From Tracking Operations to IOT—The Small Business Perspective

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Abstract

Mapping individual items onto a virtual representation and keeping track of their properties now finds wide acceptance in larger enterprises and networks in the form of tracking and tracing. However, even if underlying technologies are ripe enough for off-the-shelf frameworks, small enterprises are still largely left unpenetrated due to present-day tracking applications still being optimized for massive use with little variability. Also, higher-level functionalities, such as inter-organizational transparency and integration of different networks—typically attributed to the "Internet of Things" concept are still awaiting wider implementation. The paper presents a track-and-trace framework along with pilot implementations focusing on the small-business sector and highlighting enhancement possibilities towards an Internet of things.

1. Introduction

Today's industrial production, delivery, as well as other—so far, less observed—life cycle phases of physical objects raise a number of challenges which can be tackled by the unique—and *automatic*—identification of the subjects of these operations, along with the proper IT architecture built thereon. While some of the related functionalities are already common practice with large—in some cases, even medium-sized—enterprises [13, 7, 5, 10] or organizations [6, 15, 4], the same cannot be said about small companies or organizations. Another notable technology penetration lag can be observed regarding more advanced item-related services allowing the bridging of organizational borders, and moving towards the *Internet of Things (IOT)* concept. The 6th Framework EU project *TraSer—Identity-Based Tracking and Web-Services for SMEs* was conducted with the goal of advancing in both of the aforementioned problem areas by providing a solution framework especially conceived for small enterprises while allowing the implementation of advanced item-related services in both intra- and inter-organizational contexts [8].

The paper aims at presenting the findings of pilot implementations of the project that are relevant to the IOT concept. After giving a general overview of the problem domain (Section 2), a summary of the TraSer solution platform is given (Section 3). Hereafter, selected pilot implementations are presented to illustrate the gradual development of services and solutions using unique identification, working towards the introduction of a true IOT operating across company borders (Section 4). Finally, findings of the pilots are summarized and conclusions are given with an outlook towards future development beyond the scope of the completed project (Section 5).

2. Problem statement

A number of vital problems in today's production, delivery, usage and disposal of products can be solved by improving the *observability* of the processes in question [1, 4, 14]. This, however, requires one to depart from the—currently still widespread—approach of observing merely the stock level, and keep track of relevant entities individually [12]. Today's focal terms in this domain are *tracking* (i.e., keeping track of an individual's selected properties) and *tracing* (i.e., observing the individual's interaction with other identifiable entities, especially as summarized over a longer period of the past) which—especially if enabled in a larger access domain spanning company borders—pave the way towards more complex services related to the given individual, and thus contributing to an IOT. From the point of view of unique identification, functionalities of this domain can be grouped into four hierarchical layers as follows (see also Fig. 1, and [8]):

- An *identification infrastructure* alone means the mere presence of an identification technology, and the possibility of meeting decisions on the spot, based on local knowledge about the identified object.
- *Identifier-based operations* already presume the existence of a central information repository which assists in meeting local decisions (e.g., if an entity is authorized to pass through a facility gate).
- *Tracking-based operations* give individual reading acts a meaning, since detecting an ID at a given time and place (plus, optionally, other conditions) implies

that the item in question was physically present at the point of reading. This event is then stored in a database, so that it becomes possible to keep track of what occurred to it during its life cycle. The same applies to interactions with other instances.

- *Advanced item-centric services* become necessary if relevant parts of the life cycle take place under the authority of other parties, or the complexity of the processes require to maintain transparency across organizational borders. In such cases, item-related data and services (e.g., notification, subscription) are shared among process participants with proper access restrictions.

While full exploitation of an IOT requires all four functionality layers, most of today's state-of-the-art solutions still culminate in implementing *tracking-based operations* only. Underlying technologies have already brought forth standards and solutions, e.g., standards set by EPCglobal including EPCIS—EPC Information Services—linking services to physical objects of unique identity [2, 3], allowing the implementation of IOT principles. However, even if the ripeness of implementations has reached the level of off-the-shelf solution frameworks [9], the latter still require high initial investment and are optimized for large production volumes and less product variability, thus still not being attractive enough to small-scale users. The consequence is that small enterprises solely remain occasional users of tracking systems of larger companies they are suppliers of. When working without a powerful central player (i.e., operating in production networks with partners of comparable size), small enterprises usually refrain from using elaborate item-level practices, even though this may result in the network losing the competitive advantage of small-business flexibility, as well as risk non-compliance with emerging production transparency and traceability requirements such as *Authorized Economic Operator (AEO)*.

