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IOT FREQUENCY BAND CHANNELIZATION IN INDONESIA AS A RECOMMENDATION FOR MACHINE-TO-MACHINE COMMUNICATION PREPARATION IN THE 5G ERA

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ABSTRACT

This study aims to provide recommendations regarding frequency and channel settings for machine-to-machine (M2M) communication in preparation for the 5G era in Indonesia. In the rapid development of the Internet of Things (IoT), M2M communication is becoming increasingly important to support efficient and reliable connectivity between IoT devices. In this study, we conduct an in-depth analysis of the available frequency spectrum in Indonesia, considering existing regulatory constraints and technical requirements. The results of this study show that the frequency bands 920-925 MHz and 925-928 MHz suit M2M communication in Indonesia with the suggested channel settings. These recommendations are based on spectrum availability, M2M communication needs, and relevant technical requirements. Implementing these recommendations is expected to increase the efficiency and reliability of M2M communications in Indonesia, facilitate the further development of IoT technology, and prepare Indonesia well to face the 5G era. This study contributes to designing a regulatory framework and optimal spectrum use to support successful M2M communications in Indonesia.

Keywords*: frequencies, Indonesia, IoT, regulation.*

I. INTRODUCTION

INTERNET of Things (IoT) technology allows everything to be connected and is often used in various industries such as agriculture, education, health and transportation [1]. The development of IoT technology and widespread connectivity is driven by the low-cost, low-power consumption, and large-scale connectivity enabled by 5G technology [2-3]. Consequently, IoT has been later referred to as the Internet of Everything (IoE) [4]. Although 4G is popular, 5G is emerging as a promising alternative to meet users' more stringent performance requirements regarding reliability, latency and throughput [5, 6]. 5G is used in a wide range of applications, from IoT to smart homes to Industry 4.0, and has been defined by the ITU as three usage scenarios. While 4G remains popular, 5G is emerging as a promising alternative to meet the increasingly stringent performance requirements of users, including reliability, latency, and throughput [5, 6]. 5G is being utilized in a wide range of applications, including IoT, smart homes, and Industry 4.0, and the ITU has defined three usage scenarios for 5G.

However, with the increasing number of IoT devices expected to reach 22 billion by 2025, building an efficient, adaptable, and cost-effective IoT system is becoming complex due to IoT connectivity and various application requirements [7-8]. This requires regulation governing the frequencies used for IoT and the need for network slicing for 5G IoT deployments to create opportunities for new business models [9]. One of the main conclusions of this technology is the need for efficient network slicing and new adaptive network slicing management to cope with the demands of using services for different user needs [10]. Communication modules commonly used in Indonesia are WiFi, Bluetooth, LoRa, GSM, NB-IoT, and SigFox [6].

Network slicing will play a crucial role in the deployment of 5G IoT, enabling the creation of new business models and facilitating dedicated frequency channeling for IoT in the IoT era. This presents

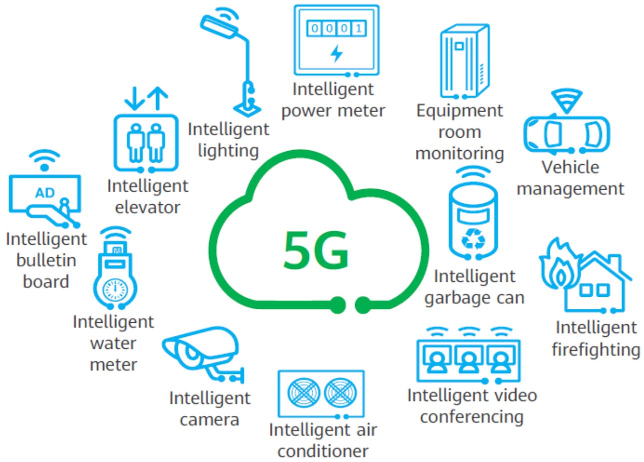

Figure 9. 5G and IoT Connect Access to Multiple Devices [1]

significant opportunities for the development of tailored services and optimized network resources for IoT applications. This fact is proven by many studies and papers on this subject [11]. In a recent study by Kahn et al. [12], the latest advancements in network slicing for the IoT industry were explored, focusing on use cases such as smart transportation systems, smart industries, smart homes, and smart care. The study highlighted the importance of scalability, interoperability, and efficient resource allocation. Other researchers have also emphasized network slicing as a key technology for enabling various use cases of 5G. They have identified the need for a new adaptive network slicing management scheme to handle service requests with varying user needs. The convergence of IoT and 5G networks is expected to impact all aspects of life, as shown in Figure 1.

Several authors have proposed IoT-based 5G solutions for specific use cases. For example, Kurtz et al. [13] propose and implement a slicing mechanism using SDN and OVS controllers for SDN/NFV-based 5G networks. However, data path management requires changes such as encapsulation to separate tenants and user mobility in 5G networks. On the other hand, Diaz-Rivera et al. [15] propose the Network Selection Slice Function (NSSF) to allow slice selection to meet the 3GPP functionality specifications in the data plane.

