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Consumed Energy Reduction Techniques for Cellular Mobile & Smartphones

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Declaration of Authorship

We, declare that this thesis titled, "Consumed Energy Reduction Techniques for Cellular Mobile & Smartphones" and the work presented in it are our own. We confirm that:

- This work was done wholly while in candidature for a Bachelor degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.

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Abstract

Modern day mobile technologies have taken wireless connectivity to a whole new level and now a mobile phone number is a universal identity. By definition, 3G represents the convergence of various 2G wireless telecommunication systems into a single uniform global system which includes terrestrial and satellite components in its functioning. The 3GPP and 3GPP2 standards (used in 3G) provide some mechanisms for the cellular network operator and the mobile device to optimize some metrics, but to date, deployed methods to minimize energy consumption have left a lot to be desired. Many deployments have been done recently to minimize the energy consumed by mobile phones by not affecting the quality of network as well. Many algorithms have been proposed for example TOP, TailEnder, MakeActive, MakeIdle etc. In this thesis we provide a study on these algorithms, mechanisms and their efficiencies to help overcoming further problems and research.

Keywords

Cellular Networks, Energy Saving, 3G Networks, Power measurement, Mobile applications, Cellular Communications

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Contents

Declaration of Authorship **i**

Abstract . . . iii

. . . iii

Keywords . . . iii

. . . iii

Acknowledgements **i**

List of Figures **iv**

1 Introduction **1**

1.1 Summary of Objectives . . . 3

2 Background **4**

2.1 3G State Machine . . . 4

2.1.1 CELL_DCH . . . 5

2.1.2 CELL_FACH . . . 5

2.1.3 CELL_PCH . . . 6

2.2 Tail Time and Tail Energy . . . 7

2.2.1 Tradeoff Considerations to Optimize Radio Resources . . . 8

2.2.2 Feasibility of Tail Prediction . . . 8

2.2.3 Cellular Energy Consumption . . . 9

2.3 Fast Dormancy . . . 10

3 Related Works **11**

3.1 Tail Aggregation: TailEnder . . . 11

3.2 Tail Time Tuning: TOP . . . 12

3.3 Leveraging the wasted Time: TailTheft . . . 13

3.4 Traffic Aware strategy: MakeIdle & MakeActive . . . 14

3.4.1 MakeIdle Algorithm . . . 14

3.4.2 MakeActive Algorithm . . . 15

4 Motivation and Objectives **17**

4.1 Motivation . . . 17

4.2 Objectives . . . 18

5 Problem Statements and Proposal **20**
5.1 Problem Statements 20
5.2 Our Proposal Statements 21

6 How Do We Approach **23**
6.1 Data Batching at the Base Station 23
6.2 Base station and Mobile Station Synchronization 24
6.3 Cross Layer Optimization 25

7 Tools and Equipments **30**

8 Drawbacks and Future Works **32**

9 Conclusion **34**

Bibliography **35**

List of Figures

2.1 RRC State Machine for 3G Network 5
2.2 Cellular Energy Consumption 9
2.3 Fast Dormancy 10

3.1 MakeIdle Algorithm 15
3.2 Optimal Decision 15
3.3 MakeActive Algorithm 16

6.1 Data Batching Technique 24
6.2 Full Duplex Technique 25
6.3 Round Trip Time & Switching 27
6.4 Switching Condition 27
6.5 OSI Model of 3G Network 28

7.1 Ericsson RBS3000 31

Chapter 1

Introduction

Having a mobile phone nowadays is one's passport to the entire world. Modern day mobile technologies have taken wireless connectivity to a whole new level and now a mobile phone number is a universal identity. 3G wireless networks refer to near future developments in personal and business wireless technology, especially relating to mobile communication. It will escort in many benefits, such as roaming capability, broad bandwidth and high speed communication.

By definition, 3G represents the convergence of various 2G wireless telecommunication systems into a single uniform global system which includes terrestrial and satellite components in its functioning. Network operators and telecommunication service provider's world over, are embracing the recently adopted global third generation wireless standards in order to cater to emerging user demands and to offer new services. The 3G wireless technology represents a shift from voice-centric services to multimedia-oriented services like video, voice, data services etc. The most interesting and useful aspect of it is its ability to unify existing cellular standards.

Statistics show that, mobile phones are ubiquitous today with an estimated cellular subscription of over 4-5 billion worldwide. Most phones today support one or more of 3G, GSM, and WiFi for data transfer. For example, the penetration of 3G is estimated at over 15% of cellular subscriptions worldwide and is over 70% in some countries. 20% of these billions of mobile phones today have "broadband" data service enables on them and this fraction is growing rapidly. Smartphones and tablets with wide area 3G cellular connectivity have become a significant and in many cases dominant mode of network access.

Improvements in the quality of such network connectivity suggest that mobile Internet access will soon overtake desktop access, especially with the continued proliferation of 3G network. Wide-area cellular wireless protocols need to balance a number of conflicting goals: high throughput, low latency, low signaling overhead (signaling is caused by mobility and changes in the mobile device's state), and low battery drain. The 3GPP and 3GPP2 standards (used in 3G) provide some mechanisms for the cellular network operator and the mobile device to optimize these metrics, but to date, deployed methods to minimize energy consumption have left a lot to be desired.

In principle, simply turning the radio off or switching it to a low-power idle state is all it takes to reduce energy consumption. This approach does not work for three reasons. First, switching between the active and the different idle states takes a few seconds because it involves communication with the base station, so it should be done only if there is good reason to believe that making the transition is useful for a reasonable duration of time in the future. Second, switching states consumes energy, which means that if done without care, overall energy consumption will increase compared to not doing anything at all. Third, the switching incurs signaling overhead on the wireless network, which means it should be done only if the benefits are substantial relative to the cost on the network.

Many deployments have been done recently to minimize the energy consumed by mobile phones by not affecting the quality of network as well. Many algorithms have been proposed done example TOP, TailEnder, MakeActive, MakeIdle etc. Among them the last two algorithms are very promising to reduce the tail energy with a very high amount of improvement recovering most of the previous drawbacks. Our work is to adopt the last contribution and make an approach to reduce further energy if possible by adding some extension to that approach. This idea might overcome some further problems.

1.1 Summary of Objectives

Our work consists of the following ideas or contributions:

- Implementing MakeActive algorithm to base station end which might reduce more energy at the mobile station end. This includes reducing number of state transitions in RRC layer and thus reducing switching energy and tail energy.
- If both the mobile station and base station have data to exchange to each other, our approach is to turning on the radio for transmission at the same time to transmit. In this case mobile station can send and receive simultaneously at the same time. Thus reducing unnecessary tail energy and transition energy further.
- After a complete transfer, if we can calculate the Round Trip Time (RTT) about the upcoming acknowledgments and find out that if the amount of energy being in High state during RTT is greater than the energy by switching to Idle state and then High State again, then it is better not to wait in the High state and switch the states.
- Cross-layer optimization is an escape from the pure waterfall-like concept of the OSI communications model with virtually strict boundaries between layers. The cross layer approach transports feedback dynamically via the layer boundaries to enable the compensation for e.g. overload, latency.

Our future experiment consists of analyzing the procedures with a huge amount of data sets that should be provided by network service provider. Then with proper simulation technologies, we will try to implement the system and then evaluate the system whether it makes such an improvements or not. So far, these ideas are seemed to adopt the previous techniques and by theoretically it should work. We will be looking forward to progress our work further on this purpose.

Chapter 2

Background

This section describes the topics related to the underlying techniques and algorithms of cellular mobile phone energy consumption.

2.1 3G State Machine

The Radio Resource Control (RRC) protocol, which is a part of 3GPP standard, incorporates the state machine for energy management. The figure of RRC state machine for 3G network is given below in figure 2.1.

The base station maintains two inactivity timers, T1 and T2, for each mobile device. For a device maintaining a dedicated channel in the Active (Cell_DCH) state with the base stations no data activity to or from the device for T1 seconds, it will switch the device from the dedicated channel to a shred low-speed channel, transitioning the device to the "High-power Idle" (Cell_FACH) state. This state consumes less power than Active mode but still consumes a non-negligible amount of energy. If there is no further data activity between the device and the vase station for another T2 seconds, the base station will turn the device to either Cell_PCH state or Idle state. In these two states the device consumes essentially no power which can be negligible on some purpose.