The above reasons let one conclude that in the small-business sector, certain demands exist for a reasonably low-cost framework for item-level operations. In the ideal case, such a solution platform should also enable future development of advanced item-level services typical for IOT applications.

3. The TraSer framework

While the main goal of the—already completed—6th Framework EU project *TraSer* was the development of a tracking and tracing solution framework especially tailored to the needs of small and medium-sized enterprises, this section shows that it also allows further enhancement of item-centric services—also across company borders when needed—in accordance with the IOT concept.

The implementation of the TraSer solution platform (see also [11]) relies on *Web Services (WS)*, a widely-supported standard with a large spectrum of off-the-shelf frameworks and specific extensions, both commercial and open-source. WS allow more flexible configuration of communication (as opposed to "classical" EDI (Electronic Data Interchange) which small enterprises may find too cumbersome and costly to configure and maintain).

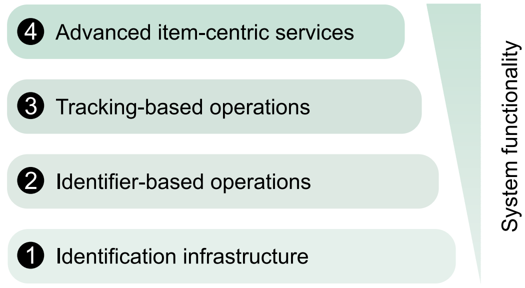

Figure 1. Hierarchy of functionalities based on unique identification of material in manufacturing, delivery, operation and disposal processes

3.1. TraSer network components

The TraSer solution platform allows participants to build a TraSer network where two components can be distinguished: servers (nodes) and clients. Fig. 2 depicts a simple TraSer network—also note that several of such networks can exist independently without any central governing service or authority, i.e., there is no such entity as "*the* TraSer network".

TraSer servers store item-related data accessible to authorized parties. A given unique item is assigned to one and the same server for the entire life-cycle of its ID, and the TraSer-internal notation of the item's unique identifier directly specifies the address of the corresponding server (see also comparison with ONS/EPCIS at the end of this section).

The servers process requests in the form of XML queries which allow more flexibility in customizing the data models used by the partners, and, in the longer term, enable the establishment of explicitly defined and negotiable data models as a foundation for efficient cross-company communication. TraSer servers can also forward queries or updates to each other—these node-to-node connections span a part of the TraSer network (see Fig. 2: part *a)* depicts a small network of several nodes and part *c)* stands for a company which operates a TraSer server within its own IT infrastructure).

Server-to-server communication in the form of forwarded updates or queries is practiced if the set of item information in question is maintained by different servers, and as a consquence, queries or updates need to be forwarded. This is typical for production networks where the products of several manufacturers are combined to a composite item, and information about the sub-assemblies possibly resides in different servers of the same TraSer

