Spectral and energy efficiency of massive MIMO with zero forcing hybrid precoding

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Abstract-This paper investigates the achievable spectral efficiency (SE) and energy efficiency (EE) of massive MIMO for hybrid architectures using zero forcing hybrid precoding, where the base station(BS) has perfect channel state information and baseband processing is done by zero-forcing precoding. An approximated upper bound on the achievable SE for hybrid architecture is explained. Based on the analytical expression, we find that the total achievable SE increases with the number of BS antennas and the signal-to-noise ratio (SNR). Compared to full digital architecture, hybrid architectures enjoy a much higher achievable energy efficiency and spectral efficiency.

Index Terms- Spectral efficiency, hybrid architectures, massive MIMO, zero-forcing, energy efficiency.

Introduction

Massive MIMO stands for Massive Multiple-input multiple-output, where base station (BS) is equipped with large number of antennas. It provides both higher spectral efficiency (SE) and energy efficiency (EE) [7,8] . Multiple-antenna (MIMO) technology is emerging wireless communication technology and has been incorporated into wireless broadband standards like LTE and Wi-Fi. Basically, more amount of antennas at the transmitter/receiver provides the more possible signal paths and the better the performance in terms of data rate and link reliability.

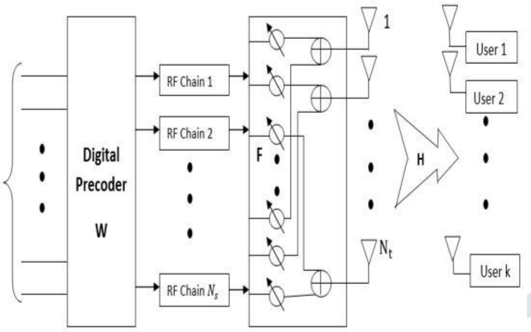
In this paper we use hybrid analog/digital precoding architectures, which uses a small number of RF chains to control the large-scale antenna array[11]. It performs digital precoding and analog processing. In full digital architecture each antenna requires dedicated RF chain which increases the cost and power consumption of the system. To overcome this problem, hybrid analog/digital precoding architecture is employed. In this technique array of antennas are connected with the single RF chain which reduces the cost and power consumption of the system.

The achievable SE and EE of multiuser massive MIMO for hybrid architecture is investigated.

- In hybrid architectures with ideal phase shifters, we derive an upper bound on the achievable SE for finite number of BS antennas. Based on the derived analytical expressions, the effects of the number of base station antennas, the SNR, the number of users are presented.
- We use power consumption model to evaluate the total achievable EE by applying the analytical result of the achievable SE.

SYSTEM MODEL

This figure represents the narrowband massive MIMO system of hybrid architecture based on phase shifters, where the BS is equipped with transmit antennas, which is connected to RF chains, and simultaneously serves K single antenna users. In this technique, we assume that the number of BS antenna is much larger than the number of users, i.e, >K and the number of RF chains equals to the number of activated users in hybrid architecture, i.e, =K.



In this paper, digital precoding and analog processing is explained. If Gaussian inputs are used, the received signal after analog processing and digital precoding, can be expressed as,

y=√ **GF** x+n, **(1)**

where P denotes the total transmitted power of the BS, **W** denotes the digital precoding matrix of K×K dimension and **F** denotes the analog processing matrix of ×K dimension. n is the additive white Gaussian noise. **G** be the K× channel matrix from the users to BS.

The channel matrix is modeled as[4],

G=H $^{1/2}$ **(2)**

where **H**∈ $^{K\times1}$contains the fast-fading coefficients, whoseentries are independent andidentically distributed i.e,complex Gaussian random variables with zero-mean and unitvariancedenoted *CN*(0, 1), and **D** is an *K*×*K* diagonal matrixwith diagonal elements given by [ ] , = . Herein, the large fading = ⁻ models both path loss and shadowing, where is the distance from the *k*th user to the BS,*γ* is the decay exponent, and is a log-normal random variable.

