Performance of Subcarrier and Power Allocation Orthogonal Frequency-Division Multiplexing on Millimeter Wave

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Abstract
Local multipoint distribution system (LMDS) that operated in millimeter waves can be used to fulfill the need of bit rate higher than 40 Mbps. However it has problem when applied increasing rapidly. Services that require the availability of high speed data channels such as high speed internet, digital video, audio broadcasting and video conferencing continues to increase. The need for the provision of high speed data channel can be performed with local multipoint distribution service (LMDS).

LMDS systems are operated at range frequency 20-40 GHz. Systems that operated at frequencies higher than 10 GHz are vulnerable to interference the receiving signal caused by rain attenuation. Therefore the applications of LMDS system in tropical countries, such as Indonesia, require special handling due to rain attenuation that occurs at 80 dB with a frequency of 29 GHz with a 5.7 km long link [1].
The novel mechanism to increase the quality and capacity of system is cross-layer mechanism approach [2] [3]. It is developed the integrated framework at Physical (PHY) layer and media access control (MAC) layer.

Cross-layer Approach in multiuser orthogonal frequency-division multiplexing (OFDM) can be obtained by using the joint subcarrier and power allocation (JSPA) technique and Adaptive Packet Scheduling. These are support by the availability Channel State Information (CSI) and Arrival Traffic Information. The previous research was study the joint subcarrier Allocation and power on channel-aware queue-aware (CAQA) [4] and Resource Allocation and Cross-layer Scheduling on multicarrier wireless network [5] [6].

The application of JSPA technique on millimeter wave transmission is interrupted by rain attenuation. Rain attenuation measurements have been performed using optical disdrometer gauges placed at ITS Surabaya [7]. This study is aim to know the benefits of JSPA techniques for improving performance system on broadband networks in tropical countries, especially Indonesia to increase the capacity, data rate, utility and fairness.

2. Research Method
   2.1. Rainfall Measurement
   Precipitation measurements performed in Surabaya using an optical disdrometer gauges are placed on the roof of the Telecommunication Laboratory building. Optical Disdrometer work based laser systems, optical sensor with 180 mm wide x 30 mm. Measurements can be performed in real time, if there is a rain particle passing through the laser beam to detect disdrometer rainfall (mm/h) and the distribution of rain. Then the results are stored in software (Hydras and ASDO) called data parsivel shaped rainfall data and txt files. Data obtained from these measurements ASDO rain in software [7].

2.2. Generation Attenuation Rain
   The result of rain attenuation measurement in Surabaya with the distance between user and transmitter 1-3 miles:

   Stage 1: Generating the value of m, σ for four users based distance randomly generated by taking as reference the data in Table 1 [7].

   Stage 2: Generating the coefficients of rain attenuation randomly by taking the reference data in Table 2 [7].

| Link Length(km) | Average (μ) | Standard deviation (σ) |
|----------------|-------------|------------------------|
| 1              | -1.0539     | 2.0574                 |
| 2              | -0.4554     | 2.1248                 |
| 3              | -0.1321     | 2.1719                 |

| Link 1 | Link 2 | ψ     | ρ_{SST} |
|--------|--------|-------|---------|
| 1      | 1      | 45°   | 0.9065  |
|        |        | 90°   | 0.8467  |
|        |        | 135°  | 0.7132  |
|        |        | 180°  | 0.6784  |
|        | 2      | 45°   | 0.8484  |
|        |        | 90°   | 0.7434  |
|        |        | 135°  | 0.6139  |
|        |        | 180°  | 0.5996  |
| 2      | 2      | 45°   | 0.8103  |
|        |        | 90°   | 0.6869  |
|        |        | 135°  | 0.5717  |
|        | 3      | 45°   | 0.5371  |

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step 3: Prepare 4x4 covariance matrix:

\[
C = \begin{bmatrix}
\sigma_1^2 & \rho_{12}\sigma_1\sigma_2 & \rho_{13}\sigma_1\sigma_3 & \rho_{14}\sigma_1\sigma_4 \\
\rho_{12}\sigma_2\sigma_1 & \sigma_2^2 & \rho_{23}\sigma_2\sigma_3 & \rho_{24}\sigma_2\sigma_4 \\
\rho_{13}\sigma_3\sigma_1 & \rho_{23}\sigma_3\sigma_2 & \sigma_3^2 & \rho_{34}\sigma_3\sigma_4 \\
\rho_{14}\sigma_4\sigma_1 & \rho_{24}\sigma_4\sigma_2 & \rho_{34}\sigma_4\sigma_3 & \sigma_4^2
\end{bmatrix}
\]

