Energy Efficient CM2M Communications in E-healthcare Systems

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Abstract – **In this paper, cognitive machine to machine (CM2M) gateways in e-healthcare systems are presented by accessing a number of channels via periodic sensing and spectrum handoff. An optimal energy efficient spectrum management mechanism with multiple thresholds is proposed. The developed mechanism aims to reduce energy consumption in the system by optimizing the spectrum sensing and the channel switching, while decreasing the probability of collision, with assuring the reliability thresholds, throughput, and delay. Subsequently an antenna selection sensing (ASS) scheme is used to improve sensing accuracy. The simulation results show that the energy efficiency of the CM2M gateways can be improved significantly.**

Keywords— **M2M; Cognitive Radio; CM2M; Energy efficiency; e-healthcare application.**

I. INTRODUCTION

The number of machines connected to the global network has been increased massively in the last few years. In 2012 there were 8.7 billion machines connected to the internet, and due to the growth of tablet PCs, smart devices, sensors, the number of machines reached 28.4 billion in 2017 [1]. M2M applications in medical sector become more significant for private and public entities, such as blood pressure and blood oxygen levels, temperature, and electrocardiograms (ECG) [2]. This leads to better efficiency in the e-healthcare systems like early patient discharge from hospitals and faster returns to their normal lives, reducing the total cost of the patient' s family and the government spending.

However, the use of wireless M2M communications in e-healthcare systems creates new and complex interference scenarios. This intricacy is generated by medical devices which are normally sensitive to electromagnetic interference (EMI) [3] caused by wireless antennas. The interference can cause many problems to the medical machines (e.g. waveform distortion, howling automatic shutdown, and automatic restart), which can be hazardous to patients using healthcare services. Furthermore M2M applications in healthcare systems, need to be energy efficient and able to work for a long period of time (e.g. 10 years) without battery replacement, while at the same time the Quality of Service (QoS) should be sufficient to ensure the reliability thresholds required in e-healthcare applications. Cognitive radio smart technology can help to address all the aforementioned challenges. E-healthcare applications can benefit from the new functionality that can be achieved by the combination of cognitive radio and M2M communications (CM2M), CM2M can help to avoid spectrum interference and improve spectrum and energy efficiency in the e-healthcare system [11].

A number of studies have proven that a "spectrum hands-off" operation can increase the throughput of the secondary users (e.g. CM2M gateways) when a number of channels available for spectrum sharing [4], where the CM2M gateways can switch to another free channel and proceed data transmission in case the current used channel busy.

The use of CM2M in e-healthcare applications has recently gained attention in published literature [5]–[7]. In [5] Weightless technology is addressed, considering e-healthcare applications in CM2M communication over TVWS bands for improved spectrum utilisation and longer battery life. In [6] CR and M2M technologies are discussed, including the features they can offer to the medical sector. In [7] mechanisms are suggested for improving energy efficiency in CM2M applications; the mechanisms mainly focus on spectrum discovery schemes such as non-cooperative, cooperative and time-division energy-efficient schemes. To the best of the authors' knowledge, small consideration has as yet been given to the subject of energy efficiency in CM2M e-healthcare applications, especially in relation to using spectrum handoffs and the wait/switch tradeoff with multiple CM2M gateways. In addition, no previous work has considered the scenario with multiple CM2M gateways or addressed delay and the collision among them.
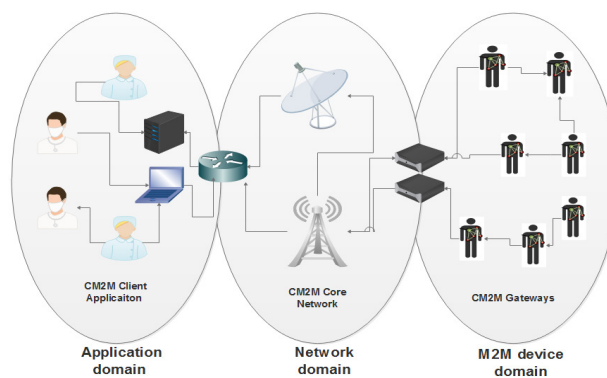

