LTE TECHNOLOGY UPDATE: PART 2

Energy Impact of Emerging Mobile Internet Applications on LTE Networks: Issues and Solutions

Maruti Gupta, Satish C. Jha, Ali T. Koc, and Rath Vannithamby, Intel Corporation

ABSTRACT

Mobile Internet applications run on devices such as smartphones and tablets, and have dramatically changed the landscape of application-generated network traffic. The potent combination of millions of such applications and the instant accessibility of high-speed Internet on mobile devices through 3G and now LTE technology has also changed how users themselves interact with the Internet. Specifically, the radio states in LTE such as RRC_Connected and RRC_Idle were designed with more traditional applications such as web browsing and FTP in mind. These traditional applications typically generated traffic only during Active (Connected) state, and once the user session ended, usually the traffic ended too, thus allowing the radio to move to Inactive (Idle) state. However, newer applications such as Facebook and Twitter generate a constant stream of autonomous and/or user generated traffic at all times, thus erasing the previously clear demarcation between Active and Inactive states. This means a given mobile device (or user equipment, in LTE parlance) often ends up moving between Connected and Idle states frequently to send mostly short bursts of data, draining device battery and causing excessive signaling overhead in LTE networks. This problem has grown and attracted the research community's attention to address the negative effects of frequent back and forth transitions between LTE radio states. In this article, we first explore the traffic characteristics of these emerging mobile Internet applications and how they differ from more traditional applications. We investigate their impact on LTE device power and air interface signaling. We then present a survey of state-of-the-art solutions proposed in literature to address the problems, and analyze their merits and demerits. Lastly, we discuss the solutions adopted by 3GPP including the latest developments in Release 11 to handle these issues, and present potential future research directions in this field.

INTRODUCTION

Fourth-generation (4G) technologies such as Long Term Evolution Advanced (LTE-A) have enabled the always-on always-connected model of Internet connectivity. However, this has led to increased issues of reduced battery lifetimes of mobile devices and attracted the attention of a huge research community [1–3]. Before the introduction of smart mobile devices (e.g., smart phones, e-readers, and tablets), the most popular Internet applications included those such as HTTP web browsers and FTP. These applications generate traffic in a very specific pattern comprising distinct Active and Inactive sessions, as shown in Fig. 1. The Active sessions consist of several bursts of packet arrival activity with interarrival times within the bursts in the range of a few to hundreds of milliseconds, while Inactive sessions are the times when the active session ends (i.e., the user closes the application and there is no data transmission) [4, 5]. Third Generation Partnership Project (3GPP) Releases 8, 9, and 10 (LTE and LTE-Advanced) were designed before applications such as Facebook and Twitter were in widespread use over mobile devices. LTE's power management model, where the user equipment (UE) stays in RRC_Connected state during Active sessions and moves to RRC_Idle during Inactive sessions, is well suited to the previous generation of popular applications, and was effective at minimizing UE power consumption and other air interface resources. However, it is no longer good enough to effectively address the power consumption issues for new and emerging mobile Internet applications. We use the terms Connected and Idle for RRC_Connected and RRC_Idle, respectively, throughout the rest of this article .

Recent developments in the field of smart mobile devices and the exponential growth in the number of mobile applications targeted for such devices have changed the traffic profile considerably. The demarcation between Active and Inactive sessions has either been blurred (since users sometimes do not close a session, but let it run in the "background" instead) or previously Inactive sessions are now witnessing frequent autonomous application-initiated small packet transmissions, as depicted in Fig. 1 [5, 6]. As a result, the UE is unable to stay in Idle state for the duration of the entire Inactive session. Instead, there is now a constant stream of random aperiodic traffic comprising very small amounts of data such as status update messages

0163-6804/13/$25.00 © 2013 IEEE

and keep-alives, which is sent during Inactive sessions, causing the UE to frequently move between Connected and Idle states. This has created two major problems:

- Higher device power consumption due to increased time spent in Connected state by the UE
- Excessive signaling messages due to frequent transitions in the network

We examine both of these problems in greater detail later.

Further organization of this article is as follows. Various power management schemes in 3GPP Releases 8, 9, and 10 are discussed next. We then present a survey of state-of-the-art solutions proposed in the literature to address the device power issues in LTE, and to analyze their merits and demerits. Next, we present the solutions adopted by 3GPP in Release 11 to handle these issues. The potential 3GPP Release 12 and beyond solutions are discussed. Finally, we end with some concluding remarks.