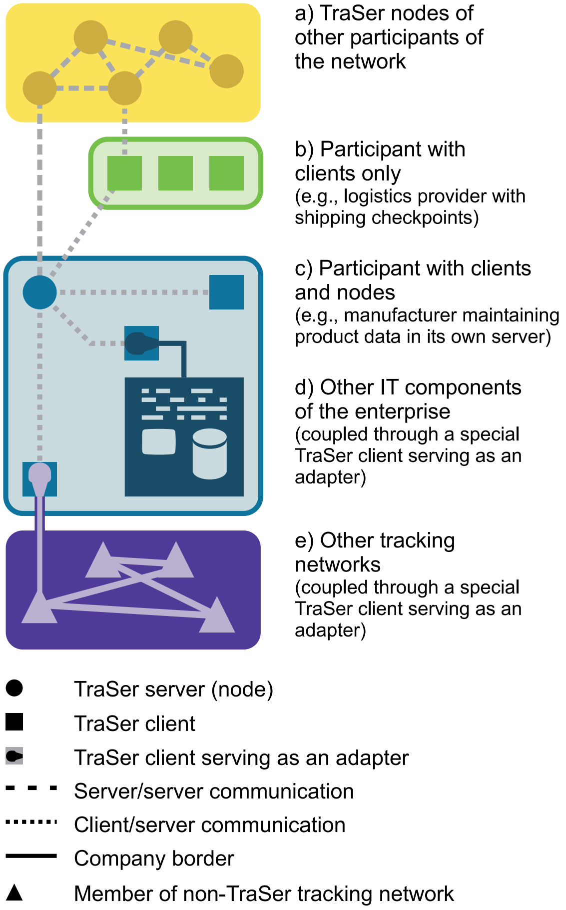

Figure 2. Simplified example of a TraSer network

network. Also, the data of a given item can be extended by further properties which are not necessarily located in the same server (e.g., when a manufacturer wishes to add its own relevant notes to the item description of its supplier). *The capabilities of network-wide update/query forwarding show that the TraSer solution framework is well-suited for transparent cross-company operations, a key property of IOT.*

TraSer clients form the other main group of components in a TraSer network. Clients connect the servers with the rest of the world by providing external interfaces and addressing one or more servers with item-related queries or updates. Clients can be fitted with various kinds of interfaces, i.e., they can be designed for human operators, peripheral devices (readers, etc.), other components of the enterprise infrastructure (stock management, ERP), and other tracking and tracing systems. Since TraSer interface specifications are freely available, users can develop specific clients tailored to their given needs.

Fig. 2 shows several specialized cases of client use. Companies which do not have their own TraSer-tracked items (e.g., logistics partners not maintaining their own transportation asset data in a TraSer system but updating the shipment information of a manufacturer's products; or a small supplier which lets a larger partner care about hosting its product data) are not required to operate their own server, as shown in part *b)*. The company in part *c)* operates, aside from the TraSer server, several specialized clients. One of these serves as an adapter for accessing other components of the manufacturer's IT infrastructure (part *d)*), while another client was customized as an interface towards another tracking network (part *e)*). *Clients acting as adapters to other infrastructure components or networks are vital for building an integrated IOT, lifting compatibility-related access restrictions to an isolated TraSer network.*

3.2. Relevance of TraSer to small-scale users

As already mentioned before, the TraSer solution platform has been optimized for application by small-scale users, i.e., small organizations or SMEs. Here, some of the key properties are highlighted which can make TraSer attractive to small-scale or occasional users, as well as those seeking an easy entry-level solution to explore the track-and-trace and IOT domains without locking themselves in any permanent technological or organizational commitment.

Low-cost installation and use—Aside from the basic solution package being freeware (and also being present in an open-source community at *sourceforge.net*), starting to operate the TraSer server and client instances requires a minimum of computational resources and IT specialist work force. In essence, any company already operating its own HTTP server and having its own specified web address can begin using its own TraSer server right away (including the independent issuing of its own identifiers)—this also implies that outsourcing the task of server operation to third parties does not rapidly inflate the costs either.

Setting up and operating clients can be low-cost as well, especially because TraSer does not stick to one given technology of physical ID carriers: as long as the given ID carrier can support the required identifier length, any technology from RFID to optical identification can be used. Thus, users can pick their preferred solution from a large spectrum between RFID-enabled automated field clients over a client application with a bar code reader, down to the low-end extreme of a web client with manual ID entry.

Network independence and compatibility—TraSer favors small-scale users in keeping a reasonable balance between the freedom of independent issuing of identifiers and the ability to adapt to networks operating by other standards. Most of these advantages are owing to the *ID@URI* identifier notation used internally by TraSer. Here, the globally unique identifier is composed of two parts: *ID* and *URI*, none of them being a full identifier alone. The *URI* part is a direct pointer to the address where the TraSer server maintaining the data of the given item can be contacted. In our case, *URI* is, in fact, a URL.

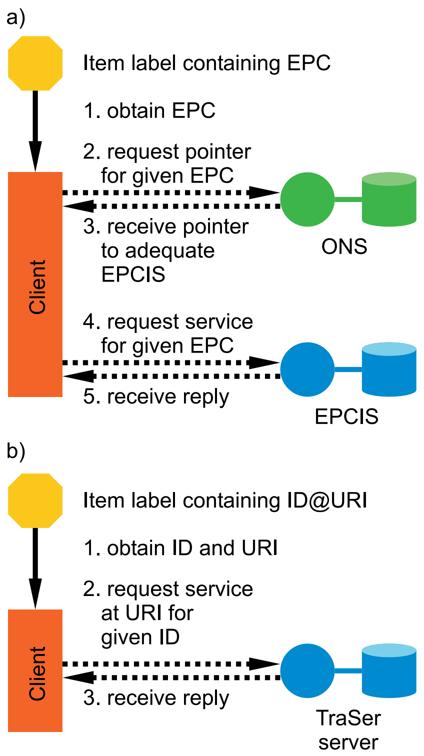

Figure 3. Comparison of service address resolution and access a) with ONS/EPCIS, and b) with TraSer

