π-movers, and π-nodes as well as informal abstracts including π-protocols and the Physical Internet management systems (PIMS). The PI will thus lead to the development of an open logistics system for connecting the physical objects to the global Internet. This concept suggests significant organizational evolutions, in which the logistics objects are expected to be intelligent and autonomous since they are a communication channel and a stock of information at the same time. In this context, the PI is a key player poised to benefit from the Internet of Things (IoT) [16] revolution since millions of π-containers are moved, tracked, and stored by a variety of the π-nodes and π-movers each day. By embedding intelligent capabilities such as sensing, communication, and data processing into the PI components, IoT enables seamless interconnection of the heterogeneous devices and to get complete operational visibility and allow for the best real-time decisions in the logistics processes. For example, IoT enables managers to monitor the performance of machines, ambient conditions, energy consumption, status of inventory, or the flow of materials. Thus the benefits are contingent upon the design of IoT architecture for the PI and particularly the IoT services ubiquitously to manage and control efficiently the industrial automation processes in the logistics domain. However, much of the PI and IoT literature, to date, has been largely disjointed without much emphasis on theory or practical applicability [17]. This paper examines the trends of IoT applications in the PI and uncover various issues that must be addressed to transform logistics technologies through the IoT innovation. In this regard, the main contributions of paper are summarized as follows:

- The PI paradigm accompanying the state-of-the-art developments of related projects are highlighted. In addition, the proposition design for the components of PI is introduced toward IoT application in the PI. Particularly, an active distributed system is proposed for the PIMS to enable smooth flows of the π-containers through the π-nodes.
- An information framework is proposed based on exploiting the IoT embedded in the physical devices of the PI and their active interaction.
- An service-oriented architecture (SOA) is proposed and described for IoT applied for the PI. Such SOA then exploits the information framework to create and deliver IoT services for the PIMS.
- By adapting the proposed framework, a case study aiming at developing an IoT service is presented to illustrate an efficient management service of logistics operations in the PI.

The rest of the paper is organized as follows: Section II describes the key infrastructure enabling the PI and our proposition design to create an IoT in the PI network. In Section III, we propose an SOA, which is designed to adapt to the logistics environment to provide the IoT logistic services. After that, Section IV introduces a case study used the proposed IoT architecture as well as the proposed SOA architecture to create and deliver a value-added services for the PI management. Finally, Section V concludes the paper and proposes further developments.

II. IOT INFRASTRUCTURE FOR PHYSICAL INTERNET

In this section, we will present the key elements including π-containers, π-nodes and π-movers as well as the state-of-the-art proposition design that enables the IoT for the Physical Internet.

A. Π-CONTAINERS

The π-containers are a key element enabling the success of the PI operation. The π-containers are classified into three functional categories: transport, handling and packaging containers (termed as T/H/P-containers respectively) with their corresponding modular dimensions [18]. The proposition is introduced in [19] to design the modular sizes of these π-containers. Although the set of modular dimensions must be subject to an international standard committee, the partners of the CELDi PI project [20], [12] developed a mathematical model to determine the best container size to maximize space utilization. In parallel, the project MODULUSHCA[5] funded by the 7th Framework Program of the European commission is the first project to design and develop π-containers (termed as M-boxes in this project) dedicated for fast-moving consumer goods (FMCG). Generally, the FMCG includes daily used goods of consumers with wide range of small/medium sizes such as pharmaceutical, consumer electronic, personal care, household care, branded and packaged foods, spirits and tobacco. The M-boxes are sized and designed by the methodological engineering process introduced in the research [10]. They demonstrated that a set of external dimensions of π-containers including the following values in meters {0.12, 0.24, 0.36, 0.48, 0.6, 1.2, 2.4, 3.6, 4.8, 6, 12} increases the space utilization at the different unit load levels [11]. With the modularity and interlocking structure, the encapsulation concept [8] is applied to create efficient unit loads that facilitate material handling processes such as moving, loading, or storage. Fig. 1 illustrates such concept realized by composing nine smaller π-containers to create a composite π-container as an efficient unit load.

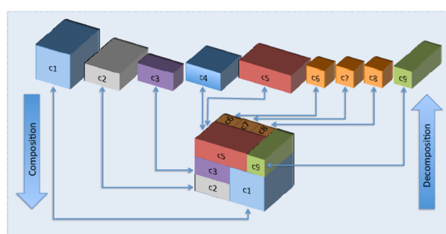

FIGURE 1. An example of encapsulation concept that composes nine π-containers to create an efficient unit load [21].

Note that, the physical encapsulation is applied in the three types of π-containers. Accordingly, a P-container

[5] MODULUSHCA project, www.MODULUSHCA.com

containing directly several passive goods is placed in a H-container, itself contained in a T-container. In deed, number of smaller π-containers are optimized such as their composition block (composite π-container) fits perfectly with the internal space of a larger π-container.

