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Agenda Item:	**15.7**
Source:	**Fujitsu**
Title:	**An Efficient Hierarchical Modulation based DL Data Transmission for LTE-Advanced**
Document for:	**Discussion and Decision**

1. Introduction

The solution relevant to the hierarchical modulation has been adopted in the digital video broadcast (DVB) standard [1]. The strategy of using such a modulation was first addressed in [2], and thereafter, further proved in [3]. The concept of this modulation scheme is to separate the modulation orders; assigning higher order to the receiver, who is close to the transmitter, while assigning low order to the receiver, who is far away from the transmitter. The advantages on this type of modulation have been reported for multimedia traffic in wireless networks [4].

In this contribution, we attempt to employ the hierarchical modulation technique in LTE-advanced, to meet the fairly aggressive performance targets in terms of sector throughput and cell coverage [5]. In reality, a two-user transmission scenario is taken into account, that each eNode-B simultaneously transmits the data to paired users. Our attention is mainly focused on maximizing the transmission throughput using a sophisticated hierarchical modulation mechanism. We select two users whose information bits are hierarchically mapped on two mutually independent physical channels. As a consequence, one user's performance is improved without sacrificing the other user's performance. In the hierarchical modulation based transmission (HMT), the best two users pairing is concerned with selecting the worse quality user who maps the bits into most-significant bits (MSB) while selecting the better quality user who maps the bits into less-significant bits (LSB).

The system level simulation confirms that the HMT scheme is capable of improving the performance for both sector throughput and cell coverage. According to our numerical investigation, HMT scheme with the classical proportional fairness scheduler may roughly achieve 22% sector throughput gain and 20% cell coverage gain.

2. Hierarchical Modulation based Transmission

In this section, we specify the system model, and define some basic hierarchical modulation channels. Relying on the mutual information criterion, in theory, we intuitively provide some evidence, showing the hierarchical modulation based transmission (HMT) scheme surely offers notable performance gain.

2.1. System Model

Without loss of generality, we simply assume that the network contains only one eNode-B serving two UEs, denoted UE-0 and UE-1, as illustrated in Figure 1. We further assume that the link performance of UE-1 is much better than that of UE-0 on the down-link (DL), thanks to the assumption that UE-1 is physically closer to the eNode-B whereas UE-0, to certain extent, is far away from the eNode-B resulting in a large propagation loss. With such a channel model, the link performance between eNode-

B and UE-0 needs to be improved by alternatively using transmit diversity, repetition, low modulation and coding scheme (MCS), and cooperative transmission.

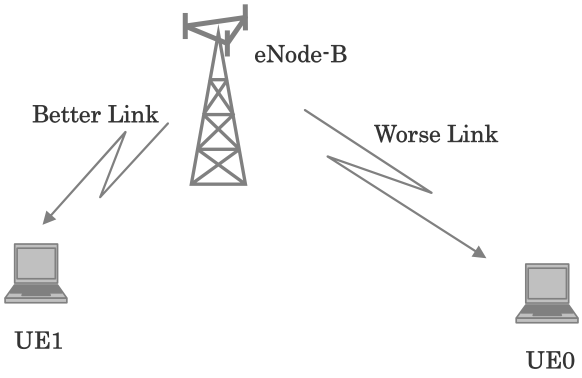

Figure 1: System model.

It is assumed that eNode-B attempts to transmit the data to UE-0 and UE-1, which are mapped into mutually independent physical channel-0 and channel-1. The physical channel defined here could be orthogonal frequency division multiple access (OFDMA) based channel resource. In most existing systems, as illustrated in Figure 2 (a), a mapping process is independently carried out in individual channels; eNode-B maps the data bits into channel-0 for UE-0, and maps the data bits into channel-1 for UE-1. As a consequence, it could result in an inefficient data transmission, particularly when two UEs experience unbalanced channel links.

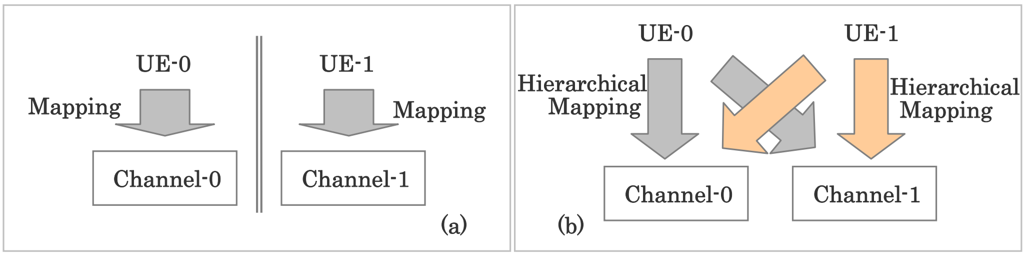

Figure 2: Symbol mapping for UE-0 and UE-1 on channel-0 and channel-1, (a) independent mapping, and (b) hierarchical mapping.

Another alternative associated with the proposed hierarchical modulation mapping scheme between UEs may be preferably utilized. As depicted in Figure 2 (b), for UE-0, eNode-B maps the portion of the bits from a symbol or multiple symbols into channel-0 and maps the remained portion of the bits from the same symbol(s) into channel-1, and so does for UE1. This may aim at improving the performance by properly pairing two different UEs.

2.2. Definition of Hierarchical Modulation Channel

A modulation channel defined as a physical channel is used for mapping a modulation symbol. With respect to a hierarchical modulation channel (HMC), the definition is quite different, that contains more channel dimensions. Figure 3 exemplifies some hierarchical modulation channel structures with 16QAM and 64QAM, where 16QAM related channel consists of the channel components of MSB0 and LSB0 for physical channel-0, and the channel components of MSB1 and LSB1 for physical channel-1. Similarly, 64QAM related channel consists of the channel components of MSB0, SB0 and LSB0 for physical channel-0 and the channel components of MSB1, SB1 and LSB1 for physical channel-1.

Many combinations of the hierarchical modulation channels may be considered for data transmissions associated with UE0 and UE1. Here, we give some typical examples to show how HMC can be formed using 16QAM and 64QAM modulations, as depicted in Figure 3.

- With 16QAM for both physical channels, (MSB0+MSB1) may form one HMC for UE0, and (LSB0+LSB1) may form another HMC for UE1.
- With 64QAM for both physical channels, (MSB0+MSB1+SB0) may form one HMC for UE0, and (LSB0+SB1+LSB1) may form another HMC for UE1.
- With 16QAM for physical channel-0 and 64QAM for physical channel-1, (MSB0+MSB1+LSB0) may form one HMC for UE0, and (SB1+LSB1) may form another HMC for UE1.

