Energy Efficient Algorithm for High Speed Packet Data Transfer on Smartphone Environment

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Abstract: Energy efficiency is the main concern of the 21st century. The smartphone could be a trendy battery operated device and also the experience of the smartphone usage is entirely counting on the battery life. The state of the Smartphone can be Screen_OFF and Screen_ON. Majority of the time spent by the user on the phone is in screen off mode however 30% to 40% of the battery power consumption in this state through Always_On Apps. These apps send tiny burst to their server for various functions at a specific interval of time and keep RRC state busy. This paper proposes an energy-efficient algorithm for high-speed packet data transfer on a Smartphone called PSEO (PS Energy Optimization). It schedules data communication throughout the screen off state based on the radio signal quality. PSEO regulate Data_ON and Data_OFF period while not affecting the user convenience based on the independent value of RSRQ. The proposed research saves the energy up to 28.88%, 78.60% and 16.20% on average of total network energy, Screen_Off energy, and overall smartphone energy respectively.

Keywords: 3G/4G, Cellular Network, Energy Consumption, Radio Signal Strength, RSRQ, Smartphone.

I. INTRODUCTION

The power consumption of the hand-held devices is a crucial issue nowadays. The increase of the mobile internet traffic and rise of mobile Apps are the foremost deciding factor in battery backup. The long timeline of energy efficient researches underlines nearly 80% of the internet traffic is generated by mobile apps therein 30% to 40% of the traffic is generated by asynchronous network activities while not the knowledge of the users [1, 2]. However, achieving energy efficiency in smartphone when connecting high-speed data network with varied asynchronous traffic continues to remain difficult and yet it’s an iconic challenge to handle. Broadly speaking, the mobile usage is classified into two categories that are Active and Inactive. The study [2] underline up to 40% of the total smartphone energy is consumed at the time of screen off. The very fact is that the magnitude relation of screen state ON and OFF of the typical phone is 1:3 respectively, thus most of the time the UE isn’t operated by the user however it operated by some hidden factors. That influencing factors are networks and Apps. Generally, the mobile Apps are often classified based on their characterization that is Social Network, Gaming, Multimedia, Utility, Location Service and Instant Messenger. Among those, all the Apps are often updating data with their server through short message known as keep-alive messages. Even the cloud-based applications are worst in behavior as a result of that sort of Apps have to update themselves fairly often through notifications that sort of Apps are known as Always-On Apps. A typical smartphone has N number of Apps been incessantly generate these sorts of short network burst are known as asynchronous network traffic. These short bursts have terribly less packet load, as an instance, weather applications have a connection with their server for less than 3 sec and also the payload is a smaller amount than 2 kb. Even a typical social network App having an association to the server for 2 to 4 sec and transfer a short payload about 1 to 3 kilobyte [3]. This asynchronous traffic generated from client or server as well. The one will not predict and optimize server generated traffic however the researches can optimize user-generated one. The paper propose an adaptive radio connection management scheme called PS Energy Optimizer (PSEO) to minimize the energy consumption of radio network when the smartphone is in inactive (Screen is Off). This model schedule data network connection based on the radio signal quality only when the phone is in Screen_OFF mode. It uses the periodic scheduling time without affecting user experience and at the same time reduce ton of RRC connection requests. The architecture does not influence the data scheduling when the screen is ON and the wireless hotspot is active. The rest of this paper is organized as follows. Section II highlights the juice of literature review. Section III and Section IV introduce the contextual of the work. Section V presents the architecture of PSEO and its components. This section elaborately discusses the working principles of PSEO with algorithm and calculation of PS Cycle time for Data On. Section VI presents the experimental data and results. Section X concludes the research.

II. LITERATURE SURVEY

A. Power Consumption of the 3G Radio Interface

Feng Qian and Oliver Spatscheck team done such remarkable work regarding Screen_Off energy optimization and the team proposed lot of measurement results and arose number of research problems as well. The research [2] introduced two optimization techniques such that fast dormancy and batching. The study [4, 5, 6] focuses on settings of critical inactivity timer values that determine when to release radio resources after a period of inactivity. Aruna Balasubramanian et al [7] in front of the smartphone energy consumption research and they proposed a measurement-driven model for measuring the energy consumption of network activities (3G, GSM and WiFi) and developed energy efficient protocol called TailEnder to minimize the cumulative network energy consumption. Moo-Ryong Ra et al [8] suggested architecture called SALSA which is an optimal online algorithm to fine tune Energy-Delay trade-off and
achieve 10-40% of energy gain. The research [9] reveal personalized network activity-aware predictive dormancy technique, called Personalized Diapause (pD) to automatically identifying user-specific tail-time transmission characteristics for various network activities. Guangtao Xue [10] determine a scheme SmartCut, which effectively mitigates the tail effect of radio usage in 3G networks with little side-effect on user experience. The study [11] proposed a user-level dynamic decision algorithm to have fine-grain user level optimization to set dynamic tail time.

B. Offloading and Traffic Aware

Study [12] found local computation limitation at the smartphone is the real bottleneck for opening most webpages and propose an architecture, called Virtual-Machine based Proxy (VMP), to shift the computing from smartphones to the VMP because reason of the long delay and high power consumption in web browsing is not due to the bandwidth limitation most of time in 3G networks. The research [13] proposed an energy-aware approach for web browsing based on browsing speed and user responses in 3G based smartphones. Ya-Ju Yu et al [14], develop an energy adaptive approach and design an energy-efficient downlink resource allocation scheme to support multimedia applications.

C. Inactive mode and radio signal strength

The research [15, 3] proposed a methodology ExpCO2 to reduce smartphone energy consumption, when it’s not interactively used by the user, particularly in Screen OFF state. The experimental result shows that particular amount of energy is consumed during inactive mode of smartphone. The optimization control network activity by toggle the data state ON and OFF at the Screen OFF and this reduce energy consumption upto 34% without affecting the Quality of Experience. Xiaomeng Chen et al [16] introduced a new system called HUSH screen-Off energy optimizer to reduce smartphone energy consumption by 15.7% due to background activities in the screen-Off state. The study [17] present a novel technique called LoadSense for a cellular client to obtain a measure of the cellular load, locally and passively, that allows the client to determine the ideal times for communication when available throughput to the client is likely to be high. Nishkam Ravi [18] proposes a new context-aware battery management architecture for mobile devices (henceforth CABMAN). Ning Ding et al [19] proposed what-if analysis to quantify the potential energy savings from opportunistically delaying network traffic by exploring the dynamics of signal strength experienced by users.

