PS Energy Optimization: A Proposed Model of Adaptive Radio Connection Management

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Abstract

Energy efficiency plays the key role in modern research, significantly in a smartphone. 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 operative mode of the smartphone is classed into 2 states, Screen_OFF and Screen_ON and a typical user used their phone around four hours per day. Majority of the time 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 a model known as PSEO (PS Energy Optimization) to scheduling 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 experience based on the independent value of RSRQ.

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

1. 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 is operated by some hidden factors. That influencing factors are networks and Apps. Generally, the mobile Apps are often classified based on their characterizationthat isSocial 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. Usually cloud-based applications are worst in behavior and even they have to update themselves fairly often through notifications to their server.These kinds of Apps are known as Always-On Apps. A typical smartphone withN number of Apps have been incessantly generated these sorts of short network burst (notifications)which is known as asynchronous network traffic. These short bursts have terribly lessen 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.

This paper proposes 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. This 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 3 and Section 4 introduce the background of the work. Section 5 presents the architecture ofPSEOand its components. Section 6 presents the working principles of PSEO with algorithm. Section 7 discussesthe mechanism of calculating PS Cycle time for Data On, and Section 8discusses the derivations regarding the calculating the total Energy of PS Cycle Time. Section 9measuring radio energy during Data_On and Section 10 conclude the research.

2. 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 ofinactivity.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-awarepredictive dormancy technique, called Personalized Diapause (pD) to automatically identifying user-specific tail-time transmissioncharacteristics 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 userexperience.The study [11] proposed a user-level dynamic decision algorithm to have fine-grain user leveloptimization to set dynamic tail time.

B. Offloading and Traffic Aware

Study[12]found local computation limitation at thesmartphone is the real bottleneck for opening most webpages and propose an architecture, calledVirtual-Machine based Proxy (VMP), to shift the computingfrom smartphones to the VMP because reason of the long delay and high power consumption inweb browsing is not due to the bandwidth limitation most oftime in 3G networks.The research [13] proposed an energy-aware approach forweb browsing based on browsing speed and user responses in 3G based smartphones. Ya-Ju Yu et al [14], develop an energy adaptive approachand design an energy-efficient downlink resource allocation scheme tosupport 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 anovel technique called LoadSense for a cellular client to obtain ameasure of the cellular load, locally and passively, that allows theclient 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-awarebattery 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 dynamicsof signal strength experienced by users.

3. 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) muststay 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 timeperiod, also known as the Radio Resource Control (RRC) tail time [7],is necessary and important for cellular networks to prevent frequentstate promotions (resource allocation), which can cause unacceptably long delays for the UE, as well as additional processing over-heads for the radio access network [21, 22]. Today's cellular carriersuse a static and conservative setting of the tail time in the order ofmany seconds,these times are recommended by 3GPP (based on versions) and configured by network providers.Previous studies revealed this tail time tobe the root cause of energy loss and radio resource inefficiencies in both3G [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.

4. 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 Appinitiates 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.

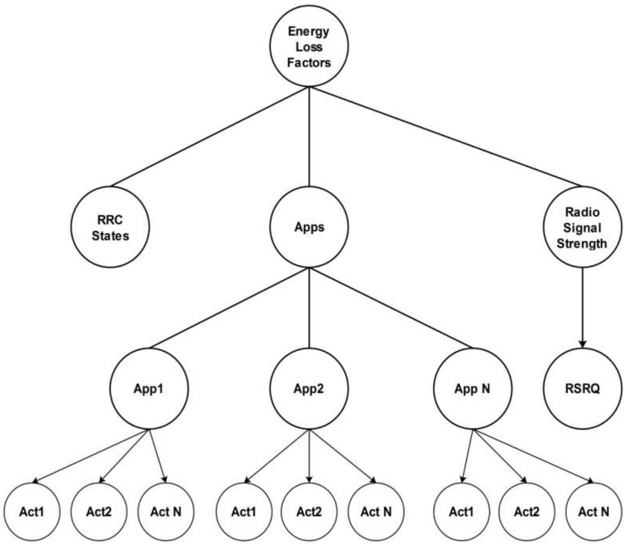

Fig 1. Factors of Energy Loss in Screen Off

5. 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 independent of the type of networks3G/4G and does not require any additional network parameters and major changes in operating system, and hence is completely generic one. 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.