Where [8]:

\[
\rho_{m,n} = \frac{1}{\sigma_s\sigma_m}\left[\ln\left(\rho_{SST}\sqrt{\exp(a)\left(\exp(\sigma_n^2) - 1\right) - \exp(b) + 1}\right) - b\right]
\]

\[
a = 2\mu_n + \sigma_m^2 + 2\mu_m + \sigma_n^2
\]

\[
b = \mu_n^2 + \frac{\sigma_m^2}{2} + \mu_m^2 + \frac{\sigma_n^2}{2}
\]

\(\mu\) is the average (mean), \(\sigma\) is the standard deviation, \(\rho_{SST}\) is the rain attenuation coefficient, \(\rho_n, \rho_m\) is the attenuation coefficient of normal rainfall, \(n\) and \(m\) are the links 1 and 2.

Step 4: Obtain the rain attenuation value of each user by the equation:

\[A = \exp (X)\]

\[X = C_{x}^{1/2}Y + m_x\], \(A\) as the rain attenuation values, \(Y\) is a matrix of 4 1 Gaussian (\(\mu = 0\) and \(\sigma = 1\)) and \(m\) is a vector of \(m\). Then enter the data for LMDS system parameters that can be seen in Table 3 [9].

| Parameter                  | Units     | Formula                              | Value         |
|----------------------------|-----------|--------------------------------------|---------------|
| Transmit Power into        | dBW       | \(P_{tx}\): transmit power per      | 0             |
| Antenna                   |           | carrier                              |               |
| Transmit antenna gain      | dBi       | \(G_t\): Gant                        | 15            |
| Frequency                 | GHz       | \(f\): Transmit frequency           | 30            |
| Path Length                | Km        | \(d\): Hub to Subscriber Station    | 2             |
| Path Length                | Km        | Range                               |               |
| 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        | \(L_{tot} = FSL + LFM\)             | -129,013      |
| Receiver Antenna Gain      | dBi       | \(Gr = Gant\)                       | 30            |
| Effective Bandwidth        | MHz       | \(BRF\): Receiver Noise Bandwidth   | 80            |
| Receiver Noise Figure      | dB        | \(NF\): Effective Noise Figure      | 5             |
| Thermal Noise              | dBW/ MHz  | \(10\log(kT_o)\)                    | -143,85       |
| System Loss                | dB        | \(L_{sys} = G_t + L_{tot} + Gr\)    | -84,013       |
| Received Signal Level      | dB        | \(R_{SL} = P_{tx} + L_{sys}\)       | -84,013       |
| Thermal Noise Power        | dB/ MHz   | \(N_0 = 10\log(kT_o) + NF\)         | -138,859      |
| Spectral density           |           |                                      |               |
| Carrier to Noise ratio     | dB        | \(C/N = \frac{R_{SL} - N_0}{10\log(BRF)}\) | 35,8151       |
2.3. Joint Subcarrier and Power Allocation (JSPA)

OFDM-based LMDS systems are applied in millimeter wave channel, channel conditions \( p_i(f) \) which varies depending on the weather, making it necessary for performance optimization subcarrier allocation and power allocation. Dynamic Subcarrier Allocation (DSA) applied for Subcarrier allocation and Adaptive Power Allocation (APA) for Power allocation. JSPA simultaneously to optimize cross-layer to reach the optimum achievable value of fairness. The combined DSA and APA optimization can be formulated with [5] [6]:

\[
\frac{1}{M} \sum_{i} U_i(r_i) = \frac{1}{M} \sum_{i} U_i \left( \log_2 \left( 1 + \beta p_i(f) \rho_i(f) \right) \right) df
\]

\( p_i^*(f) = \text{power emitted optimum.} \)

