

SMART PORT WHITE PAPER

2019 SMART PORT





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Introduction

Ports play an important role in promoting international trade and regional development. Operational efficiency is crucial for ports, given that about 90% of global trade relies on maritime transportation. Industry 4.0 and Internet Plus drive ports to transform and upgrade to digital, automated, and smart operation. With 5G, Huawei and Shanghai Zhenhua Heavy Industries Company (ZPMC) will team up with global leading telcos to promote this transformation and upgrade to build efficient and environment-friendly smart ports.

Smart ports require communications systems to support low latency, high bandwidth, and high reliability communication services in order to handle control data and multi-channel video data of port equipment. With legacy communication based on optical fiber and Wi-Fi, network deployment, operation and maintenance are costly and network performance for such data handling is often suboptimal with poor stability and low reliability. 5G is expected to address such challenges thanks to its low latency, large bandwidth and capacity, and high reliability as well as its support for private network solutions and end-to-end (E2E) application performance guarantee .

1. Trends

1.1 Global Development

As listed in table 1, in 2018, the container throughput of the world's top 20 ports reached in total 340 million twenty-foot equivalent units (TEUs), an average growth of 3.23% compared with 2017.

Table 1 Container throughput of the world's top 20 ports in 2018 (1,000,000 TEUs)

Ranking	Port	Country	Year		Growth (%)
			2018	2017	
1	Shanghai	China	42.01	40.23	4.42
2	Singapore	Singapore	36.60	33.67	8.70
3	Ningbo Zhoushan	China	26.35	24.61	7.07
4	Shenzhen	China	25.74	25.21	2.10
5	Guangzhou	China	21.92	20.37	7.61
6	Busan	South Korea	21.59	20.49	5.38
7	Hong Kong	China	19.59	20.77	-5.68
8	Qingdao	China	19.30	18.30	5.46
9	Tianjin	China	16.00	15.07	6.17
10	Dubai	UAE	14.95	15.40	-2.90
11	Rotterdam	Netherlands	14.51	13.73	5.68
12	Klang	Malaysia	12.03	11.98	0.42
13	Antwerp	Belgium	11.10	10.45	6.22
14	Xiamen	China	10.70	10.38	3.08
15	Kaohsiung	China	10.45	10.27	1.71
16	Dalian	China	9.77	9.71	0.58
17	Los Angeles	US	9.46	9.34	1.27
18	Tanjung Pelepas	Malaysia	8.79	8.26	6.39
19	Hamburg	Germany	8.73	8.80	-0.80
20	Laem Chabang	Thailand	7.96	7.78	2.51

Data Resource:Alphaliner

1.2 Autonomous and Intelligent Port

Ports around the world face common challenges of increasing labor costs, heavy labor intensity, harsh working environments, and insufficient personnel. Reducing costs and improving efficiency through automation have become the industry's overarching goals. Digital innovations and artificial intelligence (AI), big data, Internet of Things (IoT), 5G, and autonomous driving provide new impetus for port automation. Higher-level automation has been used for container terminals to improve productivity and efficiency and ensure competitiveness. According to data from the International Maritime Information website:

- Nearly 75% of port operators believed that automation is critical in order to maintain competitiveness in the next three to five years.
- 65% of port operators view automation as a lever for operation security.
- Respondents were optimistic about the overall return on investment. About one third thought that automation could increase productivity by 50%, while about one in five said automation could reduce operating costs by more than 50%.

At present, there are dozens of automated container ports worldwide. As the shipping throughput increases year by year, global ports are undergoing reconstruction to achieve higher automation level.

1.3 Transformation and Innovation of Modern Ports

Under the background that global ports are moving towards 5G and gradually accelerating the upgrade and innovation, the intelligentization and informatization construction of ports are regarded as an important means to improve the core competitiveness of ports. It is also the key to reducing logistics costs and improving logistics efficiency. In this context, many ports have tried to apply information technologies such as IoT, big data, cloud computing, and geographic information system (GIS) to port operation. Some automated ports have been put into operation.

ZPMC cooperated with COSCO Shipping Ports Limited in 2012 to commercialize Xiamen Automated Port in March 2016. In this case, container throughput was significantly boosted while zero accident was recorded.

ZPMC has applied the world's leading intelligent control system and world-class full automation technology equipment to Qingdao Autonomous Port. In this case, operation manpower is reduced by about 85%, and operation efficiency was increased by 30%. The designed operation efficiency is to reach 40 natural containers per hour, which is with the highest automation level and the highest cargo handling efficiency globally by far.

The world's largest and most technologically advanced Yangshan Port is the first to use automated equipment and control systems including automated guided vehicles (AGVs). In this case, automated operation supports the port to have the world's largest container throughput for seven consecutive years.

