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Capacity with a pOsitive enviRonmEntal and societAL footprInt: portS in the future era

COREALIS
THE PORT OF THE FUTURE

Intra-Terminal Operations State of the Art Review

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List of Acronyms

Abbreviation / acronym	**Description**
3GPP	3rd Generation Partnership Project
4GP	Fourth Generation Port
5G	Fifth Generation
5GP	Fifth Generation Port
AAS	Adaptive Antenna System

Abbreviation / acronym	Description
AI	Artificial Intelligence
AR	Artificial Reality
BI	Business Intelligence
CAPEX	Capital Expenditure
CCTV	Closed-circuit television
CE	Circular Economy
CFS	Container Freight Station
CMMS	Computerized Maintenance Management Systems
CO2	Carbon Dioxide
COTS	Commercial Off-the-Shelf
D1.1	Deliverable number 1 belonging to WP 1
D3.1	Deliverable number 1 belonging to WP 3
DGPS	Differential Global Positioning Systems
DSL	Digital Subscriber Line
EAM	Enterprise Asset Management
EAS	Enterprise Archive Solution
EC	European Commission
EDI	Electronic Data Interchange
eMBB	enhanced Mobile Broadband
ERP	Enterprise resource planning
ESPO	European Sea Ports Organisations
ETSI	European Telecommunications Standards Institute
eV2X	Enhanced Vehicle-to-Everything
FTTx	Fibre to the x
Gbit (Gb)	Gigabit
GIS	Geographical Information Systems
GOS	Gate Operating System
GPRS	General Packet Radio Service
GPS	Global Positioning Systems
GTO	Global Terminal Operator
HHT	Hand Held Terminal
ICT	Information and Communication Technology
IMT	International Mobile Telecommunications

Abbreviation / acronym	Description
IoT	Internet of Things
IP	Internet Protocol
ISPS Code	International Ship and Port Facility Security Code
IT	Information Technology
ITU	International Telecommunication Union’s
KPI	Key Performance Indicator
LNG	Liquid Natural Gas
LTE	Long Term Evolution
M2M	Machine to Machine
Mbit (Mb)	Megabit
MEC	Multi-access Edge Computing
MIMO	Multiple Input Multiple Output
MIS	Management Information Systems
ML	Machine Learning
mMTC	massive Machine Type Communications
MNO	Mobile Network Operator
MTC	Machine Type Communications
MU-MIMO	Multi-user MIMO
NB-IoT	Narrowband Internet of Things
NFV	Network Functions Virtualisation
NR	New Radio
OCR	Optical Character Recognition
OFDM	Orthogonal Frequency Division Multiplexing
PCS	Port Community System
PdM	Predictive Maintenance
PPP	Public Private Partnership
QC	Quay Crane
QoS	Quality of Service
RAN	Radio Access Network
RCM	Reliability-Centered Maintenance
RDT	Radio Data Terminals
RF	Radio Frequency
RFID	Radio-Frequency Identification

Abbreviation / acronym	Description
RoRo	Roll-on/roll-off
SCADA	Supervisory Control And Data Acquisition
SDN	Software-Defined Networking
SDO	Standard Development Organisations
SNOI	Signal not of Interest
SOI	Signal of Interest
SSS	Short Sea Shipping
SWS	Space Weather Services
TEN-T	Trans-European Transport Network
TMS	Terminal Management System
TOS	Terminal Operating System
UHF	Ultra High Frequency
UNCTAD	United Nations Conference on Trade and Development
URLLC	Ultra-Reliable and Low Latency Communications
VHF	Very High Frequency
WLAN	Wireless Local Area Network
WMS	Warehouse Management System
VMT	Vehicle Mounted Terminal
WP	Work Package
VR	Virtual Reality
WSN	Wireless Sensor Networks
VTS	Vessel Traffic System

Executive Summary

This deliverable presents the state of port intra-terminal operations. It also provides an analysis of the current status and developments on intra-terminal operations and asset management, as well as a review of scientific works on leveraging data analytics for providing data-driven control actions to intra-terminal operations. This deliverable builds on the outcomes of Deliverable D1.1, which gives an overview of the port of the future challenges, enablers and barriers.

The port industry is changing rapidly due to new requirements that ports have encountered and will face in the future. While efficient ports are vital to the economic development of their surrounding areas, the related ship traffic, the handling of the goods in the ports and the hinterland distribution can cause a number of negative environmental impacts. Therefore, ports need to consider environmental issues as well as their relationship with its surrounding area carefully when planning intra-terminal operations.

Due to the increasing levels of automation and the increasing size of vessels, the ports require bigger investments to infrastructure and other equipment in order to perform intra-terminal operations effectively and survive in competition. The European Commission's infrastructure policy and port governance models are some of the measures aiming to respond to this problem. Furthermore, information systems developed for asset management and terminal operations management in general, have helped ports to design and monitor their operations, as well as enable better utilization of the assets.

The rapid development of information and communication (ICT) technologies such as the Internet of Things (IoT), machine learning and 5G networks, offers huge opportunities for ports to optimize their intra-terminal operations. As the useful life of terminal assets is rather long, many ports have terminal infrastructure that do not allow the best possible use of modern ICT solutions designed for intra-terminal operations. However, the potential of new technologies for improving the port's intra-terminal operations is so high that the old equipment and infrastructure may need updates sooner than their useful life would end.

1. Introduction

The significance of ports for the European Union is irrefutably high: 75% of all international goods traffic is handled via ports. For inner-EU goods traffic, waterway transport amount to 40% of all cargo. In 2011, the EU ports handled about 3.7 billion tons of goods whereof 70% were bulk, 18% container, 7% Ro-Ro (roll-on-roll-off) and 5% break bulk traffic. [1]. Taking 2011 as year of reference, the total goods volume is forecasted to rise by 50% until the year 2030 [2].

In addition to the increased cargo volumes, the port and maritime sector are facing several other new challenges and requirements. For example, due to enlarged vessels and companies merging, cargo volumes are concentrating in a few ports to be handled in a small amount of time. The other typical issues are related to environmental concerns and new security requirements. Obviously, investments are needed to increase capacity, but the problem is that there is limited amount of space for totally new ports, and the current ports are usually in the middle of existing neighbourhood limiting possibilities to enlarge their area. Therefore, the approach of COREALIS project is to try to use the existing infrastructure as efficiently as possible in order to minimize the needs for building new ports or making significant enlargement investments for current ports. Implementing latest technological solutions would help to better utilize the existing port area and its infrastructure.

1.1 The purpose of the deliverable

This deliverable is a part of WP3 on the Port of the Future Intra-Terminal Operations of the COREALIS EU-project. Formerly published COREALIS deliverable D1.1 *Port of the future challenges, enablers and barriers* makes a comprehensive and systematic recording of current, mid-term and long-term challenges that European ports are facing in the era of digital revolution regarding operational capacity/efficiency, hinterland connectivity, environmental footprint and sustainability concerning climate change, societal acceptance and inclusion in public-private partnerships. This deliverable goes deeper into this topic by reviewing the state-of-the-art of port intra-terminal operations by discussing (i) the analysis of the current status & developments on intra-terminal operations and asset management; (ii) the literature review of scientific works on leveraging data analytics for providing data-driven control actions to intra-terminal operations.

In general, COREALIS proposes a strategic, innovative framework, supported by disruptive technologies, including Internet of Things (IoT), data analytics, next generation traffic management and emerging 5G networks, for cargo ports to handle upcoming and future capacity, traffic, efficiency and environmental challenges. It respects the limitations that many European ports are facing concerning the port land, intermodal infrastructure and terminal operation. It proposes beyond state of the art innovations that will increase efficiency and optimize land-use, while being financially viable, respecting circular economy principles and being of service to the urban environment. Through COREALIS, ports will minimize their environmental footprint to the city, they will decrease disturbance to local population through a significant reduction in the congestion around the port. They will also be a pillar of economic development and business innovation, promoting local start-ups in disruptive technologies of mutual interest. COREALIS innovations are key both for the major deep sea European ports in view of the mega-vessel era, but also relevant for medium sized ports with limited investment funds for infrastructure and automation.

1.2 Used methods

Seven experts from VTT, NEC and CNIT participated in the writing of this deliverable. All the authors wrote about their expertise area and the deliverable is a combination of this expertise.

The content is based on literature review of scientific articles, research documents, deliverables of past EU projects, and company websites. Each author used his or her own expertise on the field and selected the most appropriate literature review methods to select the suitable literature for this deliverable. Based on the review, this deliverable covers different types of topics by using different viewpoints.

2. Current requirements from ports related to intra-terminal operations

The port sector is continually evolving in order to adapt current challenges. The main challenges for port nowadays include, among others, increased vessel sizes, mitigating the environmental impact of transport and investing in new value added services. These challenges put pressure on infrastructure and investments, such as the extension of berths, quays, locks, deepening of basins and canals and reconfiguration to enable manoeuvring of larger ships. Ports require new facilities, new operational procedures and coordination of the different services provided by the port actors in the context of door-to-door logistics. [2].

2.1 Increased size of vessels

The increased size of vessels has greatly affected container terminals in several ways. First, big vessels require particular investments in terminals such as the need for bigger cranes, deeper sea routes, etc. Secondly, the operations of big vessels concentrate on certain terminals, as the operations require particular investments and the big vessels operate most economically in long-distance lines. Therefore, the ports that serve mega-vessels strengthen their role as transhipment ports while the other ports nearby mainly operate as feeder ports [3]. Third, due to their high volumes and operating costs, the big vessels visit the terminals for longer intervals while at the same time require rapid loading and unloading operations. This requirement forces terminals to arrange the needed capacity for unloading and loading and for quayside operations whenever such a vessel arrives, as it may choose another terminal if the quay is not available and waiting times would be too long [4], [5].

2.2 Environmental impact

The EU strives for minimising dependence on oil and mitigating the environmental impact of transport [6]. In addition, energy trade is developing with a shift from oil and refined products towards gas. This causes a need for gasification facilities in ports; potential volumes of dry biomass and CO_2 transport and storage [2]. According to ESPO/EcoPorts [7], the ports' main environmental priorities include air quality and energy consumption.

According to the Directive 2014/94/EU Member States should provide an appropriate number of LNG refuelling points for maritime and inland waterway transport in order to enable ships to circulate throughout the TEN-T Core Network by 2025. [8]. LNG must be stored in cold (ca.- 160°C) complicating the handling, maintenance and distribution, as well as causing higher risk than traditional fuels. This requires new distribution and handling infrastructure, and significant investments from both port authorities and ship owners. [6].

There are currently 24 large-scale LNG import terminals and 8 small-scale LNG facilities in Europe[1]. In addition, many new terminals are being considered or planned, as well as there are numerous plans for expansion of existing terminals or terminals currently under construction. Many European import terminals have adapted, or are adapting, their facilities to provide new services related to LNG. These include:

- ship reloading – the transfer of LNG from the terminal into a vessel (including smaller ships)
- transhipment – the direct transfer of LNG from one vessel to another
- bunkering – the loading of LNG onto bunkering ships for supply to LNG-fuelled ships
- truck loading – the loading of LNG onto tank trucks which transport LNG in smaller quantities
- a cooling down and gassing up service – making use of LNG to cool down and gas up ships. [9].

