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Optimizing downlink throughput of IEEE 802.16j wireless relay networks via parameterized modeling

Dowon Hyun[a] **and Ju Wook Jang**[b]

Department of Electronic Engineering, Sogang University

1 Shinsu-dong, Mapo-gu, Seoul 121–742, Korea

a) *snatcher@eeca1.sogang.ac.kr*

b) *jjang@sogang.ac.kr*

Abstract: We propose a parameterized modeling technique for wireless relay networks based on IEEE 802.16j standard operating in non-transparent mode. Our modeling is able to represent the downlink throughput in a concise closed form and thus very useful for predicting the downlink system throughput with a few estimated parameters. The key parameters include α which represents how much portion of the whole data from MR-BS to be transmitted over access link without going through relays ($0 \leq \alpha \leq 1$). Another key parameter is r, which determines how much portion of DL (down link) zone is used for access ($0 \leq r \leq 1$). We also add a parameter θ_i, which determines how much portion of the data to be relayed via RSi ($0 \leq \theta_i \leq 1$). Our contribution lies in that our formula can be used to estimate the expected downlink system throughput without going through extensive simulation in the early design stage for IEEE 802.16j relay systems. Optimization can be easily performed using our formula.

Keywords: IEEE 802.16j, throughput modeling, throughput optimization

Classification: Science and engineering for electronics

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1 Introduction

We identify key parameters affecting the downlink throughput of the IEEE 802.16j relay networks such as the portion of the whole data from MR-BS to be transmitted over MR-BS access link (α), the portion of the access zone in DL subframe (r), the portion of the data to be relayed via RSi (θ_i), and the number of RSs (k). We also add the maximum amount of data that can be carried over wirelsss links (D_{BM}, D_{RMi}, and D_{BRi}) as wireless environment changes. We propose a parameterized modeling technique for IEEE 802.16j relay networks operating in non-transparent mode using these parameters. We also propose a simple downlink throughput optimization scheme that can be performed in one step.

Previous modelings [3, 4, 5, 6, 7] are not comprehensive since they deal with a subset of our modeling parameters. Table I summarizes the parameters used in previous modelings as well as our modeling.

Table I. Proposed modeling vs. known modeling.

	Proposed	[3]	[4]	[5]	[6]	[7]
MR-BS access link throughput(D_{BM})	O	O	O	O	O	O
RS access link throughput(D_{RMi})	O	O	O	O	O	O
Relay link throughput(D_{BRi})	O	O	O	O	O	O
Potion of the whole data from MR-BS to be transmitted over MR-BS access link(α)	O	X	X	X	X	X
Portion of the access zone in a DL subframe(r)	O	O	O	O	O	X
Portion of the data to be relayed via RS i (θ_i)	O	X	X	X	X	X
Number of RSs(k)	O	X	O	X	X	O

The main contribution of this paper is a parameterized modeling which can be used to predict the downlink system throughput of wireless relay networks based on IEEE 802.16j standard operating in non-transparent mode. The closed form formula resulting from our modeling can be used to optimize

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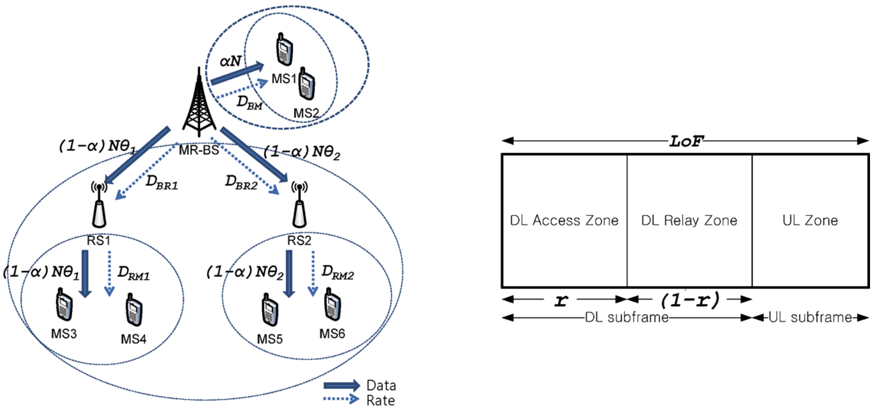
the throughput.

