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An analytical model driven by fluid queue for battery life time of a user equipment in LTE-A networks

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ABSTRACT

During the Discontinuous Reception (DRX) mechanism, a User Equipment (UE) turns off most of its components for a prolonged period. The battery charge of a UE, which is a continuous quantity, arises as a fluid model. In this scenario, we represent the system as the reservoir where battery charge gets accumulated or is depleted gradually over the time, subject to a random environment constructed by the DRX mechanism. Therefore, the DRX mechanism acts as the background process for the fluid queue model of the battery charge. In a UE, battery charge available at any time t is considered as the fluid available in the reservoir. Different discharging rates are considered for the various states of the DRX mechanism. Using the fluid queue model, cumulative distribution function for the battery life of a DRX enabled UE is derived. Further, the expression for the mean battery life is obtained and analyzed numerically.

1. Introduction

In recent years, smartphones have emerged as the basic commodity for the young generation. However, some of the major constraints for the smartphone users are, short battery life due to various applications, large display screen and high data rates. For the current generation Long Term Evolution/Long Term Evolution-Advanced (LTE/LTE-A) introduced by Third Generation Partnership Project(3GPP), a power saving mechanism known as Discontinuous Reception (DRX) mechanism has been launched [1,2].

LTE/LTE-A standard supports two types of Radio Resource Control (RRC) modes, RRC_ CONNECTED and RRC_IDLE [3]. These modes are categorized based on the handling of RRC connection. The fundamental difference between LTE/LTE-A DRX and other existing DRX mechanism is that LTE/LTE-A DRX mechanism allows a UE to enter a sleep period while the UE is in RRC_CONNECTED mode, i.e., still registered with evolved NodeB (eNB), and therefore leads to more power saving in UEs [4].

In previous years, various surveys have shown that as the battery capacity of the UEs is improved, the screen size and other data packet processing also have been improved in that time span [5, 6]. This is one of the reason that why has the increased battery capacity not improved the battery life of UEs significantly over the time. Also while using UEs, most of the activities involved are web browsing, gaming and multimedia apps which again leads to battery consumption at a high rate [7].

In this paper, battery content of a DRX enabled UE is investigated. Further, an analysis is performed to improve the battery life of a UE. Battery content of a UE is called charge which is a real quantity whose discretized approximation would not be as good. Considering that, we have used fluid queue modeling technique to model the battery charge of the UE. In general, fluid queues are used to represent a model where some amount is depleting or accumulating gradually over a time, subject to a random environment [8,9].

In past, various studies have been performed to reduce the energy consumption in smartphones. For example, a risk-theoretic Markov fluid queue model is proposed for the computation of the first battery outage probabilities in a given finite time horizon [10]. Further, this model is used in obtaining the optimum operational parameters for the threshold policies. In [11], the outage probability performance of a new relay selection scheme for the energy harvesting relays based on the wireless power transfer is investigated. A finite-state Markov chain is developed to capture the evolution of relay batteries under the proposed relay selection scheme. But this system may become complex with the increase in the number of relay nodes and further, Markovian-based analysis turns even more difficult. An efficient transmission scheme is proposed for the downlink of an OFDMA multicell multiuser system with multiuser decoding capable receivers. This scheme works optimally

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in small network scenario but fails to do well in large network scenarios [12].

An approach to automatically access to the Power Line Communication (PLC) network by identifying the modulation of signals is proposed. Further, an MIMO based cooperative modulation identification scheme is developed for the power saving [13]. An enhanced intercell interference coordination by considering centralized processing controller with almost blank subframe (eICIC-CPC-ABS) is proposed for the heterogeneous networks (HetNets). This method provides significant savings in transmitting power [14]. In [15], authors demonstrated that by controlling both transmit power and stored energy usage of Base Stations (BSs), energy costs can be effectively reduced. Specifically, they propose a two-stage BS operation scheme where an optimization and control subproblem is solved at each stage, respectively. In [16], downlink-power-control scheme is presented for femtocell with no overhead signaling exchange with the macrocell. The transmit power can be reduced by 52.6% which leads to a power effective solution in UEs.

To study the effect of the battery charge level on the energy consumption of the battery operated devices, a set of measurements have been framed [17]. On the basis of these measurements, the authors have found a clear correlation between battery voltage level and the power consumption. In [18], a battery life extension method has been proposed. A technique of selective data reception on a UE according to the state of a battery in the UE is used. In this work, the authors have proposed that the battery state information of a UE is transmitted to the corresponding application server with keep-alive signaling or initial signaling messages. An analytical model fitting has been proposed for the specific DRX mechanism by using a semi-Markov process [19]. Two key performance indicators affected by the DRX mechanism, the power saving factor and the average buffering delay of the radio-off periods, are derived. Information about the battery life is discussed in [20,21]. The battery life of mobile devices have been improved by focusing on improving the energy efficiency of the hardware and the software. Some of the ways of improving energy efficiency are like, by reducing the amount of data being transmitted, increasing the capacity of the internal battery, or restricting the resources allocated for the idle (background) applications [22].