For mitigating the environmental impact, Member States should provide shore-side electricity supply for both inland waterway and seagoing vessels. Electricity supply shall be installed as a priority in ports of the TEN-T Core Network, and in other ports, by 2025. [8]

The circular economy concept (CE) refers to resource efficiency and sustainability. According to the CE approach, waste can be turned into a resource by reusing, repairing, refurbishing and recycling existing materials and products. [10]. The essence of CE in ports includes [11]:

- minimising the use of inputs and the elimination of waste and pollution;
- maximising the value created at each stage;
- managing flows of bio-based resources and recovery of flows of non-renewable resources in a closed loop; and
- establishing mutually beneficial relationships between companies within each circular chain.

2.3 Trends in requirements from ports

Trends in logistics and distribution systems have led to an increased need for value added services within the area of the port [2]. Traditionally, ports have been seen as the interface between land and sea [12]. Later, the port has been integrated more tightly as a part of supply chains, and the role of the port has enlarged to be as value adding supply chain echelon. A typical way for a port to add value is to improve its supply chain flexibility e.g. by offering warehousing services. When the goods are stored in the port area, it is easier to response varying ship departure times. The other value adding services are container loading or unloading, and small manufacturing such as adding some missing components as late installation to enable smooth transport operations to port. [13].

[1] The list of these terminals can be found from: https://www.kslaw.com/attachments/000/006/010/original/LNG_in_Europe_2018_-_An_Overview_of_LNG_Import_Terminals_in_Europe.pdf?1530031152 (accessed November 1st, 2018)

When the port is expected to be a more integral part of supply chain and value adding echelon, there is a need to involve different kinds of supporting actors to the operations of port. As the port area is limited and congested, the logistics center that the port is creating together with other logistics related organizations in its hinterland becomes the essential factor [14]. As access to sea is limited and there is limited possibilities to increase the length of quayside, the port may need to concentrate on ship loading and unloading operations and leave value added operations to the other organizations in its hinterlands [15]. Therefore, it is necessary to develop the smooth transport connections between the port and the logistics actors of its hinterland, and ensure that the services that the port is not able to locate in its area can be found in hinterland [16].

UNCTAD (United Nations Conference on Trade and Development) has proposed to use the term port generations to reflect a port's function as a supply chain information and knowledge hub. Currently, major Asian ports, such as Shanghai, Singapore, Hong Kong and Busan are considered as fourth generation ports (4GP), but based on article by Lee et al. [17] Hong Kong and Singapore are close to meet the definition of fifth generation port (5GP). [18]. Even if the definition of port generations by UNCTAD may not be the best possible way to classify ports and monitor their evolution as stated in COREALIS D1.1., the description of aspects, features and criteria will give an overview of the expectations of the requirements that the port will encounter in the future.

Table 1 shows five aspects, eight features and 12 criteria which makes the port as 5GP. The criteria are the distinctive criteria to make a port a 5GP, thus they are not port performance criteria in general. [17].

Table 1. Key components of the fifth generation ports (5GP) [17]

Aspects (5)	Features (8)	Criteria (12)	Definitions	References
A. Service	Service quality	(A1) Reliability	Productive, quality and reliable services provided for port users, minimizing their uncertainty	[19], [20]
		(A2) Resilient system	Resilient system with proactive actions responding to any risks and accidents (including natural disasters) at the port in terms of operator's responsiveness	[21], [22]
B. Technology	Communication system	(B1) SWS	Development of SWS integrating port MIS and logistics EDI network system using IT, and nano- and bio-technologies	[18], [23]
	Information of technology	(B2) RFID or other IT applications	Applications of RFID or other IT to port operation and management	[24]
C. Sustainable development	Symbiosis of port and city	(C1) Coordination of port and city development	Port and public authorities coordinate port and city development for sustainability	[25]
	Green Environment	(C2) Integrated development	Integrated development of technical system to reduce gas emission and pollution with incentive pricing system	[25], [26]
		(C3) Green port development	Friendly environment which means the sustainable measures will benefit the port city	[26], [27]
D. Cluster	Clustering	(D1) Port cluster management	Port clustering management and policy supported by port authority and government	[28], [29]
		(D2) Maritime cluster management	Creative financial incentives and social infrastructure to attract ship owners and cargoes by creating jobs and value-added in the port city and adjacent cities	[28], [30]
E. Hub	Globalized hub link	(E1) Port infrastructure	Accommodating mega carriers without any technical limitation to improve port efficiency	[20], [31]
		(E2) Port connections	Connectivity to other ports including feeder service with major carriers' callings	[32], [33]
	Logistics Hub	(E3) Inland connections and value-added function	Logistics chain for high value-added in association with free trade zone or logistics complex	[13], [32]

2.4 Changing port work

Trends in port work are related to the market, technology and environment domains. Market related trends are mainly due to mega container vessels and the introduction of Global Terminal Operators (GTOs). Larger vessels require e.g. handling of larger volumes within shorter time windows and new terminal equipment (e.g. gantry cranes with longer outreach) for serving these vessels. GTOs may cause changes in employment (e.g. deregulation) and work practices (e.g. more flexible working schedules). [34].

Technology affects port work in several ways. Containerization and new cargo handling equipment requires qualified and experienced port workers to handle such specialized terminal equipment. Labor costs and workforce availability are the key factors driving terminal automation. Automation also increases predictability, facilitating in this way planning of material flows. In addition, the increasing use of ICT systems reduces the need for work force at ports. Internet of Things (IoT) replaces manual data collection and processing, which eliminates potential human errors. [34]. However, automation requires large investments, and full automation may be a too expensive solution for many cases. Therefore, automation level will increase gradually in many ports, and that is why the need for port workers will remain, even if the ways of working will change. [35].

For the understanding of environmental aspects and impacts, training programs are needed. The use of renewable energy production, alternative fuel vehicles in the port/terminal area and alternative-fuelled cargo handling equipment require training in order to perform operation, management and maintenance successfully and safely. [34].

3. Asset management and port strategies

The availability of adequate port infrastructure and good performance affects the European Union's competitiveness in the global markets, growth potential and the development of a more sustainable transport system. Investments are needed to adapt port infrastructure and facilities to suit new transport and logistics requirements. The situation is challenging as the sector is continually evolving and has the potential to make existing port infrastructure obsolete or require significant upgrade. [2]

3.1 Asset management and business goals

Infrastructure asset management goals need to be in line with those of the strategic business goals to achieve the long-term stakeholder value. In order to support business operations infrastructure asset management pursue several goals that are presented in Figure 1. [36].

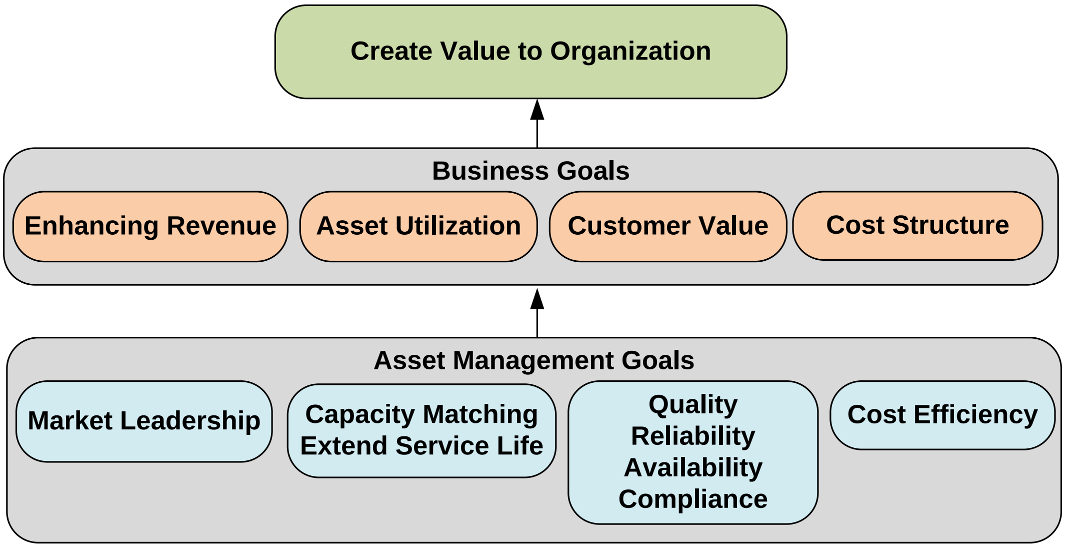

Figure 1. Relationship between the asset management and business goals [36].

The four goals of asset management are [36]:

1. Cost efficiency: manage and operate infrastructure asset cost efficiently.
2. Capacity matching: match the capacity of infrastructure assets to support business needs.
3. Meeting customer needs/requirements: customer value can be enhanced through providing "quality" assets, such as reliability, dependability, compliance to safety and environmental regulation and timeliness. Infrastructure assets must also be in good, durable and reliable conditions that comply with regulatory requirements.
4. Market leadership: asset management aims to be forward looking in order to sustain competitive advantage through market leadership, innovation and creativity.

These goals require asset managers to make decisions that will maximise their financial performance, achieving excellence in their service level and minimising their risk exposure. [36].

3.2 Infrastructure policy

The transportation sector is subject to many forms of policy measures that are also related to port infrastructure. These include institutional; planning and investment; operational, regulatory and licensing; and pricing, cost recovery, taxation and subsidy [37]:

- Institutional policy measures are related to the role of governments, public authorities and private sector in developing and operating transport infrastructure and services. [37]. Port governance models (see Section 3.3) affect the distribution of responsibilities and ownership of infrastructure.
- The planning and investment policies define the criteria for economic, financial or environmental and safety standards to govern public investments and controls that they are applied to the private sector investments.
- Operational, regulatory and licensing policies aim for example to regulate and control infrastructure and service operations.
- Pricing, cost recovery, taxation and subsidy policies define the principles for tariff setting, level of cost recovery to be achieved for publicly owned transport infrastructures, and the circumstances in which subsidies are justified.

Transportation infrastructures are highly capital intensive. European Union has investment strategies to connect ports to the trans-European network. EU funding will be possible in 2014-2020 under the new TEN-T guidelines, the Connecting Europe Facility and the new approach of the Structural Financial Instruments [2]. In addition to public funding, private investment in infrastructure projects or mechanisms for generating more resources from off-budget sources would be needed. New financial instruments and the public-private partnerships have played an important role in this process. [37]

Efficient pricing is a prerequisite to efficient port infrastructure investments [2]. Port Authorities can establish the structure and level of port prices according to their own commercial and investment strategy. EU strives for guidance on common classification criteria for vessels for the purpose of voluntary environmental charging, taking into account internationally agreed standards. Port infrastructure charges may vary according to the port's economic strategy and the port's spatial planning policy. The aim is to promote a more efficient use of the port infrastructure, short sea shipping or a high environmental performance, energy efficiency or carbon efficiency of transport operations. [38]. The impacts of such a system are not clear. Environmental charging could lead in raising prices resulting in reduced business volumes and negative financial impacts, especially if the implementation of the schemes is on a voluntary basis and competitive ports would not implement environmental charging at all. However, environmental charging schemes could also serve as potential attractors to generate profits, improve image and increase the position of a port in the market. [6].

