Base-Station Duty-Cycling and traffic buffering as a means to achieve Green Communications

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***Abstract*—In this paper, we propose Base-Station (BS) Discontinuous Transmission (DTX) as a means for saving energy. Traditional proposals utilize DTX at the BS to enable sleep modes under lightly loaded scenarios. However, we propose to shape the traffic to enable more frequent sleep modes at the BS, while ensuring the Quality of Service (QoS) requirements of the application in terms of delay are successfully met. The results show that our DTX proposal has a significant potential even under moderately loaded scenarios. The system Energy Efficiency (EE) gain is achieved in our proposal by exploiting the classical Energy-delay tradeoff. We show the performance of our scheme in the presence of realistic system power models proposed within the framework of EARTH project.**

I. INTRODUCTION

Telecommunication networks have experienced tremendous success causing proliferation and demand for ubiquitous heterogeneous broadband mobile wireless communications. Up to now, innovation has targeted to improve wireless networks' coverage and capacity while meeting the Quality of Service (QoS) for users admitted in the system. Nowadays, the number of mobile subscribers equals more than half the global population. Forecast on telecommunication market assume an increase in subscribers, per subscriber's data rate and, the roll out of additional base stations for next generation mobile networks. The undesired consequence is the growth of wireless networks' energy consumption that will cause an increase of the global carbon dioxide (CO_2) emissions and, impose more and more challenging operational cost for operators. Communication energy efficiency represents indeed an alarming bottleneck in the telecommunication growth paradigm.

Subsequently, there has been recent drive from both industry and academia to save energy of Information and communication Technologies (ICTs) to reduce CO2 emissions and also to reduce the network operating costs. Energy efficiency improvement at the system level can be achieved only if improvements are experienced in the whole communication chain for different operational load scenarios. Several investigations are ongoing in this research area, ranging from energy efficient cooling of base stations, to innovative energy efficient deployment strategies and frequency planning [1] [2] [3].

There have been several studies conducted by researchers in past few years to propose Energy Efficient (EE) BS mechanisms. One such proposal is to improve EE of cellular network from network management point of view in which authors propose to dynamically switch-off some Base-Stations (BSs) in low traffic scenarios and offload their traffic to neighboring cells [4], [5], [6]. Another proposal is based on *temporarily* switching off base-stations during inactive period also called Discontinuous Transmission(DTX) Schemes, see [7], [8], [9], [10]. However, the traffic from sleeping BSs is not offloaded to active BSs. The main focus of this paper is on latter schemes in which we exploit the traffic characteristics to dynamically induce more frequent DTX at the Base Station. Most of the work in past have focused on enabling sleep modes in the BS under lightly loaded scenarios, however we show in this paper that we can put the BS to sleep even at moderate load scenarios if the traffic is shaped appropriately. Such a gain in EE comes at the expense of increased delay of the packets, but this is acceptable as long as it is within the application QoS requirements.

The organization of the paper is as follows. Section II introduces the system model followed by the description of Green scheduling architecture based on DTX and traffic shaping in section III. Section IV describes the system level simulation results of the proposed algorithm. Finally, we discuss conclusions and future work in section V.

II. SYSTEM MODEL

The system under consideration is based on Orthogonal Frequency Division Multiple Access (OFDMA). We assume a downlink transmission system with K users, N chunks and T Transmission Time Interval (TTI)s, where each user is equipped with a single antenna. Perfect channel state information is assumed at both the receiver and transmitter, i.e., the channel gain on each chunk due to path loss, shadowing, and multipath fading is assumed to be known. Channel parameters are assumed to be estimated by some other method, which is not specified in this paper. The system does not employ spreading in either time or frequency; each chunk can only be used by one user at any given time. All the users send back the Channel Quality Indicator (CQI) report to the Base-station(BS) for all the chunks which then finally performs chunk and power allocation for all the users.

The arrival traffic in general for user k at time t is given by $R_k^A(t)$ bits. Let $S_i(t)$ denote the set of chunks allocated to user i at time t. Each chunk is allowed to be used by at most one user; hence, $S_i(t) \bigcap S_j(t) = \varnothing$ for $i \neq j$ and $\cup_{i=1}^{K} S_i(t) \subseteq \{1, 2, \cdots, N\}$. The transmitter finds S_i for all $i = 1, 2, \cdots, K$ and distributes power such that the objective of resource allocation is satisfied.

