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Optimizing OFDM Downlink Performance on LMDS System

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Abstract

Local multipoint distribution service (LMDS) is one of the transmission solutions for broadband applications. LMDS operates in millimeter band using and provides high bitrates services up to 40 Mbps. However, LMDS implementation in tropical countries as in Indonesia deals with rain intensity which introduces high transmission loss. In order to improve the performances of LMDS services in rainy environment, an adaptive power allocation (APA) technique is integrated. APA is a cross-layer technique which optimizes power allocation among users with fixed subcarrier division. The simulations show that the technique improves transmission capacity 9.8% in average, data rate 13.79% in average, utility 25.27% in average and fairness 25.3% in average for rain loss 30dB.

1. Introduction

Broadband services such as high speed internet, digital video, audio broadcasting and video conference experience high demands. Local multipoint distribution service (LMDS) systems operate in frequency band 20-40 GHz [1-3] is one of the existing technologies used to provide those services. The radio propagation uses carrier frequency higher than 10 GHz is able to provide wide band modulating signal in one side, but sensitive to rain loss on the other side. This problem increases when LMDS system applied in tropical countries as the rain intense [4].

Existing works deal with performance enhancements on LMDS system mostly lay on separated layer improvements [3] which may not be optimal. Therefore, the approach combining two or more neighboring layers is developed to optimize the achievement in each layer. The method is referred to as a cross-layer technique. This paper integrates physical (PHY) layer and medium access control (MAC) layer in LMDS system with multiuser OFDM by using an adaptive power allocation (APA) technique. The APA technique requires the channel state information (CSI) and the incoming traffic information [5-7]. Song and Li [5, 6] proved that the APA method improves the transmission efficiency and the allocation fairness on adaptive white Gaussian noise (AWGN) environment. Jun et al. analyzed performance improvement on power and subcarrier allocations [7].

Previous research uses joint power and subcarrier allocation (JSPA) technique on millimeter channel with selected case in Surabaya city [8]. This paper enhances previous research by considering the effect of rain to the system, with selected area is Medan city.

2. Research Method

2.1 Rain Intensity Measurement

Rain intensity measurement is performed in three different locations: Padang Bulan, Polonia and Sampali using Hellman measurement unit. The location map and measurement unit are shown in Figure 1 dan 2.

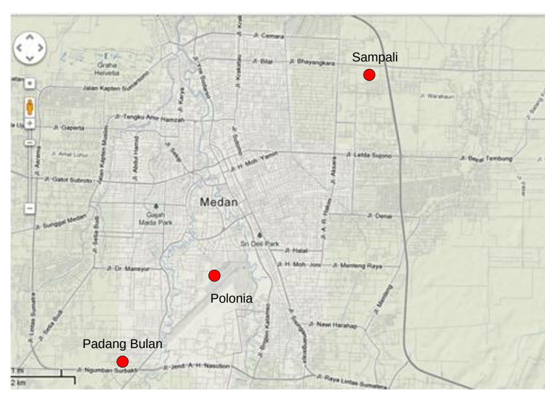

Figure 1. Rain intensity measurement location

Hellman measurement unit uses a rotary writing pad and a pen moved by floating device on a water tube. When rain enters the water tube, the water lifts the pen up and the level is recorded in a rotary pad. When the water tube is full, the siphon automatically discharges the water tube. At the same time pen moves down and the vertical line is recorded. More rain generates more vertical lines. The rain intensity is calculated from the level and the frequency of those vertical lines.

Figure 2. Rain intensity measurement unit

2.2 Rain Loss Calculation

Path loss is very important in radio communication systems, especially when the radio uses microwave and millimeter frequency bands. The higher the carrier frequency, the higher the path loss occurs. The specific path loss Y (dB/km) and the rain intensity R (mm/h) relation is a function of frequency and expressed as [9]:

$$Y(x) = aR^b(x) \tag{1}$$

The rain loss in a propagation path with length of L (km) is expressed by [9]:

$$A = \int_o^L aR(z)^b \, dz \tag{2}$$

A is the rain loss in dB, R(z) is rain intensity (mm/h), a and b are variables which depend on radio wave polarization and frequency.