Fig. 1 CM2M network in e-health system

In this paper, we propose an energy efficient spectrum management mechanism for CM2M e-healthcare system (Fig. 1) by optimising spectrum sensing and switching mechanisms. The proposed mechanism guarantees sensing reliability, throughput, delay and collision probability thresholds simultaneously. The rest of the paper is organised as follows: Section II describes the system model and explains spectrum sensing and access mechanisms. Section III formulates the optimisation problem, while section IV proposes a solution. Discussions and simulation results are illustrate in Section V, and Section VI concludes the paper.
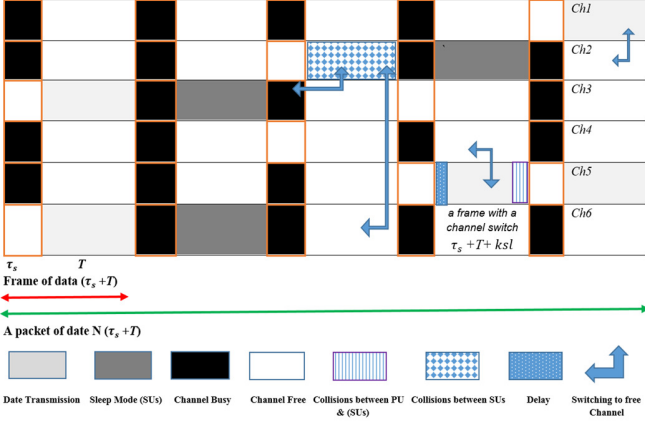

Fig. 2 CM2M gateways performance in transmitting one packet of data

II. SYSTEM MODEL

We suppose a CM2M system working in an e-healthcare environment with two CM2M gateways and one primary link. Consider that there are M channels shared between CM2M gateways and a primary user. Energy detection assumed to sense the channels, while the CM2M gateways apply wideband sensing to obtain the availability status of all channels. The additive noise is a zero-mean CSCG process. We are interested in a low SNR regime (y) and we assume that the secondary transmission is slotted in via periodic sensing at a specific time, each frame consisting of a sensing slot of durations τ_s and a transmission slot of duration T, where one of the M channels is allocated to the CM2M gateways.

We assume the spectrum handoff delay ksl, is also added after the sensing slot in the CM2M gateways frames if the CM2M gateways decide to carry out channel switching after considering the sensing result and other thresholds. The CM2M gateways at the beginning of each transmission slot may choose to transmit data on the current channel, switch to another channel with a switch delay of ksl, or stay on the current channel without transmitting; the primary transmission follows an on–off traffic model and is assumed to be continuous [8]. Fig. 2 shows the CM2M gateways performance in transmitting one packet of data.

We assume the average received signal-to-noise ratio (SNR) of the PU's signal for all channels, the false alarm probability Pf and the detection probability Pd are the same during one packet of data transmission [8]. The received signal presume sampled at sampling frequency fs, the frequency band with carrier frequency fc and bandwidth Wk.

The goal is to decrease energy consumption of the CM2M gateways to transmit a packet of data under the probability of both detection and false alarm thresholds, as discussed in [9], proposing that we can jointly optimize the sensing slot length τ_s and the stay probability on the current channel L_s so that the energy consumption of one complete data packet transmission is reduced as follows:

$$(\tau_s{}^{Optimal}, L_s{}^{Optimal}) = \min_{\tau_s, L_s} X(\tau_s, L_s) \qquad (1)$$