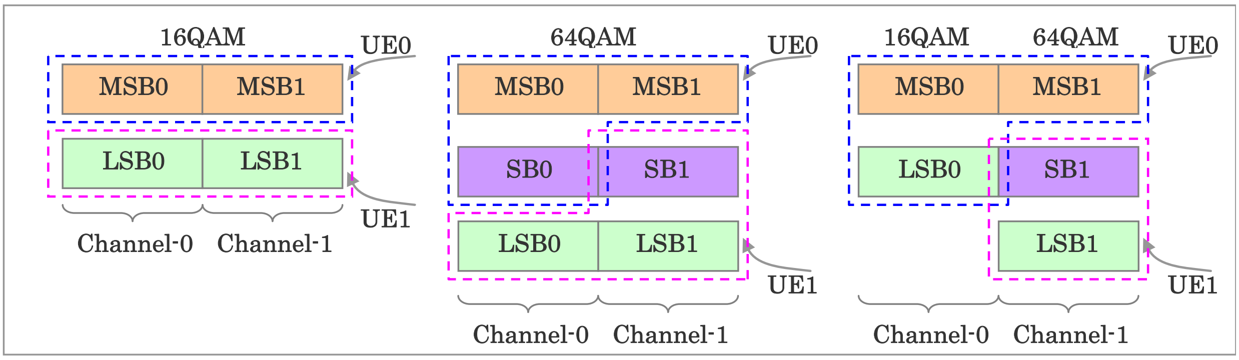

Figure 3: An example of hierarchical modulation channel types.

2.3. Theoretical Discussion with Mutual Information

At the first stage of our discussion, we exploit mutual information (MI) to show what the sufficient transmit manner is for two users with HMT under unbalanced channel conditions. This may help to theoretically understand why HMT is necessary for efficient data transmission even on AWGN channel.

Some constraints are taken into account on the assignment of physical channel resource for HMT. It is assumed that the scheduler always assigns the same amount of physical channel resource to two paired UEs. In OFDM system, for instance, the same number of sub-carriers is assigned for data transmission from eNode-B to two paired UEs. Therefore, assuming that the HMT channel for UE0 and the HMT channel for UE1 are capable of delivering data at rates of $R_0(\gamma_0)$ and $R_1(\gamma_1)$, respectively, the achievable total capacity for UE0 and UE1 can be written as

$$C_{\text{Total}}(\gamma_0,\gamma_1)=R_0(\gamma_0)+R_1(\gamma_1),$$

where γ_0 and γ_1 are the effective SNRs experienced by UE0 and UE1, respectively.

Figure 4 shows the several MIs as a function of SNR with 64QAM modulation on two independent physical channels, relying on Shannon capacity formula, normal 64QAM MI formula, HMT channel capacity with (MSB0+MSB1), and HMT channel capacity with (SB0+LSB0+SB1+LSB1). It can be observed that there are two cross points between normal 64QAM and hierarchical 64QAM:

- One is between the normal 64QAM and HMT channel with (MSB0+MSB1), where the SNR is denoted Γ_0,

- The other is between the normal 64QAM and HMT channel with (SB0+LSB0+SB1+LSB1), where the SNR is denoted Γ_1.

It can be reasonably believed that if the SNR for one UE is higher than Γ_1, and the SNR for the other UE is lower than Γ_0, the use of HMT is beneficial, and otherwise, the normal 64QAM is sufficient. Consequently, by comparing the received SNR γ_0 and γ_1 with the SNR thresholds, Γ_0 and Γ_1, and selecting two proper UEs with a large enough SNR difference, the total achievable throughput $C_{\text{Total}}(\gamma_0, \gamma_1)$ can be always maximized.

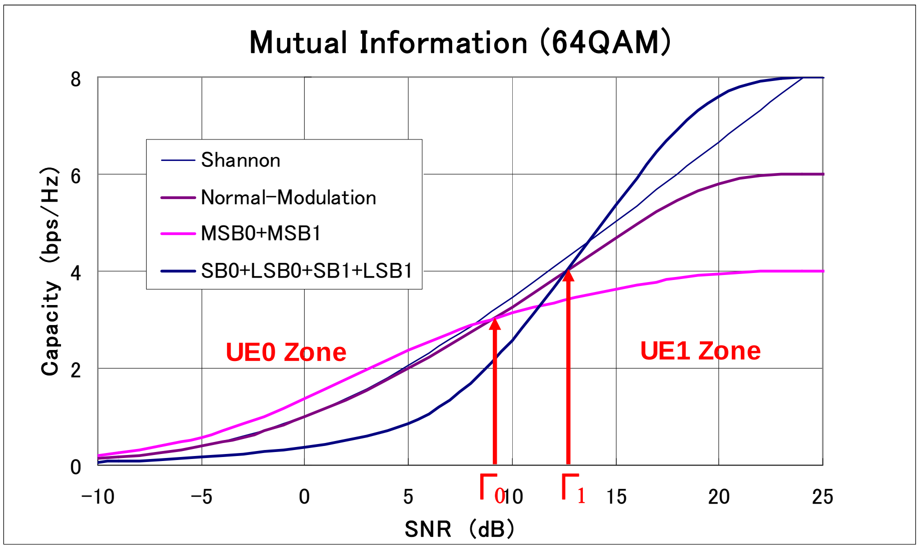

Figure 4: Mutual information for normal and hierarchical modulation with 64QAM.

2.4. HMCS Table Design

For the classical MCS design, we select the MCS table, utilizing the modulation mapping manner only relying on QPSK, 16QAM and 64QAM, corresponding to MCS0, MCS1, and MCS2 as listed in Table 1. For the HMCS design, we add two additional HMCSs on top of the classical MCSs, corresponding to MCS0, MCS1, MCS2, MCS3 and MCS4 as listed in Table 1. The detailed assumptions of classical MCS and proposed HMCS associated with MCS0~MCS4 in terms of code rate are given in Table 4 and Table 5 of Appendix 5, respectively.

Table 1: HMT channel for Hierarchical modulation.

MCS Type	HMCS Channel for UE0	HMCS Channel for UE1
MCS0	QPSK	QPSK
MCS1	16QAM (MSB0+LSB0)	16QAM (MSB1+LSB1)
MCS2	64QAM (MSB0+LS0+LSB0)	64QAM (MSB1+SB1+LSB1)
MCS3	16QAM (MSB0+MSB1)	16QAM (LSB0+LSB1)
MCS4	64QAM (MSB0+MSB1)	64QAM (SB0+LSB0+SB1+LSB1)

In Appendix 5, the link level curves for both classical MCS and proposed HMCS are illustrated in Figure 8 to Figure 14, with 1dB SNR spacing, associated with MCS0~MCS4.

To maintain the same number of control bits as used for the MCS indication in LTE, the number of HMCS levels for each UE is set to 30. That means, all HMCS components in Table 5 are not necessarily used to form the HMCS table, and some HMCS components need to be ruled out, in order not to overlap the MCS level in the designed table. Figure 5 exemplifies an MCS table (the corresponding MCS components are shown in Table 5 with red and Italian bold characters), which is used for our system level simulation.

