Received 22 July 2022, accepted 12 August 2022, date of publication 26 August 2022, date of current version 7 September 2022.
Digital Object Identifier 10.1109/ACCESS.2022.3201889

RESEARCH ARTICLE

5G Enabled Freeports: A Conceptual Framework

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This work was supported by the Department for Digital, Culture, Media, and Sport (DCMS) under its 5G Testbeds and Trials Programme, which supports innovators to explore new uses of 5G to improve people's lives, boost business, and diversify the supply of telecommunications infrastructure and services.

ABSTRACT A novel conceptual framework is developed that depicts a generic Freeport model underpinned by 5G technology. The framework is based on preliminary findings from a 5G testbed project and secondary 5G use cases from both practice and academic literature. We first provide a descriptive model of the current state of a port without 5G and Freeport status, identify the challenges and opportunities for logistics flows if Freeport status is attained and then prescribe how 5G may enable seamless logistics flows. With multiple challenges for ports generally, Freeport status increases the level of complexity of the core and support business processes that deliver goods from origin to destination. Despite that increased complexity, Freeports can attract investment and generate revenue, thus the enablement of Freeports is notionally beneficial in the long run. As complexity is anathema to smooth logistics flows, we develop a prescriptive model to exploit 5G to improve efficiency and effectiveness within a Freeport. We demonstrate the application of the prescriptive model with a 5G Freeport use case supported by simulation results, from which we aim to contribute to the overall adoption of 5G in Freeports.

INDEX TERMS 5G, descriptive model, prescriptive model, port, logistics systems, use case.

I. INTRODUCTION

5G, the fifth generation of mobile telecommunications technology, is said to be a revolutionary leap forward in terms of data rates, latency, massive connectivity, network reliability, and energy efficiency, when compared with its predecessor, 4G [1]. 5G has the capacity to support innovative new services, via autonomous vehicles and smart cities, and increase efficiency through smart agriculture, factory robotics and healthcare applications such as remote surgery. The logistics sector is one of the main industries that is actively exploring 5G's potential to improve connectivity and visibility, enhance operational efficiency and accelerate automation.

Among the other digital technologies being developed, such as Internet of Things (IoT), robotics, artificial intelligence (AI) and machine learning, the logistics sector sees 5G as having an immediate impact by enhancing 'end-to-end' supply chain visibility and thus increasing resilience to disturbances (CSCMP, State of Logistics report 2021). As the critical nodes of logistics supply chains and being a cluster of companies in the logistics sector, seaports are undergoing significant trials and applications of smart technologies to stay productive and competitive [2].

Seaports themselves play a critical role in the global supply chains of modern business, enabling the transfer of cargo between water and land-based transport modes. While historically this was the only function of ports, over time there has been a move towards carrying out storage and value adding activities as a way of improving the movement of goods within the supply chain and generating additional revenue streams for port operators [3]. Smart ports look to enhance the operations of modern-day ports, for example using automation, analytics and optimisation of product flows. By doing so, they help to manage the complexity arising from the range of value adding activities.

In parallel with port development generally, there has been the emergence of Freeports as a way of encouraging businesses to route products through specific ports and attract

The associate editor coordinating the review of this manuscript and approving it for publication was Yanxiang Jiang.

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manufacturing to specific areas of the UK. Freeports are areas that sit outside of a customs zone, with customs charges and tariffs paid once the products leave this zone. Freeports often require a higher degree of security and ability to monitor the whereabouts of products [4]. As such, a further level of complexity is added to port operations. Therefore, advocates of Freeports argue for the need to make them 'smart' i.e. having sufficient digital infrastructure and systems to ensure ports and related ecosystem actors are compliant and secure as well as more productive, efficient and competitive [5].

Consequently, there appears to be a significant opportunity for 5G technologies to support Freeport requirements, building on existing insights from the applications developed in regular port operations. This paper aims to investigate 5G applications in Freeports and explore how 5G capabilities can support the Freeport concept to enhance efficiency and productivity to the port operation, allow real- time location tracking of individual items, and replace the low value, manually intensive processes with 5G enabled autonomous systems. Despite various initiatives enabled by 5G in ports, there has been lack of studies to examine how 5G supports a Freeport - where operations are much more complex and requirements on real time visibility about cargo movement, safety and security more demanding.

A. RESEARCH CONTRIBUTION

Given this, our main contribution is a conceptual framework of a 5G-enabled Freeport developed via our empirical research. We build on insights from the United Kingdom (UK), where recent policy developments have encouraged the re-establishment of Freeports [6] and a use case involving The Bristol Port Company, as trialled in the 5G Logistics project, part of the UK Department for Digital, Culture, Media & Sport (DCMS) funded 5G Testbed & Trials (5GTT) programme. Building on our framework, future work can be conducted to operationalise the 5G enabled Freeport concept and evaluate, through potential use cases, the full impact of 5G.

Our research shows the clear benefits of 5G to freeports that arise from the seamless monitoring and control of cargo movements and the use of drones for port surveillance with low latency. Therefore, our research provides important evidence that 5G plays a critical role in building a port's digital capabilities and supporting the transition to the next generation of smart port.

Our technical novelty focuses on the use case delivery on an end-to-end network that includes the following - which were demonstrated in detail in Section IV;

- User equipment as a nano cell router
- Radio Access Network (RAN) purely as an access network
- Core network as a local endpoint providing access to the sensors connected to the nano cell router
- Our Freeport application collection on the Multi-Access Edge Computing (MEC) infrastructure for which simulations are presented against sensors connected to the nano-cell router.

The paper proceeds as follows. Section II introduces the concept of a Freeport and its developments. It also discusses the core attributes and unique advantages afforded by 5G technology, its popular use cases and how 5G has been deployed/trialled in seaports around the world. Section III presents our methodological approaches while Section IV provides a detailed account of the development of a 5G enabled Freeport model with simulation results. Section V concludes the paper and discusses the way forward.

II. BACKGROUND LITERATURE

A. FREEPORTS: DEFINITION, HISTORICAL DEVELOPMENT, AND THE NEW UK FREEPORT INITIATIVES

The concept of a Freeport is often derived from a wider definition of free trade zones. While exact definitions vary between countries, free trade zones can be considered designated areas of a country that are outside of customs purposes [7]. Any goods entering a free trade zone will not be subject to any import duties until they enter the domestic market, while goods can be re-exported without paying any duties. Where these zones are found at a port (and particularly seaport), the term Freeport may be applied. Further, as well as operating under different customs regulations, Freeports may also benefit from a broader range of regulatory differences from the rest of the country, such as tax and planning regulations [8]. It is suggested that there are 3,500 Freeports globally [9].

Examples of Freeports can be traced back to the ancient past [10] but modern-day examples can trace their roots back to the early 20th Century [11]. Early research on Freeports highlights Hamburg, Bremen, Copenhagen, Stockholm and Gothenburg as particularly successful examples [12]. However, even then, differences existed as to the functions that these ports undertook. Lavissière *et al.* [10] identify three different functions for Freeports:

- Provide storage of goods under customs exemption. Such a buffer may be close to the final market for the products but remains exempt from customs duties until entering that market.
- Allow minor transformation of goods post-manufacturing. Lavissière *et al.* [10] highlight the labelling of goods in the language of the final market as an example of this.
- Provide facilities for the manufacturing of products without customs duties being paid on components. These are effectively export processing zones, as described in [9] and a feature, for example, of Chinese Freeports [13].

There are a number of factors that lead to the successful development of a Freeport. As Anderson (1934) first identified, location is important with the port being situated on trading routes, and this remains true today [8]. Given that Freeports are seen as boosting regional development, it has also been suggested that their location should be in areas that will benefit from this [13]. Efficient operations are also important [14] and this requires modern infrastructure, both physical and digital as well as an available workforce [8], [15]. Efficiency also comes through the administrative and customs processes deployed [8], [13]. Finally, Hoyle [15] highlights the importance of security, in order to maintain separation at the port between Freeport goods and other traffic.

As Freeport operations are affected by the local regulations under which they operate, we use the United Kingdom as context for this study. The first wave of Freeports was introduced during the 1980s, with six locations being granted this status by the government [11]. Only four of these established operations with customers [16], although additional sites were opened subsequently. By 2012, five locations remained, and the government decided not to renew the licences for these. The exact rationale for this is unknown [17], although alternative ways for obtaining the benefits of the same customs were available [6].

In 2020, the UK Government launched new proposals for the development of Freeports, in response to both Brexit and the economic impacts of COVID-19 [6]. The Freeports comprise a combination of 'customs zones' (akin to free trade zones) and 'tax sites' where businesses within these receive wider tax and regulatory benefits [4]. Freeports are permitted for multiple customs zones and tax sites, but there is a limit on the size of tax sites and the maximum distance between any two designated areas is 45km. One important requirement about a Freeport is that operators would need to have secured a HMRC-approved inventory linking system that would ensure the control of movement of goods entering and exiting the Freeport customs sites, at the port and any nominated off-port locations.

Three motivations for Freeports have been stated – creating hubs for global trade and investment, regeneration and job creation, and innovation. In 2021 and after a competitive bid process the UK government announced the location of eight new Freeports in England [6]. Alongside the Government's criteria, the 'levelling up' agenda was reported to have influenced its Freeport decisions. All Freeports are expected to be operational by summer 2022 [6]. Agreement has been reached for Freeports to be created in Scotland and Wales but their locations have not been confirmed.

B. 5G TECHNOLOGY IN LOGISTICS AND PORT OPERATION

1) 5G INTRODUCTION

Mobile wireless communication technology has tended to go through a revolutionary change every ten years. Each generation of mobile communications system builds on the research and development since the previous generation and delivers significant performance enhancement in terms of data transmission speed, network capacity (i.e. the maximum number of users or devices that a network can support), throughput (actual rate of data exchange achieved), range (the physical distance from a host/originating device in which wireless technology can transmit information) and latency (the time required for a round-trip message between two communication partners across a network) [20]. Table 1 shows the development of each generation of technological development.