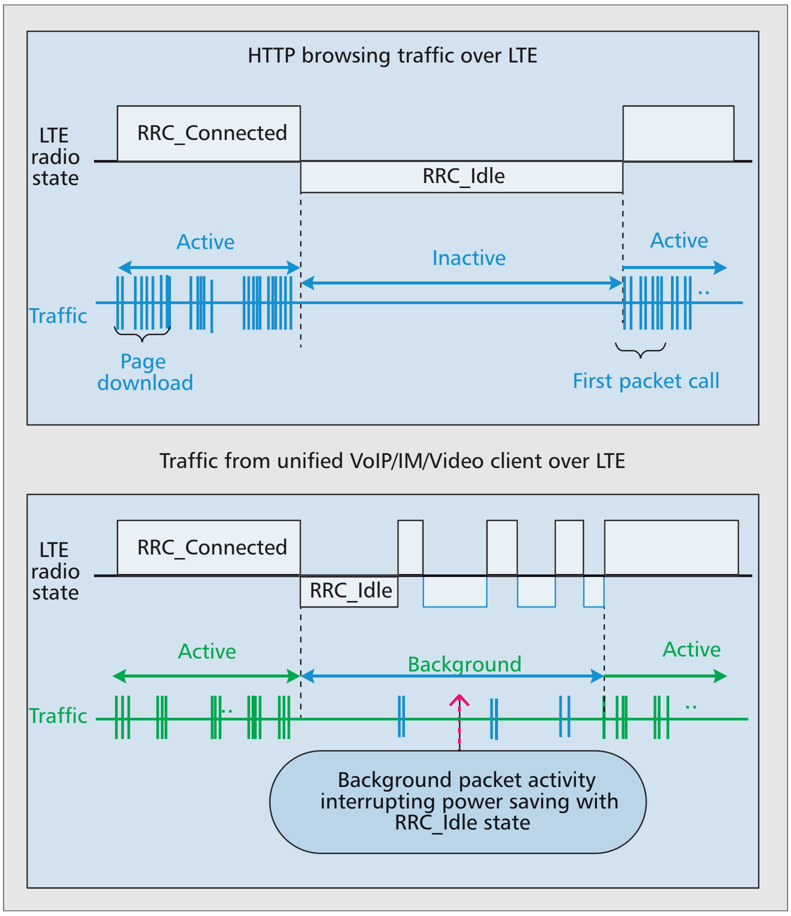


Figure 1. *HTTP browsing vs. emerging mobile Internet traffic over LTE.*

Existing LTE Power Management Mechanisms in 3GPP Releases 8, 9, and 10

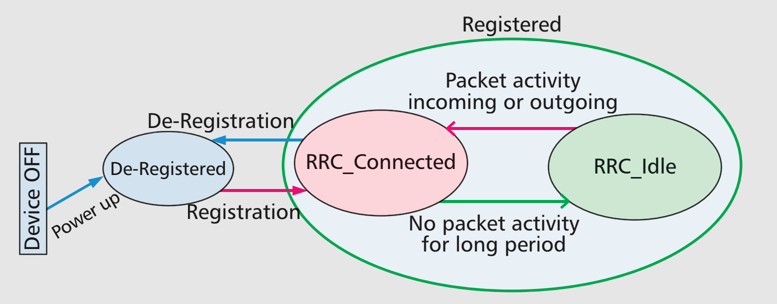
From 3GPP LTE Release 8 until Release 10, there were essentially no major changes in the power management schemes. In LTE, as shown in Fig. 2, when the device is first powered on, the UE is in De-Registered state. Once the device is registered with the network, the radio can be in either of two different radio states called RRC_Connected and RRC[1]_Idle [1, 7]. During network entry, the UE starts in Connected state, where it can listen to the network and receive/transmit data, and thus consumes higher power (i.e. about 1–1.5 W) [2, 8]. After a period of data inactivity (which depends on the RRC Inactivity Timer configured by the network operators), the UE transitions into the Idle state. The UE typically consumes much less power (i.e., in the range of a few milliwatts) in Idle [2, 8]. Typically, an RRC Inactivity Timer is in the range of a few seconds to a few tens of seconds [4, 8]. When data is received from the higher layers in Idle state, the radio starts the process of reconnecting to the network to go back to Connected state in order to send or receive data. An important point to consider here is that every transition to Connected state means that the radio is in active state not just to transmit or receive data; it also spends additional time waiting for the RRC Inactive Timer to expire to make sure no more traffic arrives before it goes back to the Idle state. This additional time spent in Connected state is often referred to as *tail time* in the literature [8, 9].

In 3G, to counter the impact of tail time and lower the UE device power consumption, the UE device vendors used a feature known as Fast Dormancy to improve device battery life. Fast Dormancy allows the UE to disconnect from the network autonomously without waiting for the RRC Inactivity Timer to expire by sending a message telling the network that it is releasing the connection [9]. However, the Fast Dormancy feature implementation in 3G proved problematic, with the UE leaving the network and then reconnecting immediately after a short time due to the nature of the new traffic pattern. The 3G network infrastructure suffered heavy congestion caused by the excessive signaling overhead of the premature connection releases and connection setups by the UE. Subsequently, the 3G feature was improved such that the UE only signaled its *desire* to disconnect from the network and awaited further network instruction (to either change its connected state or release the connection). A corresponding feature is not provided in LTE [10]. From LTE Release 10 onward, it was clarified that the UE may not autonomously disconnect from the network for power saving purposes [11].

This brings us to the problem of excessive signaling overhead mentioned earlier, stemming from the change in today's application traffic profile. Table 1 shows the scale of this problem [12]. Here, the first column shows the type of traffic. Active traffic session represents the duration of browsing traffic when the user was actively interacting with the device. Background traffic session represents the duration when the user is not directly interacting with the device and consists of applications such as Skype, Facebook, Gmail, GoogleTalk, and weather and stock updates that run in the background and generate status updates, notifications, keepalives, and automatic updates. The second to fifth columns

[1] *RRC stands for radio resource control.*

IEEE Communications | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page | Qmags THE WORLD'S NEWSSTAND®



	De-Registered	Registered	
		RRC_Connected	RRC_Idle
Registration state	EMM de-registered	EMM registered	EMM registered
RRC state	Not applicable	RRC_Connected	RRC_Idle
UE location	Unknown	eNB	Tracking area
Data exchange	No data	Data ON	Stand-by

Figure 2. *UE states in LTE at the radio and the network. EMM: Evolved packet system (EPS) mobility management.*

show how much data in bytes was sent for each byte of signaling overhead for various RRC Inactivity Timers. As can be seen from Table 1, the amount of data exchanged during active traffic sessions for each signaling byte is one to two orders of magnitude greater than can be exchanged during background traffic sessions. As the RRC Inactivity Timer increases, the state transitions between Connected and Idle states decrease. As a result, we see that the amount of data per byte of signaling increases. However, the ratio of these numbers in active and background traffic sessions still remains high.

