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Abstract
This paper examines how exploiting hyperconnectivity and modularity concepts underpinning the Physical Internet enables the parcel logistics industry to meet the worldwide challenges to efficiently and sustainably offer faster and more precise deliveries across urban agglomerations, notably across the world's megacities. It emphasizes disruptive transformations of package logistic hubs and networks, such as multi-tier world pixelization, multi-plane parcel logistic web, smart, dynamic parcel routing and hub-based consolidation, and modular parcel containerization.

Keywords
City Logistics, Parcel Logistics, Hub Design, Network Design, Physical Internet, Hyperconnectivity, Modularity, Omnichannel Logistics, World Pixelization, Logistic web, Flow Consolidation, Modular Containers

I. Introduction

The parcel logistics industry is under strong transformative pressure to offer urban agglomerations, and notably the world's megacities, fast, precise and low-price delivery services that can reliably keep high service levels under high demand stochasticity and severe demand peaks and valleys. As a response to this pressure, logistics service providers are challenging the fundamental conceptual and technological pillars upon which they have built their urban service networks and operations, seeking better competitiveness through significantly higher capability, efficiency, and sustainability [1,2,3].

Parcel logistics systems, like the ones operated by DHL, FedEx, SF Express and UPS, are commonly structured around the standard hub-and-spoke network topology, with the term hub mainly denoting a central sorting center [4]. More specifically, a hub in such topology mostly refers to an intermediate point where parcels' handling and transportation can be centralized to tap into economies of scale and consequently reduce the per-unit cost of flow [5]. This single-level view of facilities has been studied extensively in the literature to analyze and optimize the system's design and operations [6-11]. While this view is beneficial from an analytical standpoint, a multi-level view is crucial to capture the hierarchal nature of parcel logistics system design as close to reality as possible. Embracing such a wider view creates more opportunities to improve the system under the conflicting objectives of achieving cost-effectiveness and providing tight urban service offerings such as X-minutes delivery.

Parcel logistic hubs currently play roles of customer interface, parcel sortation and/or crossdocking [12-17]. The network topology linking such hubs is a key pillar of the performance of parcel logistics providers. Current factors enabling and/or limiting the performance of urban hub-and-spoke networks include, from an external perspective: travel, parking and building regulations; on-demand transport availability; the advent of connected and autonomous vehicle technologies (notably drones and droids); the growing Internet-of-Things enabled monitoring and traceability capabilities; the availability of smart transportation and delivery management systems; and, from an internal perspective: the reliance on service agreements based on cut-off times; the selection of vehicle sizes and routing logic; parcel sorting and consolidation policies; and handling unit loads.

This paper aims to apply modularity and hyperconnectivity concepts underpinning the Physical Internet (PI) [18,19] to break away from currently dominating hub-and-spoke network topology in urban environments, toward a logistic web topology [19] based on multi-plane meshed networks interconnecting hubs adapted to each plane such that each hub acts as the source or destination of other hubs. We seek the potential benefits obtained by the combination of features such as exploiting modular containers across the parcel logistics network; adapting the vehicles and handling equipment to take advantage of such containers; and exploiting live information about parcel pickup, delivery engagement, current location and time. The paper thus aims to contribute to designing the forthcoming generation of parcel logistic hubs and networks that are capable of supporting the trending goals of X-hours (ultimately X-minutes) delivery

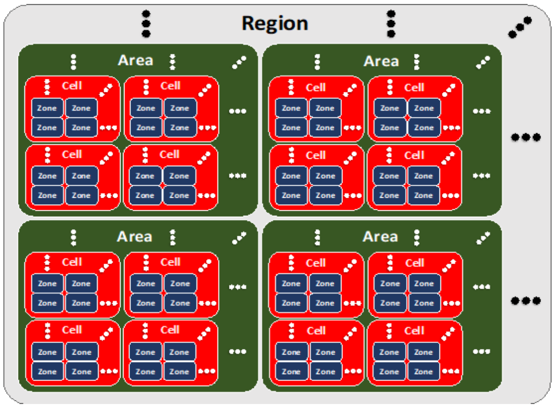

Figure 1. Proposed urban pixelization

services within megacities (e.g., Shanghai and New York) as well as much smaller cities across the world.