Additionally, the PI emphasizes the importance of informational and communicational encapsulation. This is achieved by applying IoT and embedding the accompanying technologies such as RFID, wireless sensor networks (WSNs). With such ICT integration, the π-containers become smart IoT objects [22] having basic capabilities such as identification, ambient sensing, computation, and communication. Since the π-containers are manipulated worldwide by all stakeholders, the information relating to their physical status and context must be captured, coded, protected and transfered accurately. The EPCglobal standard provides a solution that allows identifying π-containers uniquely. Concretely, the container code is created in line of RFID tag with the EPC standard. Thus, when the code is put into service, the information fed to an EPC Information Service (EPCIS)[6] is shared among stakeholders. Meanwhile, the sensing capability of the sensor node allows the ambient environment condition of the container to be monitored periodically. With such ability, the π-container is able to identify its state and report it, compare its state with the desired one, and send information (e.g., warning) when certain conditions are met. Furthermore, integrated with a memory, the sensor node can store and maintain relevant data. Applying for the PI network, since π-containers are equivalent to the data packets flowed in the Digital Internet networks, information relating to fundamental specification of π-container should be stored in the memory such as container identifier, container dimension, container category. In addition, to support routing protocols effectively, routing information (i.e. previous/next/final destination address) of the π-container provided by the PIMS is also added to the memory of the sensor. More important, any problem in the logistics process along the supply chain will be recorded in the wireless sensor node memory, so such information can be checked using any device such as a computer, tablet or even a mobile phone. Processing capability enables the nodes to perform specific tasks and provide corresponding additional functionalities for the containers. Meanwhile, enabled by integrated wireless transceivers, the π-container can communicate with the different support systems (e.g., manufacturing systems, supply chains, maintenance systems, PIMS) and other active π-containers to enable IoT as well as IoT services [23]. Practically, an example of integration of all these capabilities is the Intelligent Container called InBin[7] recently developed by the Fraunhofer Institute for Material Flow and Logistics to support transporting the perishable food products efficiently. Another project named TRAXENS[8] has been developed smart multi-modal containers (i.e., equivalent T-containers in PI) that can achieve a huge gain in efficiency, service, and protection of the planet since the visibility of the cargo containers are obtained in real time.

[6]EPCIS, GS1 standard, https://www.gs1.org/epcis/epcis/1-1

[7]inBin project, http://www.industrie40.iml.fraunhofer.de/en/ergebnisse/inbin.html

[8]TRAXENS project, http://www.traxens.com/en/

With such ICT integration, each smart π-container is represented by a corresponding intelligent agent (e.g., a smart tag, wireless sensor node, etc.) as illustrated in Fig. 2. Each agent is as a communication channel enabled by wireless communication technologies and holds a stock of significant information relating to the products and their status. In addition, it helps ensure the identification, integrity, routing, conditioning, monitoring, traceability and security of each π-container. It also enables distributed handling, storage and routing automation [21].

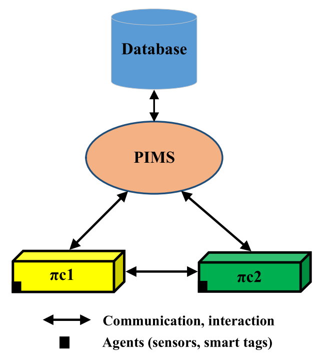

FIGURE 2. **The wireless sensors or smart tags embedded in the π-containers as their agents enable interaction between them and with a PIMS actively.**

Throughout the PI, stakeholders can access necessary data by interacting with the agents. However, based on the roles of the requesters more restricted data may be required and accessed to ensure the security and privacy of data. A Modulusca common data model proposed in [24] is composed of four data types: business data, shipment data, network data, and public data, which can be accessed by corresponding actors with the granted right to support exchanging information among the partners of the PI.

B. Π-MOVERS

In the Physical Internet, π-containers are generically moved around by π-movers. Moving is used here as a generic equivalent to verbs such as transporting, conveying, handling, lifting and manipulating. The main types of π-movers include π-transporters, π-conveyors and π-handlers. The latter are humans that are qualified for moving π-containers. All π-movers may temporarily store π-containers even though this is not their primary mission.

Since the π-movers manipulates directly with the π-containers, they are designed to exploit as best as possible the characteristics of π-containers. From physical perspective, dimensions of π-movers are innovated to subject to the modularity standard of π-container so as moving such containers or composite π-containers with different sizes is facilitated. Fig. 3 illustrates the conceptual model of π-movers designed to exploit the modularity of π-containers.

