JURNAL INFOTEL
Informatics - Telecommunication - Electronics
Website: http://ejournal.st3telkom.ac.id/index.php/infotel
ISSN: 2085-3688; e-ISSN: 2460-0997

Evaluation of cellular network performance involving the LTE 1800 band and LTE 2100 band using the drive test method

Yuliarman Saragih[1,*], Ridwan Satrio Hadikusuma[2], Agatha Elisabet S.[3]
[1,2]Faculty of Electrical Engineering, Universitas Singaperbangsa Karawang
[3]Department of Mechanical Engineering, Pusan National University
[1,2]Jl. Sunset Avenue, Bekasi 17510, Indonesia
[3]2 Busandaehak-ro 63beon-gil, Busan 46241, Republic of Korea
[*]Corresponding email: yuliarman@gmail.com

Received 23 August 2022, Revised 3 October 2022, Accepted 4 November 2022

Abstract — In the 4G Network on the cellular system, the possibility of high traffic increase is a big problem for users, the proposed solution is to reduce the possibility of full traffic and decrease the quality of the cellular system by dividing the frequency channel into several parts. The purpose of this paper is to study the effect of network optimization on the value of Key Performance Indicator (KPI) in the LTE 1800 and LTE 2100 bands. KPI values, In the LTE 1800 and LTE 2100 bands tested using the drive test method using the Telkomsel sim card provider, the results show that the LTE 2100 band on the TML 013 site has a very high CSSR number compared to the band LTE 1800 which is 99.73% after optimization. The results showed that the LTE band 2100 is better than the LTE band 1800 in terms of KPI Summary.

Keywords – Band 1800, Band 2100, CSSR, KPI, LTE

I. Introduction

The fourth generation (4G) wireless network offers much faster internet speeds than the previous generation (3G). This fourth generation cellular communication system generally uses Long Term Evolution (LTE) technology as the engine. 4G can provide a comprehensive IP solution where voice, data and traffic can reach users anytime and anywhere, at a higher data rate than previous generations [1]. 4G is also a fully integrated IP based system. This will be achieved once wired and wireless technologies are convertible and capable of delivering speeds of 100Mb/s and 1Gb/s both indoors and outdoors with premium quality and high security [2].

The 4G technology in Indonesia includes: LTE, LTE Advanced and WiMax. With the recent increase in interest in data-inspired communications and multimedia services, caused by the increase in smarter end-user devices and the search for interaction among many things; heralded by IoT, the development of 4G networks continues to be developed. Even already starting to implement modern communication infrastructure (5G) has become more challenging [3]–[5]. In Indonesia itself, LTE technology is widely used on 4G networks, especially Telkomsel providers. LTE is a name given to a project of the Third Generation Partnership Project (3GPP). LTE is a development of Universal Mobile Telecommunication System (UMTS) and High Speed Downlink Packet Access (HSDPA) technology where LTE is referred to as the 4th generation [6]. In providing speed, LTE networks have the ability to transfer data up to 100 Mbps on the downlink side and 50 Mbps on the uplink side. In addition to having data transfer speeds, LTE can also provide greater coverage and capacity of services, reduce operational costs, support the use of multiple antennas, be flexible in the use of operating bandwidth and can also be integrated with existing technologies. The operating bandwidth on LTE is flexible, which is up to 20 MHz, and the maximum work in the bandwidth range varies between

1.4 – 20 MHz. LTE has radio access and a core network that can reduce network latency and improve system performance and provide interoperability with existing 3GPP technologies[x-x]. The allocation of 4G frequencies in Indonesia ranges from 1920 MHz to 2400 MHz [7]. In this paper, the author focuses on Evaluation of Cellular Network Performance Involving the LTE 1800 Band and LTE 2100 Band Using the Drive Test Method.

