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Novel Maritime Wireless Communication based on Mobile Technology for the Safety of Navigation: LTE-Maritime focusing on the Cell Planning and its Verification

† Woo-Seong Shim · Bu-Young Kim · Chan-Yong Park** · Byeong-Hyeok Lee****

**,† Maritime Digital Application Unit, Korea Research Institute of Ships and Ocean Eng., Daejeon 34103, Republic of Korea*
***Public Safety Network O&M Center Network Control Headquarter, Korea Telecom(KT), Seoul 03154, Republic of Korea*
****Enterprise Business Group, Consulting & Implementation Unit 1, Korea Telecom(KT), Seoul 03154, Republic of Korea*

Abstract : *Enhancing the performance of maritime wireless communication has been highlighted by the issue of cell planning in the sea area because of lack of an appropriate Propagation Loss Model (PLM). To resolve the cell planning issue in vast sea areas, it was essential to develop the (PLM) matching the intended sea area. However, there were considerable gaps between the prediction of legacy PLMs and field measurement in propagation loss and there was a need to develop the adjusted PLM (A-PLM). Therefore, cell planning was performed on this adjusted model, including modification of the base station's location, altitude, and antenna azimuth to meet the quality objectives. Furthermore, in order to verify the availability of the cell planning, Communication Service Quality Monitoring System (CS-QMS) was developed in the LTE-Maritime project to collect LTE signal quality information from the onboard equipment at regular intervals and to ensure that the service quality was high enough to satisfy the goals in each designated grid. As a result of verification, the success rate of RSRP was 95.7% for the intensive management zone (IMZ) and 96.4% for the interested zone (IZ), respectively.*

Key words : *e-Navigation, maritime wireless communication, Long Term Evolution(LTE), maritime radio propagation loss model, LTE-Maritime*

1. Introduction

Human efforts to secure and enhance maritime safety are being diversified to address the problems caused by a growing amount of data to be exchanged. The e-Navigation strategy and implementation plans of the International Maritime Organization (IMO) have enabled the harmonized emergence of various e-Navigation services, which also requires more robust processing of data and information in traditional ship operations as ship safety and increased traffic efficiency. Furthermore, the advent of various e-Navigation services has led to research on new maritime communication by analyzing and leveraging the multiple on-shore radio communications(Jeong and Kim, 2008).

As one of the e-Navigation projects to implement services to the maritime users, the Republic of Korea has started the Korean e-Navigation R&D project for five years from 2016, which included the sub-project of developing the maritime high-speed wireless communication network in the coastal sea area, named as LTE-Maritime project. In the first phase of LTE-Maritime, the feasibility of LTE technology in the maritime field has been investigated in the test-bed of the Korean coastal sea area and verified the possibility of LTE communication coverage up to 100 km from the base station in maximum. Regarding the initial analysis result of the first phase of LTE-Maritime feasibility, Jo et al.(2018) has shown that LTE communication could propagate and provide meaningful service up to 100km from the field test result. However, there were also considerable differences between the prediction of the existing Propagation Loss Model(PLM) and measurements of huge sea areas.

For a potential high-speed maritime communication, several studies utilized telecommunication technologies being used on land. Lopes et al.(2014) showed a study to enable communication at sea using Wi-Fi technology in the 5.8 GHz band, and Zhao et al.(2018) proposed that LTE could be a suitable solution for long-distance communication at sea. For the maximum theoretical coverage based on LTE technology, Jo et al.(2018) have shown that LTE-based high-speed maritime wireless communication service up to 100 km could be practically possible with field test and measurement verification in the coastal area. Regarding the coverage extension of LTE

† Corresponding author, pianows@kriso.re.kr +82-42-866-3662
* bky@kriso.re.kr +82-42-866-3142
** chanyong1.park@kt.com
*** byeonghyeok.lee@kt.com

communication in sea area, Park et al.(2017) has proposed that the maximum service limit of the LTE system could be extended up to 200km in maximum by shifting the time advance parameter of LTE when the base station of LTE might be located at high altitude enough to have a line of sight to the edge of coverage.

