Low Complexity Design of Massive Access for Cellular Internet of Things

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Abstract:
To design a low complexity framework for massive access of cellular internet of things (IoT) over spatially correlated Ricean fading channels. The design is done by exploiting, a base station (BS) equipped with a large-scale antenna array and low-resolution analog-to-digital converters (ADCs) is deployed to serve a massive number of IoT devices with low-complexity successive interference cancellation (SIC) receivers. The impacts of the low complexity design on the system performance and derive closed form expressions for uplink spectral efficiencies of the cellular IoT is analyzed. Finally, simulation result shows that the uplink spectral efficiency increases as the number of base station antenna increases and intercluster interference decreases. In order to improve the spectral efficiency and to reduce complexity by mitigating intra cluster interference another detection method known as Lattice reduction is used in modification and the BER vs SNR comparison of lattice reduction and Minimum mean square error criterion is simulated.

Keywords: ADC, IoT, Intercluster interference, SIC.

I. INTRODUCTION

With the explosive growth of the internet of things (IoT), it is predicted that the number of IoT devices will reach 20.4 billion in 2020 and will eventually exceed 100 billion in the near future. In order to satisfy differential performance requirements of the IoT applications with limited wireless resources, one key point is the design of efficient multiple access schemes. Non orthogonal multiple access (NOMA), which has been recently proposed as a promising technology for addressing the challenges in 5G networks by accommodating several users within the same orthogonal resource block. The fifth-generation (5G) and even beyond 5G (B5G) wireless networks are required to support massive IoT. In order to support massive IoT over limited radio spectrum, the combination of massive multiple input multiple-output (MIMO) and non-orthogonal multiple access (NOMA) is applied to cellular IoT. On the one hand, massive MIMO can admit a large number of IoT devices by exploiting its large spatial degrees of freedom. NOMA can further increase the number of admissible IoT devices by significantly decreasing the required number of radiofrequency (RF) chains per device. A beam space based massive MIMO NOMA scheme was designed for the cellular IoT, where the devices in the same beam space were grouped in a cluster and shared both a RF chain and a transmit beam. Hence, the number of admissible devices can be much larger than the number of BS antennas. As is well known, the high implementation cost of massive MIMO caused by a large number of RF chains and ADCs is a major bottleneck for its practical applications. To fulfill the performance requirements of IoT applications, interference mitigation should be conducted at the IoT devices. In general, successive interference cancellation (SIC) is an effective way for interference mitigation in NOMA systems.

II. LITERATURE REVIEW

The Internet of Things (IoT) is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers (UIDs) and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction. The definition of the Internet of Things has evolved due to the convergence of multiple technologies, real time analytics, machine learning, commodity sensors, and embedded systems. The IoT promotes a heightened level of awareness about our world, and a platform from which to monitor the reactions to the changing conditions that said awareness exposes us to. And, like the advent of the Internet itself, the IoT enables myriad applications ranging from the micro to the macro. The main benefit of growth in the IoT is increased efficiency and lower costs. Massive IoT is an apt description of the enormous number of IoT sensors and devices that will be communicating with one another. Massive IoT refers to applications that are less latency sensitive, low4 throughput requirements; require a huge volume of low-cost, low-energy consumption.

Y. Liu, Z. Qin, M. Elkashlan, Z. Ding, A. Nallanathan, and L. Hanzo, “Nonorthogonal multiple access for 5G and beyond,” Proc. IEEE, vol. 105, no. 12, pp. 2347-2381, Dec. 2017: Non-orthogonal multiple access, which has been recently proposed for the third generation partnership projects long term evolution advanced (3GPP-LTE-A), constitutes a promising technology of addressing the aforementioned challenges in 5G networks by accommodating several users within the same orthogonal resource block. By doing so, significant bandwidth efficiency enhancement can be attained over conventional orthogonal multiple-access (OMA) techniques. The paper presents the recent literature of power-domain multiplexing-aided NOMA proposed for 5G systems has been surveyed with an emphasis on the following aspects, the basic principles of NOMA, the amalgams of multiple antenna techniques and NOMA, the interplay of NOMA and cooperative communications, and the resource control of NOMA, its coexistence with other key 5G techniques, and the implementation challenges and standardization.
X. Shao, X. Chen, C. Zhong, J. Zhao, and Z. Zhang, “A unified design of massive access for cellular internet of things,” IEEE Internet of Things J., vol. 6, no. 2, pp. 3934-3947, Apr. 2019: A three phase transmission protocol which consists of device detection and channel estimation, uplink data transmission and downlink data transmission for the cellular IoT, so as to realize massive access over limited radio spectrum is designed. Analyzed the performance of the proposed transmission protocol and derive closed form expressions for the uplink and downlink achievable rates in terms of channel conditions and system parameters. Moreover, to improve the overall performance, a length allocation algorithm by coordinating the three-phase transmission protocol in the unified sense is proposed.

