An Energy-Efficient Scheme for WiFi-capable M2M Devices in Hybrid LTE Network

Shubhranshu Singh[†*]
Shubranshu@gmail.com

Kuei-Li Huang[†*]
klhuang.cs93g@gmail.com

Bao-Shuh Paul Lin[*]
bplin@mail.nctu.edu.tw

†: Information & Communication Labs, Industrial Technology Research Institute, Hsinchu, Taiwan
*: Department of Computer Science, National Chiao-Tung University, Hsinchu, Taiwan

***Abstract*—Machine to Machine (M2M) communication has gained much interest in the recent past, both within academia and across different industries. Power saving has become a priority issue recently due to accelerated growth of mobile devices with more and more processor power, more storage capacity, better display technology and much richer-applications. It assumes even greater significance when it comes to M2M devices since unlike hand-held mobile devices which has possibility to get re-charged after certain period of time, many of the M2M devices overall life is almost equal to its one-time charged battery life. This paper proposes an energy-efficient solution for M2M devices to minimize overall energy consumption. Simulation results based on OPNET simulator show that the proposed method significantly improves power saving, especially in time-tolerant M2M applications with long periodic report cycles.**

Keywords- LTE; Machine to Machine (M2M); Power Saving

I. INTRODUCTION

Machine to Machine communication, also called as M2M communication or Machine Type Communication (MTC) [1][3][8][9][10], uses devices such as sensors and meters to capture an event such as temperature, pressure, gas or water consumption which is then sent over wired or wireless network to the server/application that translates the captured event into meaningful information for the user. In other words, unlike machine to human communication, a machine to machine communication is information exchanged over wired or wireless or hybrid network, with no or minimal human interaction.

Power saving has always been an important topic among academia as well as industries. Broadly speaking, power saving related issues can be categorized into two parts: those related to increasing the battery capacity i.e. related to improving battery technologies and those related to optimizing or reducing the energy consumed by the device. There has been much work related to the first category but the progress has been much slower than what is required. Thus improvement in battery technologies has not been able to match with improvements in other mobile device capabilities during the same period of time. There has been several works within the second category as well i.e. related to reducing energy consumption by the device. However, most of them are device-centric and try to solve the problem by, for example, better MAC protocol, IP-layer protocol or other layers of the protocol stack. Within this category, there is also work done to reduce energy consumption by better cross-layer protocol design.

This paper provides a novel energy saving mechanism for M2M devices. The mechanism is based on our proposed concept of an energy efficient network design that enables longer doze mode and optimal mode-switch-over by synchronizing M2M devices with LTE-M2M gateway power save cycle. This considers periodic as well as non-periodic Tracking Area Update, TAU [5]. The mechanism ensures download data transfer over LTE does not happen during M2M device sleep cycle.

The remainder of this paper is organized as follows: Section II discusses the related work. Section III describes the proposed method by first describing the network architecture and then proposes an energy efficient network design. Section III B provides novel mechanism for power saving of WiFi Capable M2M devices. M2M Gateway and its different components are explained in section III C. OPNET Simulation results are shown in Section IV. The paper concludes with section V.

II. RELATED WORK

A. M2M Network Architecture in LTE

Fig. 1 shows the current agreed M2M architecture in LTE [4]. The network operator provides network connectivity to M2M server(s).

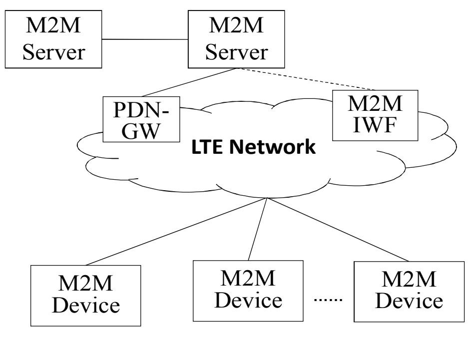


Fig. 1. 3GPP M2M Architecture

An M2M server is a server, which communicates to the LTE network and to the M2M devices through the network. The M2M server interfaces with M2M interworking function (M2M IWF) for M2M control signaling and with the packet data network gateway (PDN-GW) for M2M data communications. The M2M server provides M2M services to M2M User. The M2M server receives monitored data from the M2M devices over LTE network. Also the M2M server may send control or other relevant information to the M2M devices through LTE network. An M2M device is a UE equipped for Machine to Machine Communication, which communicates through an operator domain with M2M server(s) and/or other M2M device(s).

