A Survey of Idle State Optimizations to Improve Power Saving for M2M Communication over LTE Networks

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Abstract— M2M communication is quickly gaining popularity because of its endless possibilities. In order to take advantage of this new technology we need to use more advance networks like the 3GPP LTE/LTE-A which deliver higher throughput and can handle more active devices. LTE networks were mainly designed for H2H communication meaning that we cannot just use M2M devices over it without any optimization. LTE networks have a power saving mechanism known as Discontinuous Reception (DRX). M2M devices spend most of their time in the idle state therefore more optimization needs to be carried out in the idle state. In this paper, a survey of the available power saving mechanisms like reducing the RRC Inactivity timer, extending the DRX paging cycle and switching off the radio transceiver are studied and analyzed. Then a DRX configuration switching mechanism is proposed so as to save battery power but also ensure that delay (latency) is controlled at the same time. Further an algorithm has been proposed to be implemented at the eNB (base station) so as to assist it with the switching mechanism.

Key words: 3GPP, DRX, DRX Switching, Idle State, Latency, LTE, LTE-A, M2M, MTC, Power Saving.

I. INTRODUCTION

Machine to Machine communication (M2M) also known as MTC (Machine Type Communication) is the main driving force for the new trend in technology known as Internet of Things (IoT); actually it's an enabler for IoT. In M2M communication, machines tend to directly communicate with each other almost in a similar way as humans do. M2M is also a major driver for the growth of cellular networks such as 3GPP LTE (Long Term Evolution) because now days more packet data than voice is sent over cellular networks.

LTE networks have many advantages that include high data transfer rates, can support more active devices and also work better in high mobility among others. But LTE were created mainly for H2H (human to human) communication, therefore some optimizations have to be made on the current protocols and mechanisms to enable M2M communication over it. Several modifications are needed to address the service requirements and traffic characteristics of M2M devices in these networks. One of the most important requirement is battery power saving since M2M involve many devices like sensors and actuators that depend on a limited power source (battery).

Due to the high production of low cost sensors and actuators, there has been an increase in the innovations using M2M communications over 3GPP LTE networks. There are various applications in the market today but however all these can be categorized into five groups:

- e-Health
- Smart environment (home, office, and industry)
- Intelligent transportation
- Security and public safety and
- Other futuristic applications [4].

M2M communications have three domains; M2M device domain, application domain and the network domain. LTE network provides the network domain. LTE is a standard for wireless data communications technology and an evolution of the GSM/UMTS standards developed by 3GPP (3rd Generation Partnership Project). The goal of LTE was to increase the capacity and speed of wireless data networks and to redesign the network architecture to a simpler IP-based system with significantly reduced transfer latency compared to the 3G architecture.

M2M devices usually generate a short burst of traffic at relatively long inter-arrival time (IAT) periods on average meaning that they are more tolerant to delay than H2H communications. The IAT of M2M traffic burst can either be fixed with values of a few seconds to several hours or exponentially distributed with average of a few seconds to several hours. Each data traffic burst has a few bytes to 10 Kbytes of data [5][7]. The M2M traffic is mostly UL (Up Link). It may also be in DL (Down Link) in certain scenarios, such as an M2M server asking M2M devices for specific data updates, providing software updates, broadcast of M2M related system information and receiving data from other M2M devices are all DL M2M traffic.

Since the traffic characteristics of M2M communication are different from those of H2H communication, there is always going to be challenges in implementing M2M communication over LTE networks. These include overload and signaling control, the architecture, fulfilling the service requirements among others [1][2]. 3GPP has tried to handle most of the challenges through their continuous releases as they draw closer to fully implementing M2M communication over LTE networks [10][11]. However there are still some challenges that have not yet been fully addressed and require further research [2]. This survey is drawn from the challenge of Device power consumptions optimizations to prevent battery drain (which results from frequent changes between idle and connected modes or too long periods in connected mode).

The rest of the paper is organized as follows. Section II explains the motivation for this survey. The problem at hand is discussed in section III. An overview of DRX power saving mechanism in LTE is given in section IV. Then in section V, available literature on power saving mechanisms for M2M in LTE networks is presented. A DRX configuration switching mechanism is proposed in section VI and also how it is to be implemented. The paper is concluded in section VII.

II. Motivation

M2M communication is used in applications such as eHealth, smart metering, Automotive, city automating among others in form of a wide variety of M2M devices that basically use sensors and actuators. So there is need to ensure that these devices work for a long time without human intervention so as to get the best out of them. As a result we need to devise means to save their power especially when communicating over cellular networks like LTE.