In [16], the authors propose a framework for cutting a mix of public and private infrastructure across the Radio, Edge, and Core segments. However, their work did not demonstrate its suitability in large-scale industrial IoT scenarios and did not cover multiple concurrent use cases to demonstrate cutting suitability. Although there are many related solutions, there is still a need for practical, scalable, and flexible network solutions from the perspective of 5G data lines to meet various needs. In addition, regulation on spectrum licensing and device activation must also be considered to meet future demand in Indonesia.

II. RESEARCH METHOD

Accurate and comprehensive reference data on the available frequency spectrum in Indonesia is very important to carry out this study. The data is collected through various sources, including the Indonesian Telecommunications Regulatory Body (BRTI), the Ministry of Communication and Informatics, and other relevant regulatory authorities. In addition, information on the needs and trends of machine-to-machine (M2M) communication in Indonesia was also collected through surveys and relevant literature reviews. The data includes a deep understanding of frequency usage needs and technical requirements to support efficient and reliable M2M communications. In collecting this reference data, it is important to ensure the accuracy and validity of the information obtained so that the resulting recommendations can be properly applied in preparation for M2M communications in the 5G era in Indonesia.

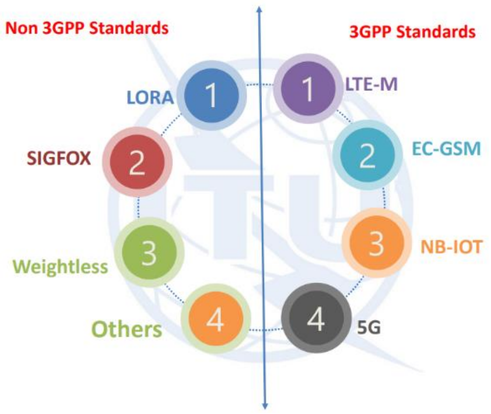

Figure 10. IoT Standardization by 3GPP

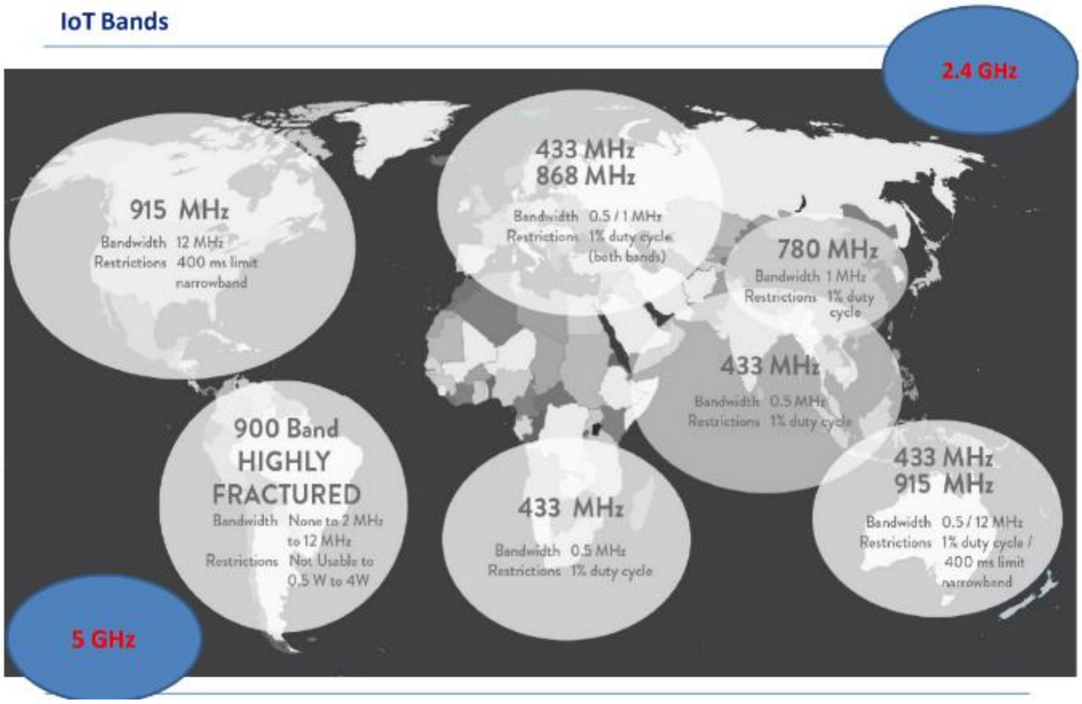

Figure 11. IoT frequency tunneling based on 3GPP recommendations

A. Reference to National Institutional Regulations

Indonesia has several regulations regarding the use of frequency spectrum for IoT. Regulation of the Minister of Communication and Informatics of the Republic of Indonesia Number 1 of 2019 stipulates that data communication system operators may only use narrowband non-cellular LPWA telecommunication devices for IoT frequencies [17]. In addition, Regulation of the Director General of Resources and Equipment of Post and Information Technology Number 3 of 2019 regulates the technical requirements for LPWA telecommunication tools or equipment as the legal basis needed to fulfil the mandate of Article 71 paragraph (1) of Government Regulation Number 52 of 2000 [18]. This regulation governs the use of non-cellular and cellular wide-area telecommunication devices that employ standard wideband or narrowband technology, as well as cellular low-power wide-area telecommunication devices that utilize Narrow Band Internet of Things (NB-IoT) or Long Term Evolution Machine (LTE-M) technology [18].