Transformation and innovation have become the inevitable trend of the world's major ports. The port industry has reached the consensus that ports are transforming from the mechanical era into the era of AI, when AI enables ports to become smarter.

2. Industry Opportunities and Challenges

2.1 Overall Port Operation Process



Taking cargo unloading as an example, the port operation process mainly includes:

- 1. In the cargo handling area, quayside container cranes move containers from vessels to horizontal transportation means such as AGVs, inner container trucks, and straddle carriers.
- 2. Horizontal transportation means move containers from quayside container cranes in the cargo handling area to the container yard. Gantry cranes remove containers from horizontal transportation means and place them in the container yard.
- 3. Outer container trucks enter through gateways to the container yard. Gantry cranes in the container yard load containers onto outer container trucks, which exit through gateways and carry containers to destinations.

Efficiency is the lynchpin of the port industry which requires year-round 24/7 uninterrupted operations. The rental of a large vessel is costly and billed on a daily basis, and merely one hour of waiting or extra operation means wasting tens of thousands of euros and even entailing customer loss. Low cargo transfer efficiency will cause direct economic loss to ports and cargo owners. Cargo overstock for a liner for just one day means a loss of hundreds of thousands or even millions of euros. For this reason, improving cargo transfer efficiency is a core service requirement for ports. Cargo transfer is mostly performed in container yards and quayside container crane areas. Remote control of vertical transportation means and unmanned driving of horizontal transportation means are the main scenarios where wireless communications can apply.

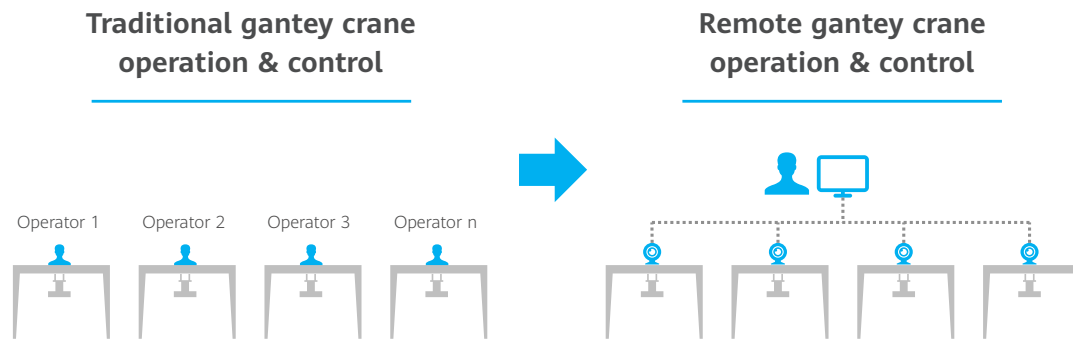
2.2 Typical Smart Port Service Scenario Analysis

Based on comprehensive surveys, discussions, and analysis with port industry partners, four typical smart port scenarios are identified that have requirements for wireless communications and can be enabled by 5G in the future:

- Remote control of gantry cranes
- Remote control of quayside container cranes
- Cross-vehicle control of IGVs
- Video surveillance and AI recognition

2.2.1 Remote Control of Gantry Cranes

In container terminals, rail-mounted gantry (RMG) cranes and rubber-tyred gantry (RTG) cranes are the most widely used types of gantry cranes. An RMG crane moves on tracks in a container yard, while an RTG crane is equipped with tires and can flexibly move containers across yards. At present, RTG cranes are more widely used and account for a high proportion in existing terminals, whereas RMG cranes are popular in new terminals. A gantry crane is about 30 meters high and the operator's cab is at the top of the gantry crane.



Restructuring in favor of remote control has seen demand for traditional gantry cranes to address the high demand for manual labor. Gantry crane operators work in cabs some 30 meters high where the conditions are difficult, and site operation can easily lead to fatigue which is a safety hazard. In order to ensure 24-hour uninterrupted operation, each gantry crane is attended in rotation by three operators, which translates into hundreds of gantry crane operators per container terminal. With remote control, cameras and programmable logic controllers (PLCs) are installed on gantry cranes so the operator can complete gantry crane operations (such as precise movement of cranes or lifting appliances and container pickup) remotely from the central control room through video surveillance. One operator can control three to six gantry cranes while working in a favorable environment, greatly reducing labor costs and improving operational security.

A single gantry crane needs to upload 5–16 channels of surveillance videos, and 1080p videos require a bandwidth of about 30 Mbps. In addition, PLC communications between the central control room and a gantry crane require a network latency of less than 30 ms. In a typical scenario, about 60 gantry cranes are deployed within a 1 km² area.

In this scenario, 5G can provide high bandwidth and low latency to sufficiently support video upload and reliable PLC communications for the remote control of gantry cranes, greatly reducing costs and lowering the threshold of restructuring.

