Input paper: [[1]](#footnote-1) ENAV23-9.4

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Agenda item [[2]](#footnote-2) (from agenda) 9

Workplan Task Number / Technical Domain 2 …………………………………

Working Group WG 2

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LTE-Maritime as an e-Navigation communication infrastructure

# Summary

Nowadays, the maritime user’s demand of emerging data services has been increasing to prevent marine accidents and improve their living condition on the voyage. With the global aspects of international organization, e-Navigation strategy was developed by the IMO for providing the harmonized collection, integration, exchange, presentation, and analysis of maritime information by electronic means. As potential e-Navigation services currently contained in IMO instruments, the maritime services (MSs) were proposed and their implementation issues have been discussed. In Korea, in order to keep pace with the global efforts for e-Navigation, six Korean e-Navigation services are being developed by considering geographic and environmental features of Korean water. Besides e-Navigation services, vessels are equipped with a lot of sensors to prevent marine accidents, and many crews and passengers want to enjoy the infotainment (information and entertainment) services for social communication and interaction with family and friends.

To support these requirements of various data services, the maritime communications providing high-speed data rates and extended communication coverage need to be developed. Unfortunately, the conventional communication systems of maritime field such as VHF, MF/HF were operated on the terrestrial radio frequency specified on the maritime missions of GMDSS convention. In case of satellite like Inmarsat, the channel capacity and operative cost are not reasonable for the private user purpose. They could be a good communication system on GMDSS missions globally but not a good solution to be used as a communication system for the various services like e-Navigation, especially in specific local water requiring high data rates for their own services.

The Republic of Korea has a plan to develop a long term evolution for maritime (LTE-Maritime) by 2020. The objective of LTE-Maritime is to provide high data rates in the order of megabits per second within the communication coverage of 100km from the shoreline. In 2017, in order to confirm the feasibility of LTE technology on maritime field, a test-bed was developed and several field experiments were conducted. The experiment results show that, although there exist the interference issues with other communication signals, LTE-Maritime can provide the data rates over Mbps and the communication coverage around 100km. Based on the analysis of the experiment results, it is expected that LTE-Maritime could be a practical solution with reliability, high data rate, and affordable cost in coastal areas.

# Discussion

LTE-Maritime is an ongoing research project in the Republic of Korea and it aims to develop the communication infrastructure based on LTE technology by 2020. This document introduces the research plan of LTE-Maritime project, and the objective and communication architecture of LTE-Maritime. Then, through the experimental results with a LTE-Maritime test-bed, we answer the question “*Could LTE technology satisfy the communication coverage and data rate requirements in maritime environments?*”. Lastly, we kindly request opinion of IALA experts about the possibility of LTE-Maritime as an international communication system of maritime field.

## Overview of LTE-Maritime project

A LTE-Maritime project which is a part of SMART-Navigation project launched in 2016 has a goal of developing a digital maritime communication infrastructure. As shown in Fig. 1, we have plan to complete the development of LTE-Maritime communication by 2020 with the budget of 31.2 million dollars. After 2021, Korean e-Navigation services being developed by activity 1 will be provided for maritime users via LTE-Maritime.

