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Refining Spectrum Fee to Increase Utilization Efficiency by Adopting ITU-R SM 2012-2 Case Study: Cellular Service in Indonesia

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Abstract. The spectrum fees called as "Biaya Hak Pengguna Frekuensi" (BHP-F) for cellular services in Indonesia are currently calculated based on apparatus, proportionally to the number of transceiver stations and radio channels. Unfortunately, the formula cannot promote the efficiency of frequency spectrum efficiency. ITU-R SM 2012-2 recommended the spectrum fee formula that can promote the efficiency; Administrative Incentives Price (AIP) also claims to promote the effectiveness of the radio spectrum utilization. By combining ITU-R SM 2012-2 with AIP, the frequency fee formula can promote not only the efficiency but also the effectiveness of spectrum utilization. This paper will explain and discus the modification of ITU-R SM 2012-2 with AIP in designing the spectrum fees for cellular services in Indonesia.

Keywords: *AIP; BHP-F formula; ITU-R SM 2012-2; spectrum fee; spectrum utilization.*

1 Introduction

Spectrum is a band of electromagnetic frequencies and often used to refer the radio frequency spectrum. This band is divided into several sub-bands; the ITU's International Radio Regulations allocate the spectrum from 9 kHz to over 275 GHz for a range of different usage [1].

As a resource spectrum is a non-homogeneous matter and has unique characteristics; different frequencies have different characteristics hence specific frequencies are more suitable for certain usage. In general, greater bandwidth transmits more information for a given period. The quality of communication can negatively be affected by interference, i.e. decreasing voice quality or data rates connection lost/ elimination in worst cases. However, some spectrum is more susceptible to the interference than others. Interference between frequencies partly depends on the technology being used and the use of more sophisticated equipment can improve receiver performance [2].

There are four parties that have interest in spectrum management: (i) the regulator that manages and allocates the usage of spectrum, (ii) the

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telecommunications services providers that have right to use spectrum by paying the licenses fee, (iii) the users that use spectrum for their communication needs, (iv) the telecommunications equipment vendors [3].

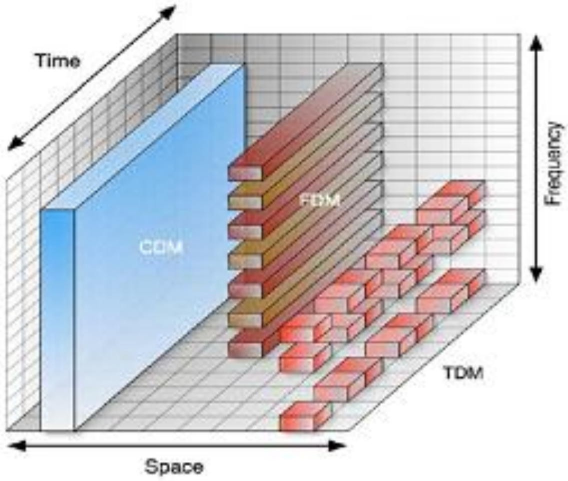

Figure 1 Three dimension of spectrum.

As illustrated in Figure 1, spectral of frequency spectrum can be represented in three dimensions: frequency dimension, space dimension and time dimension. In order to optimize the utilization of spectrum, the three dimensions should be allocated effectively. Spectrum utilization factor is expressed in the following equation [4]

$$U = B \cdot S \cdot T \quad (1)$$

where U is spectrum utilization that is defined to be the product of the frequency bandwidth (*B*), the geometric or geographic space (*S*), and the time denied to other potential users (T).

Spectrum utilization efficiency (*SUE*) is then formulated as follows

$$SUE = \{M, U\} = \{M, B \cdot S \cdot T\}, \quad (2)$$

where *M* is the amount of information transmitted in Erlang.

The spectrum fee should at least cover the regulator's management cost. However, its formula should be to promote the efficient use of spectrum in mind. Every year, providers that have the right to use spectrum have to pay spectrum fee to government and there are some methods to calculate the spectrum fee [5]:

1. Based on the spectrum management cost. Management cost consists of direct and indirect cost:

   a. Direct cost, includes cost of staff time in the frequency assignment process, site clearance, interference analysis, and cost of particular of services – for example keeping the public news and entertainment channels clear, ITU and regional international consultation cost for special group of users.
   b. Indirect cost, includes cost of spectrum management functions that is used to support the administration's frequency assignment process and the overhead cost of operating the administration's spectrum management procedures. These represent costs that cannot be identified to specific services or licensees such as general international consultation for example with the ITU and regional groups, propagation research covering many frequency bands and services, general spectrum monitoring, interference investigations arising from the complaints of rightful users and the cost of support staff and equipment.

2. Based on the user's gross income. The spectrum fee can be applied based on the percentage of gross income of a company. In the fee calculation, the value of gross income has to be directly related to the company's use of the spectrum to avoid the difficulty in accounting and auditing processes. India uses this method to collect the spectrum fee.

3. Based on the incentives fee. An incentive fee attempts to use price to achieve the spectrum management objectives and hence to provide some incentives to use the spectrum efficiently. Various elements of spectrum usage may be taken into consideration in the development of an approach or a formula (e.g. population density, bandwidth, frequency band, coverage area, exclusivity, power) and different formula may be required for different frequency bands and services. The incentive prices can be set specifically by government for special purpose. In UK, The government using the administrative incentives prices (AIP) based on opportunity to encourage the operator to utilize unused spectrum.