2.2.2 Remote Control of Quayside Container Cranes

The main service unit in the quay area is the quayside container crane. The height of a quayside container crane is 60–70 meters. Wireless networks are required to provide network coverage in operation areas. Quayside container cranes have communication requirements on both remote control and monitoring. In the remote control scenario, there are more than 20 cameras on a single quayside container crane and the uplink bandwidth is estimated to be up to 200 Mbps. In addition, the deployment of quayside container cranes is relatively dense. Typically, 8 to 12 cranes are deployed along 1 km port coastline. In addition, the vertical and horizontal moving speeds of each quayside container crane are higher than those of a gantry crane and, therefore, the remote control of quayside container cranes has higher requirements on latency.

As most container terminals are built along seashores, berths must be sufficiently submerged in water and may be equipped with bollards and fenders. For this reason, wireless network devices need to serve the production and monitoring purposes of quayside container cranes and Terminal Operating System (TOS) components, while also providing network coverage for berthing vessels in some cases.

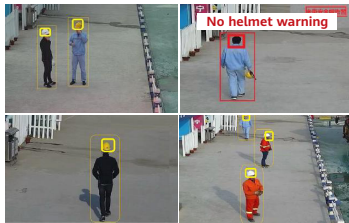


2.2.3 Intelligent Guided Vehicle (IGV) Control

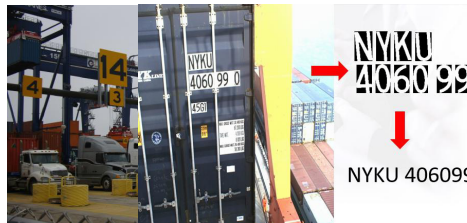
With the development of port automation, the evolution from AGV to IGV is also an obvious trend. In the near future, IGVs may also integrate at least four cameras and the demand for uplink bandwidth will reach 10–20 Mbps per IGV or AGV. 5G is expected to provide better network support for these applications. If, for example, an IGV is stuck in the operation field, the operator needs to learn the surrounding environment through onboard cameras, identify faults, and remotely control the IGV to get out of the target area. At present, the AGVs running in Shanghai Yangshan Port are equipped with surveillance cameras to locate, determine, and coordinate remote control.

2.2.4 Video Surveillance and AI Recognition

Facial recognition



Container monitoring



Robot & UAV patrol



Video surveillance can be applied in the following port scenarios:

- AI-based identification of container IDs using crane cameras and automatic cargo tally
- Security protection: intelligent analysis of operators' facial expressions and status, with alarms for fatigue and sleepiness
- Operation management: license plate recognition, facial recognition, and cargo recognition
- Intelligent inspection: rapid and intelligent inspection using unmanned aerial vehicles (UAVs) and robots

Currently, optical fibers cannot be deployed in many port areas. However, wireless backhaul, with its flexible deployment, easy adjustment and low costs, can serve as a good alternative to optical communications in temporary deployment and mobile scenarios. 5G's large bandwidth and massive connectivity capabilities effectively support the backhaul of multi-channel High Definition (HD) videos and sensor data. In combination with edge computing and AI, 5G can help synchronize and coordinate port devices and production systems. Deploying 5G alongside AI and edge computing allows for the completion of more tasks automatically, improving the intelligence and operational efficiency of ports.

2.3 Summary of Port Application Wireless Requirements

The following table lists the four typical port application requirements on 5G wireless networks.

Table 2 Summary of port application requirements on 5G wireless network

Application Scenario	Scenario Description	Overall Requirement	Network KPI Requirement		
			Latency	Bandwidth	Reliability
Remote control based on video	Remote control (signaling)	Low latency, high reliability, and low bandwidth	< 30 ms	50–100 kbps	99.999%
	Video feed (video streams)	Low latency, high reliability, and large bandwidth		30–200 Mbps	99.9%
IGV/AGV	Autonomous truck	Low latency and high reliability	< 50 ms	10–20 Mbps	99.9%
Video surveillance	Video monitoring with massive data transmission	Large bandwidth and multi-stream concurrency	< 200 ms	2–4 Mbps	90%
Sensor data collection	Data collection with low power consumption sensors	Massive concurrency	Best effort	Best effort	90%

Other technologies, such as optical cable, waveguide, and Wi-Fi, which are previously used in current ports, have technical, cost, maintenance, and security issues.

These non-cellular technologies have the following technical disadvantages:

- The Wi-Fi anti-interference capability and coverage capability are not enough to meet smart port requirements and therefore cannot support a large number of users.
- Transmission using waveguides, leaking cables, and optical fibers needs to make system-level compromise in the overall system design, for example, shortening the safety distance and lowering the device moving speed.