2 Identification of key parameters

We identify key parameters needed in a closed form modeling of the downlink throughput for IEEE 802.16j-based MMR networks.

[α: Portion of the whole data from MR-BS to be transmitted over MR-BS access link] In an example IEEE 802.16j MMR network as illustrated in Fig. 1 (a) with 1 MR-BS and 2 RSs, MR-BS either directly serves MS1/MS2 over MR-BS access link (αN) or relays data for MSs 3, 4, 5 and 6 to RSs over relay link ($(1-\alpha)N\theta_1$ and $(1-\alpha)N\theta_2$). RS1 serves MS3/MS4 and RS2 serves MS5/MS6 over RS access link. We identify a parameter α which represents how much portion of the whole data from MR-BS is to be transmitted over MR-BS access link ($0 \leq \alpha \leq 1$). Consequently, $(1-\alpha)$ is the portion of the whole data to be transmitted over relay links. For example, let N (bits) be the amount of whole data to be transmitted from MR-BS. The amount of data to be transmitted over MR-BS access link is αN and the amount of data to be transmitted over relay link is $(1-\alpha)N$.



(a) Network topology and parameters (b) Frame structure

Fig. 1. A parameterized modeling for a 2-hop wireless relay network based on IEEE 802.16j.

[θ_i: Portion of the data to be relayed via RSi] We also add a parameter θ_i, which determines how much portion of the data to be transmitted over relay links is via RSi ($0 \leq \theta_i \leq 1$). $\sum_{i=1}^{k} \theta_i = 1$ if we have k RSs. For example, $(1-\alpha)N\theta_1$ is the amount of data to be transmitted via RS1 and $(1-\alpha)N\theta_2$ is the amount of data to be transmitted via RS2 as illustrated in Fig. 1 (a).

[r: Portion of the access zone in a DL subframe] Fig. 1 (b) shows the frame structure of an IEEE 802.16j network operating in non-transparent mode. The IEEE 802.16j frame is divided into DL subframe and UL subframe. DL subframe is used for downlink transmission while UL subframe is used for uplink. For multi-hop transmission in IEEE 802.16j, each subframe is further divided into access zone and relay zone. DL access zone is a portion of the DL subframe in the MR-BS/RS frame used for MR-BS/RS to MS transmission.

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DL relay zone is a portion of the DL subframe in the MR-BS/RS frame used for MR-BS/RS to RS transmission. Here, we identify a parameter r, which determines how much portion of the DL subframe is used for access zone ($0 \leq r \leq 1$). $(1-r)$ of a DL subframe is used for relay zone. We use 28 OFDMA symbols for a DL subframe. For simplicity, we ignore the duration for the preamble and DL-MAP.

[D_{BM} (bits): Maximum amount of data that can be carried if a full DL subframe (assuming $r=1$) is used over an average MR-BS access link] An average MR-BS access link is a hypothetical link (dashed line) with the received signal power averaged over all the wireless links between the MR-BS and its subordinate MSs. D_{BM} is determined by the MCS level [8] conforming to the received signal power averaged over MSs from MR-BS. If the portion of the access zone, r, is less than 1, then rD_{BM} is the maximum amount of data to be carried over average MR-BS access link.

[D_{RMi} (bits): Maximum amount of data that can be carried if a full DL subframe (assuming $r=1$) is used over an average RSi access link] An average RSi access link is a hypothetical link (dashed line) with the received signal power averaged over all the wireless links between the RSi and its subordinate MSs. D_{RMi} is decided by the MCS level [8] according to the received signal power averaged of MSs from RSi. If the portion of the access zone, r, is less than 1, then rD_{RMi} is the maximum amount of data that can be carried over average RSi access link.

[D_{BRi} (bits): Maximum amount of data that can be carried if a full DL subframe (assuming $r=0$) is used over a wireless link (dashed line) between MR-BS and RSi] If the portion of the relay zone, $(1-r)$, is less than 1, then $(1-r)D_{BRi}$ is the maximum amount of data that can be carried over the relay link between MR-BS and RSi. Since most MR-BSs and RSs are equipped with Above Roof Top (ART) antennas under Line-of-Sight (LoS) condition, the received signal power at RS from MR-BS is strong enough to warrant the highest MCS level (64QAM 5/6). If this is the case, we may assume that all D_{BRi} is the same for all i, and we use D_{BR} instead of D_{BRi} for all RSs.

