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Experimental Evaluation of an IoT-Based Platform for Maritime Transport Services

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Abstract: In recent years, the adoption of innovative technologies in maritime transport and logistics systems has become a key aspect towards their development and growth, especially due to the complex and heterogeneous nature of the maritime environment. On the other hand, Internet of Things (IoT) solutions are gaining importance in the shipping industry thanks to the huge number of distributed cameras and sensors in modern ships, cargoes and sea ports, which can be exploited to improve safety, costs and productivity. This paper presents an experimental evaluation of a maritime platform, which enables a wide range of 5G-based services in the context of logistics and maritime transportation. Its core is a Narrow Band (NB)-IoT framework used to run massive IoT services on top of a hybrid terrestrial–satellite network and feed a OneM2M platform with significant data on maritime transport to develop high-level and value-added logistic applications on top. Among the many different services that could be provided by the maritime platform, we focus on the cargo-ship container tracking use case through the Global Tracking System, which allows for continuous container monitoring all over the seas in a port-to-port service scenario. The results of the experimental tests illustrate the capacity of the platform in managing the high number of messages transmitted by the container tracking devices (i.e., more than 3000) and its efficiency in limiting the average maximum latency and packet loss below 5.5 s and 0.9%, respectively.

Keywords: IoT; 5G; satellite networks; maritime transportation

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1. Introduction

In the globalization era, maritime transportation has assumed global dimensions, thereby gaining strategic importance. The shipping of goods has become worldwide along with supply chains and the volume of freight, which have become increasingly high. In this context, and because of an increasing growth of the global containerized maritime cargo flows, ships have become bigger and sophisticated logistic assets [1,2]. The maritime shipping market expansion has produced several innovations in terms of efficiency and standardized methods to handle freight and to optimize the cargo chain. For instance, standardized containers (i.e., [3]) are secure boxes used to effectively optimize the intermodal freight transport. However, further added value could only come from technological advances that could sustain expedited data transfer rates and higher data sharing capability to allow for new innovative logistic services, such as real-time cargo monitoring in transit and in the ports, real-time intelligence for ship activity, etc. [4].

In this regard, 5G is recognized as the enabling technology to move logistics closer to harnessing the Internet of Things (IoT) toward higher data density, transfer speeds and lower latency [5]. Indeed, 5G can support a million sensor devices per square kilometer (as opposed to 4G's 100,000 devices) that can be used to increase the visibility of cargoes in transit and in the ports. For this reason, massive IoT is indicated as one of the major 5G use cases to connect ubiquitous sensors, while the Narrow Band IoT (NB-IoT) is a promising technology for massive IoT that can coexist with 5G New Radio (NR).

On top of that, there is an increasing consensus on the idea that satellite networks can help to increase the capabilities of terrestrial networks, especially in terms of broader coverage, reliability and availability, thereby contributing to effectively address some of the 5G use case requirements [6]. With larger constellations and a decrease in end-to-end delay, satellite networks can supply the required backhaul for high-speed services and network environments that are difficult to manage by only terrestrial systems, especially in areas where it is hard to install physical infrastructure [7]. Ultimately, the provision of NB-IoT services leveraging on the enhanced capabilities of 5G along with the combined potential use of satellite networks allow for enhancing on-board ship connectivity in terms of higher data throughput and broader coverage and can pave the way to more efficient cargo shipping operations and new innovative logistic services, e.g., seamlessly connecting vessels to land while they are in open sea to provide continuous transmission of data on monitored goods [8].

In the light of above considerations, in this paper, we design and experimentally evaluate an open and flexible platform (i.e., Maritime Platform) for developing and testing innovative maritime transport services that can be built upon an on-board NB-IoT network integrated with hybrid terrestrial–satellite networks and a standard OneM2M service platform [9] to collect and elaborate data from NB-IoT sensors, making them available to develop maritime application services. These constituent elements definitely make the Maritime Platform a comprehensive 5G network and service infrastructure including mobile, satellite and terrestrial domains that allow for the development of a new breed of 5G-enabled IoT-based value-added applications in the maritime transport and, hence, foster advanced logistic services and new market opportunities for logistic operators. Among the maritime transport services enabled by the proposed platform such as container tracking, autonomous shipping, etc., the cargo ship container tracking is one of the most relevant in terms of market opportunities. Thus, relying on the presented platform, we describe the 5G Global Tracking System (5GT System), which provides to several users (e.g., cargo shipping companies, port authorities, freight forwarders) an integrated system for real time monitoring of the freight status, even when the container ship is navigating far from the coast in open sea. Indeed, containers equipped with sensors can not only give information such as location, but can give updates on temperature, humidity, etc., on goods in transit and allow for their remote and timely management, which is highly important, especially for dangerous and perishable goods.

