Comparisons of Power-saving Efficiency for QoS Traffics in LTE Network by Burst Scheduling

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***Abstract*—The Discontinuous Reception (DRX) operation is proposed in long term evolution (LTE) network to achieve efficient power management. It is hard to determine the DRX parameters for optimal power utilization especially when the channel condition and quality of services are taken into consideration. Most studies dealt with this issue by dynamically adjusting DRX parameters. However, it is a heavy burden for eNB to manage the DRX parameters of each UE individually. In addition, frequent reconfiguration on the parameters also introduces huge signaling overhead. This paper proposes the burst based scheduling for fixed DRX parameters without dynamic reconfiguration to investigate its power efficiency. Both http and video streaming traffic models were applied to examine the performance of the proposed scheme. The simulation results show that the proposed burst scheduling can significantly improve the power utilization of video streaming traffic when compared to that of the http traffic.**

***Index Terms*—Power saving, Sleep mode, resource allocation, LTE**

I. INTRODUCTION

Wireless communication has created a convenient environment in which people can ubiquitously access networks and share information, and has enabled the deployment of several multimedia services through handheld devices. The long term evolution (LTE) technology has been proposed to support broadband services in mobile environment [1, 2]. LTE is an evolution of GSM /UMTS network technologies, and adopt new radio interface and modulation to offers high bandwidth for the mobile devices. Different services have different quality requirements. LTE standard defines different QoS Levels for the provisioning of different kinds of applications. In addition to the quality of services, as mobile devices always equipped with limited energy, power saving plays an important role for the success of mobile services deployment in real environment. Therefore, the radio resource schedule algorithm shall consider not only the efficient radio resource utilization, but also the effective power utilization. Thus although the emerging wireless communication technology provides much more bandwidth for the deployment of several attractive services, the power consumption constrained the availability of mobile devices.

For the effective radio resource allocation, it is considerably more correlated and critical to the diversity channel conditions among UEs and the effective usage of the adaptive modulation and coding (AMC) scheme for transmission in OFDMA systems. A higher level of modulation and coding scheme (MCS) achieves higher spectrum efficiency and, therefore, higher system throughput if channel condition is acceptable. As the channel conditions of UEs may be different and changeable from time to time, if it is not well allocated, the service quality will be downgraded due to insufficient bandwidth. For the consideration of power saving, UE shall avoid keeping awake without either transmission or receiving. In other words, eNB had better let UE enter sleep mode if it has no sufficient radio resource to allocate to UE. However, it will introduce longer delay time when UE enters sleep mode because eNB can only deliver packets to UE who is in the awake mode. Thus the tradeoff among QoS, power saving, and spectrum efficiency is a quite complex issue to achieve effective radio resource scheduling. And the complexity of the scheduling algorithm shall not be too high to affect the resource allocation in practical applications.

The power saving issue always plays an important role in wireless mobile networks. And the provisioning of sleep mechanism is an effective approach toward this objective. In LTE, the Discontinuous Reception (DRX) mechanism is provided to allow UE to enter sleep mode for power saving. The DRX defines several parameters, such as inactivity timer, on duration, off duration, number of short cycles, etc., to manage the DRX operation. Unlike the on-demand scenario (i.e. the request/response procedure) used in the sleep management of Worldwide Interoperability for Microwave Access (WiMax) network, DRX adopts the agreement based concept. That is eNB and UE have the same recognition of the DRX parameters and UE will enter sleep mode automatically without informing eNB when the parameter value is satisfied. Among them, the inactivity timer plays the critical role of entranceway of the sleep mode. In this paper, we propose the burst based scheduling algorithm to improve the power saving of LTE UEs by considering their QoS requirements. Given by specific inactivity timers, both of http and video streaming services were adopted for experiment to analyze the effectiveness of the proposed scheme

The rest parts of this paper are as follows. The background and related works are described in the following section. The burst based scheme is proposed in the section 3. Experimental results are provided in the section 4 with discussions. And we conclude our works in the last section.

