Energy Efficient Cognitive M2M Communications

S. Alabadi, University of Greenwich, London, UK
Predrag Rapajic, University of Greenwich, London, UK
K. Arshad, University of Greenwich, London, UK
Soheil Rostami, University of Greenwich, London, UK

ABSTRACT

The number of Machine-to-Machine (M2M) devices has increased massively in the last few years and will continue to increase in the years to come. Spectrum utilisation efficiency and energy efficiency are the main challenges and design goals for M2M networks. Cognitive radio (CR) is a promising technology that can address these challenges. In this paper, the authors have proposed and developed an energy efficient mechanism to reduce energy consumption in Cognitive M2M (CM2M) networks. Their solution guarantees the throughput and reliability constraints for CM2M Devices (CM2MDs). The proposed mechanism can reduce energy consumption in CM2M networks by exploiting efficient sensing and accessing schemes for CM2MDs. The authors further develop sleep-mode/switching and accessing techniques to work efficiently with the proposed mechanism. The simulation results show that the proposed mechanism guarantees a desirable throughput and reduces overall energy consumption in the network.

KEYWORDS
CM2M, Cognitive Radio, Energy Efficiency, M2M, TVWS

1. INTRODUCTION

It is predicted that the number of M2M devices (M2MD) will massively increase in the near future. Today, there are around 4 billion such devices, while in 2022 the number of M2MDs around the world is predicted to be 50 billion (R. Lu, 2011). M2M communication is expected have a huge commercial market and will be deployed on a large scale because of the number of attractive use-cases and the advantages it can bring. It is expected that M2MDs will dominate several markets, including smart home, retail, automotive and smart cities (R. Lu, 2011). The huge number of M2M devices face many challenges, especially with spectrum scarcity, standards inflexibility, security, and energy efficiency. These challenges need effective solutions before mass deployment of this technology by 2020.

The concept of CR was proposed by Mitola and Maguire (Mitola, 1999) and is a promising technology to solve the so-called spectrum scarcity problem. The main idea of CR is that the secondary user (SU) can sense and exploit licensed spectrum opportunistically and adapt its radio parameter to communicate over the spectrum of interest without affecting or interfering with the primary user (PU) (Mitola, 1999). CR can bring various advantages for M2M communications, including opportunistic spectrum usage and energy efficiency (Adnan, 2015). CR has proved to be green (R. Lu, 2011), as the transmission power levels in secondary networks can be adjusted based on the operating environment, without interfering with the main network or causing interference with other
neighbour networks. Generally, M2MDs are expected to be low-cost and low-power and are designed to work for many years without battery replacement (Niyato, 2011). A number of M2M applications can benefit from the new functionality that can be achieved by the combination of cognitive radio and M2M communications, such as smart grid, healthcare, and car parking (Yao J, 2013). Energy efficiency in CM2M has recently gained attention in the published literature (Yao J, 2011). The current schemes for improving energy efficiency in CM2M networks mainly focus on spectrum discovery schemes such as the non-cooperative, cooperative and time-division energy-efficient schemes (Fadlullah et al, 2011). Further, the previous work addressed optimal power allocation to improve quality of service and energy efficiency in a CM2M network (Illanko, 2011). To the best of the authors’ knowledge, no previous work has considered spectrum handoffs and the wait/switch tradeoff in a CM2M network with multiple SU’s (i.e. CM2MD). In addition, no previous work has considered the scenario with multiple CM2MDs and addressed the collision among CM2MDs. In this paper, we propose an energy efficient mechanism for CM2M network by optimising spectrum sensing and switching mechanisms. The proposed mechanism guarantees sensing reliability and users’ throughput constraints simultaneously. In order to optimise overall energy consumption, our mechanism ensures that spectrum handoff is not used excessively. Instead, CM2MD may sometimes choose to stop transmission and stay in a sleep state on their current channel for a specific period of time, causing more delay and lower average throughput.

The rest of the paper is organised as follows: Section 2 describes the system model and explains spectrum sensing and access mechanisms. Section 3 formulates the optimisation problem and proposes a solution. Simulation results and discussion are provided in Section 4, and Section 5 concludes this paper.

2. SYSTEM MODEL

Consider a Cognitive M2M network with two CM2MDs having M channels shared with PU’s as shown in Figure 1. We assume the CM2MDs transmission is slotted via periodic sensing at specific times. Each frame consists of a sensing slot of durations $\tau_s$ and a transmission slot of duration $T$, where one of the M channels is allocated to the CM2MD. The CM2MD at the beginning of each transmission slot may choose to transmit data on the current channel if the channel is free, to switch to another channel, or to stay on the current channel without transmitting. The primary transmission is assumed to follow an on–off traffic model and assumed to be continuous.

Figure 2 shows the CM2M devices’ activities in transmitting a data packet by assuming six channels and two CM2MDs. The CM2MDs will make a decision before transmission on whether to switch to another idle channel or stay on the current channel only after collecting reliable information on the status of all channels. The mechanism assumed to make the CM2MDs capable of switching to another channel must perform transmission for a time duration of $T$ until the next sensing slot arrives (H. Su, 2010). If the CM2MDs stay on their current channels the devices should choose to abstain from transmitting until the next sensing slots arrives, or perform data transmission for a time duration of $T$.

We assume the spectrum handoff delay is negligible and the energy consumed during the transmission slot is close to zero if the CM2MD waits on the current channel with power off. We assume energy detection as an underlying sensing algorithm due to its simplicity. Energy detection can be used to simultaneously sense all M channels by CM2MDs using wideband sensing in order to obtain the availability of all the M channels. The average received signal-to-noise ratio (SNR) of the PU’s signal at all channels is assumed to be the same during a transmission interval and is denoted by $y$. The false alarm probability and the detection probability for the sensing process are denoted as $P_f$ and $P_d$ respectively.

The probability of false alarm should be as low as possible (for better spectrum utilisation) and the probability of detection should be as high as possible (for higher reliability). The probability of
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