Design of Ka-Band Satellite Links in Indonesia

Zulfajri Basri Hasanuddin

***Abstract*—**There is an increasing demand for broadband services in Indonesia. Therefore, the answer is the use of Ka-Band which has some advantages such as wider bandwidth, the higher transmission speeds, and smaller size of antenna in the ground. However, rain attenuation is the primary factor in the degradation of signal at the Kaband. In this paper, the author will determine whether the Ka-band frequency can be implemented in Indonesia which has high intensity of rainfall.

***Keywords*—**Ka-Band, Link Budget, Link Availability, BER, E_b/N_o, C/N.

I. Introduction

THERE is an increasing demands in using radio frequency spectrum for satellite communication links to support various services in Indonesia. This phenomenon has led to the use of higher frequency band like Ka (30/20 GHz) -band. The band is very attractive because of wider bandwidth and large data capacity, allowing small component sizes, and smaller satellite footprints[1)]. The use of Ka-band with multispot-beam satellite systems will be considered to illuminate small area with individual spot beam. At this frequency band, however, propagation effects might impair the availability and quality of satellite links during service period. Therefore, in order to design a reliability satellite links, extensive knowledge of the propagation phenomena affecting system availability and signal quality in this band is required.

In designing a reliable satellite communication links, we should determine some factors required for optimal link availability and quality of performance such as earth-space and space-earth path (a.k.a. uplink and downlink) effect on signal propagation, quality of earth station system, and the impact of the propagation medium in the frequency band of interest, etc. Therefore, this paper is organized as follows: how to design a broadband satellite link in Indonesia that works in the Ka-band frequency, the need to analyze the link budget of broadband satellite at Ka-band frequency and determine the value of BER, C/N_o and E_b/N_o, and finally determine link availability and link margin of the broadband satellite links [1].

II. System Design

In this study, the planned satellite named Unhas-sat will be placed on the geostationary orbit of Long. 108°E, with operating frequency in the uplink is 28 GHz and in the downlink is 17.7 GHz. At the ground station, the diameter of the hub antenna is 5 meters with efficiency of antenna 75% and the receiving ground station G/T ratio is 32.7 dB/K. All of the specification data given above are according to the specification of WINDS satellite as the reference. The antenna used on the client side is Ultra Small Aperture Terminal (USAT) with diameter of 45 cm and the efficiency of antenna 75%, and the receiving G/T ratio of 11.5 dB/K. Both the hub antenna and the USAT use linear polarization and the adaptive modulation (AM) with three types of modulation such as 8 PSK, QPSK and 16-QAM, respectively to be compared. The hub antenna is planned to be placed in Bogor city. This city is chosen because Bogor is located in the middle part of Indonesia and in addition there is an existing backbone network of PT. TELKOM, so there is no longer need to build a new network. Fig. 1 shows the area in Indonesia that covered by the Ka-band multi spot beam satellite.

Zulfajri Basri Hasanuddin is with The Electrical Engineering Department, University of Hasanuddin, Perintis Kemerdekaan Km. 10, Tamalanrea, Makassar, South Sulawesi, Indonesia, also as a member of The National Research Council of The Republic of Indonesia (e-mail: zulfajri@unhas.ac.id, zulfajri_basri_hasanuddin@yahoo.co.id, zulfajri@drn.go.id).

Fig. 1 Design of the broadband satellite link in Indonesia using Ka-band frequency

A. Ground Segment

In the calculation of link budget, the author uses the specification of WINDS satellite as the reference. For more details, the specification is given as follows [2]:

<u>HUB antenna</u>

Transmit Power (P_{TX})	: 215 W
Uplink Frequency	: 28 GHz
Downlink Frequency	: 17.7 GHz
Antenna Diameter	: 5 m
EIRP	: 79.3 dBW
G/T	: 32.7 dB/K

<u>USAT</u>

Uplink Frequency	: 28 GHz
Downlink Frequency	: 17.7 GHz
Transmit Power (P_{TX})	: 5 – 10 W
Antenna Diameter	: 0.45 m

EIRP : 48.8 dBW
G/T : 11.5 dB/K

TABLE I
ELEVATION ANGLE AT EACH SAMPLE OF CITY (BOGOR CITY IS THE LOCATION OF THE HUB ANTENNA WITH ELEVATION ANGLE 82.076O AND AZIMUTH ANGLE 10.4O)