LTE network also includes the following components: base stations (eNodeB), mobility management entity (MME), an old MME or serving GPRS Support Node (SGSN) that the M2M device previously communicated with, a serving gateway (S-GW), a policy and charging rules function (PCRF), and a home subscriber server (HSS). Each of these components is defined in the 3GPP standard specifications.

B. Allowed Time Period after TAU

3GPP document TR 23.888 [7] describes allowed time period after TAU/RAU [5]. The basic idea behind the solution is that after performing a TAU procedure the M2M device may stay in power-up mode and inform the M2M server of its availability for communication so that the M2M server(s) can forward all buffered traffic to the device. The M2M device may be configured not to inform the M2M server after every TAU procedure and thus reduce the frequency of allowed time periods based on the applicable time-controlled requirements. How often an allowed time period occurs is thus configurable. For example, the M2M device may be configured to stay in power-up mode after a TAU and inform the M2M server about its availability only between 1am – 5am every day.

The M2M server buffers downlink traffic for the M2M device until the M2M device informs the server of its availability for communications.

The LTE network configures the M2M device as to initiate allowed-time periods (after a TAU) according to the operator requirements and the M2M subscription options. Normally, downlink traffic does not occur outside of an allowed time period because the M2M server(s) expect the device to send first a message to announce its availability for M2M communications. However, if downlink traffic for the M2M device occurs outside an allowed time period, then the LTE network may reject or drop this traffic i.e. the LTE network need not page the M2M device outside the allowed time period.

C. Power Saving Mechanism in WiFi Network

IEEE-Std 802.11 [2] specifies power saving mechanisms for WiFi STAs. Besides, there are several research papers on various power saving mechanisms in WiFi. In general, power saving mechanism in WiFi network is designed to coincide with the communication behavior of WiFi stations (STAs). WiFi STA first decides its power save cycle. Specifically, WiFi STA determines the Listen Interval (LI) in number of Beacon Intervals (BI) during which it keeps dozing without listening for beacons from Access Point (AP). Once a WiFi STA decides to enter power save mode, it notifies to AP its decided listen interval and starts power saving mode. To receive downlink data, the STA wakes-up and listens to the beacon after LI expires. If the beacon includes availability of data packet indication, the STA will switch-back to active mode and initiate downlink data reception procedure.

Beacon interval is specified by the AP, which thus can derive a series of Target Beacon Transmission Times (TBTTs). A TBTT is a time point at which the AP transmits the beacon. TBTTs are absolute values according to the time at which the AP starts a WiFi network. That is, the AP treats the starting time as a TBTT and the time after a number of beacon intervals as a TBTT.

III. Proposed Method

A. An Energy Efficient Network Design

Fig. 2 shows M2M devices connected to the M2M gateway through non-LTE interface such as WLAN and ZigBee. M2M gateway is a multi-interface device with LTE interface as well as non-LTE interface and is configured to couple M2M devices to the LTE network. When the M2M gateway is located within coverage area of base station, the base station may communicate with the M2M gateway.

As seen in Fig. 2, there are two different networks involved in the communication between M2M devices and M2M server. These two networks i.e. capillary network and LTE network have their own power saving mechanisms and are originally designed to operate independently. Besides, from section II B, only at a specified period after TAU, server needs to send data to M2M devices via the M2M gateway.

The M2M devices forming capillary network are deployed for various applications such as disaster rescue operation, electricity, water, or gas consumption, temperature and pressure monitoring, remote health monitoring, etc [6]. M2M devices deployed for monitoring purposes monitors events and send monitored data to the M2M server for further processing and analysis by the users. M2M devices may be grouped into one or more groups of M2M devices based on criteria such as common features and location. Often these M2M devices are small, energy-constraint, limited-processing capability and uses wireless protocols such as WiFi and ZigBee for communication.