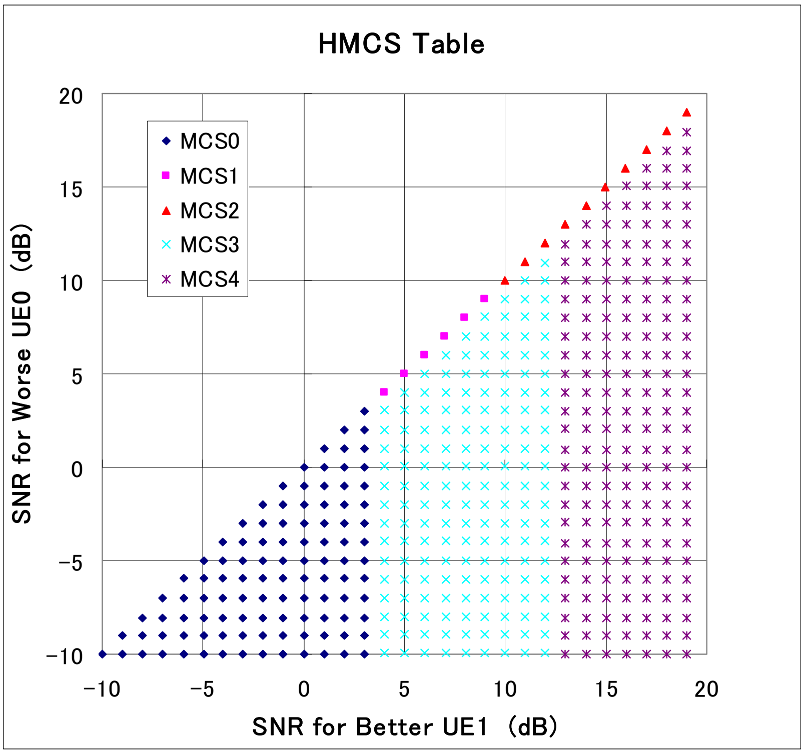

Figure 5: The proposed HMCS table.

It is worthwhile noting that the designed HMT channel listed in Table 1 and its corresponding HMCS table illustrated in Figure 5 are not the best candidate, and the more sophisticated table design is possible to be elaborated by composing of more hierarchical modulation channels.

2.5. Proportional Fairness for HMT

The proportional fairness scheduler used for HMT is implemented between two selected UEs, say UE *i* and UE *j*. At any scheduling instant, the scheduling metric $\Phi_{i,j}$ for UE *i* and UE *j* used by the proportional fair scheduler is given by

$$\Phi_{i,j} = \frac{R_i}{T_i} + \frac{R_j}{T_j}$$

where R_i is the data rate that can be supported at the scheduling for UE *i*, and T_i is the throughput smoothed by a low-pass filter at the scheduling for UE *i*.

Thus, the transmitter takes the highest metric $\Phi_{i,j}$ and allocates the resource channel to these two corresponding UEs. It is worthwhile noting that the worse quality UE always occupies the better HMT channel while the better quality UE always occupies the worse HMT channel.

The detailed description for the proportional fairness scheduler in OFDMA system can be referred to [7].

3. System Level Performance Evaluation

3.1. System Level Simulation Results

This section summarizes the system level performance under the antenna configurations of 1x2. The detailed information associated with system level simulation assumptions and system level results are elaborated in the Appendix 6.1 and 6.2, respectively.

According to the system level evaluation discussed in Appendix 6, Table 2 and Table 3 briefly summarize the system performance results in terms of aggregated sector throughput and cell coverage with 5%tile outage requirement.

Table 2: Comparison results in terms of aggregated sector throughput for simulation case-1, case-2 and case-3, with 10 and 20 UEs per sector.

	Case1	Case2	Case3
Aggregated Sector Throughput for Classical MCS (bps/Hz), 10UE case	1.4945	0.9487	1.3244
Aggregated Sector Throughput for HMCS (bps/Hz), 10UE case	1.5885	1.0797	1.3956
Throughput Gain (%)	6.29%	13.8%	5.38%
Aggregated Sector Throughput for Classical MCS (bps/Hz), 20UE case	1.5152	0.9301	1.3939
Aggregated Sector Throughput for HMCS (bps/Hz), 20UE case	1.8358	1.1334	1.6912
Throughput Gain (%)	21.2%	21.9%	21.3%

Table 3: Comparison results in terms of cell coverage for simulation case-1, case-2 and case-3, with 10 and 20 UEs per sector.

	Case1	Case2	Case3
Cell Coverage for Classical MCS (bps/Hz), 10UE case	0.05340	0.03527	0.04043
Cell Coverage for HMCS (bps/Hz), 10UE case	0.05720	0.03973	0.04150
Coverage Gain (%)	7.12%	12.6%	2.66%
Cell Coverage for Classical MCS (bps/Hz), 20UE case	0.02765	0.01772	0.02265
Cell Coverage for HMCS (bps/Hz), 20UE case	0.03268	0.02118	0.02565

Coverage Gain (%)	18.2%	19.6%	13.2%

As a consequence, the sector throughput gain achieved by HMT is 5~14% in case of 10 UEs per sector, while 21~22% in case of 20 UEs per sector. In addition, the cell coverage gain achieved by HMT is 3~13% in case 10 UEs per sector, while 13~20% in case 20 UEs per sector. It can be seen that the achievable throughput gain tends to increase in case of the large number of UEs per sector. This is because increasing the number of UEs per sector gives more freedom to the user scheduler, providing better UE pairing for HMT.

From Figure 15 to Figure 20, in addition, it can be observed that in the geometry range of 5~7dB, the user throughput gain is quite marginal due to the identical levels of SNR received by both UEs. This makes the consensus with the theoretical conclusion as drawn in Figure 4.

3.2. Description Where the Gain Comes from

The reason why the significant gain can be achieved by HMT scheme can be explained relying on the results in terms of the probability of selecting the MCS/HMCS for both classical modulation and hierarchical modulation transmissions, as illustrated in Figure 6 and Figure 7.

In Figure 6, it can be seen that the different MCS belonging to the different modulation is equally used for the data transmission, with almost the same selected probability of the MCS assignment. In Figure 7, however, with HMCS the tendency of the selected probability is completely changed, that the selected probability of HMCS0, HMCS1 and HMCS2 is fairly low, whereas the selected probability of HMCS3 and HMCS4 are significantly high. This surely justifies that the most performance gain summarized in Table 2 and Table 3 is achieved by the hierarchical modulation channels.

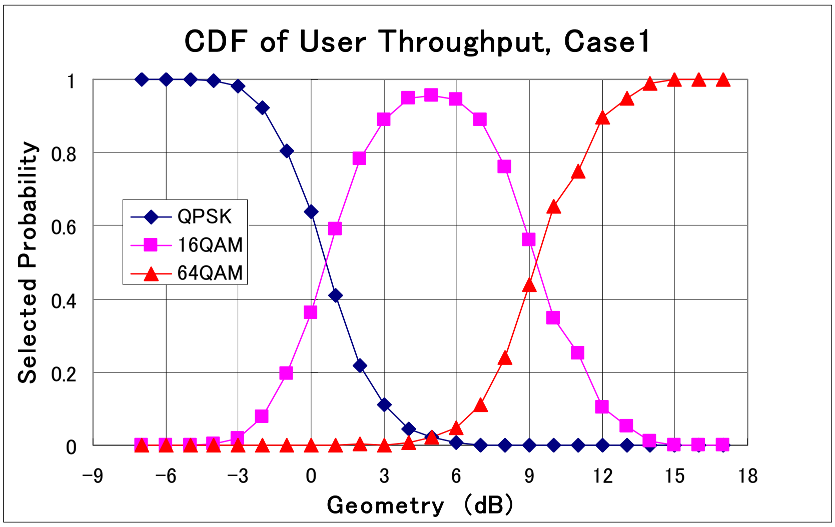

Figure 6: Probability of selecting the MCS in specified geometry with classical MCS table in case 1.