This URL is unique to the given TraSer server but not to the item—in other words, the same URL is used for accessing data of several items. The item one wishes to access is then unambiguously specified by the request sent to the aforementioned address—this request also contains the *ID* part of the unique identifier. The *ID* part of the notation must, therefore, be unique among all items handled by the same server.

While this appears fairly similar to the principles of *Object Naming Services (ONS) and EPC Information Services (EPCIS)* [2, 3], there are two fundamental differences (see also Fig. 3). First, finding the services associated with an item does not require a separate resolution mechanism, since the address of the service access point is already contained in the *URI* part of the item (and, therefore, only a *URL*$\mapsto$*IP address* resolution is needed which is readily done by the DNS lookup). Second, no central authority is needed to guarantee global uniqueness of the identifiers. This is, in a way, "piggybacking" an already existing DNS infrastructure which guarantees global uniqueness of URLs and thus preventing collisions within the *URI* part of TraSer's identifier notation. Once this is ensured, only the uniqueness of the *ID* part *per each URI*—i.e., not per each single *ID@URI* type identifier—has to be guaranteed for global uniqueness of the entire identifier. This allows the decentralization of identifier allocation and allows much independence for participants issuing new identifiers.

An independent identifier notation may raise concerns of isolation from other networks using other standards. These fears are unfounded as far as TraSer makes it easy to adapt to any "external" numbering scheme by providing means of identifier mapping. While this is facilitated by the possibility of including any instance of another numbering scheme in the *ID* part of the TraSer identifier, full conversion between identifiers is always performed by the clients. Several ways of implementing a mapping mechanism are at the users' disposal (and have already been tested in various examples), however, their detailed description is well beyond the scope of this paper.

Easy joining and leaving of a TraSer network—Even those planning a mere occasional collaboration in a TraSer network do not have to put up with much effort in becoming a member: only the common subset of data models and the new partner's access rights need to be negotiated in advance (e.g., as a part of the collaboration contract). In an optimal case, client installation kits or complete clients can already be provided by a collaborating member of the TraSer network. TraSer also leaves much room for adopting branch-specific or general data model standards that are suitable for being expressed in XML trees (within the TraSer project, the use of UN/CEFACT Core Components was examined, however, this does not mean a restriction to CC only). Leaving a TraSer network equals, on a minimal scale, to ending client communication, while cutting a server out of the network may present a larger challenge—therefore, the planned duration of collaboration is also a factor in deciding who the data of a given item will be hosted by.

4. Pilot implementations

In order to make the TraSer solution platform "industry-proof", an incremental roadmap of application pilots was followed during the project, subsequent releases moving from simple use cases towards higher levels of functionality, and from closed circulation of relatively few identified items to flow-through identifier handling, as in a supply chain. This allowed a gradual refinement of the TraSer platform where practical experience contributed to the support material for prospective users as well. In this section, several pilots are highlighted in a sequence supporting closer examination from a network-oriented point of view, and concentrating on small-business users wherever possible. First, a simple case of closed-circuit asset tracking is presented, followed by a minimalistic one-tier example, adaptation to external requirements by the supplier, and, finally, the case of a large service provider offering services to customers of various sizes.

4.1. Closed-circuit asset management

The first application pilot to use an early release of the TraSer platform was the lab equipment management system used at various labs of the Dutch research institute *TNO*. This is a “classical” closed-circuit asset tracking scenario where both items and identifiers remain in the system for a longer time. Main characteristics of the application example are as follows (see also Fig. 4 for a simplified architectural overview and a sample transaction):

