BATTERY LIFE ENERGY CONSERVATION USING DYNAMIC POWER CONTROL IN MOBILE TERMINAL

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A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL,

FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGER STATE,

IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF

MASTER OF ENGINEERING (M.ENG.) DEGREE IN

TELECOMMUNICATION ENGINEERING

APRIL, 2012

DECLARATION

I, OYEWOBI, STEPHEN SEYI (M.ENG./SEET/2007/1742) declares that the work described in this “Battery Life Energy Conservation using Dynamic Power Control Algorithm in Mobile Terminal” represents my original work and has not been previously submitted to the University or similar institution for the purpose of award of similar or any other degree.

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07/05/2012
Date

DEDICATION

I dedicate this work to my wife and son, Mrs Abigail Inusa and Mr. Derick Samson and to the Oyewobi's and Inusa's for their love and for believing in me.

ACKNOWLEDGEMENTS

My profound gratitude goes to God the owner of our breath and the giver of wisdom, who hath made all things beautiful in their time and who knows us by name even before we were conceived.

I will not fail to register my indebtedness to my supervisor Dr. E. N Onwuka for her guidance, correction, and advice without which, this work will still have remain only an idea. I shall remain indebted forever also, for the invaluable values which she has made me imbibed as my H.O.D in the Telecommunication Engineering department.

My love and appreciation goes to my wife for staying awake with me while still carrying our baby through most nights that I had to be up doing my work.

My appreciation also goes to my friends from NARSDA and colleagues in F.U.T, Minna, including Messrs Tade Durojaiye and Elisa Tiagnet all of whom we started the programme with. In particularly Messrs Adeiza, Henry, Tade, Elisa, and Galadima for their moral support, contributions and at times financial support. I will remain indebted to Messrs Adeiza and Henry, particularly for their selflessness and the sleepless nights while coding OPNET.

I will not forget to mention the professional advice of the HOD and all members of staff of the Electrical and Electronics department. In the same vein, I appreciate the advice and research meetings of members of staff of Telecommunication Engineering department, particularly the senior members including all members of our research group.

I will not fail to appreciate The Dean and all members of staff of school of Engineering and Engineering Technology, also the Dean and all members of staff of post graduate school for their support and counseling towards the completion of this programme.

This acknowledgement will not be complete without the mention of the Vice Chancellor of the University, Prof. M. S. Audu for giving us the opportunity to pursue our career.

And finally my appreciation goes to my parents Pst. And Deaconess S.A. Oyewobi for nurturing me into what I have become today. To my siblings and all those who have contributed to this work in one way and another whom I have not mentioned, your contributions are appreciated. Thank you for your contributions.

ABSTRACT

Most of our activities today are tied around being able to make a call or connecting to the internet with our Mobile devices, however to optimally utilize the network and deliver the needed satisfaction to the user the mobile device needs to be powered. Sadly most mobile devices are powered by energy-limited batteries; which imposes a constraint on mobile terminal optimal performance and on the network utility. As a result, special emphasis is now being dedicated to extending the battery life of mobile devices. This work, presents a simple and effective algorithm which conserved battery power by dynamically responding to real life network scenarios to adjust transmit power; BER(bit error rate) in measurements reports obtained from signals received from the mobile terminal were used to measure signal quality to determine the network conditions and adjust transmit power accordingly. Tests were carried out using simulation models and results were compared with the stepwise algorithm. A reasonable improvement was recorded for operation time and battery-energy saved for the mobile terminal over stepwise algorithm.

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ABBREVIATIONS

GSM	Global system for mobile
4G	Fourth Generation Network
Abc	Always best connected
BTS	Base station transceiver
MS	Mobile station
PDA	Personal digital assistant
LOS	Line of sight
ISI	Inter symbol interference
DPM	Dynamic power algorithm
HDD	Hard drive disk
VLSI	Very large scale integration
RF	Radio frequency
PM	Power management
DTX	Discontinuous transmission
VAD	Voice activity detection
VOX	Voice operated transmission
FER	Frame error rate
SACCH	Slow associated control channel

CPU	Central processing unit
LCD	Lliquid crystal display
BER	Bit error rate
FSM	Finite state machine
STD	Statistical transmission diagram
GMSK	Gaussian modulation shift keying
INT	Integer
PL	Power level
MT	Mobile terminal
ECE	Electrical and computer engineering
SIR	Signal to interference rate

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to Study

Wireless communications have grown rapidly over the last five years, and that growth is expected to continue. Besides GSM (Global System for Mobile) and 3G mobile communication systems, new communication technologies such as Bluetooth, WiFi, WiMAX, ZigBee and 4G Network are emerging [Wikersham, 2010]. Most Wireless network resources are limited and nature-provided; therefore ways of efficiently utilising them is very important to communication engineers. Power, however not nature-provided is one of the wireless network resources and is not an exception, and is very important especially in mobile, satellite and sensors networks, where the devices or nodes in the networks are mostly remote, and their continuous existence and usefulness depend so much on the batteries powering them or on power, like in the case of the Nigeria satellite which "died" due to complete drain of its stored battery power, when its solar panel shifted position.

In the same vein, it could be really frustrating to have the battery of your mobile device or terminal run out on a day when you have left your charger at home and you are in the middle of an important presentation or call, the frustration is better imagined than experienced.

Mobile devices are powered by energy limited batteries; this limited battery lifetime imposes a constraint on mobile terminal optimal performance and on the network utility [Basil, *et al* 2008], for instance the mobility of a mobile device is greatly hampered if you have to intermittently charge your device at a particular fixed point severally within a short period of time.

The mobile device needs to be up or powered, to utilize the network and deliver the needed satisfaction to the user, otherwise the network is rendered useless, and also due to the increasing popularity of the internet [Josef, *et al*, 2003], manufacturers of mobile devices are adding features that enables the users to access the internet and intranet. These new features make it possible for users to download videos, pictures, and even play music from the internet, including other multimedia services, however these additional benefits, are without the added overhead on the mobile terminal battery, with the resultant high and or fast drain on the available battery energy. This challenge leads manufacturers to incorporate power consumption awareness into electronic circuits and system designs, with the overall objective of delivering high performance with limited power consumption. The trend in technological development in the area of networking points to a future of untethered communication. The dream of ubiquitous communication- anywhere anytime with any device is already being achieved. The phrase 'anywhere and anytime' means the device will most likely be a wireless device. Also the idea of "always best connected" (abc) for users implies the device should be power confident. It is therefore not difficult to see that research into mobile terminal power conservation technologies is a very stringent need. Therefore considering the great importance of mobile terminal power in accessing the teeming wireless network resources both for today and in the future, efficient power management of a mobile terminal is critical and is subject to conservation.

1.2 Statement of the Problem.

Just a few short years ago, the expectations of cell-phone users centred around one capability: being able to reliably conduct voice calls while they were away from a wired telephone set. Since then, impressive technological advances have been achieved, now mobile devices come with a lot of multimedia features for instance they come with a high-end, 3D-graphic gaming console and high-speed wireless-Internet-connection combinations. To put it simply, cellular phones have stopped being just telephones.

However, these supercomputing and communication devices invite a complex problem: Keeping these products running on very small batteries for longer periods of time is a major challenge. As a result, special emphasis is now being dedicated to extending the battery life of such systems. Designers are expanding their operating time from a few minutes to many hours while standby times rise from hours to weeks.

In doing so, designers are stressing a multi-level matrix of theoretical and practical limits—from the fundamental laws of physics to system-level-optimization techniques. At the same time, designers must implement dynamic power-consumption-management procedures.

1.3 Scope of the Study

Much work have been done in the area of power control and power management in mobile devices, according to literature much of the research work in power control technique started in 1991/1992, Some of the early, pioneering energy-management schemes simply turned selected areas of a system on and off. These schemes were based on rudimentary utilization algorithms. It is now understood that an energy-waste cost is associated with turning off and on a section of an electronic device. Depending on how frequently a block is turned off and on, this cost may exceed the benefit of powering it off in the first place. Therefore much focus is now on implementing dynamic power-consumption-management procedures. The scope of this research work is battery-life conservation in a mobile device by dynamically adjusting the transmit power.

1.4 Objective of the Study

The objective of this research work is to develop a simple and effective power control algorithm that dynamically adjusts the transmit power of mobile device. also to implement the algorithm and to evaluate the effect of the algorithm on the energy consumption or energy saving of a mobile terminal by extensive computer simulation. And finally to compare the result of the effect developed algorithm on the battery-life of mobile terminal with the effect of existing algorithm on the battery-life of mobile terminal.

1.5 Contributions to Knowledge

This work introduced a simple and effective dynamic power control algorithm that showed remarkable power saving at a mobile terminal by dynamically adjusting transmit power as shown by results obtained from computer simulation.

It is observed that the operating time for the mobile device can be increased by the significant energy conserved at the battery as shown by simulation results compared to other algorithm for the same amount of run-time.

This work showed that "complex" is not always "right" by showing that an algorithm can be simple and yet very effective.

1.6 Structure of Thesis

Chapter 2 of this thesis report presents a literature review and some related works on the subject, their contributions, and weaknesses, it also introduces our algorithm. Thereafter Chapter 3 gives a detailed explanation of design and implementation of the algorithm. In Chapter 4 results obtained were presented. Chapter 5 discussed the results obtained.

CHAPTER TWO

2.0 LITEARTURE REVIEW

In GSM and in other traditional mobile systems a trade-off between different goals is necessary to achieve the optimal system performance. Generally, high speech quality, high capacity and low power consumption are major goals.

2.1 Radio Cell And Wave Propagation.

Due to lack of infrastructure, cost and vandalism of existing infrastructures, network operators are finding it difficult to cover all locations particularly in Nigeria. Especially, places that are remote areas for instance interior villages, and along the thousands of kilometers of roads spanning the country. So network coverage/signal is very limited in some places and non existence in most.

Technically in mobile networks we talk in terms of 'cells'. In general, a cell can be defined as the area covered by one sector, i.e. one antenna system. Coverage in a cell is dependent upon the area covered by the signal.

In radio network planning candidate sites are usually divided into urban, suburban and rural based on human-made structures and natural terrains.

he cells that are constructed in these areas can be classified as outdoor and indoor cells. Outdoor cells can be further classified as macro-cellular, micro-cellular or pico-cellular

(i) Macro-Cells

When the base station antennas are placed above the average roof-top level, the cell is known as a macro-cell. As the antenna height is above the average roof-top level, - The area that can be covered is wide. A macro-cell range may vary from a couple of kilometres to 35 km, the distance depending upon the type of terrain and the propagation conditions. Hence, this concept is generally used for suburban or rural environments.

(ii) Micro-Cells

When the base station antennas are below the average roof-top level, then the cell is known as a micro-cell. The area that can be covered is small, so this concept is applied in urban and suburban areas. The range of micro-cells is from a few hundred metres to a couple of kilometres.

(iii) Pico-Cells

Pico-cells are defined as the same layer as micro-cells.

The signal that is transmitted from the transmitting antenna (BTS/MS) and received by the receiving antenna (MS/BTS) travels a small and complex path. This signal is exposed to a variety of man-made structures, different types of terrain, and a combination of propagation environments. All these factors contribute to variation in the signal level, thereby varying the signal coverage and quality in the network.

It is an accepted fact that if a mobile terminal is constantly straining to find a network signal it will use more power than if it is not. When it is in an area with poor network coverage it will use more power to force a connection with the nearest mobile mast base station.

Because of this, it will draw more power from the battery and as a result shorten the battery life. [Andrew, 20

2.2 Impairments To Radio Transmission

The problem with radio transmission is that it is impossible to control the transmission environment. The impairments are known, but their effect as a function of time is unpredictable and hence, it is difficult to accurately model the transmission dynamically.

There are several factors that affect radio transmission conditions, in addition to noise. Some of the problems with the radio transmission are listed below [Fredrik, 2005].

(i) Free Space Loss

Any signal that is transmitted by an antenna will suffer attenuation during its journey in free space. The amount of power received at any given point in space will be inversely proportional to the distance covered by the signal. Therefore a mobile terminal far from the base station needs to radiate more power than a mobile terminal near the base station. For this reason it is pertinent that the communication engineers find a technique to reduce power loss due to free space loss. This work will help to reduce battery consumption due to unnecessary power being radiated when a mobile tries to connect to a base station very far off, and prevent receiver saturation for a mobile very close to a base station.

(ii) Fading Of Signal

As the signal travels from the transmitting antenna to the receiving antenna, it loses strength. This may be due to the phenomenon of path loss as explained above, or it may be due to the Rayleigh effect. Rayleigh (or Rician) fading is due to the fast variation of the signal level both in terms of amplitude and phase between the transmitting and receiving antennas when there is no line-of-sight. So that before a faded signal reaches the receiving antenna it is already weak, and the quality of the signal may be compromised, and therefore more power is required to transmit, and invariably more energy is drawn from the battery. Signal fading is therefore one of the major impairment to signal transmission and a reason for more power consumption.

(iii) Interference

The signal at the receiving antenna can be weak by virtue of interference from other signals. These signals may be from the same network or may be due to man-made objects.

However, the major cause of interference in a cellular network is the radio resources in the network. There are many radio channels in use in a network that use common shared bandwidth.

Today second-generation networks are seeing rapid growth in the use of devices such as personal digital assistants (PDAs), palm-top and notebook computers, and lightweight mobile phones [Rulnick and Bambos, 1996]. For users of this equipment it is advantageous or necessary to minimize energy consumption, provided, of course, that quality-of-service requirement is met. For example, it may be desirable to suspend transmission at moments when interference is unusually high. How to autonomously determine when, and at what power, a mobile terminal should attempt transmission is the aim of this work. When substantial amount of energy is conserved, which would have otherwise been loss due to interference, the device is most useful to the user and to the network.

(iv) Diffraction Or Shadowing

Diffraction is a phenomenon that takes place when the radio wave strikes a surface and changes its direction of propagation owing to the inability of the surface to absorb it. The loss due to diffraction depends upon the kind of obstruction in the path. In practice, the mobile antenna is at a much lower height than the base station antenna, and there may be high buildings or hills in the area. Thus, the signal undergoes diffraction in reaching the mobile antenna. This phenomenon is also known as 'shadowing' because the mobile receiver is in the shadow of these structures.

(v) Reflections And Multipath

The transmitted radio wave nearly never travels in one path to the receiving antenna, which also means that the transmission of the signal between antennas is never line-of-sight (LOS).

Thus, the signal received by the receiving antenna is the sum of all the components of the signal transmitted by the transmitting antenna.