III. CHARACTERIZING ENERGY CONSUMPTION IN SMARTPHONE

According to the fundamental architecture of 3G and 4G [20] the RRC state machine is that the response to regulate radio resources and paging parameters between UE and NodeB’s. After connection to RRC the user equipment (UE) must stay in a high-power state, occupying radio resources for some required time before the allocated resource is released by the network, and then the UE enters a low power state. This required time period, also known as the Radio Resource Control (RRC) tail time [7], is necessary and important for cellular networks to prevent frequent state promotions (resource allocation), which can cause unacceptably long delays for the UE, as well as additional processing overheads for the radio access network [21, 22].

Today’s cellular carriers use a static and conservative setting of the tail time in the order of many seconds, these times are recommended by 3GPP (based on versions) and configured by network providers. Previous studies revealed this tail time to be the root cause of energy loss and radio resource inefficiencies in both 3G [7, 25, 27] and 4G networks [26]. There are several kinds of researches [7, 23, 24, 28-30] fine tune the RRC state machine and achieved minimum radio energy loss. But still, there is a loophole to killing energy in the wild. As per the text, these asynchronous short network traffic wakeup RRC state continuously for a short time, because of this RRC wasted their resources at tail time unnecessarily cause extreme signaling overhead and energy consumption on UE. The problem is short wakeup of RRC is continuous arise by N number of Apps with N number of activities at frequent time interval. Background activities of Apps throughout screen on time aren’t bothering however throughout screen off is that the focus one.

IV. ANATOMIZING THE FACTORS INFLUENCING ENERGY LOSS IN SCREEN OFF STATE

During screen off the user cannot access Apps, games, and video, even the display unit is shut down. However the actual quantity of energy consumed in the screen off state that we tend to think about it’s energy loss. In this state, some factors are influence the loss of energy in UE, which are

- Apps
- RRC state
- Radio Signal

Among these App is a core factor of energy loss, RRC and radio signal is a dependent factor to Apps. Each App initiates numerous background activities and each background activities may differ by its payload and CPU utilization [Fig 1]. Obviously these App activities (Act1, Act2, ……, Act n) wakeup CPU unit and establish RRC connection between UE and RNC for a short while. The energy loss of the UE is directly proportional to the amount of activities generated by apps and number of RRC connection is established.

V. ARCHITECTURE OF PS ENERGY OPTIMIZATION

PSEO is a model to reduce energy loss in Screen_off state without affecting user experience by scheduling data connection. This model precisely focuses to minimize radio energy consumption because the radio unit is the major energy hunger in UE. It does not depend on 3G/4G networks and does not require any additional network parameters and major changes in operating system, it completely generic.
PSEO can easily integrate with all type of data network and all kind of mobile operating systems. This approach does not partial to particular App, because it deactivate all apps request through disable the data communication.

5.1.1 Screen State
It is a key factor to enable and disable the PSEO activities. PSEO become active when the screen state is Off (inactive). Once the screen is ON the PSEO is neutralize their activities and controls and enables data connection without any constraints. When the screen state is Off that time only PSEO initiate PS Cycle.

5.1.2 Background Workload
This logical unit represents the traffic which are generated by Always_On App eventually its also called client generated or asynchronous traffic. PSEO bothering about the traffic only when generated in the screen of and this traffic are handled by operating system automatically and stored in local buffer.

5.1.3 Always_On Apps
It is some time called Cloud based Apps which is tries to be always connected with their remote server to update data. Text already discussed elaborately. PSEO handling the Always_On workload which is generated only in screen Off time.

5.1.4 Data Communication Module
This module is nothing but 3G/4G interface in UE. This module is managing upload and downloads user data. The working principle of this module is controlled by operating system but PSEO control the cell link for data connection through periodic scheduling of connection.

5.1.5 Radio Interface
It managed by RRC and UE. This is backbone of data communication and entirely depends upon the user activities. PSEO indirectly control radio interface through scheduling data communication.

5.1.6 Radio Signal Strength
This part is the deciding factor of PS cycle time and the entire working principle of PSEO is directly depends on radio signal quality. This will discussed sec x.

B. Working Principles of PS Energy Optimization
PSEO schedules the data connection based on the radio signal strength and it act as a control module of data connection during screen_off. The outline of PSEO is just sense the state of the UE screen and if the screen is off then the data communication is scheduled by dynamic time slots (Fig 3). PSEO does not control the data connection in screen_on because of the quality of user experience and PSEO immediately enable the data connection when the user initiate screen_on event. PSEO split the screen_off time into number of PS cycles, each cycle has Data_on and Data_off time slot (Fig 4). The Data_off time slot is constant which is derived from the research [15], about this time nothing can be transmitted and the Apps generated traffic is automatically managed by operating system and this traffic will be transferred when the data communication is become active. The Data_on time slot is calculated based on RSRQ. The base value of Data_on time slot is 1 minute and it could be dynamic. During this slot the Apps generated background traffic in Data_off is transmitted by operating system and fetch the external traffic as well. The base value of Data_on is maintained when the signal is good otherwise it will be modified. If the signal strength is excellent the base value will be reduced and if the signal is poor the base value will be increased. That is the proposed mechanism to maintain the trade_off between the quality of user experience and energy loss. The technical specification of PSEO is discussed in forthcoming sections.
Algorithm1: PS Energy Optimization

Function DataScheduler ()

Input: ScreenState, DataState, Data_ON_sec, Data_OFF_Min, SignalStrength

Output: Minimize energy loss

Initialize: SignalStrength ← 0 where -3 ≥ Signalstrength ≥ -16

Data_ON_sec ← 60 and Data_OFF_Min ← 29

While UE is ON do
Detecting Screen Events

if Screen Event Triggered for Inactive then
  if Hotspot is disabled then
    ScreenState \leftarrow \text{OFF}
    Toggle data communication state OFF
  end if
  if Screen Event Triggered for Active then
    ScreenState \leftarrow \text{ON}
    Toggle data communication state ON
  end if
end if