4. Based on the market. In this method, the market has the opportunity to determine the spectrum fee in an auction. The provider with a highest bid has the right to use the spectrum.

2 Benchmarking

The research of spectrum fee formula has been conducted by Taiwan because the frequency usage fees in Taiwan in the past were low and did not give frequency users any incentive to invest in spectrum-efficient technologies. In addition, frequency usage fees were low compared to leased line tariffs so that users have typically preferred microwave to wire line transmission. This has led to inefficiency in spectrum usage and congestion in the microwave band. To facilitate fair access and efficient use of frequency, the current frequency usage fee structure needs to be re-examined and revised with reference to practices in other countries, including the UK, Australia, Korea, and Singapore while also taking into consideration the case of domestic frequency congestion situation in Taiwan, anticipated future spectrum needs of emerging new services, and the complaints of existing frequency users [11] (see Table 1).

Table 1 Benchmarking Spectrum Fee Formula [11].

Country	Formula and Parameters
Korea	Frequency usage fee = BFP x (√*W*+BW) x PP x SUP x SPP. Explanations: BFP base Fee Parameter is 2000 Korean Yen (less than $2) *W* antenna emission power (Watts) Taking the square root of the emission power to reflect the reach of radio coverage BW bandwidth (kHz) PP preferential parameter. It varies with different frequency bands. The parameters are higher for congested frequency bands. In order to encourage developing radio applications in the high frequency bands, the parameters will be relatively low SUP shared use parameter. The parameters will be higher for exclusive use of frequencies; and les for shared use of frequencies SPP special purpose parameter. There are different parameters for different radio service types. Frequencies used for public services should have a small parameter value
Singapore	Singapore use the spectrum fee formula based on bandwidth consumption as below : Bandwidth < 1 MHz 300 Singapore dollar per 25 kHz Bandwidth ≥ 1 MHz 12,000 Singapore dollar for the first MHz, an extra 300 Singapore dollar for each additional MHz 3500 Singapore dollar for frequency band < 20 MHz 6200 Singapore dollar for frequency band ≥ 20 MHz
Australia	Australia uses the spectrum fee formula as below Frequency usage fee = *K* x (Si,Gi) x Bi x Ai. The parameters are explained below: *K* base fee parameter Si spectrum location

Country	Formula and Parameters
	The central frequency (f_0) of a radio station could fall into one of the following eight bands: $f_0 \le 30$ MHz, 30 MHz $< f_0 \le 70$ MHz, 70 MHz, $f_0 \le 960$ MHz, 960 MHz $< f_0 \le 2.69$ GHz, 2.69 GHz $< f_0 \le 5.0$ GHz, 5.0 GHz $< f_0 \le 8.5$ GHz, 8.5 GHz $< f_0 \le 31.3$ GHz, or 3.31 GHz $< f_0$. Gi geographic location, Bi bandwidth Ai area of coverage
UK	The UK frequency authority (Radio Communications Agency of UK, 1999; Green, 1999) considers the value of a spectrum to be the difference between the marginal utilization generated from the spectrum and the marginal cost of obtaining the spectrum. This difference is the users' willingness to pay for the frequency usage fee. At times when demand for frequency is higher than its supply, the frequency usage fee can be measured as the unrealized cost savings resulting from failure to obtain such frequency. It can also be regarded as an opportunity cost, which is the cost difference between using the frequency vs. using other alternatives, like public radio services, different transmission technologies, or using frequencies in different frequency bands. Frequency usage fees may also be levied in accordance with revenues or profits. However, the frequency usage fees may constitute merely a small part of one user's total revenue while being a large part of another user's revenue. Therefore, associating frequency usage fee with a percentage of a user's revenue is not equitable among all users.
Taiwan	For the mobile service, Taiwan use this formula below : Frequency usage fee = {(BW x BFM) + (BW x ANC x BFMC)} x *d*. Note that: BW bandwidth, in MHz, assigned to a mobile service operator. BFM base fee per MHz. BFMC base fee for each mobile customer. ANC average number of mobile customers serviced per MHz of bandwidth allocated to one mobile service type. (Adding the total number of mobile customers within one mobile service type, and dividing the sum by the total bandwidth assigned to all of the operators of such mobile service type). *D* discount factors for regional service operators: for whole region operator $d = 1.0$ for north region operator $d = 0.45$ for central region operator $d = 0.25$ for south region operator $d = 0.30$ The revised frequency usage fee charging system for Taiwan has the following advantages: a. For each radio service type and each bracket of frequency band, the frequency usage fees are calculated from several concise equations of consistent structure, which generate fees directly proportional to the bandwidth consumed and power emitted. Instead of looking into

Country	Formula and Parameters
	oversimplified and discrete rate tables to figure out usage fees, these equations help make the fee pricing system fairer and more easily computerized b. Charging less for frequencies in higher frequency bands than for frequencies in lower frequency bands is simply done by setting descending base fee parameters for the respective fee equations in the ascending frequency bands. c. A few categories of usage fees are raised to reflect the true value of certain commercial radio services, such as public mobile phone service, or to relieve congestion in the frequency band of microwave transmission. On the other hand, special discounts are given to public service bureaus such as the police department, fire department, emergency rescue organizations, etc. Educational, experimental, and research use of frequencies are also heavily discounted.