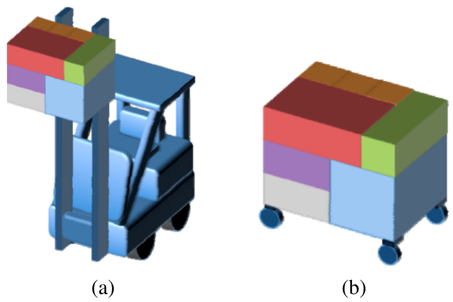

FIGURE 3. Conceptual illustration of π-movers designed to exploit the modularity of π-containers. (a) π-truck-lift. (b) π-mover.

Regarding to information perspective, the widespread adoption of IoT technologies enables smart inventory and asset management. In particular, π-movers can act as active agents, which can interact with π-containers and the PIMS for information sharing and manage them temporarily in the distributed manner. Thus, through the interaction, the basic information includes the specification of π-containers such as ID, dimensions, final destination. In addition, the status of π-container and also π-movers are monitored in real time. For example, the PIMS can be alerted when a π-truck is being over-utilized or when an idle π-pallet should be assigned to do other task. Fig. 4 illustrates an example showing the activeness of π-movers (π-pallet (πP) and π-truck (πT)) enabled by equipped wireless sensors or gateway.

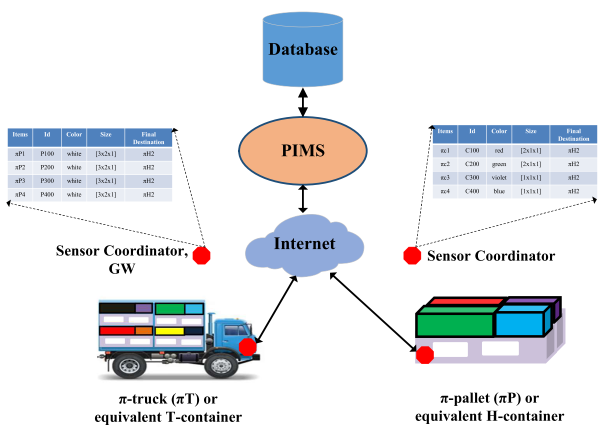

FIGURE 4. IoT logistics services provided by IoT infrastructure of Physical Internet like active πT and πP enabled by equipped wireless sensors or gateway.

C. Π-NODES

In the PI vision, the π-nodes are locations playing a role as smart interfaces to enable realizing universal interconnectivity at the operational level. For example, π-gateways enable efficient and controlled entry of π-containers into the PI as well as their exit from the PI. Generally, a π-node includes π-movers and/or other embedded π-nodes permanently or temporarily, which are collaborated for joint purposes of material handling (e.g., composing π-containers, moving composite π-containers, storing composite π-containers, etc.). Table 1 summarizes the key π-nodes designed for the PI network [21]. As container distribution centers almost logistics activities are taken place and transformed here dynamically. Thus the π-nodes must be designed so that they exploit as best as possible the characteristics of π-containers to support smooth movement of the containers. In the next section, an active distributed PIMS for these smart interfaces are proposed to enable the smooth physical flows of smart π-containers.

TABLE 1. Key π-nodes with their specific functionality in the PI.

π-node	Functionality
π-transits	Transferring π-carriers from inbound π-vehicles to outbound π-vehicles
π-switch	Unimodal transfer of π-containers from an incoming π-mover to a departing π-mover
π-bridge	One-to-one multimodal transfer of π-containers from an incoming π-mover to a departing π-mover
π-sorter	Receiving π-containers from one or multiple entry points and having to sort them so as to ship each of them from a specified exit point, potentially in a specified order
π-composer	Constructing composite π-containers from specified sets of π-containers
π-store	Storing π-containers within a specific time duration
π-gateway	Receive π-containers and release them so they and their content can be accessed in a private network
π-hub	Transfer of π-containers from incoming π-movers to outgoing π-movers

D. ACTIVE DISTRIBUTED PIMS FOR Π-NODES

Due to the high dynamic and structural complexity of the PI networks, central planning and control of logistics processes become increasingly difficult. The difficulty is amplified by the need of efficient management of a huge number of π-containers and logistics assets in each π-node.Therefore, distributed and autonomous control and management of logistics processes are required in the context of the PI. In other words, the PIMS should be designed in distributed manner enabling management of the facilities and logistics assets efficiently. In addition, the PIMS should be active to exploit as best as possible the capabilities of IoT π-facilities. The term ''activeness'' refers to the ability of PIMS in monitoring status of the logistics assets in real time and based on this information scheduling, processes are planned flexibly and effectively. In this way, the utilization of assets can be optimized. This section describes the proposed active distributed system designed to enable IoT for PI in both information and physical flow perspectives.