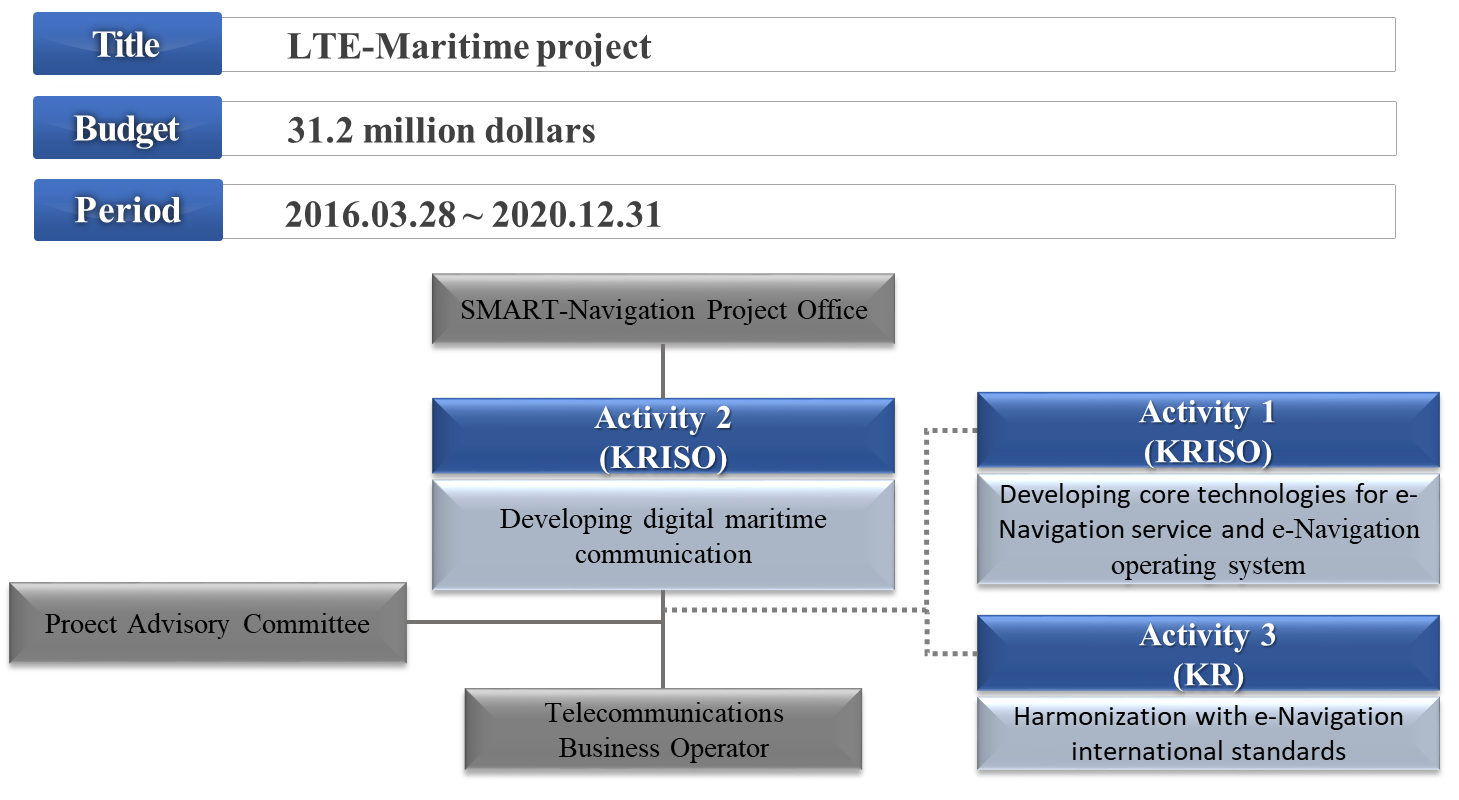


Figure 1. Overview of LTE-Maritime project

Until 2018, we had designed the LTE-Maritime communication system and had analyzed the communication performance through a LTE-Maritime test-bed developed. From 2019, we have plan to develop the hundreds of base stations (BSs) for LTE-Maritime along Korean coastal areas. After passing through a trial service, the performance of LTE-Maritime will be verified and the development process will be completed by 2020.

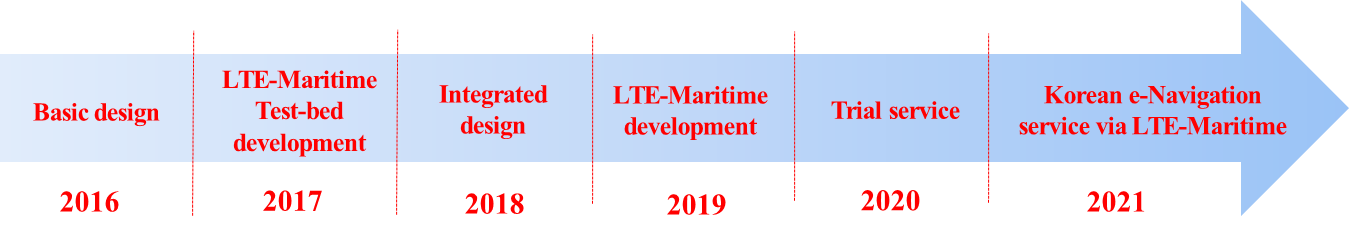


Figure 2. Process plan of LTE-Maritime project

## Objective and communication architecture of LTE-Maritime

LTE-Maritime aims at developing a new wireless maritime network that enables maritime users to access a variety of data services requiring the high data rates in coastal areas of 100 km from a shore. The overview of LTE-Maritime communication architecture in the project is illustrated in Fig. 2 and the main features of LTE-Maritime are followings.