- Several labs within TNO participate in the inventory system, each of them being responsible for maintaining information about its own pieces of equipment. To this end, each lab runs its own TraSer node and issues its own lab-specific identifiers.
- Lab staff members have their own identifiers, however, these are issued through TNO’s own staff administration. While employee IDs are, at the moment, not included in the TraSer application, they can be easily entered later on (e.g., to be able to list all instruments a given person is in charge of).
- Specific access points at the institute, so-called *booths*, are equipped with clients which can access the inventory management servers run by labs. Operation of these booths is permitted upon entering a valid staff identifier—in this case, therefore, access control is taken care of in the client, as opposed to typical TraSer networks in an open environment with potential third-party threats.
- As it is the general rule in TraSer’s internally used identifier notation, successfully reading a given identifier already delivers the address of the server which is in charge of maintaining the data of the item. In our case, every user authorized to operate the equipment management booths may access all TraSer servers within TNO’s TraSer network, granting an unrestricted view at a “limited size IOT” within the borders of TNO.

Already this first pilot successfully demonstrated TraSer’s easy adaptation to existing infrastructural conditions.

4.2. Minimal application in a supply chain

Starting July 2008, the Hungarian company *Innotec* (specializing in design, prototyping and production of plastic assemblies and smaller electric components, primarily for the automotive industry) conducted pilot tests for the use of TraSer in a supply chain with a selected small-business supplier of the company. The goal of the pilot implementation was not only an application in a flow-through supply chain scenario, but also the examination of the “low-end” limits of using the TraSer platform with the most simple configuration still feasible for supporting the existing ordering, manufacturing, delivery and quality feedback processes.

In the given configuration (see also Fig. 5), it was assumed that the supplier has either no interest in notable investment in IT equipment, or is an occasional supplier

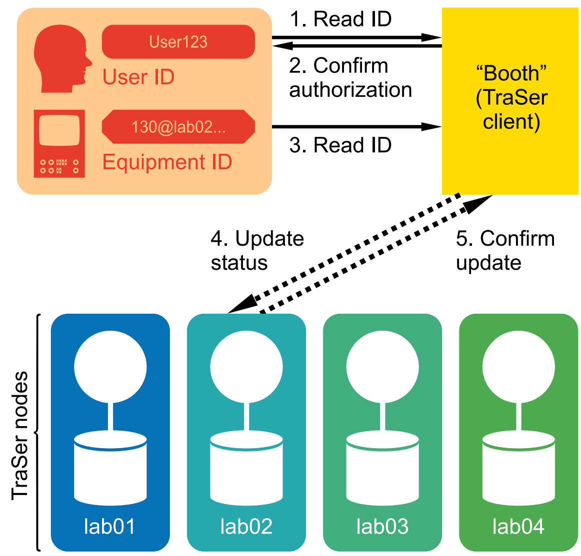

Figure 4. Closed-circuit asset tracking integrating existing user management practices

of the OEM (Innotec, in our case), so that operating its own TraSer server would not be justified. Instead, the data of the supplier’s products are maintained by the OEM, on their own TraSer server, eliminating the need of a separate server at the supplier. The arrangement was tested for the following sequence of operations:

1. *OEM places an order with the supplier.* Using the OEM’s administration client (usually a simple web interface), an adequate number of new items is created, each having its own unique identifier which will not change during subsequent manufacturing and delivery processes. Upon obtaining the corresponding set of IDs, the latter are communicated to the supplier (e.g., the supplier receives the order with item IDs already specified, and the OEM grants permission to the supplier for updating certain attributes of the items as agreed in the contract).
2. *Supplier carries out production and delivery.* During production, work pieces at the supplier receive the pre-allocated unique identifiers (i.e., a permanent link between physical and logical instances is established), and status/property changes of the items are sent to the OEM’s TraSer server as updates, in accordance with the detected events or changes. Since TraSer works independently of the physical ID carriers, the identification of items during the above processes can be realized in many ways, ranging from RFID or bar code readings to manual administration (e.g., a web interface with the adequate set of identifiers, as well as actions in drop-down lists).
3. *OEM confirms reception of the items.* The receiv-

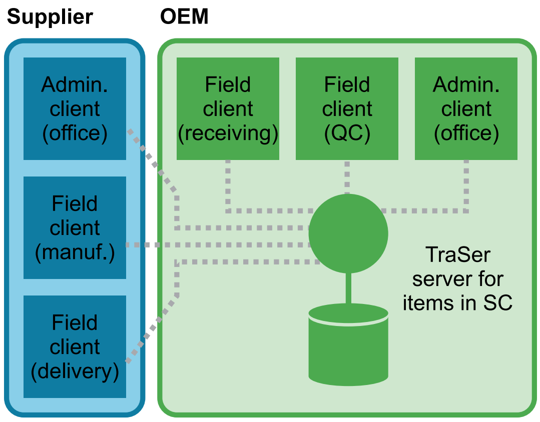

Figure 5. Minimal usage of the TraSer platform in a supply chain over a one-tier distance

ing facility (e.g., intermediate storage for incoming goods) uses a field client to identify the incoming deliveries, and confirms the reception of goods in question by updating the status attributes of the items accordingly. This change can also be detected by the supplier.