With the active distributed system, the logistics processes are monitored and controlled effectively. Thus, intention mistakes or errors can be traced and the exact processes causing such issues can be found thank to the activeness of PIMS to correct them. Generally, the main mission of π-nodes is to ensure the π-container transferring efficiently and sustainably from their inbound π-movers carrying π-containers to outbound π-movers. In addition, enabled by IoT, the logistics assets can connect to the PIMS. Therefore, all the

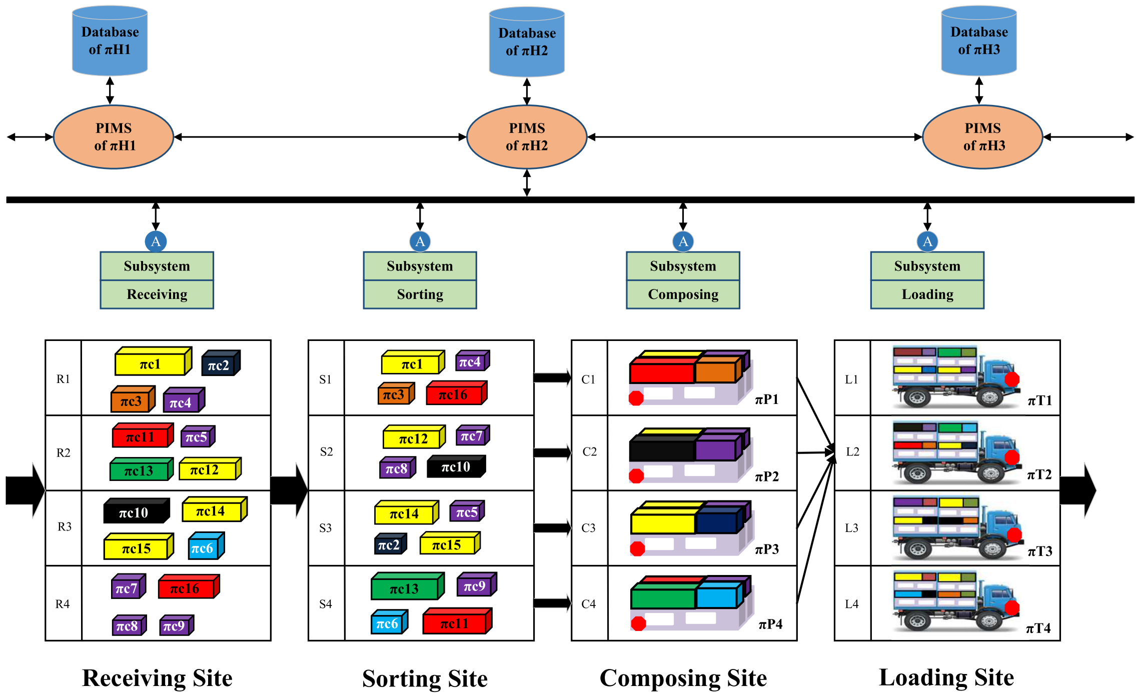

FIGURE 5. A typical distributed PIMS to manage incoming and outgoing π-containers and the logistics assets in a πH2.

π-nodes can manage not only their incoming and outgoing π-containers participating in the logistics processes but also their logistics assets in real time.

Fig. 5 illustrates such a PIMS at a π-hub distributed into active subsystems, which are responsible for single functions or corresponding services.

In the same way, a subsystem evolving specific π-containers and facilities assigned by the PIMS manages and takes its function. An active subsystem is responsible for managing a set of PI assets, inventories (i.e., π-containers, π movers) within a scheduled period to complete its specific task.

As defined in Table 1 the exchange of π-containers from carriers to another is the core activity of the π-hub (πH). The following demonstrates such exchange process in both physical and information flow with IoT integration. As shown in Fig. 5, the logistics process in the πH2 is divided in four sub-processes managed by four corresponding active sub-systems.

1) RECEIVING

At the receiving site, all inbound π-movers, and π-containers are registered, verified and scanned for validation and security purposes. At this stage, the activeness of π-facilities are exploited to cross-check the current incoming inputs against the information transmitted from πH1. After passing such initial processes, π-containers are directed to appropriate locations for their next involved processes. Usually, moving the π-containers is supported by π-conveyors or π-carriers depending on their next destination and next processes. To avoid collisions and balance the loads, the π-containers are allocated to go in different input lanes. For example, as illustrated in Fig. 5, every four π-containers are scheduled and moved in one lane (i.e., R1, R2, R3, R4) to ensure the smooth flow in both time window and space window. Table 2 illustrates a detail status of π-containers scheduled by the receiving subsystem at the receiving site. The schedule is sent to the sorting subsystem that is responsible for sorting the listed π-containers.

TABLE 2. Time and space schedule for π-containers at receiving site.