Z. Ding and H. V. Poor, “Design of massive-MIMO-NOMA with limited feedback,” IEEE Signal Process. Lett., vol. 23, no. 5, pp. 629-633, May 2016: A low-feedback non-orthogonal multiple access (NOMA) scheme using massive multiple-input multiple-output (MIMO) transmission is proposed in this paper. In particular, the proposed scheme can decompose a massive-MIMO-NOMA system into multiple separated single-input single-output NOMA channels, and analytical results are developed to evaluate the performance of the proposed scheme for two scenarios, with perfect user ordering and with one-bit feedback, respectively.

J. Zhang, L. Dai, S. Sun, and Z. Wang, “On the spectral efficiency of massive MIMO systems with low-resolution ADCs,” IEEE Commun. Lett., vol. 20, no. 5, pp. 842-845, May 2016: The low-resolution analog-to-digital converter (ADC) is a promising solution to significantly reduces the power consumption of radio frequency circuits in massive multiple-input multiple-output (MIMO) systems. The uplink spectral efficiency (SE) of massive MIMO systems with low-resolution ADCs over Rician fading channels, where both perfect and imperfect channel state information are considered. By modeling the quantization noise of low-resolution ADCs as an additive quantization noise, tractable and exact approximation expressions of the uplink SE of massive MIMO with the typical maximal-ratio combining (MRC) receivers is derived. The impact of the ADC resolution, the Rician K-factor, and the number of antennas on the uplink SE is analyzed. Finally, massive MIMO can achieve a fairly good performance with only 2-bits-resolution ADCs for a small Rician K-factor.

III. NON ORTHOGONAL MULTIPLE ACCESS

Multiple access techniques can be classified into orthogonal and nonorthogonal approaches. In orthogonal multiple access (OMA), including time division multiple access (TDMA), frequency division multiple access (FDMA), and orthogonal FDMA (OFDMA), signals from different users are not overlapped with each other. Non-orthogonal schemes however allow overlapping among the signals in time or frequency by exploiting power domain, code domain or interleave pattern, often providing better performance in comparison with orthogonal schemes in terms of throughput. Orthogonal multiple access is a suitable choice for packet domain services with channel aware time and frequency scheduling. However, further improvements in the system efficiency and QoS required for the fifth generation (5G) of mobile cellular networks and IoT applications, necessitates the adoption of NOMA schemes with high throughput efficiency. NOMA can bring many benefits to cellular systems which include but not limited to the following. Effective use of spectrum and higher system throughput through exploiting the power domain and utilizing non orthogonal multiplexing. Robust performance gain in high mobility scenarios, where orthogonal multiple access schemes obtains no frequency-domain scheduling gain as channel state information is outdate, but NOMA provide gains in high mobility scenarios as it relies on the channel state information at the receiver side. NOMA is compatible with OFDMA and its variants and can be applied on top of OFDMA for downlink and SCFDMA for uplink. NOMA can be combined with beam forming and multi antenna technologies to improve the system performance. NOMA can be easily combined with radio resource management and random-access techniques to solve the collision and overload problem in M2M communications. Using clustering and group-based scheduling, NOMA can be used in M2M communications as the multiple access technique to deliver messages of a group of devices to the base station or the cluster head. NOMA techniques can broadly be divided into two major categories, i.e., power-domain NOMA and code-domain NOMA. In Power domain NOMA multiplexing based on different power levels and in Code domain NOMA achieves multiplexing based on different codes. NOMA uses superposition coding at the transmitter end. The different power levels have been assigned to users. NOMA uses SIC (Successive interference cancellation) technique to retrieve data of both the users. The Key ideas of NOMA is that all the users are served at the same time, frequency and code. Users with better channel conditions get less power and Successive interference cancellation is used at the receivers.

