Performance Comparison of Orthogonal Code Hopping Multiplexing(OCHM) and HDR Schemes in Synchronous Downlink

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***Abstract*— We previously proposed the Orthogonal Code Hopping Multiplexing(OCHM) scheme as a new statistical multiplexing scheme in synchronous downlink and applied the OCHM scheme to IS-95 and Wideband CDMA. OCHM enables a large number of users to share the limited number of code channels through statistical multiplexing. In this paper, we compare OCHM with HDR through link-level simulation. OCHM outperforms HDR in medium and high mobility conditions, while HDR operates better in a low mobility condition.**

***Index Terms*— Orthogonal Code Hopping Multiplexing, OCHM, High Data Rate, HDR, 1xEV-DO, statistical multiplexing.**

I. INTRODUCTION

Orthogonal Code Hopping Multiplexing(OCHM) [1], [2], [3] is a new statistical multiplexing scheme in downlink, which enables a large number of users to share the limited number of code channels through statistical multiplexing. Orthogonality is preserved and however, some user symbols may collide occasionally by code hopping. We can control the number of allowable users according to their activity and the required error rate. Channel coding gain can compensate for collisions. Delay characteristic is consistent because there is no admission control[1] on a packet transmission.

We applied the OCHM scheme to IS-95 and Wideband CDMA(W-CDMA) downlink [4]. The performance of OCHM was compared with that of the conventional code division multiplexing here called the Orthogonal Code Division Multiplexing(OCDM). OCHM can accommodate a large number of users with little degradation in error rate. For example, with an activity factor of 0.1 and 64 orthogonal code channels, the number of allocable channels is 287 when a perforation probability of 20% was allowed. OCHM accommodates the number of bursty data users four times more in this condition.

High Data Rate(HDR) or 1xEV-DO[2] system adopts user diversity and adaptive modulation and coding(AMC) as its key features. It supports high speed data transmission for non-realtime data users. The HDR characteristic is different from that of OCHM. HDR schedules users using Time Division Multiplexing(TDM) signalling, while OCHM transmits packets for all users relatively slowly without signalling.

In this paper, we compare OCHM with HDR. We develop a link-level HDR downlink simulator and find relevant data rates for Ec/No values in an additive white Gaussian noise(AWGN) channel. These values are to be used in AMC. We compare our proposed OCHM scheme with HDR in the identical traffic environments and the similar system environments.

This paper is organized as follows. Section II outlines the OCHM scheme. Section III introduces HDR systems and performs HDR link-level simulation in downlink. Section IV compares OCHM with HDR in a system environment. Section V presents conclusions.

II. FEATURES OF THE OCHM SCHEME

OCHM [1], [2], [3] is to accommodate more downlink orthogonal channels than orthogonal codewords for mobile stations through statistical multiplexing. The number of dedicated orthogonal downlink channels in the OCDM-based system cannot exceed the number of codewords in the orthogonal code regardless of downlink channel activity. Since orthogonal codewords are valuable resources for the synchronous downlink of Code Division Multiple Access(CDMA) system, it is important to increase the utilization of orthogonal codewords within the maximum allowable total transmit power of the downlink in a cell. In order to increase the number of downlink channels,

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[1] It means the initial admission control for the packet. Retransmission control like automatic repeat request(ARQ) is possible.

[2] 1xEV-DO is the new name for HDR.

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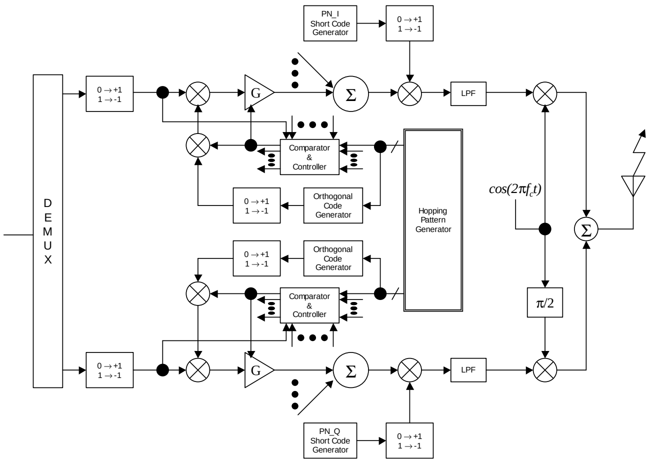
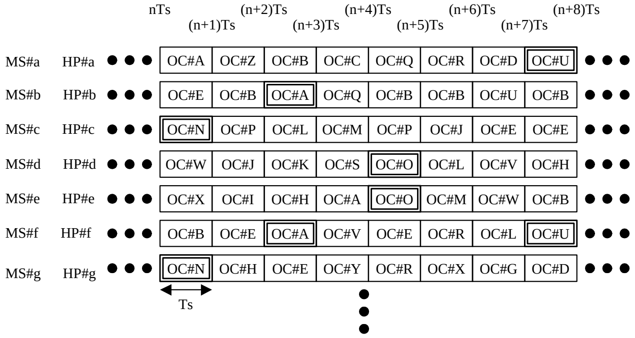