The analog processing matrix**F** is implemented by using analog phase shifters and magnitude of its entries should satisfies a constant modulus constraint such that

|[ ] , |^2 = 1/ which efficiently improves hardware cost and power consumption of system. Meanwhile, we assume that the anglesof the analog phase shifters can be extracted by taking theconjugate transpose of the channel matrix[ ] , [4].

The analog processing matrix **F** is designed

phase angle of the (n, k)-th element.

An equivalent downlink channel matrix becomes a composite matrix that consists practical channelmatrix and analog matrix, i.e., = **GF**. Therefore, weeasily know that the precoding matrices is equivalent to .

Spectral efficiency analysis

In this section, we first investigate the achievable SE of hybrid MIMO systems and derive an approximated upper bound on the achievable SE for hybrid architecture with ideal phase shifters. Based on the derived analytical expression, the effects of the number of BS antennas, the SNR, and the number of users are discussed. Then we perform Zero forcing precoding. In multi user MIMO system, Zero forcing precoding is able to completely cancel out inter-user interference. Therefore we use Zero forcing precoding. The baseband precoding matrix is given by

W= ( )$^{-1}$ where,

=**GF** and **Λ** denotes a normalized diagonalmatrix, i.e.,

[ ], = 1/√[ ], For the case under the above consideration, the achievable SE of the *k*-th user with ZF precoding can be given by

$$R_k = E\ \log_2\left\{\left(1+\frac{P}{[(\ \ )^{-1}]}\right)\right\} \quad \textbf{(3)}$$

Considering all the users, the total achievable SE of the hybrid architecture MIMO system in bits/s/Hz is calculated as

=Σ **(4)**

Spectral efficiency of ideal

In this section, we derive an approximated upper bound on the achievable SE. For hybrid architecture with ideal phase shifters, the upper bound on the achievable SE of each user with ZF precoding is approximated as,

phase shifters

= (5)

The upper bound on total achievable SE can be expressed as[9]

phase shifters

=K(1+ ((−1) + 1)) **(6)**

where, is the total achievable SE for all users.

Energy efficiency analysis

Energy efficiency is defined as the ratio of then total achievable SE to the total power consumption[3]. Therefore, the total achievable EE of system in bit/Joule can be established as

= **(7)**

where *B* is the available bandwidth, was defined in (6), and denotes the overall power consumption of system,In [12–13], we consider a realistic power consumption model of massive MIMO systems, which can be categorized as follows: Circuit power , signal processing power , signal transmission power , and fixed system power . Thus, the total power consumption can be computed as

P_{total}= + + + **(8)**

In the following, we give a more detailed discussion of each power consumption part.

= (K+1)+ K +K(+)+**(9)**

where denotesthepower consumption by asingle LNA,denotes the power consumption by a phase shifter, denotes the power consumption by a baseband processor,denotes the power consumption by a single ADC, andis the power consumption by a RF chain block (a mixer, a local oscillator buffer, a low pass filterand a basebandamplifier), respectively.

1) Circuit power: The circuit power of system is mainly caused by circuit dissipation. Circuit power is given as by eq(9)

2) Signal processing power: The total power consumption caused by signal processing can be expressed as,

$$=K \quad +(\quad \frac{\;_2{}^2 \quad +2}{\quad} + \frac{_2{}^3}{3} \quad)+ \frac{}{} \qquad \textbf{(10)}$$

Where, is the coding and decoding symbols powe = + .The term comes from the computation of the ZF

precoding matrix using the *LU*-based matrix inversion, *U* and *L* denote the number of coherence block per sec and the computational efficiency with *U* = 1800 and *L* = 12.8, respectively, and *T* represents the coherence time with *T* = 32 ms.

3) Signal transmission power: The power consumption ofsignal transmission process is proportional to the average transmit power of the BS, which can be computed as = *P*/*η*, where *η* denotes the efficiency of average transmit power at the BS.

4) System fixed power: The system structure leads to a stable power consumption.