According to White Paper SSS [37] is considered as a strategic component of the transport system since it can provide an important contribution to smart, sustainable and inclusive growth in the EU. Intra-European shipping is expected to increase and infrastructures should be strengthened and created in order to make SSS more attractive. One of the obstacles for SSS development is that accessibility costs to/from ports are costly due to inefficient infrastructures, capacity problems or poor intermodal facilities. [37].

3.3 Changed port governance models

Different port governance models (Table 2) have been under discussion for decades, and 'public versus private' has been the biggest debate [39]. Even if the debates have ended up promoting the private sector's involvement in ports, only a few countries with limited number of ports have been privatized during the past decade [40]. Since 2007, European Union has recommended to use landlord model for port governance [41], and this model has become the most common and dominant model during the early twenty-first century [40]. In a landlord model, a public port authority acts as both landlord and regulatory body, while private companies carry out port operations [42]. Due to the changing nature of port governance, the port authority no longer has an integrated and holistic role within port activities; instead, it has given the control of operations to separate organizations and at least the ownership of superstructure and equipment if it has retain the ownership of infrastructure assets [40].

Table 2. Port governance models [43].

Type	Infrastructure	Superstructure	Port labour	Other functions
Public port	Public	Public	Public	Majority public
Tool port	Public	Public	Private	Public/private
Landlord port	Public	Private	Private	Public/private
Private service port	Private	Private	Private	Majority public

Private organizations' involvement in port governance have an effect on ports' competitive position and investments are required to develop competitiveness and cargo volumes. Earlier, the ports competed against each other, but due to the involvement of private organizations operating in several ports, cooperation between ports has increased. This tendency has both good and counterproductive effects on the development of individual port. The terminals may achieve higher productivity and get additional investments by international terminal operators [44], while sometimes the operators may share the competencies and customers between the ports in a way that an individual port may end up for serving dying cargo segment and therefore it loses the interest of private investors [45].

4. Current software and infrastructure available for asset management and terminal operations

This chapter provides an overview of software and infrastructure available for asset management and terminal operations

4.1 Asset management in ports and terminals

Ports are an asset intensive industry, their critical infrastructure and other assets being essential for many economic communities. The various asset networks must be managed strategically in a systematic way to ensure an appropriate level of service to customers and stakeholders at the lowest possible cost. Effective asset management in ports is also crucial in order to remain competitive delivering business inputs to the global market. Growth in trade, competition between ports, aging infrastructure and economic pressures are some of the drivers for managing the assets effectively with modern technology and tools.

Port assets usually consist of land, roads and rails, moveable and unmoveable property, infrastructure such as breakwater, entrance channel, main basin and quay apron and superstructure including container yard, transit shed, and container freight station (CFS) and warehouses. Port equipment includes floating craft, cranes, conveyor belt, forklifts, Roll-on-Roll-off (RoRo) tractors and trailers. The assets can be material or non-material and the impact of the valuation of port assets could be quantifiable or non-quantifiable. Human resource is one of the most important assets of any port. [46]

Port asset management include at least the following aspects: infrastructure management (infrastructure monitoring and development), property (capital) management, utility management and maintenance management. The overall asset management is a responsibility of the port owner or the port authority. There is a growing need to increase port productivity and maximize the use of port infrastructure. This can be achieved e.g. with modern monitoring tools and predictive maintenance. Also new forms of ownership and financing port investments necessitate reliable port asset valuation and management. E.g. [46], [47]

Traditionally, ports have used separate systems to manage each aspect of their businesses; asset management, terminal operations, finance, procurement and inventory, human resource, payroll, management of processes and workforce. Integrating different software streamlines information flow across the numerous internal processes and systems, in order to deliver improved business performance and reduce costs. The challenge facing port operators is how to ensure all their handling equipment is managed in a way that ensures high productivity and improves reliability. Ensuring this requires well-designed IT solutions. [48]

An asset management system (AMS) is designed to monitor and maintain items of value (port's assets). It can be used to manage tangible assets such as buildings, cranes and quay walls as well as intangible assets like human capital, intellectual property and financial assets. An enterprise asset management (EAM) solution can monitor the basic requirements of a cargo terminal. An EAM solution helps in gaining real time visibility into asset usage, better govern assets, manage asset lifecycle, measure and manage energy consumption, and improve the return on assets. EAM and AMS solutions should be integrated with an enterprise resource planning (ERP) system. There are several commercial ERP systems in the market that can meet all the requirements of ports and terminals. [49], [50].

Geographic information system (GIS) technologies and GIS-based asset management is evolving technology trend in ports and terminals. GIS converts asset management standards, management practices, and institutional knowledge into an operational asset management program. The single greatest benefit of using GIS is to create a geospatial and temporal model of the built and natural environments to identify, calculate, and predict risk. [51]

Major factors in GIS-based asset management [51], [52]:

- Situational awareness and whereabouts of the assets.
- Efficient utilization of assets.
- Planning, prioritizing manpower, workers & machinery.
- Response to the emergency situations.
- Keeping the port and assets under surveillance.
- Trends and patterns of assets performance.
- Integration with existing systems.
- Cost effective and fast decision making.
- Will increase profitability.
- Increase in efficiency.
- Maximizing the utilization of Ports assets & Infrastructure.
- Quick incident response.

Much of the information on port facilities is spatial in nature, meaning the asset data can be tied to a specific location in space. GIS provide an organizing framework for this data, making it comprehensible and actionable for decisions by managers at multiple levels. As GIS technologies mature, a number of associated applications such as Computerized Maintenance Management Systems (CMMS) can further leverage the value of GIS-based data structures. [52]

There are a number of ERP, EAM, AMS, GIS etc. system providers and software available in the market. A brief list of selected companies and their software systems are presented in Table 3.

Table 3. A list of selected system providers and their software systems.

Company name and website	Main system or software	Category	Description
Assetic http://www.assetic.com/	Assetic Assets	AMS	Assetic Assets is an intelligent asset register pre-configured for over 100 asset classes. Cloud based technologies for port asset management.
AMX Solutions http://www.amxsolutions.co.uk/	Asset Management eXpert	AMS	Asset Management eXpert is a market-leading solution for physical and infrastructure asset management.
SIMCO Technologies https://www.simcotechnologies.com/	Stadium, KMS	AMS	SIMCO's Infrastructure Asset Management System allows for the selection of optimum maintenance and repair scenarios for a single element as well as for an entire portfolio of structures.
ESRI http://www.esri.com/ http://www.arcgis.com/	PortMaps	GIS	ArcGIS platform called PortMaps. Port of Rotterdam Ensures a Resilient Future with ArcGIS.
Envecon https://envecon.com/ports-and-terminal/	e.g. LogStar-products, SEAM	ERP, EAM	Envecon offers end to end solutions for Ports and Terminals, including ERP and EAM systems.
Hexagon Geospatial https://www.hexagongeospatial.com/	e.g. M.App Enterprise	ERP, GIS	Asset management across the enterprise through a number of collection techniques, including point cloud data capture, analysis, and extraction. Accurate location and condition of managed assets to more effective planning and maintenance.
SAP https://www.sap.com/	SAP ERP	ERP	SAP ERP incorporates the key business functions of an organization. One of the market leaders in the business.
IFS https://www.ifsworld.com/	IFS ERP, EAM	ERP, EAM	IFS Applications is capable of delivering more than just ERP. It has native functionality for enterprise project management (EPM), enterprise asset management (EAM) and service management.
IBM https://www.ibm.com/products	e.g. Maximo,	EAM	Maximo, when combined with the power of IoT data from people, sensors and devices, can provide warning signals from assets—reducing unplanned downtime and increasing operational efficiency.

4.2 Terminal operations management

Terminal operations management consist of various planning, control and optimization activities, and decision-making processes such as berth planning, quay crane (QC) scheduling, loading/unload sequencing, and space planning. Some resources are classified as key resources because of their high cost and the consequent expense in increasing their capacity. Key resources may include berths, QC's, and storage spaces in most container terminals. [53]

Many port authorities globally are already collecting and analyzing a high volume of data from resource conditions and terminal operations. Terminals require flexible solutions that can analyze data to predict and plan maintenance activities and costs in order to optimize operations. The industry trend has gravitated towards a single system solution that can meet the majority of the needs of a terminal. Using a system with integrated architecture removes key obstacles in IT management, as well as overall business administration. [49].

4.2.1 Terminal operating systems and software available for ports

Ports use terminal operations software and systems (TOS) to manage port and harbor facilities and services. This type of software is used by terminal operators to ensure the safety of navigation for vessels using the port and to optimize the human and material resources (traffic, terminal and cargo operations, facility management etc.) required to deliver port services in a safe and efficient manner. Ports prefer to use comprehensive systems to gain a single view of their operations, enabling them to make smarter decisions faster, which maximizes operational efficiency and improves their competitiveness. [53]

TOS is composed of sub-systems for administration, planning, scheduling, executing and reporting parts. The administration part supports the management of container move orders from shipping lines. Generally, container move orders are transferred to the terminal through electronic data interchange (EDI) or internet access. This information is basic input data for the planning part. During real-time operation, TOS constructs an optimal executing schedule for QC's, vehicles, and yard cranes (YC's) to perform the various handling tasks on time. [53]

The investments in terminal improvements usually involves a combination of software products or integrated systems, hardware, infrastructure, services and methods, including [54]:

Software systems:

- Terminal Operating Systems (TOS/TMS),
- Gate Operating Systems (GOS),
- SCADA,
- Security/ISPS,
- Access Management,
- Vessel Traffic Systems (VTS),
- Warehouse Management Systems (WMS),
- Port Community Systems (PCS),
- Maintenance Management Systems (CMMS),
- Resource Management and Scheduling,
- Berth Scheduling,

- Management Report and Business Intelligence (BI),
- KPI dashboards,

Hardware:

- Radio Data Terminals (RDT/HHT/VMT),
- Radio Frequency IDentification (RFID),
- Differential GPS (DGPS),
- Optical Character Recognition (OCR),
- CCTV,
- human biometrics etc.

Infrastructure:

- Wireless networks,
- 3G (GPRS) networks,
- narrowband RF etc.

When selecting correct software solutions, either off-the-shelf or custom-made, it is vital to ensure that the specifications are accurately constructed and supplier deliverables are contracted robustly. [54]

The future in the container handling industry is automation. All new generation cranes have multiple sensors and components, which constantly produce data, and with IoT technology, transferring the data to the cloud and from there into different functions using an intelligent analyzing tool. The trend is particularly driven by powerful information technology and paradigms already available and widely discussed in the port industry, including the internet of things, cloud computing, big data, blockchain, augmented reality etc. [55]

There is large amount of commercial software and automation system providers and developers in the market worldwide. The table below introduces a selection of popular products and service providers.

Table 4. Selection of popular automation system products and their providers.

