A Collective Intelligence Approach for the Composite PI-Containers Management

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Abstract: *Standardized, smart and modular PI-Containers are key elements for an open global logistic system. The modularity provides composition capabilities to build composite PI-containers which allow efficient and easier handling or transport. In the same way, embedded technologies confer intelligence to each PI container. They become individual intelligent objects which can not only identify themselves, but can also sense and measure their environment, and communicate with others objects. From the collaboration of individual intelligences emerges the collective intelligence. This research paper proposes a collective intelligence approach for the management of composite PI-containers in key facilities such as PI-Hubs. The cognitive abilities of each PI-container, associated to a cooperative information aggregation mechanism, are used to generate a virtual object of the composite PI container. The latter makes possible to provision new services in accordance with the users/stakeholders' requirements. A guidance information service for automated PI-container picking illustrates the proposed approach.*

Keywords: *Physical Internet, PI-Containers, Collective Intelligence*

1 Introduction - Collective Intelligence

The term collective intelligence is a combination of two words where *intelligence* is "the ability of an individual to adapt its behavior to meet its goals in a range of environments" (Fogel, 1995), and the adjective *collective* meaning "shared or done by a number of people acting as a group". The MIT Center for Collective Intelligence defined very broadly collective intelligence as *"Groups of individuals doing things collectively that seem intelligent"* (Malone, 2009). This definition, at first glance, may seem very confusing. However, it reminds us two important factors of collective intelligence:

- It makes possible new actions, competences and developments resulting from interaction within the group;

- It is not simply the addition and juxtaposition of individual intelligences, although the collective intelligence relies upon this ability of each individual. It stems from their communication ability and their relationships to the environment.

The well-known example of collective intelligence comes from the American entomologist William Morton Wheeler, and its observation of ants, not as individuals, but as one single unit working in a colony which created a superorganism due to collective efforts (Wheeler, 1965). These very simple animals, with very few competencies and limited intelligence, are able to find the shortest way from one point to another, carry heavy loads or build ant-hills. They produce highly sophisticated results through collective behaviour and communication (by the means of pheromones). Another example is the online encyclopaedia Wikipedia where anyone can create a new page of information or indeed add information to an existing page. It promotes the distribution of knowledge between users, but also gives the opportunity to change or amend information that other users have uploaded. This crowdsourcing system is not a platform aggregating anonymously produced quantifiable data, but a social media arising from collective intelligence (Detlef, 2013), in which crowd contributors/consumers, volunteer content curators and social curators play a key role.

Collective Intelligence is not something new, and a large and growing literature appears in computer networks, business, political science, sociobiology, and many other domains. However, all of these experiences demonstrate that the combinations of cognitive and cooperative mechanisms are needed to achieve a collective intelligence level (Brosnan, 2010). The basic cognitive processes such as acquisition, memory or representation … are used by each individual in order to perceive its environment and develop its own knowledge. The cooperation specifies how the individuals interact between them to solve collective problem. Mechanisms such as information sharing, confidence or feedback/control can be used to develop the synergy so that a collective decision-making emerges. If the cooperation should implicitly include an aspect of coordination between individuals, the evolution and stability of this cooperation is also strongly linked to the cognitive abilities. So, there are several enablers and disablers of a collective intelligence. In the Wisdom of Crowds, (Surowiecki, 2004) provides a framework illustrated Figure 1 where the main features (diversity, decentralization and independence) in cognitive abilities are associated to a cooperative information aggregation mechanism to achieve collective performance. The diversity and decentralization ensure that each individual of the group hold a variety of opinions that draw on their own specialized or localized knowledge. Thanks to their independence, they are able express them without being unduly influenced by others.