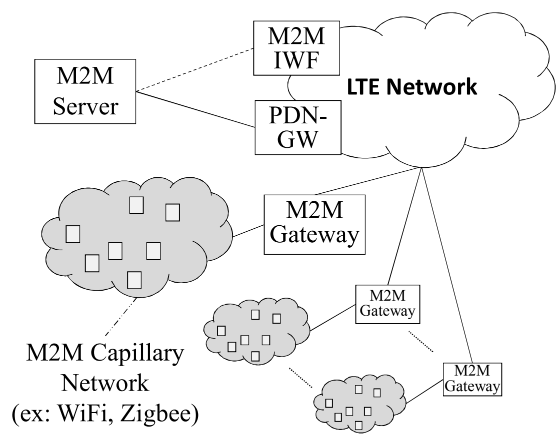


Fig. 2. M2M Architecture with Gateway

Fig. 3 shows proposed concept of an energy efficient network design that helps to significantly improve M2M device power saving. This lets M2M devices to enable longer doze mode and optimal mode-switch-over by synchronizing M2M devices operation modes with M2M gateway's LTE interface power save cycle considering periodic as well as non-periodic Tracking Area Update. Below subsection B provides algorithm details for the scenario where these M2M devices forming capillary network support WiFi interface.

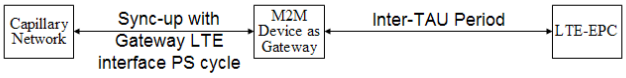


Fig. 3. An energy-efficient network design

B. Power Saving Scheme for WiFi Capable M2M devices

Figure 4 shows the synchronization mechanism for Power saving by the WiFi capable M2M devices/Station (STA). It also addresses the complex scenario where at any point of time some STA may be in sleep mode while others may be in awake or active mode. M2M gateway calculates Listen Interval and Target Beacon Transmission Time (TBTT), as shown in figure 5, and includes them in the broadcast message named W-Bcn. One implementation option could be to keep W-Bcn as an usual WiFi beacon packet with "vendor specific" extension to keep the implementation simple and backward compatible.

STA 2 in figure 4 is originally supposed to wake-up after every 3rd LI, however after receiving W-Bcn with new timer value, it changes its LI and thus can be in doze/sleep mode for longer duration. In case of STA 1, it is already in sleep mode when W-Bcn is sent by the gateway thus it wakes up at the usual time i.e. after LI = 5. Next time M2M gateway may send unicast packet to STA 1.

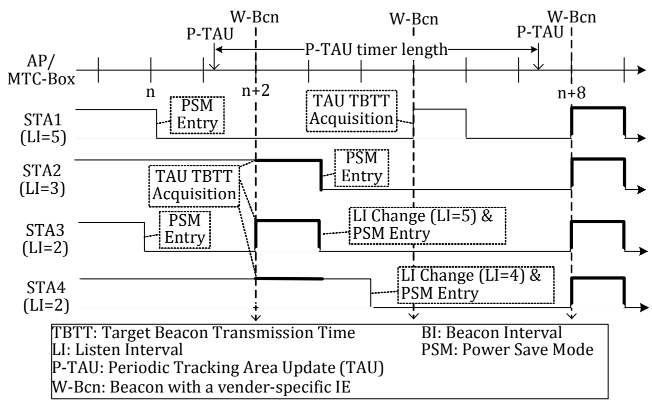


Fig. 4. WiFi power save cycle synchronization with TAU

Figure 5 shows the algorithm implemented at the gateway in order to support power saving by M2M devices. The algorithm allows gateway to calculate Listen Interval and TBTT under different scenarios. The calculated values are then sent to M2M devices over gateway's WiFi interface.

