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Packet size adjustment for minimizing the average delay in buffer-aided cognitive machine-to-machine networks☆,☆☆

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ABSTRACT

In this paper, a cognitive machine-to-machine (CM2M) network is considered in which underlaid on a macro cell, there exist some co-existing small cell based M2M networks. In each small cell, M2M network is comprised of some machine type devices (MTDs) and an MTD gateway. The MTD gateway collects data of MTDs within each small cell and transmits it to the small cell base station reusing the spectrum of the macro cell. To avoid data loss, MTD gateway is equipped with a buffer. In the considered CM2M network, MTDs with delay sensitive application are prioritized over MTDs having delay tolerant packets. In order to minimize the average delay of the MTDs, a novel packet adjustment scheme is proposed. The average delay and the average throughput of the CM2M network are computed. Simulation results show that the proposed scheme outperforms conventional policy without packet adjustment in terms of average delay of MTDs.

1. Introduction

Recently machine-to-machine (M2M) communications have attracted much attention in the literature and the number of machine-type devices (MTDs) are predicted to be in billions by 2020 [1–3]. In M2M systems, different types of MTDs including actuators, sensors, and smart meters are connected wirelessly via the reliable links. Generally speaking, MTDs transmit short data packets with low data rate compared to the conventional cellular communication. To deal with this inherent characteristics of MTDs, capillary architecture has been recently proposed, in which data of MTDs is transmitted using a hybrid structure instead of the cellular network [4]. More specifically, in the capillary M2M network, the data packets are exchanged between MTDs close together and are transmitted to the cellular network via the aggregator nodes, i.e., MTD gateway [5].

Cognitive Radio Networks (CRN) have been emerged as a promising approach to overcome the problem of spectrum shortage, and to further increase the spectral efficiency by the opportunistic utilization of the spectrum [6]. In the CRN, secondary users use the spectrum which is licensed to primary users when they are inactive [7,8]. The white space is defined by the U.S. Federal Communications Commission (FCC) as the channels that are unexploited at a certain time and location. Therefore, it is pivotal for cognitive radio based applications to precisely detect the white space [9].

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By applying buffer-aided relaying in a three-node cooperative network, considerable performance gains in terms of the throughput can be achieved [10]. In [11], a buffer-aided CRN is considered, where the secondary relay is equipped with the buffer, stores the received data from the secondary source, and transmits it to the secondary destination in an appropriate time slot. A buffer-aided link selection policy in the secondary network is proposed in order to maximize the secondary throughput under the constraint of the quality of service preservation in the primary network [11]. Authors in [12] introduce a novel buffer-aided relay selection scheme in a bidirectional CRN in which the secondary throughput is maximized. In [12], the interference between the secondary and the primary networks is eliminated via the successive interference cancellation approach, and the secondary power consumption is minimized. In [13], buffer-aided relaying concept is generalized to a full duplex CRN in order to further maximize the throughput of the secondary network.

To cope with the density of MTDs in the future Internet of things (IoT) and 5G wireless networks, new approaches to manage the radio spectrum are needed. In particular, the use of cognitive M2M (CM2M) has gained significant attention recently, in which the MTDs opportunistically reuse the resources of the cellular network [14], or TV white space [15]. Authors in [16] survey the possible application of cognitive radio concept for M2M communications from a practical point of view. In [17], a new learning approach for M2M communications is proposed. In [18], authors show how cognitive radio techniques can be deployed for M2M communication in a heterogenous small cell environments. An opportunistic relay protocol is presented in [5] for sensing the radio spectrum and canceling the interference between the cellular network and the MTDs in the CM2M network. In [19], a joint power allocation and MTDs selection policy is proposed for the buffer-aided CM2M network in which by using a buffer-aided scheme the overall throughput of the MTDs is maximized. In [20], a novel medium access control is introduced for improving the sum-rate of the MTDs and managing the total delay of M2M network. However, these existing works do not study the effects of packet adjustment on the overall delay of the M2M communicans networks.

The main contribution of this paper is as follows:

- We propose a novel buffer-aided packet adjustment scheme at the level of the MTD gateway to minimize the average waiting time delay of the MTDs' packets in a small cell based CM2M network based on the MTDs' priority orders. In particular, by using the proposed approach, some of the arriving packets can be properly combined into a larger packet or a given packet can be split into some smaller packets at the MTD gateway. In the proposed protocol, the MTDs that provide urgent application are prioritized over the MTDs with delay tolerant packets. The MTD gateway does not require the *instantaneous* channel state information (CSI) to adjust the packet size. On the other hand, for adjusting the packet size, the MTD gateway needs the status of traffic flows and the ergodic capacity of the channel between the MTD gateway and the small cell base stations (SBS). Therefore, in the proposed policy, the packet size is determined based on the *statistical* CSI.
- For this proposed buffer-aided packet adjustment policy, we derive the average delay and the overall throughput of the CM2M communication network in each small cell.
- Using extensive simulations, the proposed policy is compared with a conventional scheme in which the packet of MTDs are transmitted with their original size. Simulation results show that the average delay of the CM2M network can be reduced up to 25% in the first priority class of MTDs compared with the conventional policy. To the best of our knowledge, the packet adjustment technique for the delay minimization in the CM2M network is proposed for the first time in this paper.

The reminder of the paper is organized as follows. Section 2 introduces the system model. In Section 3, the priority based packet size adjustment scheme is proposed for the two cases of perfect and imperfect spectrum sensing. Section 4 presents the simulation results, while Section 5 concludes the paper.

2. System model

Consider a two-tier cellular network composed of a macro base station (MBS), and N SBSs, where each small cell consists of M types of MTDs, and an MTD gateway for data collection, as shown in Fig. 1. In each small cell, MTDs transmit data to the MTD gateway, and the MTD gateway forwards data of MTDs to the SBS. The network architecture in Fig. 1 mimics a capillary network, where the basic idea is to enable an efficient co-existence of the M2M data communication and cellular network. More specifically, the MTD gateway collects data of MTDs within each small cell and transmits it to the SBS. It is assumed that the small cells and the M2M communication network within them can opportunistically exploit the radio resources of the macro cell. In practice, for alleviating the negative effects of the M2M communications on the cellular network, the communications between the MTD gateway and the SBS is based on a standard 5G or LTE, whereas the communications between the MTDs and the MTD gateway is done via IEEE 802.15.x protocols [21]. Therefore, the data transmission between the MTD gateway and the SBS can cause interference to the macro cell. The macro cell can be seen as a primary network, and the small cells including the M2M communication network can be seen as secondary networks. Since the macro cell has usually a high traffic, the primary user activity can be modeled as *a high primary user activity*. In this model, the primary user exploits the spectrum most of time and the spectrum is available to secondary users for short duration of time [7]. The considered system model is an *interweave CRN* in which one of the SBSs senses the radio spectrum used in the macro cell and allocates the unused spectrum among the small cells. In order to avoid data loss, the MTD gateway is equipped with a buffer and stores the received data from MTDs. The transmit powers of the MTD gateway and the macro cell user equipments (MUEs) are denoted by P_1 and P_2 in Watts/Hz.

Because the uplink spectrum is typically lighter loaded than the downlink spectrum, we assume that the uplink radio resources of the macro cell can be reused by the small cells including M2M networks [22]. In the considered M2M communication network, there