IV. SYSTEM MODEL

A cellular IoT network operated in time division duplex (TDD) mode, where a base station (BS) equipped with N_r antennas communicate with K single-antenna devices is considered. To strike a balance between system performance and implementation complexity, the devices are partitioned into multiple clusters according to their position information. Without loss of generality, there are I clusters and the jth cluster contains N_d devices. h_k,l_j denote the N_d dimensional channel vector from the BS to the nth device in the jth cluster. Due to the random distribution of IoT devices, there may exist both line-of-sight (LoS) and non-line-of-sight (NLoS) during the signal propagation between the BS and the IoT devices. Hence, the channel vector H can be modeled as $H = h_{k,l_j} + h_{k,l_j}$. Channel is Rician Fading Channel. The mean
\( \bar{h}_{k,i,j} \) is the LoS component. The channel gain LOS component is given by the equation \( \text{LOS} = \frac{x_{ij}}{\sqrt{K_{ij} + 1}} \) (1).

With K denoting the Rician factor, \( \bar{h}_{k,i,j} \), represents the complex Gaussian distributed NLOS component with zero mean and correlation matrix. Therefore, the channel gain NLOS is given by

\[ \text{NLOS} = \frac{1}{\sqrt{K_{ij} + 1}} \text{diag}(K_{ij}) \] …… (2.2)

\[ \text{Hmean} (K_{ij}) = \frac{x_{ij}}{\sqrt{K_{ij} + 1}} \text{diag}(K_{ij}) \] * \[ \| \text{Hmean} (K_{ij}) \| \] …… (2)

\[ \text{Hhat} (K_{ij}) = \frac{1}{\sqrt{K_{ij} + 1}} \text{diag}(K_{ij}) \] * \[ \| \text{Hmean} (K_{ij}) \| \] …… (3)

\[ R_{k,i,j} = \frac{1}{\sqrt{K_{ij} + 1}} \text{diag}(K_{ij}) \] * \[ \| \text{Rmean} (K_{ij}) \| \] …… (4)

where \( R_{k,i,j} \) represents the transmit correlation coefficient of the jth device in the ith cluster in the case of NLOS.

For the transmission protocol of a TDD-based cellular IoT network, a typical data frame of length \( \tau \) consists of three phases, including channel estimation of length \( \tau_p \), uplink data transmission of length \( \tau_u \).

### Channel Estimation for Massive Access Of Cellular Internet of Things:

At the beginning of a data frame, the devices send pilot sequences over the uplink channels simultaneously for channel estimation at the BS. For effectively decreasing the overhead in the context of massive access, the devices in a cluster share the same pilot sequence, while pilot sequences across the clusters are orthogonal of each other. Then, the received signal across \( \tau_p \) symbols at the BS can be expressed as,

\[ Y_{k,i} = Y_{k,u}^+ + \sqrt{Q_{k,i}} S_{k,i} \text{diag}(h_{k,i}) n \] …….. (5)

where \( Q_{k,i}^+ \) represents the transmit power of pilot sequence from the jth device in the ith cluster,

\[ Q_{k,i} = \frac{P_{k,i}}{N_0} \] …….. (6)

\( n \) is an \( N \times \tau_p \) additive white Gaussian noise (AWGN) matrix with unit variance entries, \( h_{k,i} \) are the device and cell index, \( h_{k,i} \) is the uplink signal.

The BS in 5G cellular IoT networks is usually equipped with a large-scale antenna array for improving the spectral efficiency. Yet, it also leads to a high implementation cost, especially in the process of ADC. In order to reduce the cost, the BS usually adopts low-resolution ADCs, and the corresponding baseband received signal can be written as,

\[ Y_{k,i} = Y_{k,u}^+ + \sqrt{Q_{k,i}} S_{k,i} \text{diag}(h_{k,i}) n + \frac{n_0^2}{\sqrt{2}} \] …….. (7)

where \( \delta \) denotes the accuracy of the ADC which can be approximated as \( (1 - \frac{\sqrt{\pi}}{2} \left| 2^{-2b} \right| \) with b being the number of quantization bits and \( n_0^2 \) represents the additive Gaussian quantization noise (AGQN). In general, ADC is used to convert the received analog signal to a digital signal through quantization. According to the characteristics of ADC, the impacts of signal quantization are two-fold. Firstly, the amplitude of the quantized signal attenuates by a factor of \( \delta \). Secondly, there exists a quantization noise with variance \( (1 - \delta) \) multiplying the variance of the input signal. The coefficient \( \delta \) is the accuracy of ADC, which can be approximated as \( (1 - \frac{\sqrt{\pi}}{2} \left| 2^{-2b} \right| \). Hence, the number of quantization bits determines the accuracy of ADC. For instance, if the number of quantization bits is sufficiently large, \( \delta \) approaches 1 and there are no quantization losses and noise. Since the number of quantization bits determines the cost of ADC, practical systems prefer the use of low-resolution ADCs with a few numbers of quantization bits, especially for massive MIMO systems equipped with multiple ADCs.