Company name and website	Main system or software	Category	Description
ABB https://new.abb.com/ports	Multiple	Automation systems, remote crane operation.	ABB offers automation and electrical systems for container and bulk cargo handling.
Accenture https://www.accenture.com/	Accenture port solutions	Portfolio of technology systems and consulting services.	Accenture Port Solutions is a portfolio of technology systems, as well as consulting and outsourcing services, built on vast industry knowledge and experience with leading ports and transportation providers worldwide.
NANCENT http://nascenttechnology.com/	Multiple	Terminal Operation Systems (TOS), Automated Gate Systems (AGS).	NASCENT Technology develops comprehensive automated gate systems, advanced imaging solutions and driver centric mobile applications. Data collection, remote monitoring and control.

CyberLogitec http://www.cyberlogitec.com/	Opus Terminal	IT Solutions and Operating Systems for Ports. TOS.	Used by more than 50 major terminals around the world, Opus Terminal is a highly integrated TOS platform that provides full coverage of the entire terminal operation through combined planning operation, EDI and KPI dashboard analysis.
Kalmar www.kalmarglobal.com	Multiple	Terminal automation, container handling.	Kalmar Global provides cargo handling solutions and services to ports, terminals, distribution centres and heavy industry around the globe. One in four container moves around the globe being handled by a Kalmar solution.
Navis www.navis.com	SPARCS N4	Terminal Operating Systems (TOS) for Ports and Terminals.	The Navis N4 terminal operating system (TOS) represents more than 27 years of experience and innovation that enables terminals to optimize their operations and move cargo smarter, faster and more efficiently. One of the market leaders.
Tideworks http://www.tideworks.com/	Mainsail Vanguard®	TOS	Mainsail Vanguard is the next generation terminal operating system. Mainsail Vanguard optimizes system response times and offers a simple, cost effective means to deploy and run the terminal operating system.
TGI https://tgims.com/	OSCAR, CARROL, MARCO, TGIBOX	Maritime Software, TOS.	Software editor and integrator in the maritime industry, have been providing personalized and optimized solutions for Container and RORO terminals in France and abroad for more than 20 years.
RBS https://www.rbs-emea.com/	TOPS	Terminal Operating Systems for Container Handling.	RBS delivers turn-key solutions: expertise, systems, solutions and hardware assuming full responsibility for projects, integrating partner solutions.
Trimble https://www.trimble.com/	Trimble® LOADRITE™, DGNSS	Port and marine operations, navigation infrastructure.	Trimble® LOADRITE™ products can help you increase profitability, maximize productivity, improve operational efficiency and get control of your inventory. DGNSS Navigation Infrastructure.
Octopi: https://octopi.co/	Octopi	Terminal Operating System (TOS).	Octopi is a modern, web-based Terminal Operating System (TOS) built for small to medium cargo terminals.

Jade Logistics Group https://www.jadelogistics.com/	Master Terminal	TOS	Master Terminal is a terminal operating system (TOS) for ports and terminals handling containers and mixed cargoes. Master Terminal is built for the agile port.
PSA https://www.globalpsa.com/innovation/	CITOS®	TOS	First developed in 1988, the Computer Integrated Terminal Operations System (CITOS®) is an enterprise resource planning system that coordinates and integrates all aspects of port operations.

4.2.2 Maintenance tasks in Asset Management

Maintenance tasks are central to asset management strategies in ports, as they are directly related to the functioning and availability of port operations. To ensure such an availability, ports rely on well-defined maintenance strategies. The most common maintenance strategies include: Emergency (breakdown/run-to-failure maintenance), preventive (scheduled/routine) maintenance, predictive maintenance (PdM), and reliability-centered maintenance (RCM). Although preventive maintenance strategies seem to be most common, it is likely that ports combines different strategies at once depending on, e.g. size of the port, categories of the assets, maintenance workforce and equipment, budget, urgency, availability of spare parts, etc. These four common strategies are briefly described below:

- **Emergency (breakdown/run-to-failure) maintenance**

Also known as reactive maintenance, such a strategy addresses maintenance tasks when equipment breaks down, i.e. the failure event is the trigger of the maintenance, reparation or replacement task. Such a strategy can be effective when the equipment in question is not essential for operations and has a low cost of downtime. It is however expensive when it affects equipment that is necessary for operations.

- **Preventive (scheduled) maintenance**

Preventive maintenance involves periodically inspecting or repairing assets offline them at predetermined intervals (usually time or event-based triggers). This is one of the most common and implemented maintenance strategies. Although preventive maintenance is a relatively easy strategy to execute, it can prove costly in the long run since it does not take many factors into account that might affect an asset's productivity.

- **Predictive maintenance (PdM)**

Predictive maintenance is based on predicting failure before it happens, rather than on the average life statistics of an asset (which is the case with preventive maintenance). It relies on status of the equipment to, before deciding on the maintenance strategy. Status of the equipment can be recorded and retrieved via a CMMS or various solutions that store data about breakdowns and functioning of the equipment. The advantage of predictive maintenance (over preventive maintenance) is the potential for cost savings from reduced man-hours spent on maintenance, and more insight as to the performance and potential issues arising with the machine. It can also contribute to a longer lifetime of the assets and a more adaptive purchasing schedule for spare parts.

- **Reliability-centred maintenance (RCM)**

Equipment failure is not always linear. RCM is a maintenance strategy that addresses this with an in-depth, highly involved process that seeks to analyze all the possible failure modes for each piece of equipment and customize a maintenance strategy for each individual machine.

A summary of the maintenance strategies is presented in Table 5:

Table 5. A summary of asset management maintenance tasks strategies [56]

Strategy	Summary	Cost to Implement	Pros	Cons
Run to Failure	Fix when it breaks	Low	Ideal for low priority equipment	Can lead to runaway repair costs
Preventive	Maintenance on a predetermined schedule	Average	Best strategy to implement without expertise	Inefficient schedules compared to PdM or RCM
Predictive	Condition based monitoring triggering work orders	High	Timely and informed monitoring. More insight into causes of breakdowns	Expensive to set up – only cost effective for critical assets
RCM	Investigation of failure modes to determine best maintenance strategy	Highest	If executed properly, provides the most efficient maintenance schedule	Infeasible for most organizations that are not "elite"

Such maintenance strategies are in general monitored by CMMS, ERP or EAM systems. Examples of such systems are cited in Table 3. It is however possible for operators to include a maintenance component that can be outside of such a system and offers insights about the maintenance needs and prospects.

4.3 Software solutions for planning the layout of container terminals

A terminal operating system is necessary for efficient terminal operations in order to plan, schedule and control equipment. Currently TOS systems do not provide simulation capabilities, i.e. what-if analysis. For this simulation, software can be used, which mimics or uses TOS logic.

The most prominent commercial simulators are CHESSCON [57] and CONTROLS [58]. CHESSCON provides a set of optimization tools for container terminals. For container layout planning the simulation module can be used to find the best layout and compare various kinds of operation systems (combination of equipment types). With CONTROLS you can test a TOS in near-to-live circumstances, tune TOS parameter settings and train planners in the best usage of the TOS. However, there are also other solutions like CONTSIM [59], and consultants with their own software, e.g. CYBERCUBE [60]. Furthermore, more general discrete event simulation software like Arena [61] and Anylogic [62] can be used to create simulations of port operations.

Schwientek et al. [63] have noted that terminal planning and terminal optimization by simulation studies are typically separate tasks. Their assumption is that the terminal layout is planned statically using standard layouts, experiences, spreadsheets or other static tools, while simulations studies can be conducted to evaluate and improve the terminal design afterwards. Based on this notion, a recently started project conducted by Institute of Maritime Logistics of the Hamburg University of Technology, the Fraunhofer Center for Maritime Logistics and Services CML, German Promotion Centre for Intermodal Transport, an inland waterway terminal, and an intermodal terminal will aim to develop and test a tool that will integrate layout planning and simulation [63].

5. The level of introduction of cutting-edge and disruptive technologies for smart terminal operations

There are numerous challenges in the implementation of connected port infrastructures supporting new end-to-end logistics concepts based on extensive digitalisation of supply chains. Especially, the role of existing ports as essential multimodal hubs in these concepts is difficult to realise as their Information and Communication Technologies (ICT) infrastructures are not designed to support ubiquitous connectivity. In order to enable smooth and uninterrupted flow of goods through multiple modes of transportation, the information related to the location, schedule, amount and type of the cargo moving along its delivery path must be accessible and available to all actors in the end-to-end logistics chain in real time. In other words, the operation of future ports must be more and more optimised as part of the end-to-end delivery path, not as an isolated cargo handling entity. By providing communications interfaces and access to the data also to and from variety of actors outside the logistics chain, all available information can be utilised to minimise the impact of logistics operations on the population surrounding the port sites and environment in general.

Based on the survey results presented in [64], the most important disruptive technologies enabling digital supply chains in the future are big data analysis, Internet of Things (IoT), cloud computing, machine learning, advanced robotics, 3D printing, drones/self-guided vehicles, sharing economy and blockchains. From the connected port's ICT infrastructure perspective, most of the list items provided in the survey can be grouped under titles

- IoT,
- Physical Internet,
- 5G networks, and
- machine learning.

Based on these three groups, the following subsections discuss the utilisation of the disruptive technologies for smart ports today and in the future.

5.1 Internet of Things

The port of the Future could be seen as a service system for port transportation, based on modern electronic information technology, whose features are to provide several information services for port participants based on the collection, processing, release, exchange, analysis and usage of the relevant information. The Port of the Future as urgently needed to be closely integrated with IoT in order to achieve efficient data sharing. In that sense, IoT technology is the basis for the development of the new generation ports:

- Sensor technologies allow objects to have perception of the surrounding environment;
- Machine to Machine (M2M) platforms let them exchange data;
- IoT let all objects interconnect.

IoT, extending human senses and collecting useful data directly from the Port, can eliminate manual collection errors, improve the collection efficiency and deliver the collected data instantly to every point of the port area through Internet.

The use of IoT technologies in the port docks can facilitate strict supervision and efficient customs clearance procedures with labour and cost savings. In addition, IoT technologies can be used to implement intelligent production scheduling at the Yard and improve terminal production scheduling efficiency. Combined use of GPS, GIS, RFID and IoT technologies can also enable container tracking and monitoring, truck transport path optimization, and optimal scheduling.

IoT and different kinds of sensors have been a key feature in modern port infrastructure already for years. Sensors and sensor networks have been utilised for a variety of monitoring, tracking and safety use cases, e.g. for structural health monitoring, distance measurements and navigation [65]. Wireless IoT connectivity have been traditionally handled either with short and medium range technologies, such as WiFi and ZigBee, or with long range point-to-point radio links and commercial 2nd, 3rd or 4th Generation (2G/3G/4G) mobile networks. However, none of these traditional options can provide a communication platform that could be used efficiently and flexibly for multiple use cases ranging from high data rate video monitoring to low latency safety systems in human-machine interaction situations or to energy efficient communications for massive amount of low power sensor devices.