The remainder of this paper is organized as follows. In section II, we present a four-tier framework to pixelize urban territories served by the parcel logistics system. In section III, we introduce a corresponding parcel logistic web, depicted as a four-plane network of meshed logistics networks. The three higher planes of the logistic web correspond to a meshed inter-hub network, with hubs specialized for each tier. In section IV, we focus on smart, dynamic parcel routing and hub-based consolidation. In section V, we address modular containerization and consolidation of parcel logistics. In section VI, we synthesize the key impacts of hyperconnectivity and modularity on parcel logistic hubs. In section VII, we provide conclusive remarks and avenues for further research and innovation.

II. MULTI-TIER PIXELIZATION OF URBAN AGGLOMERATIONS

For parcel logistics purposes, we propose four-tier pixelization of urban agglomerations that is quite in line with the practices of some logistics service providers while being innovative with its generic structuring of space, which facilitates efficient multi-party multimodal logistics and transportation operations. The four pixelization tiers are unit zones, local cells, urban areas, and the overall region, as shown in Figure 1.

The first tier decomposes the territory in contiguous unit zones that vary in size depending on expected demand density: examples include a suburban neighborhood, an urban community, a campus, an industrial park, a highrise building or a set of stories of a highrise building. Except when being part of a high-rise where height specification matters, a unit zone can usually be defined as a small polytope on the world map, or as a collage of the 3m x 3m squares recently defined by www.what3words.com to map the world and made easy to locate using a unique 3-word address. Several logistics service providers use the concept of unit zones within their organization, often assigning a single courier or a small team of couriers to be responsible for all their contracted pickups and deliveries within the zone. The second tier depicted in Figure 1 clusters sets of adjacent unit zones into local cells. The third tier clusters these local cells in urban areas, and the clustering of these urban areas defines the region in the fourth tier. The definitions of zones, cells, areas, and regions are not strictly bounded by geopolitical and natural borders and are subject to dynamic evolution as logistics demand and activity evolve in the hyperconnected cities, in line with the connectography work of [20].

III. MULTI-PLANE URBAN PARCEL LOGISTIC WEB

In order to enable efficient and sustainable urban parcel logistics services, we propose a multi-plane parcel logistic web interconnecting meshed networks along four planes, as depicted in Figure 2: plane 0: inter-P/D network linking pickup and delivery points; plane 1: inter-zone network; plane 2: inter-cell network; plane 3: inter-area network. On a broader scale, this urban parcel logistic web is connected to higher-plane meshed networks, such as inter-region networks (plane 4) and inter-block networks (plane 5), allowing parcels to flow from any zone of any city to any zone of any city, whatever their region and block in the world.

Figure 3 provides an instantiation of the logistic web over the pixelized territory of a grid-shaped megacity. Its key nodes