The contribution of this work is threefold. First, we design a maritime platform within the framework of an ESA-funded project [10] to assess the feasibility of a wide set of 5G use cases. Second, we realize a testbed that reproduces all its components towards the implementation of the cargo container tracking use case. Third, we present the outcome of an extensive experimental activity where we evaluate the 5GT system through the execution of end-to-end (E2E) performance tests under realistic conditions.

The remainder of this paper is organized as follows. Section 2 provides an overview of the literature. Section 3 presents the reference scenario. Section 4 describes the 5GT system and the container tracking use case. Section 5 describes the experimental testbed and details the obtained results. Section 6 details the benefits brought by our proposed platform and discusses its limitations. Finally, Section 7 draws the concluding remarks.

2. Related Works

The adoption of innovative technologies such as cloud, IoT, artificial intelligence and edge computing in maritime transport platforms has been tackled in several works in the literature [11,12]. More specifically, in ref. [13], the authors conduct an exhaustive analysis of the digital transformation in container shipping, describing its significant benefits and the challenges it brings that require constant improvements. In ref. [14], the authors provide a survey on the enabling technologies for maritime communication networks including hybrid satellite–terrestrial networks and maritime IoT data collection and integration, which are the technologies we also adopt in this work. However, several open challenges for an efficient IoT-based data collection and processing in maritime transport still need to be tackled in the literature [15]. In fact, a large amount of data is generated from different sources and in different formats in maritime transport, which are difficult to process and require advanced tools and techniques to analyze and utilize them. In addition, various stakeholders involved in cargo transports rely and take decisions based on these data, which can lead to several advantages such as efficiency, increased safety and resource utilization, but can also bring up some issues such as low reliability, current high processing latency and the need to protect collected data from unauthorized users. Moreover, as the number of digital sensors generating IoT traffic in the maritime context is rapidly increasing [16], a variety of issues related to this traffic management arise going from ships collision avoidance [17], ships fuel consumption management [18] and vessels real-time monitoring (e.g., position, height of bridges, sailing routes, etc.) [19]. The use of IoT devices fosters the technological advancement of maritime transportation, but introduces several novel risks that can considerably impact the maritime industry such as the high cost of implementation, the accuracy of data analysis in IoT systems [20] and cyber-security threats [21]. In this work, we rely on robust NB-IoT devices that allow transmitting data from maritime containers located on ships to sophisticated applications in the cloud with minimum packet loss and low latency.

Regarding the tracking issue, currently, Radio Frequency Identification (RFID) technologies are used for monitoring cargo flow in the logistics chain, where a ‘tag’ attached to a container is interrogated by a reader with radio waves [22]. Thus, no real-time tracking is performed, as we propose in this work, and the container is tracked at precise points in the supply chain. Differently, cargo shipping companies are developing proprietary and ”siloed” real-time tracking systems [23,24] intrinsically not scalable to future scenario evolutions, in contrast with the open and standard layer that we offer with our proposed Maritime Platform. In fact, on the one hand, the OneM2M is a standardized framework for an IoT Service Layer and provides a vendor-independent software middleware with open and standard interfaces with IoT devices as well as related on-top applications. On the other hand, the NB-IoT network can be accessed regardless of the device manufacturer, provided that roaming agreements have been established among operators. Finally, few research initiatives undertook an experimental evaluation of IoT traffic management in the context of maritime transport. The VITAL-5G project offers a virtualized 5G environment for the experimentation of a set of Transport and Logistics (T&L) facilities including warehouses, hubs and ports [25]. The virtual platform enables the testing and validation of T&L Network Applications (NetApps) in real-life conditions, utilizing 5G connectivity. However, the focus of the project is on the deployment and usage of the NetApps while in this work we consider a more complex testbed including a satellite network, which brings further challenges. The EU 5GENESIS project [26] presents the design and implementation of an end-to-end experimental testbed for integrated satellite/terrestrial 5G services. The aim of the project is to test various vertical use cases such as maritime communications, IoT in rural areas, etc. The testbed builds upon five distributed experimental platforms with diverse capabilities, which makes their integration complex with respect to the prototype that we propose in this paper. Table 1 summarizes the related works while highlighting their strengths and limitations.