While 1G from the 1980s was analogue technology and only supported voice transmission, 2G was the first digital system deployed in the 1990s, supporting voice and small data provisions such as Short Message Service (SMS) and Multimedia Messaging Service (MMS). 2G provided a digital leap compared with 1G, and its data speed could achieve 64Kb/s, compared to only 2Kb/s with 1G. 3G emerged in the 2000s, combining the features of the 2G network with new technologies e.g. Universal Mobile Telecommunications System (UMTS) and protocols that delivered a significantly faster data rate and supported higher quality audio, video and data transmission [21]. 4G became available in the late 2010s due to the advancements in technology over the last decade and provided high speed, high quality and capacity data transmission over Internet Protocol. 4G allowed data transmission speed at 100 Mb/s, much faster than 3G (typically 2 Mb/s) and supported higher speed internet, high definition (HD) quality video, and mobile broadband [22]. 5G brings another major technology step, with the creation of a 'New Radio' (NR) in the 2020s. With speeds of up to 10 gigabits per second, 5G is much faster than 4G. Low latency is a key differentiator between 4G (60-98ms) and 5G ($<$1ms), therefore 5G is predicted to be a core enabler of the 4th Industrial Revolution, allowing the seamless connectivity of millions of Internet of Things (IoTs) devices and supporting mission-critical activities such as autonomous vehicles [23], [24].

5G use cases are typically identified in three categories [1], [24]:

- Enhanced mobile broadband (eMBB) – eMBB brings high-speed mobile broadband to crowded areas, allowing consumers and enterprises to enjoy high-speed streaming on demand with much improved user data rates. Typical applications include: enhanced indoor and outdoor broadband, enterprise collaboration, high-definition cloud gaming, massive content streaming, augmented and virtual reality.
- Massive machine-type communications (mMTC) – mMTC services cater to accommodate a large number of devices with a relatively low (or high) volume of data with high tolerance for latency. Devices tend to be low cost with long battery life. Typical applications include asset tracking and predictive maintenance, smart agriculture, smart cities, smart retail, energy monitoring as part of smart and integrated energy systems, smart homes, remote monitoring, intelligent surveillance, and video analytics.
- Ultra-reliable and low-latency communications (URLLC) – URLLC has extreme stringent requirements on data throughput, reliability and latency and tends to support mission critical control activities. Some of the popular example applications include autonomous vehicles and platooning, drones and robotic applications,

TABLE 1. Evolution of mobile networks and industry adaptation (Source: Authors, developed based on [1], [18], [19]).

Technologies	1G	2G	3G	4G	5G
Deployment Timeline	1984	1999	2002	2008	2015
Data rate	2 Kbps	64Kbps	2 Mbps	100 Mbps	10Gbps
Services	Single voice	Digital voice, SMS (2.5G, voice + data)	High quality audio, video and data	Dynamic information access, wearable devices	Dynamic information access, wearable devices with AI capabilities
Core network	PSTN	PSTN	Packet network	Internet	Internet
Core technologies	Analog cellular technology	Digital cellular technology	Broad bandwidth CDMA, IP technology	Undefined IP and seamless combination of broadband, LAN/WAN/PAN/WLAN	Undefined IP and seamless combination of broadband, LAN/WAN/PAN/WLAN
Acronyms SMS: short message service; PSTN: Public switched telephone network; CDMA: code-division multiple access; IP: internet protocol; LAN: Local area network; WAN: Wide area network; PAN: Personal area network; WLAN: wireless LAN.					

smart grid and metering, remote patient monitoring and telehealth, industrial automation, mission-critical services (security, safety and emergency services).

A recent survey of 40 5G use cases by the World Economic Forum [25] indicates that 93% of the use cases analysed would be enhanced by URLLC and 78% by eMBB. mMTC is perceived to be important too, contributing to 45% of the use cases analysed. While public 5G networks are being deployed concentrating on the eMBB use cases, private 5G is on the rise with early industrial adopters installing their own 5G base stations in factories and industrial parks. Although confidence in technology is high, the biggest uncertainties lie in the commercial strength of the business cases and how soon 5G fuels new products and services that customers are willing to pay for [26].

C. 5G IN PORTS

The first major use cases of private 5G networks in logistics tend to be at logistics hubs such as seaports, airports, and warehouse complexes. Major seaports around the world, including Singapore, Rotterdam, Busan and Shanghai, are investing aggressively in digitalisation to transform themselves into smart ports and meet future challenges. Smart ports will need to utilise digital solutions to address the current and future challenges faced by seaports including spatial constraints, pressure on productivity, fiscal limitations, safety and security risks and sustainability [27].

5G is seen as a key enabler to the smart port concept and the only wireless technology currently capable of connecting every container, vehicle, crane, and other assets used, both indoors and outdoors, at a major port complex. This intensive real-time and low latency connectivity delivered by 5G, if integrated with other technologies such as AI and edge computing, provide invaluable insights into a port's condition and operations. It affords a port the ability to control and optimise its operations safely and securely and make decisions in real-time, with the potential to add a level of automation before unseen.

5G also powers innovative concepts such as digital twins, an important pillar of the smart port. The precise digital representation of a live working environment is dependent on real-time connectivity between the physical asset and its virtual representation. Given the complexity of modern ports and increasingly automated logistics facilities, collecting, transferring, and visualising the data in a one-to-one dynamic virtual model has been limited by the capabilities of the existing wireless network. The top three challenges to the advancement of digital twins in logistics are cost, precise representation, and data quality. 5G and next- generation wireless could provide solutions to the latter two challenges [20].

Various 5G use cases in ports are emerging. Table 2 provides a summary of some notable cases. As evident in Table 2, the private 5G network is the dominant infrastructure among the trials and implementations. The main efforts of exploring the value generated from 5G largely lie in port automation, intelligent decision making and real- time control of cargo movement and other operations. The reported benefits tend to concentrate on port productivity gains (e.g. reducing transit time of goods in the port, improved efficiency in quays and yard operations, labour cost savings and easing of service flows), improved safety and security as well as environmental benefits.

Of those ports sampled, Port of Livorno stands out due to its deliberate efforts to assess (using both quantifiable and qualitative measures) how the benefits enabled by 5G could contribute to the development of a smart and sustainable port and deliver on UN sustainable development goals (SDGs). For instance, there has been an estimate of 8.2% reduction in associated CO_2 emissions per terminal operation, a 20% average cost reduction per year through optimising vessel berths as well 20-25% increased productivity with automated quay cranes [37].

As evidenced by Table 2, 5G technologies are currently mainly used to augment and enhance existing port and terminal operations, rather than enabling new business models and more radical innovative practices. Our paper attempts to bridge the latter and explores how 5G could enable the concept of Freeport as discussed earlier in this section.

III. METHODOLOGY

A. BRISTOL PORT FREEPORT USE CASE

Our research is firmly rooted and contextualised in Bristol Port's Freeport use case, to be trialled in the 5G Logistics project in early 2022. The multidisciplinary research team is part of a UK government funded 5G Testbed and Trails (5GTT) programme aiming to determine the business benefits

TABLE 2. Summary of emerging 5G use cases in seaports.

Country		Use case categories	Comments
Belgium	Port of Zeebrugge	mMTC	5G-ready private wireless connectivity in collaborative partnership with Citymesh and Nokia. Started in 2019, connectivity to more than 100 endpoints (e.g. tugboats, air pollution detectors, security cameras and quay sensors) across the entire port operations enables the port to track, analyse and manage connected devices across multiple port-based applications in real-time. Future use cases look at the building and maintenance of the port's offshore wind farms as well as simplifying registration of cargo at customs in response to Brexit [28].
Belgium	Port of Antwerp	eMBB	Setting up a 5G private network. The first use case in 2020 connected a tugboat to the 5G network, allowing it to stream real-time images and other data, such as radar and sonar, to the control rooms. Using this real-time information, the Antwerp Port Authority said it could increase the efficiency and safety of towing vessels across the port. This allows it to increase the number of ships entering and leaving the port each day [29].
China	Port of Qingdao	URLLC	In 2018 the Port of Qingdao successfully trialled the operation of automated ship-to-shore container cranes over a 5G connection, remotely from a control centre. The 6-month trial confirmed both the feasibility and potential of 5G applications for the development of 'smart ports' which have greater flexibility and higher efficiency levels. One of the key findings of the trial was that up to 70% of labour costs could be saved when a port uses 5G automation compared to a more traditional fully automated harbour [30].
Germany	Port of Hamburg	eMBB and eMTC	Testbed launched in February 2018. Hamburg Port Authority, Deutsche Telekom and Nokia partnered in 5G network slicing trials on private on-site deployment. 5G technology is being used to regulate traffic light signals, process environmental sensor data and support multimedia applications of virtual reality glasses and video streaming [31]
Italy	Port of Livorno	URLLC and mMTC	Digitalising port operations with 5G and IoT began in 2016 with a proof of concept to demonstrate automated remote control of unmanned ground vehicles (UGVs) for loading and unloading operations in the port area. The expectation was that robots will cooperate by working in swarms, exploiting the technology of cloud and distributed computing. UGVs and connected vehicles together with a large set of scalar sensors feature both M2M and remote controls. Savings of €2.5 million per year (through optimized vessel berthing) and 25% improvement in productivity (through 5G remote-controlled gantry and quay cranes) has been estimated [32].
Latvia	Port of Riga (Freeport)	eMBB and URLLC	Testing of several 5G use cases is taking place including utilising drone technology equipped with AI and a drone traffic management platform to determine pollution at the port [33].
South Korea	Busan Port	URLLC	Integrating 5G mobile edge computing convergence technology into its remote-controlled crane fleet and expecting to increase yard productivity by 40%, with full automation in its warehouses and guaranteed safety across all operations [34].
UK	Port of Felixstowe	URLLC	Starting in 2020, using a 5G Private Network installed by Three UK, the project will test the potential of 5G across two use cases: enabling remote-controlled cranes via the transmission of CCTV and; deploying Internet of Things sensors and Artificial Intelligence to optimise the predicative maintenance cycle of Felixstowe's 31 quay-side and 82 yard cranes [35].
UK	Port of Bristol	mMTC and eMMB	Starting in 2020, the 5G Logistics project is trialling 5G's potential for security, traceability, and real-time tracking of goods in a Freeport and Freezone scenario; autonomous drone flights for more efficient port surveillance operations and emergency response; improvements to road traffic management in HGV-heavy areas through 5G smart junctions (AI-based traffic signalling), easing congestion and improving traffic flow around the port [36]. This paper is an outcome of this project's early research and will be explored further below.

of 5G in a port setting, including its potential support of Freeport operations. Technically it will develop a smart solution capable of utilising the cutting-edge advancements of 5G for **a.** precise location tracking and cargo monitoring; **b.** the use of drones for surveillance, security and safety control. The Freeport use case was co-created by a consortium of public and private organisations, including two academic institutions, the port operator, technology service providers, a value adding manufacturing site (acting as a remote Freeport zone in the project) and a haulage company. Please note that at the time of writing, Bristol Port does not have Freeport status.s

Multiple data collection methods are used to deliver the analysis and recommendations in this paper, including interviews, regular information exchange meetings, archival documents (such as government policy documents) and secondary publications. Our approach is inductive including the development of descriptive and prescriptive models. Simulation was adopted to demonstrate why the use of 5G is more robust when data traffic increases.