Previously, there was a similar study on "Analysis and optimization of 4G LTE network in urban area with carrier aggregation technique on 2100 MHz and 1800 MHz frequencies" by Pramono *et al.*. In their research, a drive test method was also carried out to retrieve 4G data on banf 1800 and 2100 using carrier aggregation techniques. Measurements were made based on the cellular operator's target Key Performance Indicator (KPI). This study aims to analyze the implementation of optimization on LTE in terms of signal level, RSRP, SINR, throughput, user connected in accordance with KPI by a cellular operator in Indonesia. The results of comparison of the existing network value with the results of optimization on the signal level increased by 6.53%, RSRP value increased by 12.44%, SINR value increased by 22.45%, mean throughput increased by 46.83%, user rejected decreased by 1.6% . Based on the simulation results above, physical tuning and expand bandwidth techniques with carrier aggregation can be used as an alternative for operators to improve the quality of 4G services in the Surakarta area [8]. There is also research related to "Analysis of key performance indicators of a 4G LTE network based on experimental data obtained from a densely populated smart city" by Agbotiname Lucky Imoize and Orolu Kehinde. The KPI data provide candidate information required for effective network planning, performance analysis and optimization. However, inadequate KPI data could limit efficient network planning leading to escalating operational cost, and this could adversely affect the subscribers of the network. To this end, this article presents radio frequency (RF) measurements and evaluation of KPIs taken at 1876.6 MHz with a bandwidth of 10 MHz, for an operational 4G LTE network in Nigeria [9].

For the first time, research related to evaluation of cellular network performance involving the LTE 1800 band and LTE 2100 band using the drive test method was conducted. The researcher uses the 4G LTE network from the Telkomsel provider. The measurements taken are measurements using the drive test method on the LTE 1800 band and LTE 2100 band and then an evaluation is carried out to compare which frequencies have good quality based on the KPI. Data was measured using Nemo Handy software using the drive test method. By using the drive test method, information on site down or not on-air can also be obtained by taking into account signal strength, signal quality and BCCH- ARFCN/ScramSC/PCI in areas adjacent to a site. If a logfile shows low signal strength even though the distance from a site is not too far, it should be suspected that the site might be down. To achieve quality test results, the vehicle should be driven at a moderate speed of up to 30 km/h to eliminate the Doppler effect [6], [10]–[14].

II. Research Method

The study was conducted using the drive test method using a Telkomsel sim card provider. Measurements were taken during busy times at 09.00 - 14.30 because at that time user traffic increased dramatically due to work and education needs. The research was conducted in Central Kalimantan, precisely in Tamiang Layang at the TML013 site. At the time of measurement, the researcher used the Samsung Galaxy S5 user equipment with Nemo Handy software then the results of the measurement log file were analyzed using the Nemo Analyzer on the Laptop for network optimization. After the drive test was carried out, the researchers also tested the internet speed using the ookla speed test software at a distance of 100 m from the site. Taken at a distance of 100 m so that the user equipment is in the dominant area. In areas without dominant cells, the reception rate of the serving cells is similar to that of the recipient's neighboring cell rate and the downlink signal reception rate between different cells is approaching the cell re-election threshold. Receive levels in areas without dominant cells too not satisfactory. The SINR of the serving cell becomes unstable due to frequency reuse, and even accepts the quality to be unsatisfactory. In this situation, the dominant cell is often re-elected and changed to standby mode. As a result, frequent handovers or downgrading of services to the EU in connected mode due to poor signal quality. An area without a dominant cell can also consider a weak coverage area [15]–[21].

Prior to conducting the research, a literature study was conducted to collect information and data from several sources for the needs of analysis and design related to this research. After the literature study, signal data was collected using the drive test method four times. Two of them before optimization and two times after network optimization. The research flowchart can be seen in Fig. 1.

After the measurement data is collected, optimization is carried out in order to get better user quality. Optimization of the cellular network of the Radio Access Subsystem is an optimization activity on the special cellular network in the Radio Access section by observing, analyzing and making changes to both the hardware/software side related to the performance on the Radio Access side, both on the existing network or the newly installed network. new. Generally, network optimization is done by changing