The formula implemented by those countries are different based on situation in each country such as providers competition, geography, population, government expectation of income from spectrum fee, etc. The aim is the same; to create a fair and technologically neutral formulating frequency spectrum fee to increase spectrum utilisation efficiency.

The Taiwan's case study shows that power emission is not an important factor in frequency fee calculation based on apparatus; the fee is more afffected by bandwidth consumpetion and number of user achieved. The formula used in Taiwan also shows AIP, which gives discount factor for regions with different economic level.

3 Calculation of Existing Spectrum Fee in Indonesia

In Indonesia, spectrum fee namely as "*Biaya Hak Pengguna Frekuensi*" or BHP-F is comprised of the following items [6].

a. the type of radio frequency;
b. the width of band and/or channel of radio frequency;
c. the transmission power;
d. the location;
e. the market interest.

The formula of BHP-F is written as below:

$$BHP - F = \left(\frac{lb * HDLP * b + lp * HDDP * p}{2} \right), \tag{3}$$

where *HDDP* is reference for transmission power (rupiah unit), *HDLP* is reference for bandwidth (rupiah unit), *p* is EIRP of transmitter (dBm), *b* is bandwidth (kHz), *Ib* is bandwidth index, and *Ip* is power index.

Here, HDDP and HDLP are determined from the classification of frequency bandwidth and geographical zone, respectively. The bandwidth index (Ib) and power index (Ip) are classified by the type of radio communication services. Geographical zone consists of 5 zones, which depend on the economic and population growth factors; for example in satellite networks (space segment) the zone is assumed as Zone 3 (average zone) since it covers the whole country.

To illustrate how the BHP-F of some radio frequency spectrum calculation per each station and each RF channels works, an example is explained as follows.

A station uses GSM-900, 200 kHz of bandwidth, 53 dBm of EIRP of transmitter, type of transceiver as transmitter, and is located in Zone 1, then the BHP of radio frequency spectrum is:

$$BHP - F = \left(\frac{8.79 * 11772 * 200 + 4.2 * 109481 * 53}{2} \right) = 45 \text{ Billion} \tag{4}$$

The BHP-F of radio frequency spectrum is imposed at the time of license issuance and paid annually in advance. However, the use of radio frequency spectrum for specific purposes is exempted from the imposition of BHP-F rule, such as: for state's security and defense purpose, special official services, governmental agencies purpose used by the representatives of foreign countries on the basis of reciprocity principle [7].

4 Weakness of Cellular Spectrum Fee Based on Apparatus

There are some weaknesses of BHP-F calculation for cellular services in Indonesia based on Apparatus:

a. No difference in fee incentive for using low or high frequency.
   It is wellknown that the type of services categorized as mass services such as broadcasting and cellular communication are highly competitive and profitable. Hence, the interference and type of propagation at low frequency is better than the high one as the bandwidth at low frequency is scarce. Cellular services use the frequency in UHF band (300–3000 MHz), while the HDDP and HDLP as shown in Table 2 have the same value for all frequencies in that band. In the implementation there is no difference

between the low and high frequencies that is not matched with the BHP-F calculation. Ideally, there should be a different incentive fee for the low and high frequency user where the lower frequency user has to pay more than the higher one.

Table 2 HDDP and HDLP lookup table in UHF band (300 MHz-3000MHz).

	Band	Zone I	Zone 2	Zone 3	Zone 4	Zone 5
HDLP	UHF	11,772	9,418	7,063	4,709	2,354
HDDP	UHF	109,481	87,585	65,688	43,792	21,896

b. No Compensation or Penalty for Unutilized Licensed Spectrum.
Since cellular service providers have spectrum licenses paid annually, they have a special right to use the licensed spectrum exclusively and other providers are not allowed to use it. In some cases, some licensed spectrums have not been utilized by their owner. However, those spectrums cannot be used by others although they have an opportunity to utilize it. The compensation or penalty for unutilized licensed spectrum has not expressed in the BHP-F formula since it calculates only the number of stations and channel usage. There should be some compensation or penalty for the provider that has not utilized their spectrum effectively to increase utilisation.

c. Technology Dependency.
The other weakness of BHP-F calculation for cellular services is technology dependency. From the BHP-F formula, it should be noted that the parameter of bandwidth index (Ib) and power index (Ip) can be categorized by the type of service related with the technology used as tabulated in Table 3.

Table 3 Ib and Ip in GSM and FWA.

Type of service		Ib	Ip
Cellular FDMA (AMPS. NMT)	Base + out station	8.210	0.630
Cellular TDMA (GSM,DCS & PCS)	Base + out station	8.790	4.200
Cellular DS-CDMA (IS95)	Base + out station	3.400	11.710
WLL FDMA	Base + remote/out station	1,360	0,110
WLL TDMA	Base + remote/out station	0,230	0,490
WLL DS-CDMA	Base + remote/out station	0,070	0,490

d. Unfairness.
The spectrum fee formulated in BHP-F formula is calculated each station and each RF channel; for the providers that use more bandwidth, they usually pay no more for the excess bandwidth. From Table 4 for price per MHz comparison, it is shown that provider J that uses 30 MHz pays lower than provider K that uses only 20 MHz although they have the same

national right. There is unfairness caused by BHP-F formula since the provider has the ability to deliver more service with more bandwidth. To eliminate that unfairness, price per MHz for every provider must be equal because all providers have the same right and opportunity to deliver as much information.

Table 4 Price per MHz for GSM and FWA provider [9].

