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5G SPECTRUM VALUATION OF MILIMETER WAVE TECHNOLOGY: A CASE STUDY OF INDONESIA INDUSTRIAL AREA FOR ACCELERATION OF BROADBAND DEVELOPMENT

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ABSTRACT

Spectrum valuation is significant in helping policymakers prepare new technology regulations to address unique circumstances, such as location-specific services in industrial areas with larger spectrum bands. This paper presents the results of a study on the economic valuation of 5G spectrum at millimeter wave (mmWave) for accelerating broadband development. It uses a case study of industrial areas in Indonesia, focusing on the effects of frequency bands of 26 GHz and 28 GHz on three factors of an engineering-economic model: maximal cellular coverage, cost per square kilometer (in terms of capital expenditures (CAPEX) and Operational expenditures (OPEX)), and spectrum value per MHz population. The results showed that the mmWave utilization for 5G services requires higher infrastructure expenses. Population density also has a significant influence on spectrum valuation in both lower and higher frequency bands.

Keywords: *5G, Spectrum Valuation, Engineering-economic model, 5G mmWave, 5G Capex and Opex*

1. INTRODUCTION

With about 264.16 million people, Indonesia has the world's fourth-largest population. However, with a landmass of almost two million km^2 separated over 13,000 islands, its population is not equally distributed over its landmass. More than 60% of the population is concentrated on Java Island and 20% on Sumatera Island. Figure 1 shows the demographic distribution of the Indonesian population on the six main islands.

The situation is similar for the availability of physical infrastructure, such as telecommunication, electric power, and transportation, in dense urban areas, where service is much better than in the suburban and rural areas. This contrast in service also applies to broadband availability [1,2].

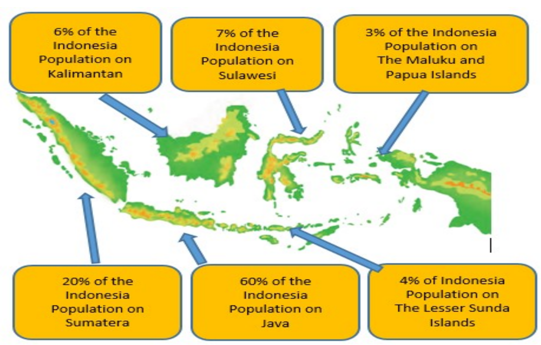

Figure 1: Demographic distribution of the Indonesian population on the six main islands [2]

This study focused on the industrial area of Jakarta, which has become a model for applying telecommunications technology; almost all of its areas are categorized as urban

Today, wireless technology in Indonesia is provided by licensed Indonesian Mobile Network Operators' (MNOs), such as Telkomsel, XL Axiata (XL), Indosat, Hutchison 3 Indonesia (H3I), Smartfren (SF), Smart Telecom (ST), and

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Sampoerna Telekomunikasi Indonesia (STI). Figure 2 shows Distribution of Mobile broadband Frequency in Indonesia [3].

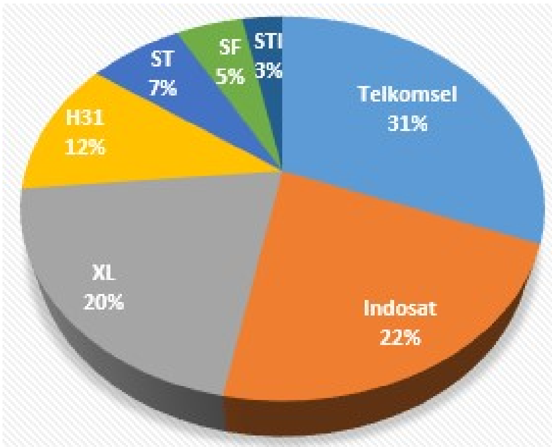

Figure 2: Distribution of mobile broadband frequency in Indonesia [3]

The number of mobile subscribers to the MNOs reached more than 133% of the population, with an internet use penetration of 56% in Q1-2019 [4-6]. Figure 3 shows that nearly half (55.7%) of Indonesia's internet users are on Java Island, followed by Sumatra Island at 21.6% [7].