Table 1. Summary of related works.

	Strengths	Limitations
[13]	Exhaustive analysis of the digital transformation in container shipping.	Empirical study based on data collected through interviews.
[11,12,14]	Survey on the enabling technologies for maritime communications networks.	Lack of concrete implementation aspects.
[15,20,21]	Comprehensive overview on data management in maritime transport, IoT systems and cyber-security threats.	Lack of concrete implementation aspects.
[16–19]	Focus the technological revolution in the shipping industry especially regarding data management.	Lack of concrete implementation aspects.
[22]	Use of RFID technology for cargo monitoring.	No real-time tracking.
[23,24]	Development of proprietary and siloed real-time tracking systems.	No scalable solutions. Hard to adopt to future scenario evolutions.
[25,26]	European research initiatives based on experimental evaluations.	Still at an early experimental stage with complex integration and testing challenges still to be addressed.

3. Reference Scenario

In Figure 1, we depict the reference scenario for operating the Maritime Platform as designed within the ESA-funded project [10]. The scenario includes a vessel equipped with:

1. A set of NB-IoT devices enabling massive IoT. Those smart objects are installed on containers and allow for transmitting positioning and status reports of goods generated by local sensors;
2. The On-board 5G cellular network is installed on board of the vessel and supports NB-IoT technology. It is composed by the eNodeB that implements the radio access and the Evolved Packet Core (EPC) that implements the core network. The eNodeB is in charge of managing the smart objects controlling the air data and signaling exchanges implementing all the means to maintain the connection with the NB-IoT modules. The EPC is in charge of authenticating the smart objects, then allowing their connection to the network.
3. The Smart mIoT gateway provides multi-backhauling ship-to-land connectivity via satellite for massive NB-IoT data. It is mainly composed of the following functions: (i) a switching function for compressing and routing massive IoT data; (ii) a monitoring function for monitoring the status of all local data; and (iii) a security function for onboard data and network protection.
4. A Satellite transceiver, called a 5G-specialized Satellite Terminal (5ST), which guarantees the connectivity in open sea via a Ku-band satellite link. The proposed solution includes the use of Ku-band frequencies to transmit and receive data even in mobility scenarios. This is considered attractive for the stakeholders (e.g., shipping lines) since the Ku-band is traditionally less expensive than the L-band that is usually used for this type of applications, which reduces the satellite bandwidth cost.

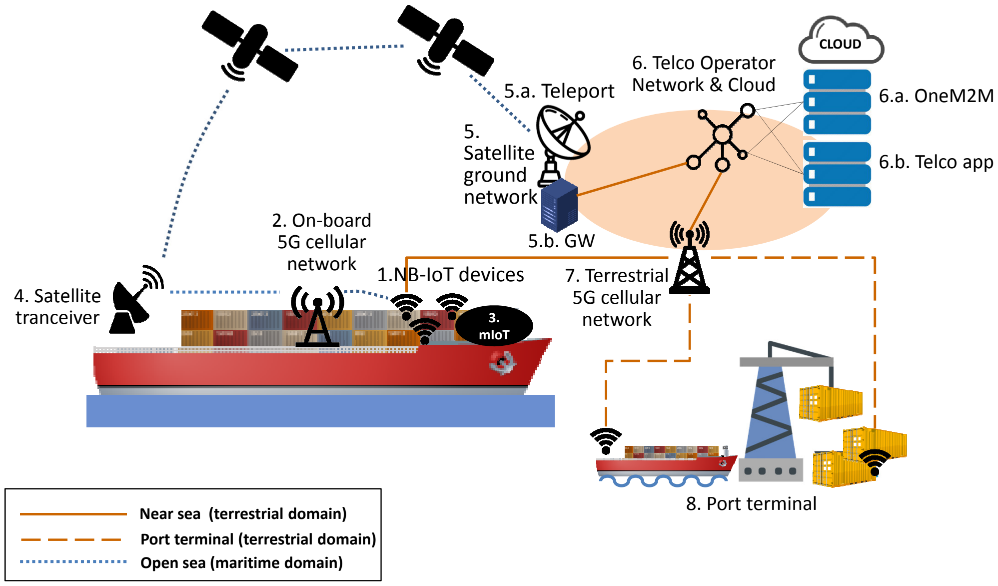

Figure 1. Reference scenario.

