La VoLTE: novel cross Layer optimized mechanism of Video transmission over LTE for DRX

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Abstract—**Power efficiency in broadband wireless access networks has emerged as a very important area of research worldwide. 4G wireless standards such as the 3GPP LTE have attempted to address this issue through mechanisms such as Discontinuous Reception (DRX) which can enhance the battery performance in user equipments (UEs) and improve resource utilization at the base station (eNodeB) especially for applications characterized by long periods of inactivity such as the WWW. However, DRX in connected mode has not been optimized for real time applications such as Mobile TV and Video on Demand (VoD) which require strict latency and QoS guarantees. This paper presents a novel mechanism, *La VoLTE,* based on time series prediction and enhanced eNodeB architecture to determine DRX opportunities during video streaming over Real Time Protocol (RTP) in a TDD-LTE network without compromising the QoS. Through extensive simulations, it is found that the proposed mechanism can result in 30-80 percent power saving over the video transmission duration depending on video data for different video quality and bandwidth requirements.**

Keywords- TDD-LTE; DRX; Power Saving; Video Streaming

I. INTRODUCTION

Emerging 4G broadband wireless technologies such as 3GPP LTE have heralded an era of mobile infotainment that has significantly boosted the adoption of multimedia services such as Mobile TV and Video on Demand (VoD) over the wireless. These developments lead to increase in the power consumption of the network infrastructure and user equipments (UEs). Moreover, recent times have witnessed heightened concern on the nature and magnitude of impact; Information and Communication Technologies (ICT) have over the delicate ecological balance and sustainability of growth in global communication infrastructure. In this context, research community worldwide have focused their attention towards greener technologies that save power at both the base station (eNodeB) and the battery powered UEs in the Evolved- UMTS Terrestrial Radio Access Network (E-UTRAN) specification of the LTE.

Time Division Duplex (TDD) and Frequency Division Duplex (FDD) are the two different flavors of the E-UTRAN specifications. TDD-LTE has several advantages over its predecessor FDD-LTE, the reason being flexibility in operation and management, ability to operate in unpaired spectrum and dynamically re-configurable uplink to downlink bandwidth ratio. To improve the battery lifetime of a mobile UE, the LTE supports Discontinuous Reception (DRX) mechanism that allows the UE to turn off parts of its transceiver circuitry at pre-negotiated intervals. DRX in the connected state of the UE saves battery power especially when the traffic is characterized by long periods of inactivity such as the WWW traffic [8]. This is achieved by interleaving short periods of active monitoring of the channel with longer periods of inactivity. It is found that DRX mechanism in LTE is not optimized for services requiring high QoS and low wake-up latencies [4, 9]. In [8], the authors have described simulation and analytical results of DRX mechanism as applied to VoIP service with guaranteed air-interface latency. Authors in [21] describe DRX Mechanism for real-time services including low frame rate video in both attached and idle modes of LTE and present power saving results. However it is not clear the manner in which the impact of DRX on video quality was measured during simulations. To the best of authors' knowledge, there is no published research paper that addresses the intricate problem of balancing the video QoS along with maximizing the power saving through the DRX optimization in TDD-LTE.

Hence, this paper focuses on the design of a novel DRX mechanism and eNodeB architecture, christened *La VoLTE*[1], for the connected mode DRX operation in TDD-LTE network wherein a video service is delivered to an UE with limited battery power. The design goal of the proposed mechanism has been to balance the mutually opposing requirements of high video quality with low power consumption during streaming. In particular, this paper proposes an algorithm to predict DRX opportunities for an UE during video streaming over Real Time Protocol (RTP) at the eNodeB through cognition of application layer traffic characteristics of a video encoded in the MPEG-4 format. Our simulation results indicate that, it is possible to achieve 30 to 80 percent reduction in power consumption during the course of streaming of a video without significantly trading off the quality. This power saving corresponds to the duration for which the UE remains inactive and switches off its radio intermittently during the reception of the video stream.

This paper has been organized as follows. In section II, an overview of the TDD-LTE air interface along with the supported frame structure and DRX mechanism is provided. Section III, presents the proposed *La VoLTE* architecture that optimizes DRX for video streaming. The proposed video frame size prediction technique and DRX operation has been described in Section IV and V respectively. Section VI contains the simulations results and analysis. Finally, the conclusions can be found in section VII.