Detecting data communication module Events

if Data communication Disable Event is Triggered then
  if ScreenState is OFF then
    Toggle data communication ON after Data_OFF_min
  end if
end if

if Data communication Enable Event is Triggered then
  if ScreenState is OFF then
    read SignalStrength
    if SignalStrength is -3 ≥ Signalstrength ≥ -16 then
      Get Data_ON_sec from DataON_TimeSlot Function
      Toggle data communication OFF after Data_ON_sec
    else
      Toggle data communication OFF
    end if
  end if
end if

End Function

Function DataON_TimeSlot()

basevalue \leftarrow 60 \text{ sec}

Get RSRQ

if RSRQ is between -3 to -5 then
  DataON_slot = basevalue - \text{subtract Seconds}
Elseif RSRQ is between -6 to -11 then
  No change of basevalue
Elseif RSRQ is between -12 to -16 then
  DataON_slot = basevalue + \text{Addition Seconds}
Return DataON_slot

End Function

C. Mechanism of Calculating PS Cycle time for Data_On

Let \( \Delta t \) is a time period of radio communication state is active that means duration of Data\_on and \( \Delta t \) is relative to be active only when R_{signal} is active and R_{signal} \rightleftharpoons \Delta t. \) Let \( \Delta t \) denotes the time unit of radio communication inactive state that mean the duration of Data\_off. It’s a fixed off bound and it does not affected by any of the network and application factors so \( \Delta t \notin R_{signal} \) where R_{signal} is an instantaneous receiving signal quality ratio on UE. R_{signal} is an independent variable which is directly related to the factors of radio interface that can be a distance and cell load, so R_{signal} \in \{distance, cell load\} [19, 32] and it’s a dynamic cumulative value which calculated by

\[
R_{signal} = \frac{\tau}{\delta} \lambda \quad \lambda > 0
\]  

As mentioned earlier R_{signal} is a cell link quality factor that influence the data transfer rate from the UE and R_{signal} \propto Data_{throughput}. The receiving ratio may differ according to the UE in same condition. Where \( \tau \) signify Reference Signal Receiving Power (RSRP) it’s an average signal strength based on RE \( \sqrt{17} \) can be calculated through

\[
\tau = \delta - 10\log(12 \times \lambda)
\]  

where \( \delta \) is RSSI and \( \lambda \) is a number of resource block (RB) which is similar to the carrier bandwidth \( \lambda \in \{1,4,3,5,10,20\} \) usually \( \lambda \) measured by MHz. Accordance of Equ (1) the can get signal ratio and the output of R_{signal} \in \{-3,-4,\cdots,-9\} which is normally measured by dBm [17]. According to the research [17, 19, 32, 33] the range of R_{signal} indicate the cell link quality and Data_{throughput}. Even R_{signal} quality can be categorized into 3 logical levels Signal\_Excellent, Signal\_good and Signal\_poor and this would be

\[
R_{signal} = \begin{cases} 
-3 > Signal\_Excellent > -5 \\
-6 > Signal\_good > -11 \\
-12 > Signal\_poor > -16
\end{cases}
\]  

From the Equ (1) and (2) the \( \Delta t \) can be calculated

\[
\Delta t = T_{avg} \pm T_{affect}
\]  

Where T_{avg} is \( \Delta t \) duration which is assumed by 1 minute based on the research [15] and the T_{affect} is a time variant which calculated based on the output of R_{signal}. T_{affect} can be calculated through the following consideration

i) If R_{signal} = Signal\_Excellent the T_{affect} will be negative value.

ii) If R_{signal} = Signal\_good the T_{affect} will be 0.

iii) If R_{signal} = Signal\_poor the T_{affect} will be positive value.
The $T_{affect}$ value is variant and it will be impact by -5 seconds. If $R_{signal} = Signal_{excellent}$ then $T_{affect}$ is subtracted by 5 sec for each RSRQ value. If $R_{signal} = Signal_{poor}$ then $T_{affect}$ is adding 5 sec for each RSRQ variation. Simply the principle is working based on the mapping (Fig. 5 and Fig.6)

![Fig 5. Correlation between Signal Strength and Data on time](image)

However if the signal strength is excellent, the Data throughput should be high [17, 19, 32, 33] so PSEO no need to maintain $\Delta t$ for 1 min, it can be reduce. If the signal strength is good, the Data throughput will be average [19, 32] so need not to modify the duration of $\Delta t$. If the signal strength is poor the $\Delta t$ duration should be increased because of low Data throughput -

![RSRQ vs T_affect](image)

**Fig 6. Mapping of Signal Strength and $T_{affect}$**

### D. Calculating the Energy of PS Cycle Time

Let $Traffic_{App}(\Delta t)$ is amount of data in bytes which is generated during the time slot $\Delta t$. $Traffic_{App} \in A(i)j, i, j \in [1, 2, 3 \ldots n]$ where $A$ is an App running in UE. $\Delta t$ is a constant time slot of data disable duration. The $\Delta t$ traffic is related to total number of apps and its activities (Eq (6)).

$$Traffic_{App}(\Delta t) = \sum_{j=1}^{n} App(i)j$$  \hspace{1cm} (6)

Let $\mu[\Delta t]$ denotes the amount of data transfer during the time slot $\Delta t$. $\Delta t$ is set from a cumulative random value calculated from finite range of RSSI, RSRP and RSRQ values (see Eq 1) and assume $\mu[\Delta t] > 0$. According to the Eq (4) $P_{\mu[\Delta t]} \propto Traffic_{App}(\Delta t)$. So the total power of one $PS_{cycle}$ can be calculated in (7). $PS_{cycle}$ is nothing but duration of $\Delta t + \Delta t$ and this would be $Screen_off \Rightarrow PS_{cycle}$

$$P_{PS_{cycle}} = P_{[\Delta t]} + P_{[\mu[\Delta t]}}$$ \hspace{1cm} (7)