Status of π-containers at receiving site					
πc	Moved by (π-mover)	Location (lane)	Outgoing time (min, max)	Next process	Next Hub
πc1	π-conveyor	R1	(07:00, 07:02)	Sorting	πH3
πc2	π-conveyor	R1	(07:00, 07:02)	Sorting	πH4
πc3	π-conveyor	R1	(07:00, 07:02)	Sorting	πH3
πc4	π-conveyor	R1	(07:00, 07:02)	Sorting	πH3
πc5	π-conveyor	R2	(07:00, 07:02)	Sorting	πH4

2) SORTING

Going out from the receiving site, the received and selected π-containers go to the sorting site which aims to sort such π-containers according to some rules as followings:

1) π-containers have the same final destination,
2) or they may have different the final destination but are scheduled to transit in the same next π-node.

Table 3 illustrates an example of status and schedule of π-containers at the sorting site.

In this example, π-containers, πc1, πc3, and πc4 having the final destination (πH3) are sorted and moved in the

TABLE 3. Time and space schedule for π-containers at sorting site.

Status of π-containers at sorting site					
πc	Moved by (π-mover)	Location (lane)	Outgoing time (min, max)	Next process	Next Hub
πc1	π-conveyor	S1	(07:03, 07:04)	Composing	πH3
πc2	π-conveyor	S3	(07:03, 07:04)	Composing	πH4
πc3	π-conveyor	S1	(07:03, 07:04)	Composing	πH3
πc4	π-conveyor	S1	(07:03, 07:04)	Composing	πH3
πc5	π-conveyor	S3	(07:03, 07:04)	Composing	πH4

TABLE 4. Time and space schedule for π-containers at sorting site.

Status of π-containers at composing site					
πc	Moved by (π-mover)	Location (lane)	Outgoing time (min, max)	Next process	Next Hub
πc1	πP1	C1	(07:04, 07:05)	Loading	πH3
πc2	πP3	C3	(07:04, 07:05)	Loading	πH4
πc3	πP1	C1	(07:04, 07:05)	Loading	πH3
πc4	πP1	C1	(07:04, 07:05)	Loading	πH3
πc5	πP3	C3	(07:04, 07:05)	Loading	πH4

lane S1. Meanwhile, πc2 and πc5 are moved in the lane S3 since their final destination is πH4. As mentioned before, sorting mission is achieved by a π-sorter that incorporate a network of π-conveyors and/or other embedded π-sorters.

3) COMPOSING

At the composing site, the sorted π-containers are composed to be composite π-containers, which are efficient loads with different sizes fitting the sizes of H/T-containers. In addition, their composing orders must be taken into account since some π-containers can be decomposed in the next π-nodes, thus they should be placed at the outermost locations of the composite π-container. In other words, any mistake in allocating π-containers can lead to the inefficiency of following logistics process. Generally, the composing task is completed by π-composers in combination with the pre-assigned π-movers such as π-pallets or larger π-containers to carry.

Table 5 illustrates an example of status and schedule of π-containers at the composing site.

After π-containers are composed to be a composite π-container, the information encapsulation is applied. Accordingly, the coordinator or gateway embedding into the π-pallet is responsible for managing their hold π-containers directly instead of the composing subsystem. This distributed management allows the PIMS reduce the management and storage cost of the related data.

4) LOADING

The loading process deals with composite π-container or H/T-container to load them into π-transporters and then to move them to next π-node. Similar to the composing process, the loading process must follow significant rule as following:

1) Number of composite π-containers including H-containers are optimized so as their spatial arrangement in a π-transporter maximizes the space utilization,
2) Since the composite π-containers may have different final destination but same next destination, their loading orders must be taken into account to facilitate the unloading process in the next destination. In this case, the last-in-first-out (LIFO) rule is applied.

Table 5 illustrates an example of status and schedule of π-containers at the composing site.

TABLE 5. Time and space schedule for π-containers at loading site.

Status of π-containers at loading site					
πc	Moved by (π-mover)	Location (lane)	Outgoing time (min, max)	Next process	Next Hub
πP1	πT2	L2	(07:05, 07:06)	Transporting	πH3
πP2	πT2	L2	(07:05, 07:06)	Transporting	πH3
πP3	πT3	L2	(07:05, 07:06)	Transporting	πH3
πP4	πT4	L2	(07:05, 07:06)	Transporting	πH3

In the example, the four π-pallets are moved and converged at the lane L2 of the loading site, at which they are loaded into the πT2 pre-assigned. On the informational perspective, the coordinator or gateway or IoT device mounted in the πT2 temporarily manages their loaded π-containers until they are handled in the next process.