[1] *La Volte* : A French duet dance form based on complex steps and close coordination. This paper title refers to the close coordination of eNodeB and UE based on rhythmic pattern of video codec to achieve power saving at UE

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II. TDD-LTE : AN OVERVIEW

LTE is the evolution of the radio access through the E-UTRAN and the non-radio aspects under the term System Architecture Evolution (SAE) which includes the Evolved Packet Core (EPC) network. Together LTE and SAE comprise the Evolved Packet System (EPS) as shown in Fig. 1. LTE is designed to support a flat all IP network architecture. In EPS network, the UE associated with the eNodeB can access packet services such as IPTV, Video on Demand (VOD), Internet etc. routed through Packet Data Network gateway (PDN GW) via the Serving Gateway (GW) as shown in Fig. 1. PDN and Serving GW use GPRS Tunneling Protocol (GTP) over UDP for user data and S1-Access Protocol (S1-AP) over SCTP for control data transfer to eNodeB's Packet Data Convergence Protocol (PDCP) and Radio Resource Control (RRC) layer respectively. User data/ IP packet is handled by PDCP layer and subsequently passed to RLC and Medium Access Control (MAC) layer for transmission over wireless channel. TDD-LTE employs an OFDM based physical layer on the downlink and Single Carrier- Frequency Division Multiple Access (SC-FDMA) based physical layer on the uplink.

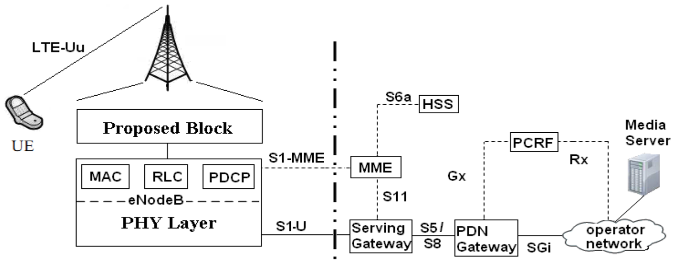

Figure 1. EPS network architecture with LTE and EPC elements

A. *WIRELESS FRAME STRUCTURE and DRX MODE*

One wireless frame in TDD-LTE is of 10 ms (milli-second) duration. Each half of the frame is divided into five sub-frames as shown in Fig. 2. All sub-frames which are not special sub-frames are equally divided in two parts and special sub-frames consist of the three fields DwPTS (Downlink Pilot Timeslot), GP (Guard Period), and UpPTS (Uplink Pilot Timeslot) having configurable individual lengths and a total length of 1ms. One time slot consists of 7 (or 6) OFDM symbols with normal (or extended) cyclic prefix. To each OFDM symbol, a cyclic prefix (CP) is appended as guard time. In the frequency domain 12 sub-carriers along with one time slot (7 OFDM symbols) in time domain form one resource block. Other relevant parameters are mentioned in Table 1 [5].

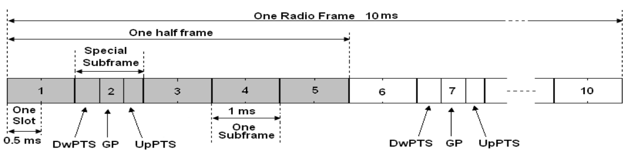

Figure 2. TDD-LTE wireless frame structure

There is a provision for DRX mechanism in TDD-LTE for conserving power on battery powered mobile UEs. An UE can enter into DRX mode of operation during active mode (DRX in RRC_CONNECTED) as well as in idle mode (DRX in RRC_IDLE). In DRX mode UE can go to sleep (for a fixed time duration) (off period) when there is no traffic longer than DRX inactivity timer or UE receives RRC (Radio Resource Control) message, and remain active when data transmission is expected (on period). One off and on period add up to a DRX cycle. During off period UE temporarily shut down its radio devices and save power. Our work is related to DRX mechanism in active mode (RRC_CONNECTED). There are two DRX cycles, short and long DRX cycle based on their duration. Both DRX cycle can be enabled separately or together. PDCCH (Physical downlink control channel) carries the downlink resource assignments and uplink resource grants. UE listens to PDCCH during on period in DRX cycle. In case of retransmission from eNodeB, UE waits until DRX Retransmission Timer expires. The DRX configuration message is generated by RRC protocol state machine present at both the UE and eNodeB. It is passed to PDCP layer in PDCP control packet data unit (PDU). Then the message in Radio Link Control (RLC) layer is carried by acknowledge mode (AM) RLC. In MAC layer DRX message is handled by logical channel Dedicated Control Channel (DCCH) and transport channel Downlink Shared Channel (DL-SCH). In physical layer it is handled by PDCCH [3] [4].