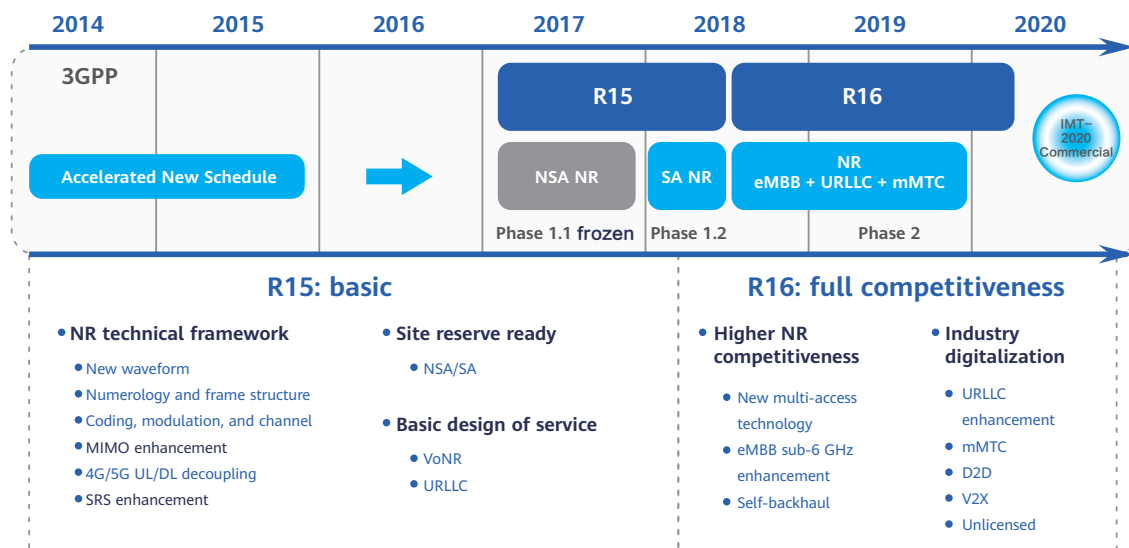
Besides these technical issues, there are more difficulties for ports to adapt non-cellular technologies. The unit cost of the existing wireless technologies or cable coil is tens of thousands of euros (depending on the difficulty of the actual construction of a port). As a result, a large number of traditional port operators cannot afford new communication infrastructures of such non-cellular technologies. Besides, such technologies require each port to maintain a professional network and communication function team, which adds extra maintenance cost and difficulty.

Table 3 Comparison between cellular network and Wi-Fi technology

Comparison Aspect	Cellular Network	Wi-Fi
Spectrum	Licensed spectrum	Unlicensed spectrum, complex interference
Mobility	Comprehensive mobility management measures, such as handover, cell reselection, and roaming	No handover mechanism, and only inter-AP reselection is performed with significant latency.
Multi-user capacity/interference	Excellent The QoS assurance mechanism is based on centralized scheduling of multiple users and supports simultaneous access of a large number of users.	No scheduling mechanism. In addition, when there are a large number of accessing users, the probability of collision is great and the performance deteriorates.
Security	Bidirectional authentication	Only unidirectional authentication. Unauthorized users can easily access the network as APs.
QoS	QoS classification	None

3. 5G Smart Port

3.1 5G Standard and Deployment Progress



The first version of the international standard (3GPP Release 15) for 5G has been finalized, and the enhanced version (Release 16) is under development and should be completed by March 2020. The future Release 17 has started technology layout and is now in the project initiation and planning phase.

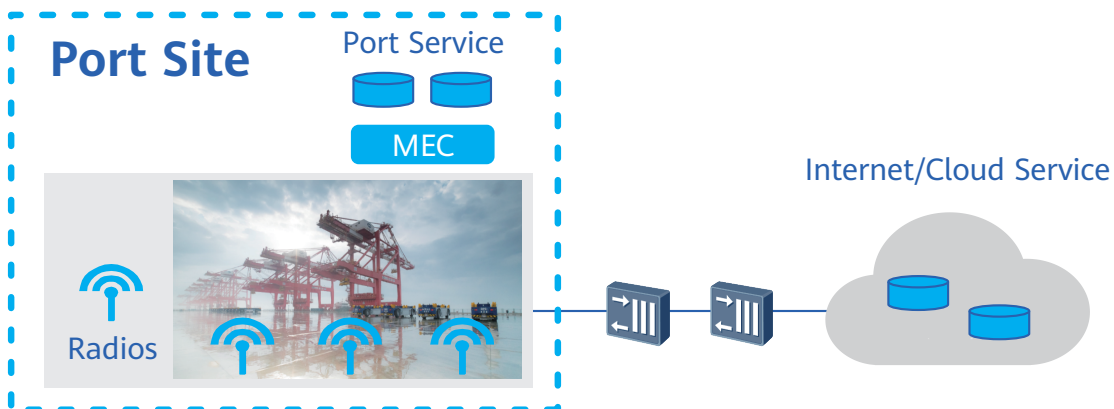
5G's high data rate, massive connectivity, and low latency mean that it can meet the requirements of the future Internet of Everything (IoE) and promote the development of industrial capacities. In terms of high data rate, Enhanced Mobile Broadband (eMBB) can reach a peak rate of 10 Gbps with an average throughput of hundreds of Mbps. As for massive connectivity, Massive Machine-Type Communications (mMTC) supports 1 million connections in a single cell. With reference to low latency, Ultra-Reliable Low-Latency Communication (URLLC) can deliver an air interface latency of 1 ms. The benefits are 10 to 100 times greater than those of 4G. Release 15, as the basic version of the 5G standard, will first enable eMBB applications. In Release 16, URLLC and mMTC will be introduced to comprehensively enable the digital construction of industries.