The total EE of system can be calculated as

$$\eta = \frac{_2(1+ \quad - \frac{(\;-1)}{(\quad\quad +1))}}{\quad + \frac{3}{} + \frac{_2{}^2}{\eta_3} \quad + + + \frac{+_3}{}} \qquad \textbf{(11)}$$

where I1=Pcd+ PRF +PADC,

I2 = PPS +PLAN+1/L+2/LT, and

I3 = PBB+PO

Numerical result

In this section, we provide simulation results to validate the derived analytical expressions. The available bandwidth is set to *B* = 1 Hz, the number of users is set to K =8, the decay exponent is = 2.1. The coefficients of the users' large fading (k = 1 , . . . , 8) are randomly generated .PLAN = 0.02Watt; PPS = 0.03 Watt; PSW = 0.005 Watt; PFR = 0.04 Watt; PADC = 0.2 Watt; PBB = 0.2 Watt; Pcod = 4 Watt; Pdec = 0.5Watt; P0 = 2 Watt for hybrid architectures, and the efficiency of average transmit power at the BS is set to η = 0.5.

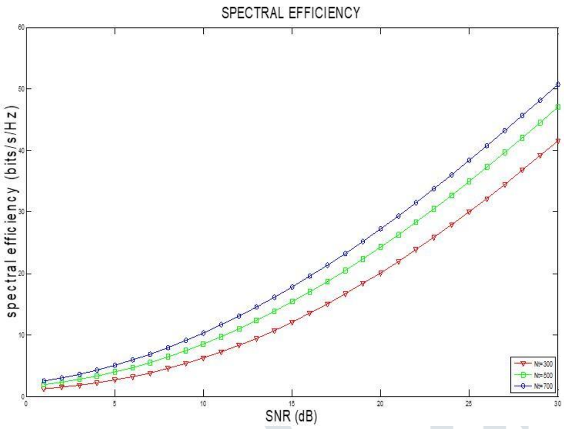


Figure 1, Simulated and approximated upper bound on the total achievable SE versus SNR for ideal phase shifters. (K=8)

The simulated total achievable SE is plotted against the average SNR for ideal phase shifters. We observe that the spectral efficiency increases with increase in number of antennas at the BS for hybrid architectures.

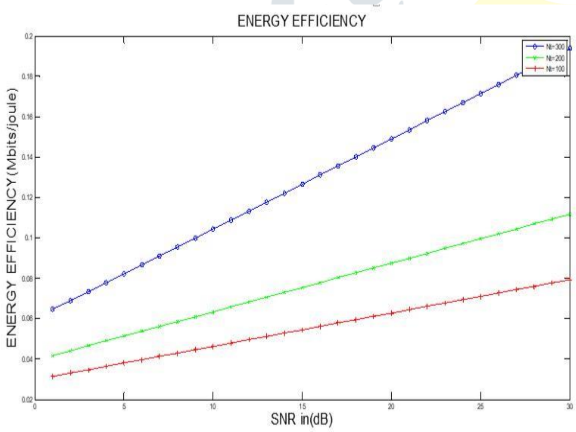


Figure 2, Simulated result for the total achievable EE versus SNR for ideal phase shifters (=128 and K=8).

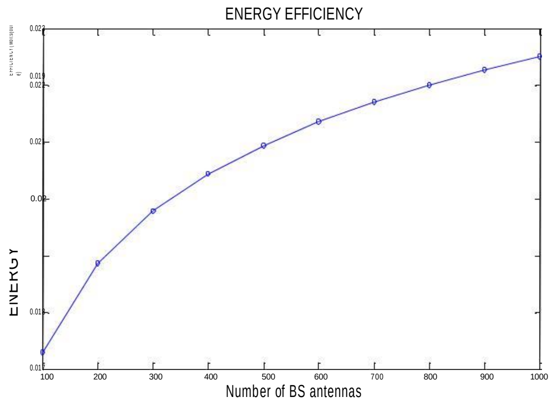


Figure 3, the total achievable EE versus the number of BS antennas for full digital architectures, ideal phase shifters (SNR=20 dB and K=8).