2.3.1. Dynamic Subcarrier Allocation (DSA)

The purpose of the DSA is to improve the performance of OFDM-based network when the transmission power is uniformly distributed throughout the frequency band. To calculate the capacity \( c_i(f) \) is transmitted can be formulated by [5]:

\[
c_i(f) = \log_2 \left( 1 + \beta p_i(f) \rho_i(f) \right)
\]

\( \beta \) is a constant value to give the desired BER, can be formulated by:

\[
\beta = \frac{1.5}{-\ln(5\text{BER})}
\]

and \( \rho_i(f) \) is a subscriber channel conditions on the frequency \( f \) of the user \( i \), where:

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

\( H_i(f) \) is the channel gain at user \( i \) at subcarrier frequency \( f \) and \( N_i(f) \) is the noise power at user \( i \) at subcarrier frequency \( f \).

If the transmitted power normalized, where \( p(f) = 1 \), then to achieve the capacity of the frequency \( f \), \( c_i(f) \), can be expressed in Equation 13.

\[
c_i(f) = \log_2 \left( 1 + \beta \rho_i(f) \right)
\]

Each user or each session has a weight expressed as CSI and related queuing time. The weight indicates the utility function used for optimization crosslayer and the balance between efficiency and fairness. For best effort traffic (non-real time traffic) adopted a utility function with \( r = x \text{ kbps} \) and is given by:

\[
U(r) = 0.16 + 0.8 \ln(r - 0.3)
\]

The ultimate goal is to maximize the number of users where the overall utility DSA to maximize justice services to users (fainess) formulated:
\begin{equation}
\frac{1}{M} \sum_{i=1}^{M} U_i(r_i) = \frac{1}{M} \sum_{i=1}^{M} U_i \left( c_i(f) df \right) \tag{15}
\end{equation}

\(M\) is the number of users. The total number of user subcarrier is the total available bandwidth that can be formulated as follows:

\begin{equation}
\bigcup_{i=1}^{M} D_i \subseteq [0,B] \tag{16}
\end{equation}

\(D_i \cap D_j = \emptyset, \quad i \neq j \quad \text{and} \quad i, j = 1,2,...,M\)

\(D_i\) is subcarrier for user \(i\) and \(r_i\) is the data rate of user \(i\).

### 2.3.2. Adaptive Power Allocation (APA)

In order to obtain the BER quality of signal information we optimized the APA performance. Water-filling algorithm is used as a function to obtain the optimal power allocation. In this theorem, fixed subcarrier allocation is known; the optimum power allocation is equation [5]:

\begin{equation}
p^*(f) = \left[ \frac{U_i^*(r_i^*)}{\lambda} - \frac{1}{\beta p_i(f)} \right]^+
\end{equation}

\(\lambda\) is constanta of normalized optimal power density.

\begin{equation}
[x]^+ = \begin{cases} 
  x, & x \geq 0 \\
  0, & x < 0 
\end{cases}
\end{equation}

Is optimal power density and \(r_i^*\) is value of optimal bit-rate [5].

Optimal resource allocation can not be directly calculated by the equation above that required an iterative algorithm. In the water-filling algorithm each user has a particular value of marginal utility, power obtained is compared to the total transmit power per user power. If the achievement of throughput as a function of power allocation, then:

\begin{equation}
c_i(f) = \int_{d_i}^{d_i'} \log_2 (1 + \beta p_i(f) p(f) df) \tag{19}
\end{equation}

Utility is the data transmission capacity that is formulated:

\begin{equation}
U(r) = 0.16 + 0.8 \ln(r - 0.3) \tag{20}
\end{equation}

\(r = ci(n).A\Delta f \quad \text{and} \quad \Delta f = \frac{B}{k}\)

\(U\) \((r)\) is expressed as a utility value, \(B\) is the bandwidth and \(k\) is the number of subcarriers for all users. The ultimate purpose of the APA is to maximize the value of fairness that is the average of all utility users, namely:

\begin{equation}
\frac{1}{M} \sum_{i=1}^{M} U_i(r_i) \tag{21}
\end{equation}
3. Results and Analysis

The data generated under 3 km from the BTS to the user based on table 1. Simulation results for an area with less than 3 km from the BTS cannot be raised more than 4 users due to a very large correlation damping. User limited to four with $90^\circ$ for each.