3.2 5G Port Private Network Solution

Mobile telcos provide ubiquitous network connections for customers. Port private networks have different requirements in terms of capacity, coverage, and latency for different service scenarios. Also in some cases, local breakout is required to keep data within a port network. To meet these requirements, a concept of Mobile Private Network including two network architecture options is proposed: hybrid network and standalone network.

3.2.1 Hybrid Network

In this scenario, a dedicated Radio Access Network (RAN) and Multi-access Edge computing (MEC) are deployed inside a port. Network control plane functions are carried out in public networks. All data plane traffic can either be terminated locally in a port or sent to public networks if required.



3.2.1.1 Deployment Solution – VCN

3.2.1.1.1 Network Architecture

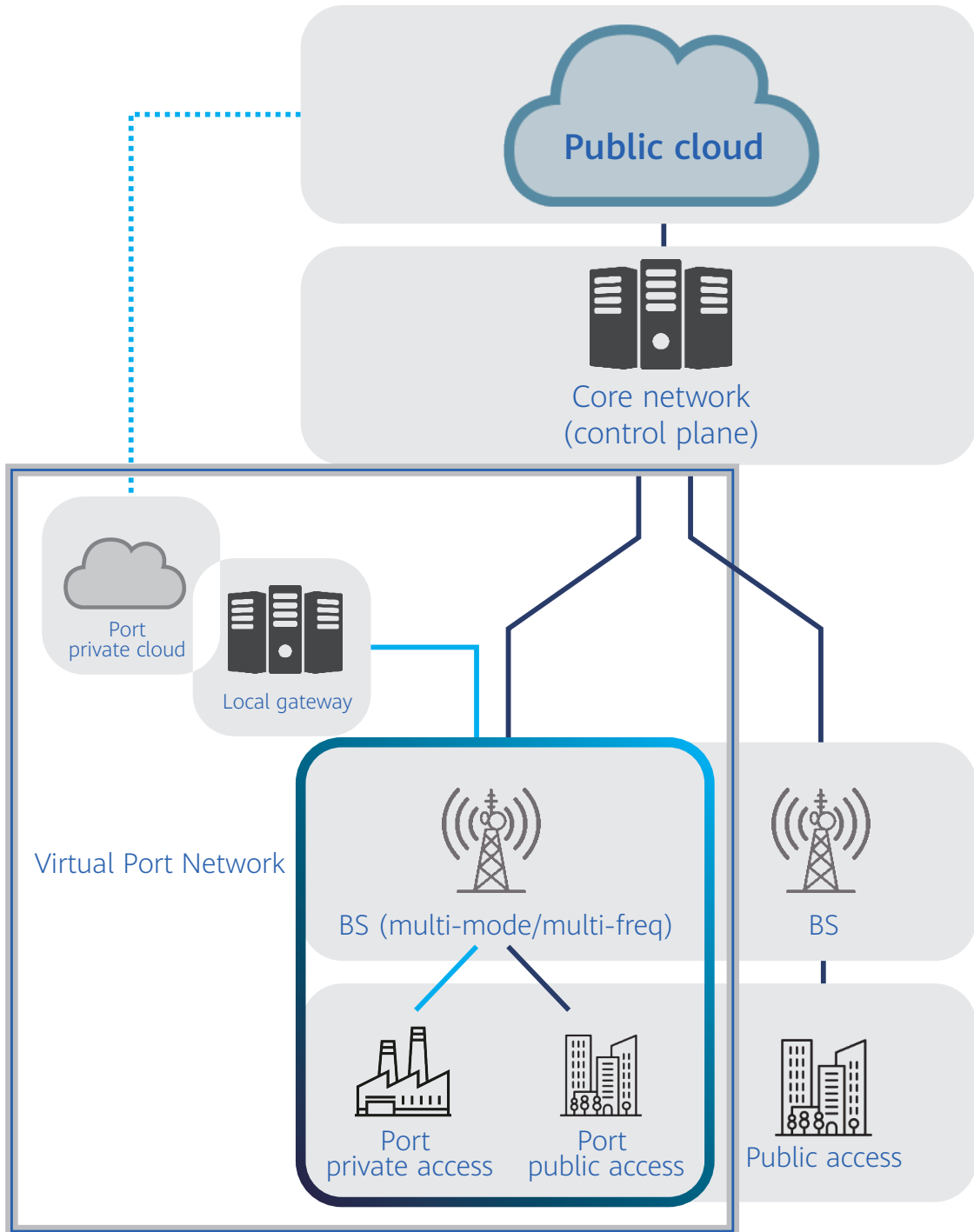
As a deployment solution, Huawei proposed 5G VCN as a hybrid architecture to provide mobile private networks to smart ports based on telcos' public networks.