A reflecting object such as a mountain reflects signal and the mobile station will hence receive both a direct signal and a fairly strong reflected signal from the reflecting object. These two signals will arrive at different times which could cause individual bits to overlap with each other and disturb the overall signal. These effect is called inter symbol interference (ISI).

(vi) Building And Vehicle Penetration

When the signal strikes the surface of a building, it may be diffracted or absorbed. If it is to some extent absorbed the signal strength is reduced. The amount of absorption is dependent on the type of building and its environment: the amount of solid structure and glass on the outside surface, the propagation characteristics near the building, and orientation of the building with respect to the antenna orientation.

Vehicle penetration loss is similar, except that the object in this case is a vehicle rather than a building.

(vii) Propagation Of A Signal Over Vegetation (Foliage Loss) And water

Foliage loss is caused by propagation of the radio signal over vegetation; principally forests. The variation in signal strength depends upon many factors, such as the type of trees, trunks, leaves, branches, their densities, and their heights relative to the antenna heights.

Foliage loss depends on the signal frequency and varies according to the season. This loss can be as high at 20 dB in GSM 900 systems [Mishra, 2004].

Moreover, as water surface is a very good reflector of radio waves, there is a possibility of the signal causing interference to the antenna radiation patterns of other cells.

2.3 Overview Of Battery Technology

The limited battery lifetime is always a bottleneck for the development of improved portable electronic products. Although, battery technology has been improved over the years, it definitely has not kept up with the advances in other technological fields. Therefore, it is left on the hands of other scientific fields to find solutions where battery technology seems to have failed. Indeed, in the last decade an intense research in various areas have been focused on minimizing the power consumption of wireless platforms [sandip, 2010].

A brief review of contemporary battery technologies and the characteristics of batteries past and future that may be relevant to designers of battery powered electronic systems are here presented.

(i) **Nickel-Cadmium:** This has been successfully used for several decades to develop rechargeable batteries for portable electronic devices. Its advantages include low cost, and high discharge rates. While Ni-Cd technology has been losing ground in recent years owing to its low energy density, it is still used in low cost applications like portable radios, CD/tape players, *etc*

(ii) **Nickel Metal-hydride:** These batteries have been in widespread use in the recent years for powering laptop computers. They have roughly twice the energy density of Ni-Cd batteries. However, they have shorter cycle life, are more expensive, and are inefficient at high rates of discharge

(iii) **Lithium ion:** This is the fastest growing battery technology today, with significantly higher energy densities, and cycle life about twice that of Ni-MH batteries. Lithium ion batteries are more expensive than Ni-MH batteries, and can be unsafe when improperly used. However, longer lifetimes have made them the most popular battery choice for notebooks, PDAs, and cellular phones.

(iv) **Reusable Alkaline:** While disposable alkaline batteries have been used for many years, reusable alkaline manganese technology has developed as a low cost alternative in which energy density and cycle life are compromised. While the initial energy density of reusable alkaline batteries is higher than Ni-Cd, it has been found to decrease rapidly with cycle life. For instance, after 10 cycles, a 50% reduction, and after 50 cycles, a 75% reduction in energy density is commonly observed

(v) **Lithium Polymer:** This emerging technology enables ultra thin batteries (less than 1 mm thickness), and is expected to suit the needs of light-weight next-generation portable computing and communication devices. Additionally, they are expected to improve over current lithium ion technology in terms of energy density and safety. However, these batteries are currently expensive to manufacture, and face challenges in internal thermal management

2.4 Battery Power Optimization Techniques.

Researchers have over the years taken up the task of finding solution to this challenge of battery power conservation where battery technology has failed, through numerous techniques. Some of these techniques are briefly described below.

(i) Dynamic power management.

There have been several efforts at optimizing system battery especially mobile terminals battery since all mobile terminals are powered by energy limited batteries, These efforts have increased with the increasing demand on mobile devices to deliver high performances with limited power consumption. Researchers have done a lot of work in the area of power control and power management to optimize battery life. For the purpose of this thesis, it is necessary to distinguish between the two concepts.

Whilst power management is a techniques used to reduce the power consumption of wireless devices by selectively putting the device into the low-power states. In power control, the energy incurred in transmission is reduced by using different transmission power levels. Ideally, power control explores a continuous control space and is more theoretically attractive. However, in reality wireless devices are only capable of changing power levels in a discrete fashion [Basil, *et al* 2008].

One of such power management techniques greatly explored by researchers is dynamic power management (DPM) for electronic devices, and mobile devices in particular. Dynamic power management is one of the most popular and successful low power design techniques in commercial electronic devices. The principles of DPM are to selectively shutdown or depress voltage/frequency of some components which are idle. In a power-managed system it is possible to set components into different states, each characterized by performance and power consumption levels. The main function of a power management policy is to decide when to perform component state transitions and which transition should be performed, depending on system history, workload, and performance constraints. A policy is a control procedure based on some observations and/or assumptions on the workload [Shun-Ren, and Yi-Bing, 2008].

Electronic circuits and systems are usually designed to deliver peak performance, but in many cases peak performance levels are not needed for most of the operation time. Consider a cellular phone for instance, when the user is making or receiving a call with the cellular phone or a Personal computer (PC), when the user is compiling a C program he /she wants to have maximum performance. However, when the user is carrying the phone in his pocket or he/she is thinking of what to write next during a text-editing session on a PC, he/she does not need maximum performance or the full computational power of the system. Low power consumption is required to achieve acceptable autonomy in battery-powered systems

In the same vein, electronic systems can be viewed as collections of components, which may be heterogeneous in nature. Some components may have mechanical parts, e.g., hard-disk drives (HDD), or optical parts, e.g., displays. For example, a cellular telephone has a digital very large scale integration (VLSI) component, an analog radio-frequency (RF) component, and a display. Such components may be active at different times, and correspondingly consume different fractions of the telephone power budget. Similarly, main components of portable computers are VLSI chips, HDD, and display. It is often the case that the HDD and the display are the most power-hungry components [Etoh, 2005], and thus efficient use of them is important to achieving long operating times between battery recharges.

Dynamic power managers can be of different embodiments, according to the level, component, system, and network respectively, where DPM is applied, and to the physical realization style e.g., timer, hard-wired controller, and software routine. Typically, a power manager (PM) implements a control procedure based on some observations and/or assumptions on the workload. The control procedure is often called policy [Dutta and Sheel. 2002]. An example of a simple policy, ubiquitously used for laptops and palmtops, is the timeout policy, which shuts down a component after a fixed inactivity time, under the assumption that it is highly likely that a component remains idle if it has been idle for the timeout time.

DPM has proved to be a powerful methodology for reducing power consumption in electronic systems. In a power-managed system, the state of operation of various components is dynamically adapted to the required performance level, in an effort to minimize the power wasted by idle or underutilized components.

However, [Sandip, 2010] showed how this simple minded policy may turn out to be inefficient. Firstly, since these policies have to be run on an operating system, they come with additional overhead. Another weakness of the DPM is that based on its stochastic and predictive nature, policies are implemented on prediction of future events based on past history and or events resulting sometimes in over predictions and under predictions; consequently, a policy is likely to issue more shutdown commands and degrade performance. On the other hand, a policy can be conservative in power saving and issue fewer shutdown commands. While performance and accuracy improve, these policies consume more power.

(ii) Discontinuous Transmission.

Discontinuous transmission is another technique that has been employed in system power optimization, especially in wireless network, where it has been used to preserve and prolong mobile terminal battery, much research work have also been done in this area.

Discontinuous transmission (DTX) is a method for optimizing the efficiency of wireless voice communications systems by momentarily powering-down or muting a mobile or portable telephone in the absence of voice input. Each party in a typical 2-way conversation speaks slightly less than half the time, so if a transmitter is on during voice input only, the phone's duty cycle can be cut to less than 50%. That condition conserves battery power, eases the workload of transmitter components, and frees the channel, allowing the system to take advantage of available bandwidth by sharing the channel with other signals. DTX circuits operate with voice activity detection (VAD), which in wireless transmitters is sometimes called voice-operated transmission (VOX) [Ashay, *et al.* 2009].

The idea of discontinuous transmission is based on the fact that a person speaks less than 40% of time in normal conversation, so turning the transmitter off is assumed to save power. In order to distinguish voice and background noise, very accurate Voice Activity Detector are used. While transmitter is off, the receiving end will hear a total silence, which is due to the nature of digital transmission. To avoid this, a comfort noise is generated trying to match the characteristics of background noise.

Discontinuous transmission when activated in a mobile device or system have been found to conserve substantial amount of battery energy, however, some of the problems with DTX is the need for DTX circuits which consumes additional power when this feature is turn on, and at times when the Voice Activity Detector mistakes background noise for voice and it is transmitted, battery energy is wasted in transmission

(iii) Discontinuous Reception.

Another method used to conserve power at the mobile station is discontinuous reception, and it is very similar to discontinuous transmission already discussed. In discontinuous reception the paging channel, used by the base station to signal an incoming call, is structured into sub-channels. Each mobile station needs to listen only to its own sub-channel. In the time between successive paging sub-channels, the mobile can go into sleep mode, when almost no power is used, thereby conserving battery energy [Croce, 2004].

(iv) Power Control.

Power control refers to the strategies or techniques required to adjust the transmitted power to the minimum so that more power than necessary is not radiated. Power control regulates the transmitted power to achieve desired signal strength. According to literature much of the study on cellular network power control started in 1992-1993, power control is divided into two parts, fast power control and outer loop control. The fast power control is used to counteract the effects of fast fading by adjusting the transmitted power of the mobile in order to achieve a given Signal to Interference Ratio (SIR) target [Sklavos and Touliou, 2007].

Outer loop power control is used to maintain a certain quality in terms of Frame Error Rate (FER). This is done by comparing a measured FER value with a FERtarget and using the difference to regulate the SIRtarget used by the fast power control [Sklavos and Touliou, 2007].

(vi) Step Wise Power Control Algorithm

The base station controls the power output of the mobile through the concept POWER CONTROL as discussed above. GSM standard defines five classes of mobile stations, according to their peak transmitter power, rated at 20, 8, 5, 2, and 0.8 W. A table of GSM power levels is defined, and the base station controls the power of the mobile by sending a GSM "power level" number. The mobile then adjusts its power accordingly. In virtually all cases the increment/decrement between the different power level numbers is 2dB. Signal quality is measured by mobile and base station. The mobile station passes results of its measurements to the BS, which is responsible for power control. Measurement reports are sent in Slow associated control channel (SACCH) about once in 480 ms.

Some of the problems with existing power control algorithms are complexity owing to the amount of parameters that needs to be predefined. The other problem is the usage of a fixed target value for all situations. Also the fixed increment of 2db between different power level numbers is too rigid in my opinion, assuming a mobile terminal needs to jump between two extreme power levels due to sudden and sharp drop in signal quality.

(vi) Dynamic Power Control Algorithm.

The dynamic power control algorithm being proposed in this work is an outer loop power control, which seek to evaluate and adjust the transmitted power to the desired signal strength and quality by a power regulation process that regulate the transmitted power directly to the required optimum transmitted power, unlike the step-wise power control algorithm. for instances if we think about a situation where mobile phone hears base station very well, but suddenly the strength of signal goes lower, user maybe, goes inside building, which blocks quit good radio signals.

2.5 Some Related Work on Power control/management.

As wireless communications industry is growing, users' demands for new enhanced features and long battery life are increasing. Hence, power has become the first class design constraint, when it comes to rich multimedia portable devices [Shun-Ren, 2005]. This part present previous work that have been carried out in this field, their contributions and their drawbacks.

Sklavos and Touliou (2007) titled their work, Power Consumption in wireless network: Techniques & Optimizations, in their attempt to provide solutions to the increasing energy demands, they proposed various power management techniques.

Among them, the most well known is the voltage and frequency scaling technique. Their study showed that CPUs, memories and the device's display are the modules that consume most of the power resources. Their solution is system-level based approach, A system-level approach focuses on the power consumption of the CPUs, memories, buses or the display of the device. Since according to them, the three most important contributors in power loss is CPU, the memory and the display, they employed techniques that mostly involved these subsystems. In other to minimize the power loss in the CPU in the power consumption, they employed power efficient processors. According to them, memories power loss can either be static or dynamic and in solving the problem they employed energy efficient memory schemes such as memory hierarchy, memory partitioning, and a new range of mobile/cellular memories such as cellularRAM and mobileRAM which have been designed for wireless, battery operating devices. While addressing Power Control Techniques for Displays in order to reduce the power consumed by the display they proposed the use of energy adaptive LCD systems [Sklavos and Touliou, (2007]. This technique suggests the trade off between quality and power consumption. Depending on the application requirements and users' demands, a reduction of brightness or size of the display, was also suggested for power efficiency. They claimed that this approach is further motivated by research results that showed that the window of focus, meaning the user's area of interest – utilizes only 60% of the total screen area [Sklavos and Touliou, (2007]. Based on these observations, techniques that modify the clarity of the image and colour depth of the non-active screen areas were proposed, while leaving the active screen area unchanged.

It could appear that they have solved all of the problems by tackling the three most power loss contributors as they claimed, but their solution is only a system based approach, and according to research in the study of power consumption in portable phones, the RF subsystem rank second only to video and audio processing operations which they have been silent about, and this is the main focus of our work.

Abukmail and Helal (2007) in their work Energy Management for Mobile Devices through Computation Outsourcing within Pervasive Smart Spaces, explored the opportunity Pervasive Spaces could provide as supplemental energy sources. They utilize the nature of pervasive smart spaces to outsource computation that would normally be performed on a mobile device to a surrogate server within the smart space. Their decision to outsource a computation according to them depends on whether its energy cost on the device is larger than the cost of communicating its data to the surrogate and receiving the results back. They propose an approach by which the outsourcing decision is made at runtime, while the intelligence that makes that decision is inserted at compile-time as logic that modifies the application code. The merit of their approach as they claimed is that it is application-independent and requires minimal programmer energy awareness. Additionally, they implemented a runtime support on top of Linux to facilitate for testing and experimenting with the client/server outsourcing approach. Their experimental validation and benchmarks they claimed showed a significant energy saving on the mobile device, which they believed validates their approach as a viable and novel approach to power saving and management for mobile devices.

First their approach depends on a surrogate server for computation and energy saving through Computation Outsourcing within Pervasive Smart Spaces, this makes their system' power management technique dependent, and nothing was said on power management for the surrogate, which means they assume that the surrogate will always be up or powered by some means which they didn't mention. They claimed that their system makes communication a means of energy saving, but they didn't tell us who bear the cost of communication between the system and the surrogate. Their technique involve a lot of complex programming in java and c++ . and takes a lot memory spaces and processor time, which consume reasonable amount of energy. They also claimed their outsourcing is real-time, but we know that this depends a lot on the processing power of the surrogate. Our design solves a whole lot of this problem by solving the problem of optimization within the system, and the network only.