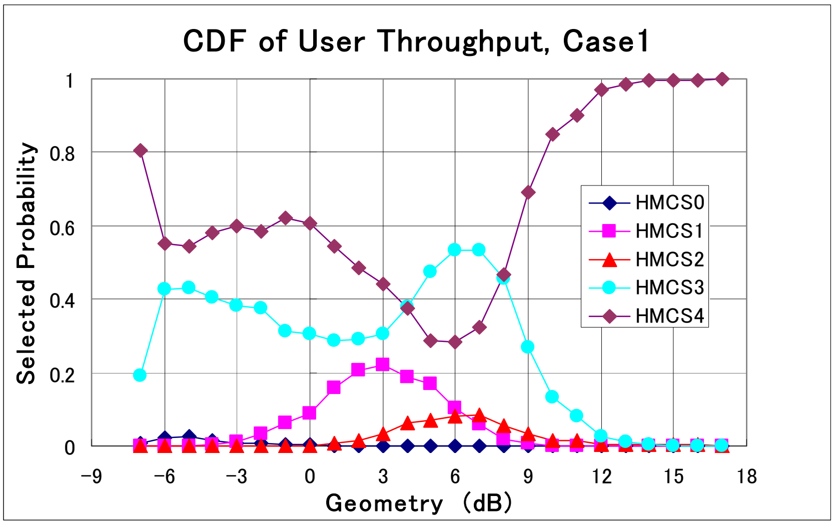

Figure 7: Probability of selecting the MCS in specified geometry with HMCS table in case 1.

4. Conclusions

In this contribution, we have proposed a novel hierarchical modulation scheme by means of two-user paired transmission under a condition of unbalanced physical channels. The proposed scheme requires designing the hierarchical modulation channel, which is utilized for the efficient data transmission. According to the system level evaluation, the fundamental conclusions can be made as follows:

- HMT scheme achieves the tremendous system performance gain. Based on LTE simulation assumptions, 21~22% sector throughput gain and 13~20% cell coverage gain have been confirmed by means of system level simulation.
- HMT scheme is simple, and only needs to introduce some additional but negligible control channels, which might be elaborately designed once the HMCS table is properly determined.
- The design HMCS table used in our system level simulation is only one example, and it is still unknown what the best HMCS table is. To completely accomplish the HMCS table design for LTE-advanced, it needs to be further investigated by performing a large amount of system level simulations.
- To meet the performance targets in the requirement of LTE-Advanced, we suggest that HMT scheme should be beneficially adopted.

5. Appendix: HMCS Table Design

The classical MCS format is tabulated in Table 4, with 30 MCS levels relying on QPSK, 16QAM and 64QAM. The corresponding link level curves are shown in Figure 8, Figure 9, and Figure 10, accordingly. The best components (30 MCS levels) selected for system level simulation rely on the scenario of the highest achievable data rate, indicated by red and Italian bold characters.

Table 4: Classical MCS Format (Code Rate) for general transmission.

MCS Index	MCS0	MCS1	MCS2
0	***0.0375***	0.27417	0.21833

1	***0.048333***	0.34917	0.25917
2	***0.061667***	***0.41***	0.2875
3	***0.08***	***0.46583***	0.35833
4	***0.103333***	***0.5225***	0.40667
5	***0.130833***	***0.59417***	0.4525
6	***0.166667***	***0.65583***	0.50917
7	***0.208333***	***0.73***	0.55167
8	***0.263333***	***0.79667***	***0.6125***
9	***0.340833***	***0.85083***	***0.65833***
10	***0.406667***	0.90167	***0.71583***
11	***0.481667***	0.9275	***0.77333***
12	***0.563333***	–	***0.825***
13	***0.641667***	–	***0.86333***
14	***0.726667***	–	***0.90833***
15	0.804167	–	–

The HMCS format is tabulated in Table 5, with 30 maximum MCS levels in each column, relying on QPSK, 16QAM and 64QAM. The corresponding link level curves are shown from Figure 8 to Figure 14, in terms of the BLER as a function of SNR.

It should be noted that MCS0~MCS2 for both cases are completely the same, nevertheless the different formats require different components.

Table 5: HMCS Format (Code Rate) for HMT.

MCS Index	MCS0	MCS1	MCS2	MCS3,UE0	MCS3,UE1	MCS4,UE0	MCS4,UE1
0	***0.0375***	0.27417	0.21833	***0.029167***	0.02	***0.025***	0.016667
1	***0.048333***	***0.34917***	0.25917	***0.0375***	0.05	***0.0375***	0.033333
2	***0.061667***	***0.41***	0.2875	***0.046667***	0.086667	***0.046667***	0.059167
3	***0.08***	***0.46583***	0.35833	***0.06***	0.128333	***0.06***	0.086667
4	***0.103333***	***0.5225***	0.40667	***0.075***	***0.18***	***0.075***	0.119167
5	***0.130833***	***0.59417***	***0.4525***	***0.095***	***0.24***	***0.095***	0.150833
6	***0.166667***	***0.65583***	***0.50917***	***0.12***	***0.329167***	***0.12***	0.203333
7	***0.208333***	0.73	***0.55167***	***0.15***	***0.403333***	***0.15***	0.258333
8	***0.263333***	0.79667	***0.6125***	***0.183333***	***0.481667***	***0.183333***	0.318333
9	***0.340833***	0.85083	***0.65833***	***0.225***	***0.5625***	***0.225***	0.3875
10	***0.406667***	0.90167	***0.71583***	***0.28***	***0.641667***	***0.28***	0.45
11	***0.481667***	0.9275	***0.77333***	***0.341667***	***0.725***	***0.341667***	***0.516667***
12	***0.563333***	–	***0.825***	***0.391667***	***0.804167***	***0.391667***	***0.578333***
13	***0.641667***	–	***0.86333***	***0.45***	0.86	***0.45***	***0.640833***
14	0.726667	–	***0.90833***	***0.505***	0.916667	***0.505***	***0.71***
15	0.804167	–	–	***0.56***	0.94	***0.56***	***0.78***
16	–	–	–	***0.61***	–	***0.61***	***0.841667***
17	–	–	–	***0.658333***	–	***0.658333***	***0.89***
18	–	–	–	***0.710833***	–	***0.710833***	–
19	–	–	–	***0.764167***	–	***0.764167***	–
20	–	–	–	***0.808333***	–	***0.808333***	–
21	–	–	–	***0.851667***	–	***0.851667***	–
22	–	–	–	0.893333	–	***0.893333***	–
23	–	–	–	0.921667	–	***0.921667***	–
24	–	–	–	0.938333	–	***0.938333***	–

25	–	–	–	0.966667	–	***0.966667***	–
26	–	–	–	–	–	***0.978333***	–
27	–	–	–	–	–	***0.985***	–
28	–	–	–	–	–	***0.988333***	–
29	–	–	–	–	–	0.989167	–