where $L_s{}^{Optimal}$ and $\tau_s{}^{Optimal}$ are the optimal stay probability and sensing slot length, respectively, while X is CM2M gateways total average energy cost of one data packet transmission, which includes spectrum sensing, spectrum handoff, and data transmission. It is worth noting that by applying energy detection, the energy consumption caused by the sensing process can be calculated by the length of the sensing slot. By assigning a target false alarm probability Pft and a target detection probability Pdt $(e.g., Pft = 0.1\ and\ Pdt = 0.9)$ for each channel, we can consider the time required to satisfy the sensing accuracy requirements while reducing this energy cost [9] as given below:

$$\tau_s^{\min} = \frac{1}{yf_s}\left(Q^{-1}(\bar{P}_f) - Q^{-1}(\bar{P}_d)\sqrt{2y+1}\right) \qquad (2)$$

III. PROBLEM

By taking into consideration the challenges and the design features in the aforementioned sections, we now present the proposed energy efficient mechanism to manage the available spectrum. We first expand the energy consumption X of the CM2M gateways, given in (1), as follows:

$$X(\tau_s, L_s) = VE_t + N\tau_s E_s + NP_x J_{sw} \qquad (3)$$

where E_t and E_s are the power (energy cost per second in Watts) due to data transmission and sensing respectively, and J_{sw} is the energy cost for one channel switching, in joules [8, 9]. Assuming that E_t, E_s and J_{sw} are known for a given CM2M e-healthcare system, N is the number of frames and the number of transmission slots of duration T seconds required to complete one packet transmission in the presence of PU. V is the time duration (in the unit of seconds) of one data packet transmission without the PU's presence, and P_x is the probability that the CM2M gateways choose to switch to a sensed-as-idle channel when the current channel is sensed as busy and at least one of the other channels is sensed as idle. As shown in (1), the CM2M gateways minimal energy cost can be obtained by jointly optimizing τ_s and L_s under reliability thresholds. Despite this it is not a convex optimization problem under all thresholds, for a given τ_s, the lower energy consumption can always be found by employing the optimal L_s as $L_s{}^{Optimal} = L_s{}^{upper}$.

And the reason for that function X become smaller as a function of L_s. Thus, the minimum value of X happens at the farthest possible value of L_s. Because $L_s{}^{Optimal} = L_s{}^{upper}$ this reveals that the probability of collision threshold is inactive in deriving $L_s{}^{upper}$[11]. Furthermore, the probability of collision threshold is vital to get the shortest sensing slot, where L_s minimum (τ_s) is calculated from the probability of collision threshold. As a

conclusion the shortest τ_s required to meet all reliability thresholds is given by:

$$\tau_s^{min,2} = arg_{\tau_s} \min\{ L_s{}^{lower}(\tau_s) \leq L_s{}^{upper}(\tau_s)\} \qquad (4)$$

where L_s minimum (τ_s) is calculated by the collision threshold as a conclusion the minimum τ_s meet collision threshold, detection probability Pdt and false alarm probability Pft is given by:

$$\tau_s^{min} = \max \{ \tau_s^{min,1}, \tau_s^{min,2}\} \qquad (5)$$

Note that $\tau_s^{min,1}$ is calculated by the reliability thresholds: the probability of detection and the false alarm probability from (2). We can get $\tau_s^{min,2}$ from the other reliability thresholds defined as the target throughput, probability of collisions, and delay.

IV. SOLUTION

Considering all the aforementioned thresholds, it will require longer τ_s, to satisfy the conditions of $(L_s{}^{lower} \leq L_s{}^{upper})$ ensuring a feasibility region of L_s, $\Delta(\tau_s) = (L_s{}^{upper}(\tau_s) \leq L_s{}^{lower}(\tau_s) \geq 0)$ and perhaps for practical values of τ_s no solution can optimize the existing problem. Furthermore, it is justified by the fact that, for a given sensing slot duration and false alarm probability, the probability of collision diminishes monotonically with any rise in the probability of detection value. Therefore, any increase in detection probability leads to a lower $L_s{}^{lower}$. Moreover, by enhancing the probability of detection, feasibility region $\Delta(\tau_s)$ becomes obtainable with shorter sensing slot time, which as results decreases the energy consumption caused to by the sensing process.