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Let $r_k(n,t)$ and $p_k(n,t)$ denote the rate and the power allocation of user k on chunk n at time t such that $r_k(n,t) = \mathcal{R}(p_k(n,t)\gamma_k(n,t))$. The function, $\mathcal{R}(\alpha)$ is discrete rate allocation function given by,

$$\mathcal{R}(\alpha) = \left\{ \begin{array}{ll} 0, & 0 \leq \alpha < \eta_1 \\ r_1, & \eta_1 \leq \alpha < \eta_2 \\ \vdots & \\ r_M, & \eta_M \leq \alpha < \infty \end{array} \right\} \quad (1)$$

,where $\alpha = (p_k(n,t)\gamma_k(n,t))$. There are M discrete modulation and coding schemes (MCS) and $\{\eta_m\}$, are the SINR boundaries to select particular MCS scheme. The data rate of selected MCS scheme, m is given by r_m.

A. BS System Power model

The Macro BS system power model is derived from EARTH D2.3[11]. It provides an accurate estimation of the BS power consumption considering the different components of the radio equipment, such as Antenna Interface, Power Amplifier, Baseband Interface, Cooling, etc. According to this model, the required input power P_{in} to attain a certain RF output power P_{out} can be computed as follows:

$$\begin{aligned} P_{in} &= P_0 + \Delta_P \cdot P_{out}, \quad 0 < P_{out} \leq P_{max} \\ &= P_{sleep}, \qquad P_{out} = 0 \end{aligned}$$

,where P_{max} and P_0 indicate the RF output power at maximum and minimum load, respectively. Δ_P is a coefficient that represents the dependency of the required input power on the traffic load.

The values of the parameters for Macro BS from EARTH D2.3 are given in Table I. The current systems do not consider sleep modes, hence sleep mode power is given by, $P_{sleep} = P_0$, however more advanced BS designs in hardware components will allow P_{sleep} to be a fraction of standby power or maybe even zero, thus completely allowing to switch-off the BS. We also assume that BS can be switched on-off, without any delay to simplify the analysis of the results. However, future work for BS sleep modes should consider the transition time to turn on BS components.

The various system parameters are described in Table II

TABLE I
POWER MODEL PARAMETERS FOR MACRO BS

P_{max}[W]	P_0[W]	Δ_P
40	712	14.5

III. GREEN SCHEDULING ARCHITECTURE BASED ON DTX AND TRAFFIC SHAPING

Before we describe the architecture in detail, it is worth discussing briefly about the traffic characteristics of applications. The statistics of traffic arrival depends on the application generating the traffic [12]. The traffic statistics of typical applications such as Voice Over Internet Protocol (VOIP), near real time video (NRTV), web traffic, etc are given Table III.

TABLE II
SYSTEM PARAMETERS

Total number of chunks	N
Total number of users	K
Maximum Delay tolerance of a packet	D_{max}
Total number of MCS	M
User Index	$k \in [1, K]$
Chunk Index	$n \in [1, N]$
MCS Index	$m \in [1, M]$
Channel for user k for Chunk n	$\gamma[k][n]$
SINR Threshold for MCS Selection	$M_{Th}[1, ..., M]$
Packet Size for MCS	$M_P[1, ..., M]$
UE current traffic arrival (bits) at time t for user k	$R_k^A(t)$
Maximum allowed transmit Power per chunk	P_{max}
UE circuit power consumption for one TTI	P_{UE}^{ckt}
Transmit power of user k for chunk N at time slot t	$P_k(n,t)$
Set of chunks allocated to user k at time t	$S_k(t) \in \{1, ..., N\}$
BS Current queue size for user, i and delay tolerance, j	$BSPkt_{delay}[i][j]$
Maximum number of retransmissions	$Retry_{max}$