B. DESIGN SCIENCE APPROACH

We adopt a design science approach to the research [38] with the exploitation of use cases, which have been applied to software design [39]. Use cases may be defined as the telling of narratives, that need to be designed, to guide users in how to undertake a sequence of activities for a system to deliver value to actors, i.e. stakeholders as users of the system. The use case approach is particularly powerful in helping to capture and explain unambiguously the complex dynamics inherent in system requirements specification from design through to implementation [40]. Unlike traditional software development where actors are seen as outside the system [40], our method is more akin to the systems thinking learning-cycle approach where actors, processes and technologies are inherently part of the whole [41].

Jacobson *et al.* [42] propose six principles for the development of use cases. These principles are aligned with the software design stages of envisioning (understanding the business and capturing requirements), reverse engineering (develop models of the 'as is' business and legacy information systems) and forward engineering (synthesising the new information system including testing via numerical simulation') [43]. Such a three-stage approach has direct analogue with general, business and logistics systems design techniques [44]. The six principles, and how we exploit them in this research, are;

Principle 1 – Keep it simple by telling stories: the stories we tell of existing secondary cases and the existing situation in the case port are via written narratives in the former, based on publicly available information, and narratives in written and pictorial form in the latter. For the case of Bristol Port we have exploited several primary data sources including interviews with actors, observations of existing processes, collection of archival documentation of existing information systems, and workshops with internal and external stakeholders.

Principle 2 – Understand the big picture: we take a whole systems approach to the port use case with due consideration of actors (attitudes), processes (organisational ways of working) and technologies (hardware and software) [45], [46].

Principle 3 – Focus on value: the emergent property of the port system is to ensure the seamless flow of goods from origin to destination to fulfil the needs of a customer to send / receive goods [3]. The associated actors, processes and technologies, may have their own specific sub-system requirements but when combined as a whole they are simply enablers in achieving seamless flow.

Principle 4 – Build the system in slices: we exploit a deductive approach to developing a descriptive model [46] of the existing 'as is' port system. We consider the port in terms of its constituent parts namely; Port Entry, Stevedore, Transit, Storage and Linkage sub-systems and the supporting Port Information System (following [47]). Our focus for this paper is the Port Information System and its relationship to the other sub-systems.

Principle 5 – Deliver the system in increments: we provide a whole-system use case, in the form of a prescriptive outline design [46], for the exploitation of 5G in the Port Information System and its subsequent impact on the port's constituent parts. Future increments, beyond the scope of this paper, will develop detailed designs for each element of the Port Information System.

Principle 6 – Adapt to meet the team's needs: the research was cocreated and executed by a multidisciplinary team of practitioners and academics. The former consists of private organisations including port operator, technology service providers, and a haulage company, and public sector bodies including the police, who provide port security, and local governments from the region within which the port resides. The academic team has expertise in wireless digital technologies, network communications, internet of things, business systems engineering, port policy and logistics management. The project delivery involved methodological pluralism, accommodating the various disciplinary traditions and philosophies incorporated within the team.

IV. DEVELOPMENT OF A 5G ENABLED FREEPORT FRAMEWORK

A. CURRENT STATE: BRISTOL PORT

To envisage how a 5G enabled Freeport operates in practice, we first need to establish what is the current state of operations when it comes to cargo flow in a port. Based on the case study of Bristol Port, Figure 1 presents both the physical cargo and information flows of its current operations. At this stage, there are no Freeport processes in operation.

1) A HIGH-LEVEL DESCRIPTION OF CROSS BORDER CARGO FLOW

A typical import container is manifested by the Shipping Line. The Forwarding Agent nominates the container for clearance and submits the entry to the Customs system. The Port then arrives the vessel and discharges the container accordingly. The Customs system returns the routing for entry and sends clearance if and when applicable. Following this, the Shipping Line releases the container to the nominated Haulier who updates the container with Vehicle or PIN (password) details. The Port then allows the container to be loaded onto a trailer and to depart, given the driver supplies the correct Vehicle/PIN details.

With incoming cargo, government agencies like Local Customs, Port Health, and the Animal and Plant Health Agency (APHA) among others, may require the container to be checked, with any holds or releases being notified to the applicable parties. All involved parties can use Destin8™, a port community software system used by 17 major UK ports, and especially the enquiry functions to view cargo information in (near) real-time. This includes checking the Vessel expected/actual time of arrival, Cargo Landed/Loaded status, Customs Clearance status, and Outdated/Ingated status. The manifests submitted to Destin8™ are used by Customs for all fiscal control purposes and manifests submitted to the system are forwarded to a central Customs anti- smuggling system, for profiling and risk management purposes. The port police is onsite to conduct regular surveillance to ensure cargo safety and security.

2) BRISTOL PORT SPECIFIC DESCRIPTION

Typically, container shipping lines calling at Bristol Port tend to travel from Antwerp Port, Dunkirk Port and Bilbao Port. The port gets an Estimated Time of Arrival (ETA) from the shipping line and then lines up a pilot to help with berthing. Bristol port also gets an Electronic Data Interchange file from the port of loading with a loading plan and the container numbers. Information about the containers is held on Destin8™ (or known as the inventory linking system). Each container has a 5-digit Unique Vessel Identifier (UVI)[1] number which can be put onto the system. If goods are not customs released, the port chases either the customer or

[1]When a vessel is registered on Destin8 through transaction (known as VRG – Voyage registration), a 5-digit UVI is returned. When a consignment is created through the Manifest Create transactions (MFC/MIC/MCI) a 4-digit Unique Consignment Identifier (UCI) is returned. Together they form the Unique Consignment Number (UCN), which is therefore an identifier for a particular consignment within a particular vessel. The UCN remains with the consignment details until they are purged from the system and may never be amended. It is the UCN which provides the means for Destin8 and CHIEF, the Customs computer, to exchange inventory information. Thus, UVI + UCI = UCN.

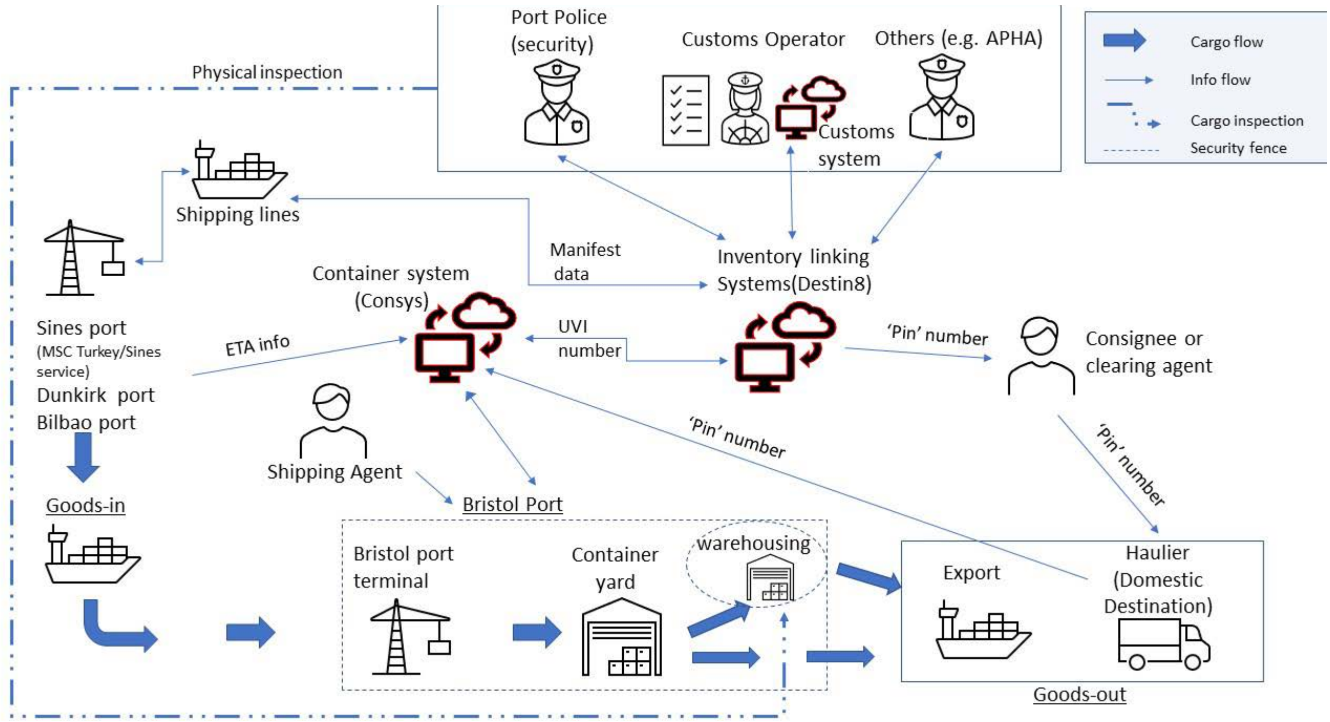


FIGURE 1. **Current state map of Bristol Port operations (Cargo and info flow).**

Customs. Customs will normally email the port with details of containers that need to be held for customs inspections. Containers will also be held due to non- payment issues (not customs related).

CONSYS is the Bristol Port information system that manages the movement and inventory of cargo within the port terminals. The system is being upgraded and internet linked. CONSYS is linked to Destin8^{TM} and when the container number is put into CONSYS, it accesses the data from Destin8^{TM}. This includes the release PIN for the haulier to collect the load once cleared. Only the customer knows the release PIN. Once a container is on a lorry, it joins a queue and then a pass is issued for the vehicle to be able to leave the port. Once off the port (detected through CONSYS), then a message is sent to Destin8^{TM} using a human operated account.