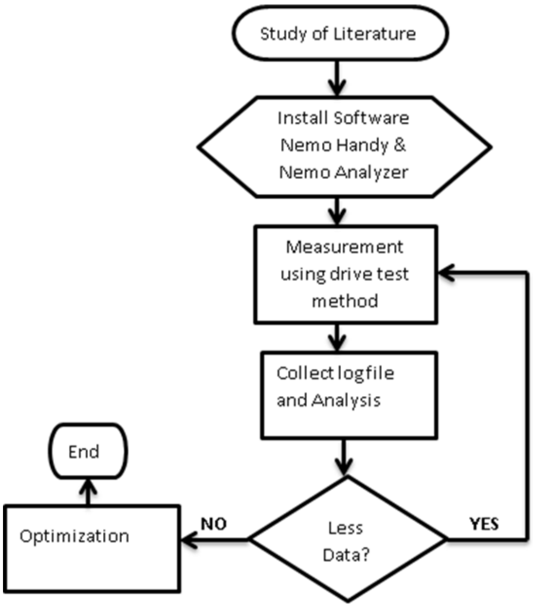

Fig. 1. Research flowchart.

the mechanical tilting or electrical tilting of the antenna and increasing or decreasing the transmitted power [22], [23]. According to recommendations from the International Telecommunication Union (ITU) there are three categories of classification of KPI for evaluating a network, namely Accessibility, Retainability, and Integrity [24].

The type of antenna used during the research at the TML013 site is the Tongyu TDQ-182020DE- 65F type which is capable of transmitting LTE with the DCS 1800, U2100, LTE 1800 and LTE 2100 system bands at once. The antenna is placed at a height of 55 m from the ground with an azimuth of 50^o in sector 1, 95^o in sector 2 and sector 3 of 270^o. In order to get optimal signal quality, it is necessary to calculate the link budget when you want to install antenna [25]. The link budget is an estimate of the maximum attenuation value of wave propagation that is still tolerated so that eNodeB/BTS and UE can still be connected properly, this attenuation/path loss value is called the Maximun Allowable Path Loss (MAPL) value. MAPL also determines the calculation of the distance or cell radius in determining the coverage area, and can determine the received power level (Received Signal Level) received by the receiver to the EU [6], [26]–[28]. The MAPL calculation for the uplink direction is as follows:

$$EIRPul = P\,eNodeB + GUe - LC \tag{1}$$

$$MAPLul = EIRPul - SRminul - Lindoor - Msf \tag{2}$$

While the MAPL calculation for the downlink direction can use the following formula:

Fig. 2. LTE 1800 network element information.

$$EIRPul = PUe + G\,eNodeB - LB \tag{3}$$

$$MAPLul = EIRPdl - SRmindl - Lindoor - Msf \tag{4}$$

with EIRP as the effective isorated radiated power uplink/downlink expressed in decibels (dB), Msf as shadow fading margin expressed in decibels (dB) and Lindoor as indoor penetration loss expressed in decibels (dB).

III. Result and Analysis

After measuring using the drive test method, the data measured using the Nemo Handy software will be directly analyzed as a reference for optimizing the cellular network in order to achieve better network performance. Measurements were carried out using user equipment from Samsung type S5 because the cellphone supports Nemo Handy software and can be done without the help of an external GPS and using a sim card from the Telkomsel provider when measuring. For analysis, researchers used Nemo Analyzer software to analyze the measurement results measured using Nemo Handy software.

The research was conducted when traffic was high, namely at 09.00 - 14.30 in the suburban area. The Network Element information on the LTE 1800 and LTE 2100 bands can be seen in Fig. 2 and Fig. 3. Network element information is needed for further log file analysis because it shows information from the bands used such as MCC, MNC, RSRP, SNR to RSRQ. To display network element information on the equipment used, the user can press dial *#0011# to open the service mode in order to view the network element information.

As shown in Fig. 2 and Fig. 3, it can be seen that Band 3 (LTE 1800) and Band 1 (LTE 2100) have a significant difference in RSRP which will greatly affect the quality of the signal speed in each band. The average RSRP on LTE 1800 is -100.3dBm and the

Fig. 3. LTE 2100 network element information.

Fig. 4. LTE 1800 plot overview.