III. SERVICE-ORIENTED ARCHITECTURE FOR THE IOT

Since no single consensus on architecture for IoT is agreed universally, different architectures have been proposed by researchers [25]. With a numerous number of things is moved dynamically in the PI scenarios, an adaptive architecture is needed to help devices dynamically interact with other things in real-time manner. In addition, the decentralized and heterogeneous nature of IoT requires that the architecture provides IoT efficient event-driven capability as well as on-demand services. In addition, the PIMS is difficult to implement and maintain at global scale due to the lack of an efficient, reliable, standardized, and low cost architecture. Furthermore, the ever-changing demands of businesses and the vastly different needs of different end users should be met by providing customization functionality to the end users and organizations under a flexible SOA. Thus an SOA is considered an efficient method achieve interoperability between heterogeneous devices in a multitude of way [16], [26], [27]. In addition, SOA is considered suitable for such demand-driven logistics chains. In particular, SOA can integrate logistics processes and information; and sharing such information can help create a better environment for real-time data exchange, real-time responsiveness, real-time collaboration, real-time synchronization, and real-time visibility across the entire logistics chain.

This section describes the proposed SOA for creating the IoT logistics services in PI. The architecture comprises four layers: physical layer, network layer, service layer and interface layer. In the following subsections, these layers are presented to adapt to the IoT of PI.

A. PHYSICAL LAYER

The physical layer involves perceiving the physical characteristics of things or surrounding environment. This process is enabled by several identification and sensing technologies such as RFID, WSN [28]–[30]. For example, by embedding an intelligent sensor to a π-container, the environment condition (e.g., temperature, humidity, etc) around it can be sensed and monitored in real-time. In addition, since communication is enabled by these sensors, the π-containers can exchange information and identify each other.

In addition, this layer is in charge of converting the information to digital signals, which are more convenient for network transmission. However, some objects might not be perceived directly. Thus, microchips will be appended to these objects to enhance them with sensing and even processing capabilities. Indeed, nanotechnologies [31], communicating material [32], [33] and embedded intelligence will play a key role in the physical layer. The first one will make chips small enough to be implanted into the objects used in our every day life. The second one will enhance them with processing capabilities that are required by any future application.

At the lowest layer of the architecture, the physical layer provides sets of information periodically or in passive mode. With the massive logistics activities, the information levels should be categorized and standardized. For example, the information used to realize the four classes of activeness of π-containers can be classified into four corresponding levels [23]:

1) Passive information: it is collected from static or dynamic data stored in the RFID tag or sensors. Such information relates to π-container specification and location for providing tracking and traceability function.
2) Triggering information: This information is perceived from sensing and detecting by adequate sensors. Therefore, detected problems are sent to the PIMS as alert message. Such information provides the monitoring function.
3) Decisional process information: This information is obtained through the interaction and communication among proximity π-containers. The management of incompatibility between π-containers is an example of services served by such information.
4) Self-organized information: The active π-containers are self-sufficient and able to provide services based on the information obtained from the π-infrastructure in the previous class.

B. NETWORK LAYER

The role of network layer is to connect all heterogeneous things together and allow them to share the information with other connected things [16]. In addition, the networking layer is capable of aggregating information from existing IT infrastructures supporting the logistics processes (i.e., π-movers, π-facilities). In SOA-IoT, services provided by IoT devices or a collective group of devices are typically deployed in a heterogeneous network and all related things are brought into the service Internet [16] for further accessing and sharing. Since, the networking layer mainly provide information collected from the physical layer to the service layer, QoS management, service discovery and retrieval, data and signal processing, security, and privacy according to the requirements of users/applications are some significant issues [34]. On the other hand, the dynamic changing of network topology due to leaving or joining of IoT devices may lead to non-robust of the network. Practically, since the network is the backbone to realize the IoT, designing it must consider the following significant challenges listed in Table 6.

TABLE 6. Design considerations for IIoT applications (adapted from [27]).

Design goals	Description
Energy	How long can an IoT device operate with limited power supply?
Latency	How much time is need for message propagation and processing?
Throughput	What is the maximum amount of data that can be transported through the network?
Scalability	How many devices are supported
Topology	Who must communicate with whom?
Security & safety	How secure and safe is the application?

C. SERVICE LAYER

This layer relies on middlewares to integrate multiple source of heterogeneous information provided by heterogeneous IoT devices to create valuable services. These services in turn are exploited to support the logistics process of the active subsystem as well as end users to monitor or track their orders. This layer is responsible for identifying and realizing services that could utilize the IoT infrastructure to service operations in the logistics service. Basic traceability or tracking functions, monitoring, scheduling, routing are typical services in the logistics operations. In addition, all service-oriented issues including information exchange and storage, database management, search engines (database search, service search), and communication protocols among services are resolve by the layer [16], [26].