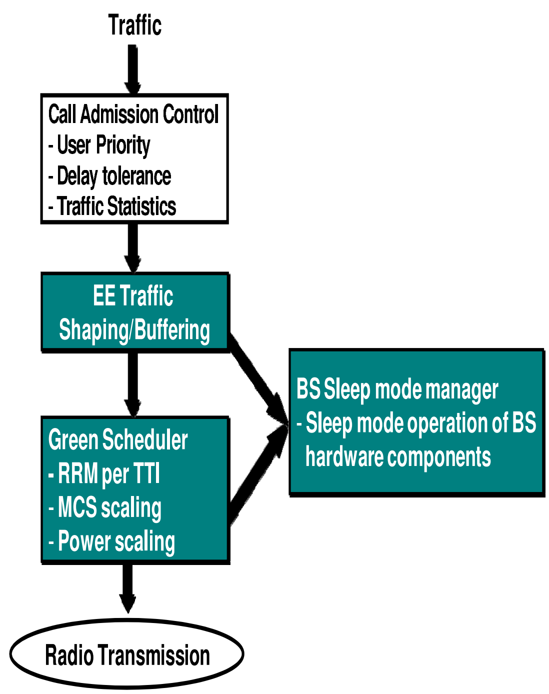
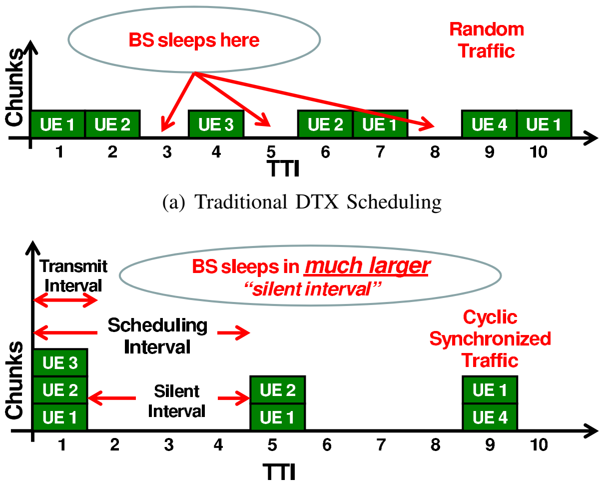


Fig. 1. Green scheduling architecture for DTX and traffic shaping

We can see from the table that traffic statistics of different applications vary greatly in terms of throughput and delay requirements. It is this delay tolerance that we intend to exploit in the scheduler to achieve significant system EE gains to enable DTX for Green Base Stations.



(a) Traditional DTX Scheduling

(b) Proposed DTX Scheduling

Fig. 2. DTX Scheduling Approaches

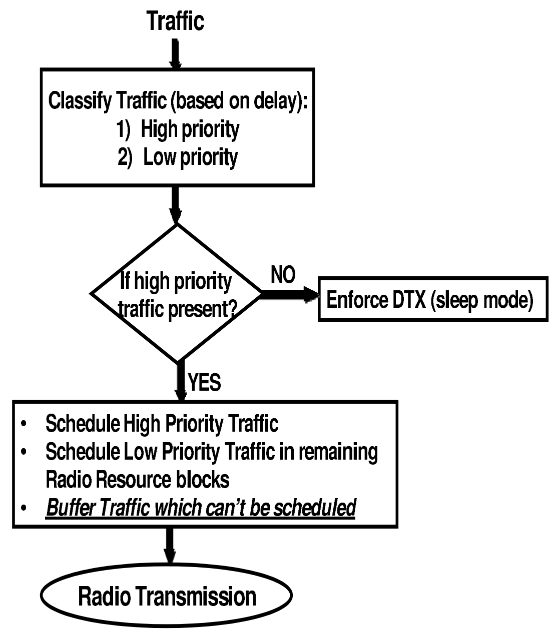


Fig. 3. Flow Chart of the Green scheduling algorithm

TABLE III
APPLICATION QOS CHARACTERISTICS

Traffic Class	Delay (ms)	Jitter (ms)	Data Rate (Kbps)	Loss Rate (%)
Web browsing	< 400	N/A	< 30.5	0
Audio Broadcasting	< 150	< 100	56-64	< 0.1
Video Broadcasting (MPEG-4)	< 150	< 150	28.8-500	< 0.001

Figure 1 shows the architecture of scheduling which enables traffic shaping to introduce DTX at the Base Station. The traffic for all the users arrive at the *Call Admission Control* (CAC) module, which is responsible for allowing the traffic resources into the system based on user/traffic priorities, etc. The CAC module provides the estimate of the traffic characteristics (for example, aggregate throughput, delay tolerance, etc.) to the *Traffic Shaping* module. The *Traffic Shaping* module is responsible for buffering the traffic in order to not violate the QoS characteristics of the traffic, especially in terms of delay performance of the application. The *Traffic Shaping* module passes the "shaped" traffic to the *scheduler*, which assigns resources in terms of radio resource blocks in each TTI. The input to the *scheduler* is channel quality indicator (CQI) estimates, based on the current channel conditions provided by each user. The *scheduler* can implement any of the OFDMA based scheduling algorithms such as Max C/I [13], Round Robin or Green Scheduler [14]. *BS Sleep mode* manager plays the key role in enabling DTX at the BS as it is responsible for putting the BS components to sleep for the inactive periods of traffic. The *Traffic Shaping* module provides input to the *BS sleep mode* manager regarding the duty-cycle of the time intervals of sleep modes of the BS.