In the equ (7), $P_{[\Delta t]}$ should be 0 because there is no data transfer during $\Delta t$ slot and assume at the end of the $PS_{cycle}$ i.e end of $\Delta t$, $\mu[\Delta t]$ and $Traffic_{App}[\Delta t]$ should be zero and let both should be zero for next cycle (Fig 7).
Proceedings of Equ (7) the total power consumption of inactive mode \( P_{\text{Scr-off}} \in P_{PS\text{cycle}(i)}(i \in \{1, 2, 3 \ldots n\}) \) and this can be calculated by

\[
P_{\text{Scr-off}} = \sum_{i=1}^{n} P_{PS\text{cycle}(i)}
\]

(8)

Proceeding of Equ (4), (7) and (8) the total radio energy gain can be calculated by

\[
\text{Energy Gain by PSEO} = P'_{\text{Scr-off}} - P_{\text{Scr-off}}
\]

(9)

Where \( P'_{\text{Scr-off}} \) is total energy consumption of radio interface in the Screen_off duration without the implementation of PSEO.

**E. Measuring Radio Energy during Data_On**

Power consumption of radio interface is directly proportional to the number of transport block send and received over data network [35]. The power consumption of radio interface in UE can be formulate into

\[
P = P_{\text{RRC State}} + P_{\text{load}} + P_{\text{Proc}}(s)
\]

(10)

where \( P \) is radio transmission energy, \( P_{\text{RRC State}} \) is power consumption to maintain RRC states including tail time. \( P_{\text{load}} \) is power consumption of sending and receiving packets and \( P_{\text{Proc}}(s) \) is energy for encapsulation and decapsulation process of packets. \( S \) is the size of the packet in bytes.

Here \( P \propto P_{\text{load}} \) and \( P_{\text{RRC State}} \) is a minimum power consumption from UE side to handle RRC states typical inactivity time setting. \( P_{\text{Proc}}(s) \) is assumed as a linear and incremental power that proportional to size of the transport blocks \( P_{\text{Proc}}(s) \propto \text{Trans}_{\text{block}} \).

Equation (10) depicts the cumulative energy of radio transmission and those energy \( (P) \) can be break into energy per packets and per processing time of packets. One IP packet can be divided into number of transport blocks and which is proportional to size of the packet as well. Here the notation of finding transport blocks.

\[
N(\text{Trans}_{\text{block}}) = \left[ \frac{S}{\text{MTBS}} \right]
\]

(11)

where MTBS is Maximum Transport Block Size and these blocks will decide the \( P_{\text{load}} \) energy [34]. The time spend to process the packets is \( N(\text{Trans}_{\text{block}})T \) in that \( T \) is transmission time interval and it decide transmission rate [34]. So the packet transmission interval should be \( I > N(\text{Trans}_{\text{block}})T \) thus

\[
P_{\text{load}} = \frac{N(\text{Trans}_{\text{block}})}{I} \times P_{\text{PacketSend,Recv}}
\]

(12)

\[\text{when } I > N.T \]

where \( P_{\text{PacketSend,Recv}} \) is a power consumption of sending and receiving one packet and \( I \) is packet sending interval. From the Equ (11) and Equ (12) the power consumption of one RRC connection is calculate from

\[
P = P_{\text{RRC State}} + \frac{P_{\text{PacketSend,Recv}}}{I} \left( \left[ \frac{S}{\text{MTBS}} \right] \right)
\]

(13)

Equation (13) depicts power consumption can be decided by the number of packets, number of transport block and packet sending and receiving interval \( I \) are the influencing factors of radio interface power consumption.

**VI. RESULT ANALYSIS**

**A. Experimental Setup**

The experimental data has been collected from 50 users from different age group and different professionals. The traces collected from android 5+ phones for 30 days. These traces include packet payloads, user input events, RSRQ value and power consumption log. During the test, the users are advised to install PSEO App in their smartphone and uninstall unnecessary Apps. The users essentially have the following Apps for network traffic monitoring and other purposes.
The test intentionally left gaming Apps. WhatsApp, Facebook, Instagram, Cricbuzz, Twitter, Youtube, Gmail, Google Play store, Browser. The test users are selected from various professionals and having their different smartphone models.

**B. Analysis of User Interaction**

The result of 30 days usage pattern reveals various interesting quantitative results and facts. Obviously each and every user has different mindset and usage patterns and it entirely depends on age and nature of job. In this study, the traces have been collected from various professionals (Table- I) and different age groups. The average age is 32 to 35 because the middle aged people are the most hungers of smartphones and the minimum age of the trace is 18 and maximum age is 65 (Table-I). The users are selected evenly from various professionals and almost cover all major area. The mechanic and taxi driver domain account 1 user each and remaining areas having minimum 2 users and above (Table-I). The analysis of the trace is clearly reveals that marketing people uses phone excessively during the working days. Marketing people, Academic people and Home makers are the top 3 highest phone users and their average usages are 4.0 hrs, 3.0 hrs and 3.54 hrs respectively (Fig 8, Fig 9, Fig 10, Table-I)

![Fig 8. Average usage of mobile phone (Screen On duration) in hours.](image1)

![Fig 9. Highest usage of mobile phone (Screen On duration) in hours.](image2)