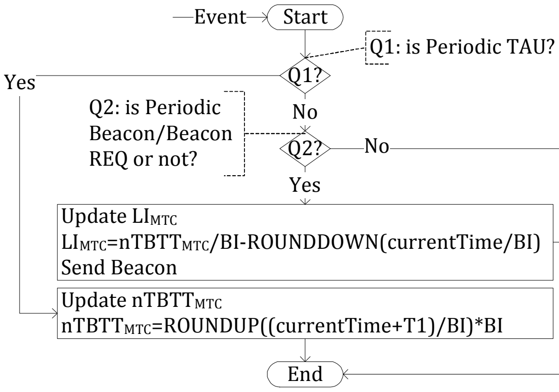


Fig. 5. Parameter Update Algorithm in M2M Gateway

C. The M2M Gateway

Since the M2M devices, except the M2M gateway, do not always have LTE connectivity, we propose to exploit the M2M gateway to enable management and monitoring of capillary network devices by M2M server/user and LTE network.

Figure 6 shows the M2M gateway block diagram and the proposed new feature-components in particular. It includes IEEE 802.11 or WLAN network interface controller (NIC) module for communicating with the M2M devices, a 3GPP NIC module for communicating with the 3GPP network, and a core module coupled to the IEEE 802.11 NIC module and the 3GPP NIC module. The WLAN NIC, WLAN module and M2M controller unit implements the proposed algorithm.

The core module includes an M2M controller unit, which further includes a database and a controller. The controller stores information regarding the M2M devices in the database and retrieves information regarding the M2M devices from the database. The core module also includes a memory manager to manage memory usage by the database, and a communication scheduler to schedule communications between the M2M gateway and the M2M devices and communications between the M2M gateway and the 3GPP network.

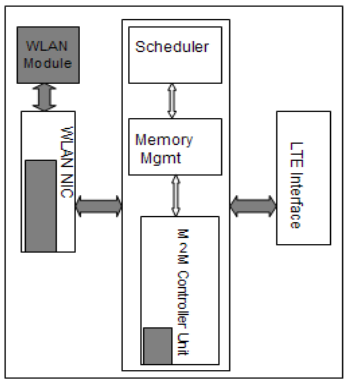


Fig. 6. M2M Gateway Architecture

The LTE NIC module includes, apart from a standard LTE protocol stack, an *M2M enable unit* configured to enable control and monitoring of the M2M devices through the LTE network. For example, the M2M enabled unit sends initial information regarding the M2M devices to the LTE network as part of an initial attach process. Also, for example, the M2M enable unit may send, periodically or non-periodically, updated information regarding the M2M devices to the LTE network using Tracking Area Update messages. This is used to update MME database of the LTE network with the initial or updated information regarding the M2M devices which can then be used to monitor and control these devices via M2M gateway.

IV. ANALYSIS

As shown in Fig. 7, we create a simulation environment using the OPNET simulator [11], in which an MTC server was connected to the LTE network and an UE with an additional Ethernet interface was connected to a WiFi AP. The M2M device which is equipped with WiFi interface communicates with the MTC server through the WiFi AP. Note that the UE and the WiFi AP are collectively treated as an MTC gateway. During a simulation run, the MTC user requests data from the MTC server which then conducts small data transmission with the MTC device. The MTC gateway enabling the proposed method queues requests until the MTC device wakes up at the beginning of next power save cycle. While waking up, the MTC device deals with all the requests queued in the MTC gateway and goes back to idle mode afterwards. The simulation time was set to 3 days in each simulation run. Among the simulation runs, some mandatory parameters were varied. The parameters and values are listed in Table 1, where values of SDT request rates mean that the SDT request inter-arrival times are exponentially distributed (i.e., a Poison process) with mean value 30 seconds. Values of power consumption of the M2M device in different operations (modes) are referred from [12]. The simulation environment settings are listed in Table 1.