The studies, as mentioned above, of mobile communication technology in the maritime field only showed the practical possibility of LTE with a considerable difference of propagation level prediction of radio waves in huge sea areas. Jo and Shim(2019) showed and explained that there was a level of difference between field measurements of up to 100km sea area and legacy PLMs such as Free Space Path Loss(Klozar L. and Prokopec J., 2011), Two-Ray Path Loss(Enaya R. and Ivica Kostanic D., 2020) and Okumura-Hata model. It meant that legacy PLMs could not be directly adopted as a propagation loss model of a nationwide maritime network with 100km coverage in maximum. In the case of Park et al.(2017), to provide overwhelming coverage, they proposed a three-slope propagation model adjusted with the field measurements to acquire the matching propagation loss model for vast sea area. The Adjusted Propagation Loss Model(A-PLM) has shown the meaningful match between predicted and test results, but the result of this study could be helpful when two base stations should be selected so far from each other that the 0-100km section of the base station serving the 100-2000km area did not overlap with that of other base stations serving the 0-100km sea area. This propagation model could also be helpful only in different frequencies between the vicinity of stations.

Considering the lack of appropriate PLM for cell planning of huge sea areas with one available frequency for LTE-Maritime, empirically, A-PLM was proposed to develop propagation loss prediction for huge sea areas of target coverage.

Following chapter 1 as an introduction to explain why A-PLM was necessary for LTE cell planning of huge sea area, chapter 2 explains the actual cell planning methods and procedure. Then, the verification of the cell planning was shown in Chapter 3, and finally, it concluded in Chapter 4.

2. LTE-Maritime Cell Planning

Considering the given development period, the A-PLM was developed using the signal quality information measured from the actual sea in each designated sea area.

The LTE-Maritime project has defined the target zone of its quality goal as two distinguished 0-30km from the shoreline as an Intensive Management Zone(IMZ) and 30-100km as an Interested Zone(IZ). The range of the distinguished zone was based on the statistics of domestic small and mid-sized ships navigating in the coastal area in aspects of maritime safety affair.

In aspects of station altitude, 100m, the figure was chosen as a separative reference to match the 50km line of sight distance. In the case of 100～500m station height, a sole A-PLM could not satisfy the comparison with the actual measurement data over the whole range, so it was

Table 1 Adjusted Propagation Models by Station Altitude and Cell coverage

Station Altitude	IMZ(Intensive Managing Zone, 0～30km)	IZ(Interested Zone, 30～100km)
0～100m	LTE-M_1, (H:0～100m, R:50km)	N/A
100～500m	LTE-M_2 (H:100～500m, R:50km)	LTE-M_3 (H:100～500m, R:100km)

Reference PLM :

$$PL_{ref} = 69.55 + 26.16\log(f_c) - 13.82\log_{10}(h_b) - 10\log_{10}(h_m) + (44.9 - 6.55\log_{10}(h_b))\log_{10}(d) \tag{1}$$

$when,\ f_c : center\ frequency,\ h_b : station\ height,\ h_m : height\ of\ user\ antenna,\ d : distance\ btw\ station$ and $user$

LTE-M_1 : $PL_{LTEM1} = 23.043 + 26.16\log(f_c) - 13.82\log_{10}(h_b) - 10\log_{10}(h_m) + (57.259 - 6.55\log_{10}(h_b))\log_{10}(d)$ (2)

LTE-M_2 : $PL_{LTEM2} = 25.864 + 26.16\log(f_c) - 13.82\log_{10}(h_b) - 10\log_{10}(h_m) + (58.782 - 6.55\log_{10}(h_b))\log_{10}(d)$ (3)

LTE-M_3 : $PL_{LTEM3} = 33.857 + 26.16\log(f_c) - 13.82\log_{10}(h_b) - 10\log_{10}(h_m) + (61.042 - 6.55\log_{10}(h_b))\log_{10}(d)$ (4)

distinguished as two A-PLMs.

The A-PLMs, which reflected the differences between the reference model used in the cell simulation and the actual measurements for each combination of the two levels of zones and base stations with altitudes of 0-100m and 100-500m, are shown in Table 1.