One more approach used widely is code offloading. In this method migrating mobile code is executed remotely in the cloud or on the dedicated servers which lead to the energy saving on the UEs [23]. Further, in [24] the optimal active power flow model for UEs is discussed. In [25], the authors have investigated battery life of a UE subject to the stochastically determined charging and discharging periods. A multi-regime fluid queue model, imposing a threshold at some value is proposed. Performance analysis of batteries of the multi-hop wireless network under energy harvesting is conducted, where the network is dependent on the renewable energy for the power consumption [26]. Further, the energy levels are modeled in the battery using a stochastic fluid-flow model to determine the availability and time-averaged latency. In recent times, a lot of work has been carried out in evaluating the performance of the DRX mechanism under various limitations and conditions. Out of these studies, most of the work define analytical model, to capture the behavior of the DRX enabled UEs for different types of traffic [27]. To the best of our knowledge, a fluid queue modeling of the battery life of a UE, equipped with the DRX mechanism has not been performed so far. This motivated us to propose a fluid queue model for examining the battery life of a UE during DRX mechanism in LTE-A networks.

In this paper, a novel approach to find the analytical results for the battery life of the UEs is considered. We have derived the battery life distribution for the Lithium polymer battery of a UE. Advantages of this type of batteries includes its light weight, reasonable size at low price, more resistance to the overcharging, etc. [18]. A two level fluid queue model is formed for investigating the battery life with different rates of discharging in the respective levels. Further, in [28], it is discussed that steady-state analysis only provides some information on the battery life, which is not sufficient viz., for studying the dynamic behavior of the battery discharge. In light of this, transient analysis conducted in this article will be of critical value, in understanding the dynamic behavior of the battery life, in controlling the discharge of the battery, and in studies relating to the rate of convergence to the steady-state. Thus, one of the main contribution of this paper lies in obtaining the distribution of battery life of a DRX enabled UE in LTE-A networks.

The rest of the paper is organized as follows. The DRX mechanism and its configuration are introduced in Section 2. Proposed analytical fluid queue model is discussed in detail in Section 3. In Section 4, an analytical model driven by fluid queue model is developed and its performance analysis is performed. Results are obtained and compared numerically in Section 5. Pointers to the conclusion and some future work directions are given in Section 6.

2. DRX mechanism and its configuration

DRX allows a UE to monitor Physical Downlink Control Channel (PDCCH) discontinuously, when the UE is not receiving the data packets from the related eNB [27]. When a UE is not monitoring the PDCCH, the UE enters in a power saving state during which most of its components are turned off. This exercise reduces the power consumption appreciably [29]. During DRX mechanism, the UE wakes up for a while from sleep to monitor the PDCCH and keeps on returning to the power saving state if packet's arrival is not detected. Moreover, if there is arrival of a packet, the UE resumes to provide service to the arriving packets in the power active state, i.e., a state during which the UE remains on, [30].

Following are the DRX parameters considered in this paper, [29, 31].

- *Inactivity timer* (T_{IN}): It is the time duration during which a UE waits before initiating the DRX. It works as a timer which re-initiates itself after a successful reception of the data on the PDCCH. On the expiration of the inactivity timer, the UE enters into a short DRX cycle.
- *Short DRX cycle* (T_S): It is the length of the first DRX cycle after the initiation of DRX mechanism in a UE. This short DRX cycle is repeated for a predetermined number of times if no data packet arrives and ends otherwise. In this duration, the UE turns off most of its components.
- *Short DRX cycle timer* (N_S): It is a timer which regulates the number of short DRX cycles before starting the first long DRX cycle.
- *Long DRX cycle* (T_L): It is the length of the first long DRX cycle which starts on the expiration of N_S short DRX cycles if no data packet arrives ($T_L \geq T_S$). Further, this cycle keeps on repeating itself for a predetermined number of times.
- *On duration timer* (T_{ON}): It is the length of a very small time interval inside a DRX cycle (short or long) at its end. During T_{ON}, the UE monitors the PDCCH for the arrival of a new packet. A packet arrival indication at the PDCCH during T_{ON} wakes up the UE, and it begins to serve the data packet.
- *Busy period* (T_B): It is a length of time during which the UE provides service to the packets after waking up from DRX.

Hence, as depicted in Fig. 1, DRX mechanism is composed of the power saving state and the power active state. Further, the power saving state comprised of the short DRX cycle and the long DRX cycle, whereas the power active state comprised of the inactivity timer period and the busy period. Thus, the DRX mechanism consists of the four states, the busy period, inactivity timer period, short DRX cycle and the long DRX cycle.

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