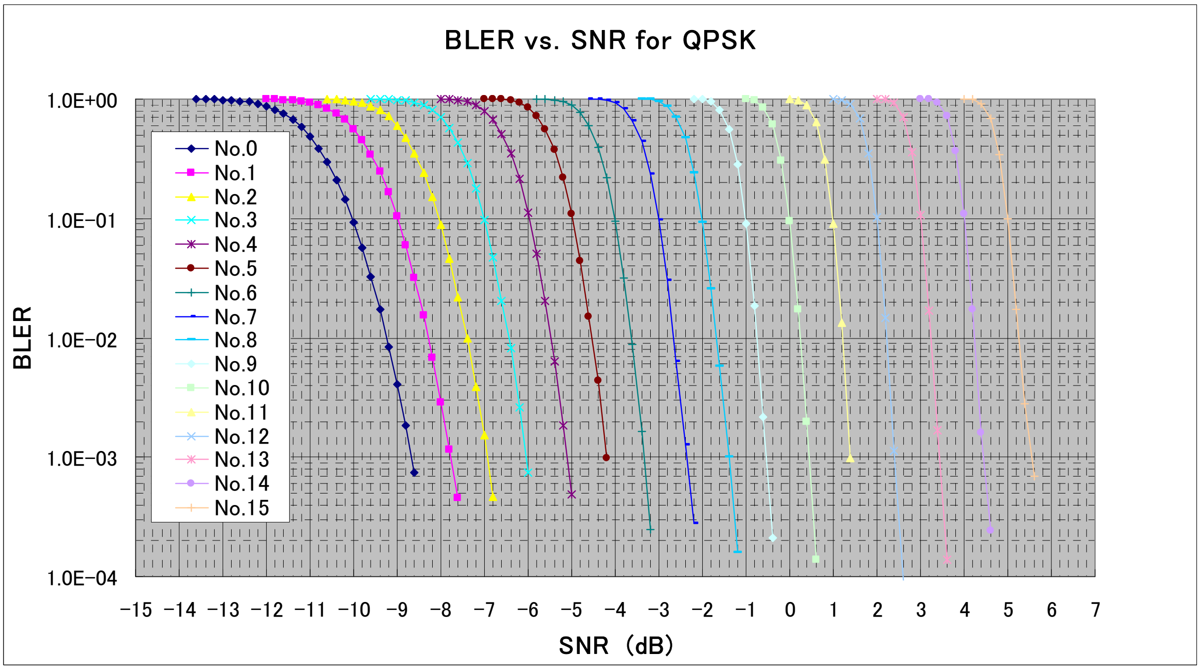

Figure 8: MCS-0 with QPSK for both paired UEs.

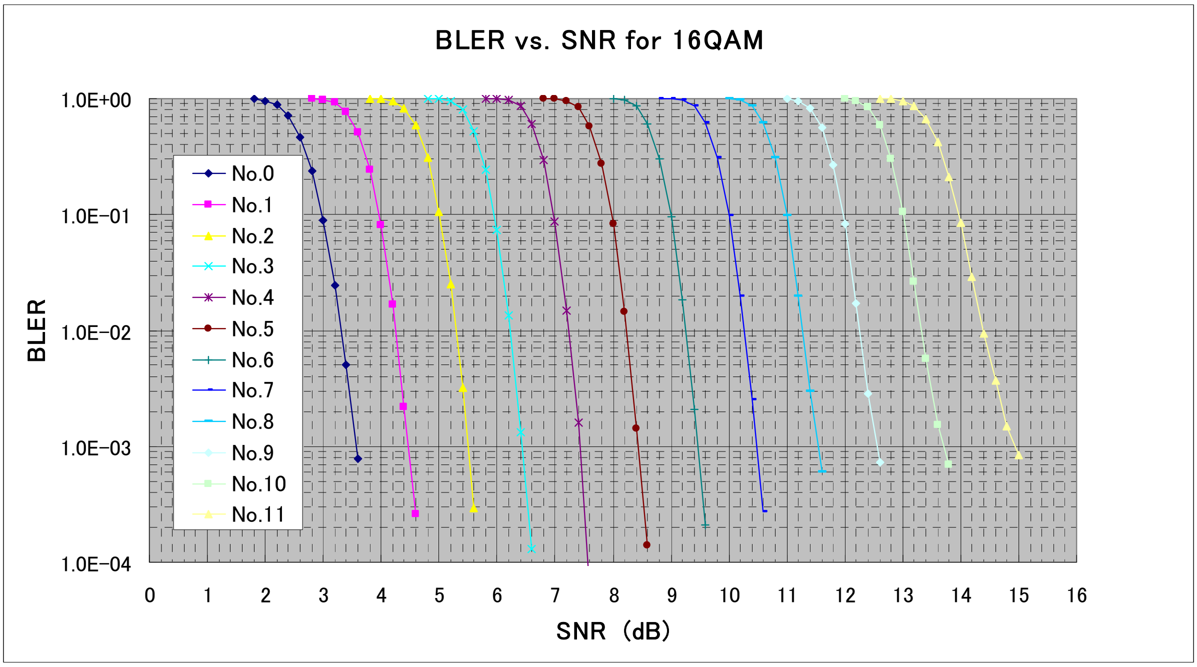

Figure 9: MCS-1 with 16QAM for both paired UEs.

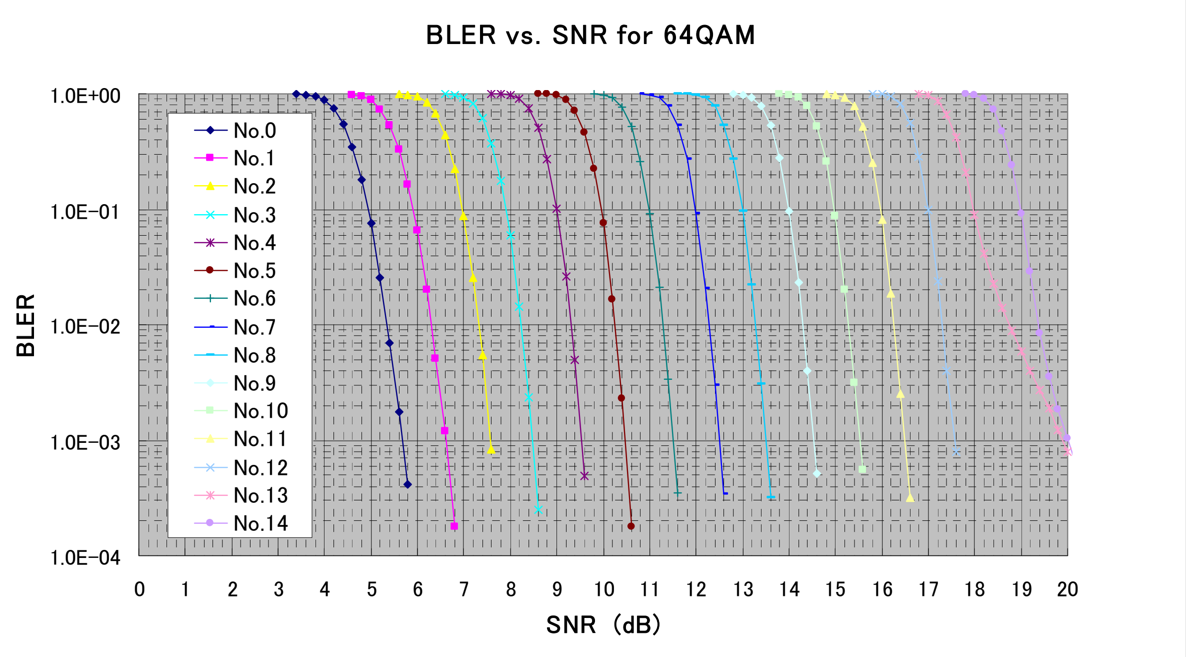

Figure 10: MCS-2 with 64QAM for both paired UEs.