2.1 Adjusted Propagation Models

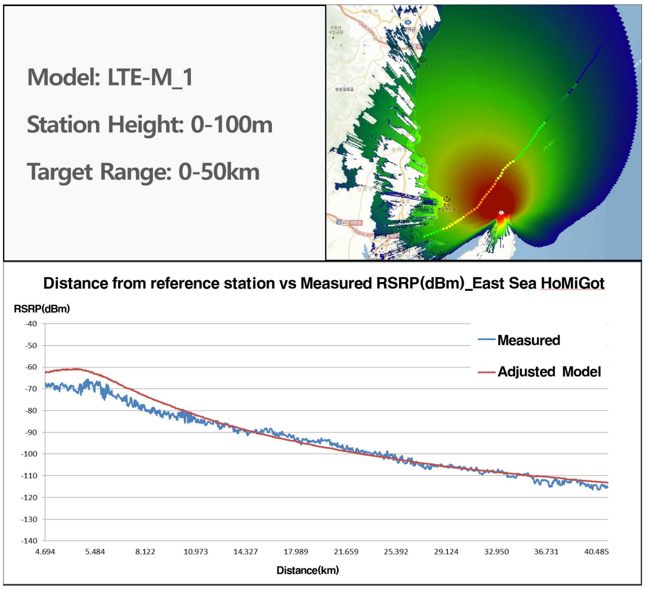

Fig. 1 Propagation Model LTE-M_1(H:0~100/R:0~50km)

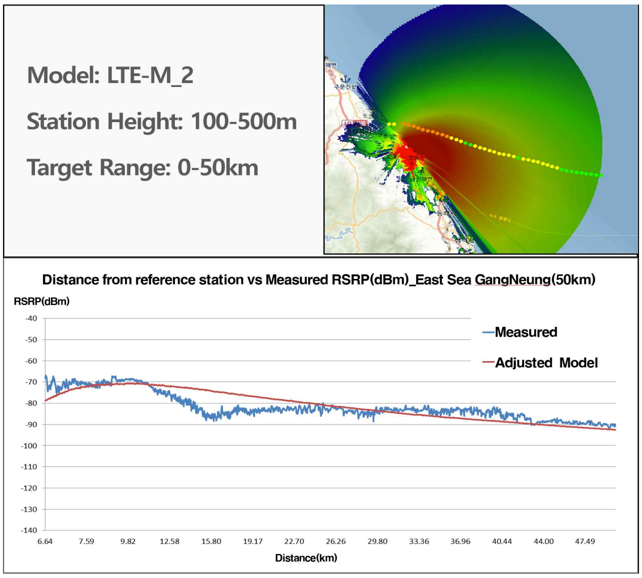

Fig. 2 Propagation Model LTE-M_2(H:100~500/R0~50km)

Fig. 1 shows the adjusted propagation loss model of the LTE-M_1 to be applied to the sea area with a radius of up to 50km when the altitude of the base station was less than 100m. It also shows a close match in aspects of the received signal to the reference within a designated coverage radius. Fig. 2 presents the LTE-M_2 model to be applied to the sea area with a radius of up to 50km when the altitude of the base station was in the range of 100~500m with the comparison result of real-sea measurement data. It also shows an almost close match only except a point of around 15km within an available simulation tolerance. Finally, the LTE-M_3 model in Fig. 3 is compared with the real sea measurement data for the sea area with a radius of 100km when the altitude of the base station was 100~500m.

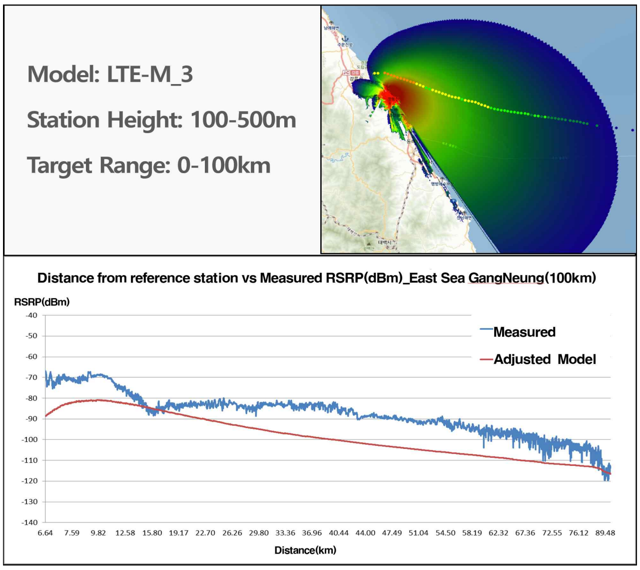

Fig. 3 Propagation Model LTE-M_3(H:100~500/R0~100km)

The A-PLM, LTE-M_3 shows less match than the previous ones, but it could be accepted considering the distance range of 0-100km and the purpose of the cell planning.