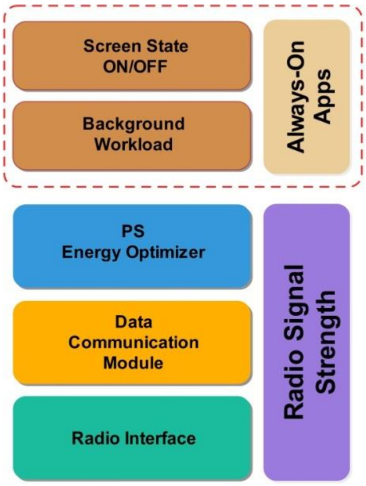

Fig 2. Architecture of PSEO

5.1 Components of PS Energy Optimization

The proposed PSEO architecture having seven logical units which are listed below (Fig 2)

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.

6. Working Principles ofPS 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.

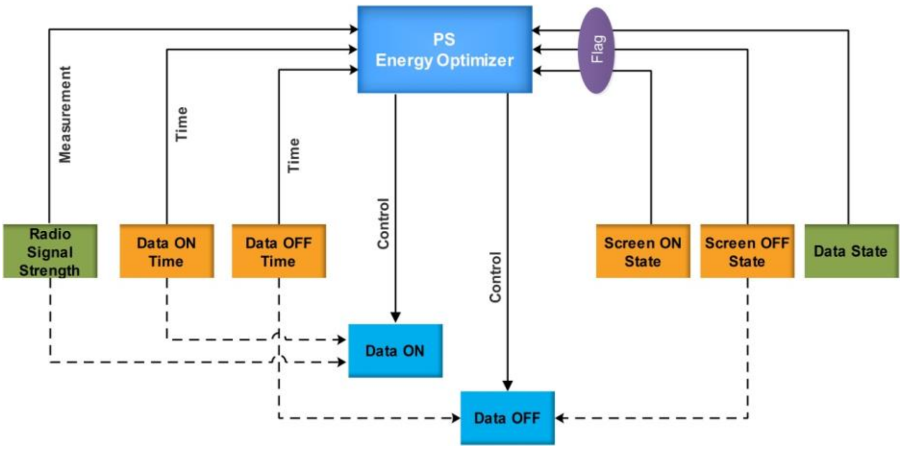

Fig 3. Functional Diagram of PS Energy Optimization

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 thistraffic 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.

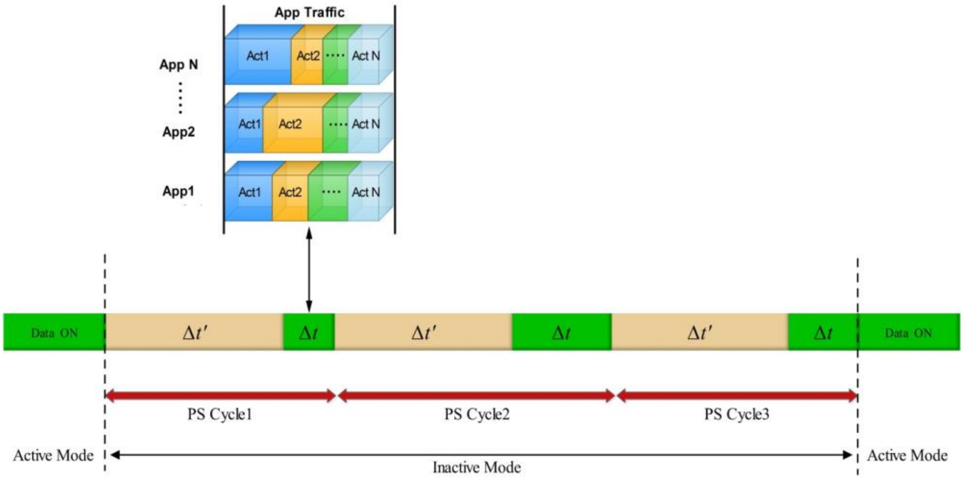

Fig 4. working structure of PSEO

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*

FunctionDataScheduler ()