There is also a Regulation of the Minister of Communication and Information of the Republic of Indonesia Number 12 of 2017 which regulates the use of technology at certain radio frequencies [19]. The frequency spectrum for IoT in Indonesia is divided into two categories, namely licensed and unlicensed, with different frequency ranges. For licensed categories, several frequency bands can be used. The unlicensed category includes frequency ranges such as 2.4 GHz, 5.8 GHz, and 919-925 MHz, which currently do not have specific regulations in place [20].

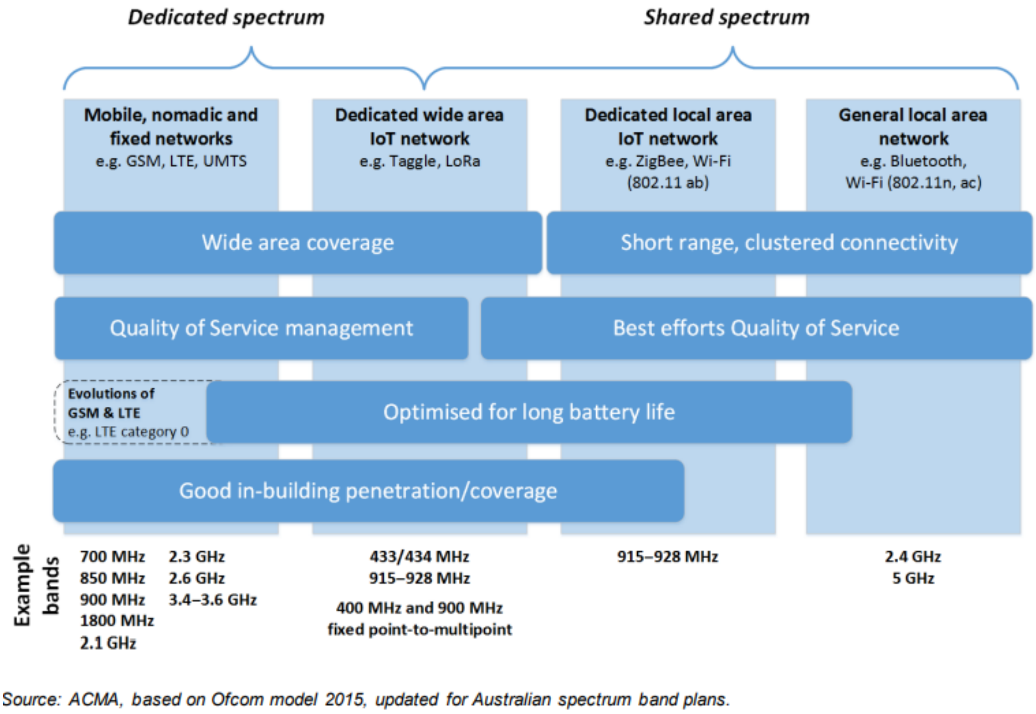

Figure 12. The spectrum of IoT that can be used

B. *International Institutional Regulation Reference*

International agencies have long provided recommendations regarding using certain IoT frequencies if used regularly, such as ETSI agencies and ITU up to 3GPP. 3GPP provides IoT frequency recommendations based on the transmission module, as shown in Figure 2.

The recommendation to use Dedicated Radio Frequency Channelization on IoT in the Short-Range Device (SRD) band has been given by 3GPP and set out in Resolution 958 (WRC-15) [21]. Attachment point 3 and Agenda Point 9.1 (Item 9.1.8) of WRC-19 address technical, operational, and network aspects, including requirements for wireless systems. While WRC-19 achieved significant outcomes, the current assessment of IoT RF bands indicates that this spectrum can offer the necessary capacity and wide coverage for IoT applications, independent of cellular systems like GSM [22].