Although Table 1 illustrates the increase in signaling overhead over the air interface, there is also a similar impact of repeated setup/release in the core network (particularly at the mobility management entity [MME] and serving gateway [S-GW]). To reduce the frequency of such transitions, it may be preferable for the UE to stay in Connected state rather than switching back and forth between Connected and Idle states.

When the UE is in Connected state, it can use a power saving mechanism known as discontinuous reception (DRX) in LTE to save power. DRX saves UE battery power by allowing the UE to monitor the downlink (DL) control channel less frequently and to go to sleep whenever there is no packet activity for the UE [2, 3]. DRX is triggered when a parameter known as DRX Inactivity Timer expires. The UE then goes through the DRX cycles, which consist of an ON Duration followed by Sleep periods during which the UE stops monitoring the DL control channel. The sleep duration can be of short periods followed by long sleep periods, depending on whether Short DRX cycle is configured or not. A detailed description of DRX can be found in [7, 13]. Figure 3 depicts an example scenario of DRX operation. For the sake of simplicity, transition to Idle state is not shown in Fig. 3. DRX is ended when the UE either sends or receives any traffic.

However, typical LTE mechanisms support DRX for only limited periods of time, after which the network releases its connection and the UE transitions to Idle. In addition, the DRX mechanism is configured by the network and usually does not change to adapt to the traffic. Note that DRX can be implemented in Connected as well as in Idle state. However, the functionality and parameters of the DRX operation in these two states are different. Since data transmission occurs in Connected state, we focus on DRX in Connected state. In the rest of this article, we use the term DRX for DRX functionality during Connected state.

To better examine and resolve the issues around the disproportionately high RRC state transitions and increased power consumption, 3GPP standards initiated a work item known as "RAN Enhancements of Diverse Data Applications" [4] in Release 11. In the following section, we investigate various state-of-the-art solutions proposed to address those issues.

Potential Air Interface Solutions to Save Device Power: A Survey

From the first two sections, we now know that emerging traffic profiles have led to the twin problems of excessive signaling overhead due to frequent transitions between Connected and Idle states and increased battery consumption due to the reduced time spent in Idle state. In this section, we present a survey of major air interface solutions that have been envisioned as potential candidates to solve the problem of energy impact of emerging mobile Internet applications on LTE devices. Detailed results for each of the potential solutions discussed below have been captured in a technical report and can be found in [4]. Later, we discuss the exact mechanism that has been adopted in LTE Release 11.

Always Connected with DRX

In this approach, the UE stays in Connected all the time, effectively eliminating the signaling overhead of state transitions from Connected to Idle. To save power, the UE uses the DRX mechanism with parameters chosen to be similar to when the UE is in Idle state.

DRX can achieve various levels of power saving depending on DRX parameters settings. For example, a high value of long DRX cycle and smaller value of DRX Inactivity Timer can achieve higher power saving by allowing the UE to transition to DRX swiftly and then, while in DRX, remain in Sleep durations for longer lengths. The question remains whether power savings achieved by using DRX are comparable to those in Idle state. This is not a given and depends on various factors such as UE mobility, and the resources required both over the air and in the core network for UE to remain in Connected state. For example, if the UE moves between cells frequently while creating little traffic activity, it will frequently be performing handovers from one cell to another. A handover from one cell to another requires transfer of all the UE's configuration information from one eNB to another and is very signaling-intensive. By contrast, when in Idle state, the UE does not have to perform handovers, and most, if not all, network resources for the UE are released. In addition, to maintain connectivity, UE has to perform various operations periodically such as scanning and providing periodic channel quality feedback measurements to the eNB, all of which also consume power. Hence, a detailed analysis is required to understand if Always Connected is a good approach or not, and if so, under what conditions.

In the next section, we describe an approach that uses the opposite mechanism of Always Connected and then present a comparison of the two mechanisms.

Fast Transition to Idle

Fast Transition to Idle is a mechanism where the UE indicates its desire to go to Idle state to the network. This indication can act as the trigger for the network to send the UE to Idle state without waiting for the mandated period of RRC Inactivity Timer. As may be recalled, tail time is one of the primary reasons the UE incurs high power consumption. In this approach, the tail time is reduced or eliminated entirely which saves power consumption and has the benefit of the UE releasing its network resources when not in use by moving to Idle state. However, the problem of recurrent transitions to/from Idle state still remains in this approach, if the UE starts requesting connection releases (i.e., Fast Transition to Idle) very frequently. Excessive transitions also increase the battery power consumption. Therefore, excessive connection release requests should be avoided in practice. A prohibit timer can be used to define minimum wait time between successive requests. The eNB may also impose an upper limit on the number of requests in a predefined time window. If the UE crosses the limit, it will be prohibited from sending further Fast Transition to Idle requests for the remaining duration of the time window.

Traffic type	Ratio of total data exchanged to total signaling overhead for various inactivity timer values			
	1 s	5 s	10 s	15 s
Active traffic session	1000	3000	5000	10,000
Background traffic session	40	100	180	270

Table 1. *Impact of change in traffic profile on signaling overhead.*

Thus, we need to examine the conditions under which this approach is better than others.