To validate the rain loss calculation, ITU-R Rec.P.530-10 is referred by using cumulative distributed of rain intensity. The calculation steps are [10]:

1. Determine rain intensity 0,01% of the intensity distribution, $R_{0,01\%}$ (mm/h).
2. Calculate the specific path loss Y.
3. Find the horizontal correlation factor $r_{0,01}$ for R=0,01% using Equation 3:

$$r = \frac{1}{1+\frac{d}{d_0}} \tag{3}$$

where r is reduction factor, d is distance (km), $d_0 = 35e^{-0.015R0,01}$ for $R_{0,01} \leq 100$ mm/h, and $d_0 = 35e^{-0.015R0,01}$ for $R_{0,01} > 100$ mm/h.

4. Calculate the average rain loss 0,01% per year using Equation 4:

$$A_{0,01} = Y_{(x)}\, d.r \tag{4}$$

5. Find the rain loss for other percentages, Ap (0,001% to 1%) by following rules:
   - Area with earth latitude higher than 30^0

$$\frac{A_p}{A_{0.01}} = 0.12\, p^{-(0.546 + 0.043 \log_{10} p)} \tag{5}$$

   - Area with earth latitude lower than 30^0

$$\frac{A_p}{A_{0.01}} = 0.07\, p^{-(0.855 + 0.139 \log_{10} p)} \tag{6}$$

Specific path loss calculation depends on signal polarization and frequency [11], as shown in Table 1.

Table 1. Parameter k and α for various frequencies and polarizations [11]

Frequency (GHz)	k_H	k_V	α_H	α_V
1	0.0000387	0.0000352	0.912	0.880
4	0.000650	0.000591	1.121	1.075
6	0.00175	0.00155	1.308	1.265
8	0.00454	0.00395	1.327	1.310
10	0.0101	0.00887	1.276	1.264
12	0.0188	0.0168	1.217	1.200
15	0.0367	0.0335	1.154	1.128
20	0.0751	0.0691	1.099	1.065
25	0.124	0.113	1.061	1.030
30	0.187	0.167	1.021	1.000
35	0.263	0.233	0.979	0.963
40	0.350	0.310	0.939	0.929
45	0.442	0.393	0.903	0.897
50	0.536	0.479	0.873	0.868

Table 2. Parameters of the LMDS system
(k=1,38.10^{-23} and T_o=298 K)

Parameter	Units	Formula	Value
Transmit Power into Antenna	dBW	Ptx: transmit power per carrier	0
Transmit antenna gain	dBi	Gt:Gant	15
Frequency	GHz	f: Transmit frequency	30
Path Length	Km	d: Hub to Subscriber Station Range	2
Field Margin	dB	Lfm : Antenna Mis-Alignment	-1
Free-Space Loss	dB	FSL = -92.45-20*log(f)-20*log(d)	-128,013
Total Path Loss	dB	Ltot = FSL + LFM	-129,013
Receiver Antenna Gain	dBi	Gr = Gant	30
Effective Bandwidth	MHz	BRF : Receiver Noise Bandwidth	40
Receiver Noise Figure	dB	NF : Effective Noise Figure	5
Thermal Noise	dBW/MHz	10*log(k*To)	-143,85
System Loss	dB	Lsys=Gt+Ltot+Gr	-84,013
Received Signal Level	dBw	RSL=Ptx+Lsys	-84,013
Thermal Noise Power Spectral density	dBW/MHz	N0=10*log(k*To)+NF	-198,859
Carrier to Noise ratio	dB	C/N = RSL-No-10*log(BRF)	98.8254

2.3. The APA Algorithm

APA performance optimization implements water-filling algorithm to achieve the expected bit error rate (BER). The algorithm is shown in Figure 3. In this paper, water-filling algorithm uses fixed subcarrier division so that optimum power allocation $p^*(f)$ fulfills Equation 7 [5]:

$$p^*(f)=\left[\frac{U_i'(r_i^*)}{\lambda}-\frac{1}{\beta\rho_i(f)}\right]^+ \quad (7)$$

In order to integrate LMDS system with the outlined rain intensity calculation, the paper uses LMDS parameters from [8] which are outlined in Table 2. Value r_i^* is optimum bit-rate and λ is a normalized power density constant.