### Uplink Data Transmission:

During the phase of uplink data transmission, the devices send their data symbols over the uplink channels simultaneously. Then, the received signal \( y_{k,i} \) at the BS can be expressed as

\[ Y_{k,i} = Y_{k,u}^+ + \sqrt{Q_{k,i}} S_{k,i} \text{diag}(h_{k,i}) n \] …….. (8)

where \( Q_{k,i}^+ \) is the uplink data transmit power, \( S_{k,i} \) is the uplink signal, \( h_{k,i} \) and \( n \) are the device and cell index, \( h_{k,i} \) is the channel vector, \( n \) is the AWGN with unit variance.

Similarly, due to low-resolution ADCs at the BS, the baseband received signal is transformed as

\[ y_{k,i} = Y_{k,u}^+ + \sqrt{Q_{k,i}} S_{k,i} \text{diag}(h_{k,i}) n + n_0^2 \] …….. (9)

To achieve a balance between system performance and computation complexity, the BS adopts the maximum ratio combination (MRC) method to decrease the inter-cluster interference.

### Uplink Spectral Efficiency:

The performance of cellular IoT in terms of spectral efficiency, and reveal the impacts of low-cost design, low complexity is analyzed.

The analysis of the spectral efficiency for the kth device in the jth cluster during the uplink data transmission, which can be computed as

\[ SE = \frac{\tau_p}{\tau} \text{E}[\log_2(1 + SINR^H_{j,k})] \] …….. (10)

Where \( SINR^H_{j,k} \) is the received Signal to interference noise ratio.

\[ SINR^H_{j,k} = \frac{p_{j,k} |v_j^H |^2}{\sum_{l=1}^L \sum_{i=1}^N |v_i^H |^2 + \sum_{l=1}^L |v_i^H |^2 + \sum_{l=1}^L |v_i^H |^2} \] …….. (11)

Where \( p_{j,k} \) represents the transmit power, \( C_i^j \) is the correlation matrix, \( L \) is the no of cells, \( M \) is the number of antennas, \( K \) is the user equipment, \( \sigma \) represents the standard deviation. The inter-cluster interference asymptotically tends to zero as the number of BS antennas increases. Therefore, it is necessary to mitigate the intra-cluster interference for further improving the spectral efficiency. Moreover, it is seen that the sum of spectral efficiency improves as K-factor increases. With spectral efficiency, it usually mean the sum of spectral efficiency of the transmissions in a cell of a cellular network. It is measured in bit/s/Hz. This is because as K-factor increases, the LoS component is dominant, and the BS may obtain accurate CSI.

### V. LATTICE REDUCTION

Due to the high throughput requirement in the fifth generation (5G) communication system, massive MIMO system was proposed. Compared to the traditional MIMO system, the base station of a massive MIMO system must be equipped with up to hundreds of antennas, leading to many challenges such as power consumption of the RF chains and decoding complexity of the massive MIMO detector. Traditional MIMO detectors can be divided into linear and nonlinear detectors. Zero-forcing (ZF) and minimum mean-square error (MMSE) detectors are typical linear detectors. The sphere decoder, K-
best detector and many variant non-linear tree-searching detectors were proposed to achieve optimal performance under the low-cost and high-throughput constraints. However, their complexity is still very high when being applied to the large-scale MIMO system with up to hundreds of antennas. Lattice reduction (LR) is a useful MIMO pre-processing technique to achieve full diversity gain performance for MIMO detection and it can also help the MIMO detector to reduce detection complexity. Recently, lattice reduction (LR)-aided detection methods have emerged as an efficient solution to the MIMO symbol-detection problem. LR-aided linear and successive interference cancellation (SIC) detectors provide the same diversity order as the ML detector, by transforming the system model with near-orthogonal channel matrices. Lattice reduction (LR) is a powerful technique that can obtain better conditioned channel matrix by factorizing the channel matrix into the product of well-conditioned matrix and a unimodular matrix. Thus, the motive behind applying LR algorithm is to obtain a channel matrix with shorter and more orthogonal basis. By applying lattice reduction with linear precoding schemes leads to tremendous improvement in the system performance. Lattices are used to develop powerful source and channel codes for many communications applications, specifically in scenarios with multiple terminals or with side-information. MMSE and LR are the two detectors used in receiver and the result of two detectors are compared. Lattice reduction (LR) reduces complexity while achieving the same diversity as that of other detection methods. Lattice reduction (LR) is a technique for multiple-input multiple-output (MIMO) symbol detection to achieve better bit error-rate (BER) performance. In detection part MMSE and LR are used to detect and the Bit error arte are compared. As SNR increases BER is decreasing in LR when compared with MMSE.