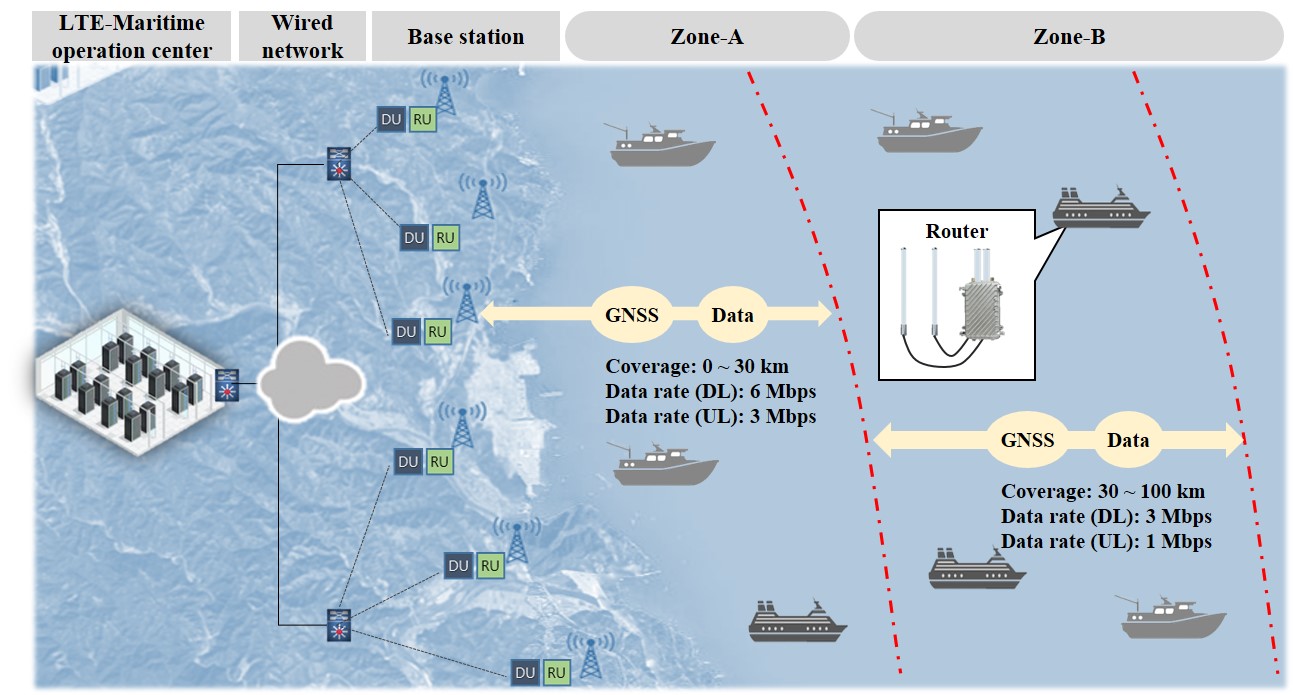


Figure 3. LTE-Maritime communication architecture

* LTE-Maritime is based on LTE technology that is a promising solution for wireless maritime network. LTE is capable of providing increased data rate, capacity, and spectral efficiency even in dynamic propagation environments with the support of advanced techniques such as multiple-input multiple-output (MIMO) and carrier aggregation (CA). Furthermore, it has the potential to provide the communication coverage about 100 km depending on the cell environments, though LTE for commercial mobile communication is designed with a relatively short cell coverage. This superiority of LTE makes us develop a single-hop network enabling ship-to-shore data communication based on LTE technology. In general, the wireless mesh networks are vulnerable to link failures caused by radio interference and they could not assure reliability. Contrary to existing maritime networks for extending the communication coverage with multi-hop transmission, LTE-Maritime enables ships to directly communicate with onshore BSs and it could improve reliability. Therefore, it is more suitable especially for the safety related maritime services that require high reliability as well as low latency.
* LTE-Maritime consists of base stations (BSs), evolved packet core (EPC) equipment, and routers. A number of BSs are located at a high altitude of mountainous areas along the coastline to assure the line of sight (LoS). Each BS is composed of multiple radio units (RUs) and digital units (DUs). The RU and DU are responsible for radio transmission and reception, and for data processing, respectively. Every DU is connected to LTE-Maritime operation center through the wired network. An EPC is located in the operation center and its entities are serving gateway (S-GW) for packet routing and charging with policy and charging rules functions (PCRF); packet data network gateway (P-GW) for quality of service (QoS) management and anchor point of external networks; mobility management entity (MME) for mobility control, authentication, and authorization; and home subscriber server (HSS) for subscriber management. On ship side, we developed the LTE-Maritime router suited for maritime environment. It is equipped to compass deck of ship with high gain antennas of 6 dBi and the antenna length of 1.2 m. It could provide better communication performance than typical mobile devices.
* The performance goal of LTE-Maritime is divided into two cases depending on the distance from the coastline. The objective of region A is to cover the area from BS to 30 km with the average data rates of 6 Mbps and 3 Mbps for downlink (DL) and uplink (UL), respectively. The objective of region B is to cover the area from 30 km to 100 km with the average data rates of 3 Mbps and 1 Mbps for DL and UL, respectively. The coverage objective was set based on the fact that 88% of marine accidents in Korea happen in non-SOLAS ships within the coverage of 100 km.