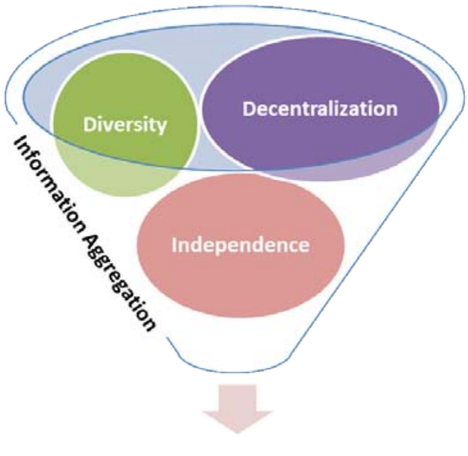

Figure 1: Surowiecki's framework

This article discusses collective intelligence in the light of smart products and how that could bring solutions to develop an efficient Physical Internet. The section 2 focuses on the collective intelligence concept apply to intelligent products/objects, also called Collective Intelligence of Things (CIoT). A collective intelligence approach for the management of composite PI-containers is proposed in section 3 and some scenarios are described in section 4. Finally, section 5 concludes the paper.

2 Collective Intelligence of Things (CIoT)

Micro-Electro-Mechanical Systems (MEMS) play a significant role in the development of intelligent products/objects. Driven by Moore and more than Moore's laws, the physical product can be easily equipped with sensors, processors, computational capability and data communication ability, in order to collect, process data and produce useful information. The major development of the Internet of Things (IoT) community in the last years is a good example (Atzori, 2010) with an increasing number of products showing more or less intelligence features. One of the most important of IoT is definitely to satisfy and to increase the users comfort (Horvath 2012), contributing to the daily rise in the quantity of new intelligent consumer products. The deployment of the product intelligence in industrial systems is also well studied since the earlier of 2000. A review of intelligent industrial product and applications in industrial domains such as manufacturing, logistics and industrial services, is detailed in (McFarlane, 2013). However, in both cases, one of the most important key elements for intelligent products is that the intelligence is a matter of degree. That's means more the product embed electronics (sensors, memory, computational power and data transmission), more it aims at revealing the product individual behavior … in order to extract "embedded" intelligence about the individual and its environment.

Meyer et al. (2009) proposed a three-dimensional classification model, illustrated Figure 2, which can be used to classify the intelligent products in comparison to their individual intelligence degree. The classification is based on three axes: the level of intelligence, the location of the intelligence and the aggregation level of intelligence.

- *Level of intelligence.* This axis is divided into three categories to discern a product able to manage its own information (information handling) with a product more intelligent able to notify a problem to the owner (problem notification). The last degree represents the most intelligent product able to take some decisions without any external intervention (Decision making);
- *Location of intelligence.* Two situations are considered. The intelligence is external (e.g. a server running a dedicated agent for the product) and the physical product uses it through communication interface (intelligence through network). A second solution is to consider intelligence at the physical product itself (intelligence at object);
- *Aggregation level of intelligence.* This axis allows us to consider an intelligent product composed from parts. When the intelligence is distributed inside each component (intelligent container), the product can manage information, notification and/or decisions about itself and from each part. Otherwise the product is regarded as an intelligent item.

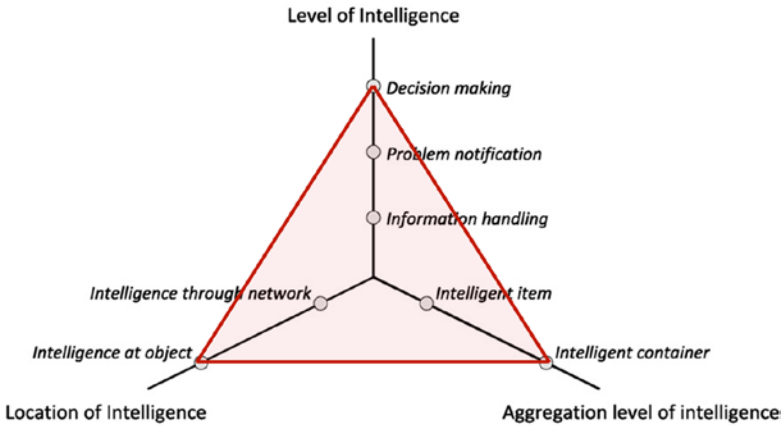

Fig. 2: Individual intelligence levels

The sum of the intelligence embedded within several individual devices, if efficiently and effectively communicated between network nodes and applications, can produce benefits above and beyond those provided by the individual pieces of equipment. In (Schreiber, 2012), the author shows that all intelligent systems (any information processing system made up of simpler devices that collaborate) have a collective intelligence potential if they can be described as a *Surowiecki machine* (Surowiecki, 2004) based on four principles:

- The devices contribute their input to the machine's aggregation mechanism, which then computes the machine's output;
- The contributions are diverse because each device is processing information in different ways (specialization), or because each device is processing different information (localization), or both;
- Each device carries out its processing mostly independently of the others, and sends its output directly to the machine's aggregation mechanism with no interference from other devices;
- The output of the machine may or may not loop back as input to the component devices.