Technology	User	BW (MHz)	BHP-F 2007 (Rp)	BHP-F / BW (Rp/MHz)
CDMA-800	B	14.76	48,310,547,876	3,273,072,349
	C	14.76	36,485,030,866	2,471,885,560
	D	9.84	38,835,940,774	3,946,741,949
	E	4.92	2,953,073,559	600,218,203
GSM-900/ GSM-1800	G	80	1,331,215,092,932	16,640,188,662
	H	65	736,531,891,098	11,331,259,863
	I	30	328,389,937,561	10,946,331,252
	J	30	24,647,702,466	821,590,082
	K	20	74,167,162,639	3,708,358,132

e. The advanced technologies in communication services make it possible that more channel are available from the same bandwidth. The spread spectrum and multi-hoping technology make the calculation of bandwidth currently in used imprecise, and at the end, the spectrum fee is difficult to calculate accurately using the BHP-F formula.
f. The BHP-F formulation which was calculated based on base transceiver station (BTS) makes the spectrum fee increases according to the increase of user and traffic. This situation is contradictive with the attempt of improving service quality and optimum spectrum utilization.

Apparatus system used in the cellulair provider calculation was thought to cause spectrum utilisation only in Java which has high level of economic acitivity and dense population as shown in Figure 2. This is the result of using the apparatus system that calculates fee based on channel number being used while the opportunities to use channel in less populated area are already closed. This condition makes providers build facilities only in financially viable area. The use of emission do not guarantee that providers will have more profit as the business revenue comes form the number of users not the emission power. Apparatus systems are more suitable to be used in poin to point communication system where emission affects area range.

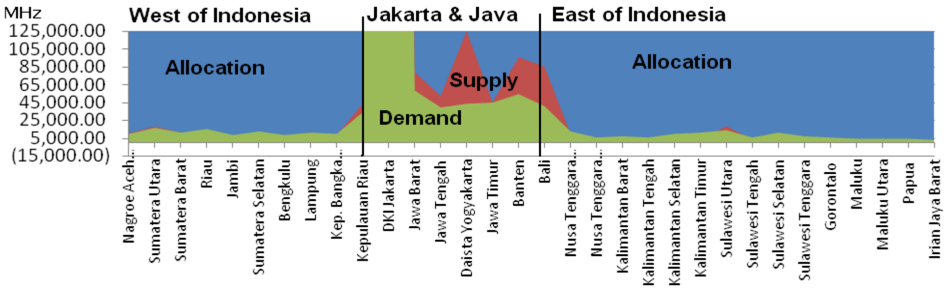

Figure 2 Spectrum Allocation vs Supply vs Demand in Indonesia.

5 Recommendation from ITU-R SM.2012-2

ITU-R SM. 2012-2 – Economic aspects of spectrum management was issued in 1998. In that recommendation, ITU has proposed an analytical model for calculating license fees on the basis of specified incentives that are designed to promote efficient spectrum use [5]. It was also developed in the framework of the BDT Asia and Pacific Project on Spectrum Validation and Licensing, Bangkok, 2000. The model is derived from the conceptual base that there is a distinct need to price spectrum and that the pricing of spectrum resources should reflect more than administrative convenience. The purpose of this model is to increase spectrum utilization efficiency. It is designed to introduce non-discriminatory access to the spectrum for various categories of users, stimulate the use of less congested (particularly – higher) frequency bands, stimulate harmonized development of radio communication services throughout the country, and cover the cost of spectrum management. It includes the consideration of the phased development and/or maintenance of spectrum management and monitoring facilities and reimbursement of expenditures of a national telecommunication administration including its international activities within ITU.

The proposed spectrum payment algorithm includes the following steps:

a. Determination of annual expenditures of the state on management of actually used spectral resource and determination of the common value of the annual payments for all spectral resources.
   Here, the total amount of the annual payments for spectral resource (*Can)* can be collected from all users where they come from share of the sum that is necessary for covering expenditures of the state on all national and international spectrum management activities, net income of the state - if applied-, etc.

$$C_{an} = C_1 + C_2 - I_{an} \tag{5}$$

where C_1 is the cost of managing the spectrum at national as well as international level; C_2 is the country's net revenue (optional) and I_{an} is the annual inspection cost.

b. Determination of the value of the spectral resource used by each radio station and, through their summation, by all stations registered in a national Spectrum Management Database.
This step is to determine the spectral resource value used by each user and then by all users. For any *i*-th frequency assignment (from their total amount n incorporated in the national database), the three-dimensional value of the spectral resource is denoted as *W*i. This spectral resource is the multiplication of frequency resource, territorial resource and time resource. A frequency resource *F*i used by *i*-th emission is determined by necessary bandwidth of the emission (MHz), calculated in accordance with Recommendation ITU-R SM.1138, taking into account that an occupied bandwidth of an emission should be equal to its necessary bandwidth [8].

$$W_i = \alpha_i \text{ x } \beta_i \text{ x } (F_i \text{ x } S_i \text{ x } T_i) \tag{6}$$

where F_i is the frequency being used, S_i is the used area, T_i is the used time, α_i is the weighted coefficient such as commercial value, social value, etc, β_i is the weight factor for spectrum exclusivity.

$$F_i = \chi B_{ni} \qquad \text{MHz} \tag{7}$$

where B_{ni} is emission bandwidth; χ is adjustment $(0 \le \chi \le 1)$ which can be used to differentiate type of services such as radio, TV, radar, etc with the same power.

$$S_i = b_{ij} \cdot s_i \quad (\text{km}^2) \qquad 1 \le j \le m \tag{8}$$

where S_i is the area covered by emission in km^2; b_{ij} is the weighted factor for category of spectrum utilisation and *m* is the number of category

$$W = \sum_{j=1}^{n} W_j \ (\text{MHz} \cdot \text{km}^2 \cdot 1 \text{ year}) \tag{9}$$

where *W*i is the i^{th} spectrum and *n* spectrum number being registered.