Fig. 5. LTE 2100 Plot overview.

average RSRP on LTE 2100 is -96dBm. Both values are taken at a distance of 100 m from the site, so the RSRP should be of small value. This large RSRP allows users to get poor service quality and don't even get LTE services. To get a good network quality, it is necessary to optimize [29]. Researchers took data using the drive test method and then analyzed for network optimization.

A. Analysis Signal Quality Overview Plot

To predict path losses on irregular surfaces during drive tests, the Cost 231 propagation model can be used. Cost 231 propagation has a working frequency of up to 2 GHz. Cost 231 propagation equation can be known by using the equation:

$$PL = 46,3 + 33,9\log 10 - 13,82\log 10hBS \\ -a(hm) + (44,9 \\ -6,55\log 10(hBS)\log 10(d) + C\,[dB] \quad (5)$$

where, hBS indicates base station antenna height(30 m to 200 m) with C = 0 dB for suburban or open environment and C = 3 dB for metropolitan area. In the field measurements, the site covers 100% of the signal and there is no cross feeder in the service area both on the LTE 1800 band and on the LTE 2100 band as shown in Fig. 4 and Fig. 5. on the LTE 1800 band, sector 1 gets 47.64% service, sector 2 gets 35.28% service and sector 3 gets 17.08% service. There are some signal reflections from sector 1 at several points in sectors 2 and 3 due to the contours of the land around the site being wet land and surrounded by swamps.

In the LTE 2100 band, 48.48% of services are obtained in sector 1, 33.95% in sector 2 and 17.58% of services in sector 3. From figure x it can also be seen that there is no cross feeder in the service area because each area covers according to the data site. The reflection of sector 1 signal in sector 3 area is caused by improper mechanical tilting antenna, so it is necessary to do a site audit. The coverage area on the LTE 1800 band is capable of reaching up to 10 km as shown in Fig. 6.

Speed tests were also carried out in each sector on the LTE 1800 and LTE 2100 bands using the ookla speed test software as shown in Fig. 2 and Fig. 3. The measurement results show that the LTE 1800 band has an average download speed of 7.76 Mbps and an average upload speed of 17.37 Mbps with an average jitter of 36 ms. While the LTE 2100 band has an average download speed of 28 Mbps and an average upload speed of 11 Mbps with an average jitter of 7.3 ms. With this average, it can be seen that the LTE 2100 band has advantages in terms of data transmission speed and better network quality. Jitter itself can be searched with the following formula:

$$Jitter = \frac{\text{total variation delay}}{\text{total packet received}} \quad (6)$$

The greater the jitter value, the worse the network

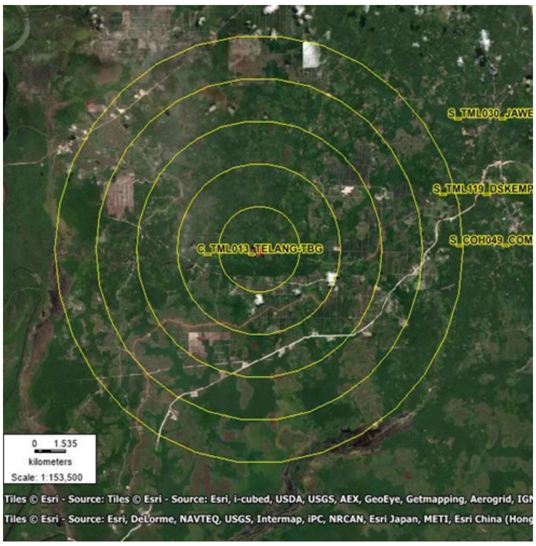

Fig. 6. LTE 1800 & LTE 2100 coverage.

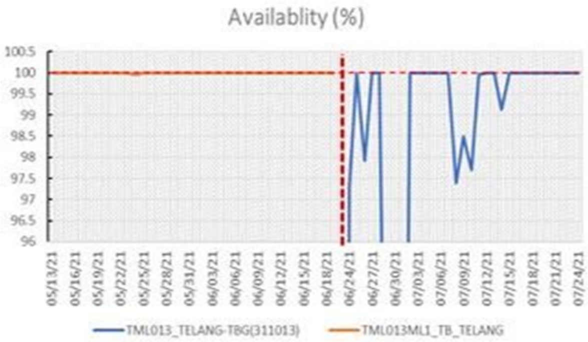

Fig. 7. LTE 1800 availability.