III. PROPOSED *La VoLTE* ARCHITECTURE

The proposed *La VoLTE* network architecture is shown in the Fig. 1. It may be observed that the proposed architecture requires no modification to the existing EPS network architecture and the proposed block is implemented as a supplementary hardware realizable module in the eNodeB without any major modifications to the protocol stack.

Fig. 3 depicts the detailed block diagram of our proposed architectural enhancement at the eNodeB for DRX mechanism employed for video streaming. This proposed block interacts with PDCP layer, RRC protocol and MAC layer of the eNodeB to optimize the DRX mechanism w.r.t video traffic characteristics at the application layer. Video data is encoded in the MPEG-4 container format with parameters mentioned in Table II using JM (18.0) Encoder [13] and carried over the RTP from the video server to the UE. Additionally without loss of generality, it is also assumed that the core network transport is over Metro Ethernet transport based on 802.3x standards and so the Maximum Transfer Unit (MTU) is limited to 1500 bytes. IP packets received by eNodeB from EPS are processed and passed to the PDCP layer. These IP packets contain encapsulated RTP/UDP packets. A RTP packet contains one or more video coding layer (VCL) [2] unit in its payload. There are three different basic payload structures for RTP packets. A RTP payload can contain single VCL Unit, multiple aggregated VCL units or single VCL unit fragmented over multiple RTP packets [1]. In this paper, we consider the single VCL unit mode and fragmented packetization of VCL unites in RTP payload with MTU size of 1500 which is used in a number of RTP/RTSP servers such as [10]. A number of VCL units form an access unit which can be decoded to generate a picture as shown in Fig. 4. In such packetization, it is possible to predict the video frame size at an intermediate location when Ethernet transport is utilized. In *La VoLTE*, IP packets size is captured from the PDCP layer

PDU and video frame trace is reconstructed. Video frames trace is subsequently processed and upcoming video frames in the immediate future are predicted. Video frame size trace prediction is described in detail in Section IV.

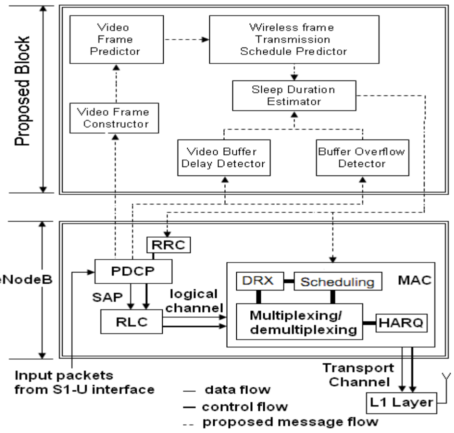

Figure 3. eNODE-B with proposed block

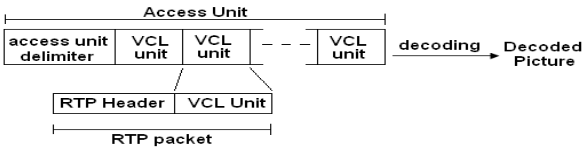

Figure 4. RTP packet and NAL unit

Due to advent of very high wire speed computing, we assume that per-flow processing of video trace information to optimize DRX opportunities at UE is practical, although being computationally intensive [11]. Based on the predicted video frame size, transmission schedule is created. This gives information about the occupied and unoccupied OFDM frames in the downlink. PDCP layer accounts for eNodeB buffer overflow and delay deadline for individual flows as per the required QoS for the video stream. This information is utilized for creating a transmission schedule that is passed to the MAC layer entity for video frame scheduling and DRX message processing as shown in Figure 3.