Pushkar and Chinta (2009) of the University of Illinois, Chicago. Electrical and Computer Engineering Department in their survey which they captioned " survey report on dynamic power management " surveyed a series a journal on dynamic power management and concluded that DPM can be applied to various levels in a system. To analyze a DPM based system, they adopted a bottom-up view. They first focus on how a power-manageable system component for example, chips has been designed. Then they moved on to see how this DPM policy is applied to a functionally complete system which binds all interacting components.

However, these simple minded policies may turn out to be inefficient. Firstly, they come with additional overhead since these policies have to be run on an operating system, Another weakness of the DPM is that based on its stochastic and predictive nature, policies are implemented on prediction of future events based on past history and or events resulting sometimes in over predictions and under predictions;

consequently, a policy is likely to issue more shutdown commands and degrade performance. On the other hand, a policy can be conservative in power saving and issue fewer shutdown commands. While performance and accuracy improve, these policies consume more power.

Also policies are system, component and most time operation-specific, therefore specific policy has to be developed for every particular operation with its own assumptions, limitations and technicalities. However, our algorithm is simple and dynamic taking into cognisance the dynamic nature of wireless network environment, this it achieves by measuring the quality, through the Bit error rate (BER) of the received signal at the base station and adjusting the transmit power accordingly.

Ashay, *et al* (2009) proposed a dynamic power control algorithms in their work "Algorithms for Transmission Power Control in Biomedical Wireless Sensor Networks" They proposed a feedback-based closed-loop algorithms for dynamically adjusting radio transmit power in body-worn devices. they evaluated the performance of their algorithm in terms of energy savings and reliability as the data periodicity and feedback time-scales vary with real life experimental set-up. Using experimental trace data from body worn devices, they first showed that the performance of dynamic power control is adversely affected at long data periods. Next for a given data period they showed that modifying the transmit power at too long time scales (around a minute) reduces the efficacy of dynamic power control, while too short a time-scale (few seconds or less) incurs a high feedback signalling overhead. They therefore advocate an intermediate range of time-scales (when permitted by the data periodicity), typically in the few tens of seconds, at which the control algorithms should adapt transmit power in order to achieve maximal energy savings in body-worn sensor devices used for medical monitoring.

While their work is good and recent, it only addressed two aspects of power control technique which affect dynamic power control, and with particular focus on wireless sensor network; namely the periodicity of data transmissions and the frequency of transmit power updates. Albeit the performance of their algorithm was tested in terms of energy savings and reliability, energy saving was not their primary interest, their primary interest was to evaluate the effect of data periodicity and feedback time-scales on dynamic power control.

Though our work employ dynamic power control, our algorithm is simple and our focus is on conserving energy at the mobile terminal using a power control algorithm that takes into consideration the ever-changing nature of the mobile network environment which we have incorporated into the algorithm by measuring two parameters; signal strength and signal quality at every measurement period.

CHAPTER THREE.

3.0 MATERIALS AND METHOD

In this chapter the simulation model is described, for example what the simulation environment looks like and how some functions works.

3.1 Simulation Model

The simulation model is based on the real-life GSM system network and all design concepts were modelled according to the OPNET design procedures. The OPNET design procedure consists of a hierarchical structure arranged as follows:

(i) The Network Project Model: A network model defines the overall scope of a system to be simulated. It is a high-level description of the nodes contained in the system. The network model specifies the nodes in the system, as well as their physical locations, interconnections and configurations.

(ii) The Node Model: The internal structure of the nodes in the network model, for the most part, is not visible at the network level. This section (the node model) presents the methods used to specify the internal structure in terms of functional elements and flow between them.

(iii) The Process Model: describes the behavior of processes (algorithms, protocols, applications) specified using Finite State Machines (FSM) and extended high-level language. The FSMs run on sets of programming codes referred to as PROTO-C. This programming language is a variant of C++. A combination of C++ codes and indigenous OPNET codes forms the PROTO-C codes.

3.2 Steps Towards Validating Experimental Hypothesis

[EXPERIMENT 1]. Set up experiment to study the effect of maximum power transmission on the battery of a mobile terminal.

=> Time taken for mobile terminal battery to get completely depleted.

[EXPERIMENT 2]. Set up experiment to study the effect of extended outer loop algorithm (dynamic algorithm) on the mobile terminal battery.

=> The effect of algorithm on mobile battery.

Time taken for mobile terminal battery to get completely depleted.

[EXPERIMENT 3]. Set up experiment to study effect of current algorithm (step wise increment) on the mobile terminal battery.

=> The effect of the algorithm on the mobile terminal battery.

Time taken for mobile terminal battery to get completely depleted.

3.3 Experiment One

3.3.1 Project Network Domain Design.

The size and scope of the networks modelled can range from simple to complex. A network model may contain one node, one subnetwork, or many interconnected nodes and subnetworks, This is because the structure and complexity of a network model typically follows those of the system to be modelled. For example, Figure 3.0 and Figure 3.1 show a network with a star topology and its corresponding network model with one centre node (the hub) and several peripheral nodes connected to it with point-to-point links respectively.

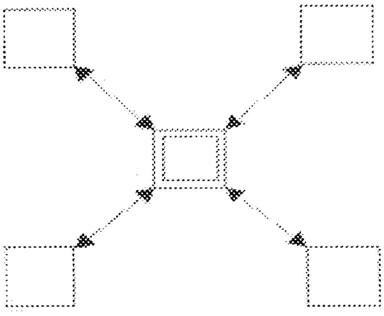

Figure 3.1 Star Topology.

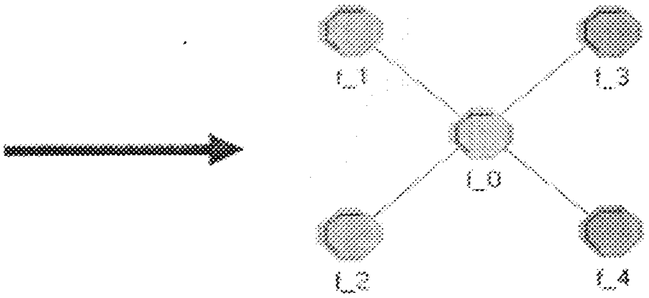

Figure 3.2 Network Model.

OPNET MODELER does not place restrictions on the number of node models that can be deployed in a communication network; instead it adopts an open approach where a modeler can develop their own library of node models to use as building blocks for their own network model. This was the approach employed in this project work. A library of emulated nodes was developed, which were subsequently used in the simulations. The project editor can provide a geographical context for network model development. Locations can be chosen on world or country maps, or customized dimensioned areas can be deployed for the network domain. These domains simulate a notion of corresponding distances, which further give a sense of real-life scenario and allow for automatic calculation of delay and other factors that are distance dependent.

The basic object used to build network models is the fixed communication node. These nodes are assigned arbitrary locations and do not change their location throughout the course of the simulation. However with recent versions (like the OPNE vT v14 used in this work), wireless functionality has been included, which allows for the inclusion of mobile and satellite nodes. Mobile nodes can be assigned trajectories to define their path of motion and their positions during the course of the simulation, hence change. Both fixed, mobile and satellite nodes need to have the ability to communicate. The link models therefore enable these nodes to initiate and sustain communication during a simulation period. Different types of link models are made available to provide the interconnection of these nodes and ensure communication. OPNET provides simplex (unidirectional), duplex (bidirectional) point to point links and bus links to allow for fixed node communication. Wireless functionality provides radio link communication channels for both fixed, mobile and satellite nodes to communicate.

For this work, in the first experiment and subsequent ones (experiments 2 and 3) two nodes are used in the network setup throughout namely; (i) The base station and (ii) the mobile terminal. Figure 3.3 is a typical view of the network domain design. The network topology was designed with the following parameters:

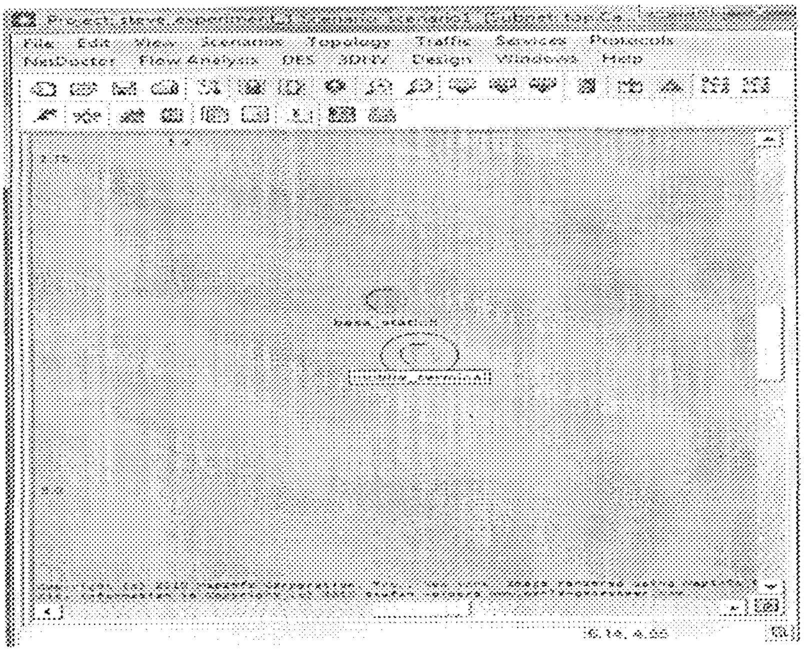

Figure 3.3 experiment one project domain.

1. Total network coverage area = 10 × 10 Km.

2. The mobile terminal was located at coordinates (0.5, 0.5) in Km.
3. The base station was located at coordinates (1.5, 1.5) in Km.

The mobile station is communicating with the base station as in real life situation. In real life however, when a mobile connects to a base station, it starts to transmit at peak power then an algorithm steps down power to a desirable power level.

3.3.2 Node Domain Design For Mobile Terminal.

The internal structure of the nodes for the most part as stated already is not visible at the network level. The node domain presents the methods used to specify the internal structure.

A node model is composed of a series of connected blocks called *modules*. Node models specify the manner in which the inputs and outputs of various modules are connected using objects called connections. Three types of connection in OPNET provided to interconnect modules are; *packet streams, statistical wires and logical associations*. Packet streams allow formatted messages called packets to be conveyed from one module to another. Statistical wires convey simple numeric values or control signals from one module to another while logical associations simply identify a binding between modules.

In experiment 1, the author is interested in the effect of transmission power only on energy consumption of the mobile terminal, barring other sources of power consumption in mobile terminal. Such as the digital very large scale integration (VLSI) component, and the display which experience has shown consume large amount of battery energy.

The mobile terminal design consist of the following modules;

(i) Packet generator: which is a standard module in OPNET

(ii) .The mobile terminal transmitter: which is also a standard module and

(iii).The mobile processor; is the author`s design, OPNET permits individual design to suit individual purpose.

A typical view of the mobile terminal node domain design is shown in Figure 3.4, the modules in this design are described below.

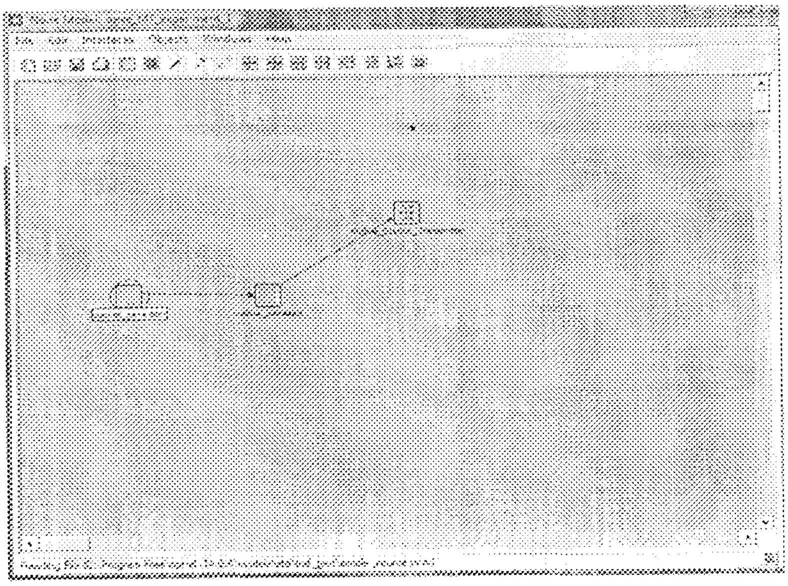

Figure 3.4 mobile terminal node domain design

(i) The Packet Generator

The Packet generator as stated earlier is a standard Opnet module used in this and subsequent experiments to establish that there is a communication between the mobile terminal and the base station, packets generated by the Packet generator in the mobile terminal node domain are transmitted from the mobile terminal and received by the base station, confirming a communication between the mobile terminal and the base station.

(ii) The Mobile processor

The mobile processor is part of the author's designs and it is designed to emulate the internal structure of mobile terminal, in this work the mobile processor does all processing work within the mobile terminal. It registers the maximum power at the beginning of transmission and records the current power (new drain value) during the course of transmission. It also ensures that the mobile terminal transmits at this value to the base station.

(iii) The Mobile terminal transmitter

This standard OPNet module was used in the model to help in transmitting the packets from the mobile terminal to the base station. The modulation scheme employed is GMSK.

3.3.3 Process modelling for mobile terminal.

Processor modules are user programmable elements that are key components of communication nodes. The tasks that these modules execute are called processes. Because it has a set of instructions and maintains state memory, a process is similar to an executing software program. The process module describes the behavior of processes (algorithms, protocols, applications) specified using Finite State Machines (FSM) and extended high-level language. The FSMs run on sets of programming codes referred to as PROTO-C. This programming language is a variant of C++. A combination of C++ codes and indigenous OPNET codes forms the PROTO-C codes. Process editors express process models in a language called PROTO-C, which is specifically defined to support developments of protocols and algorithms. PROTO-C is based on a combination of state transition diagrams (STD), a library of high level commands known as Kernel procedures and general facilities of the C or C++ programming language. A process model's STD defines a set of primary modes or *states* that the process can enter and, for each state, the conditions that would cause the process to move to another state. The condition needed for a particular change in state to occur and the associated destination states are called a *transition*. Transitions can either be conditional or unconditional.