For a complete overview of coverage goal of up to 100km of LTE-Maritime, Fig. 4 shows the comparison of A-PLMs with the legacy Two-Ray model. It could be seen that the predicted value of A-PLM in the LTE-Maritime frequency showed a similar pattern to the actual data more closely than the legacy Two-Ray model. However, the value of the predicted A-PLM was somewhat lower than the actual measured data, especially in a range over 50km because we adjusted PLM parameters for future cell planning not to be exaggerated and somewhat conservative.

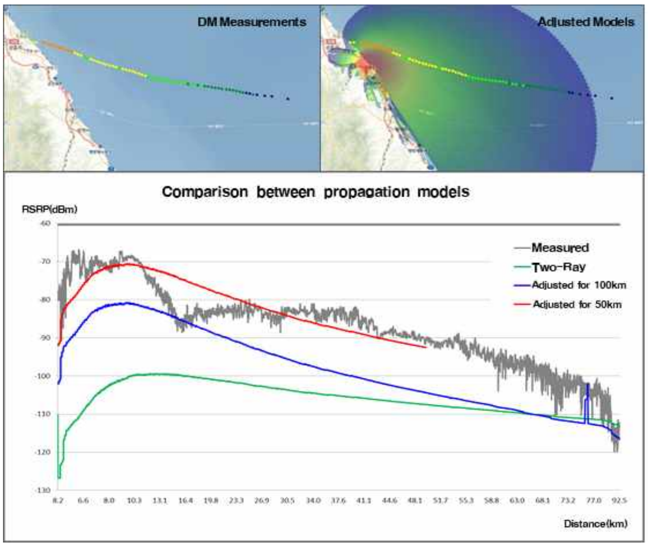

Fig. 4 Comparison of two-ray & adjusted model(for target range 50km and 100km) with field measured value

2.2 Cell Planning by Simulation

As a procedure of cell planning for telecommunication networks, the location and altitude of each base station (including tower), the presence of line-of-sight by the azimuth of antennas, and the specification of base station antenna equipment should be determined. Therefore, in the construction of LTE-Maritime, an on-site inspection of telecommunication base stations near the country's coast was conducted, and the number of antennas and azimuths of antenna equipment were considered to achieve optimal cell planning results.

The simulation tool used for cell planning was CelTREK Outdoor with the Reference model in Table 1 as a default model. This model was a Modified Hata-Epstein model that combined a modified model that extended the applied frequency band to 3,000MHz in existing Okumura-Hata models with the Epstein-Peterson method that reflected the diffraction of propagation by obstacles. Empirical correction of existing models using differences between existing Okumura-Hata models and real-world data in certain regions, such as Farhoud(2013), might be valuable to develop PLM in a particular area. Table 2 shows the parameters of the CelTREK simulation software used.

Table 2 Parameters of Simulation Tool

Parameters	Value
Frequency Band	773-783 MHz
Antenna	LTE-M. KA 2T2R / 4T4R / OTHAD
Ant. Gain	Reference Sta.(15.78 dBi) / UE(6dBi)
Ant. Height	Measured value on each ref. station
Max. Tx Power	2T2R, OTHAD(40W) / 4T4R(80W)
UE Ant. Height	10 m

2.3 Cell Planning Results

The target region of LTE-Maritime had enormously complex coastal terrain. Therefore, for a baseline of cell simulation, the data of Korea Hydrographic and Oceanographic Agency was used as a coastline. Among the quality goals of LTE-Maritime, the RSRP(Reference Signal Received Power) is shown in Table 3.

Table 3 Requirements of Signal Quality of LTE-Maritime

Zone	Range	RSRP	Success Rate
IMZ	0~30km	-95dBm	95%>
IZ	30~100km	-115dBm	90%>

As a result of cell planning, the results of A-PLM simulations that met quality targets for the sea area up to 100km from the coastlines by region of the Republic of Korea are shown in Table 4.