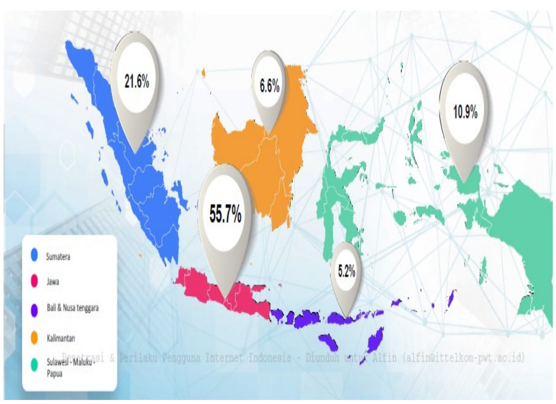

Figure 3: Contribution of Internet Users by Region [7]

The increase in internet users' growth cannot be separated from the development of the 2G - 4G cellular networks. The existing 4G is increasingly unable to meet customer needs, especially in urban areas, because of the increasing demand for bandwidth that cannot be satisfied with current technology. Therefore, the technology needs to be upgraded for wider bandwidth availability. That is why post-4G research, specifically 5G, is necessary to meet current and future needs. The mobile broadband speed in Indonesia is far behind those in other Association of Southeast Asian Nations (ASEAN) countries. Figure 4 shows the mobile broadband speeds (Mbps) in June 2019 in ASEAN [8].

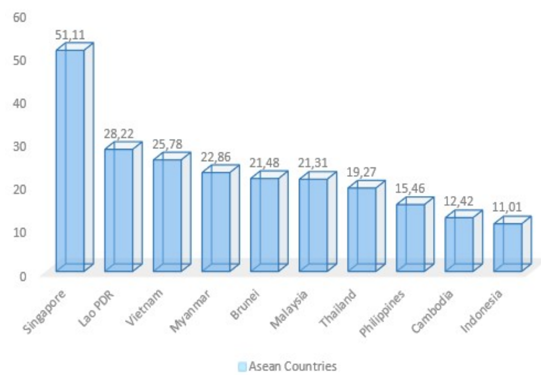

Figure 4: Mobile broadband speed [8]

The spectrum frequency band resource is very precious, and its purposes determine its worth to humankind, scarcity, and development or utilization circumstances [9]. Spectrum valuation is significant in helping policymakers prepare new technology regulations to deal with unique circumstances, such as location-specific services like industrial areas with a larger spectrum band.

To evaluate the 5G spectrum values for accelerating broadband development in industrial areas, researchers proposed modifications to engineering-economic models from previous research [10,11] based on three factors: maximal cellular coverage, cost per square kilometer in terms of CAPEX and OPEX, and spectrum value per MHz population. This study focused on calculating 5G deployment using the New Radio (NR) operating band n258 (26 GHz from 24.250 - 27.500 GHz frequency bands) and the NR operating band n257 (28 GHz from 26.500 - 29.500 GHz frequency bands) for the urban and industrial areas in Jakarta, Indonesia. Table 1 shows the frequency range 2 (FR 2) for millimeter wave (mmWave)

For cellular deployment, cell dimension is the primary element influencing cost, comparable to the number of requisite cell sites

Table 1: Frequency Range 2 (FR 2) band for mmWave [12]

NR Operating Band	Uplink (UL) & Downlink (DL) Operating Bands (MHz)	Duplex Mode
n257	26500–29500	TDD
n258	24250–27500	TDD
n260	37000–40000	TDD
n261	27500–28350	TDD

The remainder of this paper includes the following sections. Section 2 provides an overview of 5G. Section 3 presents the engineering-economic and parameters scenario, while Section 4 is devoted to discussing the study findings. Finally, Section 5 summarizes the principal conclusions of the study

2. 5G OVERVIEW

The 5G communications network is the first radio system that supports the high-frequency spectrum. This spectrum option provides the best combination of high capacity, high data rates, comprehensive coverage, and ultra-reliability. Low bands below 6 GHz meet the needs of wide bandwidth and data rates of up to several Gbps. The main spectrum options for 5G in its initial phase are about 3.5 GHz, with millimeter waves at 24-28 GHz using Time Division Duplex (TDD) technology. This technology represents the next generation, designed to provide better service delivery speed and enable innovative new services in the industrial field.