The scenario also considers terrestrial elements including the following elements:

5. The Satellite ground network includes the teleports (5.a) that are interconnected via a dedicated backbone network (for the sake of clearness, only one teleport is depicted in the figure). Each teleport supports bidirectional IoT data traffic from return/to forward links as well as data traffic to the gateway (data plane) or to control elements (control and management plane) through an internal network of switches. The satellite ground network also includes the gateway (5.b), called 5G-specialized Satellite Gateway (5SG), which is typically a full-featured IP router with a strong set of functions and protocols (e.g., various routing protocols, network address translation, firewall services) that conveys data to the external networks, e.g., Telco Operator Network, and the Internet.
6. The Telco Operator Network is a Telco terrestrial network, mainly including front- and back-hauling segments and the Telco backbone network to convey data from different access networks (e.g., 5G cellular network) as well as external networks (e.g., satellite). The Telco operator cloud deploys the OneM2M system (6.a) along with specific application components (6.b) developed exploiting, in the context of this paper, the Maritime Platform for delivering sophisticated logistics services.
7. The 5G terrestrial cellular network (with base station and core network elements) is placed at the port terminal (8) and, as an additional option, can also collect IoT data from the vessel.

The vessel can be in open sea, in near sea or docked at the port terminal. Correspondingly, we distinguish between two different operating domains for the Maritime Platform, whether the NB-IoT devices are attached to the terrestrial cellular network or to the on-board one to convey data to the OneM2M platform. More specifically:

1. Terrestrial domain—when the ship is in near sea or docked in a port terminal, the data produced by the NB-IoT devices will reach the Telco operator network (and then the OneM2M IoT system) by means of the terrestrial 5G cellular network. We consider near sea the part of the sea where a maritime telecommunications operator is not authorized to turn on its equipment. According to the Italian regulation, this area includes the sea within 2 nautical miles from the coast;
2. Maritime domain—when the ship is in open sea, the data produced by the NB-IoT devices will reach the Telco operator network (and then the OneM2M IoT system) by means of a 5G cellular network deployed on-board the vessel and the satellite network.

We consider open sea the part of the sea where a maritime telecommunications operator is authorized to turn on their equipment. According to the Italian regulation, this area begins 2 nautical miles from the coast.

4. The 5G Global Tracking System

The Maritime Platform can enable a number of different logistic applications relying on massive IoT, OneM2M platform as well as satellite networks to collect data also when the vessel is in open sea. Indeed, except for data collected from NB-IoT devices that are different depending on the application (and hence the NB-IoT smart object design has to change accordingly), the other components of the Maritime Platform are agnostic to the application.

In this paper, we take as an applicative example the case of real-time monitoring of cargo shipping status where the Maritime Platform acts as a container tracking platform, i.e., the 5G Global Tracking System and where the NB-IoT smart object design is composed by the following elements:

1. Sensors detecting container parameters (for example inside temperature), called container tracking devices (CTDs);
2. A data acquisition board interfaced with sensors and radio transceivers;
3. A NB-IoT transceiver to connect the device to maritime or terrestrial cellular network;
4. A Global Positioning System (GPS) module;
5. An additional Bluetooth 5.0 transceiver to establish a mesh network composed by all devices installed inside the containers. In case a device is not able to attach the cellular network via NB-IoT interface (due to the attenuation introduced by the stack of containers), data are forwarded to a neighbor device by means of the mesh network, enabled by a supplementary radio interface. This second device will try to transmit the received data via a NB-IoT interface. In case of failure, it will forward again the data to its neighbor device (via mesh network) and so on.

The 5GT System aims at the continuous port-to-port (and terminal-to-terminal) tracking of a large amount of goods carried by ships, even during deep sea journeys thanks to the integration between IoT, cellular network and satellite network. According to the containers or cargo ship position, the 5GT system operation could be split into three scenarios. The first two scenarios (port terminal and near sea) belong to the terrestrial domain, while the third one refers to the maritime domain. For each scenario, the data produced by the NB-IoT smart objects reach the IoT maritime platform for specific application components to be developed on top of the Maritime mIoT service framework. The scenarios are summarized in Table 2.