With the above characteristics, LTE-Maritime will be developed by 2020 in the Republic of Korea. It is expected that LTE-Maritime can support various Korean e-Navigation services for marine accident prevention and effective navigation. The Korean e-Navigation services include navigation monitoring and assistance, ship-borne system monitoring, safe and optimal route planning service, real-time electronic navigational chart distribution and streaming, pilot and tug assistance, and maritime environment and safety information. In addition, LTE-maritime network could provide various data services for maritime users with improved reliability, high data rate, long enough coverage, and low cost compared to current maritime networks.

## Test-bed implementation

In order to validate the feasibility of LTE-Maritime, we implemented a LTE-Maritime testbed in Korean waters. As shown in Fig. 4, for a LTE-Maritime testbed, 13 BSs were developed at a high altitude of mountainous regions along the coastline and they consist of 22 RUs and 14 DUs. For example, a BS in Gangneung area is composed of DU #1, RU #1, and RU #2 and it is located at 327 m high. In the stage of designing the LTE-Maritime test-bed, the location of BSs was set to be as high as possible for assuring the line of sight (LoS). Because the radio horizon distance of LoS is calculated by the height of transmitter and receiver, which has a significant impact on the communication coverage. In addition, 3 BSs of femto were developed to enhance the communication performance in the Islands area.

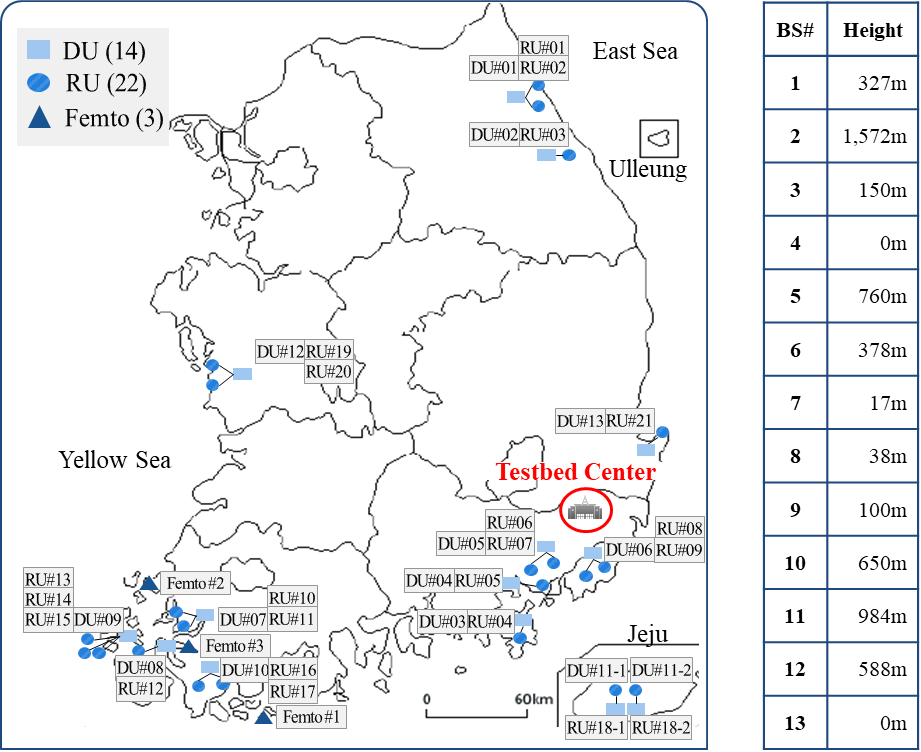


Figure 4. Base station deployment of LTE-Maritime test-bed

Fig. 5 shows the experiment environment with the LTE-Maritime test-bed. Each BS is connected to a LTE-Maritime test-bed center in Busan through the wired network. It consists of an EPC, an entity management system (EMS), and several servers. The routers developed for LTE-Maritime with high gain antenna were equipped to compass deck of ships. In onboard experiments, the LTE-Maritime router communicates with onshore BSs while a ship sails along the planned route. The laptops for performance measurement are connected to the router and they measure main communication parameters such as reference signal received power (RSRP), signal to interference and noise ratio (SINR), throughput, physical cell identity (PCI), and the number of resource block (RB) using a diagnostics monitor (DM) software installed on the laptops. In addition, for data transmission, a file transfer protocol (FTP) auto-call server was used where DL, UL, and idle periods were set to 1, 1, and 3 minutes, respectively. The frequency range of LTE-Maritime network is 728-738 MHz for UL and 778-788 MHz for DL.