LTE network is a 4G wireless network and this means faster data transmissions, low latency and more active devices with in a cell. This is so important for M2M since many devices can be deployed in a particular area.

III. Problem Statement

LTE network was mainly created for H2H communications, so all the power saving mechanisms that are adopted are best suited for H2H. Several modifications are needed to address the service requirements and traffic characteristics of M2M devices in this network. Device power efficiency is one of the crucial requirements for M2M communication, since M2M devices may have a limited power source and spend most of their time in the idle state but wake up periodically to transmit or receive small amounts of data.

In LTE networks, there is a power mechanism called Discontinuous Reception (DRX) which is used to save battery power but this is intended for H2H communications with small idle periods, therefore there is need to optimize the DRX mechanism to improve battery power saving so as to facilitate M2M communication over LTE network.

A good power saving mechanism (scheme) that puts into account the buffering delays (latency) in M2M communication over LTE network is required.

IV. DRX Mechanism in LTE

LTE network has a power saving scheme known as discontinuous reception (DRX) to enhance device power saving [3][5][7][9][12]. In DRX mode, the UE powers down most of its circuitry when there are no packets to be transmitted or received. During this time UE listens to the downlink (DL) occasionally and may not keep in sync with uplink (UL) transmission depending on whether the UE is registered with an evolved node-B (eNB) (radio resource control RRC connected) or not (RRC idle state) [3].

LTE network UE devices can have various states, when the device is first powered on the UE is in De-Registered state. Once the device is registered with the network, the radio can be in either of the two different radio states called RRC_Connected and RRC_Idle [3][9][12]. When a device is registered and enters the network, the UE starts in Connected state, where it can listen to the network and receive or transmit data, and thus consumes higher power (i.e. about 1–1.5 W) [5][8]. After a period of data inactivity (which depends on the RRC Inactivity Timer configured by the network operators), the device enters the Idle state.

A. DRX In Connected State

LTE DRX mode can be enabled in both RRC_IDLE and RRC_CONNECTED states. In the RRC_CONNECTED state DRX mode is enabled during the idle periods between packet arrivals, when there are no outstanding or new packets to be transmitted or received, eNB/UE may initiate the DRX mode [3]. The Connected state is the most active state in LTE where devices receive and transmit data, monitor physical downlink control channel (PDCCH), and listen to broadcast channel frequently.

B. DRX In Idle State

M2M devices once registered with the network can either be in connected or idle state at the Radio Resource Control (RRC) level. In this survey we are not going to consider the RRC_CONNECTED state because M2M devices spend little time in it, however we will look at RRC_IDLE state in detail and device optimizations to improve power saving.

Due to long inter-arrival time (IAT) between traffic sessions, M2M devices spend most of their time in LTE Idle state which is designed as a low power state in the LTE network. In the RRC_IDLE state, the UE is registered with the mobility management entity (MME) but does not have an active session. In this state the UE can be paged for DL traffic and the UE can also initiate UL traffic by requesting RRC connection with the serving eNB. Devices sleep in the idle state to save battery and wake up periodically to check any system information (SI) update or downlink (DL) packet arrival by listening to the PDCCH for paging message broadcast by LTE network [5]. The periodicity of wake up depends on a parameter called DRX Paging cycle.

During the idle mode, the mobility is fully controlled by UE, since the network is not aware of the UE existence continuously. UE should perform the signal quality measurements with respect to the serving and neighboring eNBs according to measurement thresholds recommended by the serving eNB. Based on the signal quality measure, the UE selects a new serving eNB when UE moves away from the current serving eNB. When the system information advertised by the new serving eNB does not include its tracking area, UE will perform a tracking area update to indicate its presence so that the network knows where to page the UE in case of DL data transfer [3].

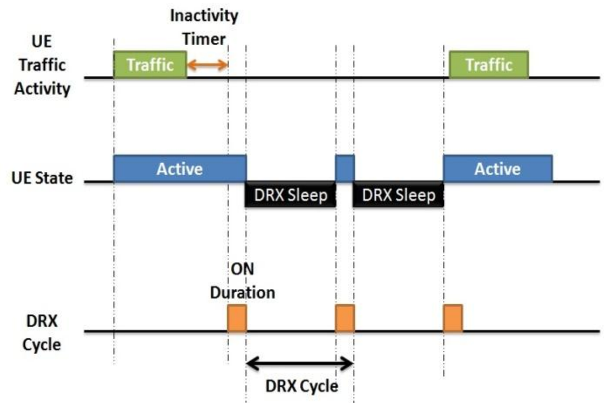

Fig. 1: UE state based on DRX cycle and Inactivity Timer in Idle state.