Figure 2.1 shows the state transition machine diagram of 3G devices. The details are stated further for necessity of description.

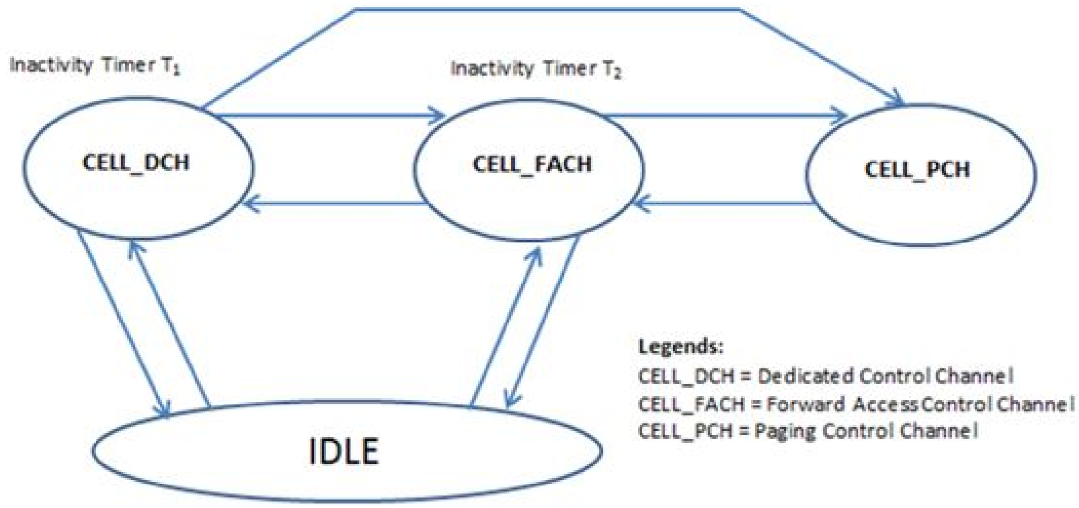

FIGURE 2.1: RRC State Machine for 3G Network

2.1.1 CELL_DCH

This state is characterized by:

- A dedicated physical channel is allocated to the UE in uplink and downlink.
- The UE is known on cell level according to its current active set.

In this state, the UE shall

- Use the connected mode measurement control information received in other states until new measurement control information has been assigned to the UE.
- Perform measurements and transmit measurement reports according to the measurement control information.
- Depending on UE capabilities, monitor the FACH to receive any broadcast messages.
- Monitor a DSCH in downlink for user data and signaling messages when instructed by UTRAN.

2.1.2 CELL_FACH

This state is characterized by:

- Neither an uplink nor a downlink dedicated physical channel is allocated to the UE.
- The UE the continuously monitors a FACH in the downlink.
- The UE is assigned a default common or shared transport channel in the uplink (e.g. RACH) that it can use anytime according to the access procedure for that transport channel.
- The UE is known on cell level according to the cell where the UE last made a cell update.

In this state, the UE shall

- Monitor a FACH to receive signaling messages or user data addressed to the UE or any broadcast messages.
- Acquire system information on the BCH and use the common physical channel and transport channel configuration and measurement control information according to that system information when no UE dedicated common physical channel and transport channel configuration and measurement control information has been assigned to the UE.
- Upon selecting a new cell belonging to another radio access system than UTRA, enter idle mode and make an access to that system according to its specifications.
- Perform measurements and transmit measurement reports according to the measurement control information.

2.1.3 CELL_PCH

This state is characterized by:

- Neither an uplink nor a downlink dedicated physical channel is allocated to the UE

- The UE uses DRX for monitoring a PCH via an allocated PICH.
- No uplink activity is possible [note: if the UE wants to make an uplink access it autonomously shall enter the CELL_FACH state].
- The UE is known on cell level according to the cell where the UE last made a cell update in CELL_FACH state.

In this state, the UE shall

- Monitor the paging occasions according to the DRX cycle and receive paging information on the PCH.
- Acquire system information on the BCH and use the measurement control information according to that system information when no dedicated measurement control information has been assigned to the UE.
- When needed according to the measurement control information, enter CELL_FACH state and transmit measurement reports.

The inactivity timers (T1 & T2) are useful because a state transition from Idle mode to Active mode incurs significant delays. Each state transition also consumes energy on the device and incurs signaling overhead for the base station to allocate a dedicated channel to the device. The inactivity timers also prevent the base station from frequently releasing and re-allocating channels to devices which causes per-packet delay for the device to be high.

2.2 Tail Time and Tail Energy

In 3G, a large fraction (nearly 60%) of the energy, referred to as the tail energy, is wasted in high-power states after the completion of a typical transfer. In comparison, the ramp energy spent in switching to this high-power state before the transfer is small. Tail and ramp energies are constants that amortize over larger transfer sizes or frequent successive transfers. The time spent in the high-power state after the transfer, or the tail time.

At DCH or FACH, when there is no user data transmission in either direction for at least t1 seconds, i.e., the inactivity timer value, the RRC state will be demoted to save radio resources and UE's energy. However, during the wait time of t1 seconds, a UE still occupies the transmission channel and WCDMA codes, and its radio power consumption is kept at the corresponding level of the state. We define a tail as the idle time period matching the inactivity timer value before a state demotion. We also refer to any non-tail time as active.

In typical UMTS networks, each UE is allocated dedicated channels whose radio resources are completely wasted during the tail time. For HSDPA, which is a UMTS extension with higher downlink speed, although the high speed transport channel is shared by a limited number of UEs, occupying it during the tail time can potentially prevent other UEs from using the high speed channel. Furthermore, tail time wastes a UE's radio energy, which contributes to up to half of a UE's total battery energy consumption based on our measurements using a power meter.

2.2.1 Tradeoff Considerations to Optimize Radio Resources

From the carrier's perspective, the most naive way to mitigate the tail effect is to reduce the inactivity timer values. However, doing so increases the number of state transitions. As information says that, completing a state promotion takes up to 2 seconds during which tens of control messages are exchanged between a UE and RNC. Such a delay degrades end user experience and increases the RNC's CPU processing overhead, which is much higher for handling state transitions than for performing data transmission

2.2.2 Feasibility of Tail Prediction

From applications' perspective, tail eliminations are performed for each data transfer, defined by applications to capture a network usage period. For example, a data transfer can correspond to all packets belonging to a same HTML page. For our research we guess that, application only needs to (i) ensure that the current data transfer has ended, and (ii) provide system with its predicted delay between the current and the next data transfer, denoted as the inter-transfer time (ITT). ITT is essentially the packet inter-arrival time between the last packet of a transfer and the first packet of the next transfer. Note that downlink (DL) and uplink (UL) packets are not differentiated as both use the same state machine.

Clearly, the ITT prediction is application specific. It is easier to predict for applications with regular traffic patterns, with limited or no user interaction (e.g., video streaming), but it is more difficult for user-interactive applications such as Web browsing and Google Map, as user behaviors inject randomness to the packet timing. For example, in Web browsing, each transfer corresponds to downloading one HTML page with all embedded objects. The browser knows exactly when the page has been fully downloaded. However, the timing gap between two consecutive transfers may be shorter than the tail threshold.

2.2.3 Cellular Energy Consumption

Two factors determine the energy consumption due to network activity in a cellular device. First, is the transmission energy that is proportional to the length of a transmission and the transmit power level. Second, is the Radio Resource Control (RRC) protocol that is responsible for channel allocation and scaling the power consumed by the radio based on inactivity timers.