The container yard is controlled with an International Ship and Port Facility Security Code pass, which limits access. There is also a secondary fence, to maintain the safety of the ship. When a ship berths, gates are locked at both ends of the quay to extend this secure area. From discharge, the container is managed through CONSYS. Whenever it is moved, the location is noted by the operator on the system. Data entry is manual at the moment, using a touch screen unit on the vehicles – reach stacker or rubber tyred gantry cranes.

In terms of the trigger for a container to leave the port, this can be from the haulage company (e.g. requesting the collection of an empty container). Sometimes vehicles turn up unplanned to collect containers, which can cause a backlog. The new system is under development and will introduce a pre-booking system, while still allowing the port to accept unannounced lorries.

3) CURRENT ISSUES

The current process is largely manual and so relies on plant drivers to update CONSYS on the status of individual containers. Bristol Port is upgrading its CONSYS with a view to automating task scheduling activities and integrating the management of the movement of containers and staff on site. However, as discussed in Section II-A, to qualify as a Freeport, the operator of Freeport custom sites needs to have an information system that is capable of monitoring the goods movement, in and out and between various sites in a Freeport zone. This means one needs to be able to pinpoint the exact location of any goods at any time within the defined territory. This calls for a real-time goods tracking solution able to capture, transmit and process the large volume of data generated from different sources at speed.

Currently most data capturing is done manually, and the port relies on Wi-Fi to transmit data. Wi-Fi has proven unreliable in industrial and port environments, with mobile crane issues among many. This hinders port productivity as operations can grind to a halt if any key activity breaks down due to poor Wi-Fi connection. The connectivity issue also has safety and security implications. The port is currently looking to use 4G to back up the Wi-Fi network but sees 5G as a long-term solution to address pertinent issues such as these.

B. FUTURE STATE: A 5G-ENABLED FREEPORT AT BRISTOL PORT

To articulate why 5G is a critical technology that will support the effective operation of a Freeport, we use Bristol Port's operative model to first discuss how it would operate as a Freeport utilising 4G and then debate why 5G can deliver better.

1) DATA AND CONNECTIVITY IN A FREEPORT SCENARIO

To address how Freeports and 4G would work together, we need to identify the requirements of Freeports. In Department for Transport (2021), it is stated that a total of 6 million containers passed through UK major ports in 2019. Of those, Bristol Port handled around 61,000 containers. To monitor goods and their state on the move, sensors are incorporated within these containers and/or vehicles, resulting in a massive requirement of bandwidth for the transmission of the sensor data.

Considering traffic from other entities, such as drones, static sensors, cameras and offices, the bandwidth requirements increase exponentially. The strategic value of such data stems from integrating the data into IoTs and feeding it into machine learning (ML) tools to support smart decision making and actions. Rather than being reactive to events and uncertainties, a Freeport can be more proactive and utilise the insights gained to predict what might happen and take more informed actions. For example, traffic control, condition monitoring control, theft prediction, emergency drone services and other control applications can produce significant value [48], [49], [50].

2) CURRENT LIMITATIONS OF 4G NETWORK TO SUPPORT THE FREEPORT CONCEPT

Port logistics are complex and currently managed by port community systems (such as Destin8 and Consys discussed above) that are providing services like: **i.** information exchange between transport operators, **ii.** electronic exchange of Customs declarations and Customs responses, **iii.** tracking and tracing goods through the whole logistics chain, **iv.** processing declarations of dangerous goods and other. Today these services, which enable ports and customs to manage their logistics and create global information databases, are mostly maintained and updated by staff in the cloud. In Figure 2 we highlight the connectivity of today's port community system and their cloud associated databases and other services. As can be seen in the figure3, the port data traffic is all transmitted over public shared cells.

While the use of 4G and Wi-Fi could support the data transfer and processing need of a Freeport concept in principle, it has its performance limitations when it comes to deal with rapid increase in the data traffic volume, velocity and computation demands. For instance, the use of drone for video surveillance and object recognition around the port requires intensive computational load, whilst those imaging processing and video analytics would have to rely on AI machine learning to detect anomaly. Under 4G, the only option for AI decision making is be hosted in the cloud, but this approach tends to result in high latency, security concerns and high- cost computing [51].

The intensive use of IoT devices for cargo tracking and monitoring also calls for high level of automation and smart applications over a high-speed and high-performance network infrastructure. Furthermore, it is observed in the literature [51], [52] that IoT performs better when deployed on MEC infrastructure. MEC reduce network latency by processing data closer to the mobile users. The expected network latency in a 4G network is typically 10-20ms which is, for many, perceived not good enough [51], [52]. Freeports 4G data traffic, passes over the public internet service provider (ISP) network which does not provide the level of reliability required for mission-critical applications as well as security.

3) HOW WOULD FREEPORTS OPERATE WITH 5G?

The 5G Logistics Freeport use case is aiming to test digital geofencing within the port that will allow real-time goods tracking within the pre-set perimeters. The first step is to enable 5G radio and deploy a virtualised core network that will enable the development of precise location tracking utilising 5G. The 5G network will interconnect sensors that will be installed on goods or in the container to enable real-time condition monitoring of goods. Moreover, sensors will deliver additional security to the transfer of goods, generating automated stock checks via long-range radio frequency identification (RFID). Digital geofencing will play a key role in monitoring goods as well as guaranteeing the path of trucks from different freezones, reassuring a valid transfer and legal compliance. The second application of 5G is the use of drones to conduct regular surveillance around the port area to ensure cargo security and safety.

In our 5G Logistics Freeport use case, a private 5G network is deployed and the cell architecture is depicted in Figure 3. The private network supports access to MEC where port community systems can host local instances, enabling faster data processing and secure cloud communication only when required. Data services would operate much faster and given the use of private network, it provides more granular control compared to direct cloud connections and enhanced security. Moreover, 5G supports real time machine learning such as predictive maintenance to be applied in scale and adaptive to changes. 5G allows the ML models to be hosted on MEC nodes on site reducing complexity and enabling nanosecond latency.

C. SIMULATION RESULTS

To further evaluate the advantage of 5G vis-a-vis 4G, this work conducted a set of simulated experiments using public 4G network and the 5G Smart Internet Lab 5G test bed at authors' institution. In particular an in house sensor emulator developed with the Python programming language was used to emulate devices that transmitted data over a controlled period of time. For each of the experiments a large number of

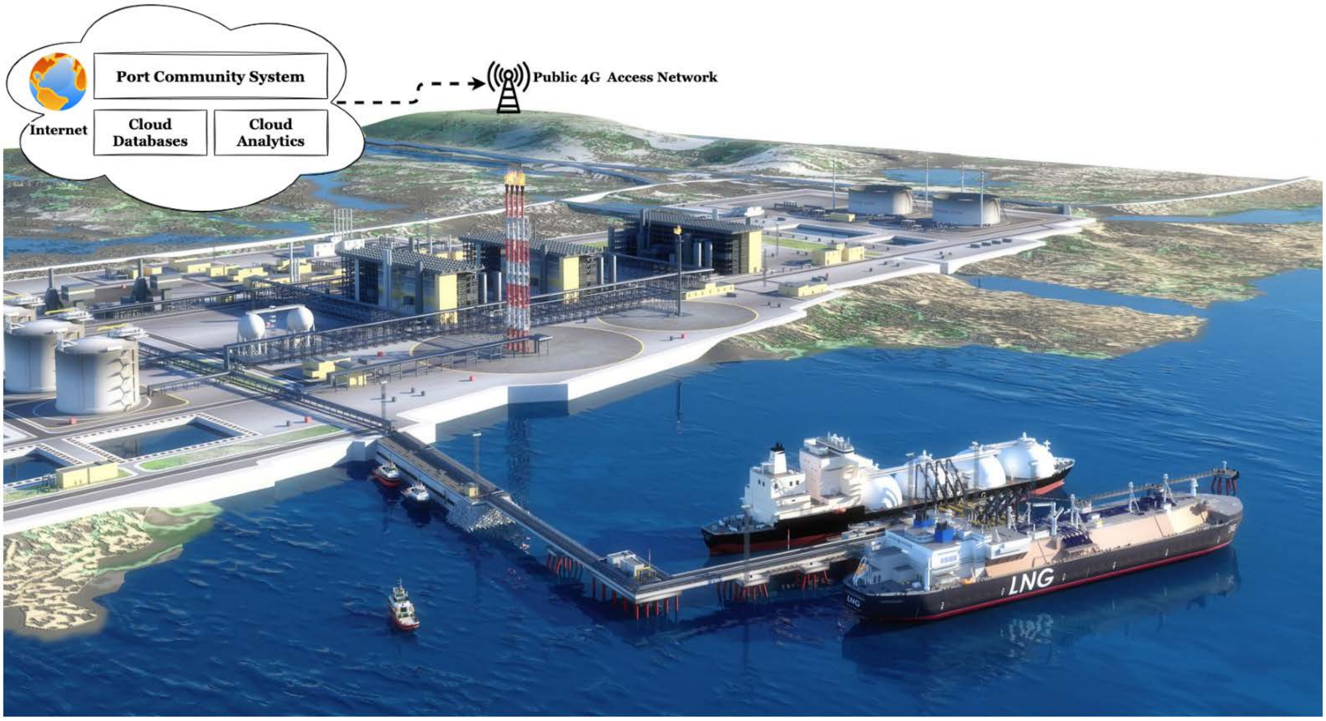


FIGURE 2. Freeport operations over 4G.