Many IoT technologies and products are needed in the construction of Intelligent Ports:

- Sensors: can sense the information to be measured and convert it into an electrical signal or other form according to certain rules. It is the primary link to achieve automatic detection and automatic control in physical environments. It can detect and sense outside signals, physical conditions (such as light, heat, humidity, pressure) or chemical compositions, and transmit the sensor data to the upper layers of IoT by utilising communication technologies.
- RFID: is a short-range wireless communications technology that can automatically identify objects and access relevant data through an RF signal. RFID devices are usually passive and low cost. RFID tags store normative information, which can be collected automatically through a wireless data communication network to a central information system, to achieve the identification of the goods (products), and to achieve information exchange and sharing through open computer network.
- Wireless Sensor Network (WSN): is a network of nodes that cooperatively sense and control the environment, enabling interaction between persons or computers and the surrounding environment. WSNs nowadays include sensor nodes, actuator nodes, gateways and clients. The cost of WSN equipment has dropped dramatically and their applications are gradually expanding from the military areas to industrial and commercial fields such as Ports.
- Network Communication Technology: is divided in two categories: short range communication (e.g. IEEE 802.15.4/ZigBee and IEEE 802.11/WiFi) and long range communications (e.g. 2G/3G/4G mobile communications and satellite communications), which can be used to provide a wireless transmission channel for IoT data. In addition, Internet Protocol version 6 (IPv6) as the key protocol for the next generation of Internet technologies, can assign an IP address for each sensor and creates a good foundation for the development of IoT.

- M2M: refers to sending of data from one terminal (machine) to another. M2M is the general technology to enhance the general machinery and equipment communication technology and network capabilities without the manual assistance of humans (Mobius®). The key components of an M2M system are field-deployed wireless devices with embedded sensors or RFID-wireless communication networks with complementary wireline access including, but not limited to, cellular communication, Wi-Fi, ZigBee, WiMAX, Digital Subscriber Line (DSL) and Fibre to the x (FTTx) technologies. While many use the terms interchangeably, M2M and IoT are not the same. IoT needs M2M, but M2M does not need IoT.

Nowadays, the IoT can be considered an important technological revolution related to smart cities, smart homes, smart factories and smart ports implementations. As the presence of smart sensing systems in ports becomes a reality, different operation areas are working in automatic mode. Examples of challenging projects related to smart ports in the IoT era can be found from Europe to Asia, to Australia, and to North America; in all of these new architecture implementations, sensing technologies play a key role.

In order to provide a single flexible communication platform for all port communication needs, the Narrowband IoT (NB-IoT) waveform in 4G and the other Machine Type Communications (MTC) enablers in future 5th Generation (5G) mobile networks seem to be the best option when it comes to the availability, cost and inter-operability of the network equipment and end user devices. For IoT use cases, it provides means to efficiently handle the connectivity needs for a massive amount of sensor devices and facilitates the deployment of local clouds for big data analysis near the network edge, minimising the transport latencies and network load related to extensive utilisations of cloud-based services.

5.2 Physical Internet

Internet transformed the way information flows around the world. The word slowly switched from analog to digital. The border between the Internet and the physical world used to be a clear and defined line. The only point of entry/output to this new network was a computer. This division became blurred with IoT. Internet became a part of our lives, with more and more connected tools: cars, light bulbs, watches etc. The Internet is not only about information and data anymore. It has an impact on our reality by controlling the temperature in a room, increasing our security during car rides etc. The one last barrier between Internet and the physical world is the logistics. While purchasing an item online, everything is seamless and fast, except for the delivery. You can choose an item and issue a payment within seconds. However, you still have to wait up to several weeks to receive the item. The world is demanding speed and efficiency. Customers expect seamless services. While the transport industry has been taking advantage of new technologies, Internet innovations are still not used to their full potential.

Logistics is the invisible backbone of our current way of life. We shop clothes made in India, electronics designed in the US and produced in Asia, fruits grown in Africa. The growth of e-commerce fosters our need for logistics. It also shows the limits of the current system. Most of the trucks and vans are not driving fully loaded. Some of them are driving empty for many kilometres between consecutive deliveries. Our transport capacity needs to be used in a more efficient way. This need for change is all more urgent as, according to the European Commission, the transports industry is responsible for almost a quarter of European greenhouse gas emissions. We need to switch from an extensive growth to an intensive one. Improving the efficiency would allow us to transport more with less vehicles. We have to look for more sustainable alternatives.

The Physical Internet aims to transport physical goods as efficiently as data flows around the web. When a file is sent across the world, it can be split into smaller pieces to take the most efficient and fastest route. Of course, the same method cannot be fully applied to the logistics, but it can be used as an inspiration. As for the Internet, logistics needs to work seamlessly. The final customer does not need to be aware of all technical details.

To achieve this goal, we need to optimize our system. It is not only about reducing empty mileage but also making sure each vehicle is loaded to its full capacity. Montreuil gave a broad estimation that, on average, trucks are loaded to only 60% of their capacity (volume or weight). The first step is to have reliable access to relevant data, i.e. efficient tracking of vehicles, knowing their direction, how full they are etc. Once you have all the needed information, the optimization process can begin.

The easiest and most important thing to tackle is the dead mileage. Many trucks are driving empty on their way back to a new location. Dead mileage needs to be reduced to its minimum. The next step is to promote co-loading solutions. Instead of dedicating one vehicle for one delivery, free space should be used for other deliveries. Depending on the material being transported you can have trucks being loaded to their full capacity but with available capacity in terms of weight or volume. In fact, feathers are not heavy but take up much space whereas steel is heavy. Combining transport to reach full capacity in terms of volume and weight is also a significant improvement in terms of optimization.

5.3 5G networks

The first set of 5G specifications was finalised in the summer of 2018 and telecom industry is now ready to start the larger roll outs of commercial 5G networks and devices. So far, 5G technologies have been in trialling and piloting phase where vendors and Mobile Network Operators (MNO) have performed different kinds of technology demonstrations and service showcases with pre-standard equipment. Consequently, even though early 5G trials have been conducted also in port environments, deployment of 5G networks for real operational use have not yet begun.

As the large-scale commercial launch of 5G is approaching fast, the potential of the new technology is starting to realise in the near future. The first wave of 5G networks brings higher data rates enabling e.g. immersive multimedia services. In the coming years, the evolution of the technology enables ultra-low latencies, ultra-reliable communications and better support for massive IoT, which open up a variety of industrial usage scenarios for the 5G networks. More details on 5G technologies and their potential use in connected smart port environments can be found from Chapter 6.

5.4 Machine learning

Port environments produce a huge amount of data from different systems related to port operations, logistics, asset tracking, vessels, vehicles, etc. To parse, combine, analyse and interpret the data coming from different system is a job where Artificial Intelligence (AI) and Machine Learning (ML) algorithms have a key role. The available data can then be utilised to smooth out different operations throughout the port with a central control system, with distributed intelligence or with a combination of both. The size of the port and the type of operations performed inside it will determine the overall complexity of the managed environment and the most suitable approach for its management.

Many current projects and initiatives in the port industry indicate a growing interest in data analytics solutions. One example of applying data analytics is the SAFER project of the Maritime and Port Authority of Singapore (MPA). Under the project, MPA has piloted three IBM analytics-based modules to improve the management of Singapore's growing vessel traffic. Another example is the Navis ATOM Labs, which is investigating the use of ML for the optimization and automation of terminal operations [66].

When combined with full connectivity and massive availability of real-time IoT sensor data, machine learning has great potential in the management of port operations. Due to their repetitive nature, the operations related to container logistics is one promising application field and history data can be efficiently utilised to enhance the performance of the algorithms. Machine learning is already starting to appear as part of modern automated port machinery control, but when combined with the latest sensor and communication technologies, it can be used not only to control the movements of individual machines, but the operations of the whole infrastructure from container movements to traffic management.

6. The level of introduction of 5G networks and lessons learned from their deployment

This chapter reviews the role of 5G as the potential technology platform for port communications. First, the key features of 5G are presented and the envisioned role of 5G systems as the main technology platform for all digital services is discussed. Then, the current state of the art in port communications and the major problems in their use are summarised. The chapter ends with a discussion on how 5G can solve the problems encountered with the current state of the art.

6.1 5G overview

International Telecommunication Union's (ITU) Recommendation ITU-R M.2083-0 [67] laid the foundation for what the 5G mobile networks, a.k.a. International Mobile Telecommunications for 2020 (IMT-2020) in the ITU terminology, should be able to offer not only to the consumers, but also for the industrial customers going through the digitisation of their business and services. The document defined three high-level services for 5G, i.e. enhanced Mobile Broadband (eMBB), Ultra-Reliable and Low Latency Communications (URLLC) and massive Machine Type Communications (mMTC). In addition, a set of capability requirements were introduced as enhancements to the current 4G technologies (IMT-Advanced in the ITU terminology). These key capability requirements are presented in Table 6.

Table 6: Key capability requirements for 5G systems [66]

Key capability	IMT-Advanced/4G	IMT-2020/5G requirement
Peak data rate (Gbit/s)	1	20
User experienced data rate (Mbit/s)	10	100
Spectrum efficiency	1x	3x
Mobility (km/h)	350	500
Latency (ms)	10	1
Connection density (devices/km^2)	10^5	10^6
Network energy efficiency	1x	100x
Area traffic capacity (Mbit/s/m^2)	0.1	10

Building on the ITU recommendations, the 5G Public Private Partnership (5G PPP) positioned 5G as the future's key technology platform for all digital services in its 5G vision for the European ICT sector [68]. 5G PPP coordinates the 5G specific calls in the European Commission's (EC) Horizon 2020 Research and Innovation Programme. In [68] 5G PPP also defined some additional key capability requirements for the European R&D community, adding e.g. mobile data volume, service deployment time, reliability and end-to-end latency to the list.

The 3rd Generation Partnership Project (3GPP) is currently the main engineering organisation responsible for the development of the key technical specifications for mobile telecommunications systems. The 3GPP specifications are then used by the regional Standard Development Organisations (SDO) around the world to produce the actual telecommunications standards. The 3GPP specifications are continuously developed, but bigger sets of new functionalities for the whole system are published as Releases[2], which contain a stable set of features for implementation. The latest Release 15 was published in the summer 2018, containing the first 5G specifications. The Release 15 features focus on delivering the high data rate eMBB service. Release 16, planned to be published in the end of 2019, extends the functionality by providing more technical enablers also for the URLLC and mMTC services, hence completing the original set of IMT-2020 services defined by ITU.

The radio access part of 5G networks will not comprise of a single radio access technology. Instead, it can provide multiple options for radio access technologies and operation frequencies depending on the usage scenario. However, in addition to the evolution of current 4G technologies better integration of non-3GPP access technologies, 5G networks include also a new radio access technology, called 5G New Radio (5G NR). It is a flexible air interface that can be configured to support any of the three key 5G services and to provide massive network capacity, very high data rates, very low latencies, ultra-high reliability and availability, support for very low-cost devices and low energy consumption, as well as energy efficient networks [69]. For IoT devices and applications, 5G provides direct connectivity to the cellular infrastructure and to the cloud services. Be it mMTC or URLLC for IoT, the same 5G platform can be utilised for connectivity and there is no need to build a separate infrastructure for long range communications nor a multi-level architecture of aggregating gateways for short range communications. The possibility to use commercial network infrastructure offers a ubiquitous, secure and cost-efficient way to provide wireless connectivity for IoT devices [70].