(a) Transmitter structure for OCHM



MS#a	HP#a	● ● ●	OC#A	OC#Z	OC#B	OC#C	OC#Q	OC#R	OC#D	OC#U	● ● ●
MS#b	HP#b	● ● ●	OC#E	OC#B	OC#A	OC#Q	OC#B	OC#B	OC#U	OC#B	● ● ●
MS#c	HP#c	● ● ●	OC#N	OC#P	OC#L	OC#M	OC#P	OC#J	OC#E	OC#E	● ● ●
MS#d	HP#d	● ● ●	OC#W	OC#J	OC#K	OC#S	OC#O	OC#L	OC#V	OC#H	● ● ●
MS#e	HP#e	● ● ●	OC#X	OC#I	OC#H	OC#A	OC#O	OC#M	OC#W	OC#B	● ● ●
MS#f	HP#f	● ● ●	OC#B	OC#E	OC#A	OC#V	OC#E	OC#R	OC#L	OC#U	● ● ●
MS#g	HP#g	● ● ●	OC#N	OC#H	OC#E	OC#Y	OC#R	OC#X	OC#G	OC#D	● ● ●

(b) MS-specific hopping patterns and their collision

Fig. 1. Orthogonal Code Hopping Multiplexing(OCHM)

Multi-Scrambling Code(MSC) [5] for W-CDMA and Quasi-Orthogonal Code(QOC) [6] for cdma2000 have been recommended. These schemes do not support the orthogonality of downlink channels. However, the orthogonality is a very valuable property of synchronous downlink.

OCHM is a statistical multiplexing scheme for orthogonal downlink in spread spectrum systems based on direct sequence. Fig. 1(a) shows the transmitter structure for the OCHM scheme. It additionally contains a hopping pattern generator and comparator & controller modules compared to conventional transmitters. The hopping pattern generator produces hopping patterns for users, and the comparator & controller module compares symbol information of users with the same hopping pattern and resolves collision problems. Since the OCHM scheme uses a mobile station (MS)-specific hopping pattern after an initial channel allocation from base station(BS), signalling messages for allocation and de-allocation of orthogonal codewords during a call are less required for bursty traffic. The conventional CDMA (here called OCDM) system is a special case of the OCHM system because a constant hopping pattern allocated by a base station (BS) is the same as a fixed orthogonal codeword allocation, as specified in W-CDMA [5], cdma2000 [6], and cdmaOne (IS-95) [7].

The hopping pattern may be based on MS identifier(ID) using electronic serial number(ESN) as an example. Since the number of available codewords in an orthogonal code for OCHM is limited and the hopping patterns are mutually independent, orthogonal spreading codewords of two or more downlink active (data transmitting) channels may be identical at a symbol time, as shown in Fig. 1(b). This event is called a collision of hopping patterns at that time, and the encoded symbols with collisions are illustrated as double-lined boxes in Fig. 1(b). For example, each MS transmits symbols according to its hopping pattern (HP). MS#c and MS#g are scheduled to send different symbols using the same orthogonal codeword, OC#N at the nth time slot, and then their symbols collide.

When collisions among the hopping patterns of downlink active channels occur, a comparator and controller at the transmitter of a base station(BS) takes one of the following two operations: If at least one channel-encoded data symbol is different from others, then all data symbols colliding at the moment are perforated[3] and are not transmitted. The channel decoder of the corresponding MS can recover the perforated data symbols of each channel if the number of perforated data symbols is less than a threshold. The transmit power during the encoded and perforated data symbol time is zero for all related channels. If all channel encoded data symbols are identical, then all the data symbols with collisions are transmitted without perforation. The transmit power during the encoded data symbol time for each channel is the sum of the assigned transmit power for all related downlink channels or the maximum among the assigned transmit power. We studied collision mitigation schemes to improve performance by reducing the degradation due to perforation [8].

