VMIMO scheme for Machine-to-Machine on Cellular Network

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Abstract
Machine-to-Machine (M2M) involves communication through a wire or wireless network without human intervention. M2M on Cellular network, also defined as Machine Type Communications (MTC) by 3rd Generation Partnership Project (3GPP), has shown great potential in the industry for its long distance wireless advantage. Different from the traditional human to human (H2H) communications, M2M communications involve a large number of terminals and network congestion may occur due to simultaneous signaling or data messages from MTC devices. In this paper, we overview the latest MTC optimization categories of 3GPP and highlight those anti-congestion solutions. Then we add a virtual MIMO (VMIMO) scheme to alleviate MTC network congestion. The simulation of VMIMO for MTC shows the effectiveness of this scheme.

Keywords: *Machine-to-Machine; Machine Type Communications; virtual MIMO; anti-congestion.*

1. Introduction

Machine to Machine (M2M) communication is seen as a form of data communication between entities that do not necessarily need human interaction. M2M communications indicated the potential for machine-type communications over mobile networks. However, wireless sensor networks or ad-hoc type networks in combination with fixed network communications are also a contender for the implementation of such applications. Since 3GPP type networks (GSM/UMTS/LTE/LTE-A etc.) are dominant in the world with ubiquitous coverage, we mainly focus on the M2M functions and architectures specified by 3GPP. In the scope of 3GPP, M2M is also referred as Machine Type Communications (MTC).

3GPP has defined general MTC Features (Low Mobility, Time Controlled, Time Tolerant, Small Data Transmissions, etc.) and typical user cases [1]. Among these user cases, network congestion by MTC applications is a big challenge. Regarding the nature of the traffics and the cause of congestion, we can mainly distinguish two classes: Congestion in the user plane and in the control plane.

Congestion in the user plane is caused by the amount of data sent and received by devices. Although it happens rarely since devices send and receive small amounts of data, it may frequently happen that a lot devices send their data at the same time leading to a congestion mainly in the EPC part.

Congestion in the control plane occurs when the devices continuously generate signaling traffic to attach to the network and it can be invoked in all the network nodes especially in MME. Even if the MTC devices send small amounts of data, they generate normal amounts of signaling as common UEs.

This paper describes the general anti-congestion solutions of 3GPP and proposes a Virtual MIMO way to this congestion issue. The related work is presented in section 2. The main solutions from 3GPP are analyzed in section3. Section 4 shows our VMIMO scheme. Simulation results are shown in Section 5 and further study is discussed in Section 6.

2. Related work

At early stage, M2M applications on cellular networks were developed based only on SMS[2], and it can only implement very limited communications without network congestions headache. As the evolution of network, MTC congestion becomes a primary issue with the big numbers of MTC devices traffic. So far, 3GPP has launched many technical reports to MTC till Release-12 and we will elaborate its progress for anti-congestion solutions in section 3.

Apart from the progress from 3GPP, few publications have been witnessed strictly on 3GPP-defined MTC congestion. In [3], Group based traffic management is presented by selecting the group leader to accumulate all the uplink traffics from its group members and delivered. However, the group is made by, not the cellular network itself, but Bluetooth technology for communications between the group members. In [4][5], MTC devices are grouped into clusters based on QoS characteristics and requirements. Network can manage radio resources on a cluster basis instead of an individual MTC device basis, which alleviates the overloads, although this QOS-based group solution is focused on LTE-A stage. In [6], scheduling scheme is used to delay-tolerance MTC traffic at the expense of the handover bandwidth reserved resource. It can enhance the utility usage of radio resource to reduce the congestion probability. In [7,8] ,some anti-congestion solutions are given in cellular network but it is not dedicated to MTC scenario.

3. Congestion solutions by 3GPP

Undoubtedly, 3GPP plays the most important role in MTC standards aspects. 3GPP starts the M2M study on Release-8 to facilitate M2M communications in GSM/UMTS[9], and they continue to Release-12. In the latest version TR 23.888[10], 3GPP has reported up to 54 solutions to improve the MTC efficiency. The 11 solutions relating to the congestion leverage are concluded in Table 1. More details of these solutions are given in [10]. The column " **Impact network nodes** " in Table 1 is inclusive all the 2G/3G/4G network nodes except Terminals(UE or MTC device).