II. BACKGROUND

Unlike 3G network, LTE proposes pure packet switch based architecture for all kinds of applications. The packet switch based architecture provides the flexibility in arranging radio resource when compared to the circuit switch based approach. Fig. 1 illustrates the network architecture of LTE. UE accesses the network through the air interface, named as LTE-Uu. And the mobility management entity (MME) is one of the core components of LTE. It is responsible for the management of bearer connection.

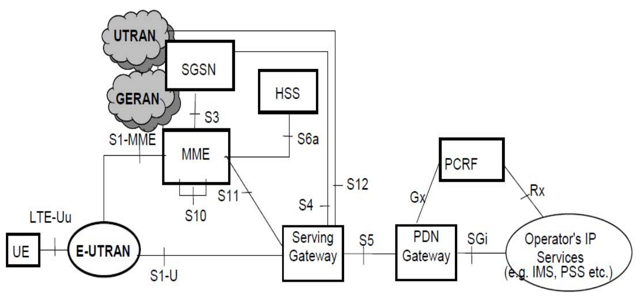


Fig.1. Network architecture of LTE

The orthogonal frequency division multiple access (OFDMA) is applied for downlink transmission in LTE. The OFDMA system has the advantages of flexible subcarrier allocation and adaptive modulation with respect to channel conditions. As the radio resource can be flexibly allocated, eNB could schedule the radio resource to the UEs that starve for the resource to satisfy their QoS first and postpone the requirements of other UEs that are not badly in need of resource. Instead of keeping awake, the UEs, who are not allocated with resource, can enter sleep mode for power saving. As mentioned in previous section, there are various parameters defined in DRX mode of LTE as shown in Fig. 2. Basically, UE cannot always in the active mode and it will enter DRX mode if it has not received any data for the inactivity period (i.e. the inactivity timer). And the DRX mode is further divided into short cycle and long cycle. Each cycle consists of an ON duration and an OFF duration. The long cycle has longer OFF duration than that of the short cycle.

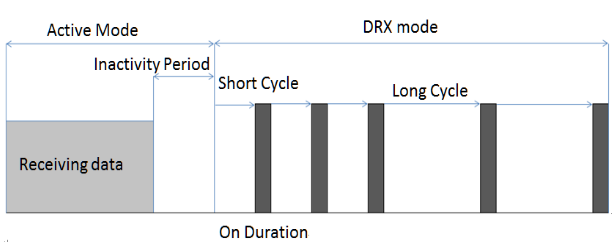


Fig. 2. The DRX mode of LTE UE

Several studies were proposed to discuss the efficiency of DRX mode. The authors adjusted the ON duration of DRX to study the relationship between power saving and packet delay in [3]. The performance of static DRX, DRX with inactivity timer, and DRX with short sleep period for web-browsing service were studied in [4]. Their results showed that UE with short sleep period and short inactivity timer has lower power consumption and better throughput than the UE with short inactivity timer, however, without short sleep period. The results indicate the importance of adapting DRX parameters to traffic characteristics. In [5], the Channel Quality Indicator (CQI) preamble scheme was proposed to evaluate VoIP performance for various DRX cycles and timers.

Most previous studies only considered either power saving efficient or sleeping period management by adjusting DRX parameters. Seldom of them investigated the effectiveness of scheduler on traffic types with different characteristics. Although eNB can dynamically adjust DRX parameters for better power saving efficiency, it is a complex task for eNB to manage the DRX parameters for each UE individually. As there are many parameters defined in DRX mechanism and they are correlated to each other. eNB needs much overhead to fine tune them for better power saving efficiency. Additionally, it introduces signaling overhead for eNB to reconfigure the DRX parameters in UE. Alternatively, eNB may also adjust its scheduling by considering the pre-specified DRX parameters for power saving. However, whether the efficiency is significant for various kinds of traffic models is doubtful and it is the objective of this paper.

