Physical Communication 25 (2017) 564–569

Contents lists available at ScienceDirect

Physical Communication

journal homepage: www.elsevier.com/locate/phycom

Full length article

Analysis and simulation of MDMA—A spectrum efficient non-orthogonal multiple access scheme for 5G communication

Wei-Han Hsiao *, Chia-Chi Huang

Department of Electrical and Computer Engineering, National Chiao Tung University, No.1001, Daxue Rd., East Dist., Hsinchu City 300, Taiwan, ROC

ARTICLE INFO

Article history:
Received 2 May 2017
Received in revised form 8 September 2017
Accepted 20 October 2017
Available online 11 November 2017

Keywords:
MDMA
Millimeter wave
NOMA
Spectrum efficiency
5G communication

ABSTRACT

In this paper, an analysis and simulation approach is used to verify the performance of a recently proposed non-orthogonal multiple access scheme called multipath division multiple access (MDMA). The spatial multipath channel (SMC), which is the distinct feature for each user, is introduced to model the matrix channel of each user, taking into account the multipath structure and massive antennas. The signal and interference powers are then derived. Thus, the corresponding bit error probability can be approximated in a closed form. Moreover, computer simulation results are shown to be consistent with the analysis results. Most importantly, it is revealed that the MDMA system can achieve the superior cellular spectrum efficiency of 25 bps/Hz/cell which fulfills the 5G cellular system requirement.

1. Introduction

Global mobile data traffic grows exponentially year by year as reported by Cisco's visual network index (VNI) [1], which shows that it has grown a thousand fold over the past ten years. Proceeding with this trend, it is forecast that there will be an eightfold increase from 2015 to 2020. Among them, more than half of the data traffic is contributed by mobile video applications and mostly comes from the increasing usage of smart devices. In addition, the data rate demand is also growing rapidly along with the traffic volume explosion. Thus, the fifth generation (5G) mobile communications are expected to achieve both high system capacity and high data rate.

The IMT-2020 released by International Telecommunication Union (ITU) in 2015 [2] has defined the framework and target requirements for future 5G communications. In the enhanced mobile broadband scenario, more stringent system performance indexes have been drawn. For example, peak data rate is increased to 10 Gbps at least and the average user data rate should be 100 Mbps. Besides, mobility should support up to 500 km/h. Most importantly, the required spectrum efficiency is three times larger than the fourth generation (4G) communication system, which is measured in the unit of bps/Hz/cell. Until now, numerous researches have been vigorously ongoing in the world shooting for the 5G vision [3].

Recent technical approaches for achieving the 5G system requirements are proposed primarily in two directions [3,4]. One direction is the evolution of the current network architecture while the other direction is the design of advanced transmission technologies. The former is evolved from the existing 4G cellular networks. The approach applies cell densification and offloading, which are known as small cells and heterogeneous networks, respectively. The latter resorts to the new air interface and unused radio spectrum. Main solutions are massive antennas, millimeter wave bands, and new waveform design such as filter bank multicarrier and non-orthogonal signaling, all of which are able to increase the system capacity and offer high data rate.

A new multiple access scheme for 5G cellular systems called multipath division multiple access (MDMA) has recently been proposed in [5], which exploits massive antennas at base stations and operates in the millimeter wave band. The MDMA concept has been shown to attain both high system capacity and high data throughput at system level, yet it is in the early stage of development that needs further investigation to verify its claim, which is the motivation of this work.

Contributions of this paper are stated below. A spatial multipath channel (SMC) is first introduced to model the matrix channel of each user in the MDMA system, taking into account the multipath structure and massive antennas. Then a rigorous analysis is given to show its bit error probability by deriving the signal to interference power ratio, which is not obtained in the original work [5]. Next, system-level and link-level simulations are presented, whose results are consistent with the analysis results. Last, but most important, the current status of the achievable cellular spectrum efficiency for several existing cellular systems are presented along

* Corresponding author.
E-mail addresses: whsiao.cm97g@g2.nctu.edu.tw (W.-H. Hsiao), huangcc@faculty.nctu.edu.tw (C.-C. Huang).

https://doi.org/10.1016/j.phycom.2017.10.014
1874-4907/

with the MDMA system, which shows the superiority of using the MDMA system that fulfills the 5G spectrum efficiency requirement.

