Spatial Filtering in Massive MIMO Cellular Networks

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Abstract -Machine-type communication (MTC) is one of the most important enabling technologies for the emerging Internet of Things (IoT). However, the potential massive access will significantly degrade the access performance of MTC. To meet the massive access requirement of MTC, we propose a spatial filtering based random access (SFRA) scheme in massive MIMO cellular networks. Specifically, the angle of arrival (AOA) information provided by massive MIMO is utilized to distinguish collided MTC devices (MTDs). To improve the preamble utilization as possible, we further propose a novel preamble reuse scheme to eliminate the influence of multipath angular spread on preamble detection at the base station (BS). Theoretical analysis and simulation results both show that the proposed SFRA scheme can efficiently reuse preambles and considerably improve the access capacity. In typical urban environments, preambles can be perfectly reused for 9 times at most. Moreover, the average access delay of SFRA is only about one seventh of that of the conventional random-access scheme when 10000 MTDs attempt to access the network simultaneously.

Keywords Random access, machine-type communication, massive MIMO, spatial filtering, preamble reuse.

I. INTRODUCTION

A wide range of applications such as e-health, consumer electronics, autonomous vehicles, and smart grids are supported by machine-type communication (MTC), which plays an important role in Internet of Things (IoT). Specifically, Cisco estimates that there will be 14.7 billion MTC devices (MTDs) in future networks by 2023. Compared with human-type communication (HTC), one of the most significant features of MTC is the massive number of access requests. According to the study from 3GPP, the number of MTDs in a single cell ranges from 1000 to 30000, which will bring massive concurrent access requests. To meet the massive access requirement of MTC, the ubiquitous cellular networks (e.g., LTE, LTE-A and 5G) are often employed to implement the access of MTDs. However, the conventional cellular networks are designed to support HTC, where a small number of HTC devices (HTDs) access the network simultaneously, and each device performs a random access (RA) procedure for initial uplink access to establish the connection with the base station (BS) before data transmission. In the RA procedure, if more than one device chooses the same preamble and attempts to access simultaneously, preambles of these devices will collide, and their RA procedures will fail. When massive MTDs perform the same RA procedure as HTDs to access the network, there will be severe preamble collisions in physical random-access channel (PRACH) due to the limited number of preambles for RA procedure. Severe preamble collisions significantly degrade the access performance of HTDs and MTDs.

II. SYSTEM MODEL

FIG shows a single-cell massive MIMO system, in which a BS equipped with D antennas serves N single-antenna devices (MTDs or HTDs). We assume that there are NP A available preambles in the access preamble set P = {p1, p2, · · · , pNP A } for RA in the PRACH. Among these preambles, a subset PM = {p1, p2, · · · , pNP } is reserved for MTC, and the other preamble subset PH = {pNP +1, pNP +2, · · · , pNP A } is used for HTC, where NP is the number of available preambles for MTC. In this work, only MTDs are considered. Fig.4.1. Illustration of a single-cell massive MIMO system. If the u-th MTD is active, it will transmit a preamble piu randomly chosen from PM with an equal probability in the PRACH.

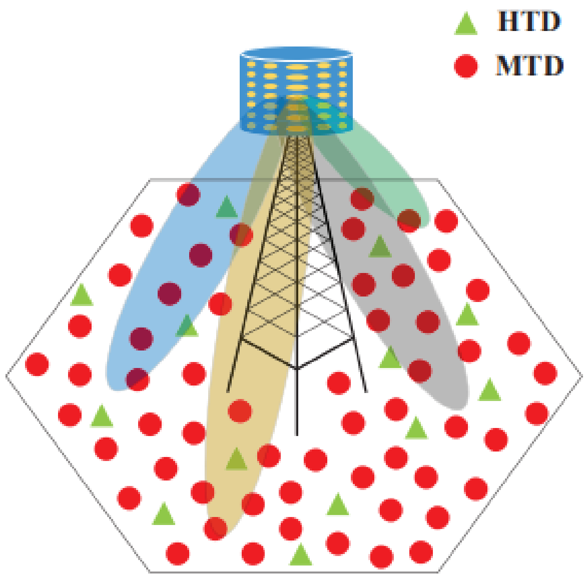

Fig. Illustration of a single-cell massive MIMO system.