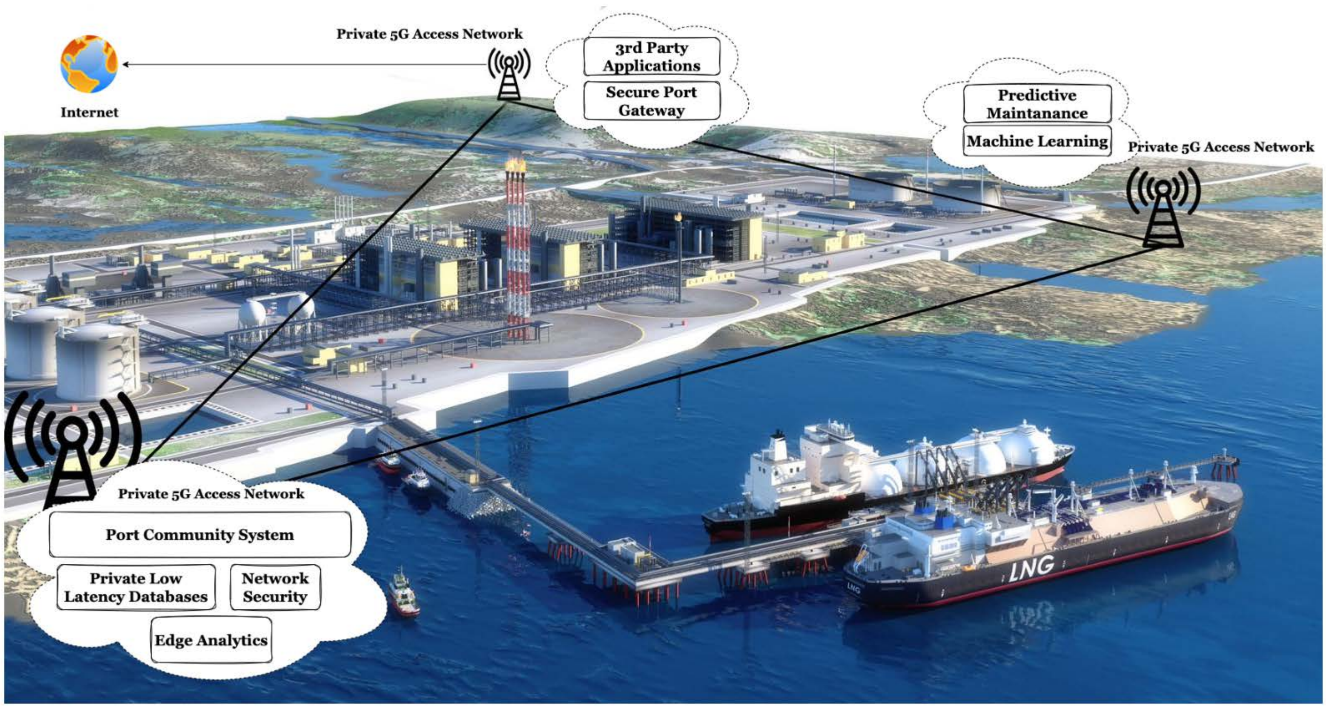


FIGURE 3. Freeport operations over 5G.

emulated devices transmitted data exactly as the transmission operated in the field trials of the project.

For this paper a total of 20 experiments was conducted from which the average value is depicted in the results section. To derive the confidence interval, the replication method with 95% confidence interval was used. Each device is simulated independently and represents IoT sensors communicating with the application collection on the MEC

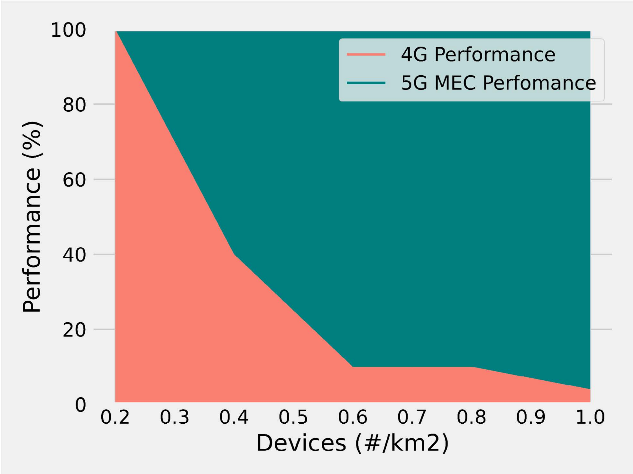


FIGURE 4. IoT service performance when increasing gradually number of devices.

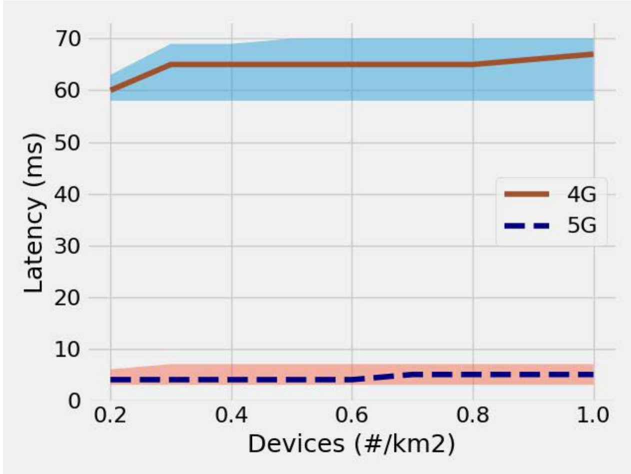


FIGURE 5. Latency per device density 4G vs 5G.

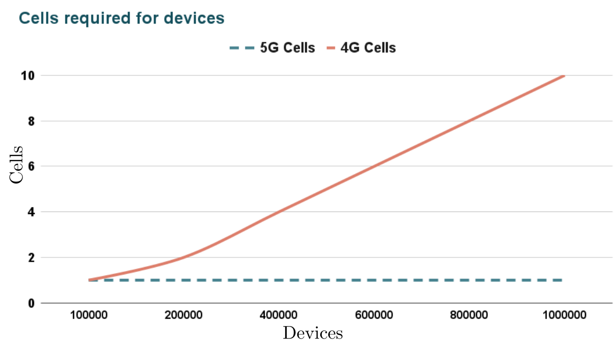


FIGURE 6. Required number of cells when devices reach 1 million per square kilometre (4G vs 5G).

infrastructure. Each device operates independently and their initialisation is parameterised to simulate a power up in the real world. Devices are configured with a particular behaviour and are powered-up as the simulation progresses in time. Each device was transmitting sensor messages including temperature, humidity and emulated location coordinates using HTTPS requests for each of the messages. The connectivity for the emulated devices used a private 5G sim card and a public 4G sim card for all the experiments. The topology of the devices was random and the traffic patterns followed a Poisson distribution with range of 10 to 100 messages per minute.

Figure 4 presents the performance of IoT service in collecting and processing data from sensor devices. In this simulation we increase the number of devices up to 1 million sensors and observe the performance of the IoT service described above. Data loss due to latency and network overload is measured as total packets lost and depicted as performance percentage for each number of total devices. As observed, 4G radio access technology deteriorates significantly when increasing devices and network traffic. In the same environment 5G new radio performs at 100%, even for 1 million devices, meaning that network traffic increase and devices increase does not impact the network performance. For large infrastructures such ports, millions of devices are expected to be deployed as well as other services for example video streaming. Therefore, 4G limitations would not allow efficient scaling for future applications.

In Figure 5 we focus on end to end latency of the 4G and 5G networks, and similarly we simulate sensor devices up to 1 million connections. We observe that the network latency is far lower in the 5G network MEC nodes compared to 4G. This analysis is interesting as time critical applications will require ultra low latency to operate efficiently. If a 4G network is deployed, applications would be limited if the network grows with additional services and devices.

To provide numerical analysis on scalability between 4G and 5G networks, we measure the number of cells required for 1 million devices. Figure 6 highlights the number of cells required for 4G radios and 5G radios, where the difference is depicted clearly. 4G networks would require 10 different cells to accommodate 1 million devices where 5G NR would enable the same amount of devices with just 1 radio. 5G radios are currently more expensive that 4G, however 5G application will become an economically viable solution when the applications and devices of the network increase exponentially and are deployed at large scale.

D. A GENERIC 5G-ENABLED FREEPORT MODEL

The Bristol Port 5G Freeport use case allows us to extract specific learnings and integrate them with the generic Freeport concept discussed in Section II to put forward a generic Freeport model at a more abstract level (as shown in Figure 7 (**A**)). We then overlay 5G technology to highlight several areas where 5G can add value (Figure 7 (**B**)). By this, we hope the proposed model is not just specific to Bristol Port but can be applied to other Free ports who would want to explore the use of 5G in supporting their operations. As discussed in Section II-A, Freeport broadly contains a port itself and several conjunctive secure customs sites (also known as a 'free zone') where businesses can import or export goods inside the UK's land border. Businesses are able to [5]:

- get relief from duties and import taxes
- use simplified declarations processes to reduce administrative burdens
- choose which rate of Customs Duty used if processing the goods changes their classification.

To operate a Freeport customs site, an operator must comply with the conditions of Freeport customs site designation and safety and security standards (see [5] for details). Of those critical conditions, there are several where 5G can add value.

The first critical condition is to ensure the safety and security of the sites and refuse permission of any movement of goods out of the Freeport customs site other than in circumstances permitted by the Freeport customs site legislation. As shown in Figure 7 **(B)**, the use of real-time cargo tracking and geo-fencing (a virtual perimeter for a real-world geographic area) can be set up to track the movement of cargo within the designated areas. Geofences can alert port operators or customs site operators when a vehicle or container is removed from the yard or worksite without authorisation.

The use of RFID tags and sensors installed within a container would allow real-time monitoring of the status of cargo at item level providing essential information about the status of the goods e.g. humidity level, temperature, location and quantity. This (close to) real time visibility is of great value to cargo consignees and consignors when the cargo (such as perishable goods) is sensitive to fluctuating conditions. The need to know where products are, in what condition and when there may be delays or disruptions is critical to supply chains so that risks can be identified, and corrective measures put in place before those risks lead to major losses. Whilst container to container tracking in ocean shipping is relatively mature now, most solutions on the market are unable to accommodate the requirements of goods movement within a Freeport zone. The 5G private network set up in a Freeport can help with the added lags of the journey, from port to yard (customs sites) and onto inland transport (rail or road, if import) or another vessel (if export).

The use of drones for patrol around the port and customs sites will further enhance the onsite security and control of cargo. Real-time video and audio data will be transmitted via the 5G network to the control room, where analytics can be used to detect abnormalities such as an incorrect truck picking up a container. This will reduce the need for regular human patrol onsite, leading to cost reductions and improved responsiveness. The drones are able to perform key tasks around the port such as inspecting infrastructure, surveillance and monitoring, incident management, berth management and the detection of emergency situations e.g. fire and rescues. Routine system inspections could ensure consistent operational integrity and access to hard-to-reach areas. Given the large surface area of a port, drones provide clear benefits when carrying out those activities, resulting in improved situational awareness and a potential reduction in the number of work accidents. The large volume of video and location data generated by drones requires a very high bandwidth and low latency for real-time data transmission, making a 5G private network the ideal solution.