A. Modeling

Video frame size information shows periodic pattern when encoded with fixed Group of Picture (GOP) parameter and can be considered as a time series. Frame size constitutes series coefficients that occur after a fixed interval equal to duration of a GOP. Modeling of video trace becomes more important when it is desirable to know the nature of the video frame size in advance. Modeling video trace provides us a basis for prediction of the network traffic when video is transmitted. A time series can be modeled as autoregressive (AR) model of order p as following

$$X_t = c + \sum_{i=1}^{p} \varphi_i * X_{t-1} + e_t \qquad \textbf{(1)}$$

Where φ_i is i^{th} *AR* model parameter, e_t is zero mean white noise with variance σ^2 and c is a constant. *AR* component in the series establish the dependency of current data on previous data. The series can also have an averaging component. A moving average (*MA*) model of order q can be represented as following

$$X_t = \mu + \varepsilon_t + \sum_{i=1}^{q} \theta_i * \varepsilon_{t-i} \qquad \textbf{(2)}$$

Where μ is the expectation of X_t and θ_i is i^{th} *MA* model parameter. Moving Average part significantly smoothens the model and decreases the noise component. In symbolic notation Autoregressive Moving Average (*ARMA*) model can be represented as following with a back shift operator *B*

$$X_t = (\varphi_1 B^1 + ... + \varphi_p B^p) X_t + (1 - \theta_1 B^1 - .. - \theta_q B^q) e_t \ \textbf{Or}$$

$$\varphi_p(B) X_t = \theta_q(B) e_t \qquad \textbf{(3)}$$

It is important to note that such modeling is valid for the time series which are necessarily stationary in nature. However it is rarely observed in video trace, as observed in unit root test [16, 17] during the experiments carried out by authors. To mitigate this non-stationary property of the series, we incorporate one more component, the differentiating term (*d)* and in notation it corresponds to Integrated (*I*) part. So the aggregate Autoregressive Integrated Moving Average model *ARIMA(p,d,q)* can be represented as

$$\varphi_p(B)(1 - B^d) X_t = c + \theta_q(B) e_t \qquad (4)$$

Here $\varphi_p(z)$ and $\theta_q(z)$ are polynomial of order p and q . $\varphi_p(z)$ and $\theta_q(z)$ should not have any roots for $| z | < 1$ to ensure causal and invertible system. A series modeled as *ARIMA* represents linear dependence on past values along with some random increments. Video files when encoded with fixed *GOP* parameter *m*, shows a repetitive pattern after the lag of *m* number of frames. It can be realized by Seasonal *ARIMA* model as

$$\Phi_p(B^m)\phi_p(B)(1-B^m)^D(1-B)^d X_t = c + \Theta_q(B^m)\theta_q(B)e_t \qquad \textbf{(5)}$$

Φ_p, Θ_q and D are seasonal AR, MA and differencing parts correspondingly. A short representation of Seasonal *ARIMA (SARIMA)* is *ARIMA (p, d, q)(P, D, Q)* ^{m} with periodicity of *m*.

B. Parameter Estimation

The most important step in modeling a data series is to find the corresponding parameters for the model. Akaike Information Criterion (*AIC*) is considered as basis for selecting best statistical model with lowest AIC value. We follow following steps for finding the required parameters:

- *We start with lower value of differencing parameter both for seasonal and non seasonal part as the higher order can lead to inaccurate results [17].*
- *Canova & Hansen test [18] is performed for seasonal data and D=1 is obtained.*
- *We perform unit root test [16, 19] on the differentiated data (since D=1) and found that it is stationary, thus d=0.*
- *We find minimum AIC value corresponding to different combination of p and q ranging from 0 to 5 and P and Q ranging from 0 to 2 for original data.*

- *We get the (p, q, P, Q) = (1,1,1,1) corresponding to lowest AIC value.*

We use open source statistical computing language R [20] and its *arima()* function for the above results and analysis.

C. Prediction

We use the ARIMA model parameters (1,0,1,1,1,1) obtained in section III.B for prediction of the future frames. Based on the *ARIMA (p,d,q,P,D,Q)* model parameters, future values are predicted using *forecast()* function in R [20]. For our purpose we read 200 samples into *arima()* function with the required parameters and seasonality value (*GOP* size). We select maximum likelihood method for estimating the parameters in *arima()* function and predict 50 future samples.