Location of USAT Antenna	Elevation Angle (Degree)	Azimuth Angle (Degree)
Balikpapan	79.4634	278.1226
Bandung	81.8086	3.2363
Denpasar	76.7226	319.9197
Jakarta	82.5239	10.5493
Makassar	75.2597	293.9233
Medan	78.2144	110.8771
Padang	80.8899	82.9006

B. Space Segment

For the space segment, the specification is given as follows:

Unhas-Sat (Based On Winds Satellite as Reference)

EIRP : 68 dBW (Multi Beam Antenna for Indonesia and South East Asia)
G/T : 18 dB/K
Uplink Frequency : 27.5 – 28.6 GHz
Downlink Frequency : 17 – 18.8 GHz

III. PROPAGATION LOSSES

A. Rain Attenuation

The major problem in link engineering for satellite communication system is to determine the excess path attenuation due to rainfall. For frequencies above 10 GHz, excess attenuation due to rainfall directly affects the transmission quality of satellite channel. Because of this condition, it is very important to accurately predict rain attenuation in designing a reliable communication system.

The theoretical study of the estimation method and the experimental measurement of rain attenuation have been done by many researchers [3]-[8]. The result of the rain attenuation for all the samples is given in Tables II and III for various percentage of link availability and percentage of time rain attenuation exceeded for uplink and downlink based on ITU-R method.

TABLE II
RAIN ATTENUATION AT EACH SAMPLE FOR UPLINK

Location	A_{rain} (0.9%) (dB)	A_{rain} (0.8%) (dB)	A_{rain} (0.7%) (dB)	A_{rain} (0.6%) (dB)	A_{rain} (0.5%) (dB)
Balikpapan	13.387	14.350	15.507	16.936	18.758
Bandung	9.915	10.642	11.518	12.601	13.758
Bogor	17.511	18.747	20.233	22.062	24.391
Denpasar	9.363	10.052	10.882	11.909	13.222
Jakarta	10.924	11.720	12.678	13.862	15.375
Makassar	12.983	13.918	15.043	16.432	18.204
Medan	11.864	12.723	13.758	15.036	16.667
Padang	15.643	16.756	18.094	19.743	21.843

TABLE III
RAIN ATTENUATION AT EACH SAMPLE FOR DOWNLINK

Location	A_{rain} (0.9%) (dB)	A_{rain} (0.8%) (dB)	A_{rain} (0.7%) (dB)	A_{rain} (0.6%) (dB)	A_{rain} (0.5%) (dB)
Balikpapan	5.236	5.636	6.119	6.719	7.490
Bandung	3.954	4.261	4.633	5.095	5.690
Bogor	6.854	7.369	7.99	8.759	9.764
Denpasar	3.765	4.058	4.414	4.856	5.425
Jakarta	4.268	4.598	4.997	5.494	6.132
Makassar	5.23	5.63	6.113	6.712	7.482
Medan	4.652	5.009	5.442	5.980	6.671
Padang	6.093	6.553	7.11	7.8	8.686

B. Cloud Attenuation

At Ka-band frequency, clouds containing liquid water can produce signal attenuation and amplitude scintillation.

TABLE IV
CLOUD ATTENUATION FOR UPLINK AND DOWNLINK

Location	A_{cloud}Uplink (dB)	A_{cloud} Downlink (dB)
Balikpapan	0.207	0.085
Bandung	0.345	0.1414
Bogor	0.343	0.1413
Denpasar	0.1048	0.043
Jakarta	0.343	0.1412
Makassar	0.0538	0.058
Medan	0.0929	0.1
Padang	0.1316	0.142

C. Path Loss

Path loss is a major component in the analysis and design of the link budget of a telecommunication system. Path loss may be due to many effects, such as free-space loss, refraction, diffraction, reflection, aperture-medium coupling loss, and absorption during propagation signal along the path. In addition, path loss also influenced by many factors such as terrain contours, environment (urban or rural, vegetation and foliage), propagation medium (dry or moist air), the distance between the transmitter and the receiver, and the height and location of antennas.

Path loss for uplink and downlink for all the samples by assuming the satellite is placed in geostationary orbit are 212.512 dB and 208.535 dB, respectively.