For a given perforation probability, the number of allocable dedicated downlink channels can exceed that of orthogonal codewords if the channel activity is low. The allowable perforation (or collision) probability depends on the channel-coding scheme. As a channel coding scheme is more powerful, the higher perforation (or collision) probability is allowable. If the channel activity of downlink channels is 0.1 and the allowable perforation probability is 20%, then the number of allocable downlink dedicated orthogonal channels with 64 orthogonal codewords is approximately 287 [2].

III. HDR DOWNLINK

A. Overview on HDR

HDR has distinctive features, such as user diversity and AMC to support non-realtime high speed data service. User

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[3] The term, *puncturing* [1] was chosen to describe the condition, but it may cause confusion with puncturing used to increase the code rate. Therefore, we adopt *perforation* which has the same lexical meaning.

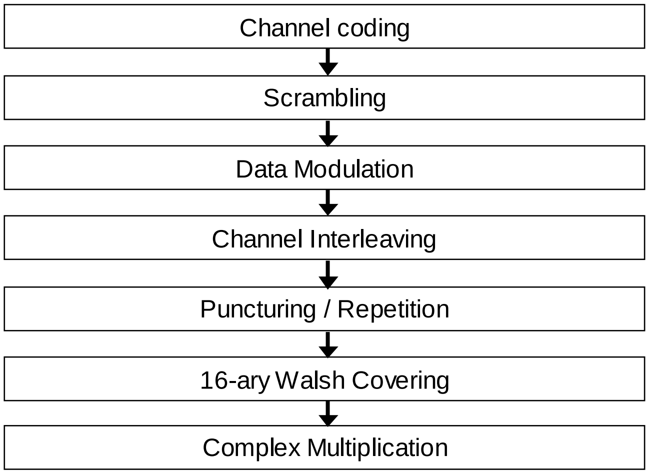

Fig. 2. Baseband processing for downlink

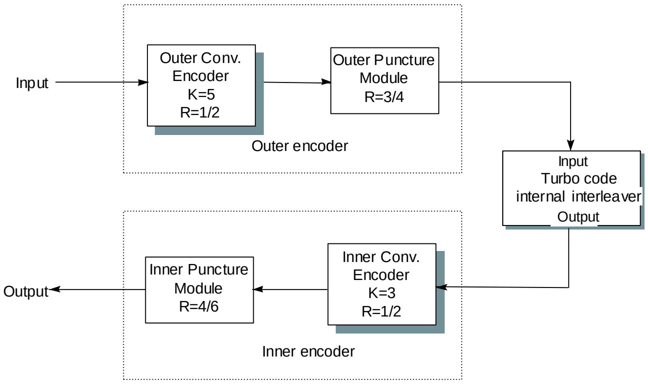

Fig. 3. Serially concatenated convolutional encoder

diversity here means that a base station selects a user with the best channel condition every time and then allocates all downlink channels to the user. AMC is a scheme which adaptively adjusts data rate by changing data modulation and channel coding methods instead of controlling power according to varying channel conditions. Some important parameters of HDR are as follows:

- Frame length: 26.67 ms
- Time slot length: 1.67 ms = 2048 chips
- Spreading factor(SF): 16
- Data rates: 38.4 $kbps \sim$ 2.4576 $Mbps$
- Data modulation: QPSK, 8PSK, 16QAM

The overall baseband processing of traffic channels is shown in Fig. 2. Input data are channel coded using serially concatenated convolutional codes(SCCC) illustrated in Fig. 3 as a special case of Turbo [9] encoders. The soft output Viterbi algorithm(SOVA) is used for iterative decoding [10], [11]. Next step is to scramble channel coded symbols and then the scrambled symbols are data modulated through QPSK(Quadrature Phase Shift Keying), 8PSK(8-ary Phase Shift Keying), or 16QAM(16-ary Quadrature Amplitude Modulation) according to data rates. The data modulated symbols are permuted by a bit-reversal interleaver, which is then followed by puncture and repetition operations. The puncture operation is to multiplex preamble, pilot, and MAC information in time and the repetition operation is to collect enough time slots and bit energy for low data rates. Walsh covering performs spreading for frequency reuse and only one user uses all code channels in the HDR downlink. Traffic data, preamble, pilot, and MAC information are time-division multiplexed before the complex multiplication. Finally, symbols are multiplied by a pseudo-noise(PN) sequence. More detailed information on HDR can be found in [12], [13].