For the purposes of evaluation, in addition to the differing power saving solutions of Always Connected and Fast Transition to Idle, two other factors, mobility and the type of traffic activity, were also considered. The impact of these factors is measured in terms of two key metrics. First is the air interface signaling overhead measured in terms of number of bytes used in sending control messages between eNB and UE over the air. It does not account for messages over the core network. The second metric is the UE power consumption, measured by the amount of time the UE spends in low power state.

The comparison was performed using simulation studies, and the results showed that for cases of low background traffic activity, a UE device's mobility state may have noticeable impact on signaling overhead. During high mobility, the Always Connected approach performs poorly due to the signaling overhead from handovers; therefore, Fast Transition to Idle does well in terms of signaling overhead. This means that at the time of handover, the network may decide that the UE should remain in Connected state or be moved to Idle state [16]. Fast

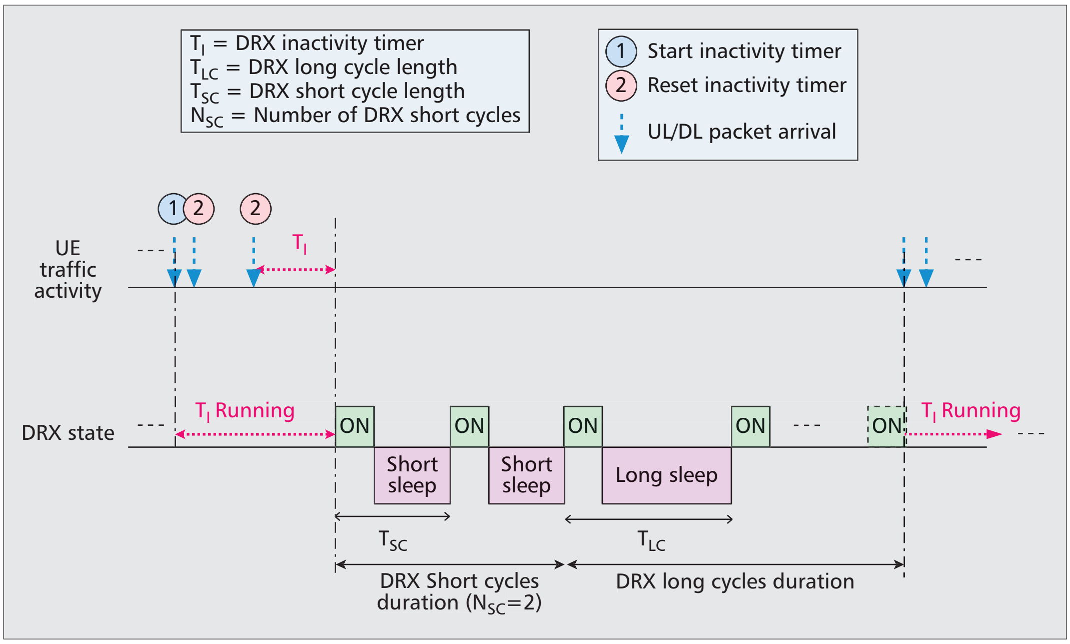


Figure 3. *A typical scenario of DRX functionality in LTE.*

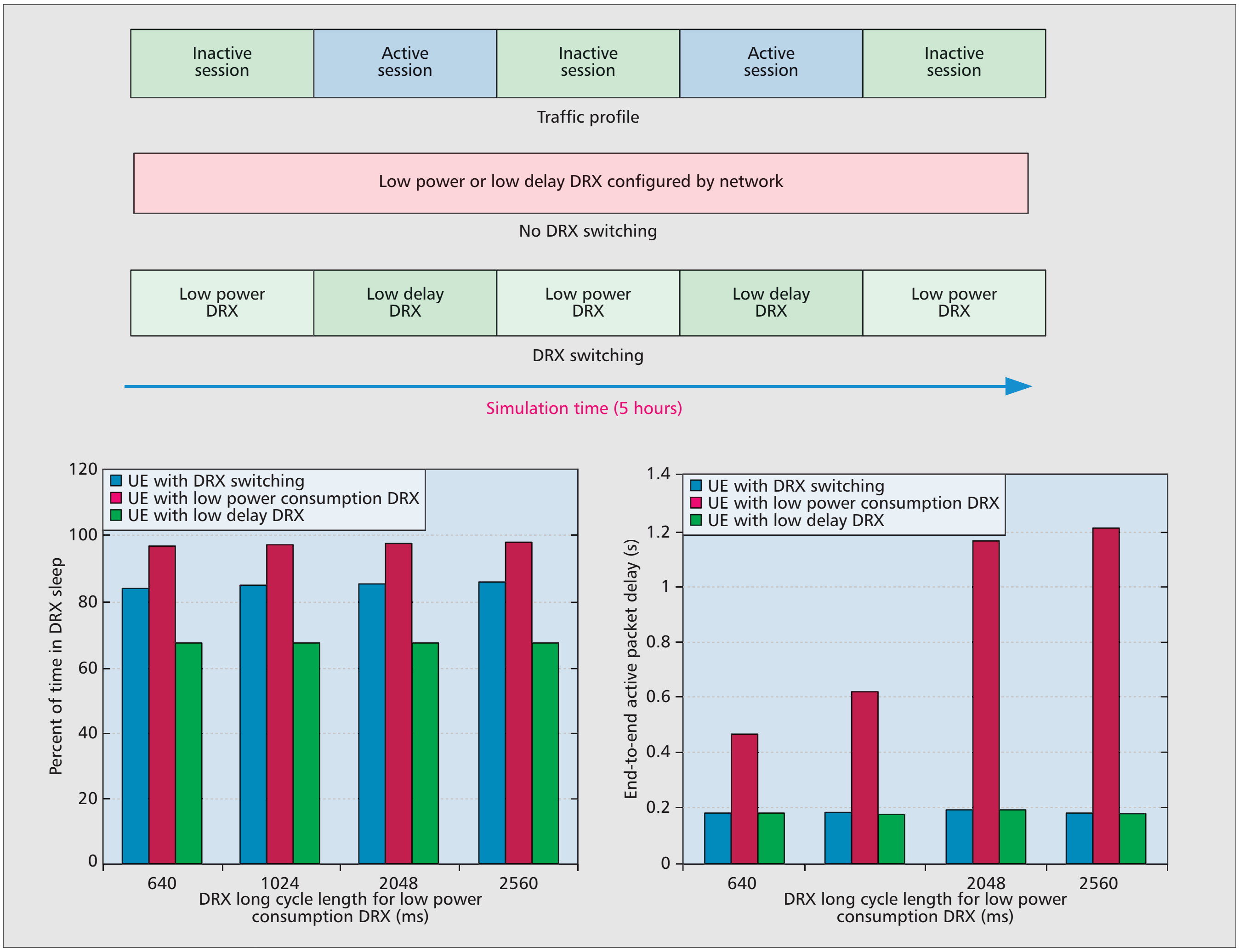


Figure 4. *A typical scenario of adaptive DRX in LTE showing benefits of DRX configuration switching (No DRX Short Cycle, On Duration =10 ms, Inactivity Timer = 30 ms).*

Transition to Idle performs better in terms of power consumption overall. But in cases of low mobility and low traffic activity, it is better to use Always Connected with DRX to achieve power savings and low overhead. However, both schemes have problems with power consumption when it comes to higher traffic activity, which is the case during Active sessions, if we use a single DRX cycle that yields high power savings (currently only a single Short and Long DRX cycle setting is supported). This is because a DRX cycle optimized for power savings generally leads to potentially increased delay, affecting the user experience for delay-sensitive traffic. Hence, it seems beneficial to look at solutions that configure DRX settings differently for different types of traffic activity. In the next section, we describe such a solution.

Adaptive DRX Switching

In Adaptive DRX switching, the DRX parameters are switched so as to adapt to ongoing traffic activity to obtain the requisite balance between power savings and performance. For example, power saving can be increased by making the DRX long cycle longer (i.e., longer sleep in each cycle) and more frequent (i.e., shorter DRX Inactivity Timer), but this creates longer delays. Similarly, delay performance can be improved by using a shorter DRX long cycle and longer DRX Inactivity Timer. Also, introducing a short cycle before going to DRX long cycle can decrease the buffering delay as DRX short sleep is smaller than DRX long sleep.

Since the UE has the information on the number and type of applications running on the device, the UE is in a better position to make decisions regarding the impact of DRX configuration on application performance. Thus, it is better for the UE to indicate to the network to which DRX configuration to switch.

