Adaptive Power Management in LTE Terminal Modem

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***Abstract*— The high-speed communication environment and high-performance mobile devices have leveraged each other. Long Term Evolution (LTE) supports high bandwidth and low latency for data transfer. However, high bandwidth transfer will spend the mobile device's battery power rapidly. To extend the user equipment (UE)'s battery life time, LTE adopts enhanced Discontinuous Reception (DRX) mechanism. Even though LTE supports DRX framework to reduce power consumption, DRX not only depends on base-station but also needs sufficient idle time to operate efficiently. In this paper, we propose a novel adaptive power management technique of LTE model which reduces the active (i.e. non-DRX period) power consumption. Our experimental results shows that a communication modem with the proposed method improves energy saving by 40.72% compared to previous modem.**

Keywords—low power; Long Term Evolution (LTE); dynamic voltage and frequency scaling (DVFS)

I. Introduction

The growth of data transmission through communication in the mobile has led to the development of the progressing 4G communications, such as long term evolution (LTE). Since LTE puts more bits into a radio wave, the more computing power phone use up modulating and demodulating that radio wave. The 64 QAM and OFDM techniques used in LTE are as complicated as they sound. Due to these newly employing techniques, LTE can support a high data rate and low latency aiming to support multiple services such as video streaming, web browsing, online game, and etc.

These high data rate for mobile devices, however, sharply increased memory usage and the data needs to be processed. As a result, mobile devices are in an idle state for less time. LTE provides the enhanced discontinuous reception (DRX) model to achieve a more power saving to prolong battery life time. By using DRX, the user equipment (UE) save power by turning off the radio frequency modem into sleep state for a predefined period when it is in an idle state. In LTE, DRX mode can be switched in both RRC_CONNECTED when an radio resource control (RRC) connection has been established. If this is not the case, the UE is in RRC_IDLE state [1]. With the enhanced DRX of the 4G services, it is still currently lacked because the UE require complex computation.

Due to the importance, various power saving techniques in communication system have been studied [2][3][4]. However, there has been no consideration in active state of DRX. Significant portion of the power savings of the UE's radio frequency block and modem hardware is dependent on the DRX.

In this paper, we propose a novel adaptive power management not only power saving in idle state but also in active state. More specifically, our technique reduced power in active state (RRC_CONNECTED) based upon dynamic voltage and frequency scaling (DVFS) technique. Since the energy consumed with CMOS circuit scales proportionally to the supply frequency and quadratically to the supply voltage.

The remainder of this paper is organized as follows: background of LTE and related work are presented in Section II. In Section III, we provide the motivation of our work. We propose a DVFS technique for advanced communication technology such as LTE in Section IV. Finally, we show the outstanding of our work in Section V, followed by our conclusion in Section VI.

II. Background

A. Discontinuous Reception Mechanism in LTE

The DRX of LTE [1] adopts UE-specific parameters determined by the evolved Node B (eNB). By using DRX mechanism, the UE can turn off the radio frequency modem into sleep state for prolonged period in order to extend battery life time. This mechanism allows the UE to not constantly monitor the PDCCH every TTI, but only during specific time interval.

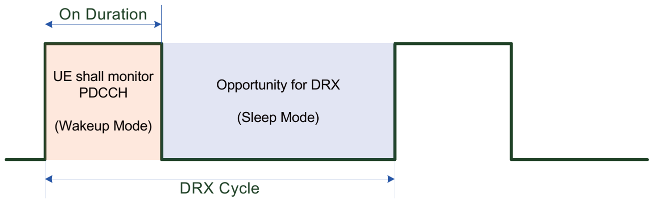


Fig. 1 DRX cycle

In DRX mechanism, the power mode consists of two states are namely RRC_CONNECTED state and RRC_IDLE state.