D. Bandwidth Calculation

Bandwidth

Transponder satellite is assumed to provide 36 MHz of bandwidth which is the occupied bandwidth while the allocated bandwidth in this design is 40 MHz.

$$BW_{allocated} = BW_{occupied} + \text{guard band} = 36\text{MHz} + 4\text{ MHz} = 40\text{MHz} \quad (1)$$

Symbol Rate

Data transmission rate or symbol rate of the system is 30 Mbps which is obtained from the following equation:

$$\text{Symbol Rate} = \frac{BW occupied}{1.2} = \frac{36\text{ MHz}}{1.2} = 30\text{Mbps} \quad (2)$$

Transmission Rate

The transmission rate in this research depends on the used modulation and the value of the symbol rate that has been calculated previously.

Quadrature Phase Shift Keying (QPSK)

Transmission Rate/BitRate= bit per symbol x Symbol Rate
= 2 x 30 Mb
= 60 Mbps

8-Phase Shift Keying (8-PSK)

Transmission Rate/Bit Rate = bit per symbol x Symbol Rate
= 3 x 30 Mbps
= 90 Mbps

16-Quadrature Amplitudo Modulation (16-QAM)

Transmission Rate/Bit Rate = bit per symbol x Symbol Rate
= 4 x 30 Mbps
= 120 Mbps

From the result above, we can see that the transmission rate of 16-QAM is greater than 8-PSK and QPSK.

Data Rate

Data transmission to be sent depends on the transmission rate, overhead and forward error correction (FEC). In this research, over head is 2% and the coding is Turbo coding while the FEC is ¾.

QPSK

Data Rate x Over Head = Transmission Rate x FEC code rate
= 60 Mbps x ¾
= 45 Mbps
Data Rate = 44.124 Mbps

8-PSK

Data Rate x Over Head = Transmisson Rate x FEC code rate
= 90 Mbps x ¾
= 67.5 Mbps
Data Rate = 66.18 Mbps

16-QAM

Data rate x Over Head = Transmission Rate x FEC code rate
= 120 Mbps x ¾
= 90 Mbp
Data Rate = 88.245 Mbps

III. Link Budget Calculation and Results

In the calculation of the link, we will calculate several parameters to determine the performance of the satellite communication system. There are several parameters to be calculated, namely C/No, C/N, E_b/N_o, BER, link availability and link margin that must be provided to overcome fading.

Uplink Calculation

In this design, the parameters to be calculated are as follows:

Carrier to Noise Power Density Ratio (C/N_o)

$[C/N_o]$ is the ratio of carrier power to noise power density. The formula of C/N_o can be given as follows:

$$[C/No]_{UP} = [EIRP]+[G/T_{SAT}] - [L_{TOT}] - 10 \log K \text{ (dBHz)} \quad (3)$$

where:

[EIRP] : Effective Isotropic Radiated Power of the earth station
$[G/T_{SAT}]$: Figure of Merit of the satellite
$[L_{TOT}]$: Total Path Loss
K : 1.38×10^{-23} J/K is Boltzmann's Constant (or [K] = -228.6 in decilogs)

TABLE V
C/NO UPLINK FOR ALL LOCATIONS

Location	C/No_{up} (99,10%) (dBHz)	C/No_{up} (99,20%) (dBHz)	C/No_{up} (99,30%) (dBHz)	C/No_{up} (99,40%) (dBHz)	C/No_{up} (99,50%) (dBHz)
Balikpapan	68,615	67,653	66,495	65,067	63,225
Bandung	71,949	71,223	70,347	69,264	67,88
Bogor	95,255	94,019	92,534	90,704	88,376
Denpasar	72,742	72,053	71,223	70,196	68,882
Jakarta	70,942	70,147	69,188	68,004	66,491
Makassar	69,085	68,151	67,025	65,637	63,865
Medan	70,103	69,243	68,208	66,931	65,3
Padang	66,222	65,11	63,772	62,12	60,022

Carrier to Noise Ratio (C/N)

A measure of the performance of a satellite link is the ratio of carrier power to noise power at the receiver input, and link budget calculations are often concerned with determining this ratio. The formula of [C/N] can be given as follows:

$$[C/N_{UP}]=[EIRP]+[G/T_{SAT}]-[L_{TOT}]-10\log K-10 \log B \text{ (dB)} \quad (4)$$

where B is a bandwidth in decibels relative to one hertz, or dBHz.