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 ← OFF

Toggle data communication state OFF

end if

if *Screen Event Triggered for Active***then**

ScreenState ← ON

Toggle data communication state ON

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        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 while
    End Function
    Function DataON_TimeSlot()
    basevalue ← 60 sec
    Get RSRQ
    if RSRQ is between -3 to -5 then
    DataON_slot = basevalue – 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 + Addition_Seconds
    end if
    Return DataON_slot
    End Function
```

7. Mechanism of Calculating PS Cycle time for Data On

Let Δt is a time period of radio communication state is active that means duration of Data_{On} and Δt is relative to be active only when R_{signal} is active and $R_{signal} \Longrightarrow \Delta t$. Let $\overline{\Delta t}$ 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 $\overline{\Delta t} \notin R_{signal}$ 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

$$R_{signal} = \frac{\tau}{\delta}\lambda \qquad \lambda > 0 \qquad \text{Equ (9)}$$

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 τ signify Reference Signal Receiving Power (RSRP) it's an average signal strength based on RE τ can be calculated through

$$\tau = \delta - 10\log(12 * \lambda)$$

whereδ is RSSI discussed in sec xx.xx and λ is a number of resource block (RB) which is similar to the carrier bandwidth $\lambda \in \{1.4, 3, 5, 10, 20\}$ usually λ measured by MHz. Accordance of Equ (9) the can get signal ratio and the output of $R_{signal} \in \{-3, -4, \cdots\cdots, -9\}$ 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

$$R_{signal}\begin{cases} -3 > Signal_{Excellent} > -5 \\ -6 > Signal_{good} > -11 \\ -12 > Signal_{poor} > -16 \end{cases} \qquad \text{Equ (10)}$$

From the Equ (9) and (10) the Δt can be calculated

$$\Delta t = T_{avg} \pm T_{affect} \qquad \text{Equ (11)}$$

Where T_{avg} is Δt 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 (Fig5)

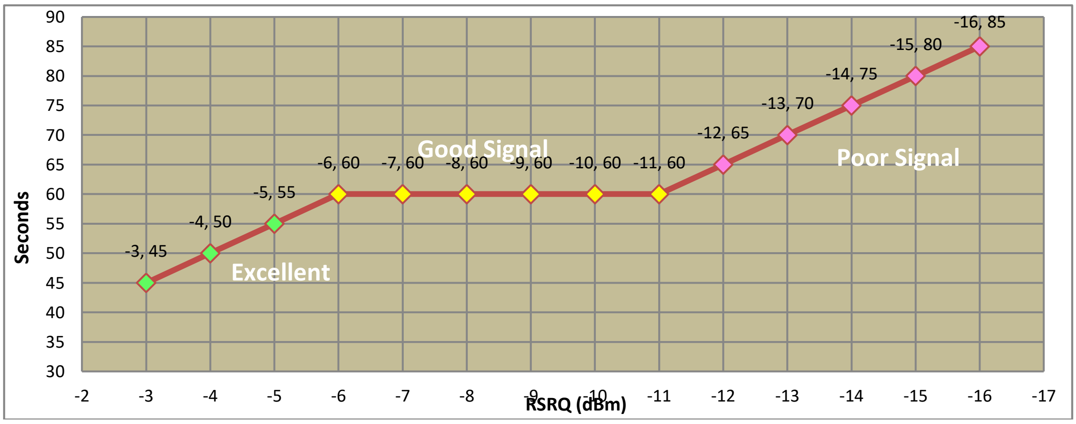

Fig 5. Correlation between Signal Strength and Data_on time