III. THE PROPOSED BURST BASED SCHEDULING ALGORITHM

As mentioned above, the inactivity timer is designed as the entranceway for UE to enter DRX mode. And UE wastes its power during this period because UE is awake without receiving any data. Hence the basic idea of the proposed scheduling algorithm is to prevent the occurrence of this situation. That is to reduce the staying period when the inactivity timer is counting down. In addition to the power saving, eNB needs to maximize the spectrum efficiency and to satisfy the desired QoS of each UE. From the spectrum efficiency point of view, OFDMA can be characterized as a kind of elastic bandwidth. Its total bandwidth (in bits) is determined by the MCS level, which is determined by the channel condition between eNB and UE. In order to coordinately consider the factors of spectrum efficiency and QoS for resource allocations, the following basic weighting function for UE i at resource block group (RBG) j, denoted as $W_{i,j}$, is provided in equation (1) to determine the scheduling priority. The UE gets higher weighting value means the higher scheduling priority.

$$W_{i,j} = (D_i)^m * (M_{i,j})^n \quad (1)$$

where D_i is the longest delay time of the packet that currently in the buffer of UE *i* and $M_{i,j}$ is the MCS level of UE *i* on the *j-th* RBG. The parameters *m* and *n* denotes the degree of the effectiveness of delay and channel condition, respectively. However, equation (1) only considers the delay budget for QoS satisfaction and the MCS level for spectrum efficiency, which lacks of the scheduling for power saving. In order to further analyze the operations between active mode and DRX mode, the power consumption model proposed by Nokia as shown in Fig. 3 is examined [6]. Fig. 3 defines 4 states, which are deep sleep, light sleep, active with data receiving (rx), and active with no data rx, of UE. And the power consumptions of each state and the state transitions are also specified.

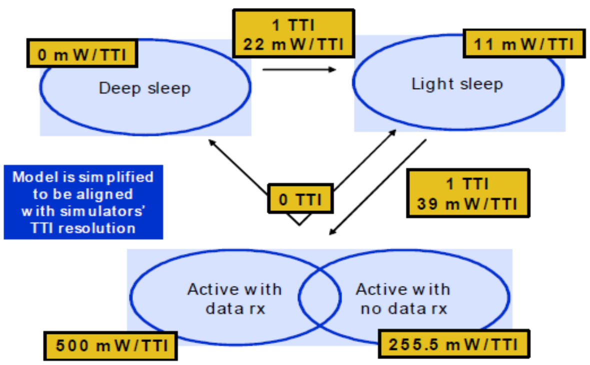


Fig. 3. The state transitions with power consumptions of UE [6]

It is noted that both of the deep sleep state and the light sleep state reflect the OFF period and ON period of DRX mode, respectively. The active with no data rx state denotes UE being in active state, however, without receiving any data. Thus, UE is counting down the inactivity timer when in this state. It is also noted that eNB only needs to allocate radio resource for UEs that are in light sleep, active with data rx, and active with no data rx states. In the proposed scheme, weighting function of equation (1) is applied for UEs that are in light sleep state. And for the UEs, which are in either active with data rx state or active with no data rx state, the burst scheduling approach is used in the weighting functions. Fig. 4 shows the comparison between the traditional scheduling and burst based scheduling. It shows the example that packets P_1 and P_2 are going to be scheduled in eNB. t_1 and t_2 are the transmission times of P_1 and P_2, respectively. $t_{inactivity}$ is the length of the inactivity timer for counting down and t_{DRX} is the duration in DRX mode (i.e. the sleep time). The concept of proposed scheme is to aggregate P_1 and P_2 packets into one burst for transmission. And UE's enters into DRX mode for power saving after sending P_1 and P_2. It is obvious that the burst based scheduling saves more power than the traditional scheme.