Figure 2 illustrates how traffic can be shaped to introduce DTX at the BS. Figure 2(a) illustrates the basic concept of Discontinuous transmission (DTX). In the basic scheme, BS is put to sleep in TTIs for which there is no traffic. The traditional DTX allows energy savings in BS for very low-load scenarios. However, the proposed DTX algorithm in Figure 2(b), the BS adaptively buffers the data for a the duration of *Silent Interval*, T_{silent} based on the traffic characteristics of the application, and then transmits it in a short burst during *Transmit Interval*, T_{tx}. We can introduce more frequent DTX at the BS by adaptively controlling the duration of T_{silent} and T_{tx}. The minimum delay experienced by the application in this case is that of *scheduling interval*, T_{sched}, assuming the duration of T_{sched} is fixed. The maximum delay experienced by the application due to this type of scheduling is $2 * T_{sched}$, assuming all the buffered data can be successfully sent in one *scheduling interval*. We however, propose an algorithm which is based on adaptively tuning T_{sched} based on the aggregate downlink traffic characteristics at the base-station.

A. Proposed algorithm for buffering and traffic shaping

In this section, we describe the proposed algorithm to implement traffic shaping and thus introduce more Discontinuous Transmission (DTX) at the base station. The algorithm to decide whether BS is put into sleep mode or not runs at each TTI. The flow chart for the algorithm for each TTI is given in Figure 3. The input traffic arrives into the BS, where it is first classified as low/high priority. We classify the traffic based on the delay tolerance the packet has before it is discarded. After that, if high priority traffic is present which has to be sent urgently in current TTI, we activate the radio of BS to initiate downlink transmission for the packet. The resources are assigned first to the high priority traffic and part of the low priority traffic is then assigned to the remaining resources

Algorithm 1 Algorithm to compute whether BS needs to be put in sleep mode

1: **for** $d = 1$ to D_{max} **do**
2: $\quad BSPktTmp[i] \Leftarrow \sum_{j=1}^{d}(BSPkt_{delay}[i][j])$
3: $\quad ActiveNbUEs \Leftarrow \sum_{i=1}^{K}(BSPktTmp[i] > 0)$
4: $\quad MinTTIs \Leftarrow \lceil \frac{ActiveNbUEs}{N} \rceil$
5: $\quad NbChunks_{est} \Leftarrow FnEstNumChunks(\gamma, BSPktTmp)$
6: $\quad BSTxTime_{est}[d] \Leftarrow \lceil max(MinTTIs, \frac{NbChunks_{est}}{N}) \rceil$
7: $\quad BSAvailTime_{est}[d] \Leftarrow d - BSTxTime_{est}[d]$
8: **end for**
9: **if** $\min(BSAvailTime_{est}) > 0$ **then**
10: $\quad SLEEP_{FLAG} \Leftarrow TRUE$
11: **else**
12: $\quad SLEEP_{FLAG} \Leftarrow FALSE$
13: **end if**

Algorithm 2 $FnEstNumChunks(\gamma, R_T)$: Algorithm to estimate the average number of chunks to send the data of all the users based on traffic and channel conditions

1: **for** $k = 1$ to K **do**
2: $\quad$ **for** $n = 1$ to N **do**
3: $\quad\quad \gamma_{max}[k][n] \Leftarrow \gamma[k][n] * (P_{max})$
{Compute Maximum Possible MCS/Packet Size for each of the chunks}
4: $\quad\quad Mcs_{max}[k][n] \Leftarrow \operatorname{argmax}_{m} \{\gamma_{max}[k][n] \geq M_{th}[m]\}$
5: $\quad\quad PacketSize_{max}[k][n] \Leftarrow M_P[Mcs_{max}[k][n]]$
6: $\quad$ **end for**
{Compute Total number of chunks which can satisfy at least SINR threshold, $M_{th}[1]$ for MCS 1}
7: $\quad UsefulChunks[k] \Leftarrow \sum_{n=1}^{N}(Mcs_{max}[k][n] > 0)$
8: $\quad PacketSize_{mean}[k] \Leftarrow \sum_{n=1}^{N} \frac{PacketSize_{max}[k][n]}{UsefulChunks[k]}$
9: $\quad UserNumChunks[k] \Leftarrow \frac{R_T[k]}{PacketSize_{mean}[k]}$
10: **end for**
11: $NbChunks_{est} \Leftarrow \sum_{k=1}^{K} UserNumChunks[k]$

of the scheduled TTI. The low priority traffic which can't be scheduled is buffered to be sent in subsequent TTIs.