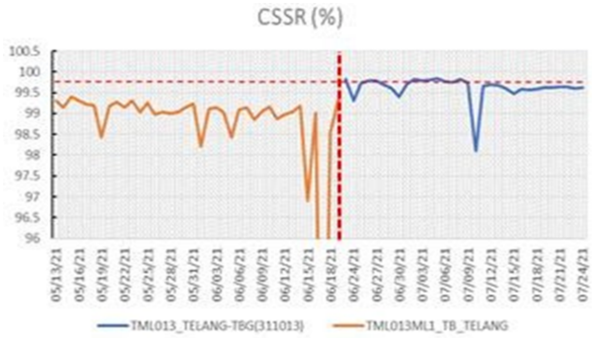

Fig. 8. LTE 1800 CSSR.

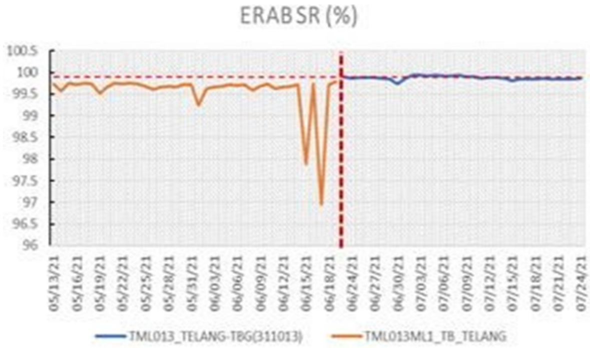

Fig. 9. LTE 1800 ERAB SR.

quality. From the speed test measurement results, the LTE 2100 band also has a lower average jitter than the LTE 1800 band.

B. Summary of KPI Performance LTE 1800

Measurements have been made using the drive test method four times to determine the KPI on the LTE 1800 band. The results show a fairly good value, especially for CSSR which has an average value of 94.65% before optimization and an average of 99.63% after optimization. KPIs can be observed in Table 1.

Table 1. Summary of KPI Performance LTE 1800

KPI(%)	Average Before	Average After	Improve-ment	Result
Availability	100	100	0.00	Maintain
RRC Est. SR	99.52	99.81	0.29	Improved
E-RAB SR	98.29	99.85	1.65	Improved
CSSR	94.65	99.63	4.98	Improved
Service Drop Rate	0.01	0.01	0.00	Maintain
Intra LTE HO SR	97.77	99.84	2.07	Improved
Inter LTE HO SR	88.76	99.61	10.85	Improved
CSFB Prep. SR	99.97	99.95	-0.02	Maintain
COI Average	7.76	10.43	2.66	Improved
Spectral Efficiency 2	1.1	1.66	0.55	Improved
DL Traffic Volume (Gbyte)	503.72	473.54	-30.18	Degraded
Payload (Gbyte)	551.58	502.88	-48.70	Degraded

The availability of the 4G network on the LTE 1800 band had decreased from July 06 to July 07 as shown in Fig. 7. while after being optimized for availability, it starts to show a stable value. The ability of users to access the network to initialize communication is very good because it has a stable ERAB success rate as shown in Fig. 9. From Fig. 8, we can also see that the Call Setup Success Rate (CSSR) shows good results, allowing users to make phone calls without having to drop calls or block calls.

From Table 1 there is a large DL Traffic volume, indicating that there are high traffic conditions on the network but has good mobility so that users can move freely from one place to another without disconnection because the table shows the Intra Freq HO SR value of 99.84% after optimization.