2.1 5G Usage Scenario

There are three usage scenarios based on the recommended ITU-R M.2083-0 [12]. Figure 5 shows the 5G usage scenario, and Figure 6 shows 5G key capabilities of IMT-2020 [12].

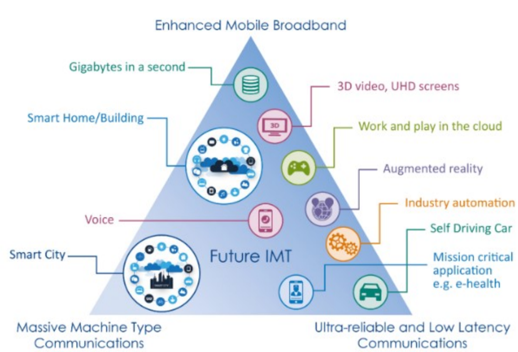

Figure 5: 5G usage scenarios [12].

2.1.1 Scenario 1: Enhanced mobile broadband (eMBB):

The demand for mobile broadband is increasing daily. In response, service providers continue to improve mobile broadband capabilities in accessing media content, services, and data. Under Scenario 1, mobile broadband users would be presented with the latest applications and additional requirements for existing mobile broadband applications to improve performance further. Examples of eMBB include augmented reality (AR), 3D/UHD video telepresence, UHD video streaming, and virtual reality (VR). The specific requirements are a minimum 20 Gbps peak data rate and a 100 Mbps user-experienced data rate.

2.1.2 Scenario 2: Ultra-reliable and low latency communications (URLLC):

To provide reliable and low latency communication capabilities, Scenario 2 would require strict requirements such as good throughput, low latency, and high availability. Examples of uRLLC include autonomous vehicles, aviation (drones), transportation security, industrial automation (including wireless control of production or industrial processes), smart grid distribution automation, and telemedicine (including remote medical operations).

2.1.3 Scenario 3: Massive machine-type communications (mMTC):

Under Scenario 3, communication capability would be characterized by connecting many devices that send sensitive data without delay at relatively low volumes. To achieve this scenario's goals, the terminal device would be manufactured at a low cost and have an exceptionally long battery life. Examples of mMTC are smart cities, wearable sensors (including real-time health monitoring of patients), smart metering, smart homes, object tracking, and smart farming or agriculture

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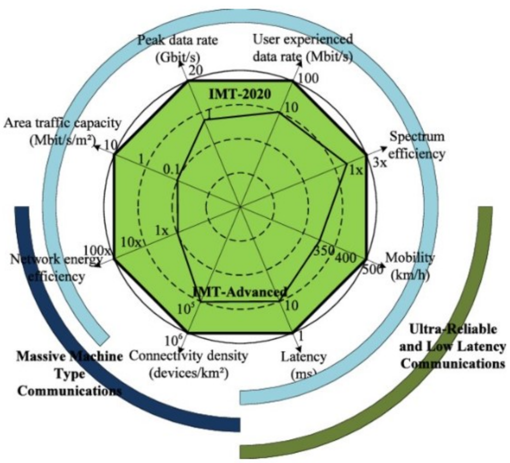

Figure 6: 5G key capabilities of IMT-2020 [12]

2.2 *5G Frequency Ranges*

5G NR is a cellular technology that can use low-band, mid-band, and mmWave (high-band) frequency as a form of additional bandwidth to achieve multi-Gigabit-per-second (Gbps) data rates to users. Figure 7 shows the 5G radio spectrum and its uses for different coverage areas [13].

2.2.1. Low band:

Low-band is the spectrum at a frequency below 1 GHz to allow 5G coverage of a large area. Indonesia has a frequency band of 700 MHz (n28) with a bandwidth of 45 MHz

2.2.2. Mid band:

The mid-band is the spectrum at higher frequencies, between 1 and 6 GHz, to offer the capacity needed to assist many connected devices and allow higher speeds for devices connected. Indonesia has a frequency band of 2,300 MHz (n30) with a bandwidth of 30 MHz, 2,600 MHz (n38) with a bandwidth of 190 MHz, 3,300 MHz (n77) with a bandwidth of 100 MHz, and 3,500 MHz (n78) with a bandwidth of 200 MHz

2.2.3. High band (mmWave):

The high-band is the spectrum at extremely high frequencies above 24 GHz with a large bandwidth, short-range radius (between 50 and 200 m), extremely low latency, and more capacity [13]. Indonesia has a frequency band of 26,000 MHz with bandwidth of 1,000-3,250 MHz (n258), and 28,000 MHz with a bandwidth of 2,000 MHz (n257).