According to the ITU Global Study on Internet Cases, IoT is defined as a public information infrastructure that allows multiple devices to be remotely monitored or controlled and exchange data via a connection to the Internet network infrastructure [23]. The ITU-R also addresses spectrum requirements and standards for IoT wireless access technologies and techniques, including protection of wireless services from the radiation of power line communication systems, harmonization of frequency ranges, technical and operational parameters for short-haul devices, and use of fixed and mobile satellite communications for IoT [24]. In addition, the frequency bands for IoT devices are governed by ITU-R 66 Resolution and Frequency bands for global/regional SRD harmonization [25]. The term SRD here refers to radio transmitters that have a low ability to cause interference to other radio devices, and the ITU recommends several SRD technologies commonly used in the Sub 6GHz band [26]

ITU-R SM.1896 recommends harmonization of frequency ranges for global and regional use of SRD, and this is an ongoing process. The recommended frequency ranges for global harmonization are 9-148.5 kHz, 3155-3400 kHz (low power wireless hearing aids, RR No. 5116), and the ISM bands listed in RR No. 5.138 and 5.150: 6765-6795 kHz, 13553-13567 kHz, 26957-27283 kHz, 40.66-40.7 MHz, 2400-2500 MHz (up to 2483.5 MHz in some countries), 5725-5875 MHz, and 57-246 GHz (with proposals to add 3.7-4.8 GHz and 7.25-9 GHz). Recommended frequency ranges for regional harmonization are 312-315 MHz (Reg. 2 and some countries in Reg. 1 & 3), 433050-434790 MHz (Reg. 1 and some countries in Reg. 2 and 3), 862-875 MHz (not in Reg. 2, in Reg. 1, and some countries in Reg. 3), and 875-960 MHz (Reg. 2 is the tuning range, but it is used in commercial cellular systems, so it cannot be used in SRDs in most countries. In some countries it is used in Reg. 1 and 3) [27].

TABLE 1
COMPARISON BETWEEN SHORT RANGE WIRELESS COMMUNICATION TECHNOLOGIES

	Bluetooth	Wif-Fi	Zigbee	Z-Wave
Frequency Band	2.4 GHz	• 2.4 Ghz • 5 GHz	• 868 MHz • 915 MHz • 2.4 GHz	• 868.42 MHz (Europe) • 908.42 MHz (USA)
Transmission Rate	1-24 Mbps	• 11 b: 11 Mbps • 11 g: 54 Mbps • 11 n: 600 Mbps • 11 ac: 1 Gbps	• 868 MHz: 20 kbps • 915 MHz: 40 kbps • 2.4 GHz: 250 kpbs	• 9.6 kbps • 40 kbps
Typical Range	1-100 m	50-100 m	2.4 GHz: 10-100 m	• Indoor: 30 m • Outdoor: 100 m
Typical Application	Data exchange between adjacent nodes such as a computer mouse, wireless headset, mobile phone, and computer	WLAN, high-speed Internet access at home and other indoor places	Home automation, building automation, and remote control	Smart home appliances, monitoring and control

TABLE 2
COMPARISON BETWEEN LONG RANGE WIRELESS COMMUNICATION TECHNOLOGIES

	Sigfox	LoRa	Zigbee	Z-Wave
Frequency Band	SubG unlicensed frequency band	SubG unlicensed frequency band	Mainly SubG licensed frequency band	SubG licensed frequency band
Transmission Rate	100 bps	0.3-50 kbps	< 100 kbps	< 1 Mbps
Typical Range	• Transmission range: 1-50 km • Low power consumption • Sigfox base station and cloud platform • Global network services	• Transmission range: 1-20 km • Low power • Low operation cost • Self-deployed base stations with higher flexibility	• Transmission range: 1-20 km • Use of licensed frequency bands, low inference • Stable rate • Use of legacy 4G base stations	• Transmission range: 2 km • Licensed frequency bands, low inference • High rate, mobility, and positioning • Support for voice services
Typical Application	Smart home appliances, smart power meters, mobile healthcare, remote monitoring, and retail	Smart agriculture, intelligent construction, and logistics tracking	Water meters, parking, pet tracking, trash cans, smoke alarms, and retail terminals	Bike sharing, pet tracking, POS, and smart elevators

In the short term, the current IMT-Advanced standard (Rec. ITU-R M.2012) will be extended to include support for IoT (e.g., NB-IoT systems). In the long term, IoT will become an integral part of the 5G IMT-2020 standards developed by ITU, bringing the benefits of IMT's large-scale economies of scale, frequencies, and globally aligned standards for all industries. The framework and general goals for the development of IMT after 2020 are detailed in ITU-R M.2083. Unlike ITU and 3GPP, ETSI classifies frequency usage based on communication range between machines, which is detailed in ETSI TR 103 375 V1.1.1 related to Smart M2MSIoT and Future Evolution standards [28].

C. Available Spectrum for IoT

Regarding spectrum supporting M2M and IoT applications, a combination of license agreements and spectrum bands may be required to support IoT use cases (see Figure 4).

ACMA has licensing agreements to drive innovation in machine-to-machine and IoT through a first-class licensing system [29]. The general spectrum can be used for machine-to-machine and IoT applications. Class licenses allow users in certain spectrum segments to work together and are not subject to a license fee but are not issued to individual users. Frequency licenses are free from potential interference and are available on ISM bands such as the 900 MHz band, 2,400 MHz band, and 5,800 MHz band [30]. In Australia, radio access to this band is provided by radio with low spectrum interference available for IoT [31].