We now describe the sub-optimal algorithm to compute whether we have urgent traffic to sent at current TTI. Algorithm 1 decides whether Base-station can be put in sleep mode depending on the channel and traffic load. Line 2 computes the total traffic at each of the users upto all the packets with delay tolerance, d. We then compute the number of users which have traffic to send in current TTI in line 3. In line 5, we estimate the total number of chunks needed to offload all the buffered data using function $FnEstNumChunks(\gamma, R_T)$. In line 6, the transmit time in number of TTIs is estimated based on the aggregated traffic unto delay tolerance d. Line 7 computes the time for which base-station can sleep and defer the data transmission. In the remaining lines 8-13, base-station is awake only if data packets needs to be sent in next TTI else they will be dropped by the application. The base-station is put into sleep mode in current TTI, if $SLEEP_{FLAG}$ is TRUE. If the BS wakes up for the current TTI, then it is kept awake for next $Retry_{max}$ TTIs to support HARQ protocols and retransmissions.

We now describe the function, $FnEstNumChunks(\gamma, R_T)$ which is used to estimate the number of chunks used to transmit all the buffered data depending on the current channel conditions. Lines 3-5 compute the packet size possible based on the maximum power allowed for transmission. For each of the users, we compute in lines 7-9 the number of chunks required to offload all the buffered traffic assuming all the resources are allocated to each of the users. Finally, in line 11 we compute the total number of chunks required to offload the cumulative traffic from all the users with active buffer.

TABLE IV
SIMULATION PARAMETERS

Total number of users, K	10
Total number of chunks, N	50
Inter-Site Distance	500m
Total BS transmit power	40Watt
Channel	Block fading with independent Rayleigh fading within each block
Coherence time of channel	10 TTIs(ms)
Distance-dependent path loss	$L = 128.7 + 37.6\log 10(R)$, R in km [15]
Traffic model	NRTV[16]
Maximum delay tolerance of application, D_{max}	$\{20, 60, 100\}$ms
Packet size, SINR threshold corresponding to each MCS	See Table I in [14]
Maximum Power allowed on each chunk, P_{max}	0.8 Watt
Maximum number of retransmissions, $Retry_{max}$	3
Total Simulation Iterations	50000

IV. SIMULATION RESULTS

In this section, we describe the system level simulation results for the proposed DTX algorithm. We consider a scenario in which variable number of cellular users are deployed in the macrocell area. The results are averaged over 10 independent runs. We simulate 50,000 independent TTIs during each run and update channel fading instances at each TTI. At the beginning of each run, UEs are randomly deployed within the macrocell coverage area. The traffic generated by cellular

TABLE V
SIMULATION PARAMETERS

Total number of users, K	10
Total number of chunks, N	50
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Channel	Block fading with independent Rayleigh fading within each block
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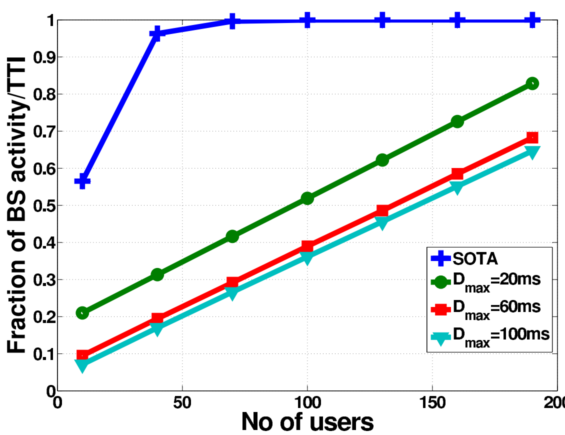

Fig. 4. Base-station activity usage (per TTI)

users is modeled as a near real time video (NRTV) traffic [16]. Finally, link adaptation is implemented in downlink transmissions for which modulation and coding schemes are selected according to momentary feedback transmitted by the served UE. We also allow retransmissions in case of channel errors and the effect of retransmissions is included in the performance results.The simulation parameters are described in Table V.