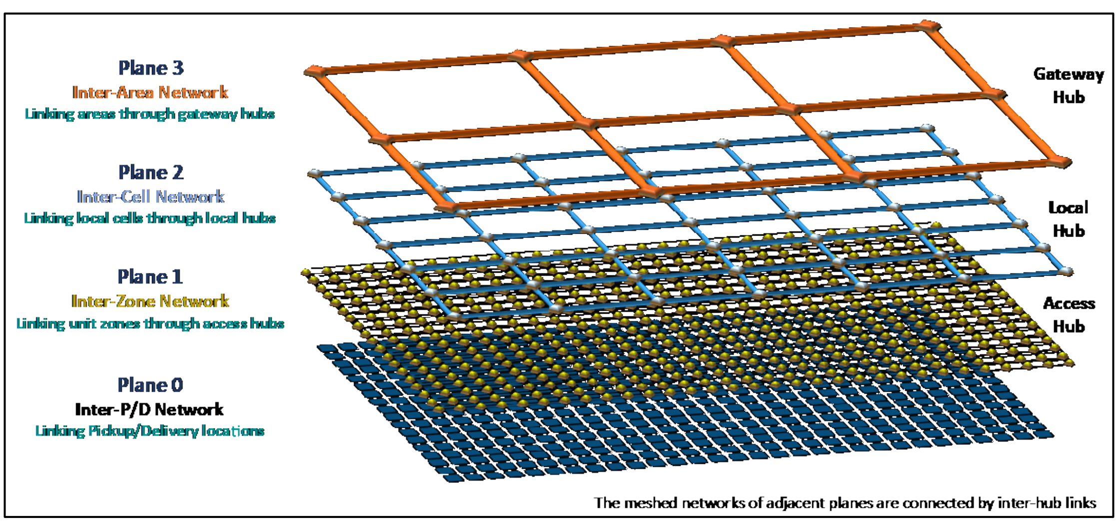

Figure 2. Proposed urban parcel logistic web

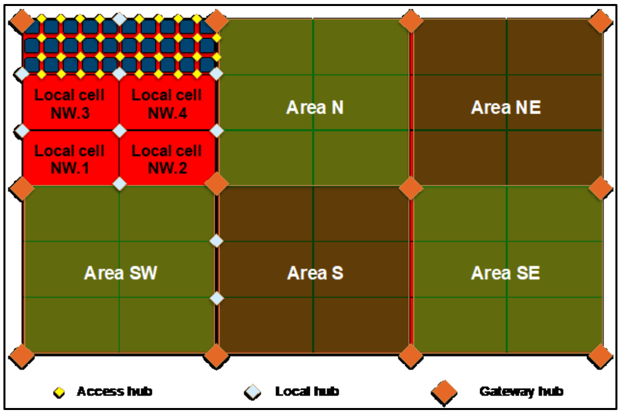

Figure 3. Parcel logistic web mapped on pixelized megacity

are pickup/delivery locations within zones, access hubs located at the intersection of neighboring zones, local hubs at the intersection of neighboring local cells, and gateway hubs at the intersection of neighboring areas.

Plane 0 of the logistic web is the inter-P/D network linking the customer pickup and delivery locations: e.g., household, office, store, factory, parking, smart locker bank, and package rooms. Each zone is directly connected to four access hubs located at its corners. These are concurrently connected to the inter-P/D network and interconnected through the meshed plane-1 inter-zone network.

The inter-zone network facilitates direct transfer of parcels between sources and destinations in nearby zones. Local cells have each been illustratively defined in Figure 3 as a rectangular cluster covering 3x5 unit zones while each urban area has been similarly defined as a rectangular cluster consisting of 2x3 local cells. Each cell and each area is connected externally to four hubs, respectively local hubs and gateway hubs. At each local hub location also lays an adjacent access hub so as to ease the linking of the plane-1 inter-zone network and plane-2 inter-cell network. Similarly, at each gateway hub location also lays an adjacent local hub, so as to ease the linking of the plane-2 inter-cell network and plane-3 inter-area network. Gateway hubs are the main interfaces between urban areas of a megacity. They act as the main hubs for consolidating inbound and outbound flows across the regions (i.e., between cities).

All possible transportation infrastructure networks are exploited for the flow of parcels between P/D locations, access hubs, and local hubs. This includes streets, avenues, backstreets, biking/walking trails, corridors, elevators, and local drone airways. In higher planes, there is gradually more opportunity to utilize the network of boulevards and highways, rapid transit system and railway infrastructures, waterways and inter-airport airways to flow parcels between local hubs, gateways hubs, and eventually, regional hubs and global hubs. Consequently, depending on the travel locations and distances, and the visiting planes and networks, multiple modes can be exploited, including walking, bikes, scooters, droids, drones, electric urban vehicles, trucks, tramways, subways, buses, barges, ships, railcars, airplanes, and airships.

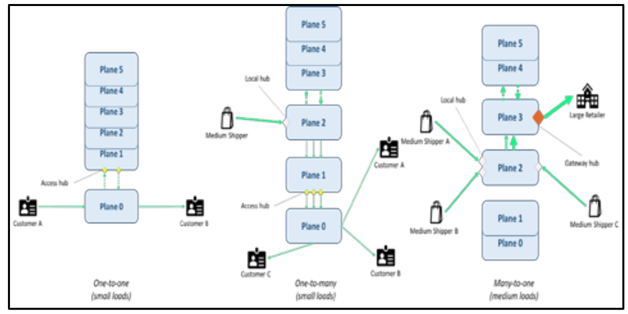

Figure 4. Parcel shipment and flow patterns in logistic web

Throughout the parcel logistic web, multiple transportation service providers may be exploited to move parcels in a synchromodal way from the source to the destination. It is also possible that different service providers operate the exploited logistic hubs in a territory. Hence, the resulting parcel logistic web is interconnecting multi-plane, multi-party, and multimodal meshed logistic networks.