[LoF (sec): Length of a frame] We add a parameter LoF, which is the length of a frame as illustrated in Fig. 1 (b). In this paper, we set LoF to 5 ms according to WiMAX Forum Release-1 system profiles [9].

Now we are ready to represent the downlink throughput of IEEE 802.16j MMR networks in a closed form using the above parameters.

3 Modeling Downlink Throughput of IEEE 802.16j using Parameters

3.1 Modeling downlink throughput

The amount of data to be transmitted over MR-BS access link between MR-BS and its subordinate MSs is αN. Maximum amount of data that can be carried in a DL access zone is rD_{BM}. Thus the number of required frames (actually the number of required access zones) is $\lceil (\alpha N)/(rD_{BM}) \rceil$. Trans-

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mission duration over MR-BS access link is a product of $\lceil(\alpha N)/(rD_{BM})\rceil$ and LoF.

In RS access link transmission, the amount of data to be transmitted from RSi to MSs is $(1-\alpha)N\theta_i$ and the maximum amount of data that can be carried in a DL access zone is rD_{RMi}. Thus the number of required frames is $\lceil((1-\alpha)N\theta_i)/(rD_{RMi})\rceil$. In relay link transmission, the amount of data to be transmitted from MR-BS to RSi is $(1-\alpha)N\theta_i$ and the maximum amount of data that can be carried in a DL relay zone is $(1-r)D_{BRi}$. For simplicity, we assume that DL relay zone resources used for RSi in the MR-BS frame are allocated proportionally to the amount of data to be transmitted to RSi. We also assume that all D_{BRi} is the same for all i, and we use D_{BR} instead of D_{BRi}. The number of required frames (actually the number of required relay zones) is $\lceil((1-\alpha)N)/((1-r)D_{BR})\rceil$.

The total transmission duration needed for transmission of the whole data can be obtained by taking the maximum of the transmission durations derived above. Thus, downlink throughput T_{th} and total transmission duration T_{delay} for the amount of data N can be represented as in (1). (We assume k RSs are used).

$$\begin{aligned}
&T_{th}(\alpha, r, \theta_i, D_{BM}, D_{RMi}, D_{BR}, LoF)\\
&\quad = N/T_{delay}(\alpha, r, \theta_i, D_{BM}, D_{RMi}, D_{BR}, LoF, N)\\
&\quad = N/(MAX(\text{The number of required frames over MR - BS access link},\\
&\qquad \text{The number of required frames over relay link},\\
&\qquad \text{The maximum number of required frames over RS access link}) \times LoF)\\
&\quad = 1/\left(\left\lceil MAX\left(\begin{array}{l}\dfrac{\alpha}{rD_{BM}}, \dfrac{(1-\alpha)}{(1-r)D_{BR}},\\ MAX\left(\dfrac{(1-\alpha)\theta_1}{rD_{RM1}}, \dfrac{(1-\alpha)\theta_2}{rD_{RM2}}, \cdots, \dfrac{(1-\alpha)\theta_k}{rD_{RMk}}\right)\end{array}\right)\right\rceil \times LoF\right)
\end{aligned} \tag{1}$$

One may argue that the transmission duration should be obtained by adding the maximum of MR-BS access and the longest RS access plus transmission duration for relay. Note that each frame consists of one access zone and one relay zone. Thus the number of frames needed is not the addition of two numbers, one number for access and the other number for relay. Rather it should be the maximum of the two numbers. Each of the three terms inside the leftmost MAX() actually represents the number of access or relay zones. MR-BS access may be overlapped with RS access. Thus we have Equation (1).