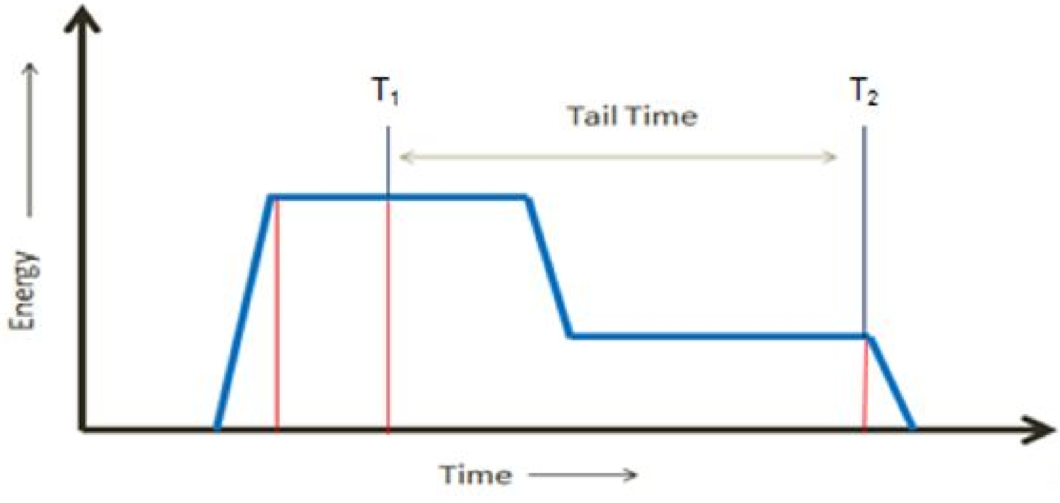

Figure 2.2: Cellular Energy Consumption

The radio remains in the IDLE state in the absence of any network activity. The radio transitions to the higher power states, DCH (Dedicated Channel) or FACH (Forward Access Channel), when the network is active. The DCH state reserves a dedicated channel to the device and ensures high throughput and low delay for transmissions, but at the cost of high power consumption. The FACH state shares the channel with other devices and is used when there is little traffic to transmit and consumes about half of the power in the DCH state. The IDLE state consumes about one percent of the power in the DCH state.

The transition between the different states is controlled by inactivity timers. Figure 2.2 shows the instantaneous power measurements for an example transfer. The graph shows the time taken to transition from a high power to a low power state. Instead of transitioning from the high to the low power state immediately after a packet is transmitted, the device transitions only when the network has been inactive for the length of the inactivity timer.

This mechanism serves two benefits:

1. It alleviates the delay incurred in moving to the high power state from the idle state, and
2. It reduces the signaling overhead incurred due to channel allocation and release during state transitions.

Since lingering in the high power state also consumes more energy, network operators set the value of the inactivity timer based on the performance/energy trade-off with typical values being several seconds long.

2.3 Fast Dormancy

The fundamental reason why inactivity timers are necessary is that the network has no easy way of predicting the network idle time of a UE. Therefore the RNC conservatively appends a tail to every network usage period. This naturally gives rise to the idea of letting UE applications determine the end of a network usage period since they can make use of application knowledge useful for predicting network activities. Once an imminent tail is predicted, a UE notifies the RNC, which then immediately releases allocated resources.

Based on this simple intuition, a feature called fast dormancy has been proposed to be included in 3GPP Release 7 and Release 8. The UE sends an RRC message, which we call the T message, to the RNC through the control channel. Upon the reception of a T message, the RNC releases the RRC connection and lets the UE go to IDLE (or to a hibernating state that has lower but still non-trivial

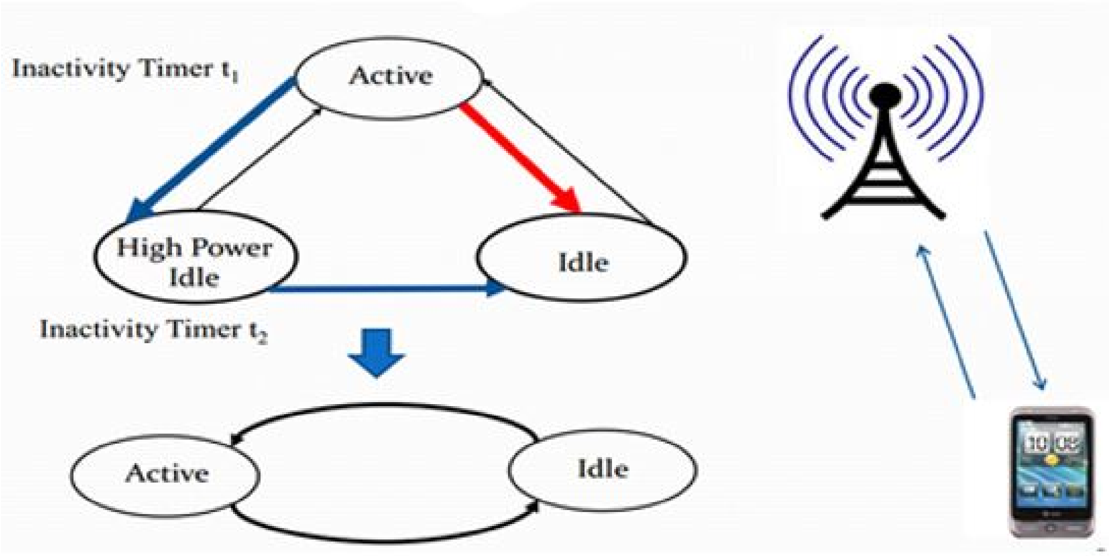

Figure 2.3: Fast Dormancy

promotion delay). This feature is supported by several handsets. To the best of our knowledge, no smartphone application uses fast dormancy in practice, partly due to a lack of the OS support that provides a simple programming interface. But we will use this feature in our work.

Chapter 3

Related Works

This section describes various works, algorithms and techniques that helps to reduce the consumed energy of mobile phones in 3G UTRAN network. These techniques have different mechanisms but a common goal to reduce Tail Energy of mobile phones during data transmission and recieption.

3.1 Tail Aggregation: TailEnder

TailEnder tries to aggregate small transmissions into large ones so that the occurrence of Tails (and thus energy consumption) can be reduced. The aggregation is achieved through prefetching and delayed transfer. However, a lack of a high prediction accuracy of future transmissions may result in unnecessary energy consumption in the aggregation. For example, if only a small amount of the prefetched data is needed by the user in the future, the aggregation only reduces a few future Tails, but imposes high energy consumption for the prefetching itself. In this case, the aggregation has a chance of increasing the energy consumption instead of reducing it. Furthermore, even after the aggregation, there are still a number of Tails with heavy energy waste.

TailEnder uses a simple online algorithm to schedule transmission of an incoming request r_i . The main idea is to transmit a request r_i if either

- the request's deadline is reached or
- the request arrives within a fraction x of the tail time T since the previous deadline i.e. the request arrives within time x.T after the previous deadline.

Suppose that a request arrives after the radio has been in the high power state for x.T seconds. If the request arrives closer to the previous transmission, i.e. x is close to zero, then transmitting immediately is better as it amortizes the Tail time of the previous transmission. However, if the request arrives much later, i.e. $x \gg 1$, it is better to wait until the request's deadline to improve the chances of amortizing the Tail time over future requests. As x increases, the scheduling decision changes from immediate transmission to waiting until deadline. The goal is to determine an arrival time threshold t, such that for $x<t$ immediate transmission is better, and if $x \geq t$, waiting until the deadline is better.

3.2 Tail Time Tuning: TOP

The duration of Tail Time needs to be determined based on the tradeoff between

1. the amount of energy wasted in the Tail Time, and
2. the overhead of state promotion.

Many research works suggest that a Tail Time of 10 to 15 seconds is reasonable to limit the probability of state promotion below 5%. Some others show that setting the Tail Time to 4.5 seconds can significantly reduce energy consumption. Some argue that tuning the Tail Time dynamically based on traffic patterns can better balance the tradeoff between Tail Time and state promotion, but they do not provide a dynamic tuning scheme.