A territorial resource *S*i used by *i*-th emission is determined by the territory actually occupied (covered) by the emission in accordance with certain criteria (km^2), and weighting coefficient which depends on the *j*-th category of the territory actually occupied by the emission and also number of categories. The number of categories *m* and the relevant values of the weighting coefficients *b*j should be set out by a national telecommunications administration. These categories can take into account density of population and/or level of economic (industrial and/or agricultural) development of various regions of a country.

A time resource *T*i used by *i*-th emission is determined as not more than one year and for each frequency assignment represents a fraction of time related to one year, determined in that or another way, during which the radio transmitter operates in accordance with terms set out in the relevant license.

For example, if a particular TV transmitter in accordance with terms of its license is operating only 16h per day throughout the whole year, than *T*i = 0.67 year. If another 16/24 transmitter (for example an HF one used for geological expedition), in accordance with terms of its license can operate totally only 3 months per year, then: *T*i = 3/12 = 0.35 year.

c. Determination of the price for a unit of the spectral resource.

In this step, it is possible to determine the price of Δ *Can* for a qualified unit of the spectral resource where it presents as units of a national currency/(MHz · km2 · 1 year)

$$\Delta C_{an} = L\ C_{an} / W \quad \text{IDR/(MHz} \cdot \text{km}^2 \cdot \text{1 year)} \qquad (10)$$

where *L* is the adjustment factor, which is determined by the government for the next annual budget.

d. Determination of the annual payment for a specific user on a differential and non-discriminatory basis, which is determined from the actual value of used spectral resource.

General weighing coefficient can be presented from taking into account commercial value of the spectrum range used, social factor, features of transmitter location, the complexity of spectrum management functions and other coefficient (coefficients) that can be introduced by an administration reflecting its specific needs. Another weighting coefficient is exclusive of the frequency assignment.

According to equation above the price Δ *Can* for the qualified unit of the spectral resource is determined. Equation above gives the value of the spectral resource *W*i used for a particular *i*-th frequency assignment. Based on this, the amount of the annual payment *C*i from the specific user of the spectrum for this frequency assignment can be determined as:

$$C_i = C_{an} \cdot W_i \qquad (11)$$

6 Formula Calculation of ITU-R SM 2012-2 for Cellulair in Indonesia

By using the recommendation from ITU-R SM 2012-2, the spectrum fee is refined by adopting the recommended model. However, we are limiting adoption of the model in the simulation only for cellular service. In this simulation, the spectrum that has to be paid by providers depends on their spectral. The steps of simulation are outlined below.

a. Define expenditures and income of a state related with spectrum management.
   The total amount of the annual payments for spectral resource (C_{an}) comes from the total annual BHP that provider must pay on 2007 for cellular service (not included 3G) as 2.6 Billion Rupiahs. The value of this BHP-F is the non tax income, which is fixed and is not allowed to be lowered because it is vital for the government.

b. Define a spectral.
   Weighting coefficient bj is defined as population density, area (S) is defined as area per-region and uses the j-th category where for $1 \le j \le m$, m is 5 regions as stated above as shown in Table 5.

Table 5 Weighting coefficient (b) and Area (S).

No (j)	Region	Area (km^2) (S)	Population	Density (pop/km2) (b)
1	SUMATERA	450,207	44,680,030	99.24332
2	JAWA-BALI-NT	199,020	138,645,203	696.63910
3	KALIMANTAN	507,421	11,694,255	23.04647
4	SULAWESI	195,651	15,399,160	78.70726
5	MALUKU PAPUA	637,517	4,471,434	7.01383

Value of α is 1 because the cellulair services in this case study is commercial area and T value is 1 becuase of working hours of 24x365 days a year continuosly.

Cellular works in spectrum band of CDMA-450 MHz, CDMA-800 MHz, GSM-900 MHz, GSM-1800 MHz and CDMA-1900 MHz. Every band has its own characteristic, whilst the propagation of each spectrum depends on the used band. We adopt the calculation model shown in mobile radio service Annex 1 part 4 of ITU-R SM 2012-2.

Each range (R) is found using Okumura Hatta formula as below [10]:

$$L_{urban} = 69{,}55 + 26{,}16 * \log f - 13{,}82 * \log h_{bs} - A + (44{,}9 - 6{,}55 * \log h_{bs}) * \log R$$
$$A = (1{,}1 * \log f - 0{,}7) * h_{ms} - 1{,}56 * \log f + 0{,}8$$
$$L_{rural} = L_{urban} - 4{,}78 * (\log f)^2 + 18{,}3 * \log f - 35{,}94$$
$$L_{open} = L_{urban} - 4{,}78 * (\log f)^2 + 18{,}3 * \log f - 40{,}94$$

where : L is channel attenuation (dB)
f is the frequency (Mhz)
h_{bs} is height of base station antenna (m)
h_m is height of mobile antenna (m)
R is radius of cell (km)

The model assumes that the existence of homogeneous urban development is in limits of the service area using environment coefficient as shown in Table 6.