Figure 4 illustrates the benefits of DRX switching using simulation results obtained from OPNET Modeler 17.1 [14] for an LTE scenario where a UE device runs traffic with alternate Active and Inactive sessions of 1 h. The Inactive session represents the background traffic (autonomous real traffic exchange between UE and network when UE is running instant messaging applications over LTE network). From Fig. 4, we see that DRX switching can increase the power saving by 26 percent without any increase in delay of active traffic compared to that of the low-delay DRX case. This shows that

DRX switching strikes a much better balance between low power and low delay vs. using only a single DRX configuration optimized for either power or performance.

DRX switching requires a negotiation mechanism between the UE and the eNB in order to coordinate and decide about the new DRX configuration. A set of DRX configurations of different categories, such as a low power consumption category and a low latency category, may be predefined and known to UE and eNB for this purpose. The eNB can then send the most favorable DRX configuration to UE whenever needed. Note that most of the RRC resource allocation decisions are made by the network without any input from the UE. However, DRX switching may be more effective if the UE is involved in selecting the most favorable DRX configuration as the UE has better knowledge of relevant factors such as applications running on it and remaining battery power. An efficient signaling mechanism is required for the UE to convey its preferred DRX configuration to the eNB.This is also required for the Fast Transition to Idle case, since the UE needs to let the network know about its intent to move to Idle state to be allowed to release its connection. The next section provides some more details on how UE may assist the network for better performance.

Low-Overhead Connected State

In this approach, a new state is proposed where the UE may be able to transmit small amounts of data without requiring the overhead of maintaining connectivity. The Connected state is also costly in terms of other RRC resources. For example, the UE may have some uplink (UL) resources allocated by the eNB to remain synchronized with the network in UL and send a service request for possible UL traffic arrival. Furthermore, each UE needs to send channel quality and also some UL reference signals, such as precoding matrix indicator (PMI) and channel quality indicator (CQI), which take up UL resources. These allocated UL resources can remain unutilized or underutilized during Inactive periods. The UE can save power by not accessing the UL channels if there is no UL data traffic. The UE may request such a Low-overhead Connected state during periods of low traffic activity such as when it is only running background traffic. In this case, a mechanism that allows the UE to assist the network (i.e., a user assistance mechanism) may also be used so that the UE can request the network to move it to a Low-overhead Connected state.