VI. RESULTS

Extensive simulations to verify the effectiveness of the low complexity design on the system spectral efficiency is conducted. Simulation parameters are K=48; Number of single antenna devices, M = 16, Number of Clusters; d2Lambda = 0.5; Nm = 3, Number of devices for m-th cluster; Mrange = 16:16:144, Range of Base Station antennas; Mmax = max (Mrange); Maximum number of base station antennas, tauP = 15; channel estimation of length , tauU = 50; uplink data transmission length, $Q_{ij}^U$ = 10; Transmit Power of pilot sequence, delta = 0.9; Accuracy of ADC, K = 5; Rician Factor, nbr Of Realizations = 50; number of channel realizations, B = 20e6; Communication bandwidth, p = 0.1, uplink pilot power; noiseFigure = 7, noise power = -174 + $10\log_{10}(B) + \text{noiseFigure}$; tau_c = 200; tau_p = Nm; Pilot Length

Spectral efficiency: It is the rate of information that can be transmitted over a particular bandwidth. The unit of spectral efficiency is bit/s/Hz. In the case of a communication channel or data link spectral efficiency is the net bit rate which is the useful information rate excluding error-correcting codes or it is the maximum throughput divided by the bandwidth in hertz. The spectral efficiency can be measured in terms of bit/symbol which is same as bits per channel use. It implies that bit rate can be divided by symbol rate. For massive MIMO spectral efficiency is the total sum of it throughout transmission in a network of cells. It is related to through put of the cell. When spectral efficiency increases cell through put also increases. In order to improve spectral efficiency many server users should serve in the cell with same bandwidth.

From Figure 3 it is seen that the theoretical lower bounds are tight in the whole SNR region. From Figure 4 it is seen that the sum of spectral efficiency improves as the number of BS antennas increases in uplink. As the spectral efficiency improves inter cluster interference reduces.
The sum of spectral efficiency improves as the number of BS antennas increases in uplink. Thus, it is possible to solve the problem of performance saturation at high SNR by employing more BS antennas. Moreover, it is seen that the sum of spectral efficiency improves as K-factor increases. This is because as K-factor increases, the LoS component is dominant, and the BS may obtain accurate CSI. However, for the uplink transmission, the sum of spectral efficiency improves substantially as the ADC accuracy increases. This is because the ADC accuracy not only determines the CSI accuracy, but also affects the signal quality. Figure 5 shows the comparison between the Bit error rate vs average SNR of MMSE and Lattice reduction.

VII. CONCLUSION

Non orthogonal multiple access (NOMA), which has been recently proposed as a promising technology for addressing the challenges in 5G networks by accommodating several users within the same orthogonal resource block. NOMA offers high throughput efficiency with simple system structure, which is particularly beneficial for massive IoT applications with low-cost, low-power, and low-complexity devices, and can provide system scalability to support the massive number of devices involved in IoT communication. This technology can be easily adopted by 3GPP technologies to further boost the system performance of current cellular solutions for IoT. NOMA with SIC is an optimal multiple access scheme in terms of the achievable multiuser capacity region in both uplink and downlink. The low-resolution analog-to-digital convertor (ADC) is a promising solution to significantly reduces the power consumption of radio frequency circuits in massive multiple-input multiple-output (MIMO) systems. It is found that the sum of spectral efficiency improves as the number of BS increases in uplink. The uplink spectral efficiency (SE) of massive MIMO systems with low-resolution ADCs over Rician fading channels is considered. By modeling the quantization noise of low-resolution ADCs as an additive quantization noise, expressions of the uplink SE of massive MIMO is derived and simulated using MATLAB. In the modification part the lattice reduction and mmse technique is compared with different parameters.

VIII. REFERENCES