The second critical condition is for a Freeport customs site operator to keep a detailed record of each consignment arriving at and leaving the site as well as moving from temporary storage, or between different customs sites. A comprehensive description of what information needs to be recorded is given in Appendix A.

Businesses authorised to use the Freeport customs site are required to declare goods brought into and removed from a customs site, also goods moved between different customs sites, and moved within the same customs site. Processed or repaired goods need to be disposed of. Again, a complex list of information is required to be submitted to UK's HM Revenue & Customs. Core to the information required by the government and related port and supply chain stakeholders is the real-time tracking and recording of the goods moved in, out and within the Freeport. This calls for the right digital infrastructure that could enable the efficient capturing and integrating of the large volume of required data into various information systems/applications whist ensuring data integrity and speed.

Given the large volume of data being handled, manual data capture will not be a sensible option – it is time consuming, slow and prone to entry errors. Instead, automated data capture can help to streamline complex workflows in a Freeport and accommodate much higher data volumes with speed and accuracy. Therefore, the integrative use of IoT devices/sensors (such as RFID) (for data capturing), 5G private network (for data transmission and processing) and machine learning (for data analytics) will help a Freeport and its community members to build the much-needed digital capability. The speed of information flow and the insights generated by advanced data analytics would allow decisions to be made quicker, hence dictating the faster physical flow of goods. This in turn will help to build an agile supply chain with enhanced visibility that can quickly match supply with demand.

E. A TECHNICAL PERSPECTIVE ON HOW 5G SUPPORTS THE CORE ACTIVITIES IN A FREEPORT

Table 3 below summarises the key areas where 5G would support a Freeport and utilises four key attributes of the big data concept, namely volume, variety, velocity and veracity, known as the 4Vs, to highlight how value can be created in the case of a Freeport.

1) LOCATION REQUEST

In terms of location request to support geofencing and asset tracking requirements of freeports, 5G provides clear advantages over 4G and Wi-Fi by providing accuracy of location, reliability, and lower latency data transmission that this use scenario demands. A 5G network is more deterministic, which differs from more mature, statistical multiplexed,

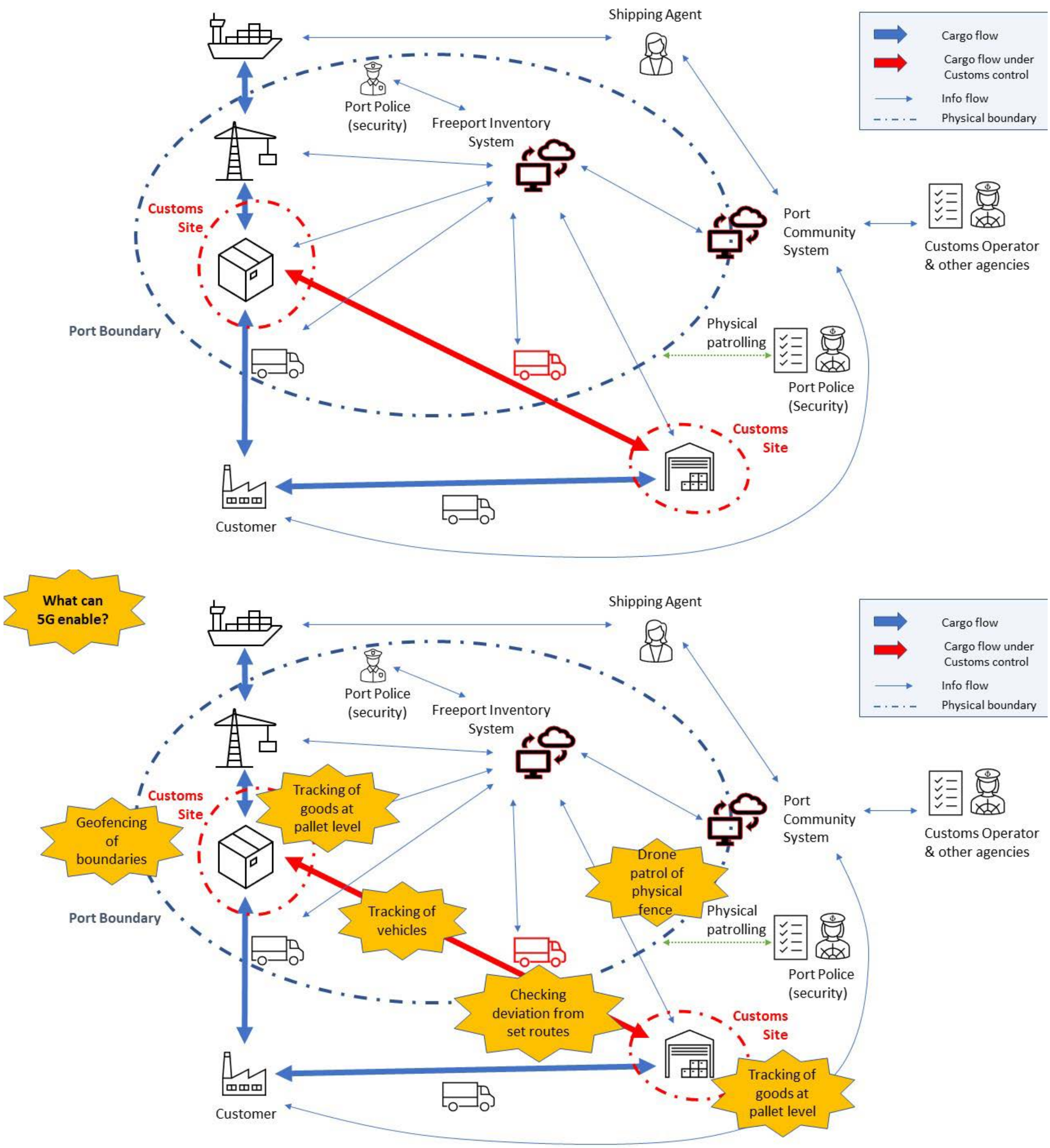


FIGURE 7. Top (A) A generic Freeport model, Bottom (B) A generic 5G-enabled Freeport model.

data networks which do not offer delivery guarantees and often experience loss and significant variable latencies due to congestion. To maintain the integrity of freeports as well as deal with the increased complexity of the additional logistics and value adding manufacturing activities, 5G can offer an on-premises location tracking service, with a significantly improved accuracy of location coordinates up to 20 to 1 (moving from meters to centimeters), if compared to the

TABLE 3. Summary of value creation by 5G in the case of a Freeport.

Activity	What happens now (4G etc.)	How does 5G enhance this?	Impact on 4Vs (added value)				Implications for Freeport
			Volume	Variety	Velocity	Veracity	How this improves Use cases
Location request	Devices self-report their location information to cloud computing infrastructure (stochastic)	5G Core functionality can request information dynamically from UEs (deterministic)	Application Driven, Scalable	The 5G core can adapt the update interval per UE allowing dynamic information gathering based on schemas.	Having functionality implemented at the MEC allows fast, hardware accelerated decision making	Deterministic latency, jitter and increase in location prediction. Subsequent increase in accuracy from 5G 3GPP release 16 onwards	UK gov requests a Freeport to have a safe and secure control and monitoring of goods movement in, out and within a Freeport zone. See section IV-D
On-site machine to machine services	Bespoke hardware and software based on precompiled libraries targeting ageing and discontinued operating systems	Cloud native architecture utilising virtualisation and containerisation architectures supporting different host operating system and hardware architectures	Scalable, Multi-tenancy provisioning	Different software vendors can share resources	Multitenancy network characteristics allow different priorities on applications	Allows true interoperability based on standards such as RFCs(Request for Comments) and 3GPPP which ensures compatibility even in continuous integration situations	Connects the different information flows as depicted in Figure 1 the current state map of the Bristol Port operations
Multiplanar and multilayers communication and security	Systems are separated between isolated islands with occasional internet-based endpoints and cloud service providers	Private networks and Cloud computing allows greater interaction between the entities. Private 5G networks offer the best possible network security today.	Customisable, secure by design	Multiplanar and multilayer hardened network architectures harnessing the power of virtualisation	Services and network can coexist on large servers providing remarkably high bandwidth	Trusted architecture utilised in large IP protocol-based datacentres that migrates into 5G core	Enhances the capabilities of the onsite private network, including interfacing with 3rd Parties outside the network.

current GPS tracking technology, and a more granular geofence definition. The improved location tracking would enable a faster detection of any deviation of goods from a designated route/area. An estimate would be less than 500ms, whilst current 4G detection time is at around 2 seconds.

Location tracking by the 5G network is specified by 3GPP in a technical standard [53]. By examining the signalling between a 5G New Radio Standalone (NR SA) Core and user equipment (UE) during the initial call setup, we observed the capabilities for location tracking as advertised by the user equipment. The signalling is based on the NGAP protocol [54] and Wireshark was used to extract the UE capabilities in relation to the [53] technical standard. For the UE modem used in the experimentation the 5GS Mobility Management (5GMM) LTE positioning protocol (LPP) capability was not present even with changes to the Modem using AT set commands. Newer modems with an updated NAS version [55] support are expected to provide this capability.

2) ON-SITE MACHINE TO MACHINE COMMUNICATIONS

5G will support and orchestrate the convergence of vertical applications onto a single common wireless network. this is expected to be accomplished through advances in network function virtualisation and software defined networking, allowing the flexible usage and configuration of network functions to enable use cases with very diverse requirements.

It is not straight forward to capitalise on the 5G location tracking capabilities if deployed in isolation. More value can be created if the tracking solution is used in combination with other technologies, for instance, with Wireless Sensor Networks and real time Machine Learning (ML). The network slicing function (one of the unique advantages of 5G) could allow a specific network configuration that is dedicated to support Machine to Machine (M2M) communications between IoT sensors. This, in turn, allows advanced concepts such as total predictive maintenance, condition and security monitoring and auto alerts. Condition monitoring uses 5G cellular- connected sensors to monitor the condition of port assets such as cranes, containers and AGVs through factors like vibration and temperature [30]. Typically, a condition monitoring software will then detect any abnormalities, while also determining when an asset is in need of maintenance, therefore reducing potential incidents and downtime. For condition monitoring, the network needs to be able to manage high connection density and transfer data in real-time with extremely high reliability, making 5G ideally suited for the scenario.