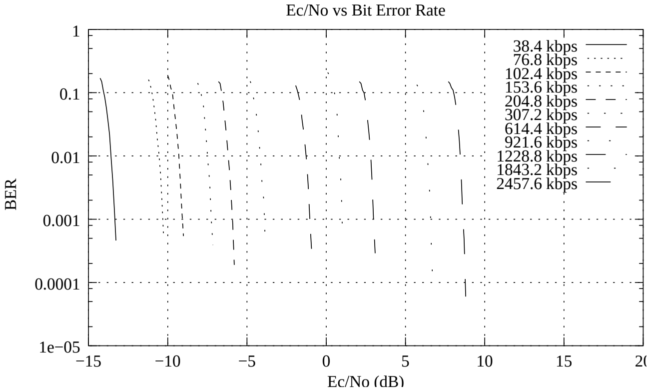

Fig. 4. Bit error rate (AWGN)

B. HDR Link-Level Simulation in Downlink

We assume AWGN channels first and then consider independent Rayleigh fading and single-path Jakes' fading [14] environments. We select three different user speeds, i.e., 3 km/h, 30 km/h, and 120 km/h in Jakes' fading. The output of this link-level simulation is generated from AWGN-only channels because it can be used for AMC in the next section.

We evaluate the bit error rate(BER) and packet error rate(PER) performance for various Ec/No values through simulation. PER is a more important performance measure than BER in evaluating the HDR system. The target PER or block error rate(BLER) for HDR systems is 10^{-2} [15]. Figs. 4 and 5 show the BER and PER performance in AWGN channels, respectively. Each steep slope representing a data rate corresponds to a specific range of Ec/No values. Fig. 6 illustrates the Ec/No values for 1% PER obtained from Fig. 5. Each cross point on the dotted line indicates the required Ec/No for each corresponding data rate. A diamond point represents the required Eb/No for the data rate and these Eb/No values remain almost constant when the data modulation method is QPSK. The required Eb/No value increases when we adopt 8PSK or 16QAM for high data rates. Table I shows the required Ec/No for 1% PER in the HDR downlink. The second column values in Table I can be used as threshold values for AMC.

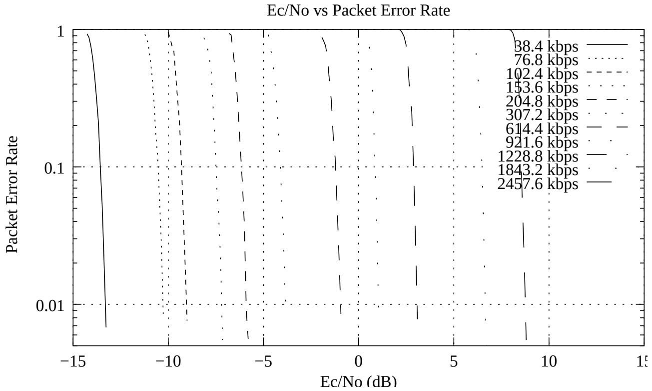

Fig. 5. Packet error rate (AWGN)

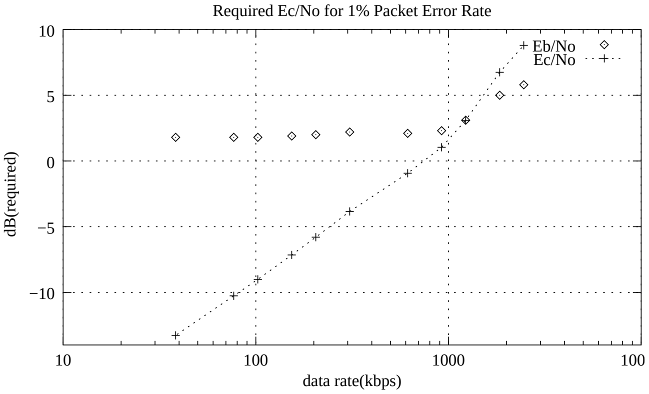

Fig. 6. Threshold for 1% packet error rate (AWGN)