3.2 Optimizing the downlink throughput using α and r

Once the formula to represent the downlink system throughput of IEEE 802.16j operating in non-transparent mode is derived as in Equation (1), we can optimize the throughput using two parameters α and r. We obtain α and r which minimize the transmission duration, hence maximizing the downlink throughput. Without loss of generality we assume that transmission duration

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for RSj access is the longest among all RS accesses ($1 \le j \le k$). We require the number of relay zones needed for MR-BS to all the RSs to be equal to that of RSj access zone. This implies we can have $(1-\alpha)/((1-r)D_{BR}) = ((1-\alpha)\theta_j)/(rD_{RMj})$. From this we can derive Equation (2) to obtain the optimal value for r.

$$r = (1 + D_{RMj}/(\theta_j D_{BR}))^{-1} \tag{2}$$

We require the number of access zones for MR-BS access to be equal to that of RSj access. Thus we have $(\alpha/(rD_{BM})) = ((1-\alpha)\theta_j)/(rD_{RMj})$. As a result, we can find the optimal value for α as in Equation (3),

$$\alpha = (1 + D_{RMj}/(\theta_j D_{BM}))^{-1} \tag{3}$$

The α and r, obtained from Equations (2) and (3), maximizes the downlink throughput represented in Equation (1).

Our contribution is in the derivation of Equations (1), (2), and (3) which can be used to optimize the downlink system throughput for IEEE 802.16j Relay Networks without resorting to time consuming simulations. Otherwise, we need to build a simulator and run it for all possible pairs of α and r, and obtain the maximum downlink throughput out of all results.

As an illustrative example, we set D_{BM} to 80640 bits, D_{RMi} to 60480 bits, and D_{BR} to 100800 bits, respectively. We also set θ_1 to 0.2, θ_2 to 0.2, and θ_3 to 0.6, respectively. Total transmission data N is set to 100 Mbits. When we scale α and r in unit size of 0.1, we need to run the simulator 99 times ($0.1 \le \alpha \le 0.9$, $0.1 \le r \le 0.9$). The maximum downlink system throughput obtained with this granularity is 16.01 Mbps. If we scale α and r in unit size of 0.001, the simulator should be run 998,001 times to obtain the maximum downlink throughput of 17.29 Mbps ($0.001 \le \alpha \le 0.999$, $0.001 \le r \le 0.999$). Fig. 2. shows the maximum downlink system throughput obtained with an exhaustive search scheme as well as the proposed optimizing formula. T_E $(\alpha, r, 0.001)$ is the calculated downlink system throughput as α and r change

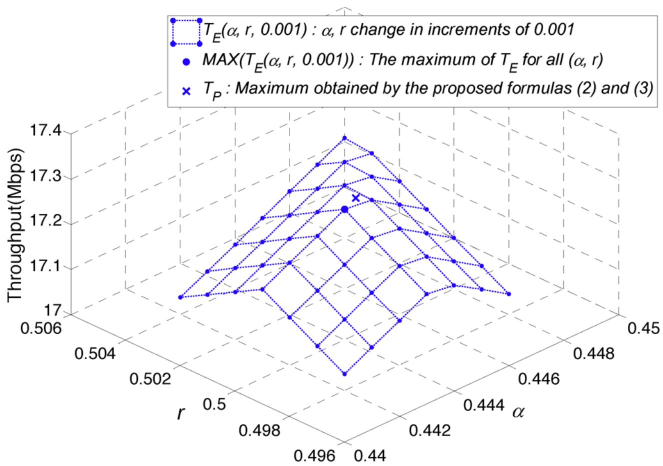

Fig. 2. The maximum system downlink throughput of IEEE 802.16j compared with the proposed optimization and exhaustive search scheme.

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in increments of 0.001. $MAX(T_E(\alpha, r, 0.001))$ is the maximum downlink system throughput with exhaustive search scheme. If we want more accurate downlink throughput, we need run more simulations.

The maximum downlink system throughput with the proposed optimization, however, obtains the optimal value of 17.3 Mbps with $\alpha = 0.4444$ and $r = 0.5$ in one step. We can obtain $\alpha = 1/(1+60480/(0.6 \times 80640)) = 0.4444$ and $r = 1/(1 + 60480/(0.6 \times 100800)) = 0.5$ from (2) and (3) since transmission duration of RS3 access link is the longest among all RS accesses. As wireless environment changes dynamically so do the coefficients D_{BM}, D_{RMi}, and/or D_{BR}. The simulator needs to be modified on any such change and run as many times as the resolution dictates. This implies that finding the maximum downlink throughput needs the massive amount of calculation and is not easily implemented for real-time, online scheduling. Our formulas (1), (2), and (3) can be easily implemented as a real time scheduling algorithm for maximum downlink system throughput without much computational overhead.

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