3) MULTIPLANAR AND MULTILAYER COMMUNICATION AND SECURITY

Data originating from user equipment (UE) can be transmitted over the multi-cell 5G New Radio (NR) network to reach the MEC platform and subsequently the MEC services. Traditionally, the UE modem provides Internet Protocol (IP) connectivity to different data producers and forwards the traffic over the radio. MEC processes data close to where it is generated and consumed. This enables the network to deliver ultra-low latency required by port-critical applications, such as the deployment of drone in our use case, or automated crane control as discussed in Table 1, Section II-B.

By processing data locally, MEC applications can reduce data transfer cost significantly and improve data security.

V. CONCLUSION

Currently and to the best of our knowledge the use of 5G as a key enabling digital infrastructure to support the Freeport concept is rare. In this paper, we provide an overview of existing use cases of 5G in ports through a review of literature. We then explore in depth how 5G may be deployed to support a particular use case i.e. the Freeport concept using Bristol Port as an exemplar for the UK sector.

Our simulation results show that 5G has clear advantages in supporting large number of IoT devices and sensors for real time tracking of cargo, as well as the use of drones for port surveillance. While 5G NR Radio simulations in the literature evaluate the overall standardisation compliance [56], connectivity state [57], mobility support [58] and positioning [59], these fall within the RAN network. The novel technical contribution introduced in the current work focuses on the use case delivery on an end-to-end network. Rather than evaluating End to End RAN simulations as in [60], we have opted to evaluate the OSI Layer 3 and 4 KPIs against our applications' requirements. We emphasise the roadmap of harmonisation of ETSI MEC standard with 3GPPP RAN and Core networking with MEC applications [61].

The business contribution of the paper is the development of a conceptual framework that depicts a generic Freeport model underpinned by 5G technology. The framework is based on the early findings from a UK government funded 5G testbed and secondary 5G use cases from both practice and academia. The current state of Bristol port was established which forms the basis for the conceptual articulation of the 5G enabled Freeport concept. Following this, a generic 5G-enabled Freeport model was developed, outlining the underlying technical protocol and process configurations.

Our early findings from this Freeport use case demonstrate that 5G has great potential to support the operation of a Freeport by **a.**) providing an ultra- fast connection for real time goods tracking and monitoring for safety and security. **b.**) enabling a new level of automation through data exchange and information transfer between government authorities, port operators, customs site operators, businesses operating within customs sites as well as other supply chain stakeholders. Our research is one of the early academic studies that offer valuable insights into the application and potential impact of 5G on port operations and its implications for Freeports. Our research also has important policy implications, given the UK government's recent announcement and roll-out of eight Freeports across the UK [22].

However, our research has limitations. We only reported preliminary technical results in this paper. Though these results are indicative of clear benefits by the deployment of 5G, we are running further field experiments and those results and full impact on Freeport operation will be reported later. The proposed generic 5G enabled Freeport model needs to be validated by future studies. We should also note that deploying 5G is not without challenges. Those range from regulatory barriers such as spectrum allocations, infrastructure investment cost vs performance issues, cyber security concerns, devices limitations, to cross- industry collaboration and skill challenges. Moreover, although opportunities are clear, value creation needs to be systematically captured and analysed to evidence the true potential of 5G technology in support the Freeport concept and more generally the port's digital transformation. Our future work will focus on these aspects.

APPENDIX A RECORDS A CUSTOMS SITE OPERATOR NEEDS TO KEEP

Source: HM Revenue & Customs [62]

A. GOODS ARRIVING AT YOUR FREEPORT CUSTOMS SITE

For each consignment you will need to keep the following:

- air waybill number or shipping number
- the customs procedure the goods have been placed under
- the date and details of any customs formalities
- details of any electronic import or export declarations - the date and time the goods arrived at the business in the site
- unique commercial identification references
- number and kind of packages
- the quantity and usual commercial or technical description of the goods
- the identification marks of the container to identify the goods and weights (gross and net)
- registration number of vehicles carrying goods to the Freeport customs site
- the details of the business in the Freeport customs site where goods have been received

The person receiving the goods must notify you that the goods have arrived, where they are:

- brought into a Freeport customs site to be declared by conduct to the Freeport customs special procedure
- under the Freeport customs special procedure that have been transferred to another business in the same Freeport customs site

Your records will need to show that this notification has taken place, and you will need to keep a copy of the information sent in that notification, and the time and date that it was received.

B. GOODS LEAVING YOUR FREEPORT CUSTOMS SITE

You must not allow goods to leave your Freeport customs site unless you have been provided with a notification and evidence to show that the goods meet the following conditions:

- they have been declared to:
  - inward processing
  - authorised use
  - transit
  - temporary admission

  - customs warehousing and moved to a place outside of the Freeport customs site (where it is covered by the customs special procedure authorisation)
- they have been declared to the Freeport customs special procedure but are to be moved directly to:
  - a place from where they are exported
  - a customs office for the purposes of discharging the Freeport customs special procedure
  - a location in Northern Ireland
  - an authorised business in another Freeport customs site
- they are domestic (including where HMRC has accepted a declaration to say the goods have moved into free circulation even if the goods are in the Freeport customs site)
- they can be removed in accordance with an authorisation by HMRC and will be moved in accordance with that authorisation

The evidence can include:

- an original (or faxed copy) of an authenticated removal note, which will be one of the following:
  - a C130
  - a system generated release note/message
- release by another, approved electronic message format (for example SMS text message)
- relevant customs paperwork (including things like proof of cleared declarations and customs special procedure authorisations)
- relevant commercial documentation that cover:
  - the destination of the goods
  - the reason for moving the goods outside the Freeport customs site

The notification must be made by a business who is authorised to operate in a Freeport customs site, or someone acting on behalf of them.

Your records will need to include the:

- notification and evidence provided to you
- time and date of the notification
- details of the business it relates to

If someone is dealing with customs for them, you must include their details in your records as well.

Your records must include details about any goods leaving your Freeport customs site, even if they do not meet the relevant conditions [62].

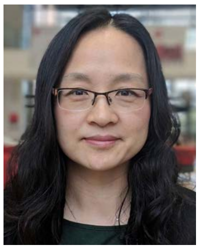
ACKNOWLEDGMENT

This research was created as part of the 5G Logistics project funded by UK's Department for Digital, Culture, Media & Sport (DCMS) under its 5G Testbeds and Trials Programme. The project is led by the West of England Combined Authority with 12 partners, including the authors' institutions and aims to demonstrate how private 5G networks can increase efficiency and productivity in the logistics sector.

REFERENCES

[1] M. Shafi, A. F. Molisch, P. J. Smith, T. Haustein, P. Zhu, P. De Silva, F. Tufvesson, A. Benjebbour, and G. Wunder, "5G: A tutorial overview of standards, trials, challenges, deployment, and practice," *IEEE J. Sel. Areas Commun.*, vol. 35, no. 6, pp. 1201–1221, Jun. 2017.
[2] K.-L. A. Yau, S. Peng, J. Qadir, Y.-C. Low, and M. H. Ling, "Towards smart port infrastructures: Enhancing port activities using information and communications technology," *IEEE Access*, vol. 8, pp. 83387–83404, 2020.
[3] A. Casaca and P. Marlow, "Fourth generation ports—A question of agility?" *Int. J. Phys. Distrib. Logistics Manag.*, vol. 33, pp. 355–376, May 2003.
[4] HR Treasury. (Oct. 2020). *Government Outlines New Plans for Freeports to Turbo-Charge Post-Brexit Trade*. [Online]. Available: https://www.gov.uk/government/news/government-outlines-newplans-for-freeports-to-turbo-charge-post-brexit-trade
[5] HR Customs. (Oct. 2021). *Get Your Business Ready to Use a Freeport Customs Site*. [Online]. Available: https://www.gov.uk/guidance/getyour-business-ready-to-use-a-freeport-customs-site
[6] D. Webb and I. Jozepa. (Dec. 2021). *UK Government Policy on Freeports*. [Online]. Available: https://www.gov.uk/government/publications/freeports-monitoring-and-evaluation-strategy/freeports-programmemonitoring- and-evaluation-strategy
[7] I. Serwicka and P. Holmes. (2019). *What is the Extra Mileage in the Reintroduction of 'Free Zones' in the UK? UK Trade Policy Observatory*. [Online]. Available: https://blogs.sussex.ac.uk/uktpo/publications/whatis-the-extra-mileage-in-the-reintroduction-of-free-zones-in-the-uk/
[8] (2020). *Freeports and Wales: Second Report of Session 2019–21*. [Online]. Available: https://publications.parliament.uk/pa/cm5801/cmselect/cmwelaf/205/20502.htm
[9] Matthew Ward. (Dec. 2021). *The Establishment of Free Ports in the UK*. [Online]. Available: https://commonslibrary.parliament.uk/research-briefings/cdp-2018-0211/
[10] A. Lavissière, L. Fedi, and A. Cheaitou, "A modern concept of free ports in the 21st century: A definition towards a supply chain added value," *Supply Chain Forum, Int. J.*, vol. 15, no. 3, pp. 22–28, 2014, doi: 10.1080/16258312.2014.11517348.
[11] A. Branch, *Elements of Port Operation and Management*. Berlin, Germany: Springer, 2012.
[12] S. A. Anderson, "Location factor in the choice of free port sites," *Econ. Geography*, vol. 10, no. 2, pp. 147–159, 1934. [Online]. Available: http://www.jstor.org/stable/140114
[13] J. Chen, Z. Wan, F. Zhang, N.-K. Park, A. Zheng, and J. Zhao, "Evaluation and comparison of the development performances of typical free trade port zones in China," *Transp. Res. A, Policy Pract.*, vol. 118, pp. 506–526, Dec. 2018. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0965856418305901
[14] R.-H. Chiu, T.-C. Lirn, C.-Y. Li, B.-Y. Lu, and K.-C. Shang, "An evaluation of free trade port zone in Taiwan," *Asian J. Shipping Logistics*, vol. 27, no. 3, pp. 423–445, 2011. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2092521211800209
[15] B. Hoyle, "Port concentration, inter-port competition and revitalization: The case of Mombasa, Kenya," *Maritime Policy Manag.*, vol. 26, no. 2, pp. 161–174, 1999, doi: 10.1080/030888399286989.
[16] R. Tomkins, "Freeports fail to see their ships come in," Financial Times, Dec. 30, 1988, p. 4.
[17] C. Barnard, A. Menon, J. Portes, and H. Whelen. (Mar. 2021). *Freeports*. [Online]. Available: https://ukandeu.ac.uk/research-papers/freeports/
[18] J. G. Andrews, S. Buzzi, W. Choi, S. V. Hanly, A. Lozano, A. C. Soong, and J. C. Zhang, "What will 5G be?" *IEEE J. Sel. Areas Commun.*, vol. 32, no. 6, pp. 1065–1082, Jun. 2014.
[19] S. S. Hussain, S. M. Yaseen, and K. Barman, "An overview of massive MIMO system in 5G," *IJCTA*, vol. 9, no. 11, 2016, pp. 1–12.
[20] DHL. (2020). *Next-Generation Wireless in Logistics Trend Report*. [Online]. Available: https://www.dhl.com/global-en/home/insightsand-innovation/thought-leadership/trend-reports/next-generationwireless.html
[21] *Generations of Mobile Systems*. Accessed: Mar. 21, 2021. [Online]. Available: https://www.3gpp.org/about-3gpp/about-3gpp
[22] Department for Digital. (Dec. 2020). *Factsheet 6: 5G*. [Online]. Available: https://www.gov.uk/government/publications/telecommunicationssecurity-bill-factsheets/factsheet-6-5g
[23] H. Galal and D. O'Halloran, "The impact of 5G: Creating new value across industries and society," World Economic Forum, 2020. Accessed: May 2, 2021. [Online]. Available: https://www.weforum.org/whitepapers/the-impact-of-5g-creating-new-value-across-industries-and-society/