The DRX parameters associated with the idle state for a given M2M device as shown in fig.1 are as follows:

- DRX Cycle, this is the sleep time plus the on duration time (when the device wakes up to listen to the PDCCH).
- On Duration timer, is the number of frames (time) over which the UE will read the PDCCH in every DRX cycle before entering the power saving mode.
- RRC Inactivity Timer, the time taken to transit a device from the connected state to the idle state when there is no packet activity. It is also known as the connected-to-idle transition tail time.

V. RELATED WORK

S.C. Jha et. al. titled "Power Saving Mechanisms for M2M Communication over LTE Networks" [5]. The authors suggest that by decreasing both the RCC Inactivity timer and the DRX paging cycle, battery power can be saved for M2M device communication over LTE networks. It was discovered that extending the paging cycle was favorable for devices with small or medium inter arrival times (IAT) and when further investigations were conducted using simulations, they indicated that also reducing the RCC Inactivity timer can save power. The two parameters were compared and the conclusion was that reducing the RCC Inactivity timer was a better approach for saving power. The limitation of this work was that even if the suggested mechanisms are valid for battery power saving for M2M devices, it's not indicated which valves to use for the RCC Inactivity timer and the DRX paging cycle in case one is to configure his equipment. Also there is no scheme to use if you are having different types of traffic and could benefit from optimizing both parameters.

L. Tang et. al. titled "Self-adaptive Power Saving Mechanism for M2M" [6]. In this research work, they use extending the DRX paging cycle as the main parameter to save battery power. It's suggested that extending the paging cycle alone is not good enough; therefore a mixture of normal and extended cycles is a better approach. So they came up with a self-adaptive power saving mechanism whereby the extended cycle is determined from the value of the previous DRX paging cycle (adaptive). They studied all the three approaches i.e. extend DRX paging cycle only, mix normal and extended DRX paging cycle and the self-adaptive mechanism and they concluded that the self-adaptive scheme saves more battery power. The problem is that extending DRX paging cycle can save battery power for M2M devices with small or medium traffic bursts, however if the IAT is more than several minutes it may be useless to use this approach.

A.T. Koc et. al. titled "Device Power Saving Mechanisms for Low-Cost MTC over LTE Networks" [7]. In this proposed work, they considered two approaches i.e. moving the LC-MTC (Low Cost Machine Type Communication) device to idle state whenever there is no packet activity and turning off the LTE radio off. Through their comparative analysis of the two approaches, it was discovered that turning off the radio transceiver outperforms moving it to idle state. LTE Radio Off approach was found to be further improved in case of LC-MTC traffic had higher traffic burst inter-arrival time. However they suggest that if the device is to be moved to idle state then a shorter RCC Inactivity timer can be used to save battery power. The main problem with this approach is that turning off the LTE radio will greatly increase delay, especially if the traffic bursts IAT is small.

R. Vannithamby et al. proposed work titled "Device Power Saving and Latency Optimizing in LTE-A Network Through DRX Configuration" [9]. In this work, the DRX mechanism is explained in detail and how it can be optimized for both active and background traffic of a UE. A DRX switching mechanism is suggested that puts in to account power saving and latency. The most important concept that was introduced in this work is that of the single bit UE assistance information called power preference indication (PPI) that can be sent by the UE to the network. PPI = 1 indicates UE's preference to go to the low power consumption state while PPI = 0 represents UE's willingness to remain in the normal state which is preferable for delay sensitive traffic. The main importance of PPI is that in case you have to design an algorithm, it can be used to send values from the UE to the network (eNB). However the optimizations presented in this work is for H2H communication and they mainly consider the connected state. Therefore the optimizations can't be adopted for M2M communications.

VI. PROPOSED MECHANISM

LTE network has a mechanism called discontinuous reception (DRX) to enhance device power saving. However this is not enough since LTE is optimized for H2H communications hence more optimization is needed in order to efficiently use it for M2M communication. Available Power saving mechanisms includes:

- Reducing the Connected to idle transition tail time (i.e., RRC Inactivity Timer).
- Extending the DRX paging cycle during the idle state.
- Maximize the time when LTE radio is turned off in between the traffic bursts.