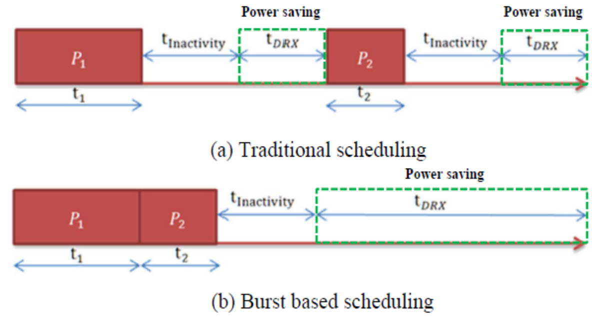


Fig. 4. Comparison of traditional and burst based scheduling

Thus if eNB is sending data to a specific UE, i.e. this UE is in the active with data rx state, we prefer eNB keeps sending data, which is queued in its buffer, to this UE to prevent it from entering active with no data state and counting down the inactivity timer. The basic idea is to give UE that is in the active state a higher weighting value than that obtained in equation (1) for the same D_i and $M_{i,j}$. Furthermore, in the proposed scheme, the weighting value of UE, which is in the active with data rx state, is designed to be getting larger as its staying time in this state increases. And if UE is in the active with no data rx state, the value will decrease as its staying time increases. The reason to proportionally decrease the weight value when UE is in the active with no data rx state is that UE is counting down its inactivity timer in this state. And its benefit of power saving is getting smaller when the inactivity timer is getting expiration. Then, based on equation (1), we propose the weight values for UE in the active with data rx state and with no data rx state by multiplying the factors, $X_i^{w/d}$ and $X_i^{n/d}$, as shown in equations (2) and (3), respectively.

$$W_{i,j}^{w/d} = (D_i)^m * (M_{i,j})^n * X_i^{w/d} \qquad (2)$$

$$W_{i,j}^{n/d} = (D_i)^m * (M_{i,j})^n * X_i^{n/d} \qquad (3)$$

where

$$X_i^{w/d} = a_{w/d} + b_{w/d} * \log_{10}(t_{(1)i} + 1) \qquad (4)$$

$$X_i^{n/d} = a_{n/d} + b_{n/d} * \frac{(W_i^{w/d(-1)} - 1)}{t_{inactivity}} * t_{(2)i} \qquad (5)$$

where $a_{w/d}$ and $a_{n/d}$ are the parameters of the initial scale values for the weighting value and $b_{w/d}$ and $b_{n/d}$ are the increasing factor. $t_{(1)i}$ and $t_{(2)i}$ represent the time that UE *i* has stayed in the active with data rx state and the current inactivity timer that is counting down of UE *i*, respectively. $t_{inactivity}$ is the inactivity timer that is set as the DRX parameter. And the value of $W_i^{w/d(-1)}$ is the weight value of UE *i* obtained when it is going to leave the active with data rx state and to enter the active with no data rx state. Thus $W_i^{w/d(-1)}$ is the maximum weight value of UE *i* when it was in previous active with data rx state because UE *i* monotonically increases its weight value in that state as presented in equations (2) and (4). For example, if the initial scale value is 1, i.e. a=1, then the value of $X_i^{n/d}$ for UE *i,* which just leaves the data rx state and enters the no data rx state, will be equal to the maximum weight it obtained in the data rx state, i.e. $W_i^{w/d(-1)}$, since $t_{(2)i} = t_{inactivity}$.

IV. Experimental Simulations

In order to examine the effectiveness of the power saving, simulations were performed thoroughly. Both http and video streaming traffic model were applied during the simulations. The parameters of both traffic models can be referred in [7]. It is noted that the http traffic model is delivered by web page basis. Each web page consists of one main object and several embedded objects. Table 1 specifies the parameters used in simulations. We adopted 6 MCS levels and applied ITU Veh-A channel model to vary the channel condition. For each UE, the channel condition (i.e. the SNR value) determined the MCS level assigned for data transmission.