4. *OEM performs quality check and decides upon further disposal of the items.* In this case, the OEM uses a field client again to record the result of the QC in the TraSer database. As an option, further disposal of the items can be represented in the database as well (e.g., local correction, return to supplier or discarding), enabling efficient communication of quality feedback to the supplier (again, polling or subscription mechanisms can be employed), resulting in the supplier's responsive actions being triggered faster than it is usual for most business-to-business communications of this kind with small enterprises.

Results of the pilot implementation have shown that this arrangement is feasible for small-business collaboration, and item data can be easily accessed by authorized parties as specified in the scenario. The seamless bridging of organizational borders, as typical in the IOT, was also successfully put into practice.

4.3. Adaptation to other IT components and external requirements

The Romanian software development company *ROPARDO* (formerly *Wittman & Partner Computer Systems)* has built several tracking and tracing solutions based on the TraSer framework for a variety of industrial companies. Here, the example of TraSer deployment at a Romanian ice cream manufacturer is presented, as it gives by far the most complete picture of possible adaptation of TraSer to other systems and requirements, as well as transparent use throughout multiple levels of a supply chain (see also Fig. 6 for a simplified outline of major components).

The key drivers of this pilot application were *i)* providing a flexible and extensible tracking service for packaging items (typically 2D-barcode-labeled boxes and pallets) throughout several stages of the supply chain while *ii)* granting easy access to relevant tracking data for other members of the supply chain (i.e., sales agents, subcontracted distributors, and customers), *iii)* coupling with existing components of the manufacturer's IT infrastructure (proprietary enterprise resource planning *(ERP)*, and sales force automation with iFinance middleware components), and *iv)* meeting preparations for future transparency and traceability requirements to be imposed on the food industry (the latter requirements being still subject to legislation assessment at the moment). The processes to be covered by TraSer are as follows:

- *Creation of new "box" instances within TraSer*, in accordance with the packing and labeling of new boxes;
- *Creation of new "pallet" instances within TraSer*, in accordance with assembling pallet loads of already packed boxes, labeling the pallets and assigning the adequate boxes to the pallet;
- *Tracking of pallet transfer between storage locations*;
- *Recording of pallet decomposition* as deliveries are broken up to individual boxes again at local distribution points;
- *Assignment of boxes to delivery vans*;
- *Checking boxes into the sites of final customers* with handheld devices which have no permanent access to the TraSer server and thus have to store the recorded box-related events until the update connection is established.

In this case, a larger number of customers and business partners have to be managed with respect to access control, while keeping the desired degree of transparency for all parties involved—this, too, will be a major requirement in a properly (and, most of all, securely) operating IOT. The use of interfacing adapters for other IT components, and the preparation for potential adaptation to other tracking specifications (i.e., the expected transparency requirements for the food industry) point towards the connection of several different tracking networks and information repositories—such heterogeneity is certain to appear in a decentrally growing and developing IOT.

4.4. Offering item-level services to customers

The most complete evolution path from closed-circuit asset management towards multiple-partner tracking in supply chains is hosted by *Itella* of Finland (formerly Finland Post). Having performed the tests required in the