Even though 5G brings new key capabilities to cellular networks, i.e. greater speed (to move more data), lower latency (to be more responsive), and the ability to connect a lot more devices at once (for sensors and smart devices), 5G NRs will not be compatible with 4G radios. However, initially all 5G devices will need also 4G because they have to rely on it to make initial connections before trading up to 5G where it is available. As 5G evolves during the coming years, 4G will also continue to improve with time. For example, the upcoming Qualcomm X24 modem will support 4G speeds up to 2Gbps. Instead of higher peak data rates, the real advantages of 5G will come in massive capacity and low latency, beyond the levels 4G technologies can achieve.

Like other cellular networks, 5G networks use a system of cell sites that divide their coverage into sectors and send encoded data through radio waves. Each cell site must be connected to a network backbone, whether through a wired or wireless backhaul connection. 5G networks will use a type of encoding called Orthogonal Frequency Division Multiplexing (OFDM), which is similar to the encoding that 4G Long Term Evolution (LTE) uses. The air interface will be designed for much lower latency and greater flexibility than LTE, though. 5G networks need to be much smarter than previous systems, as they're juggling many more, smaller cells that can

[2] http://www.3gpp.org/specifications/67-releases

change size and shape. Even with existing macro cells, Qualcomm says 5G will be able to boost capacity by four times over current systems by leveraging wider bandwidths and advanced antenna technologies. The goal is to have far higher speeds available, and far higher capacity per sector, at far lower latency than 4G. The standards bodies involved are aiming at 20Gbps speeds and 1ms latency.

5G primarily runs on frequency bands below and above 6GHz. Low-frequency 5G networks, which use existing cellular and WiFi bands, take advantage of more flexible encoding and bigger channel sizes to achieve speeds 25-50% better than LTE. Those networks can cover the same distances as existing 4G cellular networks and generally will not need additional cell sites. The real 5G innovation is happening at higher frequencies, known as millimetre waves. Down in the existing cellular bands, only relatively narrow channels are available because that spectrum is already heavily used. However, at higher frequencies around 28Ghz and 39Ghz, there are large continuous sections of spectrum available to create big channels for very high speeds. Those bands have been used before for wireless backhauling, connecting base stations to remote Internet links, but they have not been used for consumer devices before, because the handheld processing power and miniaturized antennas were not available. Millimetre wave signals also fade faster with distance than signals at lower frequencies and the massive amount of data they transfer will also require more connection capacity towards the landline Internet. Consequently, cellular providers will have to install more, smaller, lower-power base stations rather than use existing powerful macrocells to offer the multi-gigabit speeds that millimeter wave networks promise.

From the network architecture point of view, 5G relies heavily on concepts that have not been present in the previous generations of mobile technology systems. 5G network infrastructures will be programmable, cloud-based and adaptive. Such functionality is enabled with a handful of new key technologies including Software-Defined Networking (SDN), Network Functions Virtualisation (NFV) and network slicing. Extensive utilisation of these technologies throughout the infrastructure will enable 5G networks to adapt to the requirements of a large variety of use cases and services [71].

6.2 5G for vertical industries

One of the main attributes differentiating 5G from the previous generations of mobile networks is its required ability to support not only mobile broadband use cases, but also IoT and critical communications by design [67]. This means that in addition to the traditional subscribers using smart phones for Internet access and multimedia, the networks will also be able to fulfil the needs of other kinds of end users, e.g. low power sensors of industrial robots [71]. In the past, the mobile technologies and networks have been designed with a consumer end user in mind and other features have usually been add-ons resulting to less than optimal performance.

In Horizon 2020, 5G IA and 5G PPP have been in key role defining vertical use cases for 5G [72] and studying technical enablers for vertical industry needs in its Phase 1 and Phase 2 projects [73]. In Phase 3, spanning from 2018 to 2020, the focus shifts to large-scale trials and pilots performed in collaborative projects between European research community, telecom vendors and vertical industries. The showcase trials performed in the 5G PPP Phase 3 projects will complement the private 5G trials performed by telecom vendors and MNOs providing public information on the best practises and lessons learned during the implementation of the piloted services. The key developments related to the 5G trials, deployments, market developments and national regulations in EU member states can be found from the European 5G Observatory[3] website. In addition to the 5G IA, which is an association of telecom stakeholders, many key vertical industry domains have their own interest groups investigating also the possibilities of 5G from the point of view their specific needs [74].

One of the 5G PPP Phase 2 projects, i.e. 5G-MoNArch[4], focuses specifically on the utilisation of 5G technologies for port environments in one of its vertical industry use cases. The trials in the project are based on the enhanced security and resiliency of the wireless communication in 5G systems and aim to better integrate the transport and information flows in the port area. The use cases studied in the project focus on traffic management (traffic light control), infrastructure maintenance (AR/VR-assisted operations) and pollution control (wireless sensors measuring air quality). As the time of this writing, the published project deliverables include the design of the 5G-MoNArch system and analysis on the different technologies involved. However, results from the deployed use cases and experiments are not yet available (to be published by mid-2019).

6.3 Current state-of-the-art in port communications

In today's port infrastructure, a variety of different communication systems are being used for different port operations and purposes. In addition to wired connections, wireless communication solutions are also extensively exploited. However, it is typical that different operations use their own dedicated infrastructures. For example, vessel navigation systems typically utilise Very High Frequency (VHF) or Ultra High Frequency (UHF) radio modems. Similar technologies can be used by employees for internal communications in the terminal site and cranes to communicate with container carriers and vessels. In addition, commercial and private mobile networks, as well as WiFi are typically used in variety of use cases.

The port environment and entities operating in it form a very dynamic environment not only from the perspective of different types of required services, but also from their communication needs. Management and control of parallel networks is costly and their interoperation can cause problems when information needs to be transferred between systems. To make matters worse, the ports are very challenging radio propagation environments, which has resulted to extensive use of proprietary communication systems especially tailored for robustness and resiliency for a specific task or service need. In addition, high requirement for secure communications in critical applications have further contributed to the reliance on proprietary and dedicated solutions. This means that even a single actor operating in the port can be forced to rely on a number of parallel communication infrastructures and devices in order to fulfil all his/her communication needs.

Wireless communication enables a variety of new opportunities for port automation as wired communication infrastructure restricts the location and mobility of the communicating entities. Consequently, more integrated and cost efficient solutions based on commercial mobile technologies and consumer grade devices have been extensively studied also for the critical

[3] http://5gobservatory.eu/
[4] https://5g-monarch.eu/

port operations during the past years. This trend has started even before the mobile networks entered to fully IP-based architectures in 4G. However, reliance on wireless mobile communications has proven to be challenging to the data transmission reliability in port operations. The radio channel conditions can vary rapidly, the link capacities are typically lower than those of fixed connections, and the resource sharing among multiple users in a dynamically changing radio channel is more challenging than in a stable wired connection.

In order to provide the additional flexibility to the operation of port facilities and equipment with reliable and secure wireless communication networks, the current state of the art technologies require very detailed and careful planning during the deployment phase. In many cases, the only way to guarantee the required service quality is to design the infrastructure based on the worst-case scenario, which leads to excessive amount of redundant equipment and over-capacity for the majority of the time. As the radio interface brings, to some extent, uncertainty to the communications reliability and the delivery of important data messages related to, for example, the control, management, and safety operations must be guaranteed in all operational conditions, this is the only way to rapidly restore and reconfigure the hardware-based infrastructure e.g. during unexpected faults.

The coverage of the wireless network can also dramatically change due to changes in the port environment because of different kinds of large moving obstacles such as cargo containers. In addition, the radio systems are also vulnerable to self-interference, especially in dynamically changing and highly reflective environments, in which even dedicated licensed spectrum resources and careful frequency planning cannot solve the problem. Unlicensed frequency bands, used e.g. by WLANs, offer a cheaper way to build excess capacity, but are heavily occupied also by variety of other systems in many areas. Based on earlier experience in the consortium, the situation is not any easier in private sites such as container terminals. For example, visiting vessels can have different WLAN networks for their internal operations that can interfere with the access points in the terminal site.

In addition to the underlying wireless technologies utilised to maximise the radio signal quality throughout the port area, one of the most essential and difficult parts in multi-purpose communication systems is the provision of adequate service quality for a heterogeneous set of requirements. Experience has shown that seamless mobility between different available access points and networks is one of the key components towards high Quality of Service (QoS). Several mobility protocols exist, but the intelligent selection of the access points or networks is still not possible. Reliance only on the radio signal quality parameters in the selection process is not enough. Instead, additional information from the network layer and the real quality experienced by the application or service used over the radio interface should be taken into consideration when selecting the optimal communication path in the radio access network, e.g. as presented and demonstrated in [75] and [76], respectively.

6.4 Beyond state-of-the-art in port communications with 5G

The new salient features of 5G will offer new possibilities to design and deploy wireless communication networks also in demanding port environments. When compared to the previous generations of mobile technologies, the flexibility of 5G will enable it to truly be a common technology platform for all communication needs in ports. When compared to the other technologies providing local connectivity for ports with standardised equipment, e.g. WLAN, or proprietary solutions, the economy of scale for 5G will bring down the cost of building and maintaining wireless communication infrastructures. With the finalisation of the first 5G specifications during the summer 2018, the availability of the network and user equipment is rapidly enhancing and the operators will start to roll out networks for the mass markets during 2019 and 2020.

The following subsections shortly summarise how different aspects of 5G systems will amend some of the key issues experienced in port communications today (as discussed in Section 6.3) and facilitate further adoption of wireless technologies for variety of use cases in port environments.

6.4.1 Virtualisation and cloud-based services

NFV refers to the replacement of network functions on dedicated appliances, such as routers, load balancers, and firewalls, with virtualized instances running as software on Commercial Off-the-Shelf (COTS) hardware. The purpose of NFV is to transform the way networks are built and services are delivered. With NFV, any enterprise can simplify a wide array of network functions, as well as maximize efficiencies and introduce new revenue-generating services faster and easier than ever before.

NFV is a key enabler of the coming 5G infrastructure, helping to virtualize all the various appliances in the network. In 5G, NFV will enable network slicing, a virtual network architecture aspect that allows multiple virtual networks to be created on top of a shared physical infrastructure. Virtual networks can then be customized to meet the needs of applications, services, devices, customers or operators. In 5G, NFV will also enable the distributed cloud, helping to create flexible and programmable networks for the needs of tomorrow. In 5G NFV will permit a physical network to be separated into multiple virtual networks that can support different Radio Access Networks (RAN) or various types of services for certain customer segments. Network slices will be isolated from one another in the control plane and user plane, so the user experience will be the same as if it was a physically separate network.

Virtualisation of the network functions and services enables the network resources also to be scaled according to the prevailing needs. Temporal changes in private port area networks can be large and the need for wireless network capacity can increase suddenly when a large vessel enters the port. Cloud-based 5G networks can adapt to the changing needs automatically as the functionality runs as software instances in a data centre environment. More resources can be initialised when the network experiences heavy load and terminated when they are not needed [71].

The ability to flexibly scale the network resources and functionalities according to changing needs and situations makes the overall communication system more reliable, robust and energy efficient. In case of private networks running in a single data centre, the cloud-based deployment makes also the management and monitoring of the whole network easier. If multiple radio access technologies are connected to the same core network infrastructure, the selection of the optimal radio interface to utilise for network access and QoS provisioning is also facilitated as the information from all access networks is available in a central location and available for the decisions making algorithms.