Table 2. Global Tracking System operating scenarios description.

Global Tracking System Operating Scenarios	Description
1—Containers are stored in the port terminal (terrestrial domain).	The NB-IoT smart objects attach the terrestrial cell. The Telco Operator Network authenticates them. • 1a—The NB-IoT smart objects send the data to the terrestrial cell; • 1b—The terrestrial cell routes the data to the Telco Operator Network; • 1c—Data are routed to the IoT maritime platform.
2—The cargo ship is in "near sea" (terrestrial domain).	The NB-IoT smart objects are still connected to the terrestrial cell. • 2a—From the cargo ship the NB-IoT smart objects send the data to the terrestrial cell; • 2b—The terrestrial cell routes the data to the Telco Operator Network; • 2c—Data are routed to the IoT maritime platform.

Table 2. *Cont.*

Global Tracking System Operating Scenarios	Description
3—The cargo ship is in "open sea" only under the coverage of the satellite network (maritime domain).	The NB-IoT smart objects continue to be connected to the on-board cell. • 3a—The NB-IoT smart objects send the data to the on-board cell; • 3b—The on-board cell routes the data to the Smart mIoT Gateway; • 3c, 3d and 3e—The data are routed to the Telco Operator Network by means of the 5G-specialized Satellite Terminal, the satellite link and the 5G-specialized Satellite Gateway; • 3f—Data are routed to the IoT maritime platform.

5. Experimental Evaluation

5.1. Testbed

An end-to-end testbed has been implemented to verify the interoperability of all the sub-systems composing the 5GT System and assess their performance. All the components of the on-board chain (i.e., CTDs, Smart cell, Smart mIoT gateway and 5ST) were installed in the same laboratory to reproduce the physical proximity between the devices as in the cargo ship environment, while the RF channel between the 5ST and 5SG was not implemented by the satellite link, but through a local loop link. More specifically, the Smart cell, the Smart mIoT Gateway and the 5ST were directly connected as planned for the cargo-ship environment. The Smart cell antenna and the CTDs were placed inside an anechoic chamber, where the CTDs were positioned next to each other on a desk. The Smart mIoT Gateway provided the commands to turn-on and/or turn off the Smart cell, in order to simulate the near sea to open sea transition (and vice versa). During the tests, some CTDs communicated directly with the Smart Cell (through the NB-IoT interface), while some other CTDs communicated indirectly with the Smart Cell (through the mesh network). Finally, the attenuation affecting the signal transmitted by the Smart Cell was gradually increased to simulate the radio propagation issues raised by the cargo-ship environment. Figure 2 shows the communication schemes that implement the E2E testbed. The blocks colored in orange correspond to 5GT System sub-modules, while the blocks colored in blue belong to the telecommunication commercial network.

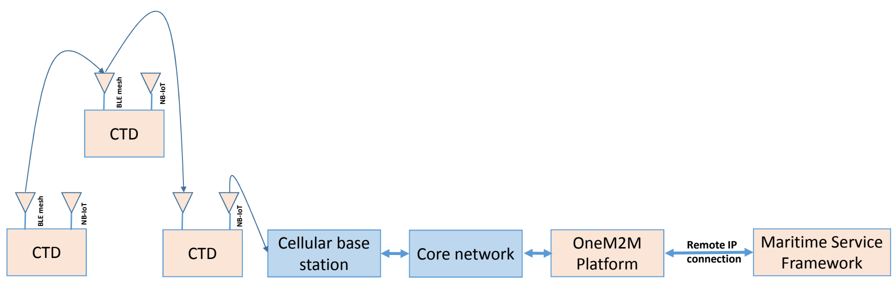

Figure 2. End-to-end testbed.

5.2. Near Sea Scenario

In this paper, we evaluate the performance of the 5GT system considering the near sea scenario. For this purpose, 8 container tracking devices equipped with SIM cards were used to generate the messages sent via NB-IoT to the commercial cellular network. The messages were then published to the OneM2M platform. After setting up the E2E testbed, each of the 8 CTDs provided a NB-IoT transmission during a single transmission interval. Overall, 405 consecutive transmission intervals were considered, each having a duration of 120 s. This then results in a total of more than 3000 NB-IoT transmissions accomplished by the 5GT system, which corresponds to "high traffic" conditions.