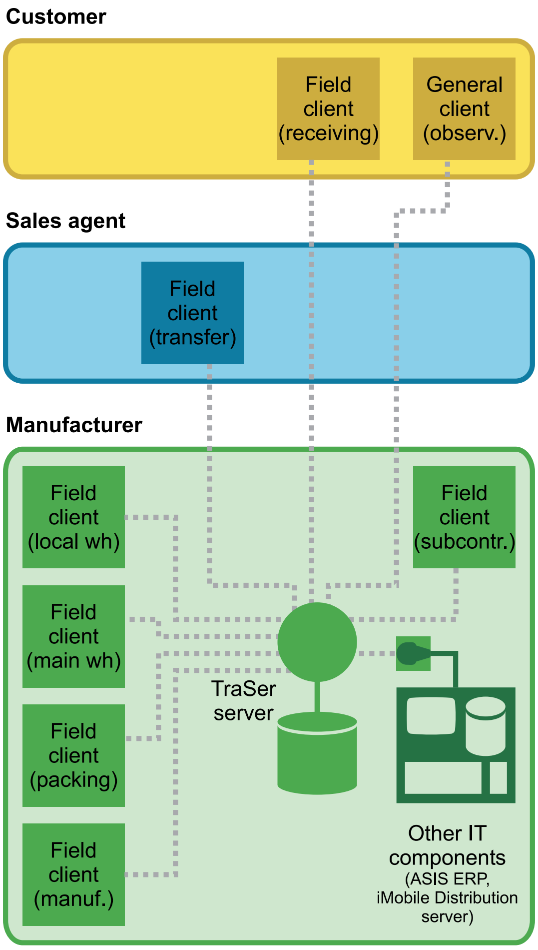

Figure 6. Use of a single TraSer server with access from several levels of a supply chain. Note that the TraSer platform is, in this example, also integrated with other IT components of the manufacturer.

TraSer project, plans for further stages have already been drawn, indicating a continuing interest in such a track-and-trace solution. Here, several scenarios are spanned which are built on each other as follows.

- *Asset identification.* Here, the goal is to identify vehicles and roll cages entering or leaving Itella's facilities. Suitable equipment was, in part, already installed in a given logistics center, and TraSer nodes can readily take over the task of enter/leave transactions. The new solution based on TraSer offers a good basis for further enhancement as well: specific clients could report yard traffic to office personnel or other components of the enterprise IT infrastructure.

- *Asset tracking.* Recording and forwarding vehicle movement, as described above, is, in fact, already leading to a higher functionality level, as it introduces tracking services. This phase allows the transparent surveillance of departure or arrival at several client-equipped locations, enabling the progress of logistics processes to be monitored. The extension of tracking to smaller transportation assets (specifically roll cages) makes it possible to give specific instructions for loading and unloading vehicles, checking the contents of a vehicle, and keeping track of the location of roll cages, thus helping to prevent loss, theft, shortage or surplus build-up of roll cages at various locations. Applying mobile clients would, in this stage, provide a cost-efficient alternative to installation of TraSer clients at destinations which are less frequented by Itella's deliveries.

- *Asset-based tracking of goods.* Here, the transportation assets tracked by the TraSer network are still in a closed circulation (as are their IDs), however, the goods moving together with the roll cages are usually participating in a flow-through supply chain and the latter items only appear in Itella's tracking system once, for a limited amount of time or logistics operations. These goods belong to companies using Itella's logistics services, and Itella can, by providing them with information about delivery progress, offer them goods tracking services, either through a human-readable web interface, or, in more advanced cases, through giving them limited access to the TraSer network by specific TraSer clients. Fig. 7 shows a simplified picture of the logistics tracking pilot in its envisaged final configuration.

Aside from delivering answers to hardware-specific challenges related to metal surfaces and dense population of readers, the pilot application series of Itella successfully demonstrated combination with existing IT infrastructure components and serves as a starting point for passing beyond the scope of the TraSer project—i.e., establishing new services for customers (many of them being SMEs and/or occasional small-scale users), partly by "piggybacking" existing solutions (closed-circuit tracking of re- usable assets).

5. Conclusions and outlook

The paper focused on possible solutions built on the item-level tracking and tracing solution platform developed by the *TraSer* project (*http://www.traser-project.eu*). Aside from giving a brief overview of the platform's capabilities, possible network structures and operations, the paper presented selected pilot implementations for both closed-loop and flow-through application scenarios, with a focus on small business users. The examination of pilot layouts and practical findings concentrated especially on transparency across organizational borders and adaptation to other IT components or information channels, reflecting some of the key requirements for building an Internet of things comprising heterogeneous components.