Many commercial mobile broadband networks operate on licensed spectrum. Spectrum licenses are usually region-based and provide exclusive access coverage to large areas [32]. Licensees are responsible for deploying and managing their network within a common technical framework that manages interference at the frequency and geographic boundaries and provides technical flexibility. However, spectrum usage may be limited if the service range deviates significantly from the originally

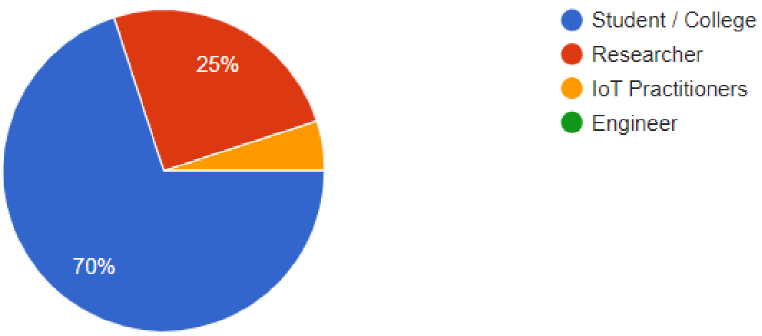

Figure 5. Respondent's Occupation

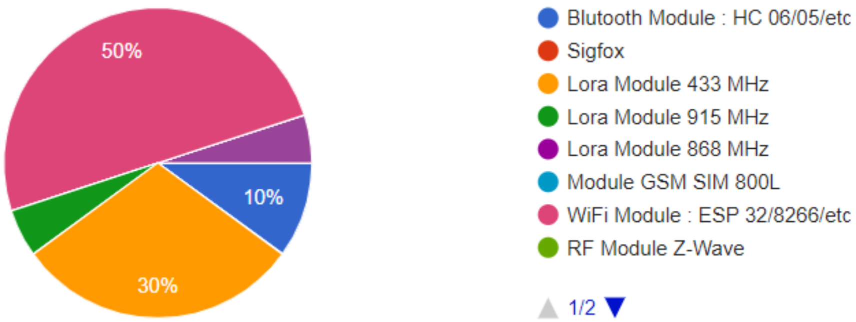

Figure 6. Commonly used communication modules

planned one because this framework is designed with bandwidth in mind [33].

D. Comparison of IoT Wireless Technologies

The latest technology suitable for IoT and M2M devices is LPWA (Low Power Wide Area). LPWA provides strong internal security, global coverage and low power consumption and enables long-distance wireless connectivity. This LPWA technology enables IoT devices to work for up to 10 years on a single battery charge, ideal for limited mobility solutions that cannot be relied upon to recharge. However, not all LPWA solutions have the same quality of service, and there is a trade-off between quality of service and battery life. In addition, the lack of standardization and limited mobility are other challenges that must be overcome. There are two types of IoT devices based on communication distance, namely short distance and long distance, which can be seen in Table 1 and 2.

E. Primary Data Collection

To collect the primary data, the authors employed a simple survey method to gather information specifically from a few Indonesians involved in designing IoT applications. The survey aimed to identify the commonly used communication modules and the frequencies at which they operate. The authors designed a targeted questionnaire related to the participants' IoT projects, including the specific communication modules utilized and their corresponding frequencies. The survey was distributed among individuals involved in IoT development, such as researchers, engineers, and IoT enthusiasts, who possessed relevant knowledge and experience in the field. The participants were asked to provide details about their IoT applications, the communication modules they employed, and the frequency bands they operated within. The survey responses were then collected and analyzed to determine the prevailing patterns and trends in communication module selection and frequency usage in Indonesian IoT designs. This primary data collection process enabled the author to gain insights into the current practices and preferences among Indonesians regarding communication modules and frequencies for IoT applications.

Based on Figure 7 above, the respondents in this survey consisted of 70% students/universities, 25% researchers, and 5% IoT practitioners. Communication modules that are often used by respondents can be seen in the graph in Figure 8.

TABLE 3
IOT SPECTRUM AVAILABLE (CLASS LICENSE) [30]

Frequency Band Spectrum (MHz)	*Description*
472.0125–472.1125	Telemetry or telecommand transmitter (100 mW EIRP max power)
0.07–0.119	Telemetry or telecommand transmitter (10 mW EIRP max power)
0.135–0.160	Telemetry or telecommand transmitter (10 mW EIRP max power)
2400–2450	Telemetry or telecommand transmitter (max. power 1 W EIRP)
5725–5795	Telecommand or telemetry transmitter (max. power 1 W EIRP)
5815–5875	Telecommand or telemetry transmitter (max. power 1 W EIRP)
915-928	Frequency hopping transmitter (maximum power 1 W EIRP)
2400-2483.5	Frequency hopping transmitter (maximum power 500 W EIRP)