Solutions Adopted in 3GPP Release 11

As mentioned earlier, in 3GPP Release 11, work item "RAN Enhancements of Diverse Data Applications" [4] was conducted to examined the issues related to frequent transitions from Idle to Connected and battery drain due to emerging mobile Internet applications in great detail. In Release 11, however, the strongest focus was on traffic generated by applications running in the background when the user is not interacting with the device. This case was found to be especially interesting due to the huge overhead of sending two or three times more signaling for each byte of data vs. when the user was actively using the device.

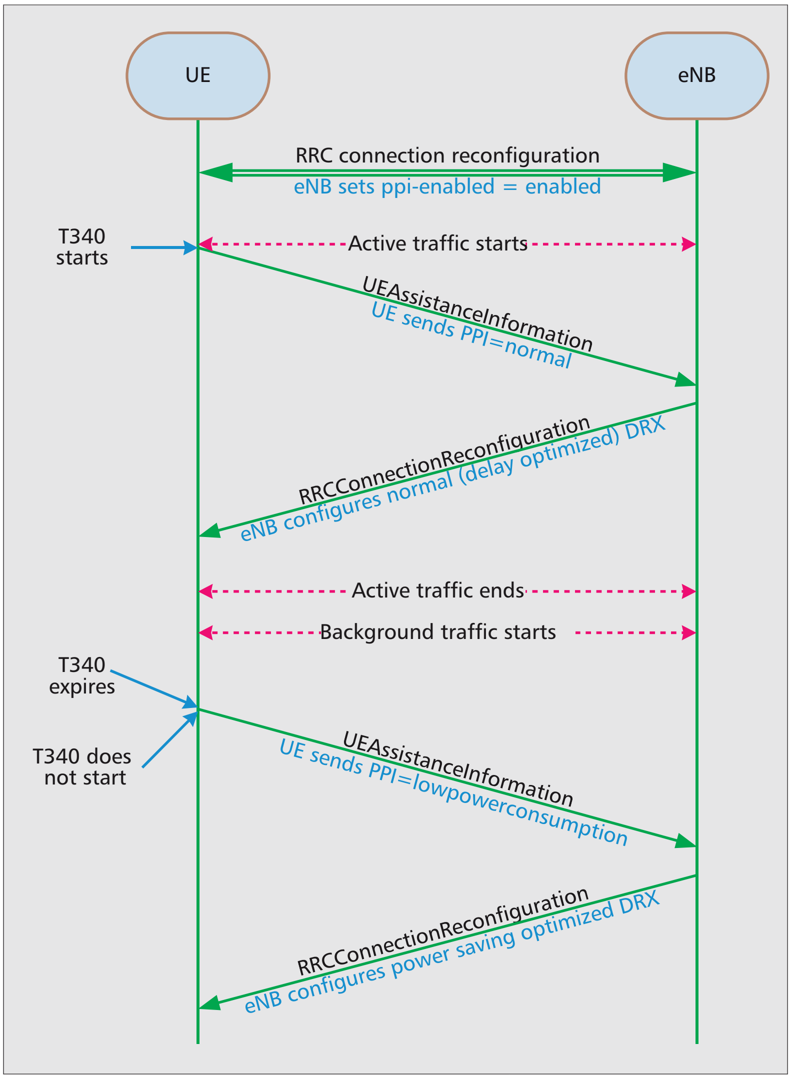


Figure 5. *A typical example showing use of UE assistance information for DRX configuration switching based on [7].*

The various solutions described earlier were examined, and finally a UE assistance mechanism was adopted that enables UE to send its preference to the network. The biggest change is that the network now recognizes the importance of UE assistance in deciding whether the device should be moved to a lower power configuration or not. For this purpose, UE can now send a single bit to indicate its preference for low power, called the power preference indication (PPI), to the network. The triggering of the PPI has been left to UE vendor implementation. Utilization of PPI to configure a low power consumption state has been left for network vendors. Network vendors can use PPI to efficiently implement any of the solution approaches discussed earlier.

For example, PPI can be an enabling basis to implement efficient DRX switching. Figure

Uplink physical resource utilization for connected devices and also mechanisms to reduce the mobility related control signaling are two other main topics that have been proposed for further exploration. Enhancements in the future releases always need to take into account battery consumption while minimizing the impact on the user experience.

5 illustrates a typical scenario of DRX switching with the help of a UE assistance message. Similarly, PPI or similar UE assistance information can also be used by the network as UE input in configuring a Low-overhead Connected state. For example, PPI = 1 can be interpreted as UE's preference to move to the Low-overhead Connected state, while PPI = 0 may be considered as UE's intention to go back to normal Connected state. PPI may also assist the network in Fast Transition to Idle, for example, by interpreting PPI = 1 as an indication to go to Idle without waiting for the RRC Inactivity Timer to expire. Note that all these power saving mechanisms (DRX switching, Fast Transition to Idle, and Low-overhead Connected) can be implemented independently and more effectively by using separate bits of PPI, which is not the case in the current 3GPP Release 11. In such a case, multiple bits of PPI are required.

Potential Research Directions and Solution Approaches for Future 3GPP Releases and Beyond

The UE Assistance mechanism adopted in Release 11 certainly helps address the UE's power consumption issues, albeit partially. However, conserving battery power while providing the desired user experience for always-on applications is still a tough challenge for future 3GPP releases. A single bit of PPI may not be sufficient to express UE's various power preferences such as various levels of power saving by adopting different DRX configurations, intent to move from Fast Transition to Idle, and/or intent to move to Low-overhead Connected state. Therefore, multiple bits of PPI may need to be incorporated in future 3GPP releases so that UE can better inform the network.