TOP is a recently proposed protocol to dynamically terminate the Tail Time when it predicts there is no transmission in the near future. However, the efficacy of dynamic tuning heavily depends on the prediction accuracy of future traffic pattern. Without an accurate prediction scheme, Tail Time tuning may only be useful for a limited number of Tails, while introducing unnecessary additional state promotions. Results show that Tail Time tuning can even increase energy consumption if without an accurate prediction. Note that in the scenario of concurrently running applications (e.g., a radio application and a sync tool) or interactive applications (e.g., web browsing), the prediction is quite difficult.

3.3 Leveraging the wasted Time: TailTheft

TailTheft is a scheme which leverages the wasted Tail Time for prefetching and delayed transfer as follows:

- Instead of eliminating the Tail Time specified by GSM/3G standard specifications, TailTheft steals the existing Tail Time for two tasks:
  - to prefetch the data likely to be requested in the future (for news, video, etc.), and
  - to defer the delay-tolerant data to be transferred later (for email, RSS, Flickr, Dropbox, etc.). In this case, a number of transmissions can be scheduled to the Tail Time of other transmissions. Thus the energy consumption is significantly reduced.
- The stealing of Tail Time is achieved through a Virtual Tail mechanism and a Dual Queue Scheduling algorithm. The Virtual Tail mechanism:
  - maintains a virtual Tail Time of the same length with the physical one after the completion of a transmission,
  - leverages the period of virtual Tail Time for prefetching and delayed transfer, and
  - switches the device from the high to the low power state at the end of the virtual Tail Time. The Dual Queue Scheduling differentiates (i) the transmissions that could be prefetched/deferred and (ii) other transmissions, and schedules the former to the virtual Tail Time of the latter.
- TailTheft conducts the prefetching and delayed transfer during the Tail Time, but does not tune the length of Tail Time. As a result, TailTheft does not increase energy consumption, even if the prefetched data would not be requested by the user in the future. In contrast, existing approaches may suffer from heavy side effect:
  - the traffic aggregation approaches would suffer if the prediction accuracy of future requested data is not high enough,
  - the Tail Time tuning approaches also would suffer if it cannot predict precisely whether there is a transmission in the near future.

3.4 Traffic Aware strategy: MakeIdle & MakeActive

This work proposes a traffic-aware design to control radio state transitions to reduce energy consumption, latency and signaling overhead into consideration. The design incorporates two algorithms:

- *MakeIdle*, which uses aggregate traffic activity to predict the end of an active session by building a conditional probability distribution of network activity.
- *MakeActive*, which delays the start of a new session by a few seconds to allow multiple sessions to all become active at the same times and therefore reduce signaling overhead. The method is appropriate for non-interactive background applications that can tolerate some delay.

This paper tackles the challenges and develops a solution to reduce 3G(LTE) energy consumption without appreciably degrading application performance or introducing a significant amount of signaling overhead on the network. Unlike currently deployed methods that simply switch between radio states after fixed time intervals, an approach known to be rather crude and sub-optimal. Their approach is to observe network traffic activity on the mobile device and switch between the different radio states by adapting to the workload.

The key idea is that by observing network traffic activity, a control module on the device can adapt the 3G/LTE radio state transitions to the workload. They apply statistical machine learning algorithms to predict network activity and make transitions that are suggested by the statistical models. This approach is well-suited to the emerging fast dormancy mechanism that allows a radio to rapidly move between the Active and Idle states and vice versa. Their goal is to reduce the energy consumed by networked background applications on the mobile devices.

3.4.1 MakeIdle Algorithm

Instead of using a fixed inactivity timer, the MakeIdle method dynamically takes decisions when to put the radio into Idle mode after each packet transmission or reception. They showed how to compute this optimal decision given a complete knowledge of a packet trace; the result is that the radio should be turned to Idle if there is a gap of more than a certain threshold amount of time in the trace, which depends on measurable parameters. Then they develop an online method to predict idle durations that will exceed this threshold by modeling the idle time using a conditional probability distribution.

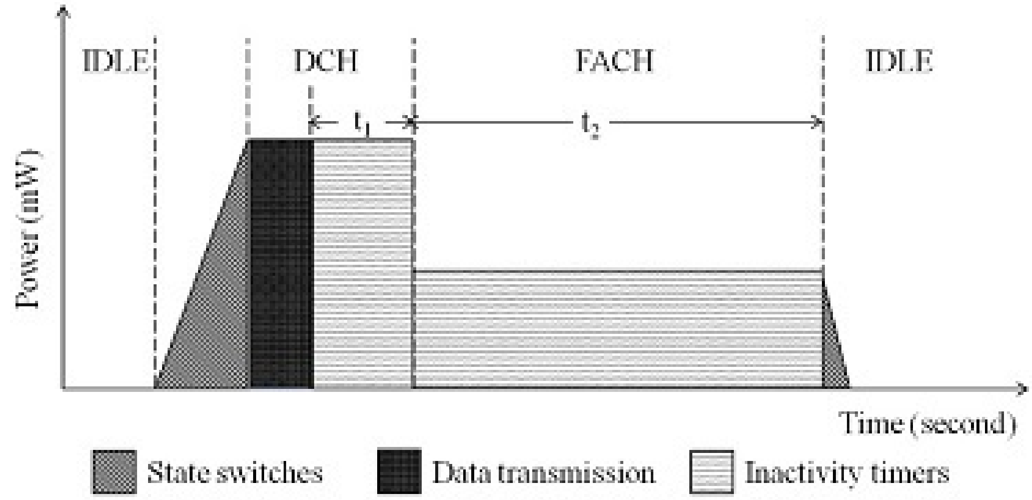

FIGURE 3.1: MakeIdle Algorithm

Figure 3.1 shows a simplified power model we use to calculate tail energy. If the inter-arrival time between two adjacent packets is t seconds, then *E(t)* is the energy consumed by the current RRC protocol with inactivity timer values t_1 and t_2 varies. E_{switch} is the energy consumed by switching the radio to Idle mode after the first packet transmission and then switching it back to Active for the second packet transmission. It is a fixed value for a given type of device and easy to measure.

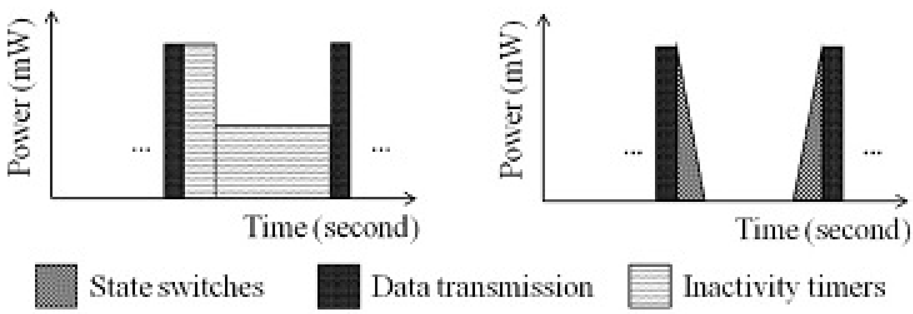

FIGURE 3.2: Optimal Decision

On the other hand if the radio switches to Idle mode immediately after the first packet transmission finishes, the energy consumed is just E_{switch}. To minimize the energy consumed between packets, the radio should switch to Idle mode after a packet transmission if, and only if, $E_{switch} < E(t)$ for a certain value of t which is $t_{threshold}$,for which the transition occurs if and only if $t > t_{threshold}$ .This expression quantifies the intuitive idea that after each packet, the radio should switch to Idle mode only if we know the next packet will not arrive soon, not arrive in the following $t_{threshold}$ seconds.

3.4.2 MakeActive Algorithm

MakeIdle reduces the 3G wireless energy consumption by switching the radio to Idle mode frequently. Figure 3.3 shows that MakeIdle may bring more state switches from Idle to Active and Active to Idle. These switches cause signaling overhead at the base station. One idea to reduce this overhead is to "Shift" the traffic burst in order to combine several traffic bursts together. The longer the earlier bursts are delayed, the more bursts we can accumulate and the fewer state switches occur.