There are many schemes to improve the probability of detection other than a typical single antenna sensing, like multi-antenna parallel sensing and cooperative sensing, but as we work under CM2M concepts and goals we must avoid extra signalling to decrease cost and hardware complexity when run a number of RF chains. Ideal possible solution here comes by applying an ASS scheme to relief the bounds of L_s. The ASS use J antennas and Z RF chains (Z < J) for the sensing process, where the CM2M gateways senses the channels for duration of time (τ_s). Furthermore, the sensing slot of τ_s period is divided into J/Z sub-slots of period τ_{as} (i.e., $\tau_s = J/Z\tau_{as}$).
Z antennas are used to proceed spectrum sensing in each sub-slot at the same time. For instance, we suppose Z = 1 and J = 2. Comparing with the multi-antenna (conventional) spectrum sensing (i.e., J antennas are employed for sensing at the same time employed for W = K RF chains), the developed mechanism can decrease hardware complexity and cost, since only one or a subset of RF chains are employed with huge number of antennas [10, 11].

V. SIMULATION

In this section, we show the efficiency of our mechanism using Matlab simulations. The numerical results are given here to prove the analysis in the previous sections. The primary user is assumed to be a QPSK modulated signal with a bandwidth of 7MHz. The sampling frequency is the same as the bandwidth of

the primary user. We consider the power required for spectrum sensing and transmission are $E_t = 65$ mW and $E_s = 45$ mW respectively.

TABLE. 1 VALUE SETTING OF SIMULATION

Parameter	Value	Description
M	6	Available channel number
v	6s	Duration of one packet data
T	0.8s	Duration of each transmission
γ	-10dB	SNR
J_{sw}	40mJ	The energy cost for one channel switching
ρ	0.4	The probability of a channel being busy
P_d	0.9	The target probability of detection
P_f	0.1	The target probability of false alarm

Fig. 3 shows ASS ($J = 2$) can increase the detection probability which ultimately leads to a smaller probability of collision than Single Antenna Sensing SAS ($J = 1$) with the same value of τ_s.
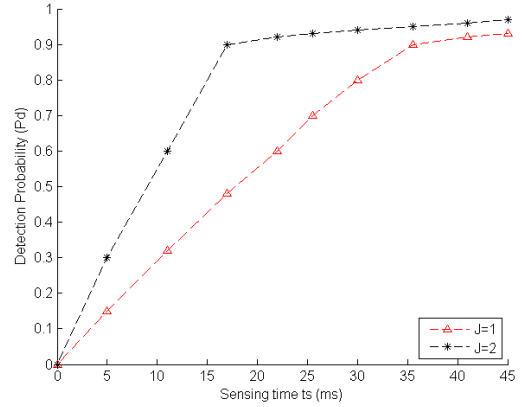

Fig. 3 Using Antenna- selection sensing ($J = 2$)

This easily can be explained by the relationship between the probability of collision and the probability of detection as the probability of collision value decrease with any increase in probability of detection, and shows that ASS needs lower τ_s and energy consumption than the traditional antenna (single) sensing when achieving similar probability of collision thresholds.
Moreover, for a given L_s, the probability of collision also monotonically getting smaller with τ_s. In fact, this easily can be explained because a higher value of τ_s leads to a higher probability of detection value and from above we know that will ultimately lead to decreases the probability of collision. Bear in mind probability of collision mainly caused from CM2M gateways switching to a channels with primary user (PU), due to failed detection.
Fig. 4 plots the L_s bounds of the CM2M gateways as function of the sensing time τ_s for SAS ($J = 1$), and ASS ($J = 2$). Using the same τ_s, $L_s{}^{lower}$ increased when additional stringent probability of collision thresholds Q (i.e, from Q = 0.4 to Qz = 0.3 under $J = 2$ in Fig. 4) used.
Such an increase in $L_s{}^{lower}$, because of the additional stringent Q, allows the CM2M gateways to remain on the current channel for a longer time to keep the probability of collision thresholds. The upper bound $L_s{}^{upper}$ is decided by measuring which