TABLE I

REQUIRED Ec/No FOR 1% PER IN THE HDR DOWNLINK (AWGN)

Data rate ($kbps$)	Required Ec/No (dB)
38.4	-13.27
76.8	-10.26
102.4	-9.01
153.6	-7.15
204.8	-5.80
307.2	-3.84
614.4	-0.93
921.6	1.04
1228.8	3.09
1843.2	6.75
2457.6	8.80

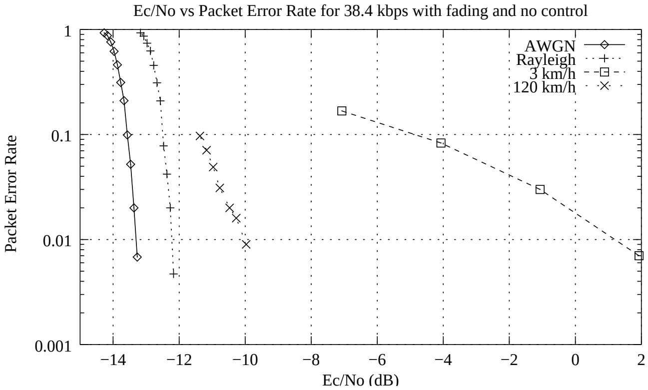

Fig. 7. Packet error rate for 38.4 $kbps$ (AWGN, Rayleigh, Jakes)

Fig. 7 shows the PER curves in several channels without power or rate control in the AWGN channel as well as Rayleigh and Jakes' fading channels. The worst result occurs in the Jakes' fading channel with low speed because deep fading becomes probable during a channel coding interval. Fig. 8 illustrates the PER curves for several data rates in Jakes' fading channels with a user speed of 120 km/h. Higher data rates yield worse performance and the result for 2.4576 $Mbps$ is extremely poor here without power or rate control because 16QAM has information on amplitude and the amplitude fluctuates and deviates in a fading channel.

IV. HDR VS. OCHM

Using link-level simulation results we evaluate AMC according to the received Ec/No. OCHM is a completely different scheme from that used in HDR. We assume similar system environments for fair comparison of both schemes. We use the same system environments described in HDR [12].

A. *Traffic Environments*

Traffic enviroments are identical for both systems. We assume 100 users with an activity factor of 0.1 in a 38.4 $kbps$ link. Arrival packet size follows an exponential distribution with a mean length of 12 $kbytes$ and interarrival time between packets is exponentially distributed with a mean of 25 seconds. The length of 12 $kbytes$ is the sum of packets in a packet call [16] and interarrival time is calculated from the activity factor. The collision probability and the perforation probability [1], [2] for OCHM are 46.2% and 26.6%, respectively, on the basis of the previous parameters. They are somewhat large values for good performance [2], [4] and they cause performance degradation in OCHM.

B. *System Environments*

First, we consider HDR system environments. HDR adaptively controls rates by means of AMC and the rate control delay is two time slots. We set data rate control(DRC) margin in the control to overcome wireless channel estimation errors due to delay. Fig. 9 shows why a DRC margin is required. The selected data rate cannot be maintained in the state of two time slots ago. Scheduling does not follow the conventional proportionally fair algorithm and we adopt *a relatively best algorithm* which selects the user on the best channel condition relative to its mean channel condition.

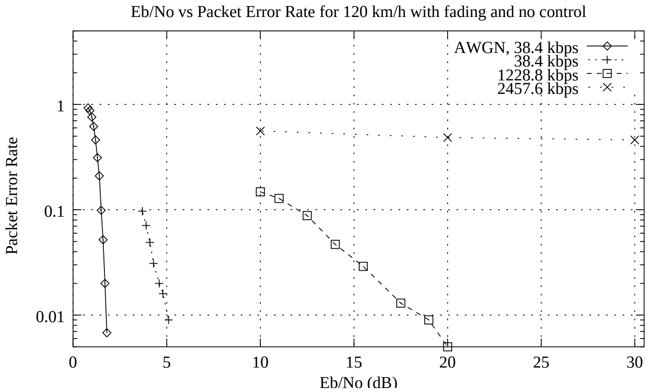

Fig. 8. Packet error rate for 120 km/h (Jakes)