TABLE 4
CANALIZATION RECOMMENDATIONS IOT FREQUENCY BY CLASS

Class Category	*Recommendation*
A (1m – 100 m)	433 MHz
B (100m – 10km)	915 MHz

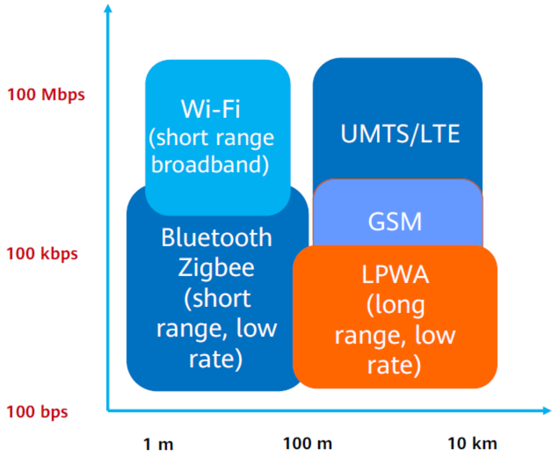

Figure 7. Classification of IoT wireless technologies

Among the 20 respondents surveyed, 50% reported frequently utilizing WiFi modules such as ESP32/8266/etc. as their preferred communication technology in the IoT projects they developed. Furthermore, 30% indicated using a 433 MHz LoRa module, 10% relied on Bluetooth modules like HC 06/05/etc., 5% utilized a 915 MHz LoRa module, and the remaining 5% opted for an NB-IoT module. Meanwhile, the data collected from this survey did not find frequent usage of IoT communication technologies such as Sigfox, Lora 868 MHz Module, GSM SIM 800L Module, Z-Wave RF Module, Zigbee, and eMTC Modules (such as the 7000C/7000A series) in Indonesia.

III. RESUL AND DISCUSSION

After collecting reference data from national and international institutions as well as secondary and primary data, the authors' conclusion is that globally most of the ISM Bands are harmonized. However, regulatory regulations may differ between countries (both national and international). Unfortunately, in Indonesia, access to ISM Ribbons is not strictly regulated in national institutional regulations. Unlike in Australia, access to the ISM Band is governed by the Radiocommunication-controlled LIPD Class License (Low Spectrum Interference compliant for IoT Potential Device Class 2 License) 2015 [30]. The LIPD Class license covers more than 50 elements that enable IoT or M2M operations, including low data rates, low power, and high latency devices that require high reliability. The frequency of canalization can be seen in Table 3.

Based on the data collected and studied by the authors, it was found that most of the licensing arrangements for classroom use are harmonized internationally. However, there are some differences in the usage of certain spectrum bands across different countries. In the case of Indonesia, the regulation of spectrum, particularly for IoT frequencies, has not been addressed in a comprehensive manner. However, it is important to note that not all foreign equipment may be used under Indonesian spectrum regulations if arrangements from a different market have been adopted in Indonesia (such as in the 900 MHz band discussed below). In this study, the authors recommend that Indonesia consider adopting a

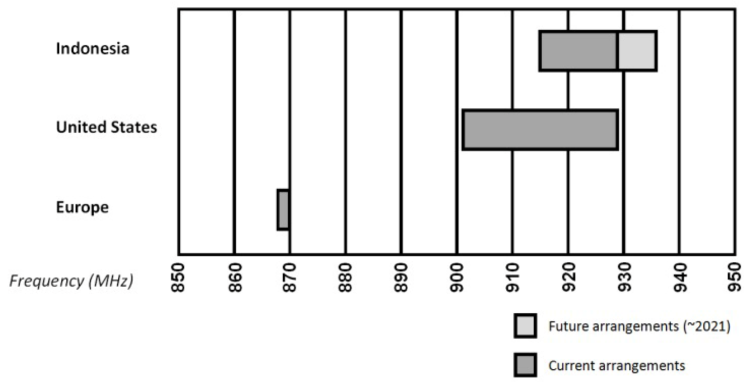

Figure *8*. International setting at 900 MHz

frequency spectrum similar to that used by Australia for making changes to the LIPD Class License. This recommendation is subject to compliance with existing institutional regulations in Indonesia.

The author also suggests updating existing regulations to support the use of devices that provide a wireless connection to the internet in line with changes abroad (this is also in preparation for the massive use of IoT in the 5G era). The proposed changes aim to provide greater opportunities for low data rate machine-to-machine and internet-of-things links using the 915-928 MHz, 2400-2483.5 MHz, and 5725-5850 MHz bands.

However, some general licensed/class IoT solutions that may exist in other regions are not applicable in Indonesia, especially in the 868 MHz bands. Based on a comparison of secondary data and reference data, it is evident that the Public Mobile Telecommunication Service System (PMTS) in Indonesia differs from that of Europe and America. Australia inherited the 'GSM' band (890-915 MHz and 935-960 MHz) from Europe, while the licensed spectrum in the 850 MHz band (825-845 MHz and 870-890 MHz) in Australia was acquired from the United States. Therefore, the authors recommend channeling the IoT frequency band, which is divided into two classes of frequency spectrum based on the scope of technology used, namely Class A Frequency Channelization (short-distance transmission) and Class B Frequency Channelization (long-distance transmission), as shown in Table 4.