IV. Smart Dynamic Hub-Based Parcel Routing and Consolidation

In general, parcels are picked up and delivered at some locations in the inter-P/D network. Depending on the distance between these locations, there are four typical flow patterns:

(1) The parcel is flowed directly from the source to the delivery location along plane 0 (inter-P/D network);
(2) The parcel is climbed to plane 1 at a nearby access hub, moved along the inter-zone network, then lowered to plane 0 at an access hub near the delivery location for final delivery;
(3) As in (2), the parcel is brought to plane 1, then from the access hub it is flowed across the inter-zone network to a nearby local hub to climb to plane 2 (inter-cell network) along which it flows until it reaches a local hub nearby the final destination, where it then is lowered first to plane 1 and then to plane 0 for delivery;
(4) As in (3), the parcel is gradually flowed from the pickup location to a nearby local hub on plane 2, then it is flowed in the inter-cell network to the appropriate gateway hub in plane 3, then flowed along the inter-area network to a gateway hub near the final destination, where it is gradually lowered from plane 3 to plane 0 for delivery.

As Figure 4 demonstrates, urban parcel logistics deals with three types of shipment patterns: one-to-one, one-to-many, and many-to-one. The shipment patterns influence the flow patterns described above.

The one-to-many shipment is a set of consolidated individual shipments that are sent from a single source (like an office or a fulfillment center of an online retailer) to different destinations (e.g., individual e-commerce consumers). The many-to-one shipment corresponds to a client requesting to receive at a specific location parcels originating from multiple sources. An example of this case would be a return center of an online retailer. In such cases, the shipments may not be fit to enter or leave the system through access hubs due to the shipment volume and/or shipper type. Entering or leaving the system directly at higher planes through facilities with higher capacity, such as local hubs and gateway hubs, facilitates delivery in such cases.

Smart consolidation of the parcel flows is paramount to logistics efficiency and sustainability. It is possible to route an individual parcel fast from source to destination by putting it alone in an on-demand vehicle (e.g., taxi, Uber/Lyft vehicle), yet this currently explodes delivery costs. The parcel industry has long been aware of the need for consolidation. In fact, the dominating way for this industry to achieve consolidation is to combine two strategies:

(1) Exploiting the hierarchical hub-and-spoke network. Using the proposed urban pixelization and hub typology, for packages delivered within a megacity, (a) route all picked up parcels to the nearest local hub for consolidation; then (b) route all parcels from that local hub to its assigned gateway hub; (c) sort and consolidate at the gateway hub, by destination and service level (same-day, next-day); (d) ship consolidated parcels toward the local hub nearest to their final destination; (e) sort and consolidate them according to the zone of each incoming parcel for final delivery. This process forces parcels to travel all across the megacity even if the distance between their source and destination is short.

(2) Imposing strict pickup cut-off times for each service level to artificially create a few high peak pickup, sortation and delivery periods per day, that are prone to ease consolidation (i.e., pickup by 6 pm for delivery on the following day).

In the hyperconnected parcel logistics, the hub-and-spoke structural constraint is removed, replaced by the exploitation of the logistic web and its multi-plane meshed networks interconnecting the hubs, with many more flow options. Also, as much faster and more precise delivery capabilities are targeted, the few-cutoff-times strategy is deemed too limiting, and thus more relaxed pickup and delivery options are offered. This means that consolidation has to be achieved otherwise, more continuously and ubiquitously, exploiting the web of interconnected logistic hubs to steer smart consolidation.

The basic logic for hyperconnected parcel flow consolidation is based on three simple principles:

(1) Implement hub-based sorting and consolidation so as to be easy, cheap, fast, reliable, and safe.

(2) Consider options for relay-based consolidation of parcels up to a specific hub along their planned route from source to destination.

(3) Smartly decide upon consolidation actions at each hub at each arrival of parcels, exploiting all current information available on contracted parcel status, consolidation options, and expected parcel demand across the logistic web.

TABLE I. CONSOLIDATION INTENSITY AT HYPERCONNECTED LOGISTIC HUBS

Shipment Size	Access Hub	Local Hub	Gateway Hub	Regional Hub	Global Hub
Individual Shipments	●	•	·		
Consolidated Load	·	●	•	•	·
Heavily Consolidated Load			●	●	●

The first principle is important: if consolidation is cumbersome, expensive, long, unreliable, and unsafe, then service operators will avoid doing multiple consolidations, preferring to minimize the number of consolidation actions as in current hub-and-spoke implementations.

The second principle exploits the interconnected meshed networks of logistic hubs. In hyperconnected parcel logistics, each parcel has a dynamically optimized route from its current location through a sequence of hubs toward its final destination. This enables to know what are the next destinations of each parcel currently in a hub, or on its way to that hub. This can be exploited to define optimized consolidations.