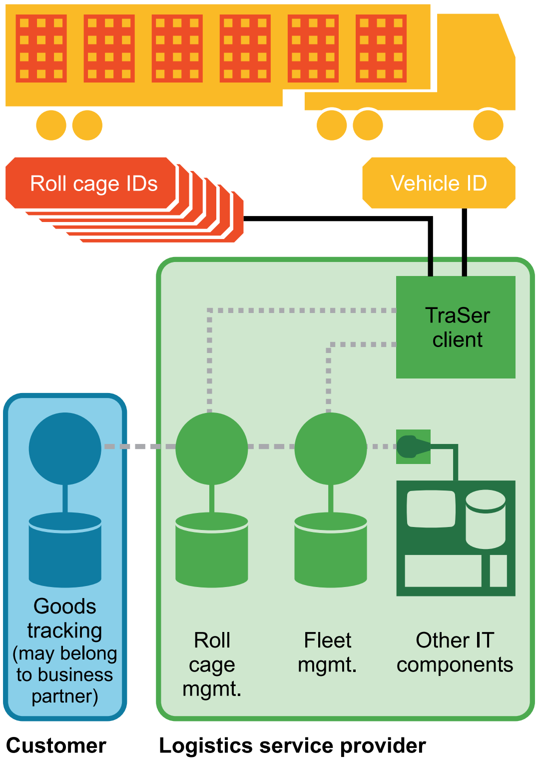

Figure 7. Offering goods tracking services for customers of a logistics service provider

The presented pilot cases reflected that in today's small business sector, the needs for cross-company transparency have not yet unfolded their full range. However, already existing or upcoming transparency and traceability requirements do imply a future need for the aforementioned capabilities. As explained through the pilot applications, the TraSer solution framework is capable of handling these expected demands and may, therefore, take its share in establishing networks conforming with the IOT concept.

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References

[1] J. Dejonckheere, S. Disney, M. Lambrecht, and D. Towill. Measuring and avoiding the bullwhip effect: A control theoretic approach. *European Journal of Operational Research*, 147(3):567–590, 2003.

[2] EPCIS. EPC information services standard reference page. http://www.epcglobalinc.org/standards/epcis, 2007.

[3] EPCIS. EPC Information Services (EPCIS) Version 1.0 specification. http://www.epcglobalinc.org/standards/epcis/epcis_1_0-standard-20070412.pdf, 2007.

[4] A. Estevez and S. Geary. Lessons from the desert. *Supply Chain Management Review*, 8(8):38–43, 2004.

[5] T. Feare. Pump up the volume. *Modern Materials Handling*, 55(3):55–59, 2000.

[6] Frontline Solutions. Hospitals prescribe RFID and bar coding. *Frontline Solutions*, 6(3):10, 2005.

[7] P. Jones, C. ClarkeHill, D. Hillier, and D. Comfort. The benefits, challenges and impacts of radio frequency identification technology (rfid) for retailers in the uk. *Marketing Intelligence & Planning*, 23(4):395–402, 2005.

[8] Zs. Kemény and E. Ilie-Zudor. Traser—identity-based tracking and web-services for smes. In *Proceedings of the 4th International Conference on Digital Enterprise Technology (DET2007)*, pages 471–479, 2007.

[9] Zs. Kemény, E. Ilie-Zudor, R. Kajosaari, J. Holmström, and F. van Bolmmestein. State of the art in tracking-based business (survey deliverable D3.1). Technical report, EU 6th Framework Specific Targeted Research Project TraSer (contract Nr. IST-033512), 2007.

[10] R. Michel. RFID: Where's the beef? *Modern Materials Handling*, 60(2):29–31, 2005.

[11] L. Monostori, E. Ilie-Zudor, Zs. Kemény, M. Szathmári, and D. Karnok. Increased transparency within and beyond organizational borders by novel identifier-based services for enterprises of different size. *CIRP Annals—Manufacturing Technology*, 58(1):417–420, 2009.

[12] M. Rönkkö. A model for item centric material control in manufacturing. Master's thesis, Helsinki University of Technology, Department of Industrial Engineering and Management, 2006.

[13] ToolWatch. Bowen engineering gets more than it bargained for with tool tracking program—toolwatch's positive results extend beyond the tool warehouse. http://www.toolwatch.com/toolwatch/casestudies/detail.php?csid=14, 2007.

[14] B. Trebilcock. RFID on the front lines. *Modern Materials Handling*, 61(1):28–30, 2006.

[15] W. Yu, P. Ray, and T. Motoc. A rfid technology based wireless mobile multimedia system in healthcare. In *Proceedings of the 8th International Conference on e-Health Networking, Applications and Services, HEALTHCOM 2006.*, pages 1–8, 2006.