Table 2. Summary of KPI Performance LTE 1800

KPI(%)	Average Before	Average After	Improve-ment	Result
Availability	100.00	100	0.00	Maintain
RRC Est. SR	99.69	99.87	1.18	Improved
E-RAB SR	99.60	99.87	0.27	Improved
CSSR	97.97	99.73	1.76	Improved
Service Drop Rate	0.01	0.01	0.00	Maintain
Intra LTE HO SR	98.67	99.68	5.64	Improved
Inter LTE HO SR	94.12	99.68	5.56	Improved
CSFB Prep. SR	100.00	99.88	-0.12	Maintain
COI Average	9.85	10.63	0.78	Improved
Spectral Efficiency 2	1.10	1.66	0.55	Improved
DL Traffic Volume (Gbyte)	143.77	196.13	52.36	Improved
Payload (Gbyte)	153.10	207.87	54.77	Improved

C. Summary of KPI Performance LTE 2100

The same measurement has been carried out on the LTE 2100 band using the drive test method four times to determine the Key Performance Indicator. The results show a much better value than the LTE 1800 band, especially in CSSR which has an average value of 97.97% before optimization and an average of 97.73% after optimization. KPIs can be observed in Table 2.

The availability of 4G networks on the LTE 2100 band also experienced a decline from July 06 to July 09 as seen in Fig. 10. while after being optimized for availability, it starts to show a stable value. The ability of users to access the network to initialize communication is very good because it has a stable ERAB success rate as shown in Fig. 11. From Fig. 12, we can also see that the Call Setup Success Rate (CSSR) shows better and more stable results than the LTE 1800 band, allowing users to make phone calls without having to drop calls or block calls.

From Table 2, it can be seen that the DL Traffic volume is much lower, indicating that there are low traffic conditions on the network so that it has very good mobility compared to the LTE 1800 band so that users can move freely from one place to another without disconnection due to the table This shows the Intra Freq HO SR value of 99.68% after optimization.

IV. Conclusion

As the traffic load increases, the probability of blocking and the number of hand offs increases. When comparing the LTE 1800 and LTE 2100 strategies, we see that the probability of blocking in the use of LTE 2100 is much lower than the probability of blocking in the case of LTE 1800. The value of the KPI in the cellular system affects the quality of the network in the case of evaluation of the LTE band 1800 and LTE band 2100. The higher the CSSR, the lower the probability of a drop call or block call occurring. In the evaluation of the network after optimization, LTE 2100 shows a significant improvement in internet quality as seen from the average availability value reaching 100%.

References

[1] J. R. Goud, N. V. K. Rao, and A. M. Prasad, "Design of triple band u-slot MIMO antenna for simultaneous uplink and downlink communications," *Progress in Electromagnetics Research C*, vol. 106, no. 1, pp. 271–283, 2020.

[2] H. O. Osuwagu, A. C. Ajibo, S. O. Ugwuanyi, J. Nwachi-Ikpo, and C. I. Ani, "Dynamic bandwidth scheduling for WCDMA uplink transmission," *International Journal of Scientific & Engineering Research*, vol. 8, no. 2, pp. 798–805, 2017.

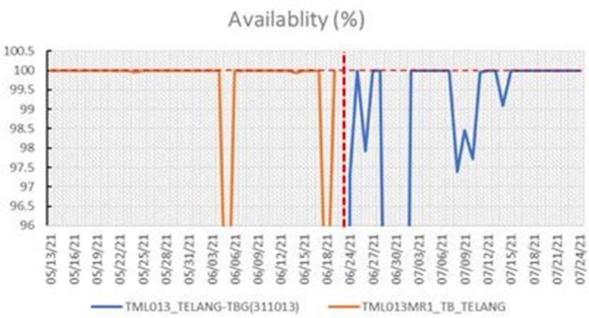

Fig. 10. LTE 2100 availability.

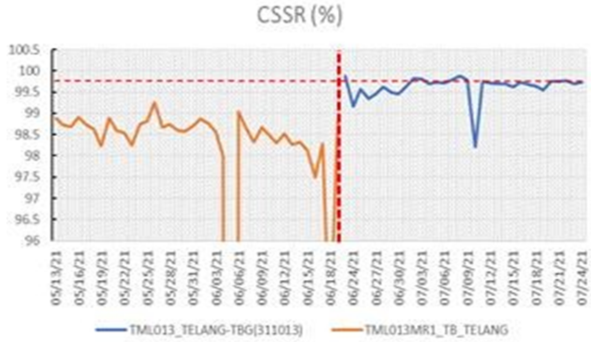

Fig. 11. LTE 2100 CSSR.