Consider the case of an access hub (the smallest and simplest hub, yet the least obvious to be a smart candidate to perform consolidation): among its current, arriving and incoming parcels, it may have enough to make a few consolidations, such as one for the gateway hub of a leading-demand city, one for the regional hub of a neighboring region, one for the northbound gateway of the current city, and one for the other access hubs in the current local cell. In such a case, there would be five consolidations: one for each of the above and one for the nearest local hub.

The third principle is to avoid considering only fixed consolidation avenues, rather exploiting the smart hyperconnected nature of the new-generation logistics to take data-driven live decisions for shipment and flow consolidation actions, exploiting all degrees of freedom enabled by applying the first and second principles.

When applying these principles, it is expected that ever more consolidation is achieved as consolidated parcels reach higher-plane meshed networks. Whereas it is frequent to deal with individual parcels at access hubs and local hubs, it is much rarer at gateway hubs, regional hubs, and global hubs. This is not the case in most current parcel logistics systems, where most parcels are individually sorted in gateway hubs, and even in global hubs. This is illustrated in Table 1.

V. Modular Containerization and Consolidation

As shown in [21], containerization has had a dramatic impact on the performance of freight logistics and transportation across the world. A container-size shipment from Chicago (USA) to Nancy (France) should have cost about 14,000 US$ in 2010 based on the actualized value of the 1960 pre-container cost of about 2,000 US$. Yet in 2010 such a containerized shipment

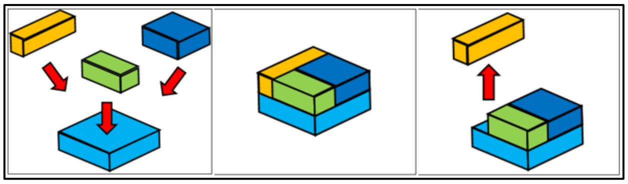

Figure 5. Dynamically interlocking and dislocking modular containers for consolidation purposes

was costing roughly 4,000 US$ due to handling, maritime transport, and trucking costs being respectively 14, 4.5 and 1.5 times smaller. World standard containers have become the norm. Container ships have been invented, with huge gains in workforce requirements and increases in carrying capacity. Ports and their handling technologies have been completely reshaped to take advantage of the simplified container handling. Multimodal trains and trucks have been invented to ease the connection between source, ports, and destination.

The Physical Internet extends containerization to embrace modular containers that are designed for logistics and are smart, connected, and environmentally friendly [2]. At full maturity, PI containers are to be standard and modular; robust and reliable yet light and thin; easy to snap to grids and to interlock together, permitting to create composite containers and to decompose them at will (see Figure 5); easy to load, unload, seal and unseal; easy to condition and clean; easy to panel for informational and publicity purposes; reusable and recyclable; easy to unfold or dismantle when off-service; and available in distinct structural grades [22].

In a combination of Lego and Russian Dolls concepts, three types of modular containers are prescribed: transport containers (PI pods), handling containers (PI boxes), and packaging containers (PI packs) [22]. The PI pods have modular dimensions around the spectrum from 12, 6, 4.8, 3.6, 2.4 to 1.2 meters, the PI boxes and packs range from roughly 1.2, 0.8, 0.6, 0.4, 0.3, 0.2 to 0.1 meters, with the PI packs dimensioned to fit within PI boxes that are dimensioned to fit within PI pods.

The parcel logistics industry has put in place a number of incentives for clients to limit the size and weight of their parcels, and to ensure proper packaging protecting the encapsulated goods from being broken due to handling and transportation shocks. So, its packaging containers (the parcels shipped by clients), tough not modular in shape and not designed to ease logistics (see [22] for further details), are cubic, relatively light, and mostly sturdy enough for single usage. When consolidating parcels, it is currently typical to put them in large reusable bags that have the advantages of not taking much space when empty and of having flexible shape. Yet these bags are not prone to automated handling, and they lead to losing control over placement and orientation of consolidated parcels. The industry is also using reusable designed-for-aircraft parcel handling containers similar to those now often used for luggage handling in airports, yet these are strictly used in aircraft, have to be loaded before air travel and emptied afterward.

Across the wider logistics industry, intra-facility modularity is at the core of several new-generation logistics facilities such as fulfillment centers, distribution centers, sortation centers, and luggage handling systems. For example, many of these centers exploit shuttle-based and/or mobile robot technologies that are designed to move standard-size totes acting as handling containers. Yet these totes are mostly dedicated to a single facility or a client-supplier dyad.