TABLE I. CHANNEL PARAMETER VALUE

S. No.	Parameters	Value
1	Bandwidth	10 MHz
2	Resource Block	50
3	No. of OFDM symbol/slot	7
4	No. of slot/frame	10
5	No. of DL slot/frame	6
6	Frame duration	10 ms
7	Modulation/ Code Rate	QPSK/0.75
8	Sub Carrier Spacing	15 kHz
9	Cyclic Prefix length	4.7 µ sec
10	Symbol Period	71.4 µ se
10	Data Sub Carriers	600
12	Downlink Data rate	5.04 Mbps

TABLE II. VIDEO ENCODING PARAMETERS

S. No.	Parameters	Value
1	GOP size	12
2	QP	25
3	Frame rate	25fps
4	Resolution	CIF(352x288)
5	Video Codec	H.264/AVC
6	Total frames	2400

IV. PROPOSED SLEEP MODE OPERATION

The DRX mode operation is based on prediction of video frame size at eNodeB. We propose introducing short DRX configuration message at a periodicity of 40 ms containing only DRX parameters. We present our algorithm for DRX mode in Fig. 5. The proposed architecture in Fig. 3 implements this algorithm. In line 2, function reads IP packets from PDCP layer and function in line 3 converts them to video frame trace using RTP packetization mentioned in section III. Function in line 7 reads video frame size and predict upcoming video frames according to mechanism discussed in Section IV. Depending on predicted upcoming video frame size, function in line 8 creates transmission schedule and in line 9 estimates unoccupied OFDM frames. The message is sent to RRC as shown in Fig. 3. RRC process DRX message and pass it to lower layers for transmission to UE. The inaccuracy in prediction mechanism may cause difference in actual video frame size and predicted video frame size. In such case a video frame or a part of it may not get transmitted. Those frames are buffered in eNodeB (line 13) and transmitted in next DRX ON period. The video frames that exceed delay deadline are dropped (line 20) in PDCP layer.

Algorithm to estimate DRX configuration based on incoming IP packets

```
1: while end_of_stream() do
2:   Read_IP_packet_Size()
3:   Convert_IP_packet_to_Video_Frame_Size()
4:   for i = 1 → frame_to_predict do
5:     Video_Frame_Size ← Read_Video_Frame_Size()
6:   end for
7:   Predict_Video_Frame_Size(Video_Frame_Size)
8:   Create_Transmission_Schedule(wireless_frame_duration,
     video_frame_duration)
9:   Estimate_unoccupied_OFDM_frames()
10:  Inform_UE()
11:  Transmitt_Video_Data()
12:  if data_remaining then
13:    Buffer_data_at_eNodeB
14:  end if
15:  if delay ≥ Video_Delay_deadline then
16:    Drop_Video_Frame()
17:    no_of_frame_droped ← no_of_frame_droped + 1
18:  end if
19:  if data_renaining > eNodeB_LIMIT then
20:    Drop_Current_Video_Frame()
21:    no_of_frame_droped ← no_of_frame_droped + 1
22:  end if
23: end while
```

Figure 5. Algorithm for DRX mechnanism

V. SIMULATION AND RESULTS

A customized event driven simulator in C is used for performance analysis of the *La VoLTE* architecture. It includes RTP packetization of video frame size trace (Section III) and then its reconstruction. This frame trace is used for prediction of upcoming video frames in predetermined time-window size to estimate occupied OFDM frames. This gives the duration for which UE should remain active for listening PDCCH message and for rest of the interval it may go to sleep. For simulation we have considered a TDD-LTE system profile as listed in Table 1. If the capacity of OFDM frames is less than the video data to be transmitted, it is stored in eNodeB buffer and processed in next OFDM frame. If eNodeB buffer is saturated, the video frame with maximum delay is dropped. This is termed as *transmission without DRX*. In case of *transmission with DRX*, the transmission schedule is created based on predicted frames and UE is informed in advance regarding DRX cycle. UE receives data in DRX on duration and sleeps for rest of the DRX cycle. In simulation we keep track of the video frames sequence number that are dropped due to buffering and delay at eNodeB. We followed PSNR and video quality relationship as mentioned in [14] and enhanced EvalVid to measure video PSNR in our simulations [15]. In this evaluation, we disable the HARQ and adaptive modulation based on channel quality, though the proposed scheme may be suitably extended. It is also assumed that impact on video quality (PSNR) due to frame drop is uniform for all encoded video frames.