Based on the defined coastline, the 100km ocean boundary was defined on the simulation tools, and the entire area of the simulated sea areas was expressed as Base Area for each region. In Table 4, column CA is the area of the sea area predicted to be over -115dBm due to the cell simulation, which was targeted in Table 3. Column CHA means that the base stations might not cover some sea areas with a limited altitude of base stations or geographical obstacles. ICA means the sea area where services were expected to be provided by the individual base station alone among the CA area.

Adding all simulated coverage nationwide, the whole sea area from the coast to 100km was 180,944.19㎢ The covered area above the service quality goal of LTE-Maritime was 178,818.04㎢ with 98.98% of all. In simulated regions, there were some regions with high ICA values such as Geyong-sang(S), Uleung, Jeol-la(South), Jeju, Chung-cheng(S), and those were expected to have possible areas with limited service quality because of their geographical characteristics. These issues should be considered for maintenance and further developments of the network.

Table 4 Estimated service quality of LTE-Maritime by cell planning

Name (Province or City)	Base Area	CA(Coverage Area)	CHA (Coverage Hole Area)	ICA(Individual Coverage Area)
Gang-won	18,885.46㎢	17,839.75㎢(94.46%)	1045.72㎢(5.54%)	0㎢
Geyong-gi	530.67㎢	530.67㎢(100.0%)	0㎢(0.00%)	0㎢
Geyong-sang(S)	10,178.21㎢	10,177.61㎢(99.99%)	0.60㎢(0.01%)	2,035.52㎢
Geyong-sang(N)	17,603.40㎢	17,603.04㎢(100.0%)	0.36㎢(0.00%)	0㎢
Uleung	19,477.45㎢	18,591.41㎢(95.45%)	866.04㎢(4.55%)	4,647.85㎢
Ulsan	3740.16㎢	3740.16㎢(100.0%)	0㎢(0.00%)	0㎢
Jeol-la(South)	33,636.58㎢	33,625.86㎢(99.97%)	10.72㎢(0.03%)	820.14㎢
Jeol-la(North)	7,409.43㎢	7409.31(99.99%)	0.12㎢(0.01%)	1,234.88㎢
Jeju	40,193.72㎢	40,183.56㎢(99.97%)	10.16㎢(0.03%)	3,091.04㎢
Chung-cheong(S)	12,641.10㎢	12,641.02㎢(100.0%)	0.08㎢(0.00%)	1,149.18㎢
In-cheon	10,252.50㎢	10,141.78㎢(98.92%)	110.72㎢(1.08%)	724.41㎢
Busan	6,395.51㎢	6,333.87㎢(99.04%)	61.64㎢(0.96%)	0㎢
National	*180,944.19㎢*	*178,818.03㎢(98.98%)*	*2,126.16㎢(1.02%)*	*13,703.02㎢*

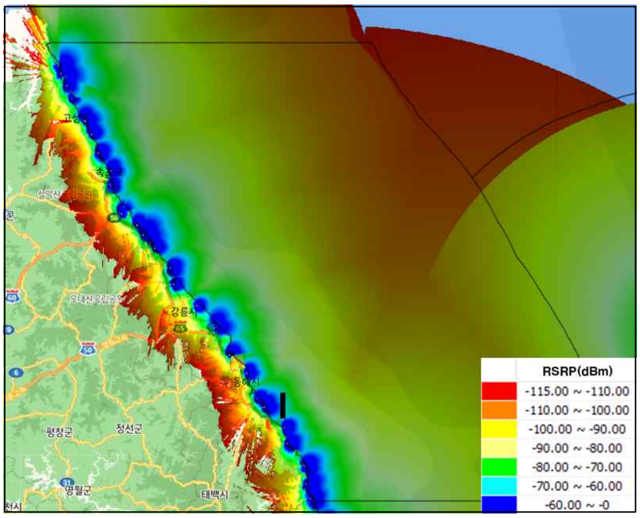

Fig. 5 Cell Simulation Result (East coast)