3GPP highlights the problem of congestion in the Core Network and gives some directions that aim to solve it. However, those solutions are a general view of what could be the directions, not a detailed approaches and no result regarding their impact on reducing congestion is given [14]. In the next section, we will propose a new anti-congestion scheme yet not considered by 3GPP.

4. Virtual MIMO for MTC

Virtual MIMO (VMIMO) is not a new concept. The VMIMO solution has been well proved in current H2H communications. The realization of Uplink (UL) MIMO is limited by the practical issue of the implementation of multiple power amplifiers in the UE, especially in the hand-set. The UL user throughput is also limited by the channel bandwidth. To mitigate these limitations, in [11], UL VMIMO is proposed to allow two individual UEs, each with single transmit antenna, to transmit independently onto the same sub-channel. By exploitation of the best UE pair with scheduling, the multi-user diversity can be explored in group with VMIMO. The key issue for VMIMO is

Table 1 Anti-congestion solutions of 3GPP

No.	Anti-congestion solutions	Impact network nodes
1	Network access control by the PLMN	HLR/HSS ,SGSN/MME
2	Optimizing periodic LAU/RAU/TAU Signalling	HLR/HSS ,SGSN/MME RAN MSC/VLR
3	Randomized triggering of time-controlled MTC operations	MTC Server
4	Rejecting connection requests by the SGSN/MME	SGSN/MME, SGW, GGSN / PGW, HSS/HLR, PCC
5	Low Priority Access Indication	SGSN/MME/GGSN/P-GW
6	RRC Connection and Channel Requests by the eNodeB/RNC/BSS	RAN MME/SGSN
7	Access Control by RAN	SGSN/MME, SGW, GGSN / PGW, HSS/HLR, RAN
8	MME/SGSN overload control by DL MTC traffic throttling	SGSN/MME
9	Rejecting connection requests at partial signaling links	SGSN/MME
10	Rejecting connection requests based on request types	SGSN/MME, SGW, GGSN / PGW,
11	Overload control within an MTC access grant time interval	SGSN/MME

pairing algorithm, which has been deeply studied for H2H communications [12,13,15,16].

Although 3GPP has not defined VMIMO for MTC so far, this scheme seems very prospective in MTC with low-mobility UEs.

Assume that the numbers of UEs is N_u, and each UE is equipped with single transmit antenna. The number of receiver is N_r. Then at the receiver, the receiver signals in frequency domain can be written as

$$Y = HS + n_0 \quad (1)$$

where Y is a $N_r \times 1$ vector representing the received signals , S is a $N_u \times 1$ vector representing the transmitted signals, H is a $N_r \times N_u$ channel matrix, n_0 is a $N_r \times 1$ noise vector representing the normalized

complex Additive White Gaussian Noise (AWGN)vector with zero means.
Minimum mean square error (MMSE) detection is utilized at the receiver side. Under the MMSE receiver, the signal can be calculated as

$$\hat{S} = (H^H H + \sigma_n^2 I_n)^{-1} H^H Y \quad (2)$$

Where H^H is conjugate transpose of the channel matrix H, σ_n^2 is the variance of the noise, I_n is $N_u \times N_u$ identity matrix, and $\hat{S}$ represents the $N_u \times 1$ calculated signal.
We herein propose one Channel correlation minimization algorithm for MTC VMIMO scenario: Orthogonality Defect Pairing Scheduling (ODPS). Orthogonality defect is an effective parameter to evaluate the orthogonality of the basis in a matrix [15]. The orthogonality defect of a VMIMO channel matrix H is defined as

$$d(H) = \frac{\prod_{i=1}^{n} \|h_i\|}{|\det(H)|} \quad (3)$$

It can be proved by Hadamard inequality that $d(H) \geq 1$, with equality obtained if all the vectors are orthogonal to each other[16]. So the pairing criteria of ODPS is to pick up the second user that can minimize the orthogonality defect of VMIMO channel matrix with the primary UE user, i.e.

$$the\_2nd\_user = \arg\min d(H) \quad (4)$$

5. Simulation Results

We make the MTC VMIMO simulation result with the main parameters in Table 2 and compare the individual throughput between VMIMO and SIMO. The simulations are performed for VMIMO and SIMO uplink systems both containing 30 UEs. The small scale fading is modeled as Rayleigh flat fading. Assume that all the UEs are fixed, which is very typical in MTC scenario.