Based on the information presented in Table 2, it is recommended that the Indonesian government establishes a standardized frequency channelization for short-range IoT devices operating in the 433 MHz frequency band. To achieve this, it is necessary to update the Regulation of the Director General of Resources and Equipment of Post and Information Technology, specifically Chapter 2 concerning the Technical Requirements for Telecommunication equipment/SRD, which currently specifies the Bluetooth frequency range as 2,400-2,483 MHz with a maximum transmit power of < -10dBW (100mW) EIRP. The proposed revision aligns with the authors’ suggestion of utilizing the HC-12 SI4463 in the 433 MHz frequency range for the Wireless Bluetooth Serial Port Controller Module. The classification of IoT wireless technology applicable in Indonesia can be referenced in Figure 7.

In establishing channelization recommendations for IoT, important considerations include available frequency slots and adherence to ITU recommendations. However, national institutional regulations must also be considered to avoid interfering with other frequencies such as cellular and aviation. Class B frequency at 915 MHz is considered efficient because it follows the recommendations from 3GPP. However, LoRa devices often use the 433 MHz frequency, which complies with the LoRa Alliance's recommendations for the Asian region in the 420-433 MHz range. Various PMTS solutions limit the ISM band size in Indonesia to 915-928 MHz. In the United States, the ISM band can be extended to 902-928 MHz. Some of the solutions already used in the US need to be modified to work in Indonesia. Other solutions operating at or around 868 MHz are already in use in Europe, but cannot be used in Indonesia because these frequencies overlap with the allocation for land cellular services. The international order for the 900 MHz band can be seen in Figure 8.

IV. Conclusion

In this study titled "IOT Frequency Band Channelization in Indonesia as a Recommendation for Machine-to-Machine Communication Preparation in the 5G Era," important conclusions are drawn regarding the preparation of machine-to-machine (M2M) communication in Indonesia for the 5G era. This study provides recommendations regarding the use of frequency and channel settings that can be used to support efficient and reliable M2M communication. In the Indonesian context, it was found that the most suitable frequency bands for M2M were 920-925 MHz and 925-928 MHz with certain channel arrangements. These recommendations are based on an in-depth analysis of the existing frequency conditions in Indonesia, M2M communication needs, and technical requirements for optimal use. The implementation of these recommendations is expected to enhance the efficiency and reliability of M2M communications in Indonesia, foster the development and broader adoption of IoT technology, and ensure Indonesia's readiness for the 5G era.

References

[1] I. F. Akyildiz, S. Nie, S.-C. Lin, and M. Chandrasekaran, "5G roadmap: 10 key enabling technologies," *Comput. Networks*, vol. 106, pp. 17–48, 2016.

[2] H. Fattah, 5G LTE Narrowband Internet of Things (NB-IoT). CRC Press, 2018.

[3] A. Ghosh, R. Ratasuk, P. Rost, and S. Redana, *5G-Enabled Industrial IoT Networks*. Artech House, 2022.

[4] T. H. Loh, Metrology for 5G and Emerging Wireless Technologies. IET, 2022.

[5] B. S. Khan, S. Jangsher, A. Ahmed, and A. Al-Dweik, "URLLC and eMBB in 5G Industrial IoT: A survey," *IEEE Open J. Commun. Soc.*, vol. 3, pp. 1134–1163, 2022.

[6] M. Jouhari, N. Saeed, M.-S. Alouini, and E. M. Amhoud, "A survey on scalable LoRaWAN for massive IoT: Recent advances, potentials, and challenges," *IEEE Commun. Surv. Tutorials*, 2023.

[7] L. Sastrawidjaja and M. Suryanegara, "Regulation challenges of 5G spectrum deployment at 3.5 GHz: The framework for indonesia," in *2018 Electrical Power, Electronics, Communications, Controls and Informatics Seminar (EECCIS)*, 2018, pp. 213–217.

[8] T. Q. Duong, Real time convex optimisation for 5G networks and beyond. IET, 2021.

[9] T.-Y. Chen, C.-H. Wang, J.-P. Sheu, G.-S. Lee, and D.-N. Yang, "Resource Allocation for the 4G and 5G Dual-Connectivity Network with NOMA and NR," in *ICC 2022-IEEE International Conference on Communications*, 2022, pp. 3784–3789.

[10] E. Sitompul and A. Rohmat, "IoT-based running time monitoring system for machine preventive maintenance scheduling," *ELKHA J. Tek. Elektro*, vol. 13, no. 1, pp. 33–40, 2021.

[11] S. Hutajulu, W. Dhewanto, and E. A. Prasetio, "Two scenarios for 5G deployment in Indonesia," *Technological Forecasting and Social Change*, vol. 160. Elsevier, p. 120221, 2020.