D. INTERFACE LAYER

In IoT, since a large number of IoT devices are made by different manufacturers/vendors and they do not always follow the same standards/protocols, there are many interaction problems with information exchange, communication between things, and cooperative event processing among different things. Furthermore, the constant increase of IOT objects participating in an IoT makes it harder to dynamically connect, communicate, disconnect, and operate. Therefore, the mission of the interface layer is to enable the services to be accessed and used by managers or end users. Web Services [34] are technologies that integrate a set of standards and protocols to exchange data between applications developed in different programming languages and they can run on any platform. Therefore, the Web Services can be used to exchange data in both private IoT devices or private networks and the Internet. Interoperability is achieved by open standards proposed by organizations such as OASIS and W3C.

IV. MANAGEMENT OF COMPOSITE Π-CONTAINERS: A CASE STUDY

Composite π-containers composed of specified sets of smaller π-containers are efficient unit loads, which are absolutely key in improving transport, storage and handling efficiency across the PI network. By exploiting the modularity and interlocking structure of the π-containers, the unit loads have different sizes that are adapted to fit with the different sizes of material handling systems such as π-pallets (see Fig. 6). Next, such sets of π-pallets, which in turn, are loaded into a π-truck such that the utilized space of the truck is maximized prior to transport as illustrated in Fig. 5.

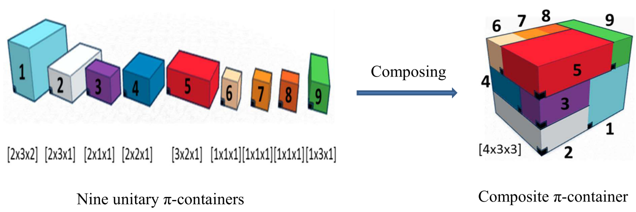

FIGURE 6. An efficient unit load (i.e. a composite π-container) is formed by composing nine unitary π-containers appropriately [35].

Because the exchange of π-containers is the core activities taken place continuously in the PI, a high frequency of transformation processes can introduce a desynchronization between the physical and information flows of the π-containers maintained and previously stored in the PIMS. For example, an unexpected π-container can be placed on a π-pallet during the composing process or in a π-truck during the loading process. This type of issue leads to inefficiency in management of logistics processes because it requires additional costs and delay in recomposing or reloading activities. In addition, in reserve processes (i.e., decomposing or unloading) the part of unitary π-containers can be decomposed (i.e., depalletized) automatically at the final destination or for order picking at the next destination. Such a process is facilitated if the position and orientation of the composed π-containers are available.

As a case study of utilizing the IoT technology, an methodology has been developed to obtain 3D layouts of composite containers, which is used for monitoring and validating such unit loads and addressing the above limitations [36]. This section presents the description of the approach as shown in Fig. 7, which is developed to provide these kinds of important information. Particularly, based on this layout, value-added services enabled by the IoT can be developed and used to enhance the efficiency of other logistics operations.

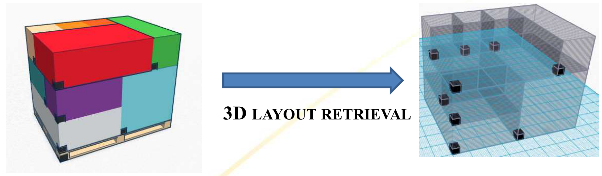

FIGURE 7. 3D layout retrieval from a composite π-container.

A. ARCHITECTURE

The proposed network architecture of IoT shown in Fig. 8 contains both fixed and mobile infrastructure.

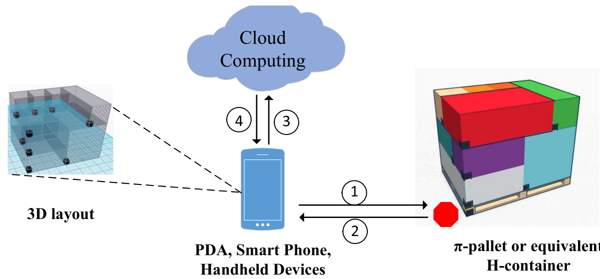

FIGURE 8. IoT architecture for 3D layout retrieval at H-container level.

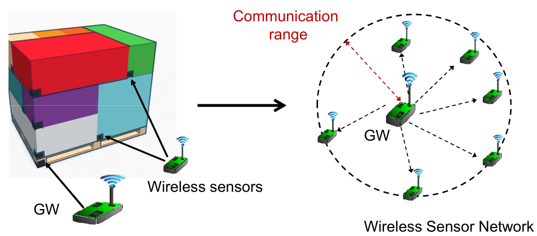

FIGURE 9. At the networking layer, an ad-hoc network is formed by nine wireless sensors and coordinated by the GW.