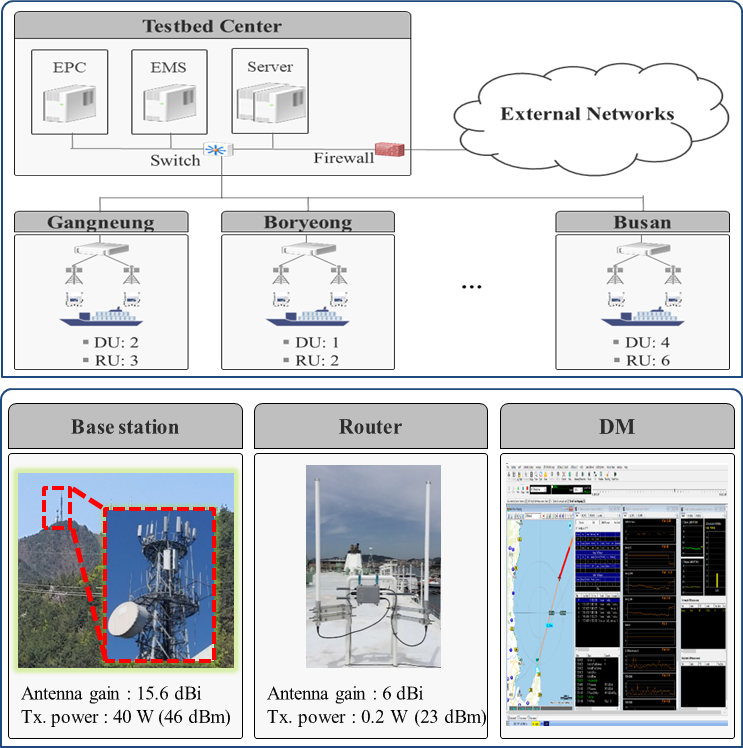
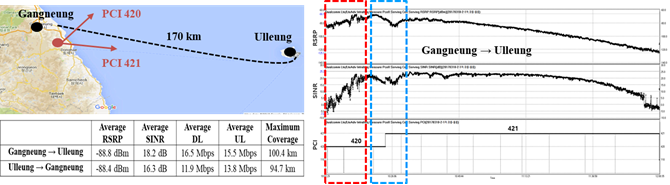


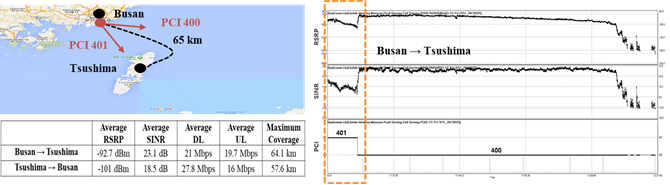
Figure 5. Experiment environment

## Performance analysis of LTE-Maritime

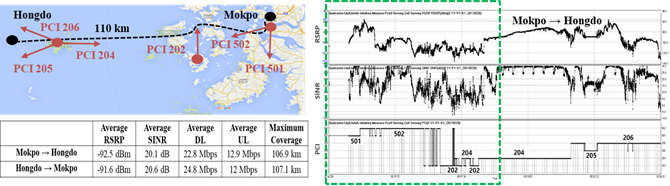
Fig. 6 shows the measured experimental results in three regions of the East sea, the South sea, and the Yellow sea. In each case, the left top picture depicts the ship’s route, the route’s distance, the location of BSs, and the direction of the antenna. The left bottom table represents the average values of RSRP, SINR, and throughput, and the maximum coverage overall route. The right graph shows the variation of each parameter value as the ship sails along the route.



(a)



(b)



(c)

Figure 6. Onboard experiment results in different regions. (a) East sea. (b) South sea. (c) Yellow sea.

For the East sea case, the variation of RSRP and SINR values has three kinds of patterns. In the red dotted box, as the ship sails away from the harbor, both values gradually increase. This is because, when the ship is near the harbor, it can not assure LoS environment due to surroundings such as buildings and mountains and also be interfered with other radio signals. In the blue dotted box, RSRP and SINR decrease as the signal strength of the neighboring cell becomes much stronger than that of the serving cell. After PCI number is changed from 420 to 421 (i.e., a handover (HO) occurs at that point), both values start to increase. In the rest of the route, the values of RSRP and SINR obviously decrease according to the distance between the BS and ship. In addition, the average throughput for both DL and UL is over 11 Mbps with the maximum coverage of about 100 km.