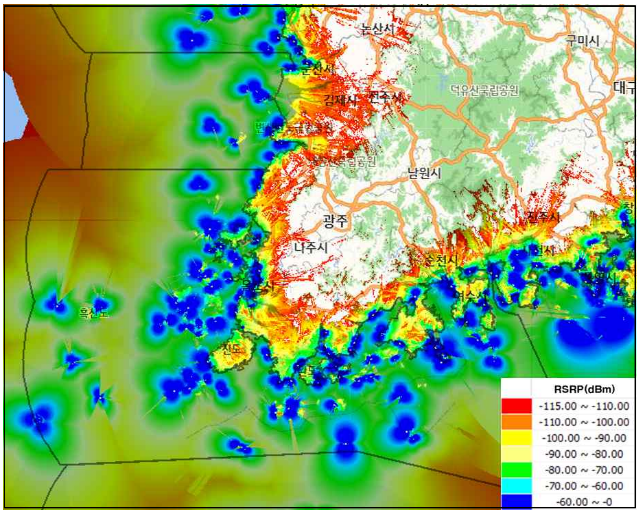

Fig. 6 Cell Simulation Result (Southwest coast)

Fig. 5 shows the cell simulation results on the country's east coast and explained the possibility that base stations lined up in a straight line along the coast could cover the service area designated. For the case of Gang-won located in east coast of the country with no ICA regions, it could be interpreted that there might be several base stations with relatively high altitudes.

The result of the southwest region of the cell simulation is demonstrated in Fig. 6 with a legend for RSRP value in dBm unit. Comparing the case of the east coast, we could expect a good quality signal strength by using the base station installed on the islands even far from the coast.

3. Verification of Cell Planning

In order to verify the cell planning, it was necessary to secure communication quality measurement data in vast range of actual sea areas. To this end, the Communication Service Quality Monitoring System (CS-QMS) was developed in the LTE-Maritime project, which collected LTE signal information from onboard equipment and analyzed the signal quality of the whole service sea area in the main control center.

Since the sea area to be verified was 180,944㎢, it was physically impossible to measure and verify the entire sea area at once. Therefore, LTE-Maritime onboard equipment was installed on tens of ships sailing across the entire service area to verify cell planning results for as wide sea areas as possible in a short period. The onboard equipment has been designed to send the quality information of the received signal to the LTE-Maritime control center located in Se-Jong city.

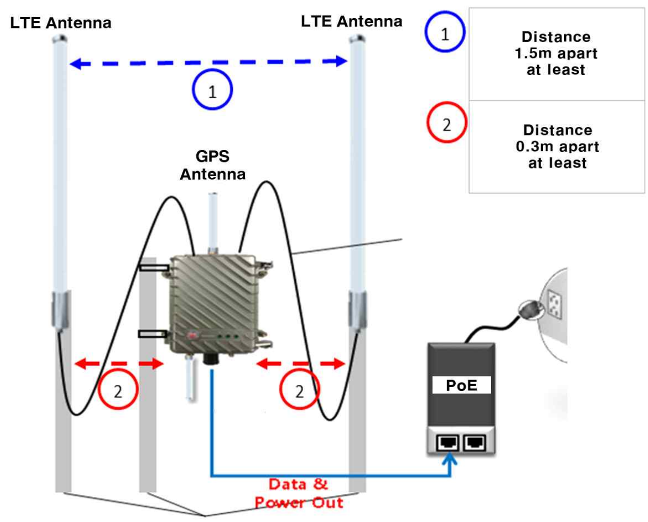

Fig. 7 LTE-M. Onboard User Equipment & Installation

When installing the onboard equipment, it was preferable to install the antenna height as high as possible and set up the distance between antennas to be at least 1.5m apart, considering the function of the equipment operating as MIMO. In addition, the distance between the equipment's main body and antennas should also be apart more than 0.3m, and the equipment was powered through the PoE(Power of Ethernet) interface.

All information of signal quality received from the ships was processed by the unit grid size of 4.5km(lat)×5.5km(lon), which was designed by the unit transformation of the coordinate system.

To verify cell planning, the average value of accumulated RSRPs on each grid was chosen in ten months to consider the weak value due to any interference during the field measurement.

By applying the grid size of CS-QMS described above, it was analyzed the number of grids for IMZ and IZ sea areas and compared the quality information accumulated in each grid with the target quality goals in Table 3. Then, it was finally calculated the number of grids of success with the satisfaction rate shown in Table 5.