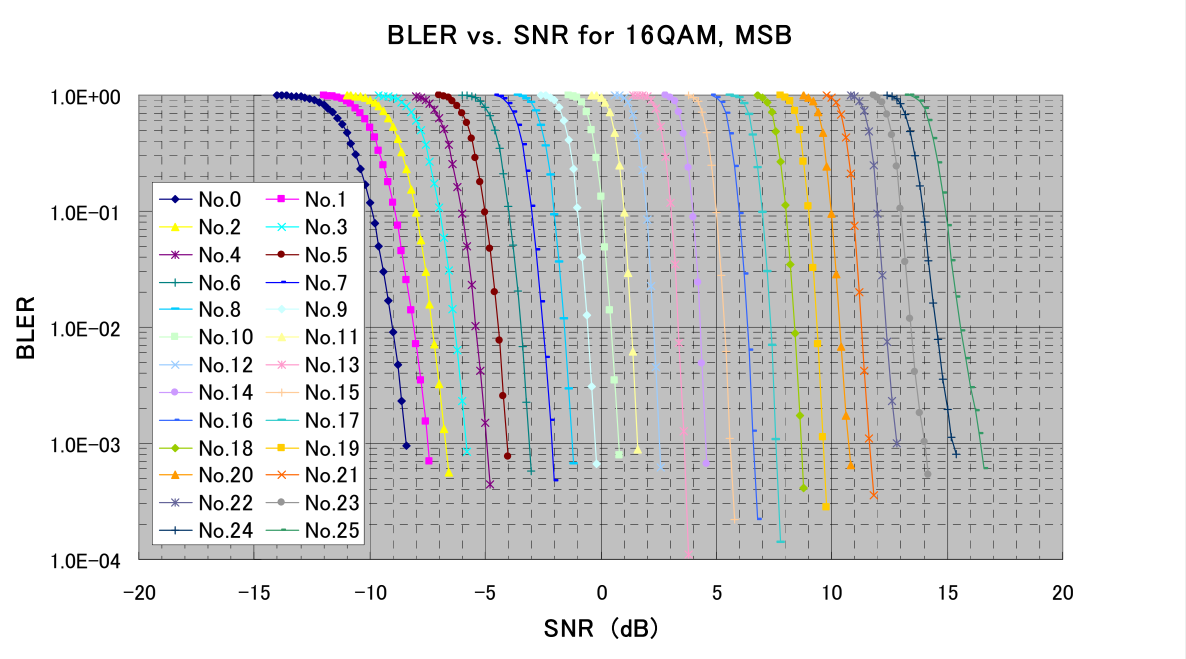

Figure 11: MCS-3 with MSB and 16QAM for worse UE0.

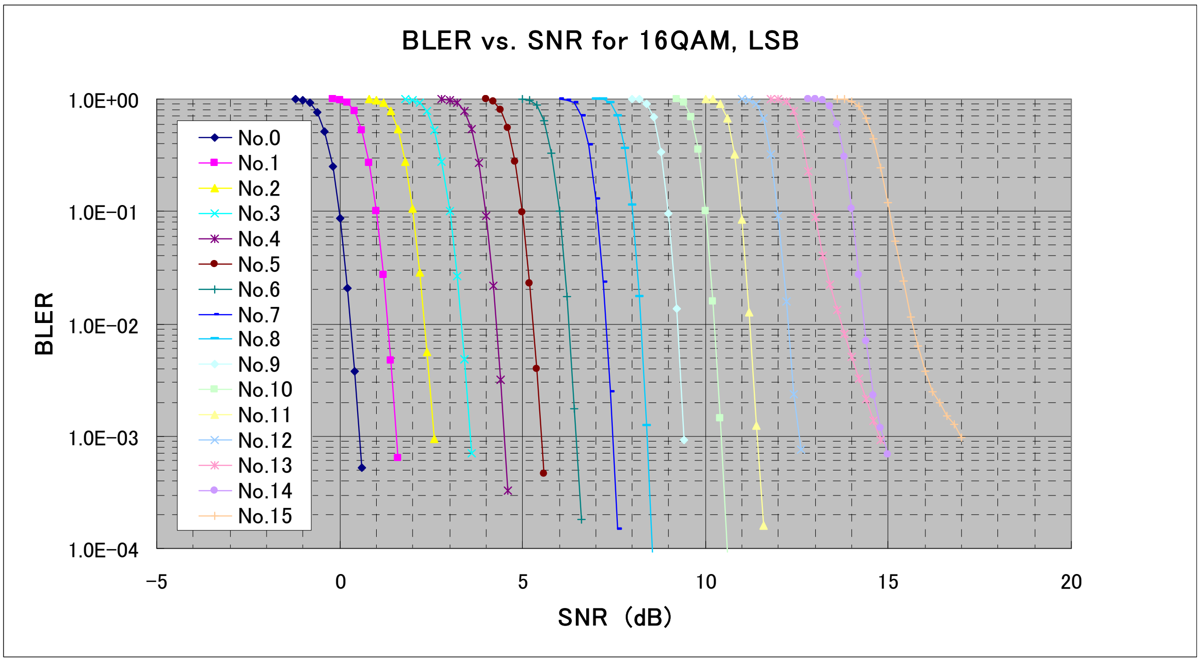

Figure 12: MCS-3 with LSB and 16QAM for better UE1.

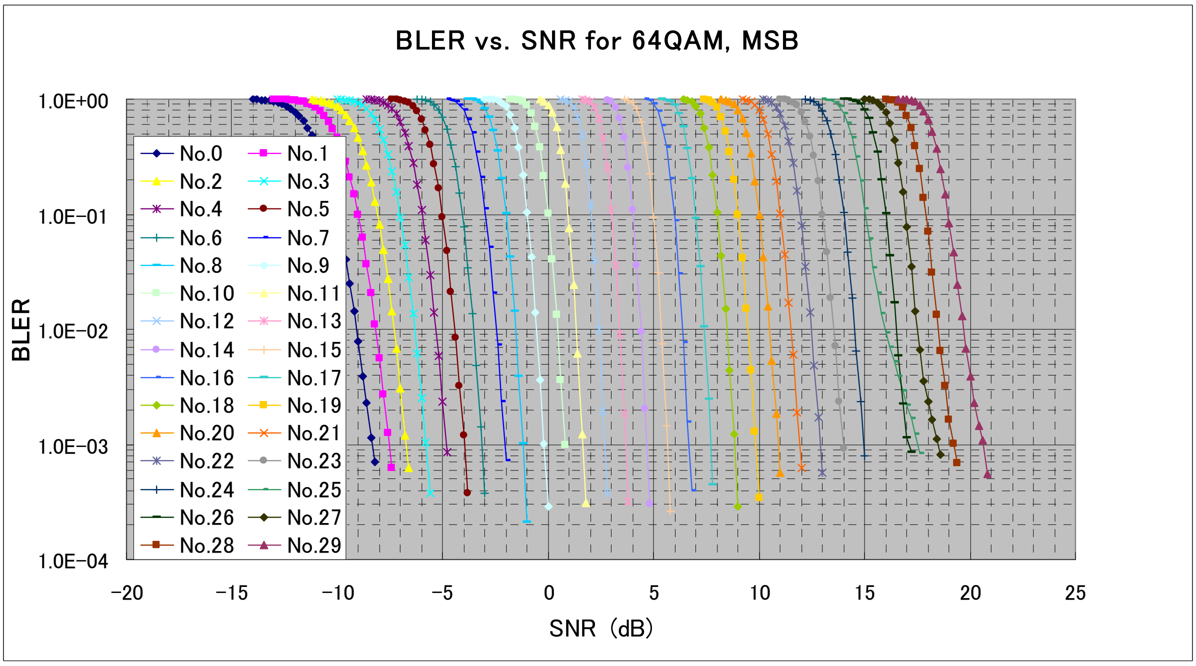

Figure 13: MCS-4 with MSB and 64QAM for worse UE0.