Table 6 Environment coefficient of Urban.

Environment Type ("morphology")	Building Median Loss, dB	Building Std. Dev, dB	Outdoor Std. Dev, dB.	Composite Standard Deviation	Desired Reliability at Cell Edge,%	Fade Margin, dB.
Urban	15	8	8	***11,31***	75,0%	***7,63***

The heights of transmitting and receiving antennas are in limits 20-200m and 1.5-10m, respectively.

Using forward and reverse budget calculation, propagation range for each frequency channel from 400 MHz up to 2100 MHz is shown in Figure 3.

Using best-fit logarithmic trendline method, the above samples give natural logarithmic function, which is used as adjustment for frequency (X_i) as follows:

$$X_i = 1.56 \ln (Fc_i) + 12.77. \tag{12}$$

Where Fci is spectrum frequency channel.

From the data above, Wi is determined as follows.

$$Wi = F_i \cdot S_i = X_i.\mathrm{Bn}_i.b_i.s_i \tag{13}$$

where X_i is the adjustment of frequency, Bn_i is the bandwidth of spectrum, b_i is the population density of weighting coefficient, and s_i is the coverage area (km^2)

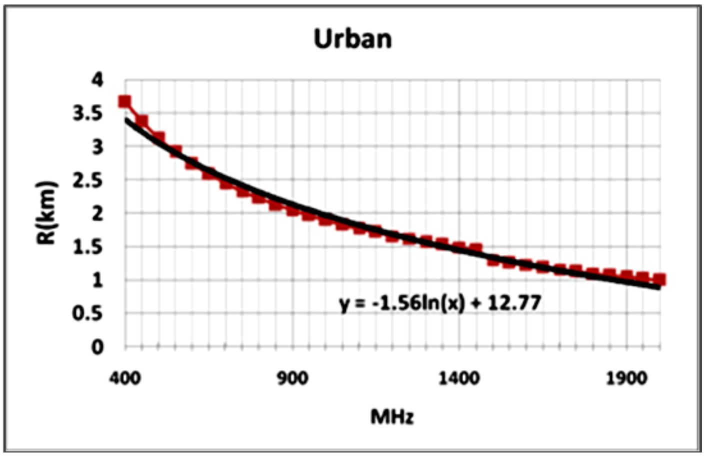

Figure 3 Frequency vs Range on band 400MHz -1900 MHz.

Ideal condition for this study is when all spectrums have been utilised in all regions to calculate *W* in order to find the spectral value. *W* value for all spectrums that is assigned to cellulair provider is shown in Table 7.

Table 7 W total for all cellular providers.

Technology	Provider	Fc	Bn (MHz)	X	b.s ($x10^6$)	W
CDMA-450	A	450	15	3.24	214,9	10,442,280,210
CDMA-800	B	800	14.76	2.34	214,9	7,428,318,492
	C	800	14.76	2.34	214,9	7,428,318,492
	D	800	9.84	2.34	214,9	4,952,212,328
	E	800	4.92	2.34	214,9	2,476,106,164
CDMA-1900	F	1900	12.5	0.99	214,9	2,666,273,761
GSM 900 / 1800	G	900	15	2.16	214,9	6,956,840,874
		1800	65	1.08	214,9	15,042,739,995
	H	900	20	2.16	214,9	9,275,787,832
		1800	45	1.08	214,9	10,414,204,612
	I	900	15	2.16	214,9	6,956,840,874
		1800	15	1.08	214,9	3,471,401,537
	J	1800	30	1.08	214,9	6,942,803,074
	K	1800	20	1.08	214,9	4,628,535,383
					Total	99,082,663,627

c. Define price for the qualified unit of used spectral resource.
From equation above we define:

Can = 2,659,647,996,865 IDR (14)

W= 99,082,663,627 MHz/km2/year (15)

For 2007, we set L=1, so

$$\Delta \text{Can} = \frac{2{,}659{,}647{,}996{,}865}{99{,}082{,}663{,}627} = 26.8 \text{ IDR/MHz/km2/year} \quad (16)$$

d. Annual fee for particular frequency assignment of every provider.

By using the equation above, in 2007 every provider should pay as shown in Table 8.

Table 8 Can per operator that should be paid.

Technology	**Provider**	**Band**	**BW (MHz)**	**C_{an} (IDR)**
CDMA-450	A	450	15	280,299,203,851
CDMA-800	B	800	14.76	199,396,273,341
	C	800	14.76	199,396,273,341
	D	800	9.84	132,930,848,894
	E	800	4.92	66,465,424,447
CDMA-1900	F	1900	12.5	71,570,040,017
GSM 900 / 1800	G	900 1800	15 65	590,528,589,369
	H	900 1800	20 45	528,532,953,961
	I	900 1800	15 15	279,922,391,132
	J	1800	30	186,363,718,942
	K	1800	20	124,242,479,295

Comparing old formula in 2007 and the new one using ITU-RS M.2012-12 in a ideal condition in which all providers are applying spectrum utilisation in all regions, it is shown that provider A to F and J and K, which use CDMA 450,800 and 1900 MHz and GSM 1800 have to pay higher fee if current formula is applied, while provider G-I, which use GSM 900 and 1800 have to pay lower fee (see Figure 4). The reason is that provider G,H, and I is a mature provider where frequency channel is utilised higher than the others and pay higher fee than the average fee paid by each provider. The new formula will encourage other providers other than the ‘big three’ to increase utilisation and increase more users and traffic while compensating the cost of spectrum fee, which is lower than current situation. This shows the new formula will promote the increase efficiency in spectrum utilisation.