In future 3GPP releases, enhancements will focus on how to handle diverse traffic profiles effectively and with minimum battery consumption [15]. In future releases, other than background traffic, there will also be a focus on active traffic such as gaming and HTTP-based streaming. Particular attention will be paid to the signaling overhead in the control plane as well as the mechanisms to improve connection establishment/release for small data bursts. Uplink physical resource utilization for connected devices and also mechanisms to reduce the mobility related control signaling are two other main topics that have been proposed for further exploration. Enhancements in the future releases always need to take into account battery consumption while minimizing the impact on the user experience.

Concluding Remarks

In this article, we investigate the impact of emerging mobile Internet applications on device power and quality of service requirements such as the latency constraints of these applications. The traffic profile of emerging mobile Internet applications differs from the traditional traffic profile as it consists of a constant stream of random aperiodic traffic comprising very small amounts of data during Inactive sessions, causing the UE to frequently transition between Connected and Idle states. We explore the device power and signaling overhead issues due to such frequent state transitions. We then present various solutions proposed in the literature to address UE power saving. Furthermore, effectiveness and limitations of these solution approaches in addressing UE power issues were analyzed. Adaptive DRX is one of the main mechanisms envisioned as a potential solution. We show that DRX configuration switching is desirable to adapt the requirements of running applications and to maintain a trade-off between power saving and latency requirements. Furthermore, we find that the user assistance mechanism adopted in 3GPP Release 11 is an effective technique to assist the network in setting a favorable RRC configuration to save UE power. Potential solutions that can be explored to address the power issues in future 3GPP Releases were also discussed.

References

[1] A. Ghosh *et al.*, "LTE-Advanced: Next-Generation Wireless Broadband Technology," *IEEE Wireless Commun.*, vol. 17, no. 3, June 2010, pp. 10–22.
[2] R.Y. Kim and S. Mohanty, "Advanced Power Management Techniques in Next-Generation Wireless Networks," *IEEE Commun. Mag.*, vol. 48, no. 5, May 2010, pp. 94–102.
[3] C. Bontu and E. Illidge, "DRX Mechanism for Power Saving in LTE," *IEEE Commun. Mag.*, vol. 47, no. 6, June 2009, pp. 48–55.
[4] "LTE RAN Enhancements for Diverse Data Applications," 3GPP TR 36.822, V11.0.0, Sept. 2012.
[5] "RRC Connection Behaviour for Background Traffic," Research In Motion UK Limited, 3GPP TSG-RAN WG2 Meeting #75bis, Zhuhai, China, R2-115245, 10–14 Oct. 2011.
[6] S. C. Jha, A. T. Koc, and R. Vannithamby, "Optimization of Discontinuous Reception (DRX) for Mobile Internet Applications Over LTE," *Proc. IEEE VTC-Fall '12*, Quebec, Canada, Apr. 2012.
[7] "Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol Specification," 3GPP TS 36.331, Rel. 11, v. 11.1.0, Sept. 2012.
[8] J. Huang *et al.*, "A Close Examination of Performance and Power Characteristics of 4G LTE Networks," *MobiSys 2012*, UK.
[9] F. Qian *et al.*, "TOP: Tail Optimization Protocol For Cellular Radio Resource Allocation," *IEEE Proc. ICNP '10*, Oct. 2010, pp. 285–94.
[10] "Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol Specification," 3GPP TS 36.331, Rel. 9, V9.12.0, Sept. 2012.
[11] "Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol Specification," 3GPP TS 36.331, Rel. 10, V10.7.0, Sept. 2012.
[12] M. Gupta, A. T. Koc, and R. Vannithamby, "Power Management for 4G Mobile Broadband Wireless Access Networks," *Handbook of Green Information and Communication Systems*, M. S. Obaidat, A. Anpalagan, and I. Woungang, Eds., Academic Press, Ch. 21, Nov. 2012.
[13] "Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC); Protocol Specification," 3GPP TS 36.321, Rel. 11, V11.0.0, Sept. 2012.
[14] "OPNET: Applications and Network Performance," OPNET Technologies, Inc., v. 17.1.
[15] "Work Item LTE RAN Further Enhancements for Diverse Data Applications," Research In Motion UK Limited, 3GPP TSG-RAN WG2 Meeting #75, Chicago, USA, RP-121291, 4–7 Sept. 2012.
[16] "Signaling Considerations for Background Traffic," Qualcomm Incorporated, 3GPP TSG-RAN WG2 Meeting #76, San Francisco, USA, R2-116036, 14–18 Nov. 2011.

IEEE Communications | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page | Qmags THE WORLD'S NEWSSTAND®

BIOGRAPHIES

MARUTI GUPTA (maruti.gupta@intel.com) received her B.E in electronics engineering from the University of Mumbai, India, and her M.S. in computer science at Portland State University in 2002. She was a Ph.D candidate at Portland State University and did her thesis work in the area of power management in network switches and routers. She joined Intel Corporation in 2006 as a network research scientist. In the past she has worked on developing micro-architecture and device drivers for low-latency high-performance networks, analytical modeling of HTTP traffic, and power saving algorithms in IEEE 802.16e/802.16m standards. Her current research interests include investigation of emerging application traffic profiles, power saving techniques at the MAC layer in LTE-A networks, and context-aware algorithms to enhance user experience.

SATISH C. JHA (satish.c.jha@intel.com) received his B.E. in electronics and communication engineering from Tribhuvan University, Nepal, in 2004, his M.E. in information and communication technologies from the Asian Institute of Technology, Thailand, in 2007, and his M.Sc. in communication networks and services from Institut National des Télécommunications, France, in 2007. He is a Ph.D. candidate in electrical and computer engineering at the University of British Columbia, Vancouver, and currently working on 3GPP Release 11/12 standard development for LTE-A as a graduate intern at Intel Corporation. His current research interests include device power saving and user experience enhancement mechanisms in LTE-A networks, MAC design and QoS provisioning in cognitive radio networks, and resource allocation in cooperative cellular networks.