5.3. Results

Three tests were performed to assess the feasibility of the 5GT system and validate its components, which are the system capacity, the maximum latency and the maximum packet loss. More specifically, the system capacity refers to the maximum number of containers that can be supported by the 5GT system. To measure this number, we rely on the maximum number of messages (i.e., NB-IoT transmissions) that can be sent from the CTDs, without breaking, to the OneM2M platform during the experimental tests. The latency refers to the time elapsed between the sending of a message by the CTD and its publication on the OneM2M platform. For each CTD, we only report the minimum and maximum registered values then we calculate the average as follows. The average minimum latency is equal to the sum of the measured minimum values of all the CTDs over the total number of CTDs, while the average maximum latency is equal to the sum of the maximum measured values of all the CTDs over the total number of CTDs. Finally, the packet loss is calculated as the number of received messages over the number of transmitted ones.

5.3.1. System Capacity

The objective of the test is to verify the maximum number of containers that can be supported by the prototype of the 5GT System.

Figure 3 shows an example of the messages sent by the CTDs. The messages mainly contain information regarding the containers status such as temperature, humidity and the containers position in the ship, in addition to the sending time and the outcome of the operation (e.g., "SEND OK"). In Table 3, we detail the number of messages sent by each CTD in the testbed. To measure the quality of the connection, we also report the values of the Received Signal Strength Indicator (RSSI), which indicates the strength of the received signal or the "Total Power". However, RSSI allows only a rough estimate of the quality of the connection, for this reason, we also report the Reference Signal Received Power (RSRP) values, which are similar to RSSI but measure the signal power from the specific sector while excluding the noise and interference from other sectors. Therefore, RSRP is a more suitable indicator to be considered. When RSRP is greater or equal than −80 dBm, the quality of the signal is considered as excellent and all data are transmitted. If RSRP is below −100 dBm, the performance of the device drops sharply up to the disconnection. Results show that a total number of 3100 messages was delivered to the OneM2M platform, which confirms the high capacity of the system. Moreover, it is clear that there is a strict correlation between the quality of the signal and the number of transmitted messages. In fact, when the RSRP is below −100 dBm, the number of delivered messages almost halved.

Table 3. CTDs delivered messages.

CTD #ID	RSSI [dBm]	RSRP [dBm]	# of Messages
7898	−68.7	−74.7	405
6940	−68.7	−74.7	405
2259	−78.9	−84.9	400
4805	−78.9	−84.9	400
5333	−82.1	−89.4	398
7464	−82.1	−89.4	398
6599	−99.2	−105.3	200
3714	−68.7	−74.7	404
		TOT messages	3100

```
dte_handle_line:
> dte_send_cmd: > dte_send_cmd:
{"msisdn":"393601413714","iso6346":"LMCU1231231","time":
"231122 190049.0","rssi":"22","cgi":"222-01-7D84-
30F2D47","ble-m":"0","bat-soc":"92","acc":"-16.1138 -
8.0569
969.7563","temperature":"28.00","humidity":"28.00","pres
sure":"1005.5351","door":"N","gnss":"1","latitude":"0.00
00","longitude":"0.0000","altitude":"0.00","speed":"
0.0","heading":"0.00","nsat":"00","hdop":"0.0"}
dte_handle_line:
SEND OK
dte_send_cmd: AT+QISEND=1,0
```

Figure 3. Example of a CTD message.

5.3.2. Maximum Latency

The test aims at measuring the latency registered by the prototype of the 5GT System to be deployed in “High traffic” conditions. During the tests, the 8 CTDs were activated and provided NB-IoT transmissions at a time interval of 120 s. Table 4 details the minimum and maximum values of latency obtained for each CTD during the experiments. The results clearly show that the maximum mean latency related to the data published on the ICON platform is equal to 5.5 s, which is reasonable. In fact, although NB-IoT has been designed for delay-tolerant applications [27], certain applications (e.g., alarms) may require a reasonably strict delay profile. For devices supporting such applications, a maximum delay requirement of 30 s is still appropriate in normal conditions for the uplink when measured from the application ’trigger event’ to the packet being published to the terrestrial oneM2M Platform. The results obtained during our experimental evaluation are far below 30 s, which confirms the good performance of the proposed platform.