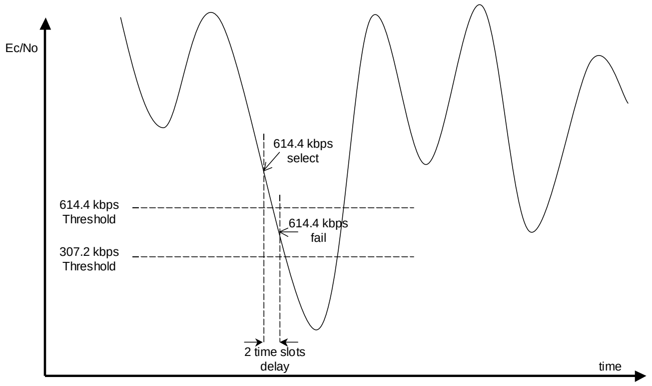

Fig. 9. DRC margin

OCHM system environments are nearly the same as those of HDR for fair comparison. The power control delay is two time slots corresponding to the rate control delay and the power control scheme has a variable step size and a dynamic range. The number of code channels in OCHM is 16 to conform to HDR baseband processing whose spreading factor is 16. The path loss and log-normal shadowing environments are assumed to be the same for both systems. We assume 5 levels with a difference of 2.5 dB in their mean Ec/No and 20 users per level.

C. *Comparison Results*

Rate control for HDR works well when the control delay is small enough to estimate channel conditions. On the other hand, channel conditions rapidly change as mobile speed increases. We choose 3 km/h, 30 km/h, and 120 km/h as the mobile speed[4]. It is expected that HDR operates badly in high mobility conditions because rate control is inaccurate due to delay. However, OCHM can take advantage of time diversity in rapidly changing fading channels because it naturally has a longer encoded packet transmission time than HDR.

TABLE II

COMPARISON RESULTS BETWEEN HDR AND OCHM

Speed	DRC margin (1% PER)	Relative mean power	Relative mean power
3 km/h	2.5 dB	0.118	-9.27 dB
30 km/h	11.5 dB	2.83	+4.52 dB
120 km/h	10.0 dB	3.36	+5.26 dB
OCHM		1	0 dB

Speed	Delay mean	Delay variance	var/mean^2
3 km/h	$1.25s$	$3.79s^2$	2.43
30 km/h	$2.04s$	$8.84s^2$	2.12
120 km/h	$2.41s$	$12.7s^2$	2.19
OCHM	$2.78s$	$7.75s^2$	1.00

We apply similar constraints to both systems for comparison. It means to set many parameter values equal. In an HDR system, the error rate decreases and throughput and delay characteristics become worse as the DRC margin increases. For OCHM, the error rate decreases and the power consumption rises high when the required Ec/No increases. Throughput and delay are inherently consistent in OCHM. We select the relative mean power consumption for the performance measure between both systems. We adjust power and DRC margin to achieve the required delay, throughput, and 1% packet error rate for both systems. Consequently, the relative mean power is the only interesting parameter value between both systems.

Table II illustrates the comparison results listed as the power levels of HDR normalized by the power consumptions of OCHM in the upper table. Even though HDR transmits at fixed power, the power level variation is normalized for the convenience of representation. HDR consumes less power than OCHM at a speed of 3 km/h and more than OCHM at 30 km/h and 120 km/h. It means that OCHM performs better in medium and high mobility conditions by time diversity and control delay.

Besides the relative mean power, we calculate the delay variances for both systems. The normalized delay variance of OCHM is smaller than HDR at all speeds. Since delay characteristics are consistent in OCHM, it can be noted that the inherent scheduling of OCHM operates well.

V. CONCLUSIONS

We developed a link-level HDR downlink simulator and obtained AMC parameters from the link-level simulator. We compared our proposed OCHM scheme with HDR in the identical traffic environments and the similar system environments. HDR supports up to a data rate of 2.4 $Mbps$ in downlink. OCHM yields better performance in medium and high mobility

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[4] These values are commonly used in 3GPP specifications.

conditions, while HDR performs well in a low mobility condition. In addition, OCHM yields a smaller delay variance than HDR.

ACKNOWLEDGMENTS

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