![Fig 10. User wise minimum Screen_On duration](image3)
Table-I. Average usage time and screen events during the log period

| ld | $\Delta^2$ | $\Delta^3$ | $\sigma_{usage}$ | $\Delta_{Low}$ | $\Delta_{High}$ | $\Delta_{Tot\ Events}$ | $\Delta_{Avg\ Events}$ | $\sigma_{events}$ |
|----|------------|------------|-------------------|---------------|----------------|----------------------|---------------------|-----------------|
| U1 | 2.5        | 1.49       | 1.93              | 0.52          | 7.3            | 2880                 | 96                  | 86.12           |
| U2 | 2.60       | 2.12       | 1.75              | 0.41          | 5.17           | 10397                | 346                 | 110.01          |
| U3 | 4.21       | 4.21       | 1.41              | 2.45          | 6.54           | 2914                 | 97                  | 14.29           |
| U4 | 5.82       | 5.38       | 2.86              | 2.17          | 11.21          | 12148                | 404                 | 160.95          |
| U5 | 1.69       | 1.20       | 1.07              | 0.57          | 3.34           | 2271                 | 76                  | 11.51           |
| U6 | 5.33       | 5.38       | 1.06              | 4.14          | 7.16           | 9197                 | 307                 | 45.28           |
| U7 | 5.66       | 5.35       | 1.43              | 3.53          | 8.07           | 1886                 | 63                  | 21.51           |
| U8 | 5.31       | 5.02       | 1.37              | 3.43          | 7.11           | 4311                 | 144                 | 15.96           |
| U9 | 1.26       | 1.42       | 0.55              | 0.52          | 2.10           | 1508                 | 50                  | 4.91            |
| U10| 5.12       | 5.24       | 2.16              | 2.15          | 8.07           | 1208                 | 40                  | 8.54            |
| U11| 3.83       | 2.15       | 2.92              | 1.14          | 7.30           | 3034                 | 101                 | 17.50           |
| U12| 3.03       | 2.48       | 1.78              | 1.00          | 5.45           | 4757                 | 158                 | 28.73           |
| U13| 2.50       | 2.19       | 0.91              | 1.26          | 4.12           | 4302                 | 143                 | 24.54           |
| U14| 3.46       | 3.45       | 0.79              | 2.01          | 4.45           | 4225                 | 141                 | 29.88           |
| U15| 2.67       | 2.80       | 0.90              | 1.14          | 3.56           | 3111                 | 104                 | 18.22           |
| U16| 2.15       | 2.18       | 0.76              | 1.14          | 3.45           | 2965                 | 99                  | 11.28           |
| U17| 3.00       | 3.36       | 0.58              | 2.14          | 3.51           | 2391                 | 78                  | 7.31            |
| U18| 2.81       | 3.45       | 1.11              | 1.14          | 4.06           | 2117                 | 71                  | 9.21            |
| U19| 2.00       | 2.18       | 0.92              | 1.06          | 3.51           | 1542                 | 51                  | 8.21            |
| U20| 1.35       | 1.45       | 0.48              | 0.56          | 2.14           | 1328                 | 44                  | 5.40            |
| U21| 3.07       | 3.51       | 1.17              | 1.14          | 4.45           | 4286                 | 142                 | 39.00           |
| U22| 3.78       | 4.45       | 1.33              | 1.10          | 5.14           | 6942                 | 231                 | 65.00           |
| U23| 1.94       | 1.44       | 1.12              | 1.30          | 4.40           | 2211                 | 74                  | 17.87           |
| U24| 3.11       | 3.01       | 0.79              | 2.29          | 4.32           | 2914                 | 97                  | 18.79           |
| U25| 2.78       | 3.14       | 1.17              | 1.18          | 4.56           | 2571                 | 85                  | 20.00           |
| U26| 2.35       | 2.45       | 1.08              | 1.14          | 3.56           | 1714                 | 57                  | 6.00            |
| U27| 3.50       | 3.56       | 0.88              | 2.16          | 4.45           | 4800                 | 160                 | 33.00           |
| U28| 2.64       | 2.45       | 0.63              | 2.14          | 3.51           | 3600                 | 120                 | 105.65          |
| U29| 3.02       | 3.11       | 0.84              | 2.16          | 4.48           | 3257                 | 109                 | 83.36           |
| U30| 3.03       | 3.19       | 0.50              | 2.41          | 3.56           | 3514                 | 117                 | 31.65           |
| U31| 2.66       | 2.56       | 0.91              | 1.28          | 4.11           | 4080                 | 136                 | 30.01           |
| U32| 2.28       | 2.45       | 0.62              | 1.08          | 3.08           | 3737                 | 125                 | 87.10           |
| U33| 1.46       | 1.11       | 0.53              | 1.08          | 2.26           | 1886                 | 63                  | 9.38            |
| U34| 1.50       | 1.21       | 0.51              | 1.09          | 2.28           | 2091                 | 70                  | 0.74            |
| U35| 1.54       | 1.29       | 0.51              | 1.11          | 2.36           | 1663                 | 55                  | 22.01           |
| U36| 2.41       | 2.45       | 0.32              | 2.01          | 3.01           | 5477                 | 183                 | 25.28           |
| U37| 1.65       | 1.45       | 0.46              | 1.01          | 2.18           | 2614                 | 87                  | 48.00           |
| U38| 3.03       | 3.16       | 0.48              | 2.18          | 3.46           | 7200                 | 240                 | 20.00           |
| U39| 3.28       | 3.16       | 0.46              | 2.55          | 4.01           | 8143                 | 271                 | 106.00          |
Energy Efficient Algorithm for High Speed Packet Data Transfer on Smartphone Environment