TABLE I. Parameters of Simulation Environment

Parameters	Content
Channel model	ITU Veh-A
Channel bandwidth	10MHz
RB Number	50
RBG size	3
RBG Number	17
CQI report interval	10ms
Resource allocation type	Type 0
Subcarrier per RB	12
Subcarrier	15 KHz
MCS, Bytes/Subframe	QPSK 1/2, 19.98 QPSK 3/4, 26.64 16QAM 1/2, 38.16 16QAM 3/4, 50.88 64QAM 1/2, 91.74 64QAM 3/4, 122.32

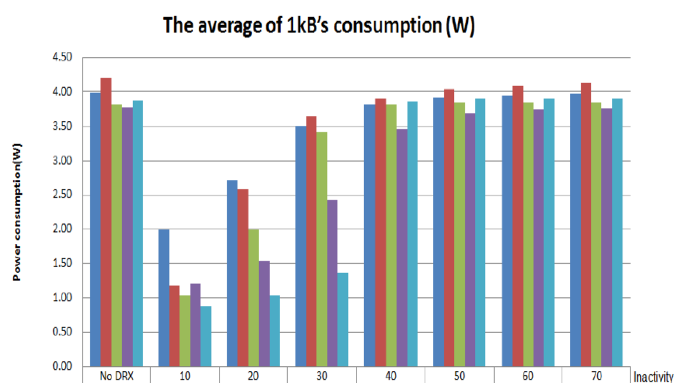
The sizes of the main object and embedded object of the http traffic are exponentially distributed with mean 10710 bytes and 7758 bytes, respectively, and the reading time between web pages is exponentially distributed with mean of 30 seconds. The average data rate of video streaming is 640 Kbps. The buffer sizes of video streaming and http traffic in eNB are 612 KB and 4 MB, respectively. The weighting function used for all UE (i.e. independent of the service) depends on the power consumption state of the UE. We examine the power saving efficiency of both traffics by varying the inactivity timer.

(1) Video streaming traffic

For the simulation of video streaming traffic model, the short and long cycles were assumed to be 16 ms and 32 ms, with 2 ms ON duration, respectively. And the number of long cycle before entering long cycle was one. We changed the parameters of the proposed weighting functions and compared them to two other schemes. The proposed schemes with 3 different weighting functions and the compared two schemes are as follows:

- Compare 1: the UE with the best channel condition always gets the highest scheduling priority
- Compare 2: the UE with the longest waiting time packet in its buffer always gets the highest scheduling priority
- Proposed 1: the proposed weighting function with m=n=1, $a_{w/d} = a_{n/d} = 1$ and $b_{w/d} = b_{n/d} = 1$
- Proposed 2: the proposed weighting function with m=2, n=1, $a_{w/d} = a_{n/d} = 1$ and $b_{w/d} = b_{n/d} = 1$
- Proposed 3: the proposed weighting function with m=n=1, $a_{w/d} = a_{n/d} = 2$, and $b_{w/d} = b_{n/d} = 1$

Fig. 5 shows the average power consumption of per 1K bytes data delivery with respect to the change of inactivity timers for the video streaming traffic. It is clear that the proposed schemes save more power than that of the compared schemes. It is also noted that the efficiency of power saving is not significant for longer inactivity timer. The average power consumptions for the inactivity timer being longer than 40ms are almost the same as the situation that without DRX mode. The reason is that UE is unlikely to enter DRX mode for longer inactivity timer. UE often keeps awaking in the active with no data rx state, and data packets frequently arrives before the expiration of inactivity timer. The inactivity timer is reset once eNB allocates the radio resource to the UE. And UE has little chance to enter DRX mode, therefore, it results in poor power utilization. The simulation results also indicate that the higher value of $a_{w/d}$ and $a_{n/d}$ (i.e. the scheme of proposed 3) leads to more power saving because it tends to arrange data to be in burst-scheduled.