We propose that modularity be core to hyperconnected parcel logistics, expanding the use of modular containers way beyond a single facility and a single party, indeed enabling modular containers to be flowed and consolidated through the logistic web and its multi-plane, multi-party, and multimodal meshed networks, even to customers [22, 23].

As the parcels are currently paid and prepared by clients, it is difficult to contemplate a fast industry-wide migration toward PI packs. Such migration will have to be gradual. A potential roadmap can be as follows:

(1) Agreement by industry leaders on a set of modular dimensions;
(2) Price incentives to use parcels of modular dimensions;
(3) Development and implementation by leaders of a first-generation set of reusable modular PI packs, with price incentives to clients for using them.
(4) Development and implementation of next generations of PI packs, exploiting learning from usage and new enabling materials and technologies.

Meanwhile, the prime space for innovating solutions and technologies for modular parcel containerization is at the handling container level, replacing the current bags by modular reusable foldable (or dismantle) boxes well designed for parcel logistics. Two categories of dimensions are prime candidates:

(1) Tote-size boxes allowing easy human, automated and robotic handling;
(2) Pallet/cage-size allowing large consolidation (e.g., fitting in a pod on the order of 1.2 or 2.4 m wide, 1.2 m deep, 1.2 or 2.4 m high).

Modular transport containers (pods) also have a high potential for large consolidation. They differ from the large handling containers as they are engineered to resist tough weather conditions (rain and water, ice, snow, sand, etc.) like maritime containers, and to be easily loaded on and unloaded from flatbed trailers, railcars, barges and so on. They notably enable efficient consolidation in modules less than a full truckload.

PI packs, boxes, and pods are to be uniquely identifiable, digitally connected, and equipped with embedded sensors (location, shocks, temperature, etc.), and will gradually have ever better state memory and reasoning capabilities that make them cognitive agents communicating and acting across the logistic web [22, 24].

Beyond the design of the containers themselves, the adaptation of handling carts, racks, devices, and robots is key to ensuring efficient modular containerization of parcel logistics, as well as the development of modular-container focused handling, sortation and storage technologies, as well as transport vehicles [25, 26]. Logistic hubs in their entirety are to enable fast, efficient, and flexible processing of active modular containers [18, 26].

To describe how modular containerization is enabling smart parcel consolidation, we first focus illustratively on the simpler yet less efficient first phase when modular containerization is implemented only at the handling container level.

Let us start by revisiting the case of section 4 on outbound consolidation in an access hub. Such consolidation can be efficiently achieved by relying on small PI boxes used by the couriers to handle and consolidate parcels toward the same hub. In fact, the access hub is to be fundamentally PI-Box engineered. All incoming parcels are to be put in a dynamically designated PI box.

In a human-centric implementation, the courier responsible for pickup and delivery within the zone is to be guided digitally through light, voice, or augmented reality technologies as to which PI box he should put each of his pickups, and which PI boxes he should take and snap to his vehicle, cart, or back for his next round of deliveries.

From the inter-zone perspective, a rider is to come to the access hub with a vehicle to pick up the outgoing parcels and to deposit ingoing parcels. His vehicle is strictly carrying PI boxes, potentially except for a space reserved for special shape parcels. The outgoing parcels are currently in some PI boxes in the access hub and must each end up in a PI box in the vehicle. The rider has two choices relative to each PI box containing the parcels he must retrieve:

(1) He takes a PI box in the access hub and inserts it into his vehicle. There may be two reasons for doing so, either the PI box is already full enough, or it still has significant empty space which will be filled by some parcels to be picked up elsewhere along his route.
(2) He opens the PI box, picks up its contained parcels, and then places them in appropriate PI boxes in his vehicle.

For the incoming parcels that he carries in PI boxes within his vehicle, he again has two choices:

(1) He transfers an entire PI box to the access hub;
(2) He takes parcels from PI boxes in his truck and transfers them to a set of inbound PI boxes within the access hub.

In local hubs at the intersections of local cells, the same type of consolidation is to occur, involving the transfer of parcels between PI boxes, from the cell-based rider vehicle or area-based shuttle vehicle to the local hub or vice-versa.

At this stage starts consolidation of PI boxes heading for the same destination. There are three ways:

(1) The parcels from several partially filled small PI boxes are grouped into a single small PI box;
(2) The parcels from several small PI boxes are transferred to a single large PI box;
(3) Several small PI boxes are composed together to become a composite large PI box (see Figure 5).