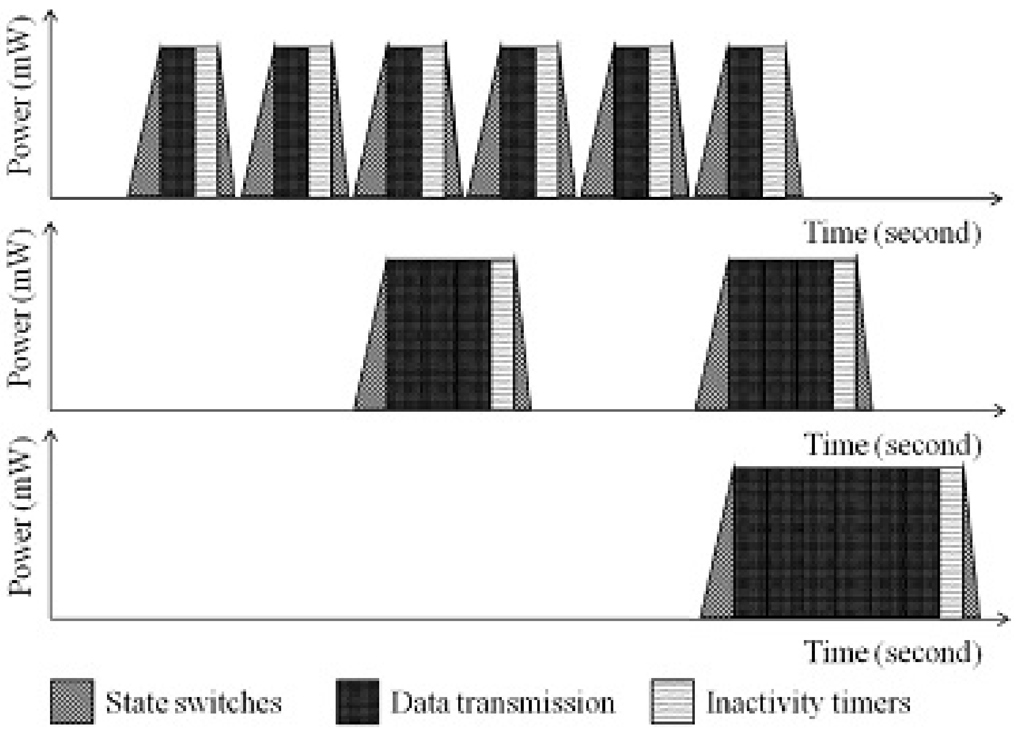

FIGURE 3.3: MakeActive Algorithm

In this section they only consider those background applications for which one can delay the traffic for a few seconds without appreciably degrading the user's experience, not user interactive applications where delaying by a few seconds is unacceptable. MakeActive focuses on reducing the number of state switches to a level comparable to the status quo. As a result the amount of delay introduced by this method should be much smaller than in previous works.

These proposed approaches will only be application for some specific applications like,

- Delay Tolerant Applications (e.g. email, message, notification)
- Web Searching Applications (e.g. Google, Yahoo, Bing etc.)

User interactive applications will not be aided by these techniques because delays in user interactive applications will not be appreciated or beneficial in fact it would be a degradation of quality of those applications.

Chapter 4

Motivation and Objectives

4.1 Motivation

This chapter includes our work motivations and the objectives that we follow throughout our experiment. Large amount active mobile phones today have "broadband" data service, and this fraction is rapidly growing. Smartphones and tablets with wide-area cellular connectivity have become a significant, and in many cases, dominant, mode of network access. Our motivation is to reduce this significant amount of energy of the mobile devices and smartphones that is running over the 3G network.

Improvements in the quality of such network connectivity suggest that mobile Internet access will soon overtake desktop access, especially with the continued proliferation of 3G networks and the emergence of LTE and 4G. Wide-area cellular wireless protocols need to balance a number of conflicting goals: high throughput, low latency, low signaling overhead (signaling is caused by mobility and changes in the mobile device's state), and low battery drain. The 3GPP and 3GPP2 standards (used in 3G and LTE) provide some mechanisms for the cellular network operator and the mobile device to optimize these metrics, but to date, deployed methods to minimize energy consumption have left a lot to be desired.

The 3G/LTE radio consumes significant amounts of energy. On the iPhone 4, for example, the stated talk time is "up to 7 hours on 3G" (i.e., when the 3G radio is on and in "typical" use) and "up to 14 hours on 2G".On the Samsung Nexus S, the equivalent numbers are "up to 6 hours 40 minutes on 3G" and "up to 14 hours on 2G".That the 3G/LTE interface is a battery hog is well-known to most users anecdotally and from experience, and much advice on the web and on blogs is available on how to extend the battery life of your mobile device. Unfortunately, essentially all such advice says to "disable your 3G data radio" and "change your fetch data settings to reduce network usage". Such advice largely defeats the purpose of having an "always on" broadband-speed wireless device, but appears to be the best one can do in current deployments.

For most of these applications (which are all background applications that can generate traffic without user input, except for Facebook), less than 30% of the energy was consumed during the actual transmission or reception of data. Previous research arrived at a similar conclusion: about 60% of the energy consumed by the 3G interface is spent when the radio is not transmitting or receiving data. In principle, one might imagine that simply turning the radio off or switching it to a low-power idle state is all it takes to reduce energy consumption. This approach does not work for three reasons. First, switching between the active and the different idle states takes a few seconds because it involves communication with the base station, so it should be done only if there is good reason to believe that making the transition is useful for a reasonable duration of time in the future. Second, switching states consumes energy, which means that if done without care, overall energy consumption will increase compared to not doing anything at all. Third, the switching Incurs signaling overhead on the wireless network, which means that it should be done only if the benefits are substantial relative to the cost of the network.

4.2 Objectives

Our objective is to reduce the energy consumption in 3G mobile devices. We propose to do it using four methods.

1. ***Data Batching at Base Station:*** Upon arrival of data at the base station,

    - each data have an arrival time and a deadline to be served
    - delay the transmission until the closest deadline amongst those
    - batch queued data together while deadline reaches

- send paging message to mobile station for waking up and transmit the data

This method reduces unnecessary state transitions and tail time which in turn reduces the energy consumed on that purpose which can avoidable.

2. ***Base station and Mobile Station Synchronization:***

   - Both the base station and the mobile station will turn on their radio to exchange data
   - Mobile station will upload and download simultaneously
   - It will reduce the tail energy also the switching energy
   - Only applicable if both mobile station and base station has data to exchange with each other

3. ***Cross-layer optimization:***

   - Cross layer approach removes strict boundaries between layers of OSI model to allow information exchange between them
   - Round Trip Time (RTT) is the length of time it takes for a signal to be sent plus the length of time it takes for an acknowledgment of that signal to be received.
   - Transport Layer manages packet sending and receiving, transmission rate, RTT calculation etc. MAC(RRC) layer manages allocation and deallocation of channels and resources for communication purpose.
   - $E(RTT) > E_{switch}$, then switch to Idle state immediately after transmission otherwise, remain in the Active State

Chapter 5

Problem Statements and Proposal

5.1 Problem Statements

Previous research works mainly focused on the energy consumption to the mobile devices by adopting many methods, techniques and algorithms. They even implemented some control modules to control the state transitions that occur due to the waiting time and tail time. But some of the methods can be modified in such a way that they would be pretty much useful to further reduce the energy that is consumed during the activity.

The ideas of problems may be thought like the below points of views:

- Is it possible to reduce more energy?
- Is it possible to implement those energy reduction mechanisms in Base station?
- What if both the base and mobile stations has data to exchange for each other?
- What could be a simple way to detect data arrival?

It can be said undoubtedly that many works have been done recently and some of them even recovered almost many problems that were faced previously. For example the MakeIdle and MakeActive algorithms recovered all the problems which rise during the implementation of previous methods like *TailEnder*, *TOP*, and

TailTheft etc.

We focused on the idea that, we will adapt the approach that is stated in the research work behind MakeIdle and MakeActive algorithm and will do some further work or modification to reduce more energy at the mobile station if possible by some possible scenarios.