For the South sea case, onboard experiments were conducted from Busan to Tsushima on an international passenger ship, in which the antenna tilt and transmission power of BS were adjusted from 0 to 10 degree and from 46 to 43 dBm considering the impact of propagation interference on a neighboring country. The orange dotted box shows a similar trend with the East sea case near the harbor due to the non-LoS environment and interference. On the other hand, the values of RSRP and SINR rapidly decrease and the communication link between the BS and ship is intermittently disconnected near the destination, because the radio signal is blocked by Tsushima Island. The average throughput for both DL and UL has relatively high values compared with the East sea case. For example, the average DL throughput from Tsushima to Busan is 27.8 Mbps. The reason is that the South sea experiment has a relatively short route of 65 km resulting in much stronger RSRP values.

The experiments on the Yellow sea have a distinct characteristic different from the other cases. In this area, there are a lot of Islands and they interrupt the transmission and reception of the radio signal. Therefore, in order to reduce the performance degradation caused by Islands, more BSs were developed in the Yellow sea region. This environment leads to frequent HOs and wide fluctuation in RSRP and SINR values as shown in the green dotted box. Nevertheless, LTE-Maritime can achieve the average throughput over 22 Mbps for DL and 12 Mbps for UL with the maximum coverage of about 107 km.

Looking at these results in terms of the maritime network performance, we can find that the LTE-Maritime testbed satisfies the maritime user’s need for high-speed communication over Mbps as well as long communication distance of 100 km. Furthermore, when the cell planning optimization that decides the network deployment such as the number and location of BSs, antenna tilt, and transmission power level is applied by 2020, the communication performance of LTE-Maritime could be more improved.

## Interference issue

Interference leads to SINR degradation and increased collision probability resulting in the reduction of overall network performance. For the case of LTE-Maritime communication in the Republic of Korea, three kinds of interferences need to be addressed.

First, as shown in Fig. 7, ultra high-definition (UHD) broadcasting service operates in right near frequency and the guard band between UHD and LTE-Maritime has a small value of 2 MHz. In addition, the signal of UHD broadcasting could be much stronger than the signal of LTE-Maritime in some region. In order to eliminate the interference from UHD broadcasting signal, BSs and routers are equipped with frequency filter.