A brief description of the PROTO-C language is given in section 3.3.4

3.3.4 Brief Description of PROTO-C Language.

1. **State Variables**—Processes maintain private state variables with named variables of arbitrary data types, including Modeler-specific, general C/C++ language, and user-defined types. This capability allows a process to flexibly maintain counters, routing tables, statistics related to its performance, or messages requiring retransmission. Arbitrary combinations of state variable values may be used in all decisions and actions implemented by a process.
2. **State Executives**— each state of a process can specify arbitrarily complex actions associated with the process entering or leaving that state. These actions, called state executives, are expressed with the full flexibility of the C/C++ language. Typical actions include modifying state information, creating or receiving messages, updating the contents of and sending messages, updating statistics, and setting or responding to timers.
3. **Transition Conditions**— Transition condition statements, which determine whether a transition should be traversed, may be expressed as general C/C++ language booleans that make reference to properties of a new interrupt as well as to combinations of state variables.

4. **Transition Executives**—Transitions may specify general actions, called executives, which are implemented each time that they are traversed. This project design employed all the above defined attributes to create the process model(s) of the mobile terminal in experiment one, and both the mobile terminal and base station in experiments two and three respectively. PROTO-C codes for each module can be found in the Appendix. Each module described in the node model design above and those that would be described for experiments one and two has their own specific process model design. The process model for experiment one is described in section 3.3.5

3.3.5 Mobile terminal process model

The process model for this module consists of three STDs linked by both conditional and unconditional transitions as shown in Figure 3.5. The process initiates in a forced stated called the *init* state. All statistical variables are initiated and registered in this state. It is followed by an unconditional transition to the *packet wait* state which serves like buffer for packets before they transited to the processor . Either of the transitions leaving this state are conditional transitions where conditions for transition are stated in the HEADER BLOCK provided in the process editor, however, the default ensures that only packets from the init state, transit conditionally to the processor. The dotted lines represent conditional transition while the unbroken lines represent unconditional transition.

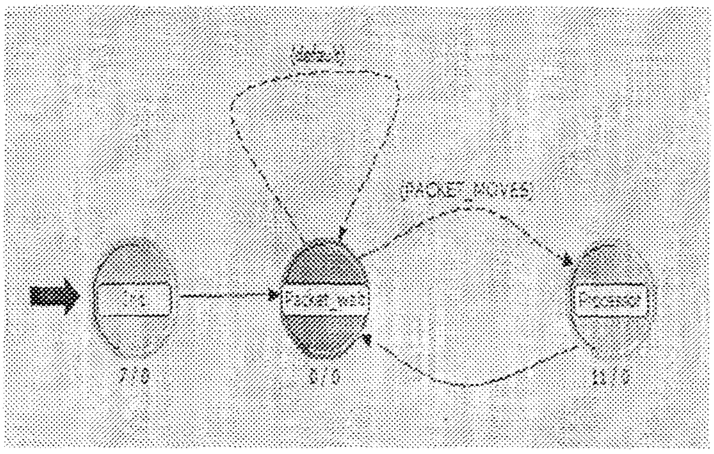

Figure 3.5 mobile processor process model design

3.3.6 Node Domain Design For Base Station.

Having described the node and process domains design for the first node which is the mobile terminal, the same will be done for the second and last node in the project network domain; the base station. Base station in experiment one is not expected to perform any task other than communicate with the mobile terminal because no algorithm was ran in experiment one. Therefore the base station consist of two standard opnet modules;

(i) Base station receiver

(ii) Base station sink.

(i) Base station receiver

The receiver was incorporated in the base station design so that the base station can receive signal from the mobile terminal and establish a communication link, as was stated above the receiver is a standard opnet module and was just incorporated into the design.

(ii) Base station sink.

The sink is also a standard opnet module and it helps to store temporarily and destroy packets received from the mobile terminal, so as to clear the base station memory space and not clog the memory space unnecessarily. The Figure 3.6 shows the node domain design for the base station.

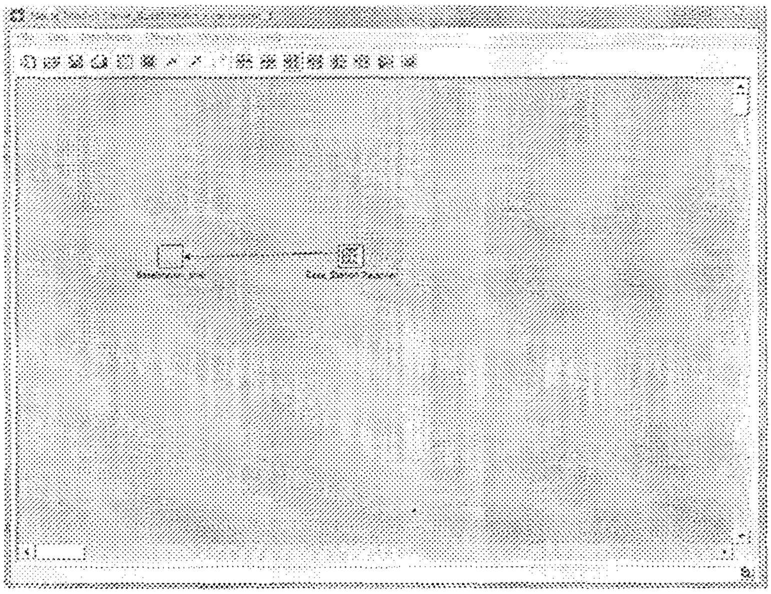

Figure 3.6 node model for base station.

3.4 Experiment Two

3.4.1 Project Network Domain Design.

There is a need to state here that network domain for the three experiments are the same with parameters set as those of experiment one. This is to be able to make fair comparison between the results from the three experiments. The figure 3.7 shows the network domain for experiment two.

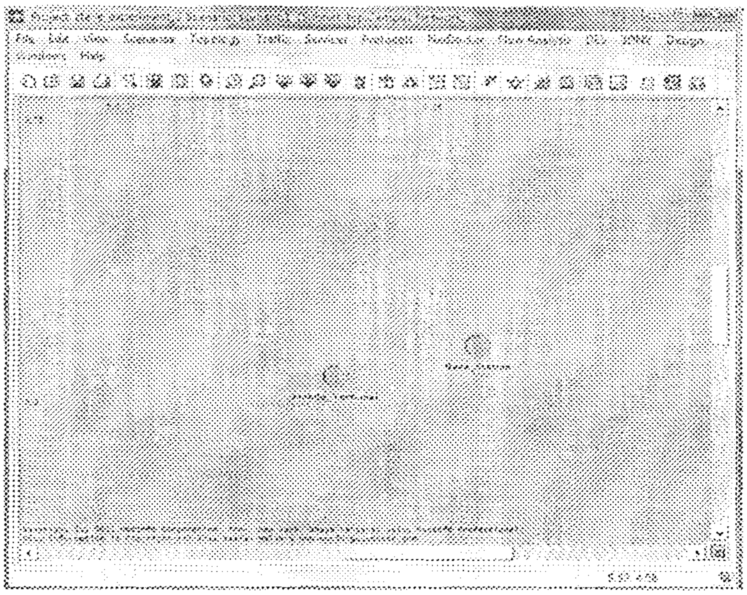

Figure 3.7 network domain for experiment two

3.4.2 MT Node domain for experiment two

The mobile terminal node domain for experiment two comprise of the following modules; packet generator, mobile processor, mobile transmitter, and mobile receiver as shown in the figure 3.8;

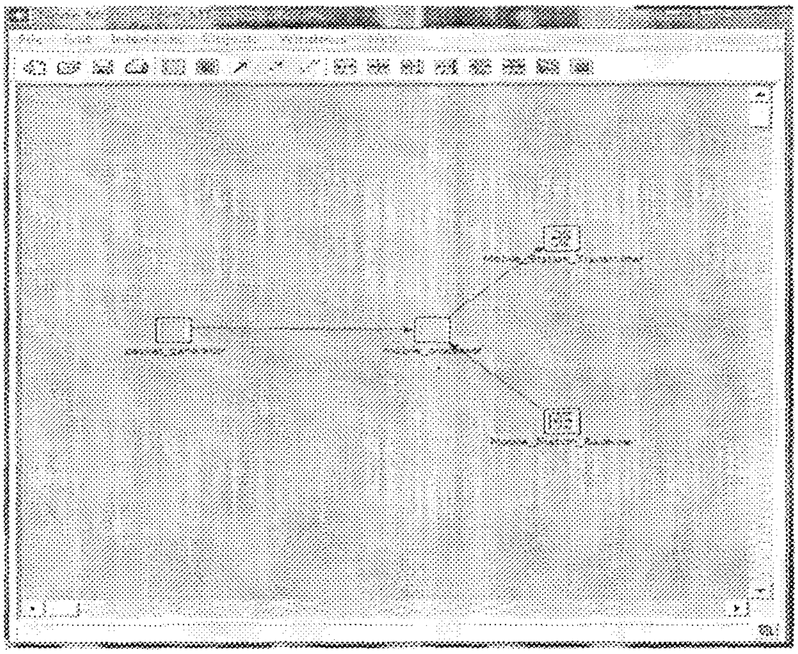

Figure 3.8 Node domain design for mobile terminal experiment two.

3.4.3 The mobile terminal receiver

The mobile terminal receiver in experiment two node design is the only addition to the mobile terminal design in experiments one, and it is included here because the mobile terminal in experiment two needs to communicate always with the base station the transmit power and the signal quality.

3.4.4 Base station node design for experiment two

The base station for experiment two consists of the following models; base station processor, base station transmitter, and the base station receiver

3.4.5 Base station transmitter and receiver

Both the transmitter and the receiver were incorporated in this design to receive and transmit information to and fro the mobile station and they are standard opnet model, the modulation scheme employed was Gaussian modulation shift key (GMSK).

3.4.6 Base station processor for experiment two

The base station processor in experiment two is part of the author`s designs and it emulates the internal structure of base station, The base station processor here, does all the processing work required at the base station, it ensures that the algorithm (step wise algorithm) runs properly and the result of the algorithm, which is the new transmit power is communicated back to the mobile terminal. The Figure 3.9 shows the base station node design.

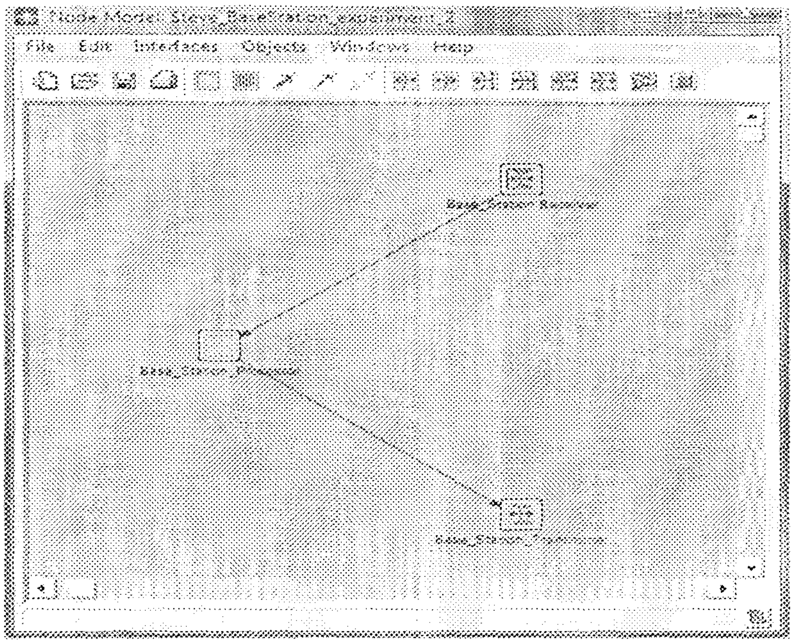

Figure 3.9 Node model design experiment two

3.4.7 BS Process design for experiment two

The process model for this module consists of three STDs linked by both conditional and unconditional transitions as shown in Figure 3.10 below.

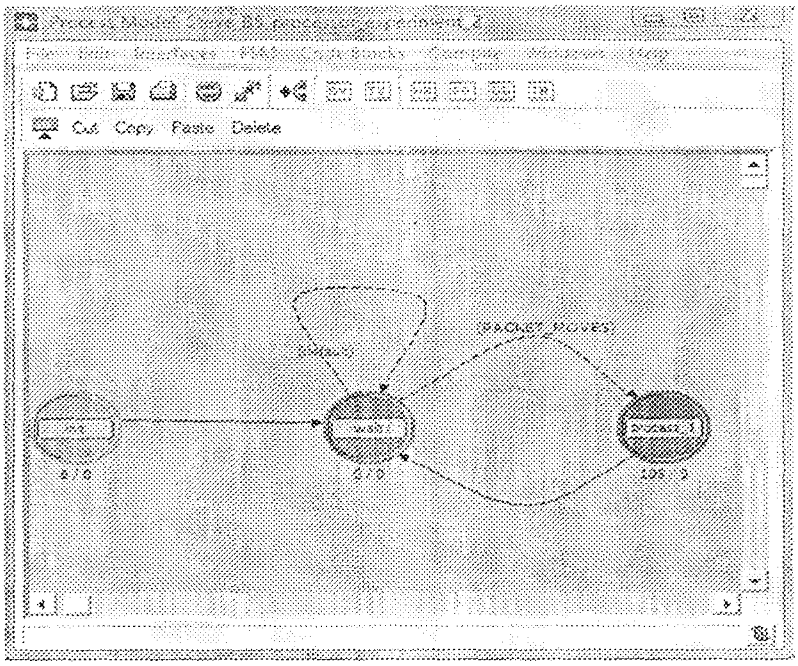

Figure 3.10 process design for experiment two

3.5 EXPERIMENT THREE.

3.5.1 Network domain design Experiment three

The network domain design for experiment three is the same as that in experiments one and two as already mentioned earlier with all parameters been the same. Reference can be made to Figures for network domains of experiments one and two respectively.