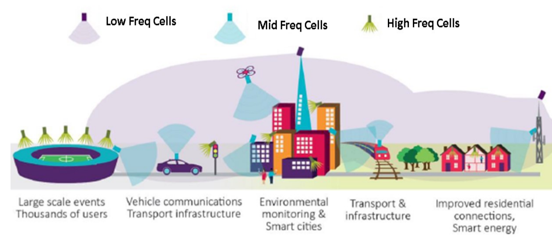

Figure 7: 5G Radio spectrum and its uses. [13]

The Indonesian Telecommunications Regulation includes the Determination of Radio Frequency Bands for testing the use of IMT-2020 technology. The regulation states that radio frequency bands that can be used in testing the use of IMT-2020 technology are as [14]. Table 2 shows 5G frequency band candidates in Indonesia.

Table 2: 5G Frequency band candidate in Indonesia [14]

Frequency Center	Bandwidth
700 MHz	45 MHz
2,300 MHz	30 MHz
2,600 MHz	190 MHz
3,300 MHz	100 MHz
3,500 MHz	200 MHz
26,000 MHz	1000-3250 MHz
28,000 MHz	2000 MHz

The bands are chosen based on several considerations, the primary one being the global frequency band test ecosystem. An additional factor is that the availability of devices used by MNOs in conducting trial tests that can only run on a specific frequency band range. The MNOs also recommend the use of the bands listed in Table 1. This extremely high-frequency becomes a challenge for every MNO in Indonesia to plan and provide its customers the best network throughout Indonesia

3. ENGINEERING-ECONOMIC MODELS AND PARAMETERS SCENARIO.

Planning for the 5G NR network coverage proposed in this study will be conducted in Jakarta's industrial area. Frequency bands 26 and 28 GHz are the recommended frequency bands for

Indonesia. Before carrying out network planning, data must be collected for the recommended link budget on the 5G NR network. Then, the calculation of coverage will yield the path loss value and maximal cellular coverage.

Calculation of the economic analysis side of 5G NR planning in industrial areas, consist of calculating input parameters for CAPEX and 0perational expenditures (OPEX) determine the output value of net present value (NPV) and the frequency band value per MHz population.

There are three factors included in the engineering-economic model; maximal cellular coverage, cost per square kilometer (CAPEX and OPEX), and spectrum value per MHz population. These factors will be discussed below.

3.1 Factor 1: Maximal Cellular Coverage

5G New Radio uses the 3D propagation model defined in 3GPP 36.873. The Urban Macrocell (UMa), Urban Microcell (UMi), Indoor Hotspot (InH), and Rural Macrocell (RMa) models apply to frequency bands of 2 - 6 GHz and are then extended to 0.5 - 100 GHz in 3GPP 38.901 [15-17].

This study used only UMi and InH for the engineering-economic scenario because the mmWave with a larger bandwidth has a short-range radius (between 50 and 200 m). Location-specific services for industrial areas, the focus of case studies in this research, must deal with settings with many buildings. Because of its frequency, the mmWave will only fit the UMi and InH propagation models. Equations (1) to (4) are propagation models for this research.