This paper is organized as follows. Section 2 first gives the system model of the MDMA scheme. Section 3 describes the virtues of MDMA. Section 4 then presents the performance analysis. Computer simulations are shown in Section 5. The spectrum efficiency evaluation is then made in Section 6. Finally, conclusions are drawn in Section 7.

2. System model

Consider a discrete time uplink MDMA cellular system with N base stations (BSs), and each BS has M antennas and serves K full-loaded users simultaneously. For system operation concern, some assumptions are made as follows.

(1) The system with massive antennas at BS operates in the 30 GHz mmWave band.
(2) The BS antennas are separated by a distance far apart, tens of wavelength, such that their received signals are nearly uncorrelated. Hence, $h_{mk}[\ell]$'s are assumed to be uncorrelated for all m, k, and ℓ, which is different from the traditional phased array approach. Since the wavelength is small (which equals one centimeter at 30 GHz), massive antennas can be practicably deployed at BS.
(3) Channel bandwidth of 200 MHz is utilized in our system, which is feasible in the millimeter wave band as already studied and implemented in [6]. In addition, the BPSK signaling is adopted.
(4) Power control is executed, i.e., large-scale fading can be neglected in the received signal of each user.
(5) A user is always served by the base station that provides the largest received power level from its beacon signal.
(6) The proposed cellular system is interference limited, i.e., the additive white Gaussian noise (AWGN) compared to the user interference is relatively small.

The wideband multipath channel between the kth user and the mth BS antennas is given by $\sqrt{\alpha_k[\ell]}h_{mk}[\ell]$, where ℓ denotes the channel tap index with $\ell = 0 \ldots L-1$, $\sqrt{\alpha_k[\ell]}$ accounts for the fading amplitude with power normalization $\sum_{\ell=0}^{L-1}\alpha_k[\ell] = 1\,\forall\, k$, and $h_{mk}[\ell]$ is complex Gaussian distributed with zero mean and unit variance. Define $\mathbf{x}_k[n] = [x_k[n]\ x_k[n-1]\ \ldots\ x_k[n-(L-1)]]^T$ to be the kth user's transmit vector over L successive unit-power transmit symbols. Then the output vector $\mathbf{y} \in \mathbb{C}^{M\times 1}$ at BS can be formulated as

$$\mathbf{y}[n] = \sum_{k=1}^{K}\mathbf{M}_k\mathbf{x}_k[n] + \mathbf{w}[n] = \sum_{k=1}^{K}\widetilde{\mathbf{M}}_k\Lambda_k^{1/2}\mathbf{x}_k[n] + \mathbf{w}[n], \quad (1)$$

where $\mathbf{w}[n]$ is the total interference including white Gaussian noise and other-cell interferences, and $\mathbf{M}_k$ is given by

$$\mathbf{M}_k \triangleq \begin{bmatrix} \sqrt{\alpha_k[0]}h_{1k}[0] & \sqrt{\alpha_k[1]}h_{1k}[1] & \cdots & \sqrt{\alpha_k[L-1]}h_{1k}[L-1] \\ \sqrt{\alpha_k[0]}h_{2k}[0] & \sqrt{\alpha_k[1]}h_{2k}[1] & \cdots & \sqrt{\alpha_k[L-1]}h_{2k}[L-1] \\ \vdots & \vdots & \ddots & \vdots \\ \sqrt{\alpha_k[0]}h_{Mk}[0] & \sqrt{\alpha_k[1]}h_{Mk}[1] & \cdots & \sqrt{\alpha_k[L-1]}h_{Mk}[L-1] \end{bmatrix}$$
$$= \begin{bmatrix} h_{1k}[0] & \cdots & h_{1k}[L-1] \\ \vdots & \ddots & \vdots \\ h_{Mk}[0] & \cdots & h_{Mk}[L-1] \end{bmatrix} \begin{bmatrix} \sqrt{\alpha_k[0]} & & \\ & \ddots & \\ & & \sqrt{\alpha_k[L-1]} \end{bmatrix}$$
$$\triangleq \widetilde{\mathbf{M}}_k\Lambda_k^{1/2}. \quad (2)$$