| User | $\Delta^a$ | Wakups$^b$ | Payload (GB)$^c$ | $\Sigma T$ | $\Sigma Avg$ | % of packets$^d$ | $\Sigma Up$ | $\Sigma Down$ |
|------|------------|------------|-----------------|------------|-------------|----------------|----------|------------|
| U1   | 21.5       | 82980      | 28.99           | 1.3E+08    | 242.53      | 4.57 %         | 31       | 258        |
| U2   | 21.4       | 23023      | 15.20           | 3E+07      | 541.71      | 5.83 %         | 55       | 346        |
| U3   | 19.79      | 82125      | 17.81           | 4.3E+07    | 446.83      | 9.20 %         | 32       | 138        |
| U4   | 18.18      | 19718      | 35.01           | 1.2E+08    | 324.77      | 3.04 %         | 47       | 111        |
| U5   | 22.31      | 104817     | 33.56           | 3.2E+07    | 243.04      | 5.60 %         | 38       | 259        |
| U6   | 18.67      | 25948      | 38.68           | 6.1E+07    | 416.62      | 4.84 %         | 59       | 330        |
| U7   | 18.34      | 126446     | 16.09           | 9.5E+07    | 482.43      | 12.06 %        | 72       | 347        |
| U8   | 18.69      | 55320      | 28.16           | 9.8E+07    | 309.55      | 4.55 %         | 46       | 279        |
| U9   | 22.74      | 159322     | 12.42           | 3E+07      | 440.05      | 11.03 %        | 83       | 266        |
| U10  | 18.88      | 199152     | 10.67           | 8.1E+07    | 442.21      | 17.06 %        | 89       | 390        |
| U11  | 20.17      | 78872      | 28.34           | 3.8E+07    | 406.22      | 4.35 %         | 32       | 286        |
| U12  | 20.97      | 50418      | 22.70           | 5.6E+07    | 436.28      | 6.19 %         | 58       | 311        |
| U13  | 21.5       | 55070      | 36.90           | 4.4E+07    | 298.78      | 3.33 %         | 43       | 160        |
| U14  | 20.54      | 56497      | 38.01           | 5.3E+07    | 262.86      | 3.42 %         | 35       | 292        |
| U15  | 21.33      | 76597      | 20.67           | 5.8E+07    | 383.09      | 6.30 %         | 54       | 229        |
| U16  | 21.85      | 80465      | 16.89           | 2.2E+07    | 410.38      | 10.52 %        | 82       | 301        |
| U17  | 21.0       | 102129     | 16.68           | 1.9E+07    | 554.78      | 7.46 %         | 46       | 361        |
| U18  | 21.19      | 112198     | 18.71           | 6.2E+07    | 324.65      | 9.21 %         | 74       | 296        |
| U19  | 22.0       | 156198     | 10.80           | 1.3E+07    | 417.89      | 10.78 %        | 71       | 120        |
| U20  | 22.65      | 181047     | 12.06           | 2.5E+07    | 521.76      | 8.74 %         | 51       | 163        |
| U21  | 20.93      | 56099      | 28.90           | 4.4E+07    | 706.19      | 4.27 %         | 57       | 158        |
| U22  | 20.22      | 34485      | 26.10           | 5.3E+07    | 533.10      | 5.08 %         | 82       | 307        |
| U23  | 22.06      | 107650     | 22.04           | 3.5E+07    | 683.73      | 4.36 %         | 49       | 184        |
| U24  | 20.89      | 82125      | 28.69           | 2.6E+07    | 474.10      | 6.41 %         | 67       | 227        |
| U25  | 21.22      | 93719      | 12.89           | 1.4E+07    | 305.65      | 11.93 %        | 76       | 329        |

$\Delta^a$ Mean of Screen On duration in hours.
$\Delta^b$ Median of Screen On duration in hours.
$\sigma_{usage}$ Standard deviation of Screen usage.
$\Delta_{Low}$ Minimum Screen On duration in hours.
$\Delta_{High}$ Maximum Screen On duration in hours.
$\sigma_{events}$ Standard deviation of Screen usage.
| User  | Total Payload (GB) | Minimum Payload (GB) | Average Payload (GB) | % of Data Transferred | Wakeups During Inactive | Total Wakeups During Inactive |
|-------|--------------------|----------------------|----------------------|-----------------------|------------------------|-------------------------------|
| U26   | 21.65              | 139756               | 18.20                | 3.1E+07               | 425.90                 | 6.23 %                        |
| U27   | 20.5               | 49788                | 30.18                | 7.7E+07               | 420.87                 | 6.12 %                        |
| U28   | 21.36              | 66384                | 20.15                | 3.5E+07               | 320.67                 | 8.58 %                        |
| U29   | 20.98              | 73083                | 32.10                | 1.2E+08               | 283.98                 | 4.15 %                        |
| U30   | 20.97              | 68086                | 19.56                | 5.3E+07               | 398.14                 | 7.27 %                        |
| U31   | 21.34              | 58574                | 26.98                | 4.1E+07               | 401.25                 | 5.29 %                        |
| U32   | 21.72              | 63729                | 22.07                | 4.5E+07               | 331.52                 | 4.11 %                        |
| U33   | 22.5               | 126446               | 12.90                | 1.6E+07               | 376.13                 | 10.89 %                       |
| U34   | 22.5               | 113801               | 12.20                | 1.4E+07               | 331.19                 | 9.39 %                        |
| U35   | 22.46              | 144838               | 16.46                | 5.4E+07               | 327.76                 | 8.16 %                        |
| U36   | 21.59              | 43530                | 15.78                | 3.9E+07               | 438.24                 | 11.81 %                       |
| U37   | 22.35              | 91564                | 14.90                | 2.1E+07               | 454.86                 | 6.15 %                        |
| U38   | 20.97              | 33192                | 25.89                | 6.5E+07               | 425.45                 | 7.05 %                        |
| U39   | 20.72              | 29395                | 14.90                | 2.6E+07               | 620.65                 | 8.23 %                        |
| U40   | 19.96              | 21945                | 34.12                | 1.1E+08               | 346.10                 | 4.13 %                        |
| U41   | 20.1               | 53825                | 17.09                | 2.5E+07               | 244.39                 | 7.09 %                        |
| U42   | 20.96              | 55707                | 15.90                | 4.9E+07               | 346.08                 | 10.74 %                       |
| U43   | 21.82              | 62235                | 21.09                | 2.0E+07               | 423.46                 | 8.71 %                        |
| U44   | 22.11              | 68086                | 10.01                | 1.1E+07               | 281.80                 | 16.87 %                       |
| U45   | 21.53              | 27375                | 13.63                | 1.8E+07               | 301.92                 | 13.41 %                       |
| U46   | 19.59              | 24894                | 28.22                | 2.8E+07               | 394.10                 | 6.28 %                        |
| U47   | 19.19              | 21472                | 26.01                | 5.9E+07               | 473.01                 | 6.75 %                        |
| U48   | 21.4               | 122555               | 13.53                | 1.9E+07               | 371.65                 | 10.13 %                       |
| U49   | 22.42              | 113801               | 10.02                | 1.3E+07               | 322.87                 | 11.84 %                       |
| U50   | 20.99              | 66942                | 13.04                | 1.3E+07               | 210.14                 | 11.42 %                       |

\[ \Delta \] user wise mean of Screen Off duration in hours.  
\[ \Sigma \] total network packets transferred.  
\[ \Sigma_{Up} \] Average of uplink packet payload during inactive (bytes).  
\[ \Sigma_{Down} \] Average of downlink packet payload during inactive (bytes).  
\[ \Sigma_{Avg} \] Average Packet payload (bytes).  
\[ U \] user wise total network wakeups during inactive.  
\[ T \] % of data transferred during inactive.  
\[ % \] user wise mean of Screen Off duration in hours.  
\[ % \] user wise total network wakeups during inactive.  
\[ % \] % of data transferred during inactive.