Downlink Calculation

Carrier to Noise Power Density Ratio (C/N_o)

$$[C/N_o]_{DW} = [EIRP]_{SAT}+[G/T]-[L_{TOT}]- [K] \text{(dB)} \quad (5)$$

where:

[EIRP] : Effective Isotropic Radiated Power of the satellite
$[G/T_{SAT}]$: Figure of Merit of the earth station
$[L_{TOT}]$: Total Path Loss
K : 1.38×10^{-23} J/K is Boltzmann's Constant (or [K] = -228.6 in decilogs)

Carrier to Noise Ratio (C/N)

$$[C/N_{DW}]=[EIRP]_{SAT}+[G/T] -[L_{TOT}]-10\log K-10\log B \text{ (dB)} \quad (6)$$

where B is a bandwidth in decibels relative to one hertz, or dBHz.

Combined Uplink and Downlink Ratio

The combined uplink and downlink ratio of C/N_o can be given as follows:

$$(N_o/C)_C = (N_o/C)_U + (N_o/C)_D \quad (7)$$

Energy per Bit to the Spectral Noise Density Ratio (E_b/N_o)

E_b/N_o is one of the main parameter in digital communication systems. The equation is given as follows:

$$(E_b/N_o) = (C/N) - 10\log[\text{TransmissionRate}/\text{BandwidthOccupied}] \quad (8)$$

Bit Error Rate (BER)

In digital transmission, the number of bit errors is the number of received bits of a data stream over communication channel that have been altered due to noise, interference, distortion or bit synchronization errors.

Link Availability and Link Margin

Link availability is the percentage of time the overall availability of the service in which the system is able to provide service without interference and to meet the specified BER. On the other hand link margin is a backup power provided in the communications link to overcome the fading. The equation to calculate the margin is given by the following equation:

$$\text{Margin} = C/N_{total} - C/N_{required} \quad (\text{dB}) \quad (9)$$

where: $C/N_{required} = E_b/N_{o required} + 10 \log (T_r/B)$
$E_b/N_{o\ required}$: $E_b/N_{o modem\ specification}$

TABLE VI
C/NO DOWNLINK FOR ALL LOCATIONS

Location	C/No_{dw} (99,10%) (dBHz)	C/No_{dw} (99,20%) (dBHz)	C/No_{dw} (99,30%) (dBHz)	C/No_{dw} (99,40%) (dBHz)	C/No_{dw} (99,50%) (dBHz)
Balikpapan	93,953	93,553	93,07	92,573	91,699
Bandung	96,18	94,872	94,501	94,038	93,443
Bogor	113,479	112,965	112,343	111,574	110,587
Denpasar	95,466	95,173	94,818	94,376	93,809
Jakarta	94,865	94,536	94,136	93,64	93,001
Makassar	93,986	93,103	93,103	92,5	91,735
Medan	94,523	94,165	93,732	93,195	92,503
Padang	93,04	92,579	92,023	91,332	90,447

TABLE VII
BER FOR ALL SAMPLES FOR QPSK MODULATION

Location	BER 99,10%	BER 99,20%	BER 99,3%	BER 99,40%	BER 99,50%
Balikpapan	$1,2377x10^{-5}$	$1,4764x10^{-5}$	$1,8621x10^{-5}$	$1,4764x10^{-5}$	$3,9517x10^{-5}$
Bandung	$7,4486x10^{-6}$	$8,151x10^{-6}$	$9,3145x10^{-6}$	$8,151x10^{-6}$	$1,4093x10^{-5}$
Bogor	$2,0549x10^{-6}$	$2,000x10^{-6}$	$2,121x10^{-6}$	$2,0009x10^{-6}$	$2,345x10^{-6}$
Denpasar	$6,742x10^{-6}$	$7,0883x10^{-6}$	$8,151x10^{-6}$	$7,0883x10^{-6}$	$1,1897x10^{-5}$
Jakarta	$8,4231x10^{-6}$	$9,6346x10^{-6}$	$1,131x10^{-5}$	$9,6346x10^{-6}$	$1,863x10^{-5}$
Makassar	$1,151x10^{-5}$	$1,327x10^{-5}$	$1,6839x10^{-5}$	$1,327x10^{-5}$	$3,338x10^{-5}$
Medan	$9,7176x10^{-6}$	$1,1205x10^{-5}$	$1,317x10^{-5}$	$1,1205x10^{-5}$	$2,4107x10^{-5}$
Padang	$1,9543x10^{-5}$	$2,5166x10^{-5}$	$3,4136x10^{-5}$	$2,5166x10^{-5}$	$9,430x10^{-5}$