Applying the proposed architecture, the four-layer IoT architecture consists of the following elements. At the sensing layer, each sensor node equipped with each π-container contains information related to the specification of its container as well as the contained shipments. In addition, ambient conditions such as temperature, humidity are sensed and stored in the sensors. A gateway (GW) placed at a corner of π-pallet is responsible for coordinating the network formed by those sensors and managing the composed π-containers. At the networking layer, the sensors and the GW communicate on IEEE 802.15.4 links [37] to form an ad-hoc network coordinated by the GW (see Fig. 9). The mobile infrastructure usually includes PDA, smart phones or handled devices. These IoT devices request information from the GW/ coordinator (flow 1 in the Fig.8). After receiving the demanded data (flow 2), it then sends it to the cloud for requesting the services (flow 3). Finally, the devices receive the services and display the layout (flow 4).

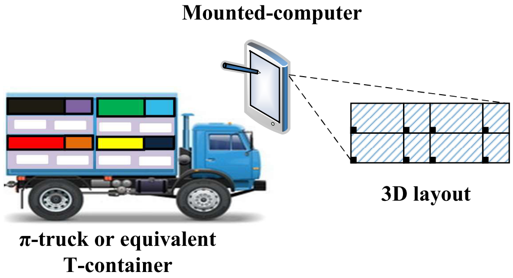

FIGURE 10. IoT architecture for 3D layout retrieval at T-container level.

At the service layer, the GW collects information from the sensors to achieve the 3D layout of composite π-container, which further is exploited to provide important services.

B. AN INFORMATION FLOW FRAMEWORK TO RETRIEVE 3D LAYOUTS

Fig. 11 shows the information framework flowing from the physical layer to the service layer for creating such layout.

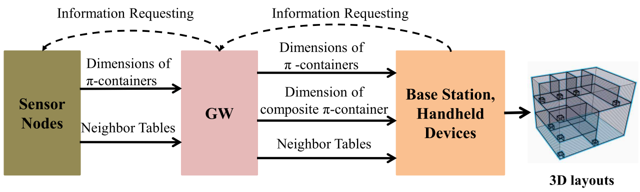

FIGURE 11. Information exchange among sensors, GW and processing points (i.e., base station, handheld devices) at the network layer.

In this framework, the required information includes the dimensions of π-containers and the proximity information obtained by neighborhood relationship among sensor nodes. In order to validate the framework, a simulation-based method has been created and described in our previous research work [36].

With such simple methodology for retrieving the 3D layout of composite π-container, the value-added IoT services can be developed to support the logistics processes in the Pi. In the next subsection, those services are introduced.

C. VALUE-ADDED SERVICES ENABLED BY RETRIEVED 3D LAYOUTS

The retried 3D layout provides the exact 3D view of spatial distribution of composed π-containers in their blocks. In addition, the locations of equipped sensor nodes are available. Thus, the sensing functionality offers distribution of environment conditions inside these blocks. In this way, the status of π-containers are monitored continuously to prevent issues in real time. Such as, the π-container equipped with adequate sensors can detect a problem (e.g., abnormal high temperature), check for detection integrity with nearby π-containers when pertinent, and send an alert message to their agents or directly to the PIMS. In another instance, proximity π-containers carrying cargoes incompatible with each other (e.g., chemical products that can contaminate each other or cause an explosion) can be detected and avoided when a π-container arrives at a π-hub, it sends to the PIMS the list of elements incompatible with its cargo.

V. CONCLUSION AND FUTURE WORKS

With rapid development in the emerging IoT technology, this paper proposes a design framework of developing an SOA for Physical Internet using IoT, which is actually motivated and strongly demanded from the logistics managers as they need the service provision to efficiently manage and control the logistics processes. In this context, we describe key infrastructure and proposition design mostly based on the advanced ICT innovation to enable IoT for such logistics domain. Furthermore, an IoT-enabled logistics service providing 3D layout of composite π-containers is presented as a case study to highlight the practical usage and merit of our proposed framework.

PI is an innovative concept in logistics. Several researches and studies since 2011 have contributed to demonstrate and give the proof of concept. Looking to the future roadmap, the goal in 2020 is to realize interoperability between networks and ICT applications for logistics. Obviously, application of IoT into PI brings huge benefits in terms of economy, environment and society. In other word, the IoT enables the PI achieve its global sustainability goal. However, deploying and realizing this revolution technology faces significant challenges mostly from the technical perspectives. For instance, since the physical facilities of the PI are equipped with smart devices (e.g., RFID, sensors) usually powered by batteries, saving their energy to prolong their operation lifetime is important. These IoT devices can be requested any time to provide information for higher layer in the SOA to develop the services. Thus they may be active always. To reduce the power consumption the WSN nodes will be asleep (low-power mode) most of the time, and it will only wake up to acquire the sensor data or to talk to another node. Several important issues such as standardization, network type, the quality of service, and logistics data protection are expected to provide a basis for further research on IoT-based logistics services.

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