**C. Analysis of Network Traffic**

This section investigates the statistics of data transfer during Screen_Off (Table-II). The average packet payload of the user is 391.08 bytes. In that, average uplink packet payload is 57.82 bytes and downlink packet payload in Screen_Off is 258.4 bytes. This data discloses thousands of minimum payload packets were transferred during the inactive mode. The users U1, U3, U5, U11, U14, U33, U45, and U48 registered their low packet uplink average of 31, 32, 35, 37, 39 and 30 bytes respectively. The inactive mode network events are triggered by Always_On apps. The individual user wise wakeups are listed in Table-II and the highest wakeups leads

![User wise network packet payload](image-url)
highest packet transmission in the Screen_Off. The trace tells the user U10 generates highest number of network wakeups in 30 days i.e 199152 wakeups, average of 6638 wakeups per day.

D. Energy Consumption Measurement

The dataset collected in two phases that is “without PSEO” and “With PSEO” (Fig 12) each of these phase data collected for 15 days from all users. The “without PSEO” means the user use their phone as it is but “with PSEO” means the mobile phone with PSEO app and set the basic time slot for PS Cycle. This Cycle time slot will be changed based on the RSRQ variations. According to the dataset the user U4 and U8 secure the highest network energy consumer that is they consume 1994 mAh and 1984 mAh respectively. Among the 50 users the U15 and U39 consume highest network energy in inactive state that is 803.25 mAh and 846 mAh respectively. After the implementation of PSEO the energy consumption of user U15 and U39 is 159.17 mAh and 166.10 mAh respectively. This energy savings directly depends on number of PS cycle and total unlock counts. The PS Cycle of U15 and U39 is 494 and 550 times respectively (Table-III).

Mechanism of PSEO reduced maximum 91.25% of network energy in Screen_Off for user U4. The U4 consume 478.64 mAh of network energy during Screen_Off before the implementation of PSEO but after the PSEO implementation the user U4 consumes 41.77 mAh (91.25%) only (Fig 13). It saves the overall energy of smartphone to 14.56% because the user actively uses mobile phone for 5.82 hrs averagely and he unlocks the screen often, so that, the user has 398 PS Cycle only and he is in moderated RSRQ variations.