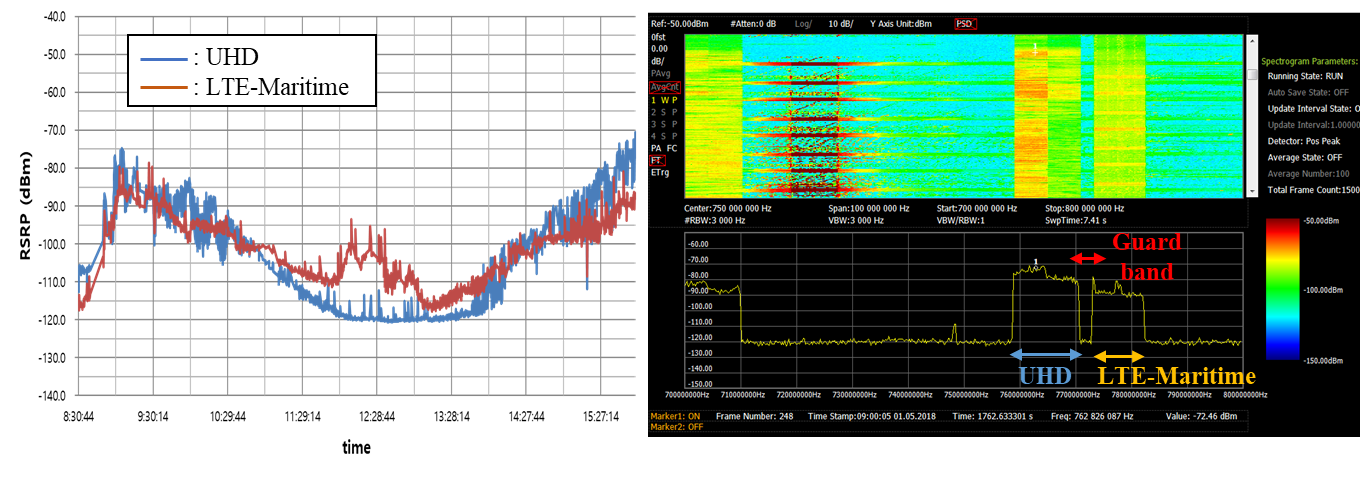


Figure 7. Interference with UHD broadcasting service

Second, public safety LTE (PS-LTE) operates in same frequency with LTE-Maritime and many BSs of PS-LTE are located in Korean coastal area. The experiment result of Fig. 8 shows the variation of PCI, RSRP, and SINR as a ship sails along the route. In red dotted circle, the signal strength of PS-LTE is better than that of LTE-Maritime resulting in call drop. During the period of call drop, the ship can not communicate with the BSs on shore. To mitigate the interference from PS-LTE signal, we have plan to use RAN-sharing technology. As shown in Fig. 9, when the signal strength of PS-LTE is better than that of LTE-Maritime, LTE-Maritime router can communicate with the EPC of LTE-Maritime through the BS of PS-LTE.