MakeActive and *MakeIdle* research work used machine learning algorithm to analyze the traffic pattern to decide further action that should be taken to complete their goal. We will do more simple approach here; we will not use the machine learning algorithm because of its complex computation and other stuffs. We will think in a simple way to reduce energy further if possible by analyzing the theoretical knowledge and then we will try to implement them to see if further improvements can be achieved or not.

5.2 Our Proposal Statements

Our proposal consists of four methods that can be adopted to reduce energy further if possible. We worked on the approaches stated in MakeActive and MakeIdle research work. We also apply some simple approaches to make the computation simple without the complexities of many other methods.

We propose three methods or techniques that can be stated like below:

1. ***Data Batching at Base Station:*** Upon arrival of data at the base station,

    - each data have an arrival time and a deadline to be served
    - delay the transmission until the closest deadline amongst those
    - batch queued data together while deadline reaches
    - send paging message to mobile station for waking up and transmit the data

    This method reduces unnecessary state transitions and tail time which in turn reduces the energy consumed on that purpose which can avoidable.

2. ***Base station and Mobile Station Synchronization:***

    - Both the base station and the mobile station will turn on their radio to exchange data
    - Mobile station will upload and download simultaneously
    - It will reduce the tail energy also the switching energy
    - Only applicable if both mobile station and base station has data to exchange with each other

3. ***Cross-layer optimization:***

    - Cross layer approach removes strict boundaries between layers of OSI model to allow information exchange between them
    - Round Trip Time (RTT) is the length of time it takes for a signal to be sent plus the length of time it takes for an acknowledgment of that signal to be received.
    - Transport Layer manages packet sending and receiving, transmission rate, RTT calculation etc. MAC(RRC) layer manages allocation and deallocation of channels and resources for communication purpose.
    - $E(RTT) > E_{switch}$, then switch to Idle state immediately after transmission otherwise, remain in the Active State

All the statements stated above should follow some assumptions for the simplicity of our work and computation. Proposal no. 1 should be implemented on the base station which will ultimately benefit the mobile station. Proposal no. 2 is only applicable only when both the base station and mobile station have some data to exchange for each other. Proposal no. 3 and 4 is made only for the simplicity of arrival prediction of future request from the basic properties it has on itself. Above all, all the proposal statements are applicable only for delay tolerable applications to reduce further energy. For user interactive applications, it will be much more difficult to adopt these methods for energy reduction. Because our work implies some delays on the methods which will obstruct the user interactive application and delays cannot be tolerated in user interactive applications also.

Chapter 6

How Do We Approach

In this chapter we will describe details about our approaches towards the proposals we made in the previous section. For the necessity of information we state that, we are following the approaches that are stated MakeIdle and MakeActive algorithms. That research work is like the main principle with which we will think about some further scenarios that can be solved by our simple approaches. The details are described below.

6.1 Data Batching at the Base Station

In *MakeActive* algorithm, it is stated that, they delays the upcoming data requests for reducing the overhead in the network. MakeIdle reduces the 3G wireless energy consumption by switching the radio to Idle mode frequently. MakeIdle may bring more state switches from Idle to Active and Active to Idle. These switches cause signaling overhead at the base station. One idea to reduce this overhead is to "Shift" the traffic burst in order to combine several traffic bursts together. The longer the earlier bursts are delayed, the more bursts we can accumulate and the fewer state switches occur.

This approach was made at the mobile station end. Now consider the scenario that what if we apply this approach to the base station. That means, when the base station has some data to send to a mobile station, it will make a small delay for further data arrival for that mobile station and then send them by Batching them together with the burst.

In this case while the mobile station will receive the data, it will not need to wait for longer time to receive all of the data instead it will be in High state, receive all the data at that time and then will go to Idle mode after the transmission.

By following this procedure will reduce the avoidable tail time. That avoidable tail time in fact would incur energy consumption called Tail Energy which would be unnecessary. But following this procedure will simply reduce the Tail Energy and also Switching Energy that was wasted earlier. Figure 6.1 describes the scenario and shows a small comparison with the current scheme that is running against our proposed scheme.

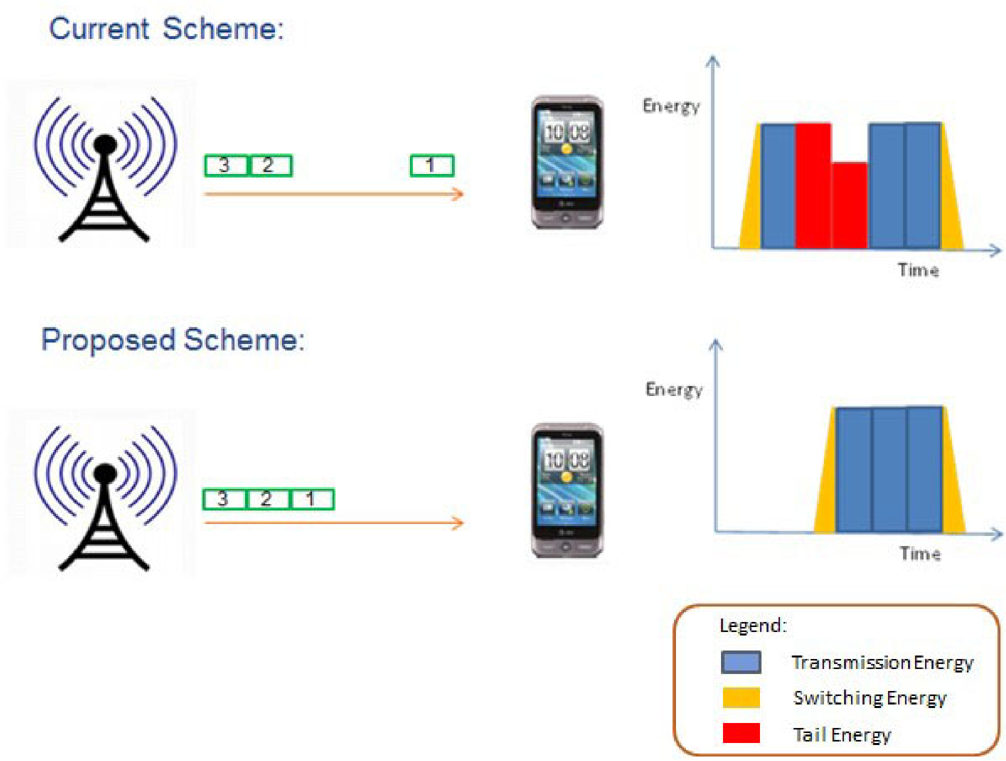

Figure 6.1: Data Batching Technique

This approach will simply be the implementation of MakeActive algorithm on the base station. Doing so will reduce the unnecessary state transitions and tail time which will in turn reduce the Tail Energy and Switching Energy at the mobile station. It is to be noted that, as mobile station can be awaken from Idle mode by simply a paging message as it stays in the Cell_PCH state if no activity occurs in the network.

6.2 Base station and Mobile Station Synchronization

As 3G network supports full duplex communication (many research works are going currently), we can use this approach to further reduce energy consumption also. Here the main concept is that, when the base station and mobile station have data to exchange for each other, instead of sending in discrete matter, they can simply turn on the radio at the same time and exchange data simultaneously. It means that mobile will send and receive at the same time by its duplex channels which will reduce unnecessary wait time in the high state and also reduce the unnecessary state transitions; which in turn will reduce energy at the mobile station.