By its very nature, NFV will enhance the viability of 5G RAN functionality and architecture, including increased automation, operational agility, and reduced capital expenditure (CAPEX) related to the network infrastructure. As mobile networks migrate from physical to virtual, NFV will improve both business agility and operational sustainability by facilitating tailored deployments of 5G networks to different customer segments through slicing, as illustrated in Figure 2.

Figure 2. Network slicing can match 5G network capabilities to a variety of use cases [77].

6.4.2 Network slicing and security

The key concept behind 5G service quality and security is network slicing. A network slice is a collection of dedicated resources arranged and configured as logical network on top of a physical infrastructure. The orchestration of network slices is based on the virtualisation of 5G networks, which separates the network functionalities implemented as software from the hardware running it. Consequently, the network slices can be set up to serve a single purpose, e.g. to provide minimal latency for a critical MTC service, or be a collection of general purpose resources in order to serve multiple user groups simultaneously. The resources allocated to a single slice can be a mix of local and distributed assets, which enables e.g. the functionality of a private port network to be extended with a service from a distant data centre or from the public Internet. A slice-based private network can also be managed as an independent entity by the user or the customer even though it would be in reality be a logical network separated from the public network [71].

From the point of view of an MNO, a network slice is an independent end-to-end logical network that runs on a shared physical infrastructure, capable of providing a negotiated service quality. The technology enabling network slicing is transparent to business customers. A network slice could span across multiple parts of the network (e.g. user terminal, access network, core network and transport network) and could also be deployed across multiple operators. A network slice comprises dedicated and/or shared resources, e.g. in terms of processing power, storage, and bandwidth and has isolation from the other network slices.

Slice types could be defined from a functional or behavioural perspective. It is anticipated that MNOs could deploy a single network slice type that satisfies the needs of multiple verticals or multiple network slices of different types that are packaged as a single product targeted towards business customers having diverse requirements (see Figure 3). For example, a vehicle may need simultaneously a high bandwidth slice for infotainment and an ultra-reliable slice for telemetry, assisted driving, etc. Similarly, the complexity of network management will be increased if diverse massive IoT terminals exist in the generic network. Thus, operators could deploy different slices for different IoT users and these slices may have special charging and control functions, making network management easier, and deployment faster.

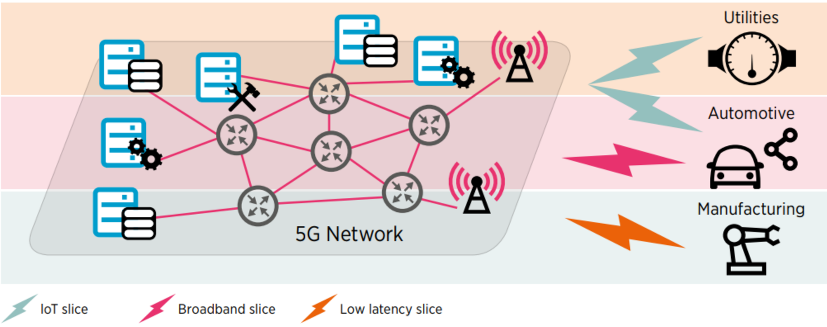

Figure 3. 5G networks can be subdivided, i.e. sliced, into virtual networks for each use case [78].

From the security perspective, 5G provides several enhancements when compared to the previous technology generations. 5G systems utilise the state of the art encryption throughout their infrastructure and interfaces, but they also provide additional properties to ensure their trustworthiness as a multi-service connectivity platform. These properties include enhanced resiliency against cyberattacks and system faults, communication security in the air interface, identity management, privacy and security assurance for the equipment utilised in the network [74]. The isolation between the network slides running on top of the same physical infrastructure is also an essential security feature provided in 5G.

6.4.3 Edge computing and machine learning

In order to better support local services with efficient spectrum usage and low latency, 5G system architecture support edge computing in the form of Multi-access Edge Computing (MEC) [77, 78] standardised by European Telecommunications Standards Institute (ETSI). With MEC, the local processing resources reside in the radio access network, which means that virtualised network functionalities and services can be located to the network edge instead of a central data centre. As the geographical distance to the services is smaller than in a fully centralised architecture, the end-to-end latency from the user to the service decreases. Local processing of data also facilitates the implementation of high capacity private networks in 5G, as the user data does not need to be transferred over the Internet to the cloud.

In addition to the enhanced spectrum efficiency, latency and security, the possibility to perform local processing enables the utilisation of distributed intelligence in the system in the form of Artificial Intelligence (AI) and Machine Learning (ML). With local learning and decision making, the automated management relying on AI/ML can perform very fast operations for the local area and global information can be synchronised over the network at a slower pace [79]. This kind of distribute approach can be very beneficial e.g. for the performance of anomaly detection and safety algorithms in human-machine interaction situations.

6.4.4 Beamforming and MIMO antennas

Beamforming is a method used to generate the radiation pattern of an array antenna by adding constructively the weights of the signals in the direction of the Signal of Interest (SOI) and nulling the pattern in the direction of the Signal not of Interest (SNOI), i.e. interference. Beamforming can be employed at both the transmitting and receiving ends in order to achieve spatial selectivity, i.e., an appropriate feeding allows antenna arrays to steer their beam and nulls towards certain directions as shown in Figure 4, this is often referred to as spatial filtering.

Figure 4. Example of a communication scenario utilising beamforming [80].

Smart antenna systems can be divided into two groups:

- Phased array systems: Phased array systems are switched and have a number of pre-defined patterns, the required one being switched according to the direction required.
- Adaptive array systems (AAS): This type of antenna uses what is termed adaptive beamforming and it has an infinite number of patterns and can be adjusted to the requirements in real time.

The concept of beamforming is to steer the transmitted signal toward the intended user. Therefore, the receiver will be the only party to recover the wanted signal from the overlay signal. Physical security can be achieved because the probability of an eavesdropper receiving the transmitted signal will be smaller than when using conventional antennas. Another advantage of beamforming is that it can be applied to mm-wave bands. Because the majority of the frequency spectrum that is suitable for dense urban cellular communication (e.g., below 5 GHz) is licensed, the only way to increase data rates in the frequency domain is by leveraging the unused frequency bands near the mm-wave range (e.g., 60 GHz and above). The main advantage of these frequency bands is their high bandwidth availability. However, the propagation characteristics of these bands are poor, even for short distances. Highly directive antennas must be used to overcome this limitation.

Beamforming can be divided into two categories depending on the signal bandwidth, i.e. narrowband beamforming and wideband beamforming. Narrowband beamforming is achieved by an instantaneous linear combination of the received array signals. However, when the involved signals are wideband, an additional processing dimension must be employed for effective operation, such as tapped delay lines or the recently proposed sensor delay lines, which lead to a wideband beamforming system.

Multiple Input Multiple Output (MIMO) antenna systems have received significant attention owing to the growing number of served users and the increasing demand for large amounts of data. Multi-user MIMO (MU-MIMO) systems might provide a breakthrough technique for improving spectral efficiency in wireless communications. MIMO has become a key technology for future communication systems as the number of requests for wireless services continues to increase, with the spectrum being finite. Recently, numerous in-depth studies have been conducted in the field of multi-user MIMO communication, in which relevant systems are referred to as massive MIMO or large-scale MIMO systems.

Massive MIMO systems are defined as an arrangement of MU-MIMO systems where large quantities of antenna elements at base stations and large quantities of antennas at terminals are deployed. Massive MIMO systems have several benefits, e.g. enhancement in throughput performance, low-cost components, low power, and efficient energy radiation. In massive MIMO systems, hundreds or thousands of antennas connected to a base station simultaneously work for considerably fewer, i.e. tens or hundreds, terminals using similar time and carrier frequency resources. The capacity increase enabled by massive MIMO systems is due to the large number of antennas that are implemented. However, using a large number of antennas causes interference problems, which can be mitigated by deploying beamforming antennas instead of conventional antennas as in the example illustration in Figure 5.

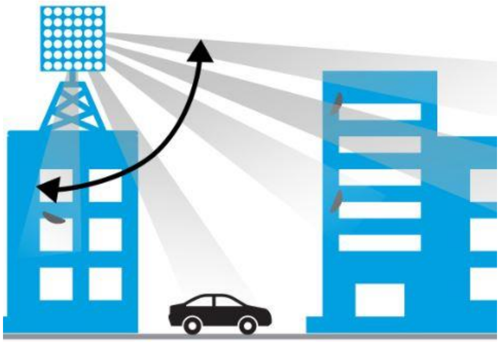

Figure 5. Example of a communication scenario utilising massive MIMO [81].

The definition of beamforming in massive MIMO systems differs slightly from the aforementioned definitions. Beamforming is a signal processing procedure used with multiple arrays of antennas at the transmitter side and/or receiver side to simultaneously send or detect multiple signals from multiple desired terminals to increase system capacity and performance. Beamforming can be realised by assembling the elements in an organised array, in which beams steered toward a specific direction are added and the other beams neglected. Although this technique is not new, it remains reinforced by developed wireless communication system organizations, namely, LTE and LTE-Advanced operators. These operators focus on integrating beamforming techniques into wireless communication systems. The energy efficiency of massive MIMO systems could be increased dramatically by deploying a large quantity of beamforming antenna elements at the base station.

6.4.5Modulation techniques and new spectrum bands

5G networks should support three major families of applications, i.e. eMBB, mMTC and URLLC. On top of this, Enhanced Vehicle-to-Everything (eV2X) communications are also considered as an important service that should be supported by 5G networks. These scenarios require massive connectivity with high system throughput and improved spectral efficiency, and impose significant challenges to the design of general 5G networks. In order to meet these new requirements, new modulation and multiple access schemes are being explored.

OFDM (see Figure 6) is able to combat the delay spread of wireless channels with simple detection methods, which has make it a popular solution for broadband transmission in the current 4G systems. However, traditional OFDM is unable to meet many new requirements for 5G networks. For example, in the mMTC scenario, sensor nodes usually transmit different types of data asynchronously in narrow bands while OFDM requires different users to be highly synchronized, otherwise there will be large interference among adjacent subbands. To address the new challenges that 5G networks are expected to solve, various types of modulation schemes have been proposed, such as filtering, pulse shaping, and precoding to reduce the out-of-band leakage of OFDM signals. 5G networks have to support not only a massive number of users but also dramatically different types of users that have different demands. Traditional OFDM can no longer satisfy these requirements, and therefore novel modulation techniques with much lower out-of-band leakage are required:

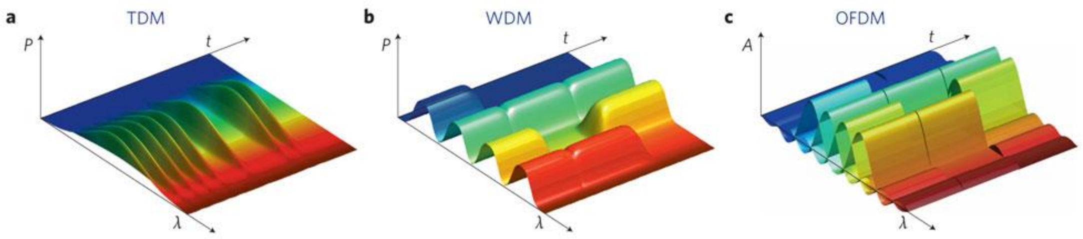

Figure 6. Representation of an OFDM signal.