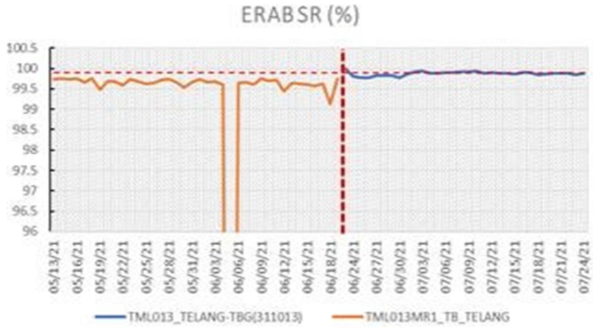

Fig. 12. LTE 2100 ERAB SR.

[3] A. Ajibo, I. Chinaeke-Ogbuka, and F. Udechukwu, "Comparative analysis of LTE backbone transport techniques for efficient broadband penetration in a heterogeneous network morphology," *TELKOMNIKA Telecommun Comput and Control*, vol. 17, no. 5, pp. 2226–2234, 2019.

[4] J. A. Hussein, S. Boussakta, and S. S. Ikki, "Performance study of a UCRN over nakagami-m fading channels in the presence of CCI," *IEEE Trans. on Cognitive Communications and Networking*, vol. 3, no. 4, pp. 752–765, 2017.

[5] D.-T. Do and M.-S. V. Nguyen, "Outage probability and ergodic capacity analysis of uplink NOMA cellular network with and without interference from D2D pair," *Physical Communication*, vol. 37, 2019.

[6] A. Augustine, I. Chukwudi, A. Cosmas, "Performance evaluation of enterprise-wide network that its backbone is based on leased trunk," *International Journal of Communications, Network and System Sciences*, vol. 8, no. 10, pp. 399–407, 2015.

[7] T. S. Rappaport, "Wireless Communication Principles & Practice," Prentice Hall PTR, second edition, 2002.

[8] S. Pramono, M. D. Ariyanto, L. Alvionita, and M. E. Sulistyo, "Analysis and optimization of 4G long term evolution (LTE) network in urban area with carrier aggregation technique on 1800 MHz and 2100 MHz frequencies", *AIP Conference Proceedings*, vol.2217, no.1. AIP Publishing LLC, 2020.

[9] A. L. Imoize, K. Orolu, and A. A-A. Atayero, "Analysis of key performance indicator of a 4G LTE network based on experimental data obtained from a densely populated smart city," *Data in Brief*, vol. 29, 2020.

[10] M. Thelander, "The murky underworld of IoT," *Signals Ahead*, vol. 11, no. 1, pp. 1–31, 2016.

[11] H. S. Hussein, "Multipath bandwidth capacity allocation and MPLS internet traffic engineering," *Journal of Advanced Computer Networks*, vol. 3, no 3, pp. 239–242, 2015.

[12] M. A. Amanaf, A. Hikmaturokhman, and A. F. Septian, "Calibrating the standard propagation model (SPM) for suburban environments using 4G LTE field measurement study case in Indonesia," in *IOP Conference Series: Materials Science and Engineering*, 2020, vol. 982, no. 1, p. 012029.

[13] H. Chen, S. Kumar, and C. C. J. Kuo, "QoS-aware radio resource management scheme for CDMA cellular networks based on dynamic interference guard margin (IGM)," *Comput. Networks*, vol. 46, no. 6, pp. 867–879, 2004.

[14] S. A. Khanjari, B. Arafeh, K. Day, and N. Alzeidi, "Bandwidth borrowing-based QoS approach for adaptive call admission control in multiclass traffic wireless cellular networks," *International Journal of Communication Systems*, vol. 26, no. 7, pp. 811–831, 2011.

[15] P. Sharma, "Evolution of mobile wireless communication networks-1G to 5G as well as future prospective of next generation communication network," *International Journal of Computer Science and Mobile Computation*, vol. 2, no. 8, pp. 47–53, 2013.