In 5G VCN architecture, one telco reserves a dedicated part of public network spectrum to generate a dedicated cell with an independent access ID to provide VCN services. Based on the Control plane/User plane (CU) separation architecture of the core network, an independent local gateway is set up in the port to provide local breakout.

The 5G VCN architecture has the following features:

- Private and public network harmony: Network equipment capabilities and spectrum are shared between private and public networks which are completely isolated. The private network is fully synchronized with the public network in terms of version and functions.
- It supports user identification and slicing awareness of both private and public networks.
- It supports network as a service on demand with full customization.
- Local data breakout makes transmission latency shortest and ensures data localization.
- It enables efficient provisioning of the dedicated network services for telcos.
- It provides lightweight 5G dedicated network services to port operators in an economically efficient way while telcos can release the full power of their spectrum and network assets for exchange of growing revenue.

The following figure shows the architecture of the 5G VCN solution.



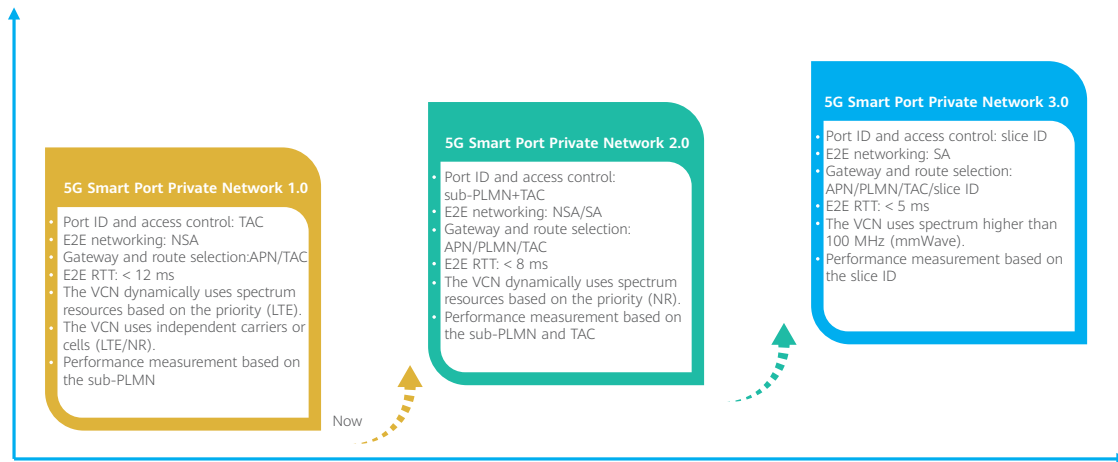
- 1.A dedicated network ID is defined for customers at a port and independent SIM cards are created for them.
- 2.An independent local gateway is established for the port based on the 3GPP CU separation architecture of core networks.
- 3.An independent cell (one LTE carrier or certain 5G spectrum) is defined for the port on either 4G/5G dual-mode base stations in the non-standalone (NSA) architecture, or 4G/5G only base stations in the standalone (SA) architecture.
- 4.In a base station, a port specific network ID is used for the port specific dedicated cell. For other public cells served by the same base station, the public land mobile network (PLMN) ID is used.
- 5.The dedicated cell uses the sub-PLMN ID and tracking area code (TAC) as the network ID for the port. If slicing is available later, the sub-PLMN ID and TAC could be changed to the slice ID. The overall networking/function and business logic remain unchanged.
- 6.Users can access either the dedicated network or the public mobile network using different SIM cards.
- 7.The dedicated cell provides independent local performance statistics.

3.2.1.1.2 Evolution Roadmap

The main advantages of the 5G smart port private network are as follows:

- Ports can define their own network name.
- It can provide guaranteed services.
- Public network users cannot access the port private network.
- The user traffic model inside the private network is relatively stable.
- The latency and throughput within the private network are stable and predictable.