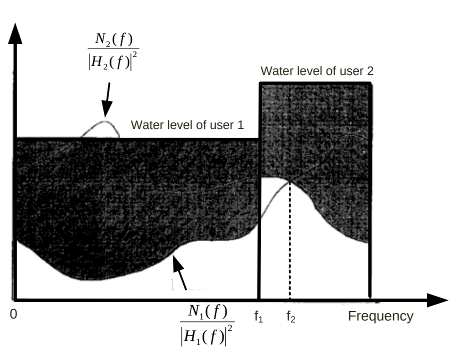

Figure 3. Water-filling algorithm

In order to obtain optimum power allocation, iterative calculation is required. Suppose that each user has marginal utility $U_i'(r_i)$, the received power is the total transmitted power divided by number of user. If the achieved throughput is a function of power allocation, then:

$$c_i(f)=\int_{D_i^*}\log_2(1+\beta\rho_i(f)p(f)df \quad (8)$$

ρ_i is channel condition, where :

$$\rho_i(f)=\frac{|H_i(f)|^2}{N_i(f)}$$

with $H_i(f)$ is channel gain, $N_i(f)$ is noise, β is BER representation:

$$\beta=\frac{1,5}{-\ln(5BER)}$$

The utility parameter, U(r) demonstrates the capability of transmitting data which is formulated by Equation 9.

$$U(r)=0.16+0.8\ln(r-0.3) \quad (9)$$

where $r=c_i(n).\Delta f$ and $\Delta f=\frac{B}{k}$.

In analysis, the LMDS system is assumed to have user with individual bandwidth B=80 MHz and subcarriers K=8000.

The fairness is achieved if the user utility closes to the average value. The fairness is determined by Equation 10:

$$\frac{1}{M}\sum_{i=1}^{M} U_i(r_i) \qquad (10)$$

3. Results and Analysis

Rain loss simulation on each LMDS user is performed before analyzing the overall LMDS performance. The distant of users to base station is set in between 1 – 3 km. As a result, maximum transmission capacity is obtained as the limit of the maximum throughput can be achieved by LMDS system. The maximum transmission capacity is calculated for three different conditions: bright, rainy and rainy with an APA technique. Table 3 shows the outcome.

Table 3. Rain loss simulation

User Number	Distance (km)	Capacity (bps/Hz)		
		Clear Sky	Rain Attenuation	
			Without APA	APA
1	2.9623	7.7463	1.9086	2.9830
2	2.5968	8.1247	6.3208	7.4439
3	1.8701	9.0695	4.5899	4.7227
4	1.1919	10.3675	10.0471	8.9401

As shown in Table 3, the average bit-rate for bright/ clear sky is 8.827 bps/Hz. The capacity decreases when the weather is rainy falling to 5.7116 bps/Hz. However, the capacity can be enhanced when APA technique applied, increasing up to 6.02243 bps/Hz. From this case, it is proven that the APA technique increases the capacity of system about 25.27 % when the path is rainy.

Further comparison can be seen in Table 4, where the average data rate when sky is clear is 176.54 Mbps. Rain causes data rate decreasing about 36.9%, down to 111.475 Mbps. Introducing APA technique within the LMDS system improves data rate to 120.4475 Mbps. It means the method achieves 13.79% improvement.

Utility simulation results 9.83 % improvement when APA is applied to LMDS system. This is depicted in Table 5, where the average utility in bright weather, rainy without and with APA 15.34613 bps/Hz, 14.853 bps/Hz and 14.97763 bps/Hz respectively.