3.5.2 MT Node domain design for experiment three

Mobile terminal node domain in experiment three set-up also comprise of four models namely; packet generator, mobile terminal processor, mobile terminal transmitter and mobile terminal receiver as shown in the Figure 3.11

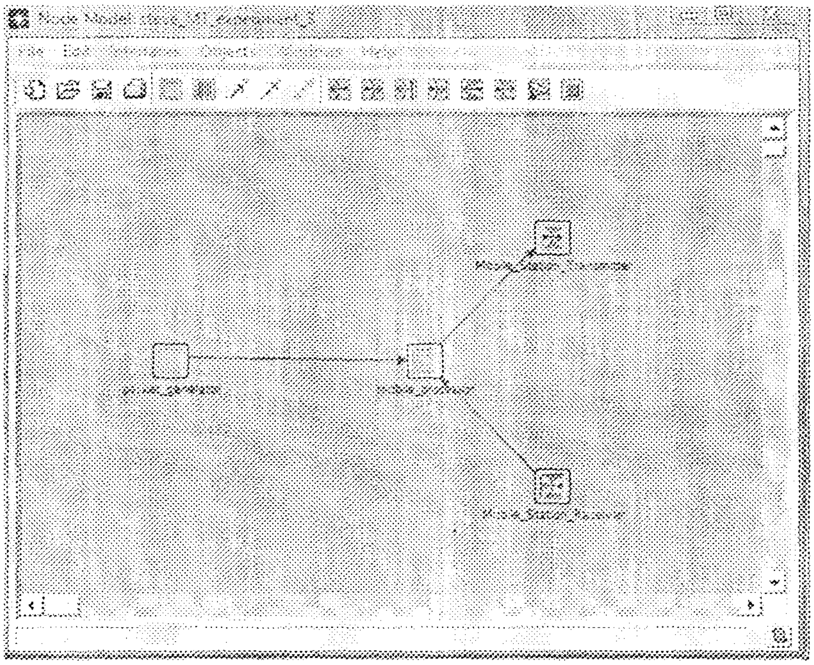

Figure 3.11 mobile terminal node design for experiment three.

3.5.3 MT process design experiment three

The mobile terminal process model for this module consists of the same number of STDs as in the design for experiment two. Which are linked by both conditional and unconditional transitions. Mobile terminal in both experiments have been designed to function in the same fashion.

3.5.4 BS node domain design experiment three

The base station node domain design for experiment three also consists of the following models; base station processor, base station transmitter, and the base station receiver as that in experiment two.

3.5.5 BS transmitter and receiver experiment three

The transmitter and the receiver were incorporated in this design to receive and transmit information back to the mobile station and both are standard opnet model, the modulation scheme employed was GMSK.

3.5.6 BS process module design experiment three.

The process model for this module consists of three STDs. It consists of an *init* state for the initialization and registration of statistical variable, a packet wait state and a processor. After initialization at the init state, there is an unconditional transition to the *packet wait* state which serves as a buffer for packets before they are transited to the processor. . Either of the transitions leaving the packet wait state are conditional transitions where conditions for transition are stated in the HEADER BLOCK provided in the process editor, however, the default ensures that only packets from the init state. transit conditionally to the processor. The dotted lines represent conditional transition while the unbroken lines represent unconditional transition.

As stated earlier it is at the process module that all algorithm, protocol, and designs are coded into the opnet moduler. It is in this module therefore that the proposed algorithm and all calculations are coded into the simulator.

3.6 Calculations

- Maximum power was set at 39Dbm as specified by GSM 900, GSM900 specify 5 classes of power.
- Maximum battery capacity is taken as 700mAH, a typical value for Nokia battery.
- One ampere-hour(1AH) is equal to a current of one ampere flowing for one hour
- So, if you have a two ampere-hour battery, then it has the capacity to flow a two-ampere current for one hour.
- A voltage of 3.7v, also typical of the model of the nokia battery.
- 700mAH x 3.7v = 2.59wH
- Approx. 3wH
- 3w x 60s =180ws =available battery power
- At this point packet arriving are captured
- *packet count* is incremented
- Available Battery Power= Maximum Capacity – Drain value.

3.7 Design

- The Dynamic Power Control Algorithm takes into consideration both RxQual (Recieved Quality) and RxLev (Received Level), which enable the MS and the BTS power to increase in case of low RxQual and low RxLev.
- If the received power or quality (RxLev or RxQual) increases or decreases from the set threshold, the power of MS or BTS decreases or increases respectively.
- If the (RxLev or RxQual) is optimum, there will not be any variation in output power.
- The instruction for the change in power for the regulation is given by

- $Pu = \alpha \quad (ssdes - rxlev_{filtered}\ ) + \beta \ (qdesDB - rxqualDB_{filtered}$ [a].
- Where α and β are the path loss respective quality compensation and $qdesDB$ and $rxqualDB_{filtered}$ are the $qdes$ and $rxqual$ mapped to C/I as in the Table 3.0.
- The power level down regulation order is given by
- $PL{=}INT(\text{-}Pu)/2$ [b].

where INT truncates the power level to a higher level value.

$BTS\,/MT\ out\ power = p_{max} - 2\ PL,$ Where p_{max} corresponds to full power.

The purpose of the outer loop (BER measurement update) in Table 3.1 is to serve the inner loop with dynamic qdes value that changes automatically. The measurement report should give the outer loop additional information about the current quality in the system.

Table 3.1 **Signal desired/received quality.**

Qdes[dtqu]	0	10	20	30	40	50	60	70
Rxqual	0	1	2	3	4	5	6	7
C/I[Db]	23	19	17	15	13	11	8	4

Table 3.2 **BER Measurement update table.**

BER(%)	< 0.2	0.21- 0.4	0.41- 0.8	0.81- 1.6	1.61- 3.2	0.321- 6.4	6.41- 12.8	>12.8
Rxqual	0	1	2	3	4	5	6	7
C/I[Db]	23	19	17	15	13	11	8	4

3.8 Flow chart

Figure 3.12 is a simple flow chart of the algorithm.

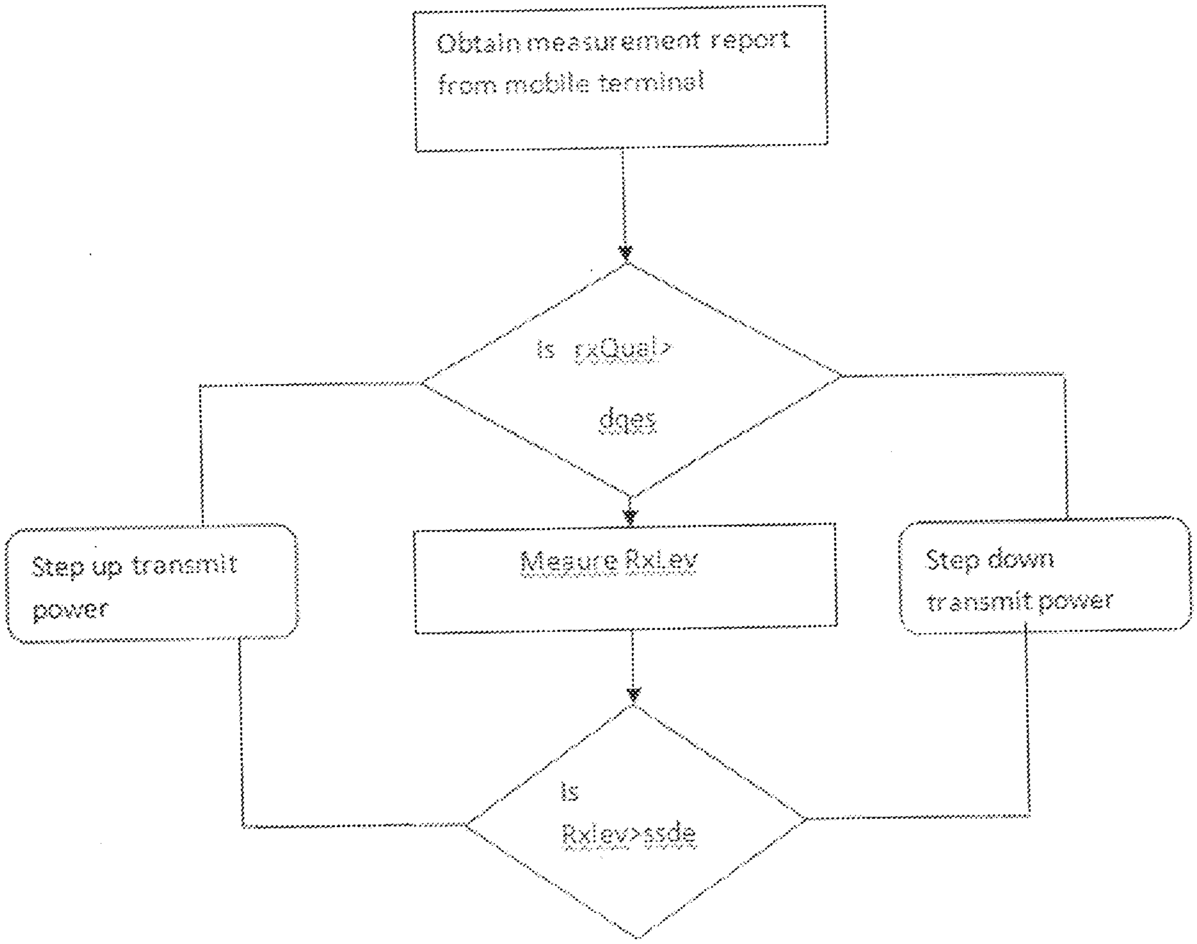

Figure 3.12 Flowchart of algorithm

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Experiment one

4.1.1 Result for experiment one (peak power transmission)

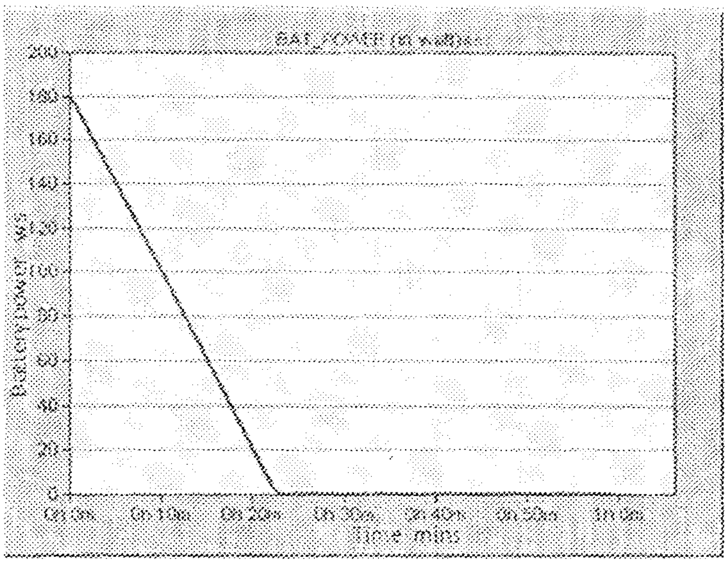

Figure 4.1 peak power (ws) transmission.

4.2 Experiment two

4.2.1 Result for experiment two: scenario I (good network condition)

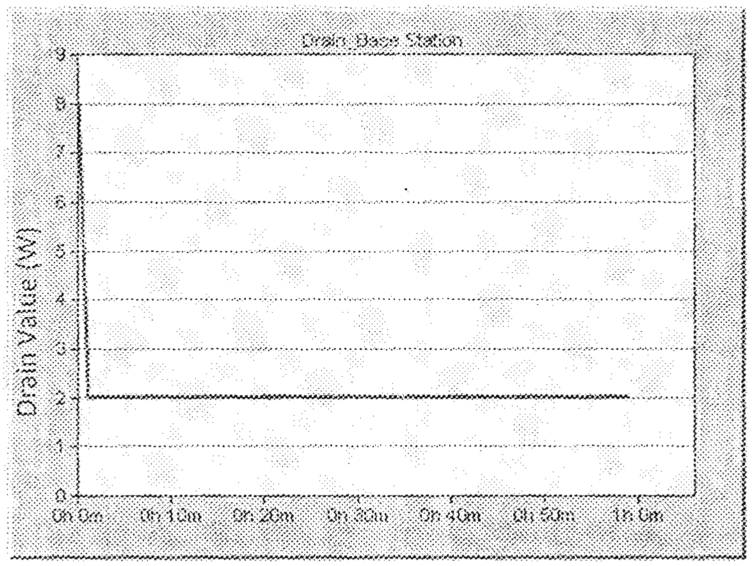

Figure 4.2 drain value (w) for scenario I experiment two

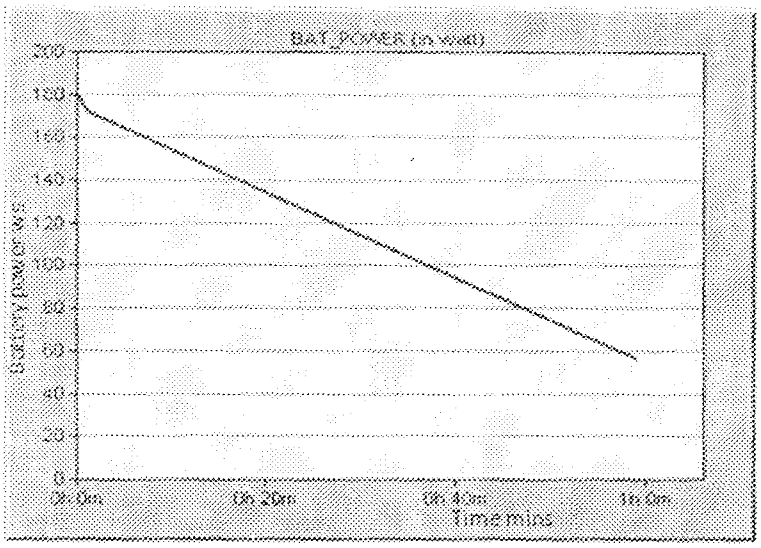

Figure 4.3 battery power (ws) scenario I experiment two.

4.2.2 Result for experiment two: scenario II (moderate network condition)

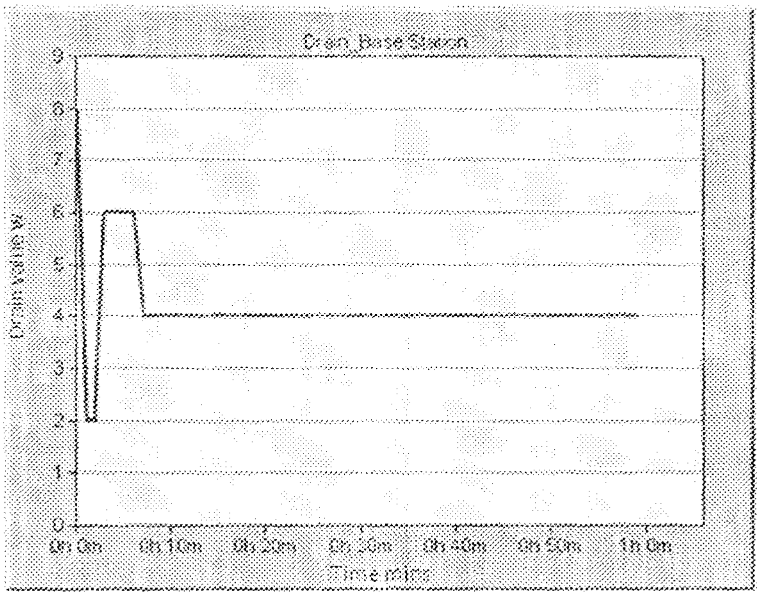

Figure 4.4 drain value (w) scenario II experiment two.