Hence, cross-fertilize knowledge can help to address problems that occur out, but also, promote the creation of new individualized customer-services. We propose in the next section a collective intelligence approach for the management of composite PI-containers in key facilities such as PI-Hubs. The cognitive abilities of each PI-container, associated to a cooperative information aggregation mechanism, are used to generate a virtual object of the composite PI container on which new services will be conceptualized.

3 Management framework for composite PI-containers

This section describes the proposed management framework based on a virtual representation of the composite PI-container obtained from a collective intelligence approach.

3.1 Framework overview

A virtual object is a virtual representation of a real object enriched with context information. The benefits of virtual view are to enable multi-party multi-use of objects in a way that is acceptable to all parties involved. A Virtual Object (VO) has multiple views, including for instance:

- business view, to serve all parties to generate a positive business;
- security view which can increase mutual trust and confidence between stakeholders;
- operational view which can contribute to optimize and accelerate processes;

In this direction, the approach proposed in this paper aims to provide the means to realize the virtual representation of the composite PI-containers. This type of real-world object is obtained from a set of stacked PI-containers. Thus, basic VOs can be composed in a more sophisticated way by forming a Composite VOs (CVOs). The advantage of this approach is that CVOs are virtual objects created dynamically in an autonomous manner. A CVO reflects the real composition of the composite PI-container and can provide services in accordance with the user/stakeholder requirements.

Based on the Physical Internet foundations (Montreuil, 2011), the Figure 3 illustrates our approach with real objects that are unitary PI-containers with Information and Communication Technologies (ICT) capabilities. They include low cost sensors and communication devices to be able to sense and measure their environment, and communicate with other PI-containers. Each VO is associated to a VO registry that includes information about the unitary PI-container, like unique identifier, the dimensions or sensors values. Information are available at the information level.

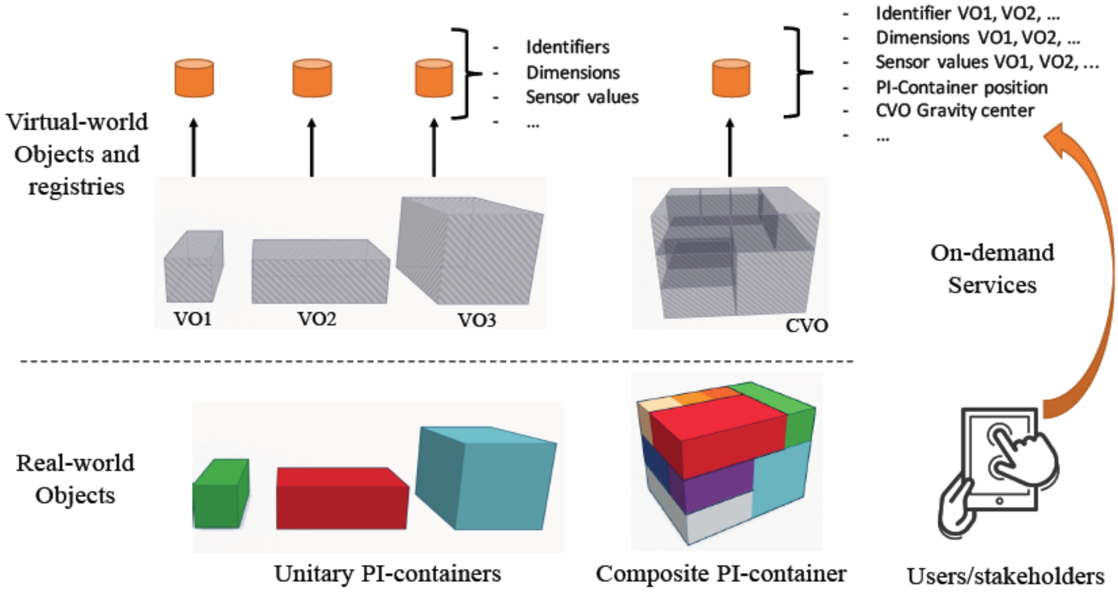

Fig. 3: CVO registry - cooperative information aggregation to achieve collective performance