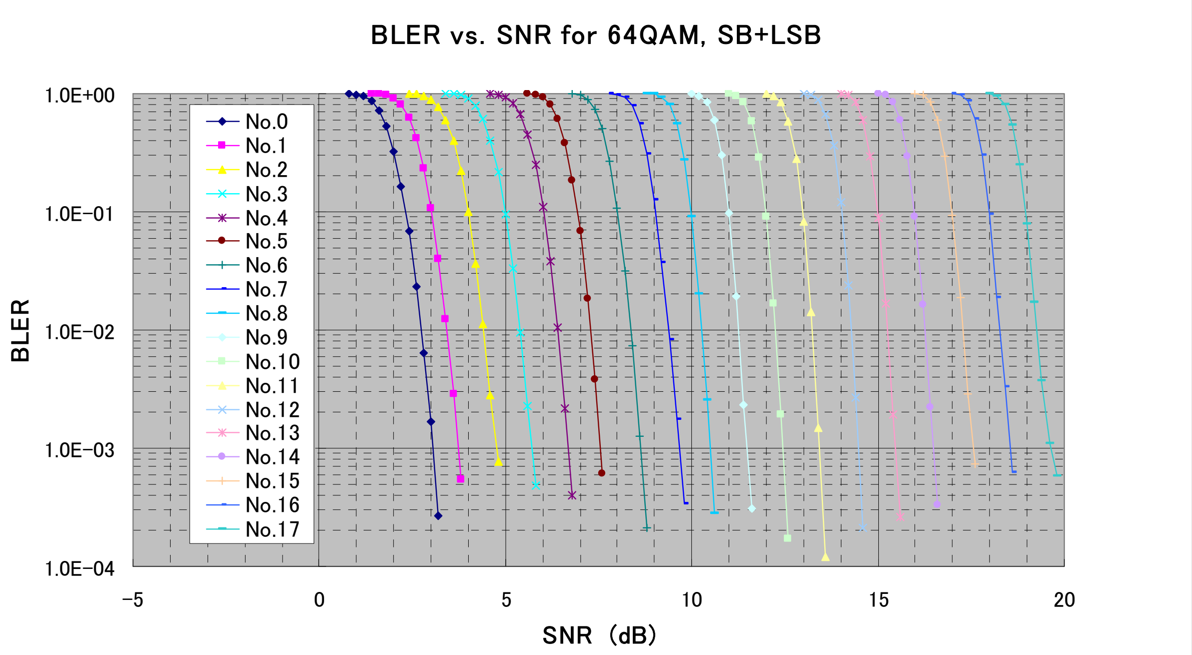

Figure 14: MCS-4 with SB+LSB and 64QAM for better UE1.

6. Appendix: System Level Simulation Details

The detailed simulation assumptions and elaborated simulation results are described in what follows.

6.1. Simulation Assumptions

The system level simulation assumptions are referred to [6] with simulation case-1, case-2 and case-3 (see Table 6) in which the CF, inter-site distance (ISD), operating bandwidth (BW), penetration loss (PLoss), UE speed, and channel model are specified.

Table 6: UTRA and EUTRA simulation case minimum set.

Simulation	**CF**	**ISD**	**BW**	**PLoss**	**Speed**	**Channel**
Cases	**(GHz)**	**(meters)**	**(MHz)**	**(dB)**	**(km/h)**	**Model**
1	2.0	500	10	20	3	TU
2	2.0	500	10	10	30	TU
3	2.0	1732	10	20	3	TU

The system level simulation focuses on the down-link with the detailed assumptions listed in Table 7.

Table 7: System Level Simulation Assumptions.

Number of Cells	19
Number of Sectors per Cell	3
Number of UEs per sector	10 and 20
Antenna Configuration	1x2
Transmit Antenna Correlation	0.3 (Corresponding 10λ Spacing)
Receive Antenna Spacing	0.5λ

Maximum Retransmission Number	3
Centre Frequency	2 GHz
Transmission Power	40 Watts (46 dBm)
Lognormal Shadowing	8dB
Noise Figure	9 dB
Transmit Antenna Gain	14 dBi
Receive Antenna Gain	0 dBi
Maximum CIR	30 dB
Path-Loss	$128.1+37.6\log_{10}(R)$
Scheduler	Proportional Fair, see section 2.5
Channel Estimation	Ideal
Traffic Model	Full Buffer
MCS Table	30 Levels, see Table 5 in section 5
Effective SINR	Mutual Information Basis [7]
Overhead	25%
MCS Feedback Interval	5msec
Number of HARQ Process Channel	8
Number of RBs per Tx per UE	10
Channel Model	TU
Bandwidth	10MHz
Number of Useful Sub-carriers per Symbol	600
FFT Size	1024
Receiver Type	MRC

6.2. Throughput Performance

The simulation results in terms of user throughput vs. geometry, and CDF of user throughput are shown in Figure 15 ~ Figure 20. The intention of revealing such a system level result is to provide the solid justifications and back up the description of system performance gain summarized in Table 2 and Table 3.

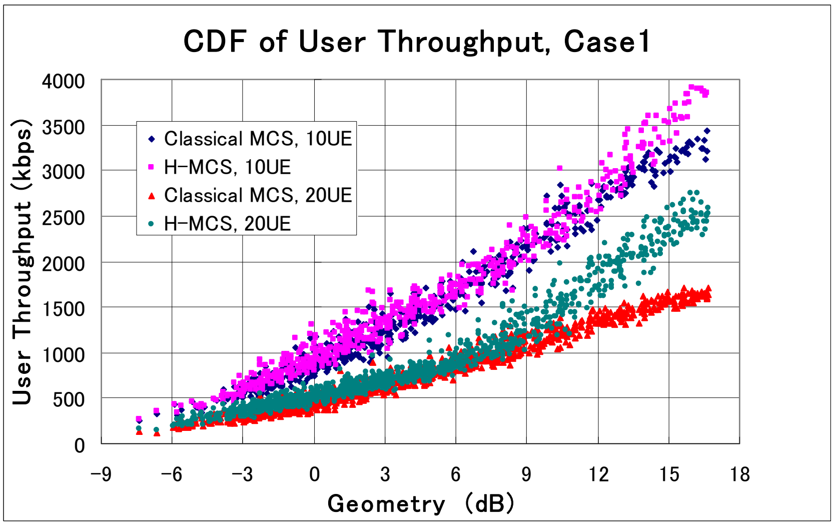

Figure 15: User throughput vs. geometry with 10 and 20 in case-1.