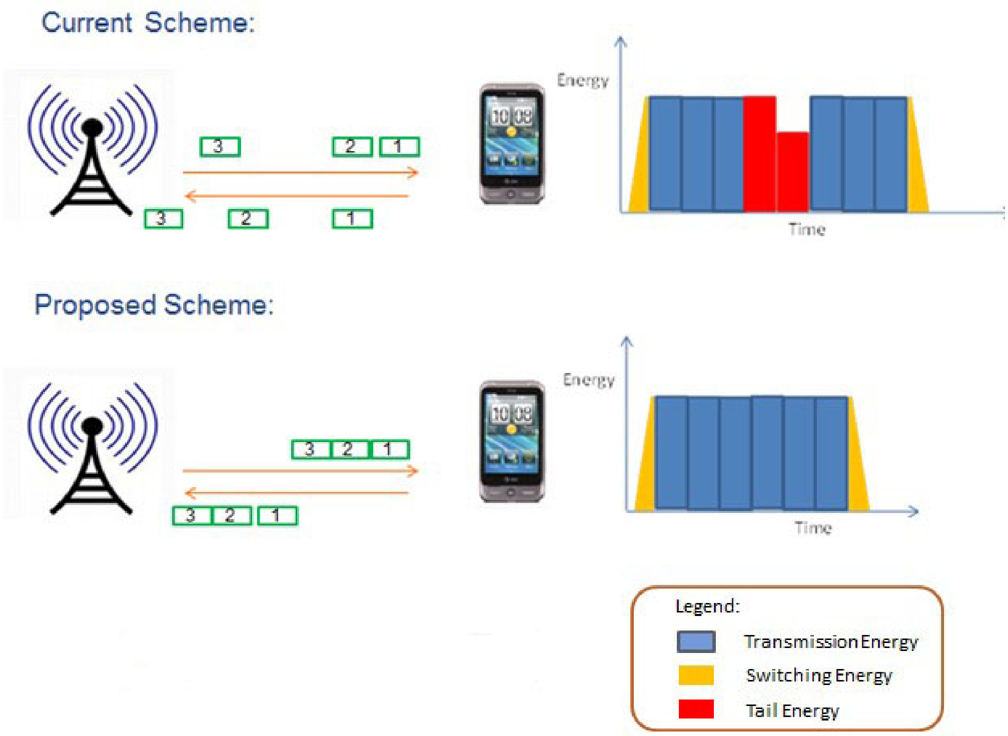

FIGURE 6.2: Full Duplex Technique

The figure 6.2 shows the scenario of our approach in graphical representation. This approach will reduce further Tail Energy and also unnecessary Switching Energy. The procedure of this mechanism is stated below:

When both mobile and base station have data packets to send: Assume, smallest deadline of data packets in mobile and base station is D_{mobile} and D_{base} respectively,

IF ($D_{mobile} < D_{base}$)
THEN IF D_{mobile} reaches to end
THEN mobile station first starts to transmit packets
AND base station starts to transmit packets
(even if D_{base} does not reach to end)
ELSE ($D_{mobile} > D_{base}$)
THEN IF D_{base} reaches to end
THEN base station first starts to transmit packets
AND mobile station starts to transmit packets
(even if D_{mobile} does not reach to end)

This synchronization method can be used under the assumption that, data packet, arrived at both base and mobile station, maintains a deadline timer.

6.3 Cross Layer Optimization

Round Trip Time (RTT) is the length of time it takes for a signal to be sent plus the length of time it takes for an acknowledgment of that signal to be received. In the context of computer networks, the signal is generally a data packet, and the RTT is also known as the ping time. In this context, the source is the computer initiating the signal and the destination is a remote computer or system that receives the signal and retransmits it. An internet user can determine the RTT by using the ping command.

Network links with both a high bandwidth and a high RTT can have a very large amount of data (the bandwidth-delay product) in flight at any given time. Such "$longfatpipes$" require a special protocol design. One example is the TCP window scale option. On the Internet, an end user can determine the RTT to and from an IP (Internet Protocol) address by pinging that address. The result depends on various factors including:

- The data transfer rate of the source's Internet connection

- The nature of the transmission medium (copper, optical fiber, wireless or satellite)
- The physical distance between the source and the destination
- The number of nodes between the source and the destination
- The amount of traffic on the LAN (local area network) to which the end user is connected
- The number of other requests being handled by intermediate nodes and the remote server
- The speed with which intermediate nodes and the remote server function
- The presence of interference in the circuit.

In a network, particularly a WAN (wide-area network) or the Internet, RTT is one of several factors affecting latency, which is the time between a request for data and the complete return or display of that data. The RTT can range from a few milliseconds (thousandths of a second) under ideal conditions between closely spaced points to several seconds under adverse conditions between points separated by a large distance.

A theoretical minimum is imposed on the RTT because it can never be less than the total length of time the signals spend propagating in or through the transmission media.

The RTT was originally estimated in TCP by:

$$\mathbf{RTT} = (\alpha \cdot Old\_RTT) + ((1-\alpha) \cdot New\_RTT)$$

Where α is constant weighting factor ($0 \leq \alpha < 1$). Choosing a value α close to 1 makes the weighted average immune to changes that last a short time (e.g. a single segment that encounters long delay). Choosing a value for α close to 0 makes the weighted average respond to changes in delay very quickly. Once a new RTT is calculated, it is entered into the equation above to obtain an average RTT for that connection, and the procedure continues for every new calculation.

Generally, if the calculated energy consumed at RTT (being in Active state) is less than the switching energy, then switch to the Idle state immediately after sending data. Otherwise staying in the High state and wait for receiving data would be beneficial. The figure 6.3 and figure 6.4 show the descriptive procedure with graphical representation.

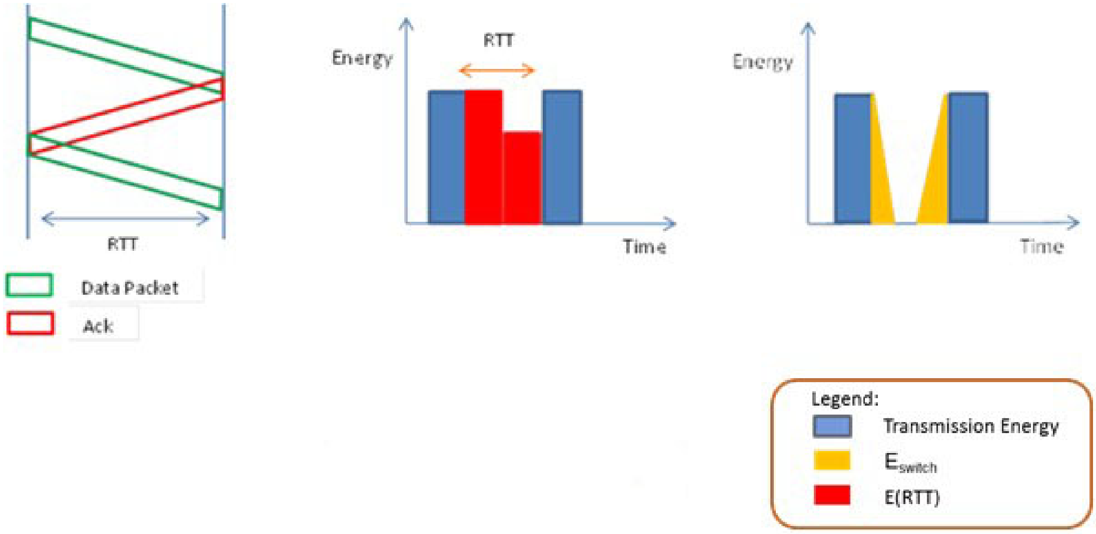

FIGURE 6.3: Round Trip Time & Switching

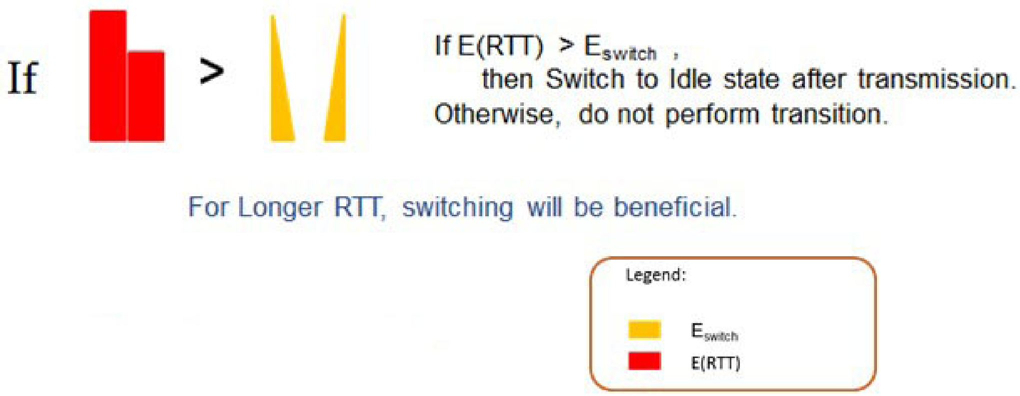

FIGURE 6.4: Switching Condition

Cross-layer optimization is an escape from the pure waterfall-like concept of the OSI communications model with virtually strict boundaries between layers. The cross layer approach transports feedback dynamically via the layer boundaries to enable the compensation for e.g. overload, latency or other mismatch of requirements and resources by any control input to another layer but that layer directly affected by the detected deficiency.