TABLE 1 SIMULATION ENVIRONMENT SETTINGS

Parameter (*Notation*)	Value(s)
WiFi AP Beacon Interval (d_{BI})	0.5 seconds
Periodical TAU Interval (power save cycle) (d)	10800, 32400 seconds
WiFi STA (M2M device) Listen Interval (LI)	10, 110, 300 BIs
Small Data Transmission (SDT) Request Rate (r)	exponential(30) seconds
Tx Power Consumption at MTC Device (e_{Tx})	330 mA
Rx Power Consumption at MTC Device (e_{Rx})	280 mA
Active Mode Power Consumption at MTC Device (e_A)	178 mA
Idle Mode Power Consumption at MTC Device (e_I)	9 mA
Simulation Time	3 days

Figure 8 shows the cumulative power consumption over time with different small data transmission request rates. The M2M device operating in a traditional power saving scheme was set listen interval to 10, 110, and 300, respectively, and denoted as "WiFi PS." We observe that the M2M device with a large listen interval wakes up less frequently, saving more power than those with smaller intervals. On the other hand, the M2M device with the proposed method, which is denoted as "M2M PS", does not wake up during Idle intervals, consuming less power than WiFi PS.

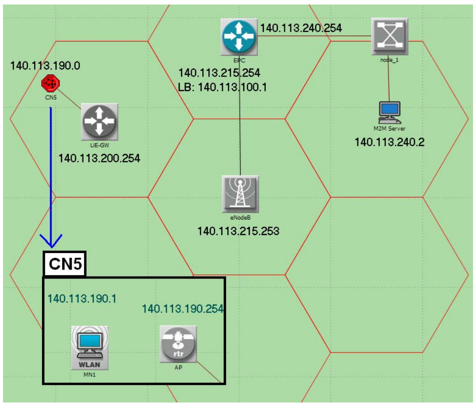
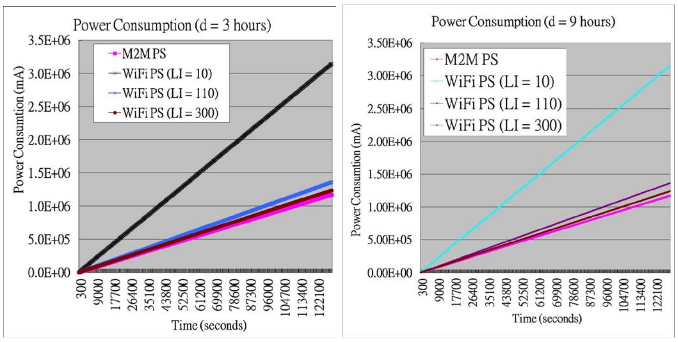


Fig. 7. Network Topology



(a) d = 3 hours (b) d = 9 hours

Fig. 8. Total Allowed Time Required vs number of M2M Devices

When *LI* is larger, WiFi PS consumes less power. This motivates us to formulate the relationship between the parameters of M2M PS and those of WiFi PS. Let the power consumption of the proposed method in a power saving cycle be e_1 and that of the traditional method be e_2. Assume d_A be the duration that the MTC device stays in active mode for receptions and transmissions, n_{Rx} and n_{Tx} be the numbers of receptions and transmissions, respectively, and d_{Rx} and d_{Tx} be the durations of one reception or one transmission, respectively. Referring to the notations of the parameters in Table 1, e_1 and e_2 can be expressed by Equations (1) and (2), respectively.

$$e_1 = d_A \cdot e_A + (d - d_A) \cdot e_I + n_{Rx} \cdot (e_{Rx} - e_A) \cdot d_{Rx} + n_{Tx} \cdot (e_{Tx} - e_A) \cdot d_{Tx} \quad (1)$$

$$e_2 = \lfloor \lfloor d / d_{BI} \rfloor / LI \rfloor \cdot d_{BI} \cdot e_A + (d - \lfloor \lfloor d / d_{BI} \rfloor / LI \rfloor \cdot d_{BI}) \cdot e_I + n_{Rx} \cdot (e_{Rx} - e_A) \cdot d_{Rx} + n_{Tx} \cdot (e_{Tx} - e_A) \cdot d_{Tx} \quad (2)$$

We answer a question to establish the relationship between the two methods: For which values of *LI*, , $e_1 \geq e_2$. The following inequality relates the relationship.