However if the signal strength is excellent, the $Data_{throughput}$ should be high [17, 19, 32, 33] so PSEO no need to maintain Δt 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 Δt. If the signal strength is poor the Δt duration should be increased because of low $Data_{throughput}$.

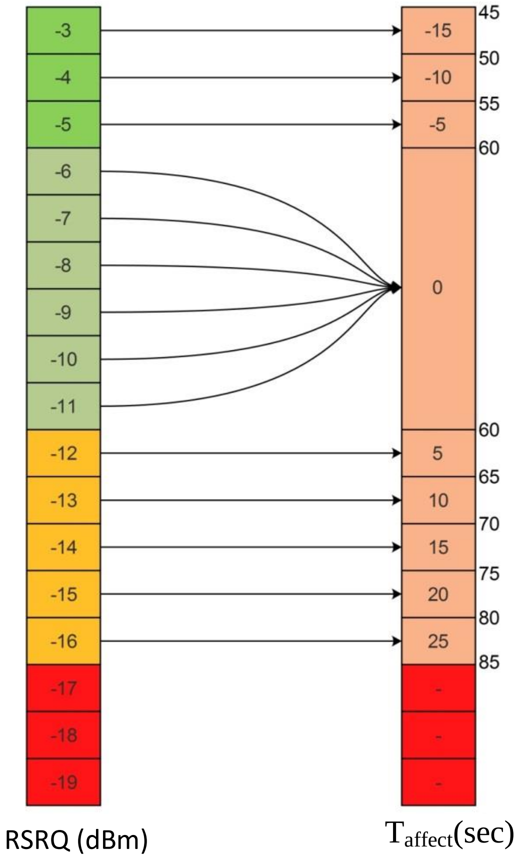

Fig 6. Mapping of Signal Strength andT_{affect}

8. Calculating the Energy of PS Cycle Time

Let $Traffic_{App\,[\overline{\Delta t}]}$ is amount of data in bytes which is generated during the time slot$\overline{\Delta t}$. $Traffic_{App} \in A(i)_j (i, j \in \{1, 2, 3 \ldots\ldots n\})$ where A is an App running in UE. $\overline{\Delta t}$ is a constant time slot of data disable duration. The $\overline{\Delta t}$ traffic is related to total number of apps and its activities (Eq (5)).

$$Traffic_{App\,(\overline{\Delta t})} = \sum_{\substack{i=1\\j=1}}^{n} App(i)_j \qquad \text{Equ (5)}$$

Let$\mu[\Delta t]$ denotes the amount of data transfer during the time slot Δt. Δt is set from a cumulative random value calculated from finite range of RSSI, RSRP and RSRQ values (see Eq 9) and assume $\mu[\Delta t] > 0$. According to the Equ (4) $P_{[\mu[\Delta t]]} \propto Traffic_{App\,(\overline{\Delta t})}$. So the total power of one PS_{cycle} can be calculated in (6). PS_{cycle} is nothing but duration of $\overline{\Delta t} + \Delta t$ and this would be $Screen_{off} \Rightarrow PS_{cycle}$

$$P_{PS_{cycle}} = P_{[\overline{\Delta t}]} + P_{[\mu[\Delta t]]} \qquad \text{Equ (6)}$$

In the equ (6), $P_{[\overline{\Delta t}]}$ should be 0 because there is no data transfer during $\overline{\Delta t}$ slot and assume at the end of the PS_{cycle} i.e end of Δt, $\mu[\Delta t]$ and $Traffic_{App\,[\overline{\Delta t}]}$ should be zero and let both should be zero for next cycle (Fig 7).

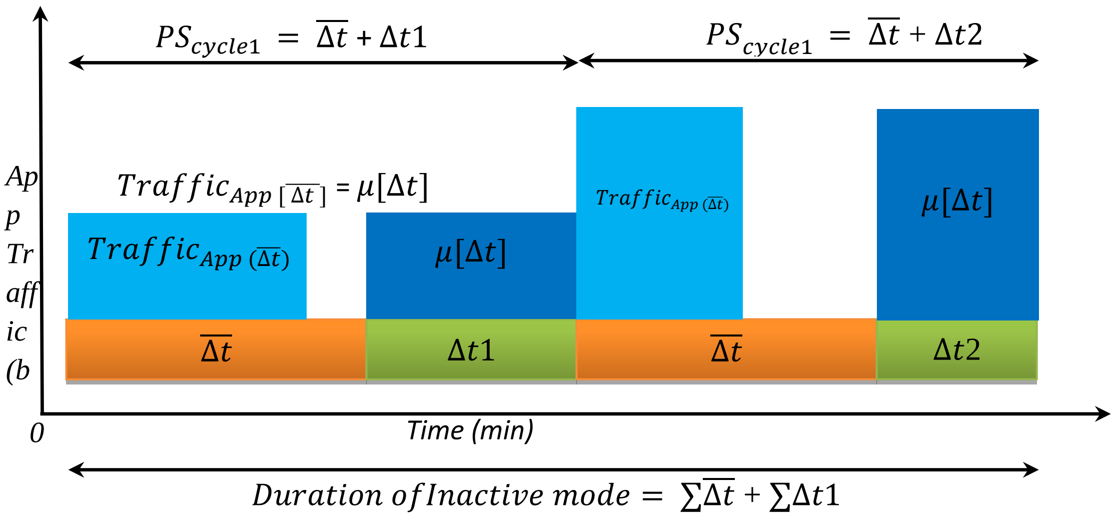

Fig 7. Characteristics of PS cycle

Proceedings of Equ (6) the total power consumption of inactive mode $P_{Scr\_off} \in P_{PS_{cycle(i)}}(i \in \{1, 2, 3 \ldots\ldots n\})$ and this can be calculated by

$$P_{Scr\_off} = P_{PS_{cycle1}} + P_{PS_{cycle2}} + \cdots\cdots + P_{PS_{cycle\,n}} \qquad \text{Equ (7)}$$

similarly