In the original OSI networking model, strict boundaries between layers are enforced, where data are kept strictly within a given layer. Cross layer optimization removes such strict boundaries to allow communication between layers by permitting one layer to access the data of another layer to exchange information and enable interaction. For example, having knowledge of the current physical state will help a channel allocation scheme or Automatic Repeat Request (ARQ) strategy at the MAC layer in optimizing tradeoffs and achieving throughput maximization.

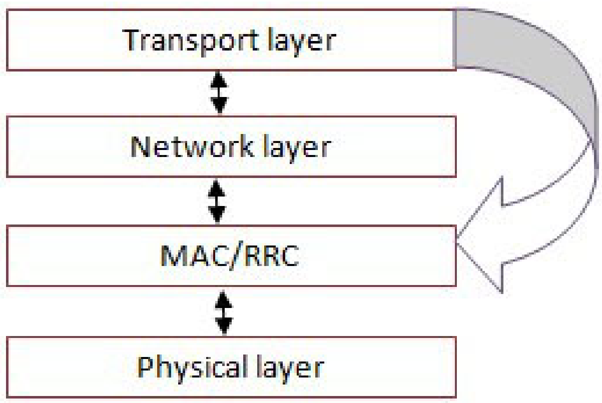

Figure 6.5: OSI Model of 3G Network

We propose a systematic solution to the problem of cross-layer optimization for delay-sensitive media transmission over time-varying wireless channels as well as investigate the structures and properties of this solution, such that it can be easily implemented in various multimedia systems and applications. Our main aim is to minimize tail time as well as tail energy. We feel like implementing the idea of cross layer optimization in order to minimize tail time.

As we know that, Round Trip Time (RTT) is the length of time it takes for a signal to be sent plus the length of time it takes for an acknowledgment of that signal to be received. Transport Layer manages packet sending and receiving, transmission rate, RTT calculation etc. MAC (RRC) layer manages allocation and deallocation of channels and resources for communication purpose.

The procedure of this mechanism is stated below:

Assume that, *E(RTT)* is the amount of energy consumed at Active State upto RTT. E_{switch} is the amount of energy consumed for switching states. Transport Layer passes calculated RTT to MAC layer and the MAC layer uses it to calculate *E(RTT)*, as well as E_{switch}. So,

IF ($E(RTT) > E_{switch}$)
THEN switch to Idle state and be Active at RTT
ELSE ($E(RTT) < E_{switch}$)
THEN remain in Active state

This approach removes strict boundaries between layers of OSI model to allow information exchange between them. It also reduce unnecessary state transitions which ultimately reduces tail energy of mobile device.

Chapter 7

Tools and Equipments

To simulate the proposed idea that we stated above, some tools and equipment are needed. Basically the whole project is best suited in Test-bed environment. To build the Test-bed, the beneath tools are required,

- Signal Generator: Ericsson RBS3000
- Mobile energy measurement apps (e.g. Nokia Energy Profiler)
- Sample simulation code to simulate 3G base station as alternatives
- Sample simulation codes of *MakeIdle* & *MakeActive* algorithm

Ericsson RBS3000 is a signal generator that works as a mini base station with a small range of broadcasting signals. Basically, this signal generator is used to simulate a 3G Base Station because in real life scenario, using a real big Base Station is costly and complex. But using this generator can easily eradicate the complexities and if experiment results as positive, then mechanisms that are used to simulate with this generator can be implemented in big Base Station.

Some features of Ericsson RBS3000 are given below:

- Radio base station configuration
- Multiplexing and demultiplexing
- Channel coding and decoding
- Modulation and demodulation

- Power consumption measurement
- Radio link configuration for dedicated and common channels
- Data-stream handling

FIGURE 7.1: Ericsson RBS3000

Mobile energy measurement applications are used to calculate the amount of energy that is consumed during a data transmission and reception on a mobile device. There are many applications that are available in Internet to use them as free. Various versions of applications and platform dependent applications are also available. For example, mobile phone environment like JAVA Symbian, Nokia Energy Profiler is an application that can be used. For Android, iOS and Windows phones, different applications are also available. Some of them are free and some of them are needed to purchase.

Chapter 8

Drawbacks and Future Works

The drawbacks that we face during the work that we will have to follow some assumptions and conditions for our proposed work i.e. there are certain environment that will allow this proposal in fact all the related works stated in the report. But this would not seem to be a big problem since we can somehow provide a solution for some particular scenario and we can modify it further to incorporate those scenarios later on.

Some conditions that are needed to be followed which are stated below:

- The proposed approach will only be application for some specific applications like
  - Delay Tolerant Applications (e.g. email, message, notification etc.)
  - Web Searching Applications (e.g. Google, Yahoo, Bing etc.)
- User interactive applications will not be aided by these techniques because delays in user interactive applications will not be appreciated or beneficial in fact it would be a degradation of quality of those applications.
- This experiment needs a lot of data from service provider to analyze the regular uses of different application and to analyze the traffic pattern, energy consumption pattern, their requests arrival rate etc. So collecting those data form various other sources would be a difficulty.

Apart from these drawbacks, we can say that, with the appropriate data set and with appropriate simulation technology, we are hopeful to implement these methods further. We faced some obstacles due to which we could not succeed for the simulation of our proposed ideas. They are stated below:

- Unavailability of Radio Base Station (RBS) device for generating signals. As we said earlier, RBS is the best suited device to do such kind of experiments to get results and outputs.
- Absence of sample 3G Base Station simulation codes was also a crucial part among the hindrances we faced. We tried to look for base station simulation codes for 3G network, but it was a hard luck for us. We looked for Network Simulator 3 (ns3), OMNeT++ etc. simulators to find sample codes for simulating an environment of 3G network as an alternative way which we couldn't succeed.
- Unattainability of simulation codes of MakeActive and MakeIdle algorithms from the author. We followed those two algorithm as a base of our proposed algorithm but without that simulation code, same techniques cannot be implemented on the base station. And based on that, synchronization, data batching and cross layer optimization mechanisms are proposed.

But we did not lose hope. We are still looking forward to work with the proposed ideas. A literature review of existing algorithms are prepared by us which includes:

- Tail Optimization Protocol (TOP)
- Tail Aggregation protocol: TailEnder
- Leveraging the wasted Time: TailTheft
- Traffic Aware Strategies: MakeIdle & MakeActive
- Descriptions of the background knowledge related to 3G mobile phone energy consumption techniques

After the research work so far, our future goal is to gather the data set and try to simulate the system. If the simulation can be done with appropriate technologies, then our further work will be to evaluate these techniques with other methods and comparing the improvements. We will be looking forward with hope to complete our goal in future.

Chapter 9

Conclusion

In this report, we have conducted an analysis on different existing techniques to measure the consumed energy of mobiles and smartphones in a 3G network. At the beginning section of this report paper, we presented the background analysis and studies. We attempted to provide sufficient explanation to understand the main objective of this research work. Following this, we presented some existing techniques to measure the wasted energy of mobile and smartphones in a 3G network. We also presented our proposed ideas with some graphical descriptions and explanations. We hope to continue our work furnter on this purpose to come up with more enhanced results.

However, we have provided a thorough description on the related topics for this purpose. We have also provided some proposed techniques that can be adopted to reduce the wasted tail energy in a more efficient way. Though it was difficult to come up with tested results and conclusions, we attempted to present the idea in details.

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