We first show the results of base-station activity usage per TTI in Figure 4. The results are compared with the State of the art (SOTA) algorithm [10] in which the base-station is not utilized for the TTI when there is no packet to be sent to any of the users. These results show that classical DTX algorithms can be used only in very low load scenarios, or in this case below 70 users. However, the proposed algorithm is capable of putting base-station to longer sleep modes even at moderately loaded scenarios. The results of the proposed algorithm are plotted with various delay tolerance, D_{max} thresholds for the application. We see that higher delay tolerance has a potential for more DTX, but $D_{max} = 60$ms is the limit of EE gain achievable from proposed DTX algorithm based on traffic shaping. Delaying the packets for higher than $D_{max} = 60$ms does not have much reduction in terms of BS activity. However, the delay tolerance values in all the cases are well below the acceptable limits of the application as described in Table III.

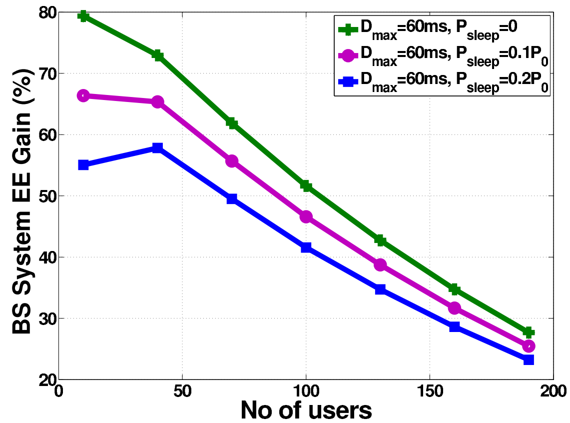

Fig. 5. Base-station system power gain

We now show the effect of utilizing different sleep mode power, P_{sleep} on the system power gain in Figure 5 for $D_{max} = 60$ms. The design of base-station components to put them into sleep mode at such a small time-duration (60ms) has a tremendous impact of the performance of DTX algorithms. The EE gain plotted in the simulation results is given by,

$$\text{EE gain} = \frac{P_w(\text{SOTA}) - P_w(\text{Proposed DTX})}{P_w(\text{SOTA})} \tag{2}$$

,where $P_w(\text{SOTA})$ is the system power consumption of State-of-the-art (SOTA) algorithm using DTX without traffic adaptation and $P_w(\text{Proposed DTX})$ is the system power consumption of the proposed DTX algorithm using traffic shaping. Ideally, $P_{sleep} = 0$ provides maximum performance of DTX based algorithms, however some base-station components, such as cooling cannot be frequently put to deep sleep or they can be only put in partial sleep mode. Due to the lack of accurate models of BS sleep modes, we compare the performance of our algorithm for various sleep mode power values. For example, $P_{sleep} = 0.2P_0$ refers to sleep mode power being 20% of the standby power consumption. It is obvious from the results that $P_{sleep} = 0$ has the maximum EE gain for our algorithm, however even with $P_{sleep} = 0.2P_0$, we can achieve significant energy savings with our proposed DTX algorithm. Higher sleep mode power, P_{sleep} values reduces the gain of DTX based algorithms. We also note that the performance of our algorithm decreases as there are less opportunities to put base-station (BS) to sleep due to the QoS requirements from the users.

V. Conclusions and Future Work

In this paper, we proposed a DTX based traffic shaping algorithm in which we buffer the traffic before transmitting and introduce delay in transmissions to enable more frequent DTX at the base-station. In essence, we exploit classical energy-delay trade off to improve EE of the cellular network. The proposed scheme introduces delay at the application, but this is acceptable as long as it is within the tolerance limits of the application QoS requirements. We should also note that the P2P traffic and traffic generated by sensor applications, like machine-to-machine (M2M) can have much larger tolerance for delay and thus are more elastic. We also showed that the gains obtained in our scheme can be exploited in moderately loaded scenarios, which is not the case for classical DTX based approaches. However, the EE gains from DTX approaches diminish in heavily loaded scenarios. The current generation of base-station hardware components are not designed to be put into sleep modes within the order of few tens of milliseconds. However, as the drive from the industry for more Energy Efficient (EE) cellular operation increases, there will be increased innovations in the design of base-station hardware components in order to put them to sleep more frequently at shorter time scales[17]. One of the biggest challenges in enabling the proposed DTX approaches in current standard is the absence of control signaling during the period when the base-station is in sleep mode. We envision that this problem will be solved either by the neighboring cells assisting the sleeping base-station to provide control signaling during sleep cycle or modifying the future releases of the LTE standard to enable longer sleep modes at the base-station without the presence of control signaling during the sleep duration. The future work will be to extend DTX at the network management level in which several base-stations coordinate their DTX cycles to improve both Energy Efficiency (EE) and also mitigate inter-cell interference.

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