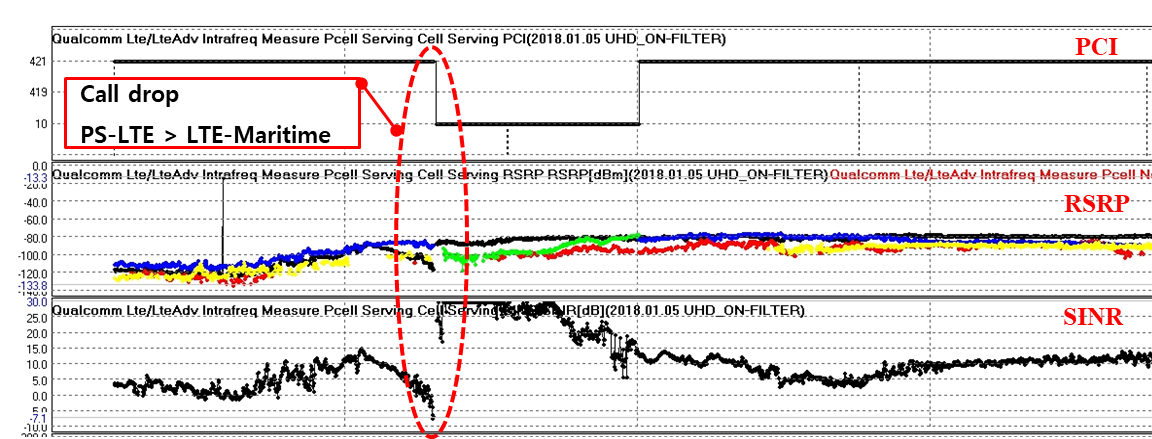


Figure 8. Interference with PS-LTE

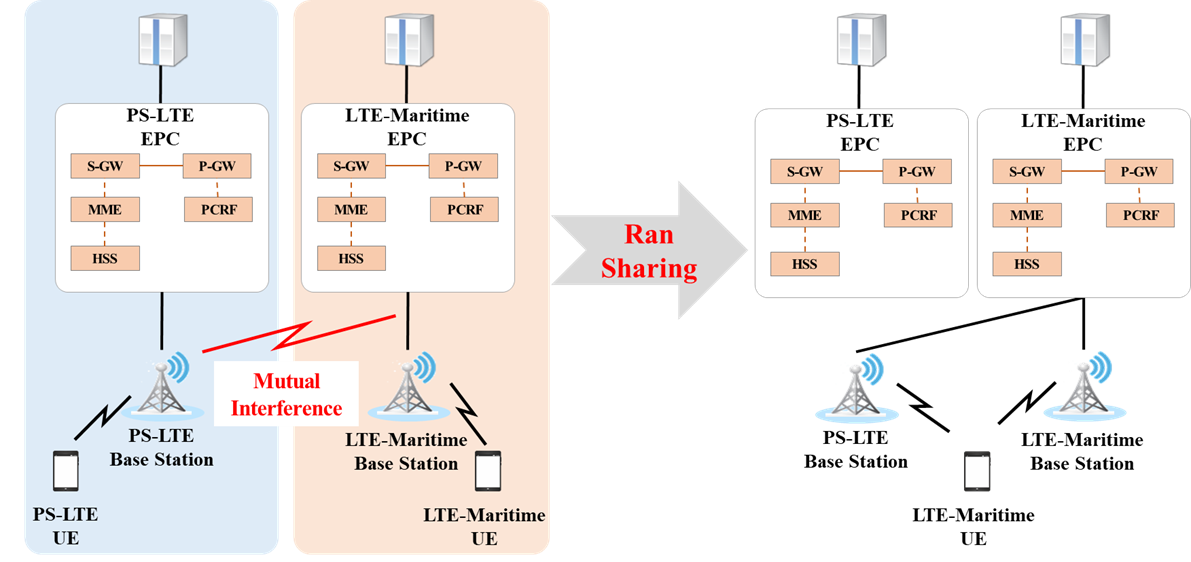


Figure 9. RAN-sharing between PS-LTE and LTE-Maritime

Lastly, LTE-Maritime may suffer from interference by the unwanted spurious signal from adjacent countries. In order to confirm the existence of spurious signal and its impact on the LTE-Maritime performance, we conducted lots of measurement on the Yellow sea region. By comparing Fig. 10 (a) with Fig. 10 (b), it is confirmed that there exists a spurious signal in the frequency range of 718-737 MHz. Fig.10 (c) and (d) show that the interference by spurious signal considerably degrades the network performance overall the route and causes call drop as shown in the red dotted box. This interference problem still remains an open issue.

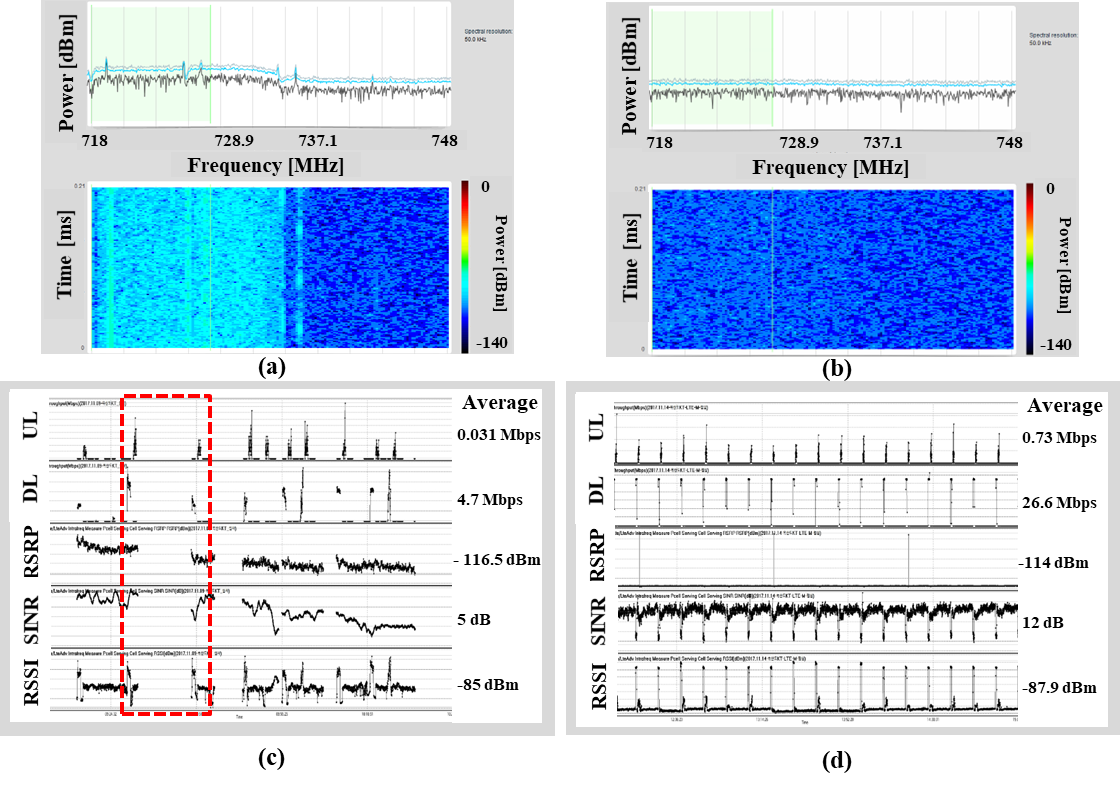


Figure 10. LTE-Maritime performance comparison with and without interference on Yellow sea. (a) RF sniffing with interference. (b) RF sniffing without interference. (c) Performance parameters with interference. (d) Performance parameters without interference.

# Action requested of the Committee

The Committee is requested to consider the information of LTE-Maritime and discuss the possibility of LTE-Maritime as a new maritime communication network in view of IALA experts. The Committee is kindly requested to consider further work plan about LTE-Maritime with consecutive submission of LTE-Maritime development and test results to the end of 2020.

1. Input document number, to be assigned by the Committee Secretary [↑](#footnote-ref-1)
2. Input papers should be assigned to a work task as listed in the Committee work plan which is available in input papers. Leave open if uncertain but consider how the paper is to be processed if not relevant to a work task [↑](#footnote-ref-2)