The COG-LO Framework: IoT-based COGnitive Logistic Operations for next generation logistics

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***Abstract*— Objective of COG-LO is implement and assess a framework which exploits *Internet of Things* (IoT) concepts and technologies to improve effectiveness and efficiency of logistic operations. The COG-LO framework is based on the *Cognitive Logistic Object* (CLO) concept which represent any entity involved in logistic operations augmented with cognitive capabilities.**

CLOs are also enriched with *social*-like capabilities and therefore, COG-LO builds on the *Social Internet of Things* (SIoT) concept. Such capabilities allow the seamless *ad-hoc* interaction between logistic entities even if managed by different operators. To this new types of relationships will be integrated in the SIoT concept.

I. INTRODUCTION

The evolution of Internet of Things (IoT) and Smart Composite Products (CPS) technologies combined with big data will change dramatically the way manufacturing and supply is organized. As supply chains are more digitized, logistics operators and all stakeholders have to embrace latest technologies in such a way that they can achieve ease of access, quick information processing, security, and, all of in one place. Planning, route optimization, capacity sensing (the ability to detect open spaces in a warehouse, port or parking lot), traceability and improved planning are some of the offered qualities/services of these innovative solutions. This not only calls for complex logistics concepts that can respond flexibly to short-term production changes, but also requires fully networked trucks that automatically adapt their route planning. Another benefit is even fewer empty runs - that lowers fuel consumption and improves haulage firms economic efficiency.

To cope with the above challenges, in the COG-LO project we are implementing and assessing tools that enable logistics processes to become more cognitive and collaborative. This is achieved by adding *cognitive* behaviour to all involved Logistics Operation objects (freight, transportation means, systems, etc.). Such objects will interact by exploiting dynamic ad-hoc social networks based on the *Social Internet of Things* (SIoT) paradigm [1].

In fact, the SIoT paradigm offers a variety of solutions that can cater for improved processes monitoring, optimization and response to changes/events. Furthermore, SIoT will allow any physical object participating in the supply chain (cargo, vehicle, warehouse, Parking slot, other transport modes, systems, etc.) to interact and negotiate potential alternatives/solutions considering their existing status/needs and exceptions identified.

The rest of this paper is organized as described below. In Section II we provide some background information which is needed to understand the following of this paper. In Section III we will present the proposed framework. Finally, in Section IV, we will draw our concluding remarks.

II. BACKGROUND AND CONCEPT

The objective of this section is twofold. On the one hand we provide background information and related work regarding current logistic solutions. On the other hand, we will motivate the SIoT integration by discussing how it can enhance the performance of the logistics operations.

A. Postal Logistic Technologies

Although there are already some standards for Information and Communication Technologies (ICT) systems to manage transport and logistics operations, a paradigm shift in is needed if logistics efficiency is to be improved, and strategic goals of reducing the environmental impact of transport are to be met. The complexity arises from the vast number of shipments and destinations, which need to be re-aligned in real-time due to various external factors. This is particularly difficult in a deterministic lead-time and the finite amount of available resources. Consequently, the optimization of properties like delivery time, resource utilization and geographical coverage is an inherent challenge of large-scale logistics operations.

A number of real-time scheduling algorithms has been developed by the logistics community since the 1980s; they were essentially Decision Support Systems (DSS) [2] and included typical DSS elements. During the 1990s, the

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introduction of Geographic Information Systems (GIS) enabled the display and manipulation of spatial information, and, thus, supported the realization of more comprehensive models of the road network, allowing more realistic modelling of path constraints [3]. Although, dynamic real-life problems often require rich models, in most of the literature on dynamic routing problems simplifying assumptions are made for relaxing the stochastic nature of those problems [5]. For example, the dynamic full-truckload pickup and delivery problem has been analyzed in [4].

The GS1 [6] System of Standards is currently the most widely recognized framework in the field and enables real-time, end-to-end visibility over the entire supply chain. It is a neutral framework, which ensures interoperability among all stakeholders and provides a standard way to identify items and locations. This allows capturing details about supply chain movements, and sharing that information with authorized partners.