[24] International Telecommunication Union (ITU). (2018). *Setting the Scene for 5G: Opportunities and Challenges*. Accessed: Mar. 2, 2020. [Online]. Available: http://handle.itu.int/11.1002/pub/811d7a5f-en
[25] *Global Future Council on New Network Technologies 5G: Society's Essential Innovation Technology*. Accessed: May 2, 2021. [Online]. Available: https://www.weforum.org/reports/global-future-council-on-newnetwork-technologies-5g-society-s-essential-innovation-technology
[26] F. Grijpink, T. Härlin, H. Lung, and A. Ménard, *Cutting Through the 5G Hype: Survey Shows Telcos Nuanced Views*. Atlanta, GA, USA: McKinsey, 2019.
[27] S. Berns, R. Dickson, I. Vonck, and J. Dragt, *Smart Ports, Point of View*. London, U.K.: Deloitte, 2017.
[28] *5G Innovation Put to a Practical Use in the Port of Zeebrugge*. Accessed: May 2, 2021. [Online]. Available: https://portofzeebrugge.be/en/news-events/5g-innovation-putpractical-use-port-zeebrugge
[29] J. O'Halloran. (Oct. 2020). *Orange Belgium Reveals First 5G Innovations in Port of Antwerp*. [Online]. Available: https://www.computerweekly.com/news/252490968/Orange-Belgium-reveals-first-5G-innovations-in-Port-of-Antwerp
[30] (2021). *Connected Port*. [Online]. Available: https://www.ericsson.com/en/news/2021/2/connected-ports-report
[31] (2018). *New Communication Standard: 5G Industrial Environment Trial Platform Launched in the Port of Hamburg*. [Online]. Available: https://www.hafen-hamburg.de/en/news/new-communicationstandard-5g-industrial-environment-trial-platform-launched-in-the-portof-hamburg—35629
[32] (2020). *The 5G Port of the Future*. [Online]. Available: https://www.ericsson.com/en/blog/2020/7/the-5g-port-of-the-future
[33] J. Donnelly. (2019). *European Port Tests 5G Solution*. Accessed: Mar. 2, 2020. [Online]. Available: https://www.porttechnology.org/news/european-port-tests-5g-solution/
[34] (May 2021). *Busan Port Authority to Integrate 5G-Enabled Computing Into Yard Operations*. [Online]. Available: https://www.porttechnology.org/news/busan-port-authorityto-integrate-5g-enabled-computing-into-yard-operations/
[35] (2021). *Port of Felixstowe Selected for UK Government 5G Trial*. [Online]. Available: https://www.portoffelixstowe.co.uk/press/news-archive/portof-felixstowe-selected-for-uk-government-5g-trial/
[36] (2021). *5G Logistics—West of England Combined Authority*. [Online]. Available: https://www.westofengland-ca.gov.uk/what-we-do/innovation/5g-logistics/
[37] R. Cardone. (2020). *The 5G Port of the Future*.[Online]. Available: https://www.ericsson.com/en/blog/2020/7/the-5g-port-of-the-future
[38] N. Cross, "Designerly ways of knowing: Design discipline versus design science," in *Design Issues*. Cambridge, MA, USA: MIT Press, 2001, pp. 49–55.
[39] I. Jacobson, *Object-Oriented Software Engineering: A Use Case Driven Approach*. London, U.K.: Pearson, 1993.
[40] K. Bittner and I. Spence, *Use Case Modeling*. Boston, MA, USA: Addison-Wesley, 2003.
[41] B. Williams and R. Hummelbrunner, "Soft systems methodology," in *Systems Concepts in Action*. Redwood, CA, USA: Stanford Univ. Press, 2020, pp. 241–261.
[42] I. Jacobson, I. Spence, and B. Kerr, "Use-case 2.0: The hub of software development," *Queue*, vol. 14, no. 1, pp. 94–123, 2016.
[43] I. Jacobson, M. Ericsson, and A. Jacobson, *The Object Advantage: Business Process Reengineering With Object Technology*. Boston, MA, USA: Addison-Wesley, 1994.
[44] M. M. Naim, P. Childerhouse, S. M. Disney, and D. R. Towill, "A supply chain diagnostic methodology: Determining the vector of change," *Comput. Ind. Eng.*, vol. 43, nos. 1–2, pp. 135–157, 2002.
[45] Y. Wang, A. Potter, and M. Naim, "Electronic marketplaces for tailored logistics," *Ind. Manag. Data Syst.*, vol. 107, no. 8, pp. 1170–1187, 2007.
[46] J. R. Dixon, "On research methodology towards a scientific theory of engineering design," *AI Edam*, vol. 1, no. 3, pp. 145–157, 1987.
[47] H.-S. Roh, C. S. Lalwani, and M. M. Naim, "Modelling a port logistics process using the structured analysis and design technique," *Int. J. Logistics Res. Appl.*, vol. 10, no. 3, pp. 283–302, 2007.
[48] M. Wazid, A. K. Das, N. Kumar, A. V. Vasilakos, and J. J. P. C. Rodrigues, "Design and analysis of secure lightweight remote user authentication and key agreement scheme in internet of drones deployment," *IEEE Internet Things J.*, vol. 6, no. 2, pp. 3572–3584, Apr. 2019.
[49] J. Zhang, J. Hu, J. Lian, Z. Fan, X. Ouyang, and W. Ye, "Seeing the forest from drones: Testing the potential of lightweight drones as a tool for long-term forest monitoring," *Biol. Conservation*, vol. 198, pp. 60–69, Jun. 2016. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0006320716301100
[50] B. Mishra, D. Garg, P. Narang, and V. Mishra, "Drone-surveillance for search and rescue in natural disaster," *Comput. Commun.*, vol. 156, pp. 1–10, Mar. 2020.
[51] J. Hwang, L. Nkenyereye, N. Sung, J. Kim, and J. Song, "IoT service slicing and task offloading for edge computing," *IEEE Internet Things J.*, vol. 8, no. 14, pp. 11526–11547, Jul. 2021.
[52] D. Sabella, A. Vaillant, P. Kuure, U. Rauschenbach, and F. Giust, "Mobile-edge computing architecture: The role of MEC in the Internet of Things," *IEEE Consum. Electron. Mag.*, vol. 5, no. 4, pp. 84–91, Oct. 2016.
[53] *5G; 5G System; Access and Mobility Management Services; Stage 3*, document TS 29.518, Version 16.9.0, Release 16, 3GPP, 2022.
[54] *NG-RAN; NG Application Protocol (NGAP)*, document TS 38.413, Version 16.9.0, Release 16, 3GPP, 2022.
[55] *Non-Access-Stratum (NAS) Protocol for 5G System (5GS); Stage 3*, document TS 24.501 Version, 16.10.0 Release 16, 3GPP, 2021.
[56] *NR; NR and NG-RAN Overall Description; Stage 2*, document TS 38.300, Version 16.9.0, Release 16, 3GPP, 2022.
[57] *NR; Radio Resource Control (RRC); Protocol Specification*, document TS 38.331, Version 16.9.0, Release 16, 3GPP, 2022.
[58] *NG Radio Access Network (NG-RAN); Xn Application Protocol (XnAP)*, document TS 38.423 Version 16.10.0, Release 16, 3GPP, 2022.
[59] *NG Radio Access Network (NG-RAN); Stage 2 Functional Specification of User Equipment (UE) Positioning in NG-RAN*, document TS 38.305, Version 16.7.0, Release 16, 3GPP, 2021.
[60] N. Patriciello, S. Lagen, B. Bojovic, and L. Giupponi, "An E2E simulator for 5G NR networks," *Simul. Model. Pract. Theory*, vol. 96, Nov. 2019, Art. no. 101933. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1569190X19300589
[61] ETSI. (2020). *Harmonizing Standards for Edge Computing, a Synergized Architecture Leveraging ETSI ISG MEC and 3GPP Specifications*. Accessed: Feb. 1, 2022. [Online]. Available: https://www.etsi.org/newsroom/news/1806-2020-07-new-etsi-white-paper-harmonizing-standards-for-edge-computing-a-synergized-architecture-leveraging-etsi-isg-mec-and-3gpp-specifications
[62] (Sep. 2021). *Operating a Freeport Customs Site*. [Online]. Available: https://www.gov.uk/guidance/operating-a-freeport-customs-site



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