3.1.1 Propagation Model for 3D-UMi Line Of Sight (LOS)

$$PL = 40\log_{10}(d_{3D}) + 28.0 + 20\log_{10}(fc) - 9\log_{10}((d'_{BP})^2 + (h_{BS} - h_{UT})^2) \quad (1)$$

3.1.2 Propagation Model for 3D-UMi Non Line Of Sight (NLOS)

$$PL3D\text{-}UMi\text{-}NLOS = 36.7\log_{10}(d_{3D}) + 22.7 + 26\log_{10}(fc) - 0.3(h_{UT} - 1.5) \quad (2)$$

3.1.3 Propagation Model for InH Line of Sight (LOS)

$$PL_{\text{InH-LOS}} = 32.4 + 17.3\log_{10}(d_{3D}) + 20\log_{10}(f_c)$$
(3)

3.1.4 Propagation Model for InH Non Line of Sight (LOS)

$$PL'_{\text{InH-NLOS}} = 38.3\log_{10}(d_{3D}) + 17.30 + 24.9\log_{10}(f_c)$$
(4).

where LOS is line of sight, NLOS is non-line of sight, PL is path loss, f_c is the center frequency in Hz, $c = 3.0\times10^8$ m/s is the propagation velocity in free space, h'_{BS} and h'_{UT} are the effective antenna heights at the Base Station (BS) and the user terminal (UT), d_{3D} is resultant of the distance between hBS and hUT (m), d'_{BP} = breakpoint distance (m), and d is the distance between BS and UT.

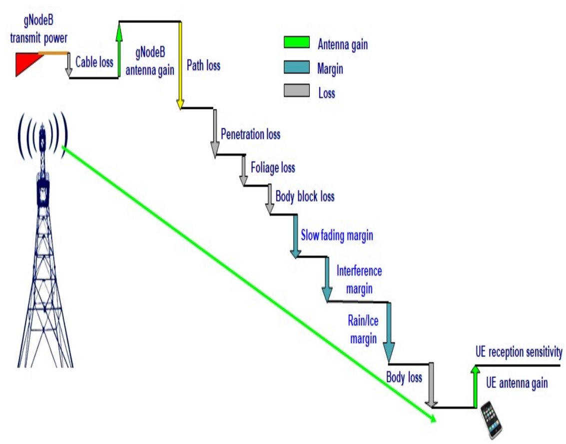

Figure. 8: Radio link budget principle [15,18].

The maximum cellular coverage is the maximum range from the center of the cell site to the cellular equipment that the received signal strength must satisfy. Figure 8 shows the radio link budget parameter principle. Table 3 shows the radio link budget parameters and symbols [15,18].

Table 3: Radio link budget parameters and symbols

Parameters	Symbols
gNodeB transmit power (dBm)	a
subcarrier quantity	b
gNodeB antenna gain (dBi)	c
gNodeB cable loss (dB)	d
Penetration loss (dB)	e
Foliage loss (dB)	f
Body block loss (dB)	g
Interference margin (dB)	h
Rain/ice margin (dB)	i
Slow fading margin (dB)	j
Body block loss (dB)	k
UE antenna gain (dB)	l

Thermal noise power (dBm)	m
UE noise figure (dB)	n
SINR (dB)	o

Based on the parameters in Table 3, the path loss equation is presented below:

Path loss (dB) = a – 10 x $\log_{10}$ (b) + c – d – e – f – g – h – i – j – k + l – m – n – o (5)

where subcarrier quantity (with symbols b) is the number of used resource blocks (RB) x the number of subcarriers per RB (depending on μ or numerology configuration). In this study, 66 RB with 120 kHz for subcarrier spacing (SCS) and path loss specified by the propagation models in equations (1) through (4). Table 4 shows the number of RB for mmWave [12] or frequency range 2.

Table 4: Number of Resource Blocks for mmWave (Frequency Range 2/FR 2) [12]

SCS (KHz)	Channel Bandwidth (MHz)			
	50	100	200	400
60	66	132	264	n/a
120	32	66	132	264

Cellular coverage is the critical element that influences cost because infrastructure expense is comparable to the number of requisite cellular towers. Table 5 shows the scenario parameters for calculating cell coverage [15,18].