Some interesting results have also been achieved by a number of EU projects addressing the ICT issues in transport and logistics. Notably, related efforts have largely been validated by industrial pilots, while also being interconnected with existing ecosystems, such as the Descartes Global Logistics Network (GLN) [7]. One major outcome of this joint initiative [8] has been the development of a Common Framework [9] supported also by various logistics projects (FREIGHTWISE, eFreight, INTEGRITY, SmartCM, SMARTFREIGHT, EURIDICE, RISING, DiSCwise, iCargo, COMCIS, eMAR, other) for information exchange between ICT systems in transport and logistics, in close cooperation with standards organizations. The framework supports interoperability among actors and communication to authorities and entities responsible for the transportation network, targeting the best possible use of the transportation infrastructure, supply chain security and fulfillment of compliance requirements.

Currently, most of the dynamic routing algorithms lack or ignore the random nature of external factors, which affect the delivery efficiency, and rely only upon online information updates for periodic re-optimization [10]. In periodic re-optimization (or rolling-horizon optimization), dynamic routing reacts to the observations from the real-world operations and does not anticipate proactively the implications from external factors such as

- missing a delivery because of the recipients absence [11] [12]
- delivery demand fluctuations during the day [13]

Anticipating the impact of external factors though can provide more robust logistic plans, which are resilient to changes [14]. Hence, it is desirable to model the dynamic behaviour of demand variation, capacity and operational capability of logistics operators.

B. Social Internet of Things (SIoT)

The SIoT paradigm [1] brings social network concepts the IoT context. The combination of these two elements allows to enjoy many key benefits deriving from the potentials of social networks within the IoT domain. Such benefits include simplification in the navigability of a dynamic network of billions of objects; robustness in the management of the trustworthiness between entities; efficiency in the dynamic discovery of services and information. The success of this paradigm is mainly due to the simplicity of its implementation in several heterogeneous application platforms [16] [17] [18] and, at the same time, to the strong effectiveness in supporting the delivery of IoT applications with Quality of Experience guaranteed. According to the SIoT model, every object is capable of establishing social relationships with others in autonomous way according to rules set by the owner.

The following are possible types of relationships:

- Ownership Object Relationship (OOR): this is created between objects belong to the same owner.
- Co-location Object Relationship (CLOR): this is created between stationary devices located in the same place (this is also called co-geolocation, CGLOR, in the following).
- Parental Object Relationship (POR): this is created between objects of the same model, producer and production batch.
- Co-work Object Relationship (CWOR): this is created between objects that meet each other at the owners workplace, as the laptop and printer in the office.
- Social Object Relationship (SOR): this is created as a consequence of frequent meetings between objects, it can happen between smart-phones of people who use the same bus every day to go to school/work, people hanging out at the same bar/restaurant/gym.
- Transnational Object Relationship (TOR): this is established between devices that interact with each other frequently [19].

Each social link is created on the basis of the profile of the end nodes (such as the type, the active services, the installed applications), their activities (such as geographical mobility and transactions) and the characteristics of their owner (such as friendship relationships). In the resulting social network each object obtains the desired information by navigating the social network one can imagine this action as an interrogation that browses the graph from friend to friend in a distributed way. This results in an efficient and scalable discovery of objects and services based on the same principles that characterize social networks for human beings. The hypothesis that a SIoT network is navigable is based on the principle of the sociologist Stanley Milgram on the phenomenon of the small world [15] and has been validated through simulations in [1].

III. COG-LO FRAMEWORK

In this section we will describe the COG-LO framework. More specifically, in Section III-A we introduce the CLO concept architecture implementing the CLO concept along with the functionality required for its exploitation is described in Section III-B.

A. Cognitive Logistic Object

Logistics Objects (LO)s are physical objects (cargo, vehicle, etc.) and systems, participating in a logistics process. A *Cognitive* LO (CLO) is a LO which is autonomous, responsive to environment and context changes, and able to learn and collaborate. In the COG-LO scenario, it is expected a multi-modal freight transport system guided by a *Cognitive Advisor* (CA), which will help CLOs in deciding about next actions, forming social networks, communicating, helping each other and solving local problems. Any action will be performed taking variables into account such as business priorities and environmental conditions. The result will be suggestions from CLOs to the Actors (drivers, managers, etc.) for more efficient, environmental-friendly and multi-modal transportation deliveries.