Parameters influenced JSPA technique on millimeter wave are capacity, data rate, utility and fairness. Table 4 shows a comparison of the capacity of clear sky conditions and the condition affected rain attenuation with JSPA and without JSPA techniques.

Table 4. Comparison of the capacity of clear sky conditions and the effect of rain attenuation with JSPA and without JSPA techniques.

| User Number | Distance (km) | Clear Sky | Capacity (bps/Hz) | Rain Attenuation |
|-------------|---------------|-----------|-------------------|------------------|
|             |               |           | Without JSPA      | JSPA             |
| 1           | 2.9137        | 7.7937    | 0.2347            | 1.6582           |
| 2           | 2.7603        | 7.9492    | 1.0636            | 3.6939           |
| 3           | 2.5896        | 8.1326    | 0.0494            | 0.4180           |
| 4           | 2.0452        | 8.8117    | 2.5721            | 4.9424           |

From table 4 shows the average capacity without JSPA technique is 0.9799 bps / Hz. Meanwhile with JSPA techniques is 2.6781 bps / Hz. This means that the capacity increase 1.6982 bps / Hz. This is because the JSPA technique is applied adaptive power allocation. Simulation performed 10,000 times iterations for more accurate results, it show in figure 4 and 5. With JSPA techniques the capacity of the average value increases from 1.002 to 10.49 bps / Hz.

Table 5. Comparison of data rate

| User Number | Distance (km) | Clear Sky | Data Rate (Mbps) | Rain Attenuation |
|-------------|---------------|-----------|------------------|------------------|
|             |               |           | Without JSPA     | JSPA             |
| 1           | 2.9137        | 155.8757  | 4,5765           | 32,9226          |
| 2           | 2.7603        | 158.9835  | 20,7394          | 76,6932          |
| 3           | 2.5896        | 162.6521  | 0,9638           | 7,6458           |
| 4           | 2.0452        | 176.2344  | 50,1554          | 104,2467         |

Figure 1. CDF Capacity
Table 6 shows that the average data rate without JSPA technique is 19.1088 Mbps and with JSPA increase to 36.2683 Mbps. Implementation of Power Allocation in JSPA technique cause increasing of data rate.

Data rate value equal to the system utility. The greater the value of its utility it shows the better performance of the system. This is because the utility associated with the value of efficiency and fairness. JSPA techniques increased the average utility value to be 13.61 to 15.49 bps / Hz.

Table 6. Utility Comparison

| User Number | Without DSA, APA and JSPA | DSA | APA | JSPA |
|-------------|---------------------------|-----|-----|------|
| 1           | 12.4292                   | 12.4197 | 14.0136 | 14.0077 |
| 2           | 13.6380                   | 13.7029 | 14.6543 | 14.6843 |
| 3           | 11.1829                   | 11.0890 | 12.9111 | 12.9397 |
| 4           | 14.3445                   | 14.4498 | 14.8873 | 14.9298 |

Figure 2. CDF Utility

Figure 3. Graph of Average Capacity

Figure 4. Graph of data rate average
Fairness values obtained from the average utility for all users. The application of JSPA technique increases the fairness system. In clear sky condition fairness is 99.99% above 15,25. While the condition affected rain attenuation without JSPA technique fairness above 15 only 86.99% and fairness increase 2.4% by using JSPA technique. Table 7 shows the comparison of fairness system affected rain attenuation.

| Condition                             | Fairness |
|---------------------------------------|----------|
| Clear sky                             | 15.2887  |
| Attenuation Rain without JSPA         | 12.8987  |
| Attenuation Rain using JSPA           | 14.1404  |

The comparison of capacity, data rate, and fairness utility of JSPA technique shows better performance improvement then without JSPA technique.

4. Conclusion

JSPA technique can increase the average of capacity to 1,002 – 10,49 bps/Hz because it has adaptive power allocation. For average of capacity above 7,7 bps/Hz JSPA technique increases up to 9,24%.

The application of JSPA technique improve the performance of data rate and utility respectively 36,283 Mbps and 13,61-15,48 bps/Hz.

For the fairness value, it just 86,99% reached 15 in affected rain attenuation condition without JSPA and fairness increase 2,4% ug JSPA technique.

The implementation of JSPA technique in OFDM downlink system at millimeter wave is recommended for area within high intensity of rain.

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