Similarly, the CVO registry contains information regarding the components of the composite PI-containers, but also information emerging from the collective intelligence and the cooperative information aggregation mechanism. This information can be exploited on demand by users/stakeholders to take some decisions during the different management processes of the composite PI-container, or to develop new services. For instance, the exact position of each PI-container or the gravity center can be stored in the CVO registry and exploited during the composition/decomposition processes of the PI-container.

3.2 Framework implementation

In previous works (Tran-Dang, 2015)(Tran-Dang, 2017), the collective intelligence framework has been implemented to retrieve the exact position of stacked PI-container within a composite PI-container. This approach is based on key functional specifications of π-containers (Montreuil 2011) where each PI-container is a smart object equipped with low cost sensors and communication devices to be able to sense and measure its environment, and communicate with other smart containers. From these individual intelligence, cognitive processes associated to cooperative information aggregation mechanism were developed at the composite PI-containers level to:

- Identify of the number of unitary PI-container that composed the composite π-container;
- Detect and identify the PI-containers in their neighbourhood;
- Collect and forward data throughout the network to aggregate information.

Like a *Surowiecki machine* described in section 2, each device (unitary PI-container) shares its knowledge (dimensions, identifiers) and perceive its environment (neighbors). Contributions are diverse and independent due to their different localization. From these inputs and the machine's aggregation mechanisms, a Constraint Satisfaction Problem has been developed, as the output of the machine, to compute and determine the CVO with its registry values. The Figure 4 illustrates the collective intelligence framework implemented.

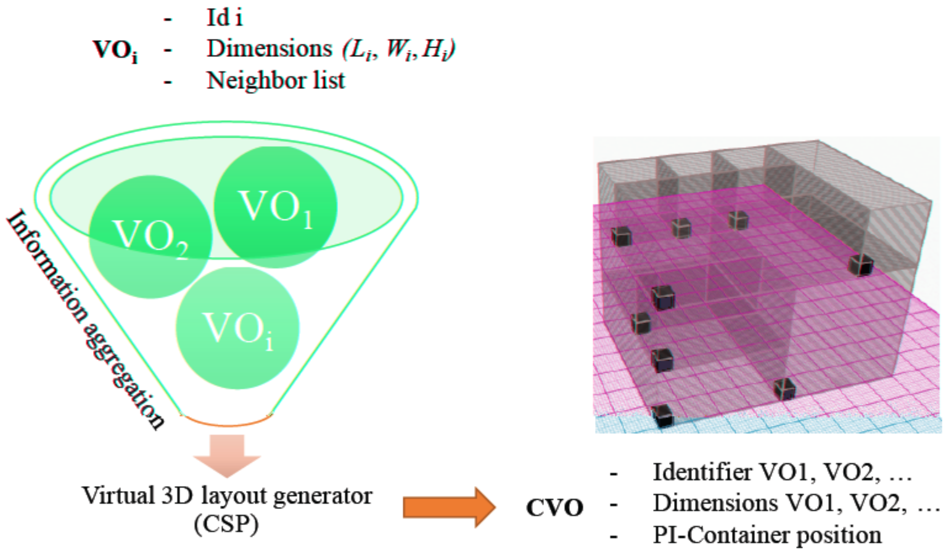

Fig. 4: Collective Intelligence framework

Based on the proposed framework in section 3, the 3D layout of a composite PI-container can be obtained from cross-fertilize knowledge. This model can help to address problems that occur out, but also, promote the creation of new individualized customer-services. We propose to illustrate in the next section several scenarios that can contribute to the development of the Physical Internet.