TABLE VIII
BER FOR ALL SAMPLES FOR 8-PSK MODULATION

Location	BER (99,10%)	BER (99,20%)	BER (99,3%)	BER (99,40%)	BER (99,50%)
Balikpapan	$1,4877x10^{-5}$	$1,7702x10^{-5}$	$2,1594x10^{-5}$	$1,7702x10^{-5}$	$4,4117x10^{-5}$
Bandung	$9,0873x10^{-6}$	$1,0147x10^{-5}$	$1,1505x10^{-5}$	$1,0147x10^{-5}$	$1,705x10^{-5}$
Bogor	$2,8083x10^{-6}$	$2,7218x10^{-6}$	$2,9118x10^{-6}$	$2,7218x10^{-6}$	$3,1391x10^{-6}$
Denpasar	$8,3283x10^{-6}$	$8,6706x10^{-6}$	$1,0147x10^{-5}$	$8,6706x10^{-6}$	$1,4167x10^{-5}$
Jakarta	$1,0558x10^{-5}$	$1,1819x10^{-5}$	$1,3467x10^{-5}$	$1,1819x10^{-5}$	$2,1619x10^{-5}$
Makassar	$1,3663x10^{-5}$	$1,6207x10^{-5}$	$1,9719x10^{-5}$	$1,6207x10^{-5}$	$3,8271x10^{-5}$
Medan	$1,1901x10^{-5}$	$1,3363x10^{-5}$	$1,6052x10^{-5}$	$1,3363x10^{-5}$	$2,7888x10^{-5}$
Padang	$2,293x10^{-5}$	$2,8907x10^{-5}$	$3,8992x10^{-5}$	$2,8907x10^{-5}$	$9,9844x10^{-5}$

TABLE IX
BER FOR ALL SAMPLES FOR 16-QAM MODULATION

Location	BER 99,10%	BER 99,20%	BER 99,3%	BER 99,40%	BER 99,50%
Balikpapan	$1,2515x10^{-2}$	$1,3188x10^{-2}$	$1,4115x10^{-2}$	$1,3188x10^{-2}$	$1,7822x10^{-2}$
Bandung	$1,0606x10^{-2}$	$1,0949x10^{-2}$	$1,1436x10^{-2}$	$1,0949x10^{-2}$	$1,3033x10^{-2}$
Bogor	$7,214x10^{-3}$	$7,1437x10^{-3}$	$7,2983x10^{-3}$	$7,1437x10^{-3}$	$7,4832x10^{-3}$
Denpasar	$1,0303x10^{-2}$	$1,0451x10^{-2}$	$1,0949x10^{-2}$	$1,0451x10^{-2}$	$1,2346x10^{-2}$
Jakarta	$1,1096x10^{-2}$	$1,1549x10^{-2}$	$1,2139x10^{-2}$	$1,1549x10^{-2}$	$1,412x10^{-2}$
Makassar	$1,221x10^{-2}$	$1,2832x10^{-2}$	$1,3668x10^{-2}$	$1,2832x10^{-2}$	$1,7036x10^{-2}$
Medan	$1,1578x10^{-2}$	$1,2102x10^{-2}$	$1,2795x10^{-2}$	$1,2102x10^{-2}$	$1,5366x10^{-2}$
Padang	$1,4381x10^{-2}$	$1,5568x10^{-2}$	$1,7133x10^{-2}$	$1,5568x10^{-2}$	$1,2557x10^{-2}$