thresholds (delay or throughput) is more significant at given time . Fig. 4 consider the throughput (τ_s, L_s^{upper}) thresholds.
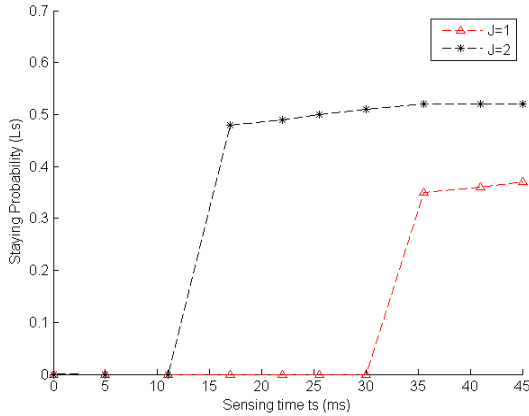

Fig. 4 L_s Bounds of the CM2M gateways as a function τ_s

Bearing in mind that any delay will yield a decrease in average throughput, and therefore the CM2M gateway will need to switch its channel repeatedly to meet its required throughput thresholds. The feasible region becomes available at $\tau_s = 16$ (ms) if ASS ($J = 2$) is used. While using (SAS) ($J = 1$), the feasibility value can only achieve at $\tau_s = 41$ ms). This confirms what we mentioned in the previous section stating that, by using the ASS, the bounds of L_s can be relief. Alike, the energy consumption in CM2M gateways due to sensing can be considerably reduced, as shown in Fig. 5.
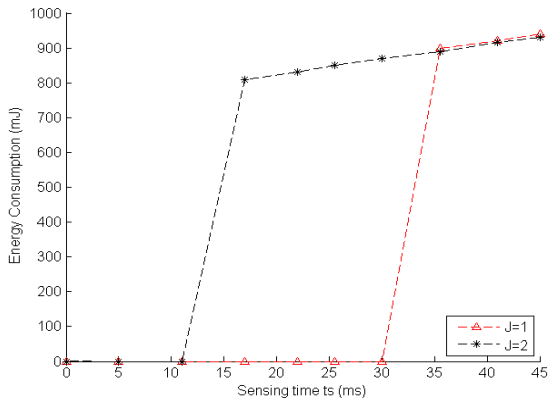

Fig. 5 The energy consumption of the CM2M gateways under various sensing mechanisms

Fig. 5 shows the energy consumption of the CM2M gateways spectrum usage under various sensing mechanisms. It proves that the best stay probability τ_s can be found at L_s^{upper}. As explained before, the optimal sensing slot $\tau_s^{Optimal}$ is also calculated by the reliability thresholds. As seen in Fig. 5 the ASS offers reduced sensing time (τ_s= 16 ms) to meet all the thresholds, compared to SAS ($\tau_s = 41$ ms). Greater $L_s = 0.48$ can be satisfied while meeting all the thresholds with smaller τ_s by using ASS.
As a total outcome, the energy efficiency of the CM2M gateways can be improved significantly by using ASS under the same thresholds.

VI. CONCLUSION

In this paper an energy efficient spectrum management mechanism for CM2M e-healthcare system has been designed. The designed mechanism simultaneously considers the wait/switch trade-off in terms of channel switching probability, sensing /throughput trade-off in terms of the period of sensing time and collision probability.

Furthermore, the proposed mechanism considers an ASS scheme for improved sensing accuracy and reduced energy consumption. The simulation results have shown the improved optimality and efficiency of our mechanism under the desired thresholds.

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