4 New individualized customer-services

The virtual view of the composite PI-container can be exploited on-demand by users/stakeholders, at any time of its life cycle. It can serve to take some decisions at different level - business, security or operational - during the different management processes of the composite PI-container, or to develop new services. This section presents two indicative scenarios where the collective intelligence framework is used to facilitate human-human, human-agent and agent-agent interacting in a Physical Internet.

- *The physical and informational integrity of composite PI containers*

The CVO can be obtained on-demand at each point of the logistic processes (transportation, storage and delivery of goods). Hence, knowledge based dematerialization of the composite PI-container can serve as a tool for permanent checking and inventory. Figure 5 illustrates a scenario where the CVO is used to facilitate trucker - logistic assistant interactions during daily operations at the PI-hub level. For instance, the composite PI-container can be checked in terms of goods conformity, transportation condition or opening tentative. This can help to strengthen mutual trust between all stakeholders in open global logistic infrastructure.

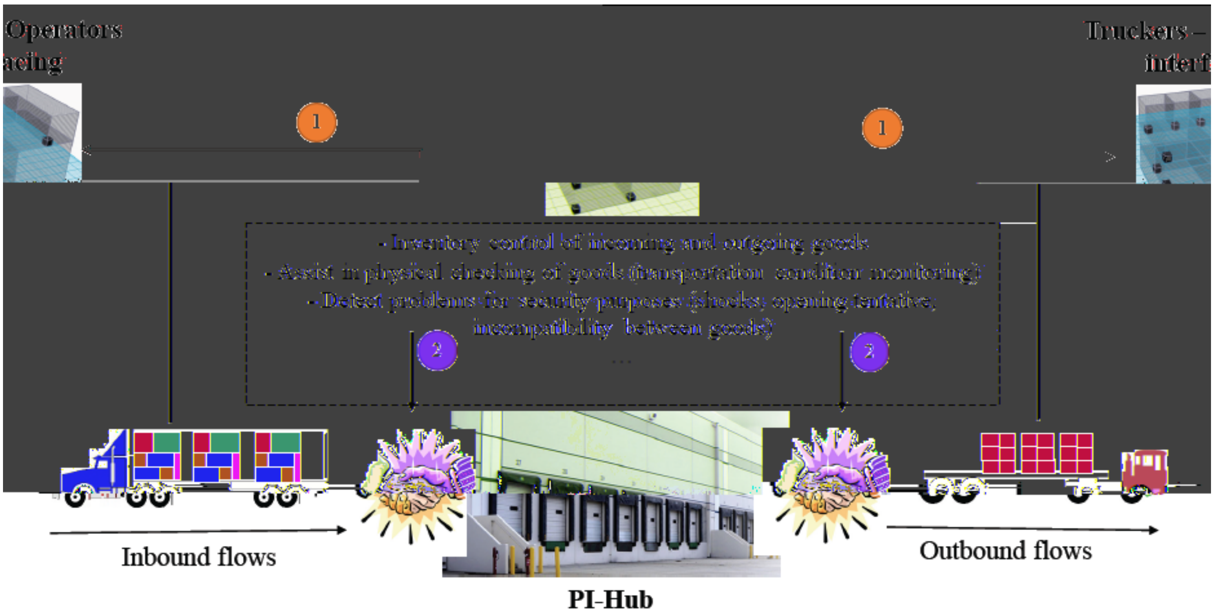

Fig. 5: Physical and informational integrity

- *Fully automated palletizing/depalletizing handling systems*

New value-added services such as guidance information for loading/unloading systems can be derived. For instance, the CVO could be used to detect and localize objects in automated palletizing/depalletizing systems that use traditionally vision sensors. From this, picking sequence and guidance information can be generated to partially unload or decompose the composite PI-container. The Fi4-g20h258iat S258i1Tcont The Fi-lfehe 2c4   5i

5 Conclusion

In this paper, general definition and concepts of collective intelligence have been presented. From the collaboration of individual intelligences emerges the collective intelligence, and we developed a collective intelligence approach for the management of composite PI-containers in key facilities such as PI-Hubs. This approach relies on the cognitive abilities of each PIcontainer, associated to a cooperative information aggregation mechanism, which are used to generate a virtual object of the composite PI container. To illustrate the proposition, two indicative scenarios are given in a Physical Internet context.

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