Starting with the area-based shuttle vehicles servicing the local hubs in the area and the gateway hubs surrounding it, the vehicles should be designed to allow easy loading, unloading and accessing of both small and large PI-boxes. This applies to all higher planes.

VI. Hyperconnected Hubs with Modular Consolidation

The combination of our transformative proposals for exploiting hyperconnectivity and modularity in urban parcel logistics provides seven fundamental transformations to the parcel logistic hub design:

(1) Hubs are to receive and ship modular containers encapsulating parcels consolidated by next joint destination (a hub or a zone);
(2) Hubs are to exploit pre-consolidation to avoid sorting all parcels and containers, with more container sorting and crossdocking in higher-plane hubs;
(3) Hubs are to have less direct sources and destinations, as these are to mostly include intermediate hubs from the same plane or adjacent planes;
(4) Hubs are to be ever more inherently multi-party and multi-modal service providers;
(5) Hubs are to break away from fixed cut-off times, exploiting more agility through dynamic and responsive shipping times;
(6) Hubs are to be capable of conducting smart, dynamic decisions on the parcel and container routing and consolidation, and also performing smart, dynamic orchestration of their internal flow;
(7) Hubs are to be active agents within the logistic web, dynamically exchanging update information on the status of parcels, containers, vehicles, routes, and the other hubs; and adjusting their decisions accordingly.

Overall, flowing through the hubs must be considered easy, cheap, fast, reliable, safe, and secure, as leverage for exploiting logistic-web-wide asset sharing and flow consolidation toward fast, precise, agile, efficient, secure, and sustainable pickup and delivery of parcels.

Figure 6 conceptually contrasts the design of a contemporary central urban hub in a hub-and-spoke network with a hyperconnected gateway hub exploiting modular containerization in a logistic web.

The contemporary hub is channeling all the parcel bags received from incoming trucks toward a primary sorting zone where each parcel is taken out of its bag and then sorted individually according to clustered sets of destinations and put accordingly in an appropriate bag for secondary sorting. The secondary sorting zone is composed of a set of subzones dedicated to each cluster of destinations, where incoming bags are emptied, and the individual parcels are further sorted and bagged according to their respective destination and service level (e.g., same-day, next-day). Each bag out of secondary sorting is flowed to the appropriate dock for loading into the truck heading toward its target destination, directly or after a temporary staging depending on the service level and dock/truck availability.

The hyperconnected gateway hub receives small and large modular containers consolidated according to the same joint

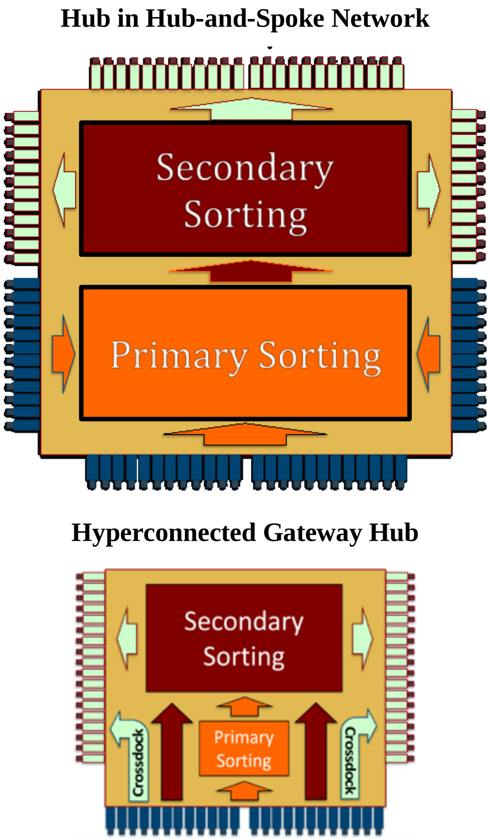

Figure 6. Contrasting a central hub in hub-and-spoke network and a hyperconnected gateway hub with modular containerization

target destinations. The typical workflow patterns through the hub are as follows:

(1) Incoming modular containers whose target next destination is the current hub are channeled to the primary sorting zone where they are consolidated into small or large modular containers according to the clusters of next-destination targets,service levels, and the expected number of consolidable parcels. These may be heading to a dock (directly or after staging if truck/dock is not available) if the sorted parcels head to a single target next destination, or otherwise to the secondary sorting zone.