It can be seen that the total achievable EE is increased with increase the number of BS antennas. Hence, number of antennas to maximize the total EE, furthermore as increasing number of BS antennas, the achievable EE of Hybrid architectures always outperforms that of the full digital architecture

Conclusion

In this paper, we investigated the achievable SE and EE of massive MIMO system for hybrid architectures using zero forcing precoding.

The achievable SE and EE is increased with increase in number of antennas. Compared to full digital architecture, hybrid architectures enjoy a much higher achievable energy efficiency and spectral efficiency.

References

[1]H. Q. Ngo, E. G. Larsson, and T. L. Marzetta, "Energy and spectral effi- ciency of very large multiuser MIMO systems," *IEEE Trans. Commun.*, vol. 61, no. 4, pp. 1436–1449, Apr. 2013.

[2] Q. Bai, A. Mezghani, and J. A. Nossek, "On the optimization of ADC resolution in multi-antenna systems," *in Proc. 10th Int. Symp. Wireless Commun.* Syst. (ISWCS'13), Aug. 2013, pp. 1–5.

[3] D. W. K. Ng, E. S. Lo, R. Schober, "Energy-efficient resource allocation in OFDMA systems with large numbers of base station antennas," *IEEE Trans. Wireless*

Commun., vol. 11, no. 9, pp. 3292–3304, Sep. 2012

[4] A. Alkhateeb, O. E. Ayach, G. Leus, R. Heath, "Channel estimation and hybrid precoding for millimeter wave cellular systems," *IEEE J. Sel. Topics in Signal Proc.*, vol. 4, no. 5, pp. 831–846, July 2014.

[5] Q. Bai, A. Mezghani, and J. A. Nossek, "On the optimization of ADC resolution in multi-antenna systems," *in Proc. of the Tenth Int. Symposium on Wireless Commun. Systems (ISWCS)*, Feb. 2013, pp. 1-5.

[6] B. Hassibi and B. M. Hochwald, "How much training in needed in multiple-antenna wireless link?," *IEEE Trans. Inf. Theory*, vol. 49, no. 4, pp. 951–963, Apr. 2003.

[7] H. Q. Ngo, E. G. Larsson, and T. L. Marzetta, "Energy and spectral efficiency of very large multiuser MIMO systems," *IEEE Trans.Commun.*, vol. 61, no. 4, pp. 1436-1449, Apr. 2013.

[8] A. Hoorfar and M. Hassani, "Inequalities on the Lambert W function and hyperpower function," J. *Inequalities in Pure and Applied Math*., vol. 9, no. 2, pp. 1–5, 2008.

[9] W. Tan, S. Jin, C. K. Wen, and T. Jiang, "Spectral efficiency of multiuser millimeter wave systems under single path with uniform rectangular arrays," *EURASIP J. Wireless Comm. and Networking*, vol.181, pp. 1-13, Nov. 2017

[10] G. Auer and et al., D2.3: Energy efficiency analysis of the reference systems, areas of improvements and target breakdown. *INFSO-ICT-247733 EARTH, ver. 2.0, 2012. [Online]. Available: http://www.ict-earth.eu/*

[11] F. Sohrabi and W. Yu, "Hybrid digital and analog beamforming design for large-scale MIMO systems," *in Proc. IEEE International Conf. on Acoustics, Speech and Signal Processing (ICASSP)*, Apr. 2015

[12] J. C. Roh and B. D. Rao, "Performance analysis of multiple antenna systems with VQ-based feedback," *in Proc. Asilomar Conf. 2004, Pa- cific Grove, CA*, Nov. 2004, pp. 1978– 1982.

[13] C. Kong, C. Zhong, M. Matthaiou, and Z. Zhang, "Performance of downlink massive MIMO in Ricean fading channels with ZF precoder,"in *Proc. IEEE ICC*, Jun. 2015, pp. 1776-1782.