The following diagram provides an evolution roadmap for the 5G smart port private network:



3.2.2 Standalone Network

In this scenario, a complete private cellular network, including both radio access and core network, is deployed at a port. All port terminals will access this private network which hosts both control plane functions and data plane functions locally. It could interwork with the Internet if needed.



3.3 5G Port Service Features and Supporting Components

The 5G commercialization is continuously progressing. Its ultra-high bandwidth, ultra-low latency, and massive connectivity features have large convergence potential in the port industry. Through uploading massive machine vision videos to cloud for multiple purposes, 5G will have long term impacts on the port infrastructure, transportation scheduling, business model, and governance model. In addition, the machine vision cloud is able to support remote viewing, monitoring and controlling of the machines. Such controlling requires not only large uplink bandwidth for videos but also low latency and high reliability in the downlink for control signals. Machine vision cloud will change work methods and improve work efficiency in various industries.

Release 15 5G is able to provide basic support for AGV guidance and control as well as remote control of RTG cranes. The introduction of 5G uplink capacity enhancement, low latency, and high reliability will enable the advanced features of these applications.

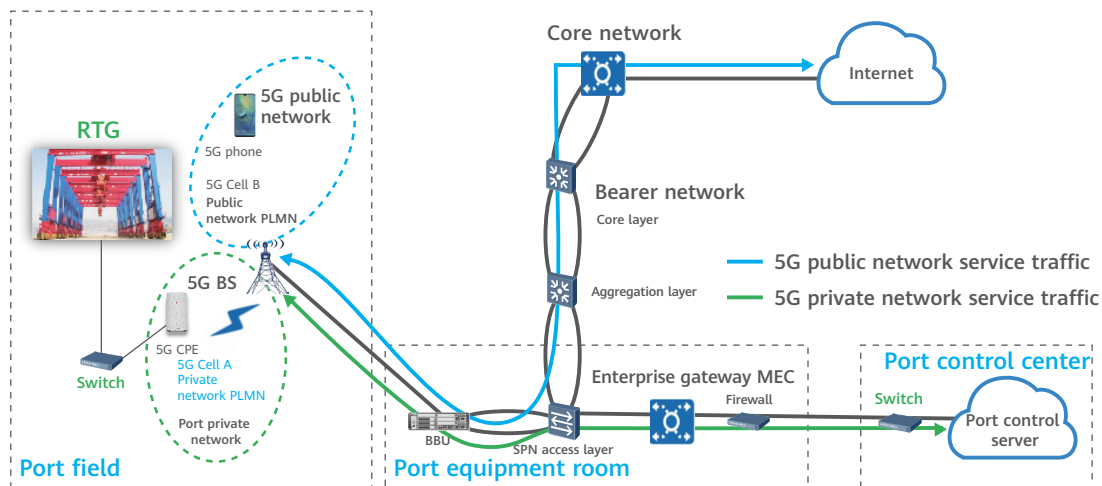
During the joint innovation with port operators and telcos, Huawei found that the interconnection between 5G and the existing information system of the port has many potential issues. For example, 5G needs to carry Ethernet Layer 2 protocols, networking with existing devices without changing their addresses while ensuring video monitoring quality and E2E control latency. Huawei provides partners a series of ecosystem components, including business prototype system and service quality assessment components, to accelerate commercialization of 5G smart port private network.

4. 5G Smart Port Use Case

In China, China Mobile proposes three options for smart port deployment based on the customization level of wireless network resources: 1. mixed network, i.e. the port has dedicated frequency and shares base station with public network; 2. virtual network, i.e. the port shares both frequency and base station with public network; 3. physical network, i.e. the port has dedicated frequency and base station.

5G VCN is an efficient architecture to deploy mixed network in the port. In 2019, China Mobile, ZPMC, and Huawei embarked on a pilot trial of 5G smart ports at multiple ports in China. Taking Shanghai Yangshan port as an example, the Guangdong container terminal of the port has about 150 RTG cranes, which were all manually operated. In line with the current trend of industrial automation, the port operator had already verified the modernization of RTG cranes, so that they could work via 5G remote control, with the help of ZPMC, China Mobile, and Huawei. China Mobile deployed a 5G VCN at the container port to implement intra-port local data distribution and low service latency. Private network users and public network users are isolated by spectrum and share the 5G basic communications network. The industrial control protocol and port equipment video data are carried by 5G. In this trial, requirements for remote control of these cranes are as follows:

- Uplink bandwidth required for video transmission: 30 Mbps per RTG
- Latency required for remote signaling control: less than 30 ms



In the Shanghai Yangshan port project, China Mobile took the advantages of 2.6 GHz and 4.9 GHz to enable the flexible selection of frequency solutions based on industry customers' service requirements, and leveraged its experience in building and optimizing the world's largest 4G network to meet tailored requirements. Through spectrum coordination and consolidation of public and private networks, a high-quality wireless port network was built, a manifestation of industry-leading E2E private network and delivery capabilities. The business model of "network as a service" enables the integrated network slicing service platform to provide highly reliable, high-performance, and easy-to-deploy private network services for vertical industries, better meeting the customization requirements of industry users.