[16] A. Agarwal and K. Agarwal, "The next generation mobile wireless cellular networks-4G and beyond," *American Journal of Electrical and Electronic Engineering*, vol. 2, no. 3, pp. 92–97, 2014.

[17] N. I. Hamid, M. R. Khandokar, T. Jamal, M. A. Shoeb, and M. Z. Hossain. "In quest of the better mobile broadband solution for south asia taking wimax and LTE into consideration," *Journal of Telecommunication*, vol. 2, no. 1, pp. 86-94, 2010.

[18] S. B. Rejeb, N. Nasser, and S. Tabbane, "A novel resource allocation scheme for LTE network in the presence of mobility," *Journal of Network and Computer Applications*, vol. 46, pp. 352–61, 2014.

[19] H. Shariatmadari, R. Ratasuk, S. Iraji, A. Laya, T. Taleb, R. Jantti, and A. Ghosh, "Machine-type communications: current status and future perspectives toward 5G systems," *IEEE Communications Magazine*, vol. 53, no. 9, pp. 10-17, September 2015, doi: 10.1109/MCOM.2015.7263367.

[20] L. Yang, Y. Xie, X. Wu, J. Yuan, X. Cheng and L. Wan, "Partially information-coupled turbo codes for LTE systems," *IEEE Transactions on Communications*, vol. 66, no. 10, pp. 4381-4392, Oct. 2018, doi: 10.1109/TCOMM.2018.2841907.

[21] L. Li-fu, L. Hai-wen, L. Hong-liang and G. Yong-jun, "Research and implementation of Viterbi decoding in TD-LTE system," in *2017 IEEE 2nd Advanced Information Technology, Electronic and Automation Control Conference (IAEAC)*, 2017, pp. 890-894, doi: 10.1109/IAEAC.2017.8054142.

[22] G. A. Hussain and L. Audah, "RS codes for downlink LTE system over LTE-MIMO channel," *TELKOMNIKA Telecommunication, Computing, Electronics and Control*, vol. 16, no. 6, pp. 2563–2569, 2018.

[23] V. Vakilian, T. Wild, F. Schaich, S. ten Brink and J. - F. Frigon, "Universal-filtered multi-carrier technique for wireless systems beyond LTE," in *2013 IEEE Globecom Workshops (GC Wkshps)*, 2013, pp. 223–228, doi: 10.1109/GLOCOMW.2013.6824990.

[24] C. Chen, Q. Pei and L. Ning, "Forecasting 802.11 traffic using seasonal ARIMA model," in *2009 International Forum on Computer Science-Technology and Applications*, 2009, pp. 347-350, doi: 10.1109/IFCSTA.2009.207.

[25] C. O. Ohaneme, V. E. Idigo, S. U. Nnebe, E. N. Ifeagwu, "Analysis of interference and channel capacity in a CDMA wireless network using dynamic channel assignment (DCA) strategy," *Int. J. Comput. Networks Commun.*, vol. 4, no. 5, pp. 149–163, 2012.

[26] P. N. Rani and C. S. Rani, "UFMC: The 5G modulation technique," in *2016 IEEE International Conference on Computational Intelligence and Computing Research (ICCIC)*, 2016, pp. 1–3, doi: 10.1109/ICCIC.2016.7919714.

[27] Y. Zhang, K. Liu and Y. Liu, "A novel PAPR reduction algorithm based on SLM technique in UFMC systems," in *2018 IEEE/CIC International Conference on Communications in China (ICCC Workshops)*, 2018, pp. 178–183, doi: 10.1109/ICCChinaW.2018.8674491.

[28] C. D. M. Ambatali and J. J. S. Marciano, "Performance evaluation of the UFMC scheme under various transmission impairments," in *2016 IEEE International Conference on Communication, Networks and Satellite (COMNETSAT)*, 2016, pp. 24–28, doi: 10.1109/COMNETSAT.2016.7907410.

[29] G. A. Hussain and L. Audah, "Downlink LTE system performance improvement by using BCH codes over LTE-MIMO channel," *International Journal of Integrated Engineering*, vol. 10, no. 4, pp. 95–101, 2018.