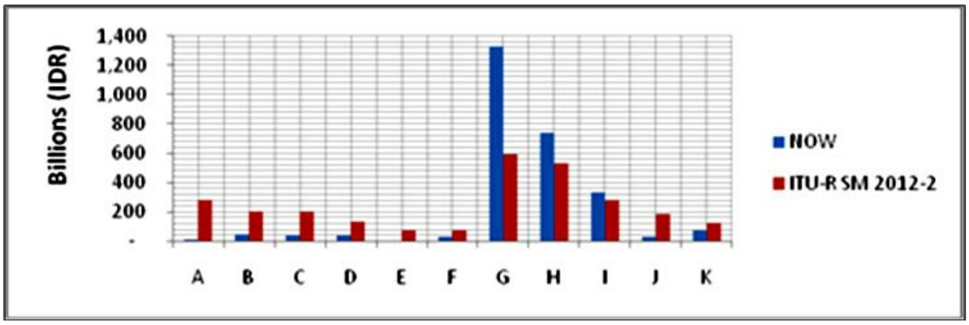

Figure 4 Spectrum fee paid by each operator.

7 Proposed Spectrum fee Formula

As explained above, the ITU SM 2012 uses BHP-F calculation based on bandwidth combined with potential economic value, which is unique in frequency band and spectrum spectral being used.

The problem might occur if ITU SM.2012 is implemented directly because BHP-F is calculated based only on frequency being used, and the effort to increase service development in region of economically unfeasible in Indonesia is difficult to execute.

Additional program as incentive to increase spectrum utilisation and nunber of users especially in economically unfeasible area such as in East part of Indonesia, will be introduced to solve the problem. This incentif is based on AIP (Administrative Incentive Price) method where government applies an incentif as administrative procedures. Spectrum exclusivity value is also being considered as fee will be calculated not only based on spectrum in use, but the unused spectrum is also calculated because it hinders other providers to utilise the spectrum.

Below is several alternatives of BHP-F formula. The proposed method is the modification of ITU-R SM2012 formula, where several coefficents are used or redefined to give incentive while at the same time holding the principle of neutrality to technology and fairness to unique technological opportunity that charaterize the spectrum bands.

a. ALTERNATIVE-1. Value of *S* is based on area of spectrum being utilised owned by each provider.

$$\text{Spectrum\_fee} = X * B * S_{used} * \text{unit\_price} \quad (17)$$

Where X is frequency band utilisation coefficient, B is the bandwidth, and $S_{used}$is the potential number of user in the region being utilised.

b. ALTERNATIVE-2. Value of S is found by adding AIP coefficient based on utilised area of each provider and its right, 0.3 for right, and 0.7 for utilised area.

$$\text{Spectrum\_fee} = X * B*(0.3*S_{right} - 0.7*S_{used})*\text{unit\_price} \quad (18)$$

Where X is coefficient frequency band, B is the bandwidth channel, and S_{used} is potential number of users in the utilised region, and S_{righ} is the potential number of users in area with the right being hold by the provider.

c. ALTERNATIVE-3. S value is the potential number of users which can be achieved converted to realized users which has been achieved.

$$\text{Spectrum\_fee} = X*B*S_{real}*\text{unit\_price} \quad (19)$$

Where X is the coefficient of frequncy band utilisation, B is the bandwidth channel, and S_{real} is number of users acheved.

Comparing all three modifications using the redefinition above to the old BHP-F and ITU-R.SM.2012-2 shows that alternative-3 give lower gap to the difference between the two, showing direct relation between channel being used and the number of customers (see Figure 5).

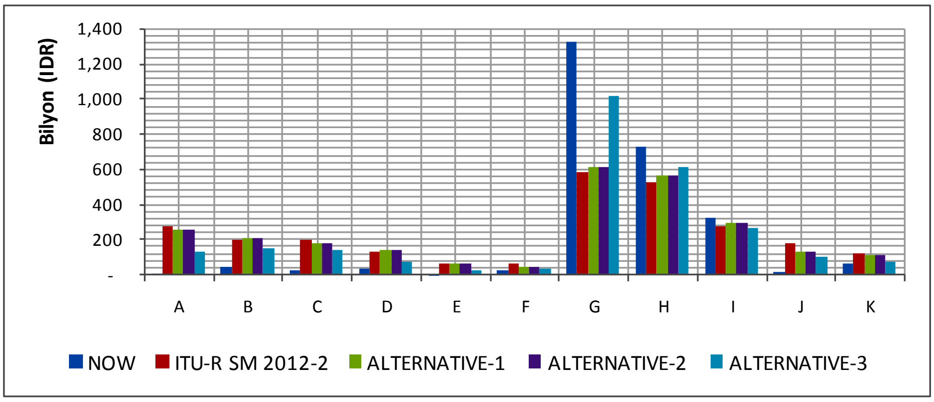

Figure 5 Comparison of calculation of spectrum fee.

Other than the above methods, incentives can also be given based on the highest service traffic record. This incentive needs data of incoming and outgoing traffic and then divided them with the bandwith being used and coverage service area. Figure 6 shows the traffic record per Mhz per square km.