TABLE X
E_B/N_O FOR ALL SAMPLES FOR QPSK

Location	Eb/No 99,10% (dBHz)	Eb/No 99,20% (dBHz)	Eb/N0 99,3% (dBHz)	Eb/No 99,40% (dBHz)	Eb/No 99,50% (dBHz)
Balikpapan	18,9945	18,8305	18,6105	18,3085	17,8555
Bandung	19,4605	19,3705	19,2545	19,0965	18,8685
Bogor	20,5185	20,5435	20,4885	20,4635	20,4225
Denpasar	19,5505	19,5065	19,3705	19,2325	19,0355
Jakarta	19,3355	19,2275	19,0855	18,8765	18,6095
Makassar	19,0685	18,9175	18,7125	18,4305	18,0185
Medan	19,2205	19,0945	18,9265	18,6955	18,3595
Padang	18,5575	18,3185	17,9985	17,5505	16,8885

TABLE XI
E_B/N_O FOR ALL SAMPLES FOR 8-PSK

Location	Eb/No 99,10% (dBHz)	Eb/No 99,20% (dBHz)	Eb/No 99,3% (dBHz)	Eb/No 99,40% (dBHz)	Eb/No 99,50% (dBHz)
Balikpapan	17,2336	17,0696	16,8496	16,5476	16,.0946
Bandung	17,6996	17,6096	17,4936	17,3356	17,1076
Bogor	18,7576	18,7826	18,7276	18,7026	18,6616
Denpasar	17,7896	17,7456	17,6096	17,4716	17,2746
Jakarta	17,5746	17,4666	17,3246	17,1156	16,8486
Makassar	17,3076	17,1566	16,9516	16,6696	16,2576
Medan	17,4596	17,3336	17,1656	16,9346	16,5986
Padang	16,7966	16,5576	16,2376	15,7896	15,1276

TABLE XII
E_B/N_O FOR ALL SAMPLES FOR 16-QAM

Location	Eb/No 99,10% (dBHz)	Eb/No 99,20% (dBHz)	Eb/N0 99,3% (dBHz)	Eb/No 99,40% (dBHz)	Eb/No 99,50% (dBHz)
Balikpapan	15,9842	15,8202	15,6002	15,2982	14,8452
Bandung	16,4502	16,3602	16,2442	16,0862	15,8582
Bogor	17,5082	17,5332	17,4782	17,4532	17,4122
Denpasar	16,5402	16,4962	16,3602	16,2222	16,0252
Jakarta	16,3252	16,2172	16,0752	15,8662	15,5992
Makassar	16,0582	15,9072	15,7022	15,4202	15,0082
Medan	16,2102	16,0842	15,9162	15,6852	15,3492
Padang	15,5472	15,3082	14,9882	14,5402	13,8782

TABLE XIII
SAMPLE OF LINK MARGIN FOR ALL LOCATION FOR QPSK

Location	*Margin* 99,10% (dB)	*Margin* 99,20% (dB)	*Margin* 99,3% (dB)	*Margin* 99,40% (dB)	*Margin* 99,50% (dB)
Balikpapan	14,595	14,431	14,211	13,909	13,456
Bandung	15,061	14,971	14,855	14,697	14,469
Bogor	16,119	16,107	16,089	16,064	16,023
Denpasar	15,151	15,073	14,971	14,833	14,636
Jakarta	14,936	15,341	14,686	14,477	14,21
Makassar	14,669	15,14	14,313	14,031	14,619
Medan	14,821	15,256	14,527	14,296	13,96
Padang	14,158	14,75	13,599	13,151	12,489

From various results above, we can see that QPSK and 8-PSK have shown good results compared to 16-QAM. However, all the modulation types can be applied in Indonesia by using Ka-band frequency.

VI. CONCLUSION

Ka-band can be implemented in Indonesia for availability 99.10% - 99.50% by using the specification of WINDS satellite such as the uplink frequency 17.7 GHz and the downlink frequency 28 GHz, linear polarization, with hub specification which has transmit power 215 W, diameter antenna 5 m, EIRP 79.3 dBW and G/T 32.7 dB/K and also the specification of USAT with EIRP 48.8 dBW, antenna diameter 0.45 m and G/T about 11.5 dB/K.

All the modulation types such as QPSK, 8-PSK and 16-QAM can be applied in Indonesia according to the results which have shown good performance.

In subsequent work, the author will extend the same work for other parts of Indonesia which is not yet included such as eastern part and test an intelligent system based on the prediction of bit errors in Indonesia.

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