(2) Incoming large modular containers whose target next destination is not the current hub are crossdocked directly to their outgoing dock if the truck is available, or staged until it becomes available.

Incoming small modular containers whose target next destination is not the current hub are either sent to secondary sorting for being composed with other containers with the same target and service level for increased handling efficiency, or crossdocked directly to their outgoing dock if the truck is available (or staged until it becomes available).

(3) Modular containers out of the primary sorting and channeled to the secondary sorting are emptied and their parcels are re-sorted in terms of their specific next target destinations and service levels, then consolidated into small or large modular containers according to clusters of next-destination targets, service levels, and the expected number of consolidable parcels. They then head to a dock directly or after staging if the truck/dock is not available.

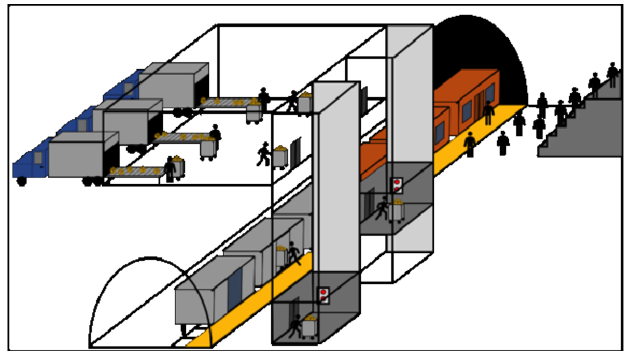

Figure 7. Hub-based interconnection of truck-based and subway-based transport for smart urban synchromodal flow

Figure 6 highlights three distinctive features of hyperconnected gateway hubs vs. their contemporary versions:

(1) Their workflow pattern exploits the incoming preconsolidated modular containers, and shapes further consolidation as pertinent;

(2) Their primary and secondary sorting zones are generally smaller due to the smaller number of individually sorted parcels and the smaller number of target destinations induced by inter-hub relay transport and hub-based consolidation, and the non-reliance on artificial workload peaks associated with fixed cutoff times, and are thus generally smaller than their contemporary counterparts;

(3) They tend to have fewer docks as they have fewer sources and destinations, and these are often intermediary hubs, they do not rely on artificial receiving and shipping peaks generated as a result of fixed cutoff times, and they can exploit multi-party vehicles with fast modular container loading/unloading.

Hyperconnected parcel logistic hubs can also allow intermodal crossdocking activities that tap into the urban transportation infrastructure. Illustratively, Figure 7 provides a rendering of a hub enabling synchromodal transportation of parcel containers exploiting road-based trucking and subway-based transport. It highlights two key features of hyperconnected urban logistics: the exploitation of urban infrastructures whenever pertinent and the interconnection of people and freight logistics. Such characteristics are bound to become ubiquitous, with the wide variety of potential complementary urban modes of transportation and delivery. Autonomous vehicles, from drones and droids to trucks, are to require smart design of hyperconnected logistic hubs so as to be exploited efficiently and sustainability.

Given the above considerations, in order to ensure high performance, hyperconnected parcel logistic hubs ideally require:

(1) Operations to be error-proof, with no parcels being put in the wrong container and no container getting shipped to the wrong next destination;

(2) Modular containers to be tracked and traced continuously using the Internet-of-Things technologies, so as to enable fact-based dynamic decisions;

(3) Standard operating protocols to be enforced to ensure seamless, efficient multi-party co-operation [27];

(4) Exploitation of smart hub management and execution systems, interconnected to a digital logistic-web platform, with smart analytics, decision making, optimization, and simulation capabilities.

VII. Conclusion

In this paper, we have addressed how the Physical Internet's hyperconnectivity and modularity conceptual pillars enable shaping a new generation of highly meshed urban parcel logistic networks and hubs providing an efficient and sustainable way to tackle the challenging pickup and delivery services ever more expected by the urban markets. We have introduced several new concepts such as urban pixelization and urban logistic web; a hyperconnected hub typology; hub-based consolidation; modular parcel containerization with transport, handling, and packaging containers; and hyperconnected hub design characteristics.

Each of the introduced concepts opens numerous avenues for further research and innovation, starting from this primer presentation and developing, assessing, instrumenting, and pilot testing them. Furthermore, whereas this paper has focused on urban parcel logistics, several of the introduced concepts can be expanded to wider regions toward intercity, inter-region, and global parcel logistics; and to encompass, beyond parcels, overall freight logistics, within urban agglomerations and across the world, again opening a plethora of research and innovation avenues.

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