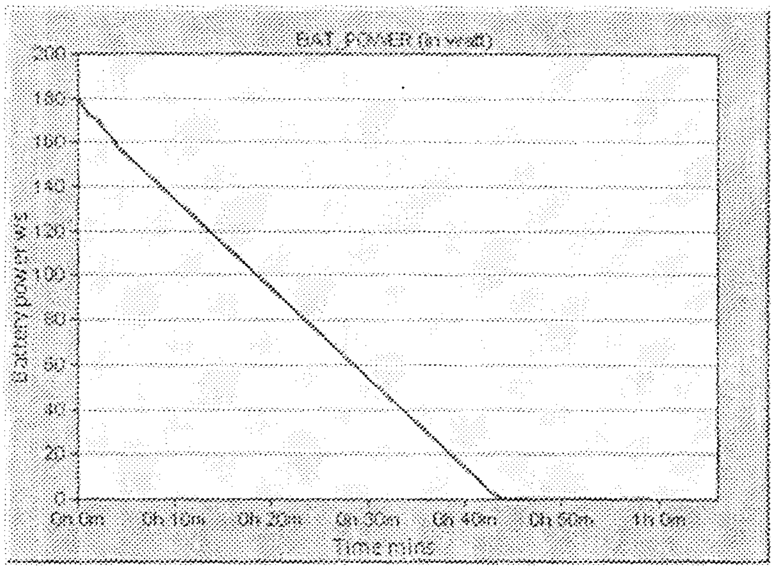

Figure 4.5 battery power (ws) scenario II experiment two.

4.2.3 Result for experiment two: scenario III (bad network condition)

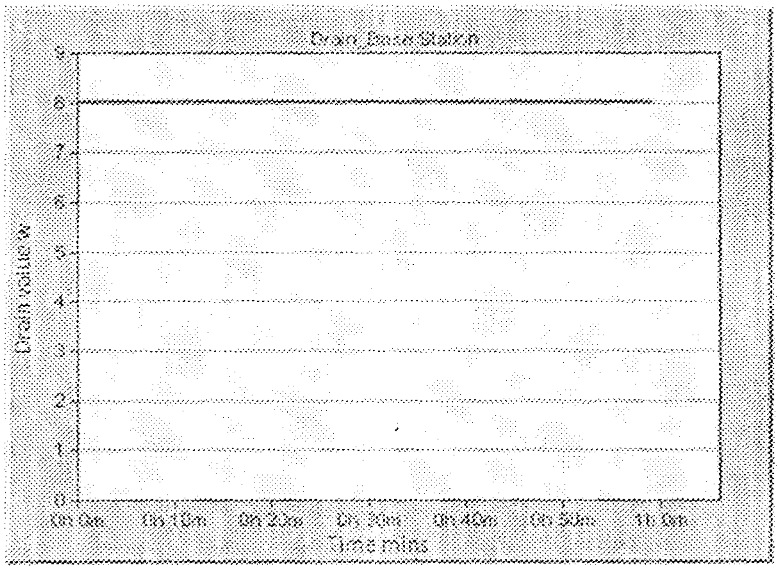

Figure 4.6 drain value(w) scenario III experiment two.

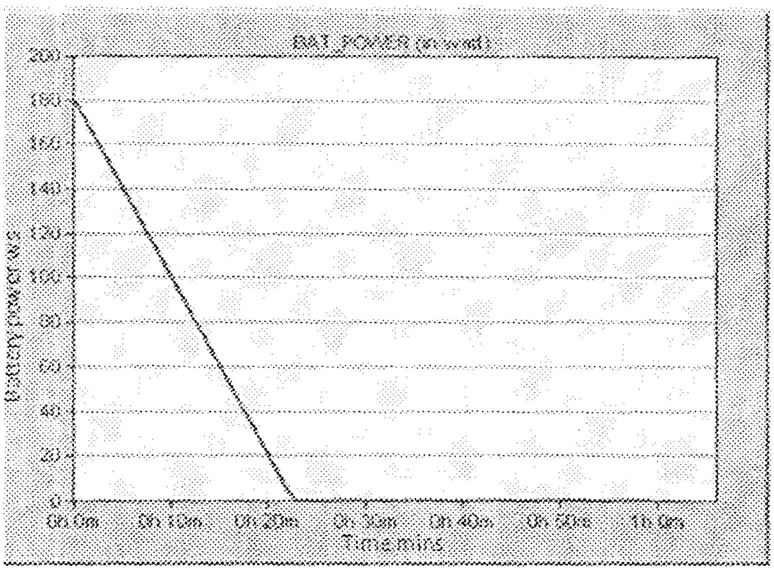

Figure 4.7 battery power (ws) scenario III experiment two.

4.3 Experiment three

4.3.1 Result for experiment three: scenario I (good network condition)

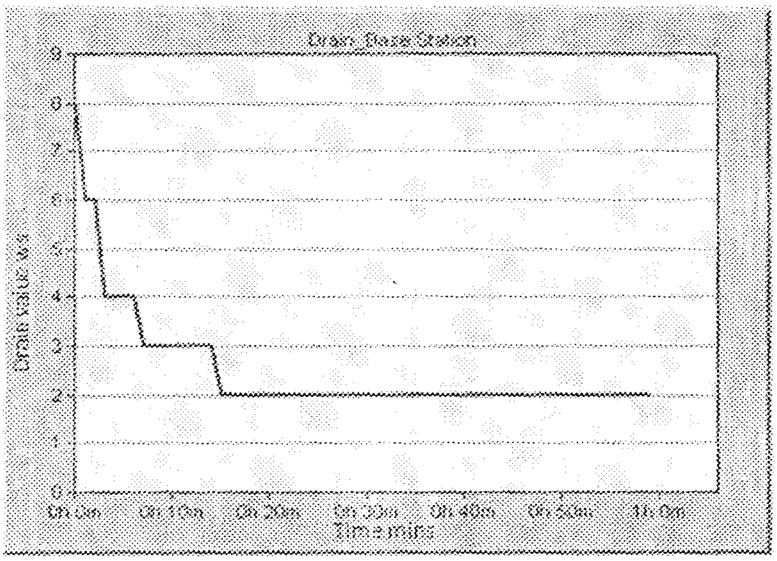

Figure 4.8 drain value (w) scenario I experiment three.

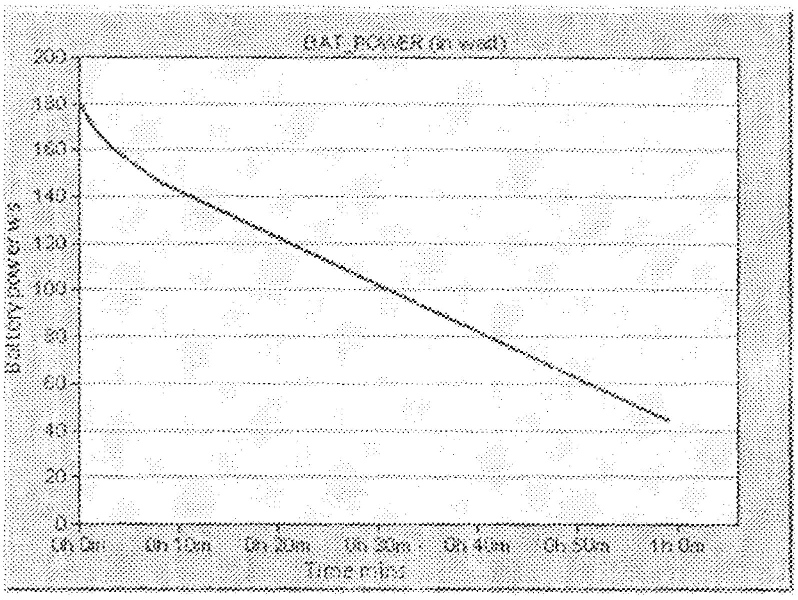

Figure 4.9 battery power (ws) scenario I experiment three.

4.3.2 Result for experiment three: scenario II (moderate network condition)

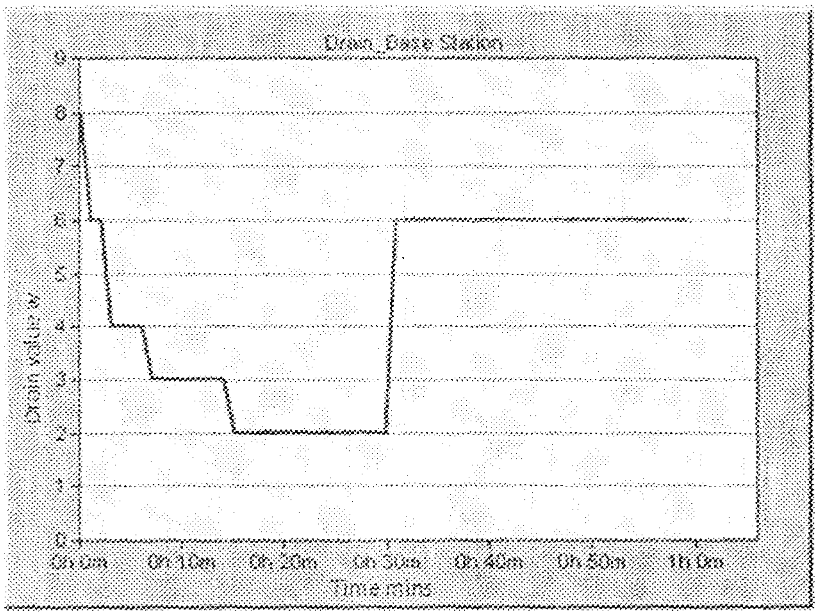

Figure 4.10 drain value (w) scenario II experiment three

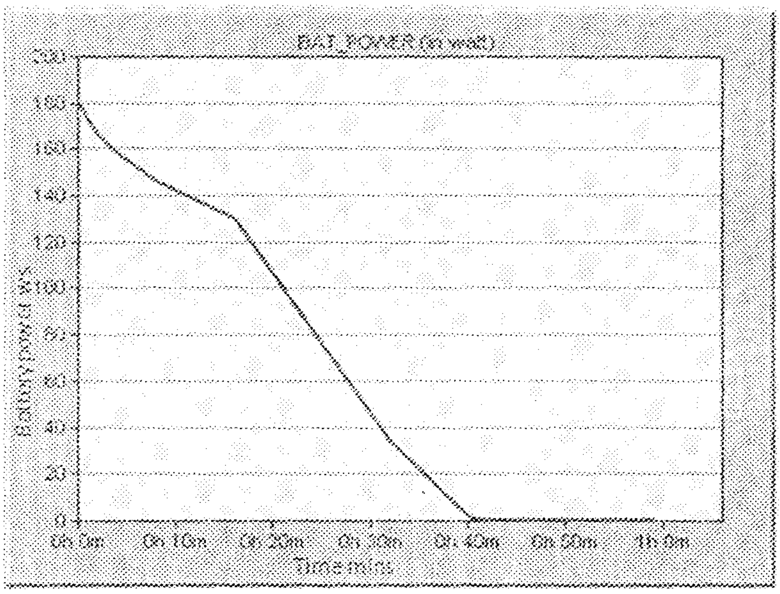

Figure 4.11 battery power (ws) scenario II experiment three.

4.3.3 Result for experiment three: scenario III (bad network condition)

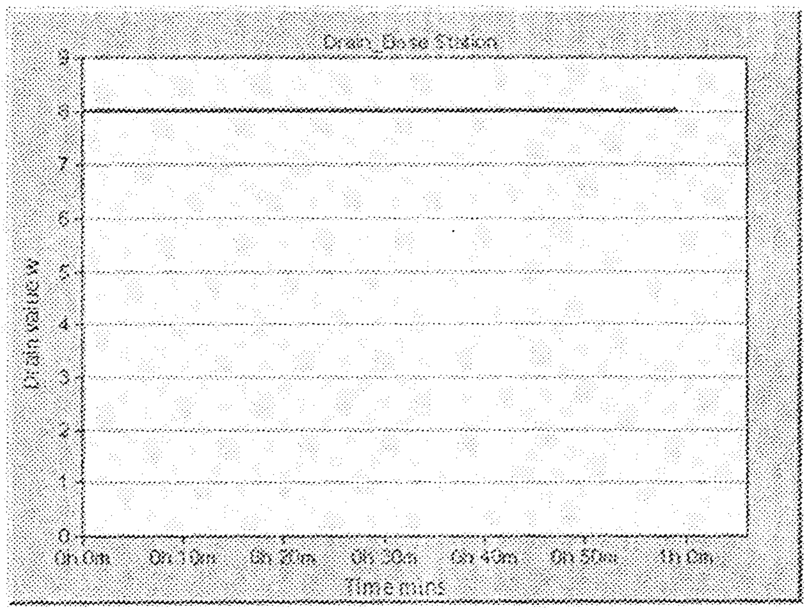

Figure 4.12 drain value (w) scenario III experiment three

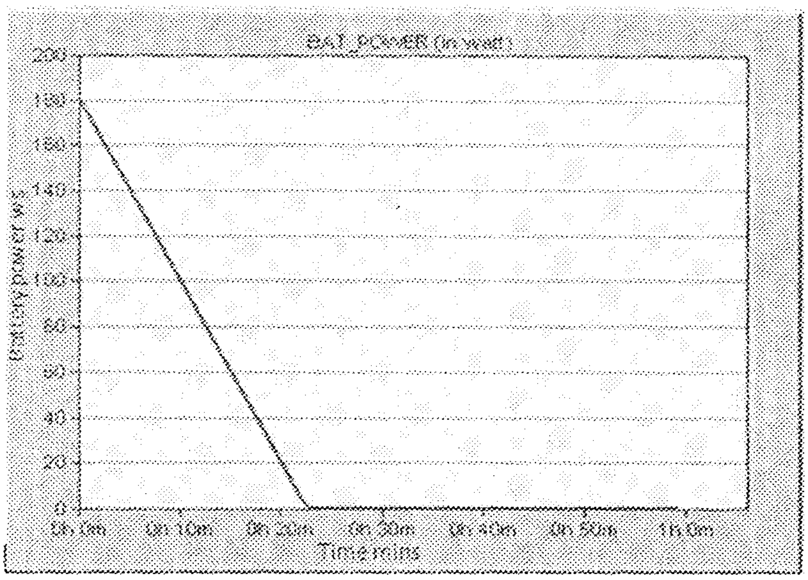

Figure 4.13 battery power (ws) scenario III experiment three.