B. Related Work

There are some researches have studied power saving in LTE. In [2], an adjustable power management using a hierarchical cascaded power gating and a hierarchical multi-level clock gating was proposed. They define five power saving islands with a combination of power gating to have the maximum power saving in the LTE. In [3], a DRX-aware scheduling method is proposed where the UE is going soon to return to sleep should have priority. Another paper have studied DRX mechanism for power saving. In [4], a variant of the M/G/1 queues was presented in order to explore the performance of the DRX. In [7], they presented an overview of an adjustable feature of the DRX cycle of the LTE DRX using a semi-Markov process. However, existing DRX mechanism is a method that exploiting an idle time. It depends on service and eNB operation policy.

III. MOTIVATION

Downlink of LTE scheme is performed in units of 1ms sub-frame (Transmit Time Interval, TTI). Therefore, the PHY layer hardware of modem terminal has to process the subframe every 1ms. In other words, the hardware has hard real-time constraint of 1ms.

The PHY layer hardware that must be processes within 1ms of data complexity is a quite variable depending on kind of service, states of the channel, and scheduling policy of base station. Accordingly, the operational status of each hardware block and its execution time is also variable. Thus, the slack time that data is processed within one subframe is changed. In other words, Every TTI does not need to be decoded at maximum frequency. By utilizing this slack time, adaptive power management would be able to perform during the communication.

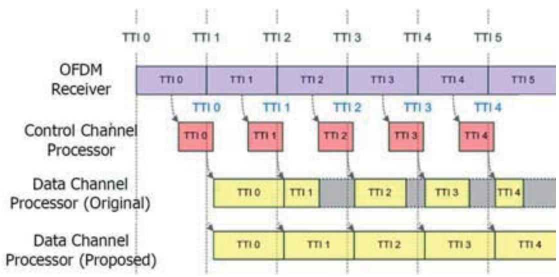
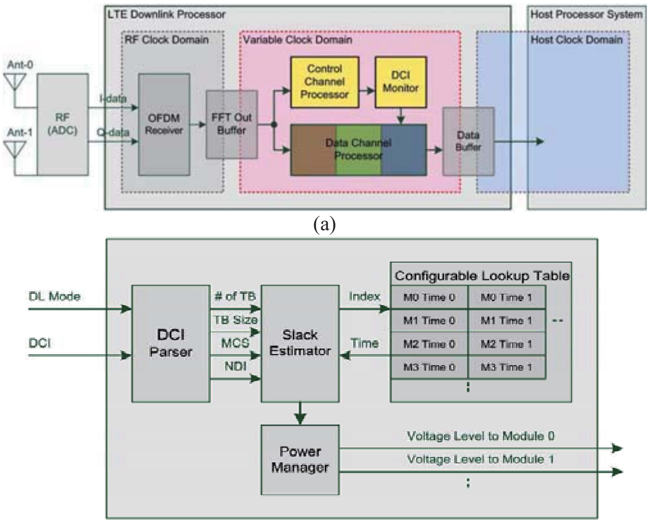


Fig. 2 The motivated example

Fig. 2 shows the motivated example of our study. As shown in this figure, existing data channel processor (DCH-Proc) cannot exploit the variable slack time, because voltage and frequency pair of existing DCH-Proc is fixed. However, DCH-Proc adopting our proposed method performs power management by lowering voltage and clock speed of processor do not exceed the deadline of 1ms. In this figure, data channel processor of the proposed method takes full advantage of slack time and optimizes power that are without the delay time.

IV. PROPOSED METHOD

The overall structure of our proposed method is shown in Fig. 3. It consists of control channel processor (CCH-Proc), DCH-Proc, and DCI monitor. *CCH-Proc* decodes the control channel of each subframe and pass the data control information (DCI) to DCI monitor. *DCH-Proc* acts to extract the DCI based on data obtained by the CCH-Proc. *DCI monitor* plays the most important role of our method. It analysis of DCI and perform power management. Also, it predicts the size of the data that must be processed within subframe from decoded DCI at the CCH-Proc, estimates the run time of corresponding each hardware block, determines the appropriate power policy, and applies to the DCH-Proc to decode the received packet.