Table 5: Scenario Parameters and value for maximal cellular cell coverage

Parameter	UMi	InH
gNodeB transmit power (dBm)	50	50
Bandwidth (MHz)	100	100
Resource Block	66	66
Subcarrier spacing (SCS)	792	792
gNodeB antenna gain (dBi)	25	25
gNodeB cable loss (dB)	0	0
Penetration loss (dB)	27	34
Foliage loss (dB)	8	0
Interference margin (dB)	0.5	0.5
Rain/ice margin (dB)	3	0
Slow fading margin (dB)	4	8
Body block loss (dB)	3	8
UE antenna gain (dB)	5	5
Thermal noise power (dBm)	-94	-94
UE noise figure (dB)	4	4
SINR (dB)	-7	-7
Tx Antenna Height (meter)	10	3
Rx Antenna Height (meter)	1.5	1.5

3.2 Factor 2: Cost Per Square km in Terms Of Capex and Opex

In this section, the researchers provide an overview of the economic model for a non-virtualized 5G infrastructure for Indonesia's MNOs. OPEX and CAPEX are the expense of deploying and operating a cellular network [11,19,20]. The Capex component is defined as:

$CAPEX_i = CCells_i + CBackhaul_i + CCore_i$ (6)

$CCells_i = Cmicro_{cells} + Cpico_{cells} + Cmicro_{build} + Cpico_{build}$ (7)

where $CAPEX_i$ consists of the sum of CAPEX expenses for all asset cell deployments, including equipment, planning, and installation costs ($CCells_i$). This study only considered 5G microcell, 5G picocell, fiber, and microwave backhaul for 5G transport ($CBackhaul_i$) and 5G core expenses ($CCore_i$).

The OPEX component is defined as:

$OPEXi = OCellsi + OBackhauli + \eta CAPEX$ (8)

$OCells_i = Omicro_{cells} + Opico_{cells} + Omicro_{build} + Opico_{build}$ (9)

where $OPEX_i$ is the sum of OPEX costs for all asset cells ($OCells_i$). This study only considered 5G microcell, 5G picocell, fiber, and microwave backhaul ($OBackhaul_i$) for 5G transport and 5G core expenses ($OCore_i$). The charge correlated with upgrades and marketing is the charge ratio η.

The total annual cost of one cell with the sum of CAPEX and OPEX expenses is $Cost_{percell}$. It is required to settle for the CAPEX investment at an annual interest rate of i over Y years [21,22]:

$$Cost_{per\ cell} = CAPEX * \frac{i(1+i)^Y}{(1+i)^Y - 1} + OPEX$$
(10)

In this study, simulations were based on hexagonal cell coverage and the cost per square kilometer according to the formula: [13,15]:

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$$Cost_{per\ km^2}(f) = \frac{Cost_{per\ cell}}{Area_{per\ cell}} = \frac{Cost_{per\ cell}}{2.6 * r_{max}(f)^2}$$

(11)

Today, 5G equipment costs are not available to the public. However, 5G network equipment with increased achievement is similar in cost to 4G Technology.

Table 6 shows the costs of calculating the OPEX and OPEX [13-15,19].

Table 6: Assumption Parameters for Annual CAPEX and OPEX

Parameter	Symbol	Value
Interest Rate	i	6%
Loan Duration	Y	10 years
Core Network	*core*	\$5,000
Micro-cell Equipment	$Cmicro_{cell}$	\$1,000
Pico-cell Equipment	$Cpico_{cell}$	\$700
Micro Build Insertion Cost	$Cmicro_{build}$	\$782
Pico Build Insertion Cost	$Cpico_{build}$	\$247
Maintenance Cost Ratio	η	0.04
Backhaul Equipment	*CBackhaul*	\$4,800
Backhaul Insertion	$CBackhaul_{insert}$	\$419
Micro-cell Site Maintenance	$Omicro_{cell}$	\$143
Pico-cell Site Maintenance	$Opico_{cell}$	\$143
Backhaul Site Maintenance	*OBackhaul*	\$143
Number of Backhaul	NBH	2

3.3 Factor 3: Spectrum Value Per MHz Population

The basic unit of measure for spectrum values in the spectrum trade is \$ (dollars)/MHz (bandwidth of the spectrum) - POP (population of the region covered by the spectrum license). The spectrum's economic value is equal to the present value of the benefits that the MNO can earn from it, and the yearly NPV is equivalent to the annual net return of revenue minus the yearly cost [19,21].