The new modulation techniques for 5G networks currently need to consider backward compatibility with traditional OFDM systems but should also have the following key features to address the new challenges:

- High spectral efficiency: New modulation techniques should be able to mitigate out-of-band leakage among adjacent users so that the spectral efficiency of the system can be improved significantly by reducing the guard band/time resources.
- Loose synchronization requirements: Massive number of users are expected to be supported, especially for IoT, which makes synchronization difficult. Therefore, new modulation techniques are expected to support asynchronous communication scenarios.
- Flexibility: The modulation parameters (e.g., subcarrier width and symbol period) for each user should be configured independently and flexibly to support users with different data rate requirements.

Due to their favourable properties, such as radio wave propagation and available bandwidth, bands in the ranges 3300 – 4200 MHz and 4400 – 4990 MHz will be the primary spectrum bands between 1 GHz and 6 GHz for the introduction of 5G. Parts of these bands are being considered for first trials and introduction of 5G services in a number of countries and regions in the world, including:

- Europe: 3400 – 3800 MHz;
- China: 3300 – 3600 MHz, 4400 – 4500 MHz, 4800 – 4990 MHz;
- Japan: 3600 – 4200 MHz and 4400-4900 MHz;
- Korea: 3400 – 3700 MHz;
- US: 3100 – 3550 MHz (and 3700 – 4200 MHz).

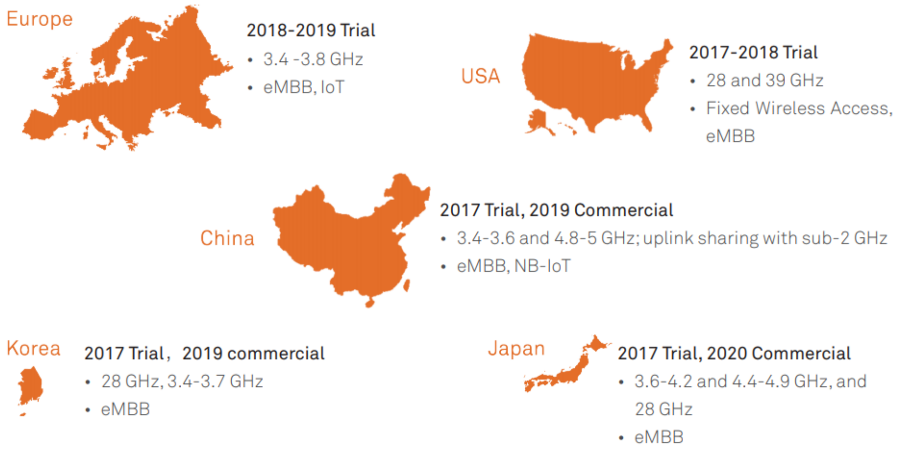

Figure 7. 5G Industry Progress Around the World [82].

The four mobile companies operating in Italy have fought hard, with an auction that has seen very high bids compared to other European countries. Even the medium-frequency 5G spectrum has reached its peak with offers above the average. The auction saw the comparison between operators to buy 1275 MHz of spectrum in the 5G bands by implementing the 5G European Action Plan. More precisely:

- 1000 MHz in the 26GHz band
- 200 MHz in the 3.7 GHz band
- 75 MHz in the 700 MHz one.

The 3.7 GHz band, with a relatively small amount of the spectrum offered - 200 MHz - was the one with the highest raises and which has the largest revenue in the state coffers. The band has been awarded by Vodafone and Tim on the width of 80MHz and Wind Tre and iliad of 20MHz [83].

In Germany on the other side, Deutsche Telekom (DT) and Telefonica Germany strengthen their alliance in view of the German auction for the 5G scheduled for the spring of 2019. The two companies announced the expansion of an existing partnership with a network-sharing agreement that plans to connect almost 5,000 Mobile Base Stations in Germany to DT's fiber-optic network. This will reduce costs and lead times for the 5G networks in Germany: it will be "an ideal starting point" for upgrading the current 3G and LTE antennas.

In general, the European situation is still in a deadlock and Italy represents the first concrete reference in this sense.

Spectrum harmonization remains important for the development of 5G, and even more important for higher frequencies in order to support the development of a new ecosystem as well as the deployment of very advanced antenna systems. Examples of ongoing 5G trials and pilots around world include the following activities on different frequency bands above 6 GHz:

- In Europe the range 26 GHz has been identified as a 5G pioneer band and work is well underway in order to harmonize the band in Europe for 5G before WRC-19 through adoption of a harmonization decision and to promote this band for worldwide use.
- China is targeting to deploy commercial 5G networks to meet the demands for the extremely high peak data rates in the ranges 26 GHz and 42 GHz.
- Japan will be deploying its first commercial 5G network to meet agreed international technical specifications for the 2020 summer Olympic games in Tokyo with a larger-scale field trial through 2018 and 2019.
- Korea introduced early pre-commercial 5G trials during the PyeongChang 2018 winter Olympic games. This activity included early 5G demonstrators in PyeongChang, Seoul and in other Korean locations.
- US has adopted new rules to enable rapid development and deployment of next generation 5G technologies and services in licensed spectrum in the band 28 GHz, but also in the range of 38 GHz.

In addition, the frequency bands 600 MHz, 700 MHz, 800 MHz, 900 MHz, 1.5 GHz, 2.1 GHz, 2.3 GHz and 2.6 GHz may be of particular interest for both traditional and new non-traditional applications and are key to deliver necessary 5G broadband coverage for applications such as IoT, industry automation, and business critical use cases [84]. Figure 8 summarizes the status of the allocated and targeted 5G frequency bands around the world.

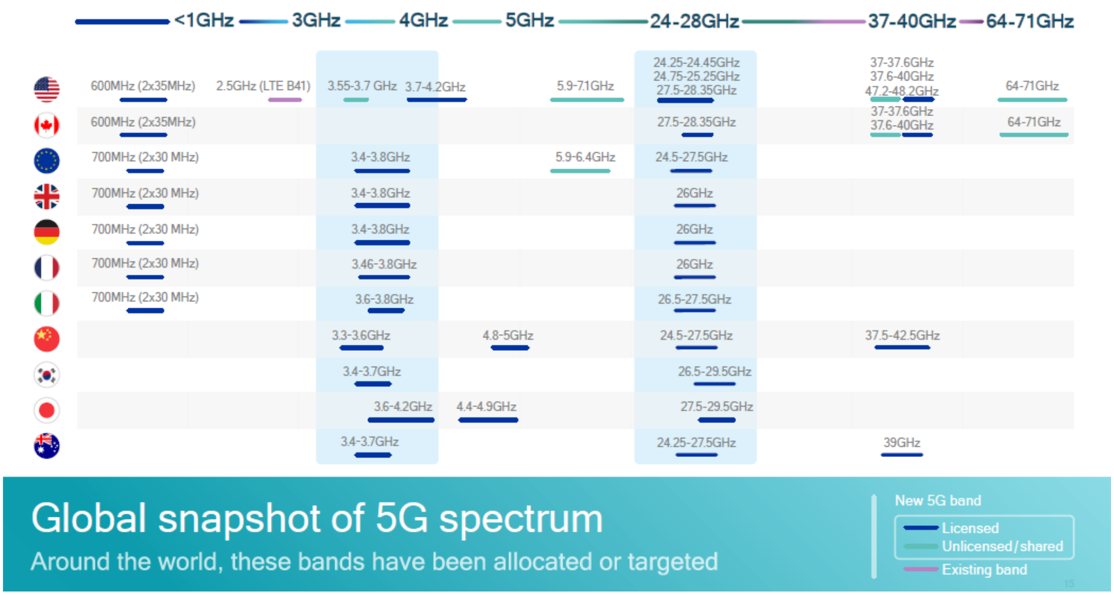

Figure 8. Summary of 5G frequency bands around the world [85].

7. Conclusions

Current trends such as globalization, digitalization and automation, servitization and climate change require the port sector to evolve. Globalization has led to larger container vessels causing terminal investments e.g. related to bigger cranes and loading/unloading capacity. Port infrastructure and good performance, including automation, improve ports' business and EU's competitiveness. However, port infrastructure is highly capital intensive and automation requires large investments. Thus, the optimal automation level and adequate infrastructure should be carefully considered in port's strategic plan.

On the other hand, environmental concerns are gaining more importance. Vessels are increasingly using environment friendlier fuels, such as LNG. This results in new services and infrastructure related to e.g. ship reloading, transhipment, bunkering and truck loading of LNG. The concept of circular economy can help ports to tackle environmental challenges and reduce environmental impacts. As a result, environmental friendliness can contribute to the competitiveness of ports and promotion of innovations.

Ports are an asset intensive industry with critical infrastructure. Systematic asset management has gradually been adopted by the port industry as an integrated strategy. Port management and specific conditions of each port influence vastly the asset management goals, structure and implementation. Integrating asset management system (AMS) with other enterprise management systems (EAS, ERP, etc.) can provide synergies, save resources and lead the port authority into sustainable development strategy. GIS-based asset management systems combined with emerging technologies such as 5G, IoT, physical Internet, cloud computing and AI, are technology trends in the comprehensive management of ports and terminals. There is a large number of software system providers in the market offering solutions for the management of port assets and terminal operations. Competition drives the development towards more effective and innovative use of new technologies. In addition, development of asset management systems have enabled new kinds of business models, which decrease the port's need for investments and its risks. E.g. real-time data of asset usage enables business models where assets are owned by third party and the port (or port or some other operator) will pay for the asset owner based on the usage information.

The rapid development of ICT technologies has also affected port infrastructures in a profound way. Ports are currently starting to be more and more automated and connected. However, the latest technologies are usually introduced to new sites whereas the existing port infrastructures are developing at a slower pace. Utilization of disruptive technologies can even out this imbalance between new and existing ports by facilitating the transformation of older sites towards smart terminal operations. Especially the availability of a common wireless communication platform in the form of 5G networks may open up new possibilities for variety of actors, machines and humans, to interoperate in connected ports.

The flexibility of 5G networks may also play a key role in specialized usage environments such as ports and container terminals. 5G is not only about higher data rates, lower latencies, enhanced reliability and better support for cellular IoT, but it also enables the creation of logical private networks for port operations with its cloud-based architecture. Here, the concept of network slicing is the key enabling technology, which provides the means to isolate resources from the physical network infrastructure of a commercial MNO for dedicated industrial customers, such as connected ports, with guaranteed level of service quality. The cloud-based architecture relying on virtualized resources also enables the industrial customers to utilize their own communication infrastructure as part of the overall 5G network. For example, application servers providing edge computing capabilities for services requiring extremely low latencies or utilizing sensitive data, can reside in the port area and process the data locally without the need to transfer it to a remote data center over the Internet. The possibility to include isolated resources and local processing to the network infrastructure enhances the security of the overall system and facilitates the utilization of other disruptive technologies, e.g. machine learning algorithms, in time critical use cases.

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