In the proposed framework, each CLO is associated with the digital representation of the physical entity called *Virtual Cognitive Logistic Object* (VCLO). As in [1], a VCLO implements the required functionality for the management of the entity communications and the support of the common control plane functions.

Furthermore, a CLO must have a social behavior, therefore the digital counterpart implements a series of services offered by SIoT to establish relationships with other VCLOs, exchange information and modify the behavior of the CLO in order to optimize the logistics offer. Such approach is quite common in the IoT domain, where it is a widely used technique adopting a digital counterpart of the physical one [20]. In fact, it is possible to give virtual objects some features that physical object cannot implement due to their intrinsic limitations in terms of energy, computing, and communication capabilities.

B. Architecture

To improve current technology for logistic support thus, meeting the challenge of solving the interoperability problems, we propose the introduction of a system that manages the logistics both in the control plane and in the data plane. The proposed architecture consists of several functional blocks, grouped in the following *layers*, as shown in the Fig. 1:

- Infrastructure Layer
- Interaction Layer
- Coordination Layer
- Intelligence Layer
- Application Layer

The **Infrastructure Layer** represents the physical entities that will collectively carry out the actual logistics processes. In that respect, it enables the circulation of information, which lies at the core of the cognitive logistic approach, taking the variety and heterogeneity thereof into consideration. A fundamental information type concerns data collected from CLOs sensors and other sensing devices spanning across the logistics network. An important aspect is their analysis and processing, in order for useful knowledge to be extracted, decisions to be made, actions to be performed, and new knowledge to be generated and incorporated into the system.

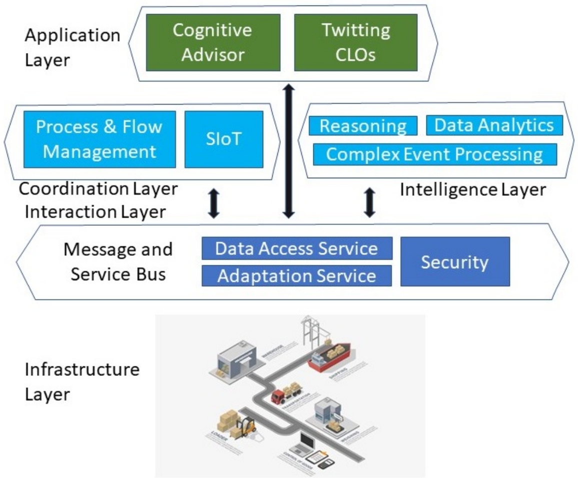

Fig. 1. Cognitive Framework Architecture.

The proposed framework fosters sensed data to be combined with other types of information. These shall include structured data (e.g., ERP records, WMS reports, etc.); historical process files, unstructured data (broadcasting/community/individual services, web sites, etc.); contextual data at local and global level (e.g. traffic status, environmental conditions etc.).

The **Interaction Layer** provides the mechanisms for the effective interaction between the CLOs, being also the single point of reference controlling the access of the rest of the architectural blocks to the Infrastructure Layer.

It will comprise an intelligent, semantic Message and Service Bus (MSB), providing for asynchronous and synchronous communication, data and service access, security, privacy protection and trust establishment. A very fundamental duty of the MSB will be the transformation of the Platform Independent Model (PIM) of the underlying components operational behaviour to a Platform-Specific Model (PSM). In that respect, Adaptation Services will provide common abstractions of the operational aspects of the underlying components, being, consequently, responsible for translating any method call into the specific protocol. Further, the Data Access Service will provide a unified solution for accessing information stored in heterogeneous systems or collected on the fly, under a common transnational interface. Regarding data security and privacy, a policy-based access and usage control framework, grounded on provisions stemming from the legislation (e.g., the GDPR), it will regulate respective operations; that is, not only it will control access to and usage of resources and services, but it will also drive the application of cryptographic mechanisms, as well as other related technologies. On the other hand, trust will be established by means of subjective and objective trust between CLOs, will be investigated a blockchain-based distributed ledger devised for the enforcement of smart contracts reflecting the corresponding, between the participating entities and records management for transparency and visibility.