$$\text{Value}(f) = \text{NPVyearly}(f)$$
$$= \text{Area} * (\text{Revenue}_{per\ km^2} - \text{Cost}_{per\ km^2}(f))$$
$$= \text{Area} * (\alpha * \mu POP - \text{Cost}_{per\ km^2}(f)). \qquad (12)$$

where μPOP is the population density of the region. The annual revenue is comparable to μPOP, and the population density of the region with factor α is expressed in the following formula:

$$\$/\text{MHz} - POP(f) = \frac{\alpha * \mu_{POP} - Cost_{per\ km^2}(f)}{Bandwidth * \mu_{POP}} \qquad (13)$$

Factor α can be acquired from Equation (14) if the spectrum band and \$/MHz-POP of reference frequency f_0 are acquainted. The \$/MHz-POP of the spectrum band at any other frequency in the same frequency range can be calculated with Equation (14):

$$\frac{\$/\text{MHz} - POP(f)}{\$/\text{MHz} - POP(f_0)} = \frac{\alpha * \mu_{POP} - Cost_{per\ km^2}(f)}{\alpha * \mu_{POP} - Cost_{per\ km^2}(f_0)} \qquad (14)$$

Table 7: NR operating band, reference frequency, bandwidth and \$/MHz-POP

NR Operating Band (GHz)	Reference Frequency f_0 (GHz)	Bandwidth (MHz)	\$/MHz-POP
n258	26	1000	\$0.0030
n257	28	4500	\$0.0045

Table 7 shows the NR operating band, reference frequency, bandwidth, and \$/MHz-pop [23-25]. The \$/MHz-pop data for the NR operating band n258 (26 GHz) and n257 (28 GHz) ranges were based on auction data from the benchmark informed in "Case study 5G launches in Korea", "The latest in demographic and population data online" and "Italian 5G spectrum auction". The auction benchmark from South Korea is for 28 GHz, and Italy is 26 GHz. The population density (μPOP people/km^2) in urban areas of South Korea is 528 and 201 in Italy [24].

4. RESULTS AND DISCUSSION

Tables 3 through 7 show the input parameters for the results and discussion presented below. The results are shown in Figures 9 through 11 with the UMi and InH 3D propagation model (3GPP).

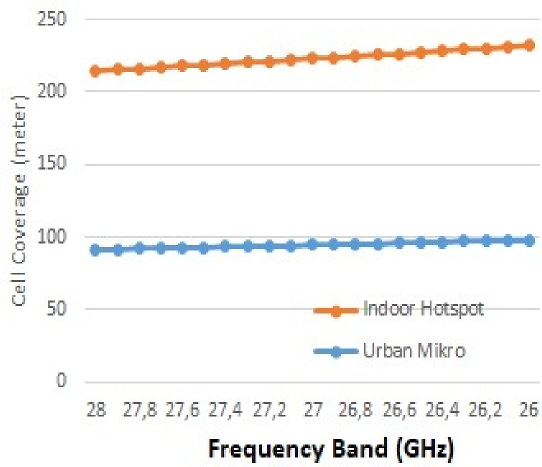

Figure 9: Results of factor 1: maximal cellular coverage vs. frequency band (GHz)

Figure 9 shows the 5G maximum cellular coverage in meters from the higher frequency band to the lower frequency band; as the frequency band increases, the maximum cell coverage decreases. For the higher frequency band of 28 GHz, the maximum cellular coverage is 58.88 meters in Urban Micro and 140.8 meters in Indoor Hotspot. For the lower frequency band of 26 GHz, the maximum cellular coverage is 63.19 meters in Urban Micro and 153.37 meters in Indoor Hotspot. Consequently, the lower the frequency band, the higher the maximum cell coverage, and the smaller the cell site; less cell coverage will be required to cover the service area. Therefore, MNOs will need to invest more money into operating and deploying the target area's cellular network if the frequency band is higher. Hence, the cost of cellular network infrastructure will increase as the frequency band increases