4.4 Comparison of result from experiments two and three

4.4.1 Comparison of scenarios I results.

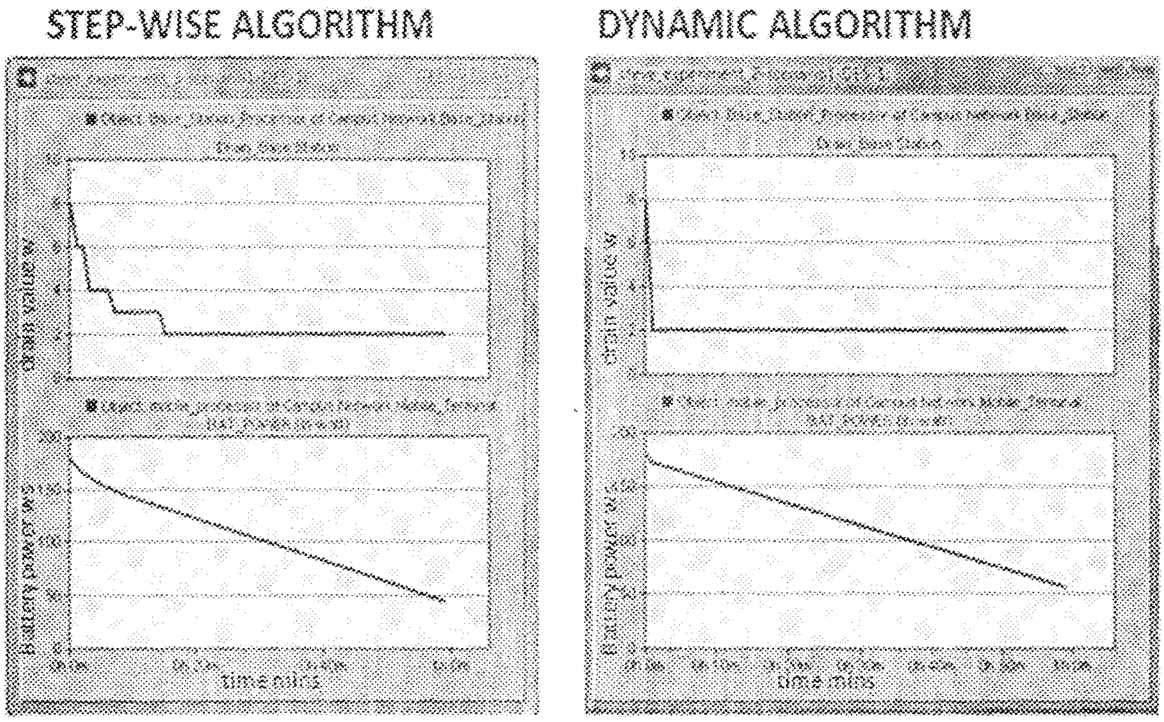

Figure 4.14 comparison of results: scenarios I.

4.4.2 Comparison of scenarios II results

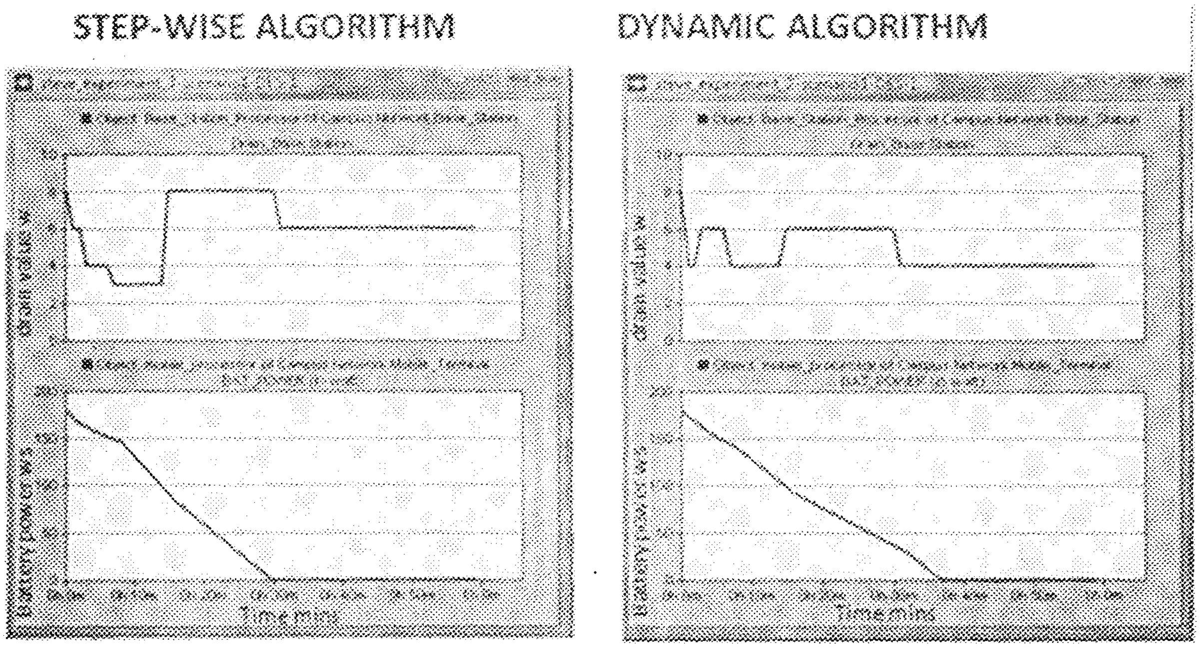

Figure 4.15 comparison of results: scenarios II.

4.4.3 Comparison of scenarios III results.

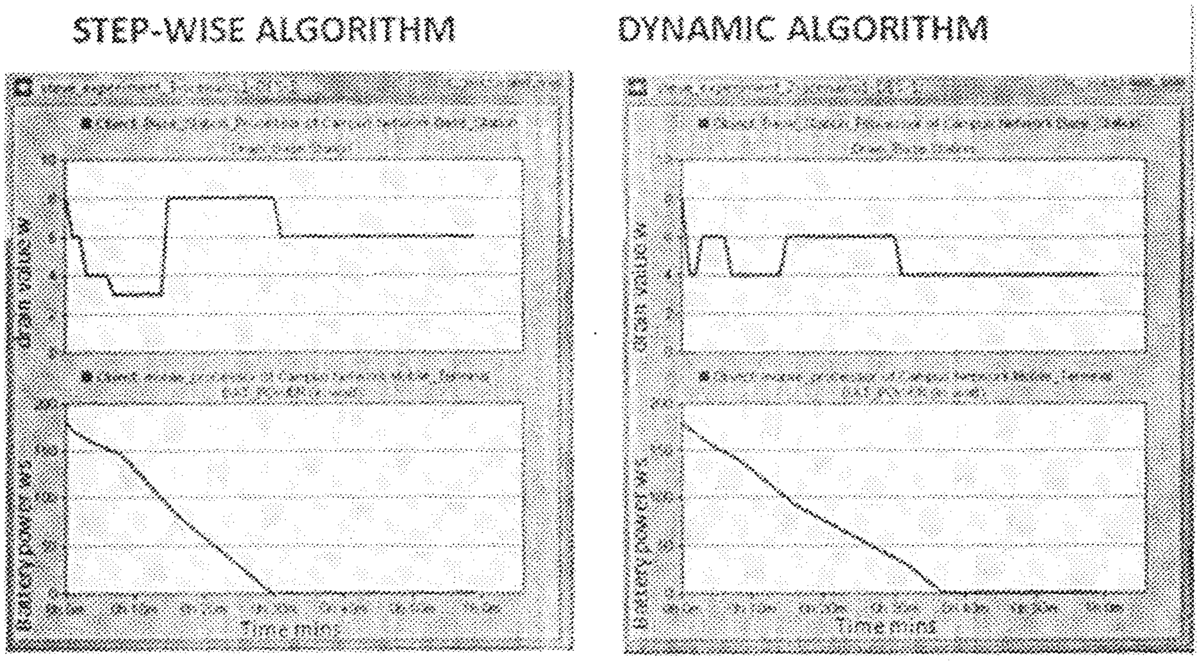

Figure 4.16 comparison of results: scenarios III.

4.5 Result Discussion

4.5.1 Experiment one

Figure 4.1 is the results of experiment one showing the graph of a mobile terminal transmitting at peak power. Recall that when a mobile terminal connects to a base station it starts transmitting at peak power, then its transmit power is step down by the algorithm in use by the base station. However in the case of experiment one no algorithm was used throughout, in other words the mobile terminal transmitted at peak power throughout the experiment.

Experiment one is used as a "control experiment". Results from experiment one allow us to see what happens at continuous peak power transmission. It also enables us to appreciate the need for the use for an algorithm and give answer to such question as "why need an algorithm?"

Available battery power at the start of the experiment was 180ws, the total duration of the experiment was 1 hour, which implies that the mobile terminal continuously transmit to the base station for 1 hour at peak power. Result from the graph indicates that the battery power of the mobile terminal was completely depleted after about 23 minutes of peak power transmission.

4.5.2 Experiment two: scenario I (good network condition)

In Figure 4.2 results of drain value (transmit power) of a mobile terminal transmitting to a base station over a good network condition is presented. The dynamic power control algorithm was in use. It could be seen that the mobile terminal initiated a transmission at 8w (39Db) to the base station, and the transmit power was immediately step down to 2w. This is because 8w was unnecessarily too high to maintain the good connection under the prevailing good network condition. Thereafter 2w of transmit power was maintained throughout the experiment. This was used throughout because at 2w of transmit power the mobile terminal hears the base station well.

Figure 4.3 shows the graph representing the resulting effect of the regulation process on the battery power for a mobile terminal transmitting to a base station in good network condition, with the dynamic power control algorithm in use. Available battery power at the start of transmission was 180w and after 1 hour of transmission, 122w of battery power was used up in transmission. Remaining 58w of battery power at the end of 1 hour.

4.5.3 Experiment two: scenario II (moderate network condition)

Figure 4.5 presents the graph of the mobile terminal transmitting to the base station at moderate network condition, with dynamic power control algorithm being used. According to the graph, transmission started at peak power of 8w (39Db) and was immediately stepped down to 2w. However transmit power was stepped up to 6w due rapidly changing network condition after a few minutes of transmission, and transmission continued at this value for about 5 minutes. Thereafter it was stepped down to 4w and transmission continued at 4w for the remaining part of the experiment.

Figure 4.5 shows the effect of the foregoing power changes on the battery of the mobile terminal, with the available power of 180ws getting completely depleted after about 44 minutes of transmission between the mobile terminal and the base station.

4.5.4 Experiment two; scenario III (bad network condition)

Scenario III in all experimental set up represents transmission in bad network condition, Figure 4.6 therefore shows the graph of the drain value (transmit power) of a mobile terminal transmitting to a base station in bad network condition for experiment two.

Dynamic power algorithm was used. Transmission started at peak power of 8w as usual, but unlike the two previous scenarios, transmission continued at 8w throughout the experiment. This is because of the very bad network condition. Algorithm did not step down power, because mobile terminal required maximum power to connect to the base station. A close look at the graph shows that it is the same as the graph of experiment one. Where Mobile terminal transmitted at peak power because no algorithm was used, however here algorithm is used, but algorithm did not step down power because mobile terminal required maximum power to connect to the base station. Therefore battery power got used up at 23 minutes after the start of experiment as shown in figure 4.7 as was the case in experiment one.

4.5.5 Experiment three: scenario I (good network condition)

Figure 4.8 shows the graph of the drain value (transmit power) of a mobile terminal transmitting to a base station under good network condition. Step wise algorithm is being used in this case. The graph shows that the mobile starts transmitting at peak power of 8w but gradually steps down transmit power to 2w after 15 minutes of transmission before stabilizing at 2w of transmit power throughout the experiment. This is because 8w was a high transmitting power to transmit at; therefore algorithm stepped down transmit power to 2w. This is the optimum power for mobile terminal to transmit to the base station at the prevailing good network condition. However the power regulation was done in steps of 2 because of the stepwise algorithm used.

Figure 4.9 showed that 136w of battery power was used in transmission with only 44w of battery power remaining after 1 hour of transmission between the mobile terminal and the base station.

4.5.6 Experiment three; scenario II (moderate network condition)

The results here as shown by Figure 4.10 present a gradual descent to 2w of transmit power from 8w of peak power transmission by a step of 2 as regulated by the stepwise algorithm, however due to changing network condition. Transmit power was stepped up to 6w, where it eventually stabilized and continued till the end of experiment.

Figure 4.11 showed the corresponding battery power used during the period of transmission. 180w of battery power was available at the start of transmission, and this was slowly being depleted after 20 minutes of transmission. Thereafter a sharp increase was noticed in battery consumption and eventually battery power was completely used up at 41 minutes of transmission.

4.5.7 Experiment three: scenario III (bad network condition)

Results for Scenario III experiment three is presented in Figure 4.12 and it shows the transmit power for a mobile terminal transmitting to a base station at peak power of 8w, which it maintained throughout the transmission because of bad network condition. The stepwise algorithm being operated at the base station did not send a power step down regulation message to the mobile terminal. This was because the network condition was very bad; therefore the mobile terminal needed the maximum power to transmit to the base station.

4.5.8 Comparison of results

(i) Scenarios I: dynamic and stepwise algorithms.

In the results of both the stepwise and the dynamic algorithms for scenarios I; represented in Figure 4.14 where the mobile terminal initiated a connection to the base station at peak power of 8w under good network condition. Both algorithms calculated transmit power of 2w to be optimum to maintain a good connection between the mobile terminal and the base station for the prevailing network condition. Whilst the dynamic algorithm stepped down power to 2w directly from 8w, stepwise algorithm stepped down from 8w to 2w in steps of 2.

The effect of both regulation processes can be seen on the battery power of the mobile terminal. While 100w of battery power was used in 25 minutes of transmission using the stepwise algorithm, the same amount of battery power was used 38 minutes when the-dynamic algorithm was used.

After 1 hour of transmission between the mobile terminal and the base station under good network condition, for stepwise algorithm, available battery power left was 40w. However for dynamic algorithm available battery power left was 60w

(ii) Scenarios II: dynamic and stepwise algorithms.

Figure 4.15 shows results for transmit power and available battery power for a mobile terminal transmitting to a base station at moderate network condition. The graph of stepwise algorithm showed that the mobile terminal initiated a connection as usual at peak power of 8w, then it dropped transmit power to 3w in steps of 2. Transmission continued at this power level for 5 minutes before transmit power was the stepped up to 8w due to changes in channel conditions. Power stabilized at 8w for 10 minutes before it was finally stepped down to 6w, which was optimum for the rest duration of transmission.

For the same network conditions and transmission duration, the dynamic algorithm stepped down transmit power from peak power of 8w directly to 4w, and then stepped it up to 6w. Transmission continued at 6w for 10 minutes, unlike in the stepwise algorithm where it was 8w. Finally transmit power was stepped down to 4w, and it continued at 4w till the end of transmission.