Table 4. Result of data rate simulation

User Number	Distance (km)	Data rate (Mbps)		
		Clear Sky	Rain Attenuation	
			Without APA	APA
1	2.9623	154.93	37.22	59.66
2	2.5968	162.49	123.26	148.88
3	1.8701	181.39	89.50	94.45
4	1.1919	207.35	195.92	178.80

Table 5. Result of utility simulation

User Number	Distance (km)	Utility (bps/Hz)		
		Clear Sky	Rain Attenuation	
			Without APA	APA
1	2,9623	15.2468	14.1058	14.4833
2	2,5968	15.2849	15.0638	15.2149
3	1,8701	15.3729	14.8078	14.8509
4	1,1919	15.4799	15.4346	15.3614

In order to validate the results, 10.000 iterations are performed. The CDF iteration results that The APA technique improves capacity from about 0.00389 – 10.45 bps/Hz increase to about 1.002 – 10.49 bps/Hz. Utilities are improved from 9,141 – 15,47 bps/Hz to 13,61 – 15,49 bps/Hz. These improvements are depicted in Figure 5 and Figure 6.

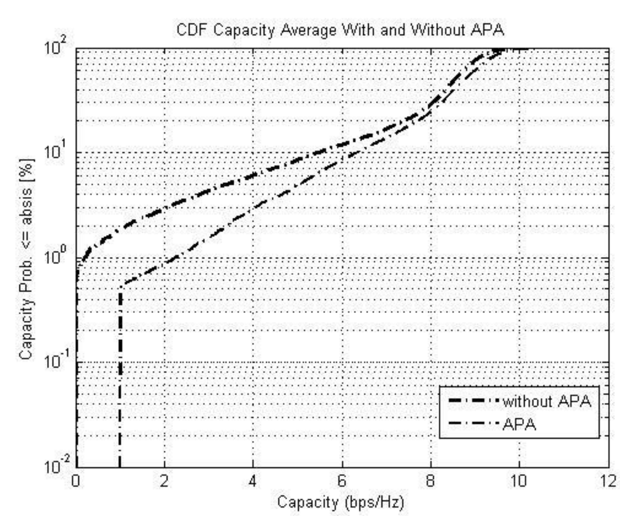

Figure 5. The CDF of Capacity

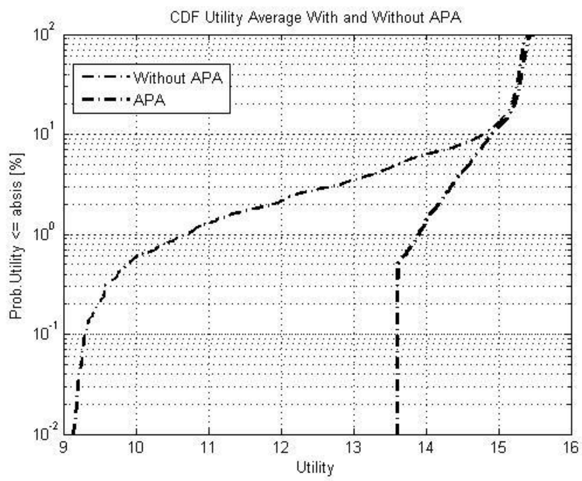

Figure 6. The CDF of Utility

In term of fairness, the calculation produces 15.3461 for bright weather, 14.8530 for rainy without APA and 14.9776 for rainy with APA. Therefore, the fairness improvement caused by APA implementation is about 25.3%.

4. Conclusion

The adaptive power allocation (APA) technique is able to improve the LMDS performance, especially when the system implemented in the area with high rain intensity, such as in Indonesia. The simulations show that the improvements on LMDS capacity, data rate and utility on rain intensity 30 dB reaching 9.8 %, 13.79 %, and 25.27% respectively. While system fairness increases 25.3 %.

This paper has discussed the APA implementation on OFDM downlink for LMDS system which is used in rainy environment. However, the power distribution among user or the fairness is subject of propagation paths. Future work may explore APA implementation in both sides: base station and user to improve fairness.

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