$$
\begin{aligned}
& e_1 \geq e_2 \\
& \Rightarrow d_A \cdot e_A + (d - d_A) \cdot e_I \geq \lfloor \lfloor d / d_{BI} \rfloor / LI \rfloor \cdot d_{BI} \cdot e_A + \\
& \qquad (d - \lfloor \lfloor d / d_{BI} \rfloor / LI \rfloor \cdot d_{BI}) \cdot e_I \\
& \Rightarrow d_A \geq \lfloor \lfloor d / d_{BI} \rfloor / LI \rfloor \cdot d_{BI} \geq \lfloor d / d_{BI} \rfloor / LI \cdot d_{BI} \geq d / LI \\
& \Rightarrow LI \geq d / d_A
\end{aligned} \tag{3}
$$

Note that only the power saving cycle, d, and the active interval of the cycle, d_A, affects LI. It is easy to determine the power save cycle d, which is a constant. However, d_A is determined by the small data transmission request rate and the service time of tackling a request. The mean of d_A can be expressed by Equation (4), where d_{SDT} is the duration of a small data transmission and $X_{SDT}(\cdot)$ denotes the number of requests, which is a Poisson distribution with parameter $(d - \overline{d_A}) \cdot r$.

$$
\begin{aligned}
& d_A = d_{SDT} \cdot E[X_{SDT}((d - d_A) \cdot r)] = d_{SDT} \cdot (d - d_A) \cdot r \\
& \Rightarrow d_A = d_{SDT} \cdot d \big/ (1 + r \cdot d_{SDT})
\end{aligned} \tag{4}
$$

Since the LI field is only 8-bit long, it is unable to represent a value more than 65535 in the field. This implies that the M2M PS method is especially suitable for M2M applications with long power save cycle. For example, M2M devices of smart meter applications report gas measurement data daily, implying that the small data transmission request inter-arrival time equals 86400 seconds. With d being 10800, the derived LI is 86411. Using the maximal representable value, 65535, instead, we can expect the WiFi PS method cannot save as much as the proposed method during idle mode.

V. CONCLUSION

The paper provides an energy efficient design for LTE hybrid network. The hybrid network consists of M2M devices with non-LTE interface forming capillary network and the LTE network. These two networks are connected by LTE-M2M gateway. Based on the proposed network design, the paper provides a novel power saving mechanism specific to WiFi M2M devices. A robust M2M gateway assists in effective integration and power saving of M2M devices. The paper elaborates on different components and features of the proposed M2M gateway.

Simulation results and analysis of the proposed mechanisms are provided. Simulations are performed using OPNET simulator. Simulation results show that the proposed method significantly improves M2M device power savings, especially in time-tolerant M2M applications with long periodic report cycles.

ACKNOWLEDGEMENT

This research is supported by the Information and Communications Research Lab (ICL), Industrial Technology Research Institute (ITRI), Taiwan via ITRI Grant Project Code B301AR2P20.

REFERENCES

[1] ETSI TC M2M www.etsi.org

[2] IEEE Std 802.11-2007, “Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, Part 11,” Jun. 2007.

[3] 3GPP, http://www.3gpp.org

[4] 3GPP TS 22.368

[5] 3GPP TS 23.401

[6] ETSI, “TR102 732, Machine to Machine Communications (M2M); use cases of M2M applications for eHealth”

[7] 3GPP TR 23.888 draft, version 1.3.0, Jun. 2011.

[8] C. Kim, et al., "Global Wireless Machine-to-Machine Standardization," Internet Computing, IEEE, vol. 15, pp. 64-69, 2011.

[9] L. Shao-Yu, et al., "Toward ubiquitous massive accesses in 3GPP machine-to-machine communications," Communications Magazine, IEEE, vol. 49, pp. 66-74, 2011.

[10] W. Guo, et al., "An adaptive medium access control mechanism for cellular based Machine to Machine (M2M) communication," in Wireless Information Technology and Systems (ICWITS), 2010 IEEE International Conference on, 2010, pp. 1-4.

[11] OPNET Simulator http://www.opnet.com/

[12] L. M. Feeney, and M. Nilsson, "Investigating the energy consumption of a wireless network interface in an ad hoc networking environment," in Proceedings of INFOCOM 2001