Table 5 Verified Result of LTE-M. Cell Planning

	IMZ	IZ	SUM
No. of Grid	2,310	4,575	7,075
Pass Grid	2,402	4,412	6,814
Pass Rate	95.7%	96.4%	96.3%

4. Conclusion

In order to establish a high-speed maritime wireless network based on LTE technology in huge sea areas up to 100km from the coast, the cell planning of the communication network was an essential step and should be processed with the PLM appropriate to be applied for

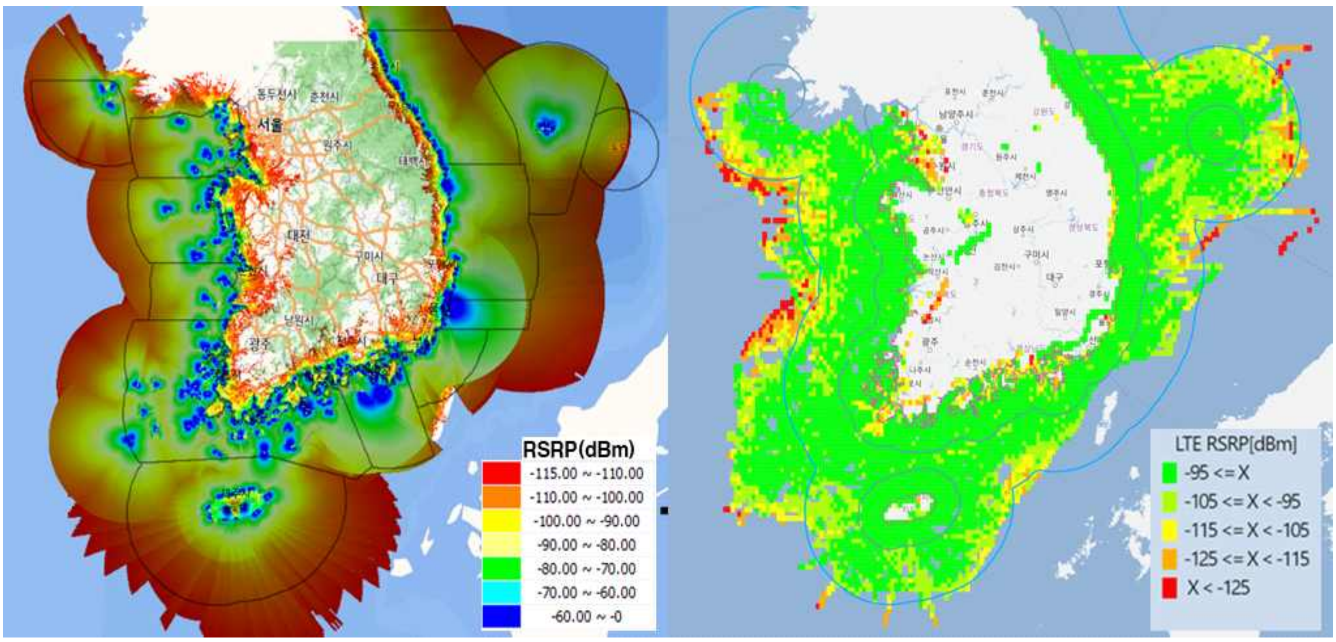

Fig. 8 Verification of Cell Planning of LTE-M (left: Cell Planning Result, right: Field Measurement in 10 months)

the service area of sea. The legacy PLMs, which have been generally used, were unsuitable for long distances and far sea areas up to 100km from the coastline.

To overcome this issue, the basic model of the software to be used for cell planning was empirically adjusted using real-sea LTE signal measurement and developed three A-PLMs as a result. Finally, these A-PLMs were applied to the cell planning software to satisfy the quality goals of the LTE-Maritime.

As a result of verification, we found the quality level of IMZ(more than -95dBm) with a goal of 95% success rate was satisfied with the 95.7%, and IZ(more than -115dBm) with a goal of 90% success rate was also satisfied with the 96.4%. However, considering that those success rate figure was driven during the period of resolving the interference problem of the surrounding network and was obtained while performing network optimization, it would be expected to be improved through the actual operation of the network in additional time.

LTE-Maritime is the world's first high-speed communication network in the sea that guarantees LTE service to a certain level higher than the quality target for the sea area of up to 100km. While the internet on land produces massive value-added services for our lives, LTE-Maritime can be expected like an internet infrastructure to implement the fourth industrial revolution of the ocean. Furthermore, it is expected that the novel high-speed wireless communication network, e.g., LTE-Maritime and Maritime-S2X, will be expanded to be used for maritime autonomous surfaced ships and unmanned ships.

Acknowledgements

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