Table 2 Simulation Parameters Value

Parameters	Value
Antenna configuration	1T2R
UE traffic	Full Buffer
Noise Density	-174dBm/Hz
Path loss	128.1+37.6log(R), R in *Km*
Scheduler	Round-Robin
Target BLER	10%
Receiver type	MMSE
Snapshot number	1000

In order to simulate the scenario that different UE locates in the position of different distance from the BS and experiences heterogeneous environment in a feasible way, each UE is set a given SNR value ranging from 0dB to 30dB , all different from each other. From Fig 1, the unequal average received SNRs of different UEs in VMIMO system range from 0 (user 1) to 30 dB(user 30). And the user throughput is respectively calculated by VMIMO and SIMO modes.

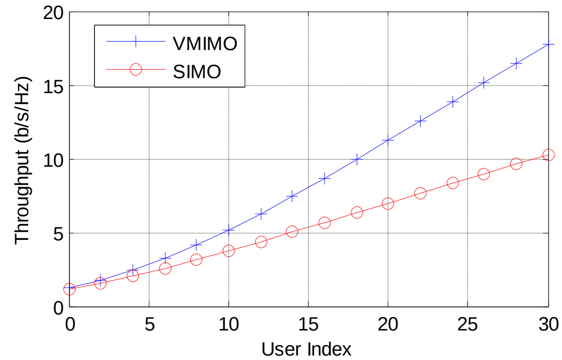

Fig. 1 Throughput by VMIMO and SIMO

It is clearly observed that VMIMO Throughput is better than SIMO. Although to the low SNR user, the gap is not so big. To the high SNR user, the throughput gap between VMIMO and SIMO is obvious. i.e. VMIMO performs better in good transmission conditions.

6. Discussions

We analyze VMIMO would be more suitable to tackle the MTC devices than H2H by three following reasons:

A. UL is the main traffic direction for MTC

Most MTC applications are reporters. They can sensor the circumstance and surroundings and give the report to the MTC server. MTC devices are power-limited machines with simple control function, so the control data from Downlink(DL) is relatively low(e.g. Industrial metering and Surveillance systems). It is totally different to cellphone users, who often download data from servers, leading to high DL traffic.

B. VMIMO for MTC is easier to pair than H2H

Effective pairing is the key point of VMIMO. It is very difficult to pair two nomadic cellphone users. Even cellphone is stable, the slight motion of cellphone antenna will penalty the pairing function. However, MTC device is in low mobility, and always deployed in certain group with similar UL links. Therefore, it is easy to pair up within the same group.

C. MIMO is not suitable for MTC

MTC device is in small data transmission generally and no need MIMO to improve its throughput capacity. MTC device cannot afford enough power for long time MIMO pair computing. Even two antennas are big burdens to some MTC devices.

While the proposed VMIMO for MTC is just a start and need for further study, it is suggested that MTC should apply the simple pairing algorithm for MTC devices' poor power and computing capacity. It would be better if the algorithm is pre-defined and rarely re-configured. Moreover, it can get more benefits for big UL traffic applications such as video surveillance.

7. Conclusions

The VMIMO scheme is well defined in H2H Communication, and we propose it to MTC scenario. To the VMIMO solution for MTC, the pairing algorithm shall be simple and pre-defined in the given MTC group. For the non-moving case, like remote metering, the pre-defined MTC pair can use the same UL channel to transmit the data by VMIMO, thus the total traffic can be reduced dramatically when all the MTC group members are paired up. Compared with other anti-congestion solutions, this VMIMO optimization is very effective.

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