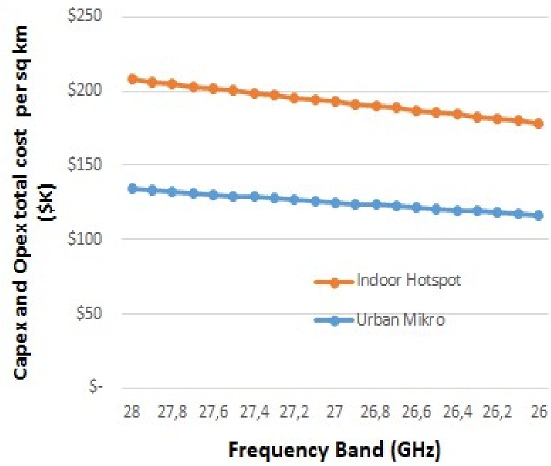

Figure 10: Results of factor 2: Cost per square km in terms of CAPEX and OPEX vs. frequency band (GHz)

Figure 10 shows the CAPEX and OPEX expense per square km in thousands of dollars ($K) from the higher frequency range to the lower frequency range. As expected, the upper-frequency range costs more to deploy and operate by the MNOs than the lower frequency range in urban areas. Figure 10 shows the increased tendency of the infrastructure costs to increase from 24.250 - 27.500 GHz to 26.500 - 29.500 GHz. These frequency ranges are the 5G candidate frequency bands for Indonesia

Figure 11 shows the spectrum value per MHz population ($) vs. frequency (GHz) from the higher frequency band to the lower frequency band. The Indoor Hotspot shows the estimated spectrum value is higher than Urban Micro. As shown in Figure 6, the range of values for the spectrums at the two-frequency band are 0.0664 ~ 0.0782$/MHz-POP for Indoor Hotspot and 0.0045 ~ 0.0225$/MHz-POP for Urban Micro.

Figure 11 shows that the lower frequency bands' value is higher than the higher frequency bands for the 5G spectrum, not only for Indoor Hotspot but also for Urban Micro.

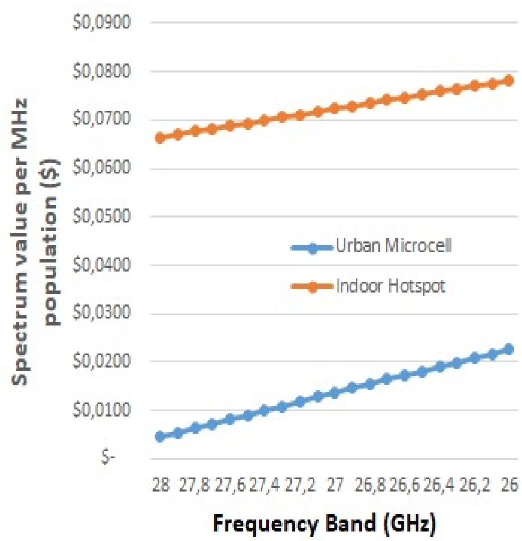

Figure 11: Result of factor 3: Spectrum value per MHz population ($) vs. Frequency Band (GHz)

5. CONCLUSION

This study proposed an economic valuation of 5G spectrum at millimeter wave (mmWave) for accelerating broadband development using a case study of industrial areas in Indonesia. The valuation method was based on the review and modification of previous research. We utilized the engineering-economic modeling based on three factors: maximal cellular coverage, cost per square km in terms of CAPEX and OPEX, and spectrum value per MHz population. Spectrum frequency bands at 26 GHz and 28 GHz were considered in specific locations like Jakarta-Indonesia's industrial area. In most cases, the deployment and operating expenses for MNOs would decrease as the frequency band decreases, and the frequency band value per MHz-POP would increase as the frequency band decreases.

Therefore, we concluded that the mmWave utilization for advanced cellular broadband services requires higher infrastructure investment. However, population density significantly influences the spectrum valuation in both lower frequency bands and higher frequency bands. Based on this study's results, mmWave is suitable for Urban Microcell and Indoor Hotspot because mmWave with a larger bandwidth has a short-range radius (between 50 and 200 m). It also has a high capacity to accelerate broadband development, especially in urban areas.

The results of the study are used as a starting point for regulators and MNOs, which can be further investigated by other stakeholders or vertical Industries. To summarize, it serves as the foundation in the near future for more comprehensive strategies.

Finally, there is a restriction to this research in the sense that the findings are predefined variables subject to the three methods. In order to extend the criteria to be more detailed and cover more concerns in the 5G spectrum valuation of an Indonesian industrial area case study, a further research is needed.

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