The **Coordination Layer** incorporates the appropriate mechanisms on the one hand for the provisioning, management, monitoring and optimization of the Infrastructure Layer and, on the other, for the effective coordination of resources and their actions towards business objectives. About that, will be in charge of orchestrating CLOs operations and, therefore, the framework will put the means in place for work-flow modelling, instancing, execution, and orchestration.

Additionally, adaptability of operational processes will also be supported with respect to all kinds of events, real-time data fluctuations and overall context. A key component of the Coordination Layer will be the *Social Internet of Things* module, which will be responsible for discovering and managing the social-like relationships between CLOs. In fact, by augmenting CLOs with the social dimension two major advantages can be achieved: (a) an overlay network spanning CLOs across several platforms can be built having the typical features of social networks, i.e., it is navigable and has a small diameter, (b) interactions are preferred between CLOs that are neighbours in the social network and therefore are likely to have trustworthiness relationships with each other.

The actor owning a certain CLO will set the policies that the CLO will implement to establish and maintain the social-like relationships. This is needed to allow users that use the framework to control the flow of their information so guaranteeing an acceptable level of privacy, contributing to the overall by design data security and privacy.

SIoT [1] will be enriched with the functions required to discover, establish and maintain new types of relationships between CLOs which are specific of the logistic scenario. Examples of such new types of relationships may include

- *Riding Relationship*: it is established between a parcel and the vehicle which is carrying it.
- *Neighborhood Vehicles Relationship*: it is established by vehicles that are geographically near each other.
- *Travelling Together Parcel Relationship*: it is established by parcels that are delivered by the same vehicle in the same trip.
- *Parcel-Receiver Relationship*: it established between the parcel and the smartphone of the person that must receive the parcel.

The **Intelligence Layer** provides the necessary logical inference mechanisms for knowledge extraction and formalization, learning and reasoning, as well as cognitive behaviour of the underlying entities. To achieve this, the Intelligence Layer will consist of multiple technologies able to merge and aggregate data from different logistics entities and CLOs to identify patterns and propose operation improvements.

Secondly, predictive with event processing will enable to foresee the impact of state changes of one or more operations and determine the corresponding effects on multiple stakeholders; the Intelligence Layer will be coupled with exact optimization algorithms and heuristics for enabling CLOs adaptation to operational changes from the external environment in near real-time. In particular, the proposed framework will couple and optimization for considering the effect of optimization control measures to the performance of operations in an environment with continuous external variations.

The **Application Layer** consists of the Cognitive Advisor (CA) and the Tweeting CLOs. The CA will provide the logistics operator with visualized decision support for routing optimization. CA interacts with the MSB to visualize the formalization, reasoning and cognitive outputs of the Intelligence and Coordination layers. The Tweeting CLO will be the generic prototype consisting of the appropriate APIs that will receive the messages from the logistics objects and vehicles and transmit them to the CLOs in the same network and to the CA via the MSB.

IV. Conclusions

In this paper we have described the framework for cognitive logistics that we are developing within the COG-LO project. More specifically, we have described the conceptual innovation of the project which is the Cognitive Logistic Object (CLO). CLOs are all entities involved in the logistic processes augmented with cognitive capabilities that allow them to be autonomous, responsive to environment and context changes, and able to learn and collaborate. CLOs implement social-like functionality which allow them to establish relationships between each other that mimic friendship between humans. This is in line with the Social Internet of Things (SIoT) framework. In the paper we have also described the architecture which will implement the COG-LO framework. The COG-LO project will exploit the above capabilities to meet the requirements given by final users included in the project consortium like European postal operators (such as Post Slovenia, Croatia Post, Hellenic Post) and logistic operators (such as EKOL Logistics).

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