Table 4. Minimum and maximum latency.

CTD #ID	RSSI [dBm]	RSRP [dBm]	Latency Min/Max [s]
7898	−68.7	−74.7	1/4
6940	−68.7	−74.7	1/4
2259	−78.9	−84.9	1/5
4805	−78.9	−84.9	1/5
5333	−82.1	−89.4	1/6
7464	−82.1	−89.4	1/6
6599	−99.2	−105.3	2/10
3714	−68.7	−74.7	1/4
		Average Min Latency	1.1
		Average Max Latency	5.5

5.3.3. Maximum Packet Loss

This test aims at verifying the maximum packet loss of the 5GT System. During the experiment, the 8 CTDs sent NB-IoT data during an interval of 120 s, while an attenuation was introduced by shielding the CTD antennas to provide statistically significant results. Table 5 presents the results obtained during the experiments. More specifically, the number of transmitted and received messages is detailed for each CTD. The results show that the average packet loss is equal to 0.9%, which is reasonable. It is worth pointing out that both in Tables 4 and 5, measured RSSI and RSRP values are in line with latency and packet loss measurements. More specifically, when RSRP values become lower than −90 dBm values, performance is worse and both maximum latency and number of not received messages increase.

Table 5. Maximum packet loss .

CTD #ID	RSSI [dBm]	RSRP [dBm]	# of Tx/Rx Messages
7898	−68.7	−74.7	405/405
6940	−68.7	−74.7	405/405
2259	−78.9	−84.9	402/400
4805	−78.9	−84.9	402/400
5333	−82.1	−89.4	402/398
7464	−82.1	−89.4	402/398
6599	−99.2	−105.3	205/200
3714	−68.7	−74.7	405/404
		Packet Loss	0.9%

6. Discussion

In this work, we presented the 5G Maritime Platform, an experimental platform that fosters the deployment and testing of 5G-based logistic services in the context of maritime transport while exploiting massive IoT data. The platform is enabled by the recent convergence between 5G, NB-IoT and satellite network deployments. In addition, horizontal-integrated service platforms for IoT services such as OneM2M allow for IoT-based applications to be developed in vendor- and device-independent ways, thus allowing for new service and business opportunities for both network operators and service providers. All the components of the platform have been deployed and experimentally tested in a real testbed, thus producing significant and realistic results. However, further research efforts need to be performed and some open challenges still need to be investigated in the light of large-scale deployments of the 5G Maritime Platform. Currently, the majority of satellite communication networks are still based on proprietary hardware and on constrained network resources, which limits the benefits taken from the integration with 5G and the support of new applications. In addition, the current lack of worldwide NB-IoT roaming agreements between telecommunication operators may prevent the adoption of solutions such as the 5GT System, where the NB-IoT smart objects installed in the cargo shipping containers (and having a single SIM card provided by a given operator) are carried all around the world. However, some encouraging initiatives have been taken towards this direction. For example, recently Deutsche Telekom announced the extension of NB-IoT services thanks to the roaming agreements signed with several network operators worldwide [28]. Finally, an additional important point is the related to cyber-security aspects. In this regard, the system architecture of the 5G Maritime Platform has to be compliant with ISO/IEC 27001:2013 [29] and the guidelines on maritime cyber risk management issued by the International Maritime Organization (IMO) [30].

7. Conclusions

In this work, we presented the Maritime Platform, an open and flexible platform that allows for the deployment and testing of 5G-based logistic services in the context of maritime transport while exploiting massive IoT data. We focused in particular on the 5GT System, i.e., a global tracking system based on massive IoT data collected from containers. The paper reports the results of measurements we performed on the 5GT system using an experimental testbed to assess its feasibility. The obtained results indicate the capacity of the implemented prototype to handle a large number of IoT messages and to address the requirements in terms of latency and packet loss. In fact, the experimental testing campaign was performed under high traffic conditions with more than 3000 NB-IoT accomplished transmissions without any CTD break down, which shows the robustness of the 5GT system. Moreover, in most of the experiments, data were correctly received and published on the OneM2M platform (i.e., only 0.9% of loss), thus confirming the proper design and deployment of all the components. As future work, more complex scenarios (i.e., open sea) including the satellite communication will be evaluated.

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