	No DRX	10	20	30	40	50	60	70
Compare 1	3.99	1.99	2.72	3.51	3.81	3.91	3.95	3.97
Compare 2	4.20	1.17	2.58	3.64	3.90	4.03	4.09	4.13
Proposed 1	3.81	1.04	1.99	3.43	3.81	3.85	3.84	3.84
Proposed 2	3.77	1.21	1.53	2.43	3.46	3.69	3.75	3.76
Proposed 3	3.88	0.88	1.04	1.36	3.86	3.90	3.90	3.90

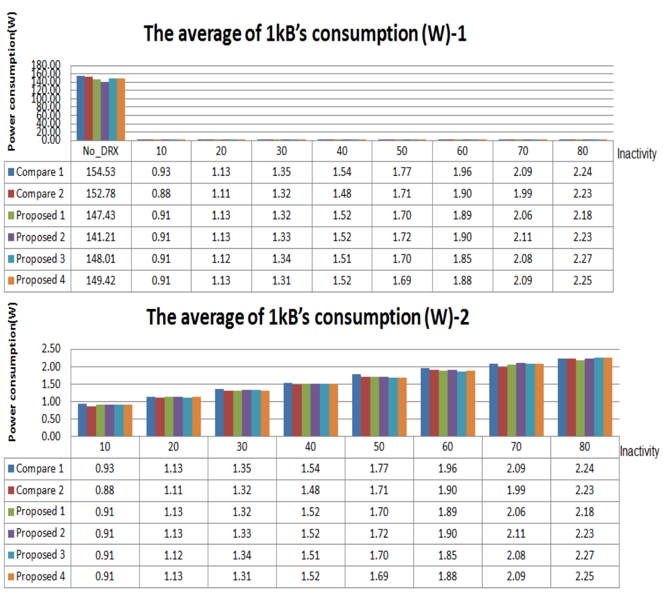
Fig. 5. Comparisons of average power consumption for video streaming

(2) Http traffic

For the simulation of http traffic, the short and long cycles were assumed to be 32 ms and 128 ms, with 2 ms ON duration, respectively. The number of long cycle before entering long cycle was also one. Four variations of the proposed scheme with different weighting functions and two compared schemes were compared in this simulation.

- Compare 1, 2, and proposed 1: the same as in previous video streaming simulation
- Proposed 2: $X_i^{w/d}$ =2, $X_i^{n/d}$ =1 (i.e. $a_{w/d}$ =2, $a_{n/d}$ =1, $b_{w/d}=b_{n/d}$ =0)
- Proposed 3: the proposed weighting function with m=2, n=1, $a_{w/d}=a_{n/d}=1$ and $b_{w/d}=b_{n/d}=1$
- Proposed 4: the proposed weighting function with m=n=1, $a_{w/d}=a_{n/d}=2$, and $b_{w/d}=b_{n/d}=1$

The average power consumptions of http traffic with respect to different inactivity timers are shown in Fig.6.



	No_DRX	10	20	30	40	50	60	70	80
Compare 1	154.53	0.93	1.13	1.35	1.54	1.77	1.96	2.09	2.24
Compare 2	152.78	0.88	1.11	1.32	1.48	1.71	1.90	1.99	2.23
Proposed 1	147.43	0.91	1.13	1.32	1.52	1.70	1.89	2.06	2.18
Proposed 2	141.21	0.91	1.13	1.33	1.52	1.72	1.90	2.11	2.23
Proposed 3	148.01	0.91	1.12	1.34	1.51	1.70	1.85	2.08	2.27
Proposed 4	149.42	0.91	1.13	1.31	1.52	1.69	1.88	2.09	2.25

	10	20	30	40	50	60	70	80
Compare 1	0.93	1.13	1.35	1.54	1.77	1.96	2.09	2.24
Compare 2	0.88	1.11	1.32	1.48	1.71	1.90	1.99	2.23
Proposed 1	0.91	1.13	1.32	1.52	1.70	1.89	2.06	2.18
Proposed 2	0.91	1.13	1.33	1.52	1.72	1.90	2.11	2.23
Proposed 3	0.91	1.12	1.34	1.51	1.70	1.85	2.08	2.27
Proposed 4	0.91	1.13	1.31	1.52	1.69	1.88	2.09	2.25