Here we define $\mathbf{M}_k$ as the *spatial multipath channel* (SMC) of user k, which is of dimension $M \times L$.

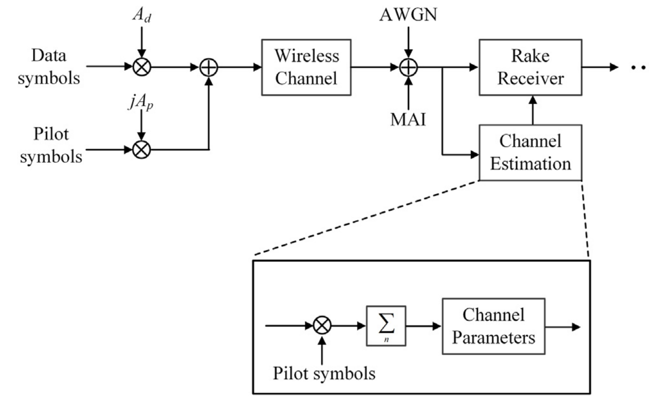

Fig. 1. The receiver block diagram at BS.

Note that all the rows in the SMC are non-orthogonal and each row acts like CDMA's spreading codes having unity spreading gain due to the wideband transmission and normalized fading power. With the help of M antennas, a processing gain of M is achieved in SIR by Rake receivers which will be proved in Section 4. Thus, the MDMA system uses SMCs of different users as the distinct features to separate its serving users in both spatial and temporal domains.

The multipath in the MDMA system is estimated at the base station side by sending pilot signals from each user as shown in Fig. 1. Note that there are M Rake receivers and M channel estimation blocks for M BS antennas. For illustration purpose, here we just plot the block diagram for one antenna; the other $M-1$ antennas are the same. In addition, the pilot symbols are quadrature multiplexed with the data symbols with amplitude scaling factors A_p and A_d such that $A_d^2 + A_p^2 = 1$. The channel parameters are extracted by matching the received signal with the user's pilot signals. The estimated channel is then sent to the Rake receiver. Finally, outputs of M Rake receivers from all M BS antennas are coherently combined to form a decision metric for data detection.

3. Virtues of MDMA

Since all users' multipaths are different due to the assumption 2 in Section 2, they can be used as the unique signatures for all users to distinguish each other in this multiple access scheme. Thus, the spatial multipath channel $\mathbf{M}_k$ defined in (2) is a key feature for each user in the MDMA system. Massive antennas with the spatial multipath channel $\mathbf{M}_k$, provide a processing gain (instead of spatial multiplexing gain) to suppress the multiple access interference and boost up the received SIR. The benefits of using the multipath together with massive antennas for multiple access are summarized below.

(1) Because the multipath channel is wideband, the radio channel power can be utilized by RAKE receivers at BS.
(2) By the Law of Large Numbers, the instantaneous channel power will approach the ensemble average of the channel power when the number of channel taps are large, which is the case for the wideband transmission.
(3) The accumulated power statistics for the first 10 largest channel paths (taps) are given in Table 1 for which we normalize the total power to unity. It is seen that the accumulated power of the top 10 largest paths occupies the 90% of total channel power. Thus, just a few dominant paths are sufficient to contain a large amount of channel powers for Rake receivers as shown in Table 1.