[12] L. U. Khan, I. Yaqoob, N. H. Tran, Z. Han, and C. S. Hong, "Network slicing: Recent advances, taxonomy, requirements, and open research challenges," *IEEE Access*, vol. 8, pp. 36009–36028, 2020.

[13] F. Kurtz, C. Bektas, N. Dorsch, and C. Wietfeld, "Network slicing for critical communications in shared 5G infrastructures-an empirical evaluation," in *2018 4th IEEE Conference on Network Softwarization and Workshops (NetSoft)*, 2018, pp. 393–399.

[14] R. Trivisonno, M. Condoluci, X. An, and T. Mahmoodi, "mIoT slice for 5G systems: Design and performance evaluation," *Sensors*, vol. 18, no. 2, p. 635, 2018.

[15] J. J. D. Rivera, T. A. Khan, A. Mehmood, and W.-C. Song, "Network slice selection function for data plane slicing in a mobile network," in *2019 20th Asia-Pacific Network Operations and Management Symposium (APNOMS)*, 2019, pp. 1–4.

[16] T. Taleb, I. Afolabi, and M. Bagaa, "Orchestrating 5G network slices to support industrial internet and to shape next-generation smart factories," *Ieee Netw.*, vol. 33, no. 4, pp. 146–154, 2019.

[17] Menteri Komunikasi dan Informatika, Peraturan Menteri Komunikasi dan Informatika Nomor 1 Tahun 2019 tentang Penggunaan Spektrum Frekuensi Radio Berdasarkan Izin Kelas. Indonesia, 2019.

[18] Direktur Jenderal Sumber Daya dan Perangkat POS dan Informatika, Peraturan Direktur Jenderal Sumber Daya dan Perangkat POS dan Informatika tentang Persyaratan Teknis Alat dan/atau Perangkat Telekomunikasi Low Power Wide Area. Indonesia, 2019.

[19] Menteri Komunikasi dan Informatika, Peraturan Menteri Komunikasi dan Informatika Nomor 12 Tahun 2017 tentang Penggunaan Teknologi Pada Pita Frekuensi Radio 450 MHz, 900 MHz, 2.1 GHz, dan 2.3 GHz Untuk Penyelenggaraan Jaringan Bergerak Seluler. Indonesia, 2017.

[20] D. Kusumawati, B. Winarko, and W. Pradono, "Analisis Kebutuhan Regulasi Terkait dengan Internet of Things [The Analysis of The Required Regulation of Internet of Things]," *Bul. Pos dan Telekomun.*, vol. 15, no. 2, pp. 121–138, 2017.

[21] A. R. Mishra, Fundamentals of network planning and optimisation 2G/3G/4G: evolution to 5G. John Wiley & Sons, 2018.

[22] International Telecommunication Union, "World Radiocommunication Conference 2019 (WRC-19), Sharm el-Sheikh, Egypt, 28 October to 22 November 2019," 2019. https://www.itu.int/en/ITU-R/conferences/wrc/2019/Pages/default.aspx (accessed Oct. 28, 2019).

[23] International Telecommunication Union, *Radio Regulations - Appendices*, 2020th ed. 2020.

[24] International Telecommunication Union, *ITU-R studies in support of the Internet of Things*. 2017.

[25] International Telecommunication Union, "SM.1896 : Frequency ranges for global or regional harmonization of short-range devices," 2018. https://www.itu.int/rec/R-REC-SM.1896/en (accessed Aug. 20, 2022).

[26] International Telecommunication Union, "Technical and operating parameters and spectrum use for short-range radiocommunication devices," 2021. https://www.itu.int/pub/R-REP-SM.2153-8-2021 (accessed Aug. 20, 2020).

[27] International Telecommunication Union, Radio Regulations ITU-R Recommendations incorporated by reference, 2020th ed. 2020.

[28] European Telecommunications Standards Institute, "SmartM2M; IoT Standards landscape and future evolutions," France, 2016.

[29] S. Painuly, S. Sharma, and P. Matta, “Future trends and challenges in next generation smart application of 5G-IoT,” in *2021 5th international conference on computing methodologies and communication (ICCMC)*, 2021, pp. 354–357.

[30] Work Stream 4 of the Internet of Things Alliance Australia, *Spectrum available for IoT*. Australia, 2016.

[31] 3GPP, “Standardization of NB-IOT completed,” 2016. https://www.3gpp.org/news-events/1785-nb_iot_complete (accessed Aug. 18, 2022).

[32] H. U. Mustakim, “Tantangan Implementasi 5G di Indonesia,” *INTEGER J. Inf. Technol.*, vol. 4, no. 2, 2019.

[33] J. Iannacci, “Internet of things (IoT); internet of everything (IoE); tactile internet; 5G–A (not so evanescent) unifying vision empowered by EH-MEMS (energy harvesting MEMS) and RF-MEMS (radio frequency MEMS),” *Sensors actuators a Phys.*, vol. 272, pp. 187–198, 2018.