Fig. 6. Comparisons of average power consumption for http

The upper part of Fig.6 shows that UE without DRX mode consumes much more power than that with DRX mode. Furthermore, its power consumption is also much more than that of the video streaming traffic type also without DRX mode. The main reason is that the data rate of http traffic is much less than that of the video streaming, hence it results in more power consumption per transmitted data unit in http traffic. The lower part of Fig. 6 precisely compares the average power consumptions by setting different values of the inactivity timer. It shows that the average power consumption increases as the inactivity timer gets larger accordingly. However, the difference between the compared schemes and the proposed schemes is not significant. This phenomenon is mainly due to the characteristics of the http traffic. The http traffic is basically already burst within one web page, however, with a very long average reading time, which is 30 seconds in this simulation, between page arrivals. There is no traffic arrived during the reading time and the length of the designed inactivity timer is much shorter than the inactivity timer. Thus, UE enters active with no data rx state after completing the transmission of one web page and it is not possible to aggregate data from two web pages into one burst due to the long reading time. Thus UE always enters DRX mode after the expiration of the inactivity timer. Consequently, the shorter inactivity timer results in lower average power consumption.

The above simulation results indicate that the scheduling mechanism has limitation to achieve power saving. For the example of http traffic, although the proposed burst scheduling scheme tries to minimize the frequency and duration of active with no data rx state, its effect is much less than the adjustment of inactivity timer. Because the http traffic always has long reading time between web pages when compared to the traffic characteristics of other services.

V. Conclusions

In this paper, we study the power saving issue in LTE network and propose the burst scheduling by considering the state transitions of power consumption to analyze its efficiency. The proposed scheme works out different weighting functions for different states to determine the scheduling of UEs. The purpose of the proposed weighting functions is to reduce the dwelling time in the state of active with no data rx can be minimized and, therefore, the power can be saved. Both video streaming and http traffics were adopted for exhaustive simulation to investigate the effectiveness. The simulation results show that the proposed scheme can effectively save power for the video streaming traffic, however, the power saving of http traffic is dominated by the inactivity timer. We analyze the results in detail and conclude that this phenomenon mainly due to the web page based characteristic of http traffic. The results will be helpful to clearly identify the factors, which affect the power consumption, of different service types. The obtained results can be referred for the design of power saving scheduling. Furthermore, the results reveal that power saving efficiency of some traffic, such as http, is not sensitive to the scheduling mechanism. The flexible and dynamic adjustment the DRX parameters will be an effective way when compared to the sophisticated scheduling scheme. And this is our ongoing works.

VI. Acknowledgment

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References

[1] 3GPP TS 36.300 V9.2.0. Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2.

[2] 3GPP TS 36.321 V9.0.0, Evolved Universal Terrestrial Radio Access (E-UTRA) Medium Access Control (MAC) protocol specification.

[3] Chandra S. Bontu and Ed Illidge, Nortel, "DRX Mechanism for Power Saving in LTE ", IEEE Communications Magazine, pp. 48-55, June 2009.

[4] Jeroen Wigard, Troels Kolding, Lars Dalsgaard, Claudio Coletti, Nokia Siemens Networks, Res. Center Aalborg, Aalborg East, Denmark, "On the User Performance of LTE UE Power Savings Schemes with Discontinuous Reception in LTE", Communications Workshops 2009, IEEE ICC Workshops, pp. 1-5,June 2009.

[5] Aho Kari, Puttonen Jani, Henttonen Tero, Dalsgaard Lars , " Channel Quality Indicator Preamble for Discontinuous Reception ", Vehicular Technology Conference (VTC), pp. 1-5, 2010-Spring.

[6] 3GPP TSG-RAN WG2 Meeting #57bis, R2-071285,St. Julian's, Malta, Agenda item:5.2.3, Source: Nokia , Title: DRX parameters in LTE.

[7] 3GPP TR 25.892 V6.0.0, Technical Specification Group Radio Access Network, Feasibility Study for Orthogonal Frequency Division Multiplexing (OFDM) for UTRAN enhancement.