In this 5G VCN, one set of base station hardware supports both public and virtual private network services, and can implement CU separation of the core network. A local gateway was deployed at the MEC node to control data flow within the port. China Mobile defined an independent sub-PLMN ID and provided independent SIM cards. One base station supports multiple PLMNs, with public and private network users accessing cells with different PLMNs. A data gateway is selected based on the APN, PLMN, or TAC to distribute data. In this case, the cloud machine vision components were used to implement imperceptible 5G integration with the port's systems, adapt to Layer 2 and Layer 3 networking, and perform E2E service quality evaluation.

In addition, the high bandwidth and low latency capabilities of 5G on the 5G VCN have been verified. The solution can sufficiently support remote control of RTG cranes to improve operational efficiency and security, and compared with optical fibers and Wi-Fi, the solution reduces system construction and maintenance costs. As the first step in smart port exploration, the 5G remote-controlled gantry crane provides a valuable reference for future practices, which will be of great significance to the building of future smart ports.

5. Future Prospect of 5G Smart Port

In the future, the construction and management of smart ports will be crucial to the port industry. Port operations will continue to develop, following trends such as device automation, intelligent scheduling, and data visualization. Remote control of RTG cranes is only an initial attempt at 5G application in the industry. 5G will promote the all-around automation of traditional terminals, create new applications, and improve production efficiency.

As a pioneer of 5G technology, Huawei believes partnership is not just important, but vital to the port industry. In China, Huawei and China Mobile have been consolidating partnerships with ZPMC through projects such as the Shanghai Yangshan Port and Ningbo Port. In West Europe, Huawei and ZPMC will work with telcos on solving other complex port scenarios.

During the upcoming global wave of port automation and intelligence, Huawei 5G will become a powerful driving force. Huawei and ZPMC will collaborate with global leading telcos to develop more effective solutions for port customers leveraging technologies such as AI, cloud computing, big data, and IoT.

Appendix:

Introduction to ZPMC

Shanghai Zhenhua Heavy Industries Co., Ltd. (ZPMC) is a well-established manufacturer, and a state owned company listed on the A and B shares on the Shanghai Stock Exchange. The major shareholder is China Communication Construction Co., Ltd. (CCCC), one of the world's top 500 companies. ZPMC's business covers eight sectors, port machinery, heavy maritime industry, steelworks, and maritime transportation and installation, as well as emerging domains such as smart city, civil expenditure and integrated development. ZPMC is represented in markets in 102 countries and regions, and occupies more than 70% of global market share for container bridge products. ZPMC is one of the world's largest port machinery heavy-duty equipment manufacturers, and owns a fleet of 20 transportation ships which are from 60,000 dead weight tonnage (DWT) to 100,000 DWT to deliver products to all over the world.

The main business of CCCC covers infrastructure design and construction (ports, terminals, roads, bridges, railways, tunnels, and municipal engineering), dredging (for infrastructure and environmental protection), equipment manufacturing (including port machinery, road construction machinery, and large steelworks), as well as foreign trade (encompassing international engineering contracting and import/export trade). CCCC is the world's largest port design and construction company, with services including highway and bridge design and construction, dredging, container crane manufacturing, and offshore oil platform design. It is China's largest international engineering contracting company and highway investor, and has the largest civil fleet in China. In 2019, CCCC became No. 93 in the Fortune 500 list.

Acronyms and Abbreviations

Acronym or Abbreviation	Full Spelling
COSCO	China COSCO Shipping Corporation Limited
AGV	automated guided vehicle
APN	access point name
eMBB	Enhanced Mobile Broadband
eMTC	Enhanced Machine-Type Communication
IGV	intelligent guided vehicle
MEC	mobile edge computing
MME	mobility management entity
PLC	programmable logic controller
PGW	packet data network (PDN) gateway
PLMN	public land mobile network
RAN	radio access network
RMG	rail-mounted gantry
RTG	rubber tyred gantry
SGW	serving gateway
SMF	session management function
TAC	tracking area code
TEU	twenty-feet equivalent unit
TOS	Terminal Operating System
UPF	user plane function
URLLC	Ultra-Reliable Low-Latency Communication
VCN	virtual campus network

Contacts:

E-Mail: XLabs@huawei.com

Official Web: <https://www.huawei.com>

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