Fig 12. Basic Setting of PS Cycle time slot of PSEO

| User | Without PSEO | With PSEO |
|------|--------------|-----------|
|      | Δa | Δb | Δc | Δd | Δe | Δf | Δg | Δh | ΔEnergy |
| U1   | 1252 | 41% | 513.32 | 512 | 863.88 | 129.13 | 384.19 | 74.84 | 9.61     |
| U2   | 1841 | 38% | 699.58 | 528 | 1362.34 | 151.89 | 547.69 | 78.29 | 18.26    |
| U3   | 1317 | 38% | 500.46 | 584 | 974.58 | 100.12 | 400.34 | 79.99 | 12.52    |
| U4   | 1994 | 24% | 478.44 | 398 | 1658.72 | 41.77 | 436.67 | 91.27 | 14.56    |
| U5   | 1541 | 30% | 462.3 | 524 | 1248.21 | 57.84 | 404.46 | 87.49 | 9.99     |
| U6   | 1506 | 36% | 542.16 | 548 | 1144.56 | 100.12 | 442.04 | 81.53 | 13.71    |
| U7   | 1548 | 32% | 495.36 | 465 | 1222.92 | 74.03 | 421.33 | 85.06 | 13.6     |
| U8   | 1984 | 33% | 654.72 | 674 | 1527.68 | 120.59 | 534.13 | 81.58 | 17.81    |
| U9   | 1567 | 41% | 642.47 | 485 | 1096.9 | 162.74 | 479.73 | 74.67 | 14.54    |
| U10  | 1710 | 35% | 598.5 | 495 | 1214.1 | 143.57 | 644.08 | 80.18 | 29.28    |
| U11  | 1343 | 34% | 456.62 | 686 | 993.82 | 88.72 | 367.90 | 80.57 | 11.15    |
| U12  | 1310 | 41% | 537.1 | 600 | 890.8 | 141.87 | 395.23 | 73.59 | 12.36    |
| U13  | 1706 | 43% | 733.58 | 632 | 1108.9 | 126.75 | 606.83 | 82.72 | 28.23    |
| U14  | 1926 | 41% | 789.66 | 611 | 1367.46 | 199.00 | 590.66 | 74.80 | 23.63    |
| U15  | 1785 | 45% | 803.25 | 494 | 1142.4 | 159.17 | 644.08 | 80.18 | 29.28    |
| U16  | 1668 | 41% | 683.88 | 493 | 1100.88 | 164.52 | 519.36 | 75.94 | 20.78    |
| U17 | 1223 | 37% | 452.51 | 535 | 880.56 | 96.70 | 355.81 | 78.63 | 16.95 |
|-----|------|-----|--------|-----|--------|-------|--------|-------|-------|
| U18 | 1342 | 43% | 577.06 | 555 | 858.88 | 177.74 | 399.32 | 69.20 | 19.02 |
| U19 | 1674 | 38% | 636.12 | 605 | 1222.02 | 141.75 | 494.37 | 77.72 | 12.06 |
| U20 | 1637 | 37% | 605.69 | 466 | 1211.38 | 127.48 | 478.21 | 78.95 | 11.67 |
| U21 | 1911 | 32% | 611.52 | 533 | 1433.25 | 122.88 | 488.64 | 79.91 | 16.29 |
| U22 | 1227 | 37% | 453.99 | 569 | 907.98 | 88.04 | 365.95 | 80.61 | 10.46 |
| U23 | 1312 | 44% | 577.28 | 529 | 813.44 | 189.37 | 387.91 | 67.20 | 19.4  |
| U24 | 1907 | 39% | 743.73 | 547 | 1373.04 | 178.24 | 565.49 | 76.03 | 26.93 |
| U25 | 1362 | 41% | 558.42 | 531 | 898.92 | 159.86 | 398.56 | 71.37 | 9.73  |
| U26 | 1845 | 36% | 664.2  | 608 | 1365.3  | 142.69 | 521.51 | 78.52 | 17.39 |
| U27 | 1283 | 35% | 449.05 | 564 | 923.76 | 95.73  | 353.32 | 78.68 | 10.71 |
| U28 | 1748 | 31% | 541.88 | 596 | 1328.48 | 100.05 | 441.83 | 81.54 | 11.05 |
| U29 | 1721 | 35% | 602.35 | 620 | 1307.96 | 114.56 | 487.79 | 80.98 | 15.25 |
| U30 | 1226 | 39% | 478.14 | 618 | 821.42 | 127.79 | 350.35 | 73.27 | 9.74  |
| U31 | 1426 | 33% | 470.58 | 605 | 1040.98 | 97.06  | 373.52 | 79.37 | 17.79 |
| U32 | 1419 | 44% | 624.36 | 465 | 908.16 | 114.77 | 509.59 | 81.62 | 16.99 |
| U33 | 1264 | 44% | 556.16 | 588 | 783.68 | 181.34 | 374.82 | 67.39 | 11.72 |
| U34 | 1850 | 43% | 795.5  | 571 | 1221   | 164.47 | 631.03 | 79.32 | 19.72 |
| U35 | 1869 | 32% | 598.08 | 531 | 1439.13 | 107.56 | 490.52 | 82.02 | 24.53 |
| U36 | 1697 | 31% | 526.07 | 581 | 1374.57 | 69.95  | 456.12 | 86.70 | 13.83 |
| U37 | 1862 | 43% | 800.66 | 524 | 1173.06 | 166.24 | 634.42 | 79.24 | 22.66 |
| U38 | 1275 | 32% | 408    | 555 | 1007.25 | 55.68  | 352.32 | 86.35 | 8.6   |
| U39 | 1880 | 45% | 846    | 550 | 1222   | 166.10 | 679.90 | 80.37 | 19.43 |
| U40 | 1896 | 30% | 568.8  | 630 | 1535.76 | 78.07  | 490.73 | 86.27 | 16.36 |
| U41 | 1000 | 43% | 430    | 567 | 680    | 107.60 | 322.40 | 74.98 | 16.12 |
| U42 | 1919 | 36% | 690.84 | 520 | 1439.25 | 142.71 | 548.13 | 79.34 | 27.41 |
| U43 | 1329 | 42% | 558.18 | 540 | 850.56 | 120.94 | 437.24 | 78.33 | 16.82 |
| U44 | 1596 | 38% | 606.48 | 571 | 1149.12 | 139.81 | 466.67 | 76.95 | 11.39 |
| U45 | 1691 | 44% | 744.04 | 574 | 1048.42 | 112.74 | 631.30 | 84.85 | 31.57 |
| U46 | 1811 | 30% | 543.3  | 600 | 1394.47 | 94.96  | 448.34 | 82.52 | 14.47 |
| U47 | 1507 | 41% | 617.87 | 450 | 1054.9 | 155.36 | 462.51 | 74.86 | 11.29 |
| U48 | 1454 | 43% | 625.22 | 585 | 959.64 | 182.57 | 442.65 | 70.80 | 10.8  |
| U49 | 1282 | 41% | 525.62 | 594 | 846.12 | 148.71 | 376.91 | 71.71 | 12.16 |
| U50 | 1510 | 41% | 619.1  | 555 | 1072.1 | 149.54 | 469.56 | 75.85 | 15.66 |

Δ Total Avg Network Energy consumption per charging (mAh).
Δ% % of network energy consumption in inactive without PSEO.
Δ Network Energy consumption in inactive without PSEO (mAh).
Δ Total PS Cycle Occurred.
Δ Total Avg Network Energy consumption per charging (mAh).
Δ Network Energy Consumption in inactive mode.
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\[ \Delta^E \] Network Energy gain in inactive mode (mAh).
\[ \Delta^V \] % of network energy gain in inactive Compare % with without PSEO value (mAh).
\[ \Delta^{Energy} \] % of overall energy saved.

![Graph showing Energy Consumption without PSEO vs PSEO optimization](image)

**Fig 13. Comparison of “without PSEO” and “with PSEO”**

Finally, the PSEO reduce the energy consumption of smartphone in inactive mode is 28.88%, 78.60% and 16.20% of network energy, Screen_Off energy and overall smartphone energy respectively. This model does not affecting QoS because it optimizes only on Screen_Off network transfer and 99% of the users tell PSEO is comfortable and only 2 users feel it was inconvenience.

**VII. CONCLUSION**

Modern gadgets specifically smartphone detain day-to-day activities and it requires consistent energy constantly every day. This research focuses on the energy loss of Smartphone and proposed a contemporary architecture to save energy. This paper proposed a generic model of PSEO to attenuate the energy loss on UE throughout Screen_OFF mode periodically. The model recommends data On/Off period is ±1, 29 min respectively as a result of Data_On duration is variant depends on RSRQ. The findings of the research is

- A typical user actively spends 2.54 hrs/day of their time with the smartphone.
- Averagely 38% of network energy consumed during the Screen_Off state.
- Averagely 78881 wakeups initiated by network Apps during the Screen_Off.
- The Average uplink packet size is 57.82 bytes during the inactive mode.
- If the RSRQ is high, the network latency is reduced and when the RSRQ is low the latency became high.

Apart from the above result, the PSEO save the energy up to 28.88%, 78.60% and 16.20% on average of total network energy, Screen_Off energy, and overall smartphone energy respectively and it saves averagely 466.35 mAh per user every day (assume the users drain their battery completely every day)

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