(a)

(b)

Fig. 3 The overall architecture of proposed method. (a) Downlink processor (b) DCI monitor

Fig. 2 (b) shows the structure of the DCI monitor. It consists of DCI parser, Slack Estimator, Configurable look-up table (LUT), and power manager. *DCI Parser* receives the DCI that decoded by CCH-Proc and parses of DCI according to downlink mode. DCI contains all information of the processing time of receiving data. Thus, decoding DCI is major role of our work. This result is passed to the slack estimator. The *slack estimator* calculates the total run time of hardware block chain of the DCH-Proc using pre-defined LUT, and also calculates the slack time of DCH-Proc of sub-frame. Based on the calculated slack time, the *power manager* determines the optimal voltage and frequency pairs. *LUT* has the size of transport block (TB), runtime of each hardware block depending on modulation and coding scheme (MCS). Finally, *DCI monitor* scales down the operating voltage and frequency while preserving deadline guarantees.

V. EXPERIMENTAL RESULTS

For the experiments, we validated our method by simulating the energy consumption of an RTL simulator. The power values were measured by using the power theater tools [6]. We assumed that 20MHz bandwidth of communication environment and best channel condition. Also, the benchmarks are composed variable size of TB and MCS including link adaptation according to channel condition.

We conducted experiment to compare the performance of our proposed method with that of the original scheme. Firstly, we evaluated only dynamic power management (DPM) method. DPM reduces the power consumption by shutting down when it is idle. Secondly, we applies DVFS method to decoding packet. The comparison results are summarized in Fig. 4 and Fig. 5.

As shown in Fig. 4 and Fig. 5, all of benchmarks are superior in terms of energy saving except in case 1 and 2, energy saving of proposed method are same as that of DRX only method. There are no energy savings because there are no time slack in that case. DRX with DPM method shows a power saving which 15.19% on average. Using DRX with DVFS method, it saves power 40.72% on average.

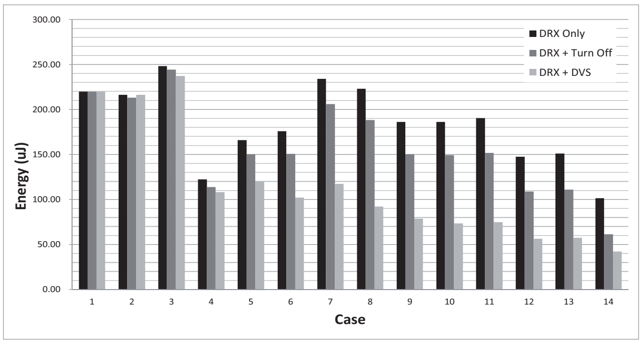


Fig. 4 Energy dissipation comparison

The effectiveness of energy saving and saved power ratio of our proposed method is shown in Fig. 5. As shown in this figure, proposed method can save a lot of power. Consequently, proposed method showed impressive results for the original DRX method.

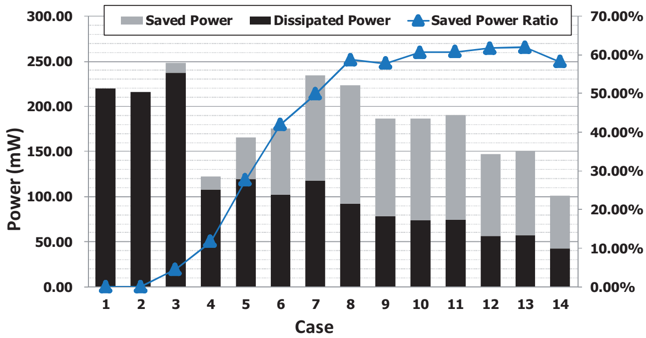


Fig. 5 The energy saving ratio and saved power of proposed method

VI. CONCLUSION

Advanced mobile communication technology such as LTE which provides higher data rate leads more complex processors usage, especially in modem part. Until now, most power saving activities in LTE model focused only DRX mechanism which utilizes IDLE time. We propose an aggressive power saving method in active state.

ACKNOWLEDGMENT

This work was supported by Samsung Electronics and by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (2013R1A1A2011208).

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