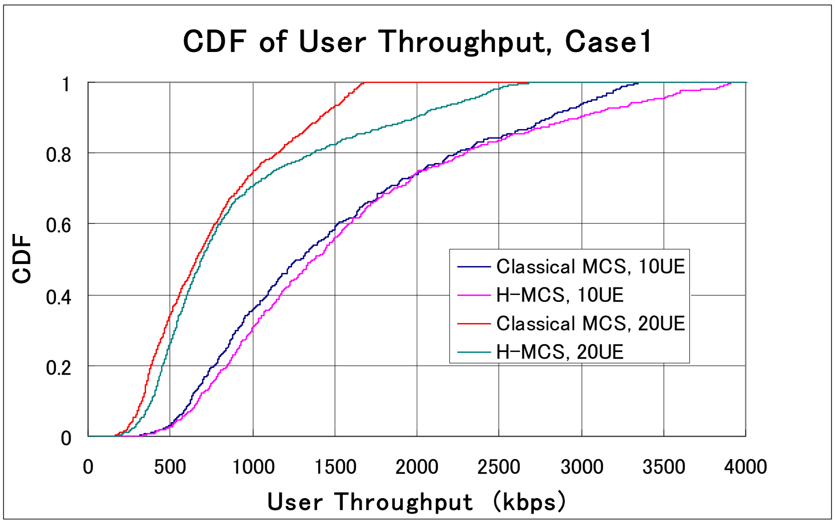

Figure 16: CDF of user throughput with 10 and 20 UEs in case-1.

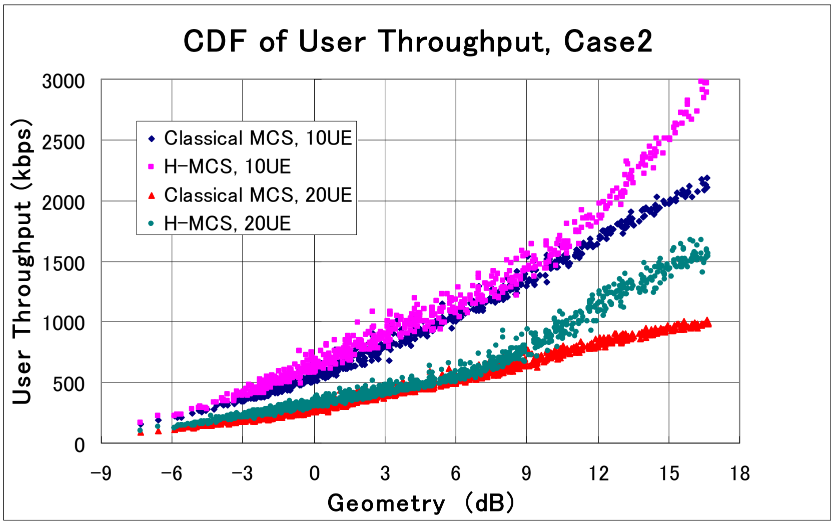

Figure 17: User throughput vs. geometry with 10 and 20 in case-2.

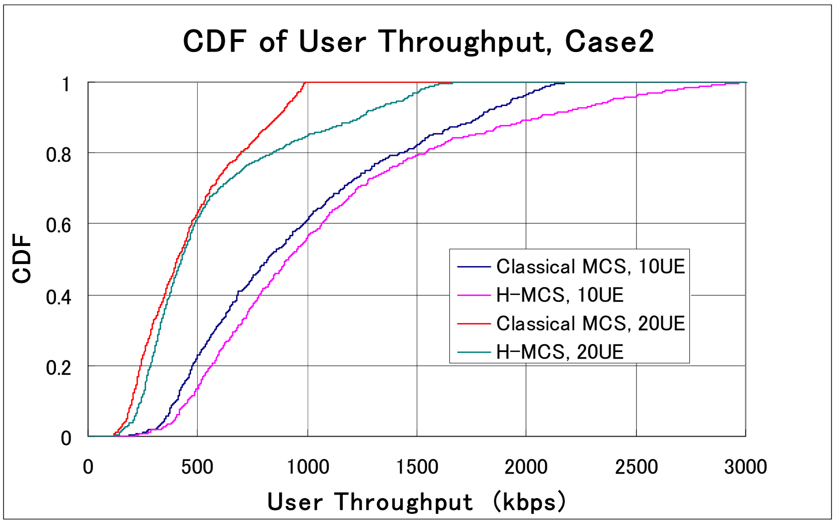

Figure 18: CDF of user throughput with 10 and 20 UEs in case-2.

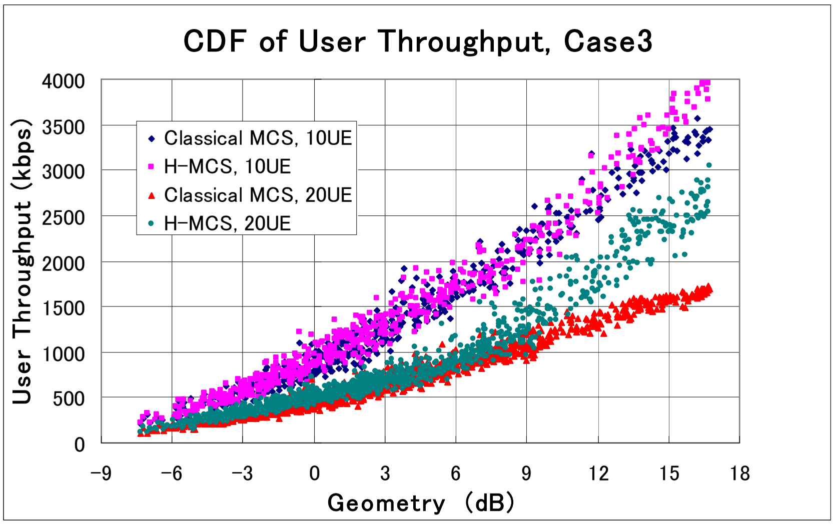

Figure 19: User throughput vs. geometry with 10 and 20 in case-3.

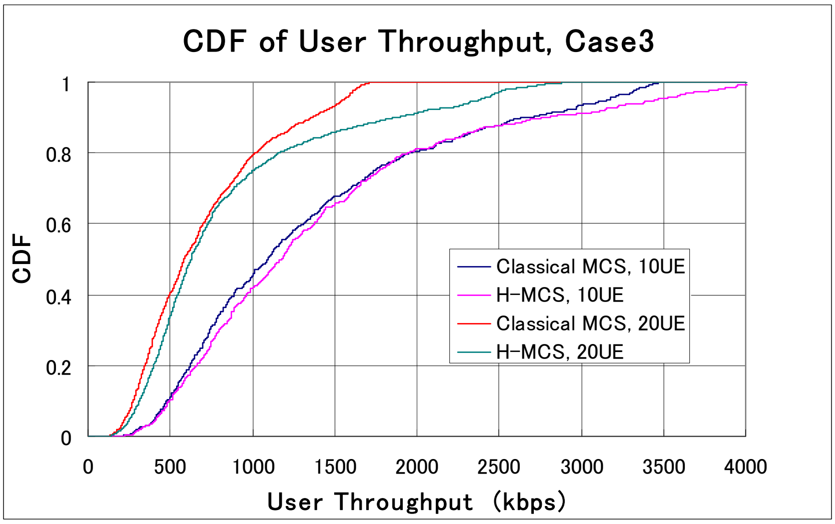

Figure 20: CDF of user throughput with 10 and 20 UEs in case-3.

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