III. PREVIOUS WORK

Machine-type communication (MTC) is one of the most important enabling technologies for the emerging Internet of Things (IoT). However, the potential massive access will significantly degrade the access performance of MTC. Tomeet the massive access requirement of MTC, we propose a spatial filtering based random access (SFRA) scheme in massive MIMO cellular networks. Specifically, the angle of arrival (AOA) information provided by massive MIMO is utilized to distinguish collided MTC devices (MTDs). To improve the preamble utilization as possible, we further propose a novel preamble reuse scheme to eliminate the influence of multipath angular spread on preamble detection at the base station (BS). Theoretical analysis and simulation results both show that the proposed SFRA scheme can efficiently reuse preambles and considerably improve the access capacity.

IV. PROPOSED METHODOLOGY

The main method in the proposed system is spatial filtering based random access scheme. It uses the following technics

1) Spatial Filtering Based Sectors Partition of a Cell

- This is the technic used to get the angular range of Angle of Arrival (AOA) from the signal.
- A beam forming matrix is used to detect the AoA.
- A cell division is performed then.
- We assume that the approximated beam patterns of these beamforming vectors have non-overlapping main-lobes designed to cover the full angular range. With NQ beamforming vectors, a cell can be divided into NQ sectors equally.

2) Preamble Reuse Scheme

- Sectors in a cell are independent in space, and it is easy to see that preamble in the subset for MTC can be reused among different sectors.
- At the BS, the beamforming vector wi is used to filter preamble signals whose AOAs are located in the AOA range of Si.
- The preamble reuse scheme that can avoid the false alarm of preambles in neighbour sectors is desired.

3) **Spatial Filtering Based Random Access Procedure**

- Utilizing the above-mentioned preamble reuse scheme, the conventional RA scheme can be modified into an efficient SFRA scheme.
- The main steps involved in spatial filtering are Preamble Transmission, Random Access Response Transmission, Radio Resource Control Connection, and Contention Resolution Message Transmission

V. SIMULATION/EXPERIMENTAL RESULTS

We evaluate the performance of SFRA with simulation experiments and compare the simulation results with the theoretical analysis results. The conventional RA scheme which is often used as the comparison benchmark in many works and the non-orthogonal RA (NORA) in are also simulated to make a comparison with the proposed scheme. In the simulation, we consider two different MTD position models to evaluate the access performance at MAC layer: uniform position model and cluster position model in which MTDs are concentrated on several spots. For SFRA, the preamble set reserved for MTC is divided into two parts: Podd and Peven, one for “odd” sectors and the other for “even” sectors. We consider the angular spread in urban environments, whose typical range of root mean square (RMS) is about 3 0 ∼ 200. The Simulation parameters are shown in Tabel

TABLE I
Simulation Parameters

Parameters	Value/Assumption
Number of MTDs (U)	2000∼100000
Number of preambles (N_P)	20
Number of beamforming vectors (N_Q)	12,18
Packet arrival rate (λ)	0.5/s
RA slot period (T_s)	5ms
Backoff indictor (T_{wait})	20ms
RAR window size (T_{RAR})	5ms
Maximum retransmission times (L)	5
Cell radius (R)	500m
RMS of the delay spread (t_{rms})	0.3us
Preamble detection threshold factor (β)	15
Length of preamble sequence (N_{ZC})	839
Channel model	multipath channel [20]
Number of detectable paths (N_b)	10
Maximum transmission power	23dBm
Front-to-back ratio, FBR (η)	0∼30dB

VI. CONCLUSION

In this paper, we proposed a spatial filtering-based RA scheme (SFRA) to meet the massive access requirement of MTC in massive MIMO cellular networks with a limited number of preambles. The key idea of our proposed SFRA scheme lies in combining the AOA information and the preamble index to improve the preamble utilization as possible in the cell with multipath angular spread. Through theoretical analysis and simulations, it is shown that the proposed SFRA scheme can achieve much better performance than NORA and the conventional RA scheme. Specifically, in typical urban environments, preambles can be perfectly reused for 9 times. Under an access success probability requirement of 99%, the access capacity provided by the proposed SFRA is much greater than that of NORA and the conventional RA scheme, and the average access delay of the proposed SFRA scheme is much less than that of these two schemes. Moreover, the proposed SFRA scheme can also combine with TA-assisted RA schemes to further improve the access performance in massive MIMO cellular networks. In the future works, the efficient SFRA scheme under high-speed mobility scenario, and the combination of ACB scheme and SFRA can be considered.

VII. FUTURE SCOPES

To improve the preamble utilization as possible, we further propose a novel preamble reuse scheme to eliminate the influence of multipath angular spread on preamble detection at the base station (BS).

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