We perform extensive simulations on multiple video files and found that for a larger video file sleep duration is lesser for a given bandwidth. We present video trace statistics, DRX Off Duration (OD) and Video Quality in terms of PSNR for different video files in Table III. We present number of video frame dropped and PSNR variability with allocated bandwidth per UE with and without DRX in Fig. 6. PSNR shows monotonous but non-linear increase with increase in allocated bandwidth. This variability in PSNR is due to prediction inaccuracy of the proposed mechanism. There may be situations where the transmission opportunity is scheduled according to the predicted trace, and the actual traffic is more than the predicted, in which case the frames are either buffered or dropped. The variation in PSNR is compensated by proportional change in sleep interval.

TABLE III. DRX OFF DURATION (OD) IN PERCENTAGE , BANDWIDTH (BW) (MBPS) AND PSNR (DB) FOR MEAN BIT RATE (MBPS)

Video files	**Mean bit rate (Mbps)**	**PSNR= 35 dB**		**PSNR= 40 dB**		**PSNR= 45 dB**	
		OD	***BW***	***OD***	***BW***	***OD***	***BW***
coastguard	1.45	26.5	1.43	30.0	1.5	49.6	2.4
akiyo	0.180	76.2	0.192	79.2	0.31	80.1	0.46
mother-daughter	0.226	72.0	0.195	77.5	0.26	79.9	0.45
silent	0.468	72.9	0.415	73.0	0.45	76.0	0.49

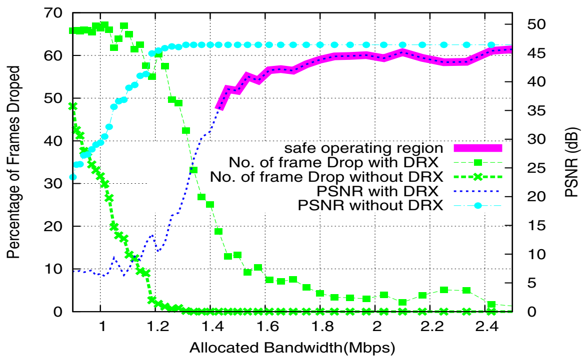

Figure 6. Video frames dropped and PSNR variability with allocated bandwidth per UE with and without DRX.

We can observe from Fig, 6 and Table III that the optimum bandwidth required for video transmission with sleep mechanism for acceptable quality is around mean bit rate corresponding to the video trace. For example, in case of Coastguard video, from Table III, mean bit rate is 1.45 Mbps. In Fig. 6 the optimum bandwidth for acceptable video quality (>37.5 dB PSNR) [14] is in the above operating region. Fig. 7 shows sleep duration in percentage for different videos and for different bandwidth allocations. We observe Coastguard video is having lesser sleep duration as compared to other video files, this is due to the fact that it has comparatively higher mean bit rate as shown in Table III.

VI. CONCLUSION

In this work we present a novel architecture and method for DRX mechanism in case of video streaming over RTP/UDP transport in EPS. Our simulations show that the power saving and video quality can be traded off with available data rate to find an optimal operating region. Significant power saving of 30-80% as can be observed in Fig. 7, has been observed without compromising the QoS for the various video sources simulated. This work may be further extended for other video applications considering multi-user efficient resource scheduling with DRX mechanism.

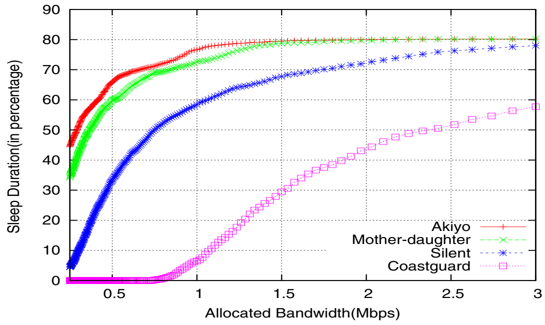

Figure 7. Sleep Duration (in percent) for different Allocated Bandwidth per user at eNodeB. We can see for higher allocated bandwidth value, sleep duration increases. Thus power saving can be traded-of with bandwidth.

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