$$P_{Scr\_off} = \sum_{i=1}^{n} P_{PS_{cycle(i)}} \qquad \text{Equ (7.1)}$$

Proceeding of Equ (4), (6) and (7) the total radio energy gain can be calculated by

$$Energy\ Gain\ by\ PSEO = P'_{Scr\_off} - P_{Scr\_off} \qquad \text{Equ (8)}$$

Where P'_{Scr_off} is total energy consumption of radio interface in the Screen_off duration without the implementation of PSEO.

9. 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

$$P = P_{RRC_{State}} + P_{load} + P_{Proc}(s) \qquad \text{Equ (1)}$$

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

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

Equation (1) 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.

$$N(Trans_{block}) = \lceil S/MTBS \rceil \qquad \text{Equ (2)}$$

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

$$P_{load} = \frac{N(Trans_{block})}{I} \times P_{Packet_{Send\_Recv}} \qquad when I > N.T \qquad \text{Equ (3)}$$

where $P_{Packet_{Send\_Recv}}$ is a power consumption of sending and receiving one packet and I is packet sending interval. From the Equ (3) and Equ (2) the power consumption of one RRC connection is calculate from

$$P = P_{RRC_{State}} + \frac{P_{Packet_{Send\_Recv}}}{I} \left(\left\lceil {}^{S}/_{MTBS} \right\rceil \right) \qquad \text{Equ (4)}$$

Equ (4) 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.

Conclusion

This paper conferred a generic model of PSEO to attenuate the energy loss on UE throughout inactive mode. This model periodically schedules the data connection without affecting the user experience. PSEO is managing PS Cycle time depends on the RSRQ for higher data throughput. Thispaper proposed an extremely relevant algorithm to cut back energy loss and mentioned relevant equations and derivations to the algorithm. 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 preliminary measurement data collected to confirm the impact of energy loss and the elaborate study are going to be conducted and therefore the result analysis is going to be present in the forthcoming papers.In future, the algorithm can be upgrade to allow the user todownload data inthe Screen_off mode and hear the online radio.

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