ALI T. KOC (ali.t.koc@intel.com) received his B.S. in electrical and electronics engineering from Bilkent University, Turkey in 2001, and his M.Sc. in electrical engineering from the University of Texas at Dallas in 2005. He has been working at Intel Corporation since June 2005 as a senior network software engineer. He worked on power control, interference mitigation, and power saving mechanisms for IEEE 802.16e and IEEE 802.16m in the past. His current research interests include device power saving and user experience enhancement mechanisms in 3GPP LTE-A networks.

RATH VANNITHAMBY [SM] (rath.vannithamby@intel.com) received his B.A.Sc., M.A.Ss., and Ph.D. degrees in electrical engineering from the University of Toronto, Canada. He is currently a senior research scientist and manager at Intel Labs, Intel Corporation. He leads and manages a team responsible for 4G/5G cellular research. Prior to joining Intel, he was a researcher at Ericsson responsible for 3G research. He has published over 40 scientific articles and has over 100 patents granted/pending. He has authored chapters of three books. He has served as a Guest Editor for the *EURASIP JWCN* Special Issue on RRM for 3G+ Systems. He was a TPC track chair for PIMRC '11. He is a co-chair for a workshop, Machine-to-Machine Communications for the Next Generation Wireless Networks, for IEEE ICC '13. He is a an editor for *IEEE Communications Surveys and Tutorials*. He has also served on TPCs for major IEEE wireless communication conferences including ICC, GC, VTC, WCNC, and PIMRC. His research interests are in the areas of 4G/5G broadband mobile networks, energy efficiency, QoS for mobile Internet applications, cross-layer techniques, and machine-to-machine communications.

Communications Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page

Trends in Small Cell Enhancements in LTE Advanced

Takehiro Nakamura, Satoshi Nagata, Anass Benjebbour, and Yoshihisa Kishiyama, NTT DOCOMO, INC
Tang Hai, Shen Xiaodong, Yang Ning, and Li Nan, China Mobile Research Institute

Abstract

3GPP LTE, or Long Term Evolution, the fourth generation wireless access technology, is being rolled out by many operators worldwide. Since LTE Release 10, network densification using small cells has been an important evolution direction in 3GPP to provide the necessary means to accommodate the anticipated huge traffic growth, especially for hotspot areas. Recently, LTE Release 12 has been started with more focus on small cell enhancements. This article provides the design principles and introduces the ongoing discussions on small cell enhancements in LTE Release 12, and provides views from two active operators in this area, CMCC and NTT DOCOMO.

Introduction

Explosive demands for mobile data are driving changes in how mobile operators will need to respond to the challenging requirements of higher capacity and improved quality of user experience (QoE). Currently, fourth generation wireless access systems using Long Term Evolution (LTE) [1] are being deployed by many operators worldwide in order to offer faster access with lower latency and more efficiency than 3G/3.5G. Nevertheless, the anticipated future traffic growth is so tremendous that there is a vastly increased need for further network densification using small cells to handle the capacity requirements, particularly in high traffic areas (hot spot areas) that generate the highest volume of traffic. To optimize performance and provide cost/energy-efficient operation, small cells require further enhancements and in many cases need to interact with or complement existing macrocells. In this regard, a number of solutions have been specified in recent releases of LTE (i.e., Release [Rel]-10/11, and more solutions are to be studied in coming releases (Rel-12 and beyond). Network densification using small cells has been of great interest in 3GPP since Rel-10, with techniques such as coordinated multipoint (CoMP) transmission/reception and enhanced intercell interference coordination (eICIC) being introduced [2]. This article discusses the recent trends and the state-of-the-art technologies related to the design of small cells. First, a brief review of the main features related to small cells in LTE up to Rel-11 is provided. Then the status of the ongoing discussions and the agreements reached so far in Rel-12 are presented. Finally, the operators' views of CMCC and NTT DOCOMO on small cell enhancements are provided.

Recent Trends in Mobile Data Usage and the Rise of Small Cells

In recent years the proliferation of high-specification handsets, in particular smartphones, has led to unprecedented market trends being observed. Image transfer and video streaming, as well as innovative cloud services are reaching an increasing number of customers. In 2011 alone, the volume of mobile data traffic grew 2.3 times with a nearly threefold increase in the average smartphone usage rate [3]. In the future, the amount data traffic will grow at a pace never seen before. Many recent forecasts project mobile data traffic to grow more than 24-fold between 2010 and 2015, and thus beyond 500-fold in 10 years (2010–2020), assuming that the same pace of growth is maintained. Thus, the capacity of future systems needs to be increased significantly so that it can accommodate such growth in the traffic volume. Revenue growth is becoming more challenging after many operators worldwide introduced flat rate tariffs. Further reduction in the deployment cost of small cells will therefore be a necessity in the future.

3GPP Status toward REL-12 and Beyond

In order to continue to ensure the sustainability of 3GPP radio access technologies over the coming decade, 3GPP standardization will need to identify and provide new solutions that can respond to future challenges. To this end, 3GPP initiated a workshop on further steps in the evolution of LTE toward the future (i.e., Rel-12 and on) in June 2012. There were 42 presentations from 3GPP member organizations, including

 0163-6804/13/$25.00