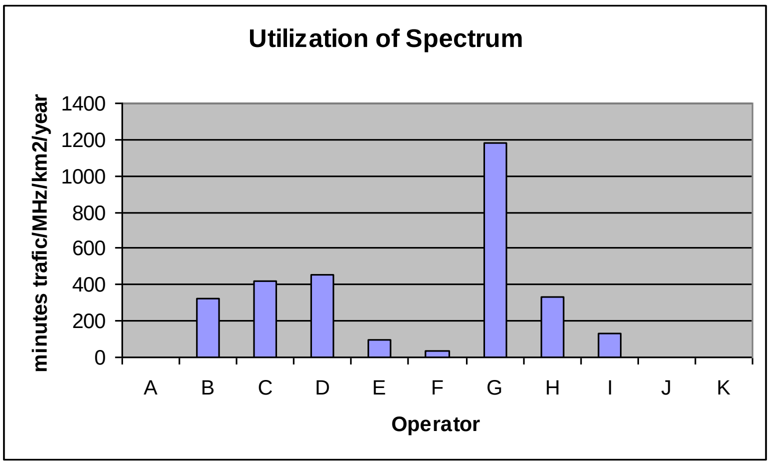

Figure 6 Scenario of calculation spectrum fee with erlang/MHz/km^2.

By using alternative-2 and setting upper limit of ideal traffic per MHz per km^2, a provider which has achieved the upper limit will get the Q reduction factor, which is the difference of current traffic per MHz per km^2 from the ideal traffic being set.

$$Spectrum\_fee = X*B*(0.3*S_{right} + 0.7*S_{used})*Q*Unit\_price \quad (20)$$

Where X is the frequency band coefficient, B is the channel width, S_{used} is the potential number of users in the utilised region, S_{right} is the potential number of users in the region with right, and Q is the incentive to traffic achievement.

The spectrum fee formula has to include the incentives. Furthermore, the spectrum fee formula has also to make the spectrum utilization optimum, since it is the key point to know that the spectrums are used efficiently. To accomplish it, we need to simulate the formula above consists of incentive factors into techno-economic of provider industry. By simulating the formula, the spectrum utilization can be obtained optimally.

8 Comparison Existing BHP-F Formula and ITU SM 2012-2 Formula

By comparing the Existing BHP-F Formula and ITU SM 2012-2 Formula, it is clear that the existing formula will increase rapidly especially to provider which has built or will build many BTS to improve its service quality. Simulation of BHP-F calculation below shows that the BHP-F is increasing with the increase of spectrum utilization while the graphic can be seen in Figure 7.

The formula ITU-R SM 2012-2 shown in Figure 8 has other advantages than merely payment stability; it is technology neutral, it considers the opportunity benefit to licence owner of lower and higher frequency band, and it considers the economic value of a region, which show fairness concept.

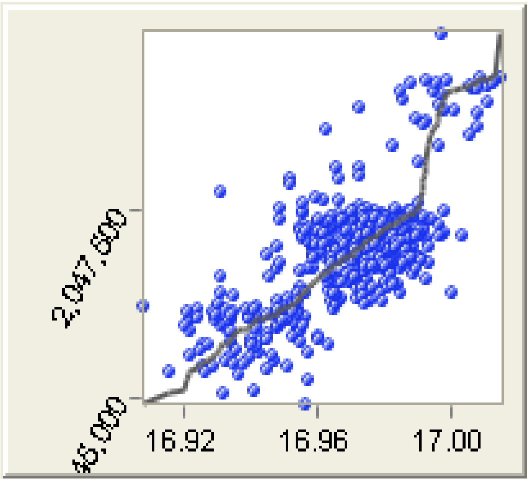

Figure 7 Graphic of BHP-F utilisation (BHP-F Existing).

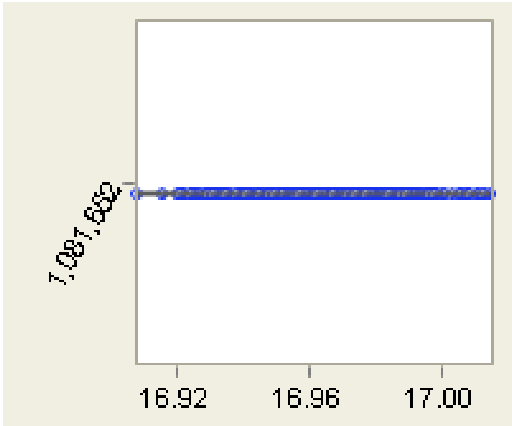

Figure 8 Graphic of BHP-F utilisation (Formula ITU SM 2012-2).

9 Conclusion

It has been shown that the spectrum fee based on the BHP-F formula that is calculated for each station and each RF channel has no ability to promote the efficiency of spectrum usage and to push providers to use the spectrum effectively. Further, it has also no ability to force providers to utilize the spectrum for all part in Indonesia.

It has also been demonstrated that the spectrum fee based on the ITU-R SM 2012-2, which is modified as proposed/new formula of BHP-F, can overcome the problem of BHP-F formula and can provide fairness for every provider since the provider with the same right pays the same price.

Lastly, introducing some incentive scenario could encourage the utilization of spectrum efficiently. Therefore, government should give compensation to the provider that succeeds in achieving higher spectrum utilization.

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