The above mechanisms have their merits, but if the RRC Inactivity Timer is reduced, it will improve battery power but will increase delay (latency) too. And if the DRX paging cycle is also extended again more delay will occur. Therefore we need to strike a balance between power saving and allowable delay because a M2M device can send or receive different types of traffic. In this section a DRX configuration switching mechanism is introduced, the solution must be able to save more battery power and also strike a balance on what acceptable delay can be allowed in order for M2M communication to occur over LTE networks.

A. DRX Configuration Switching Mechanism

It's the work of the eNB to select the power scheme to use during transmission even without first consulting the UE. However the UE knows best the different types of traffic it normally sends or receives and also how much battery power is left.

In 3GPP release 11 [12][14], a UE assistance information called the power preference indication (PPI) was introduced so that the UE can help in the selection of the power mode to use. How to signal the PPI was left to the device vendor and how to read the PPI was left to the network provider. PPI uses a single bit to indicate the power preference i.e. PPI=0 indicates that that the traffic is delay sensitive and PPI=1 indicates that the low power mode can be used.

DRX configuration switching mechanism will use two sets of configurations; one for low power and the other set for delay sensitive traffic and the parameters that will change will be the RRC Inactivity Timer and the DRX paging cycle values. The power preference indication (PPI) will be used by the M2M device to indicate to the eNB which preference it wants to use. PPI=1 will be used to indicate low power and PPI=0 will be used to indicate that the traffic is delay sensitive.

Fig. 2 and algorithm 1 below show the process that will take place during the DRX configuration switching mechanism, note that the M2M device will only signal the PPI value if it has changed to avoid over signaling, but the eNB will always check the PPI value before sending data as long as the device is still connected.

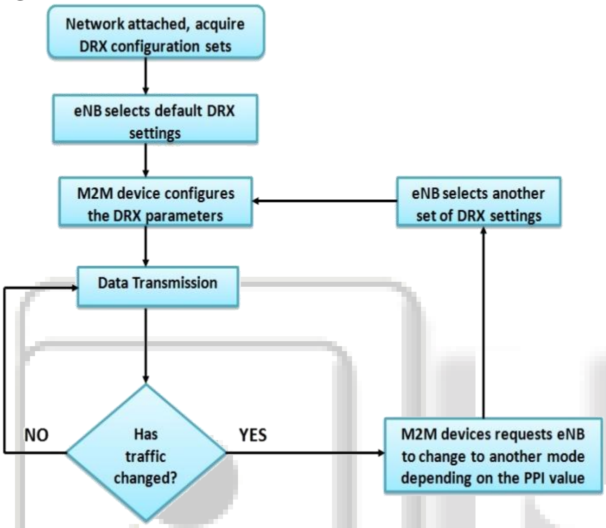

Fig. 2: Flow chart showing DRX configuration switching mechanism

Algorithm 1 DRX Configuration Switching

DRX_Config ← { $RRC\_Inactivity\_Timer_{max}$, DRX_Cycle_{min} }
while connected **do**
ppi ← PPI from M2M device
if *ppi* = = 1 **then**
DRX_Config ← { $RRC\_Inactivity\_Timer_{min}$, DRX_Cycle_{max} }
else
DRX_Config ← { $RRC\_Inactivity\_Timer_{max}$, DRX_Cycle_{min} }
end if
return *DRX_Config*
end while

B. *Implementation*

To implement the DRX configuration switching mechanism, first determining the actual values of DRX paging cycle and RRC Inactivity Timer that can improve power saving with an acceptable latency will be done. Also determining when it is most beneficial to totally switch off the radio transceiver of the M2M device will be established. The proposed solution (mechanism) is subsequently analyzed through MATLAB for appropriate mathematical or numerical study. The theoretical results are then verified through intensive simulations using OPNET network simulator.

Simulation parameters: Standards parameters for LTE DL transmission will be used, but the DRX parameters like RCC Inactivity timer, DRX paging cycle and the Inter-arrival time (IAT) values will be varied in order to study the effect on battery power.

Performance measure: performance will be determined depending on the battery power saved and the delay or latency allowed.

VII. CONCLUSION

Battery power will always be an issue as long as you are using sensor nodes (M2M devices) for data collecting and pre processing. To enable M2M communication over LTE network, the issue of battery power saving has to addressed. The DRX mechanism can save power but can further be improved by properly combining optimizations of the DRX paging cycle, RRC Inactivity timer and moving the device directly to radio off mode.

When more battery power is saved, it means that the device will last longer in the network without need for human intervention. This is so important for monitoring applications like flooding detection, tracking among others.

VIII. ACKNOWLEDGMENT

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