The resulting effect of the different regulation processes was seen on the graph of available battery power for the two different algorithms. For the stepwise algorithm the available battery power got completely depleted after 29 minutes of transmission, whilst for the dynamic power algorithm available battery power was completely depleted after 38 minutes of transmission.

(iii) Scenarios III: dynamic and stepwise algorithms.

Figure 4.16 presents a comparison between results obtained for the stepwise and dynamic algorithms. In scenarios III for both algorithms, the mobile terminal is transmitting to the base station in bad network conditions.

A close look at the graphs of results in Figure 4.16 shows that the results are the same for both algorithms. This was so because the network condition was extremely bad, the mobile terminal had to transmit at maximum capacity of 8w throughout the duration of transmission. This was to enable it maintain good connection to the base stations throughout the duration.

The effect on the available battery power was similar also because the same amount of power was drawn from the battery for transmission.

Therefore irrespective of the algorithm used, when network conditions are on the extreme the algorithm allows the mobile terminal to transmit at maximum capacity.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The need to make batteries of mobile devices last for longer periods of operations and standby times is no longer in doubt. However the task is overwhelming due to the fact that advancements in battery technologies have not been in tandem with advancements in other fields of electronics. Therefore the task of finding solution to this problem became a challenge to communications engineers. It was for this reasons that research works in the field of power management and power control began in the early 1990s. The author undertook a literature review of past research works in this field, and considered the different approaches different researchers have adopted at trying to finding a solution to the challenge, their major contributions, and the gap in knowledge.

Consequently, in trying to fill this gap "battery life energy conservation using dynamic power control algorithm in mobile terminals" is presented in this thesis:

1. Which uses BER in measurements reports obtained from signals received from the mobile terminal to measure signal quality to determine the network conditions.
2. The algorithm also used signal strength as one of the metrics in its power regulation process.
3. The algorithm was simple and effective; it reduced processor run-time
4. The algorithm increased operation time for mobile terminal by 40% compared to other algorithm as confirmed in the results.

5. The algorithm saved available battery power for the mobile terminal by 30% compared to other algorithm as indicated by the results.
6. The algorithm dynamically responded to different real life scenarios by generating different results for the three different simulated scenarios considered.

5.2 Recommendations and future works.

This research work is not exhaustive of the subject of battery life optimization, power control and power management as is any research work. The author therefore, welcomes further work on this research work and recommends this thesis to form part of the literature review of such works, to give insight into the subject and serve as a guide to those who wish to take a foray into the interesting subject of battery life optimization.

For those wishing to do more work in this aspect, they can look at multiple mobile devices in the network domain as the author has only considered one mobile terminal interacting with a base station. This however is not the case in real life scenario; they should look at the effect of transmission power and interference of other devices on the battery power of a mobile terminal.

They can also explore ways in which mobile devices can adopt cognitive radio to monitor, manage and optimize their power.

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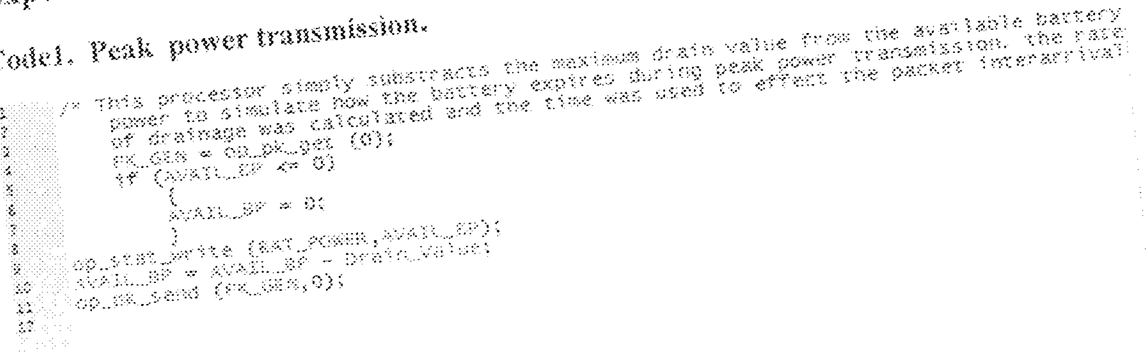
APPENDIX A

OPNET Source Codes

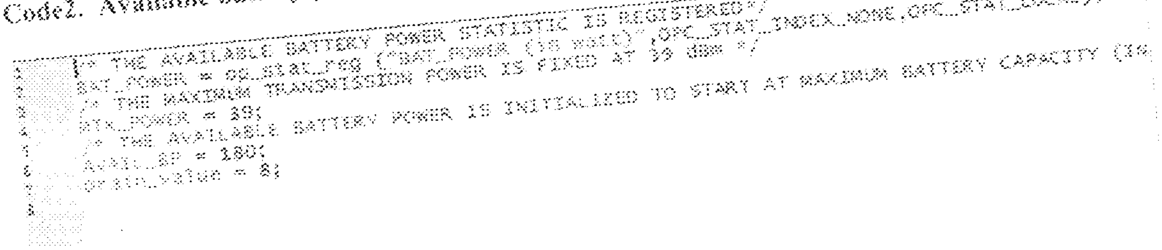
Experiment one

Code1. Peak power transmission.



```
/* This processor simply substracts the maximum drain value from the available battery
   power to simulate how the battery expires during peak power transmission. the rate
   of drainage was calculated and the time was used to effect the packet interarrival
   PK_GEN = op_pk_get (0);
   if (AVAIL_BP <= 0)
       {
       AVAIL_BP = 0;
       }
op_stat_write (BAT_POWER,AVAIL_BP);
AVAIL_BP = AVAIL_BP - Drain_Value;
op_pk_send (PK_GEN,0);
```

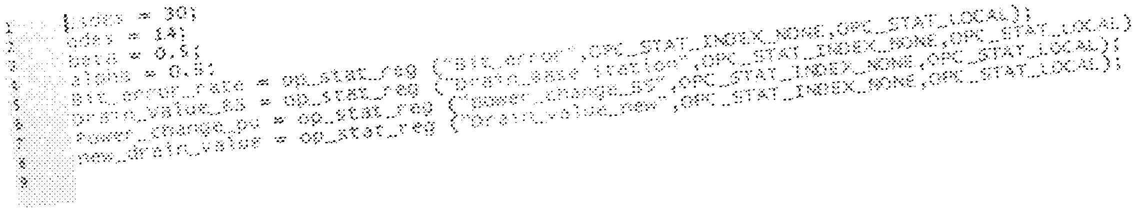
Code2. Available battery power.



```
/* THE AVAILABLE BATTERY POWER STATISTIC IS REGISTERED*/
BAT_POWER = op_stat_reg ("BAT_POWER (18 watt)",OPC_STAT_INDEX_NONE,OPC_STAT_LOCAL);
/* THE MAXIMUM TRANSMISSION POWER IS FIXED AT 39 dBm */
MTX_POWER = 39;
/* THE AVAILABLE BATTERY POWER IS INITIALIZED TO START AT MAXIMUM BATTERY CAPACITY (18
AVAIL_BP = 180;
Drain_value = 8;
```

Experiment two

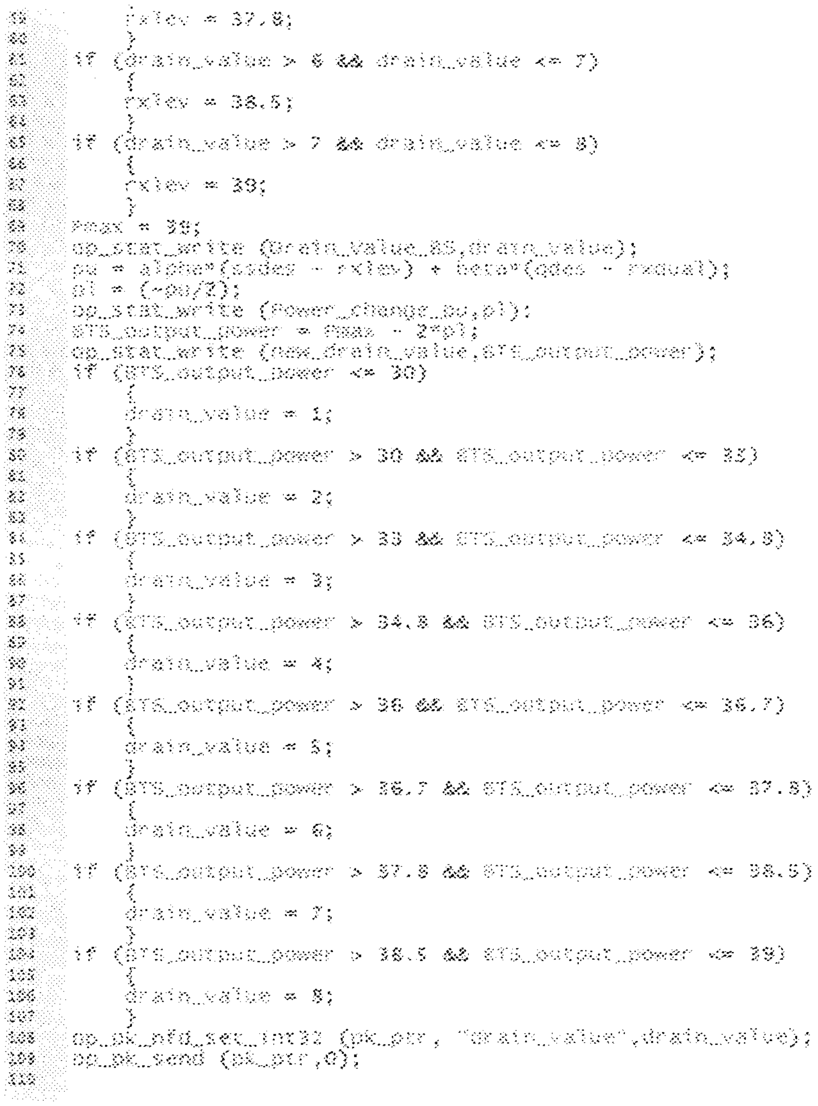
Code3. Initializing parameters



```
Lides = 30;
odes = 14;
beta = 0.5;
alpha = 0.5;
Bit_error_rate = op_stat_reg ("Bit_error",OPC_STAT_INDEX_NONE,OPC_STAT_LOCAL)}
Drain_value_BS = op_stat_reg ("Drain_Base station",OPC_STAT_INDEX_NONE,OPC_STAT_LOCAL)
Power_change_pu = op_stat_reg ("power_change_BS",OPC_STAT_INDEX_NONE,OPC_STAT_LOCAL);
new_drain_value = op_stat_reg ("Drain_value_new",OPC_STAT_INDEX_NONE,OPC_STAT_LOCAL);
```

Code4. Stepwise algorithm

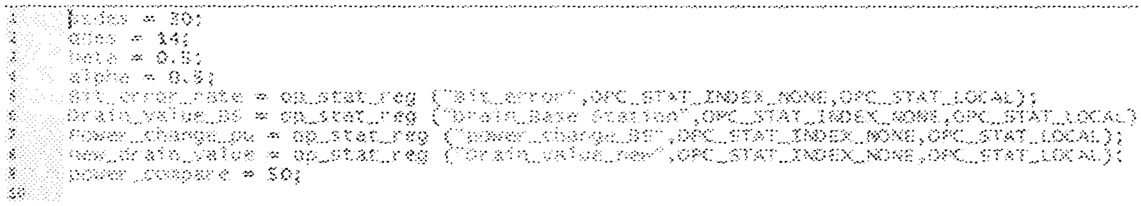
```
pk_ptr = op_pk_get (0);
op_pk_nfd_get_int32 (pk_ptr,"ber",&BER);
if (BER >= 0 && BER <= 2)
    {
    rxqual = 23;
    }
if (BER > 2 && BER <= 4)
    {
    rxqual = 19;
    }
if (BER > 4 && BER <= 8)
    {
    rxqual = 17;
    }
if (BER > 8 && BER <= 16)
    {
    rxqual = 15;
    }
if (BER > 16 && BER <= 32)
    {
    rxqual = 13;
    }
if (BER > 32 && BER <= 64)
    {
    rxqual = 11;
    }
if (BER > 64 && BER <= 128)
    {
    rxqual = 8;
    }
if (BER > 128)
    {
    rxqual = 4;
    }
op_stat_write (bit_error_rate,BER);
op_pk_nfd_get_int32 (pk_ptr,"drain_value",&drain_value);
if (drain_value >= 0 && drain_value <= 1)
    {
    rxlev = 30;
    }
if (drain_value > 1 && drain_value <= 2)
    {
    rxlev = 33;
    }
if (drain_value > 2 && drain_value <= 3)
    {
    rxlev = 34.8;
    }
if (drain_value > 3 && drain_value <= 4)
    {
    rxlev = 36;
    }
if (drain_value > 4 && drain_value <= 5)
    {
    rxlev = 36.7;
    }
if (drain_value > 5 && drain_value <= 6)
    {
```



```
    rxlev = 37.8;
    }
if (drain_value > 6 && drain_value <= 7)
    {
    rxlev = 38.5;
    }
if (drain_value > 7 && drain_value <= 8)
    {
    rxlev = 39;
    }
Pmax = 39;
op_stat_write (Drain_Value_BS,drain_value);
pu = alpha*(ssdes - rxlev) + beta*(qdes - rxqual);
pl = (-pu/2);
op_stat_write (Power_change_pu,pl);
BTS_output_power = Pmax - 2*pl;
op_stat_write (new_drain_value,BTS_output_power);
if (BTS_output_power <= 30)
    {
    drain_value = 1;
    }
if (BTS_output_power > 30 && BTS_output_power <= 33)
    {
    drain_value = 2;
    }
if (BTS_output_power > 33 && BTS_output_power <= 34.8)
    {
    drain_value = 3;
    }
if (BTS_output_power > 34.8 && BTS_output_power <= 36)
    {
    drain_value = 4;
    }
if (BTS_output_power > 36 && BTS_output_power <= 36.7)
    {
    drain_value = 5;
    }
if (BTS_output_power > 36.7 && BTS_output_power <= 37.8)
    {
    drain_value = 6;
    }
if (BTS_output_power > 37.8 && BTS_output_power <= 38.5)
    {
    drain_value = 7;
    }
if (BTS_output_power > 38.5 && BTS_output_power <= 39)
    {
    drain_value = 8;
    }
op_pk_nfd_set_int32 (pk_ptr, "drain_value",drain_value);
op_pk_send (pk_ptr,0);
```

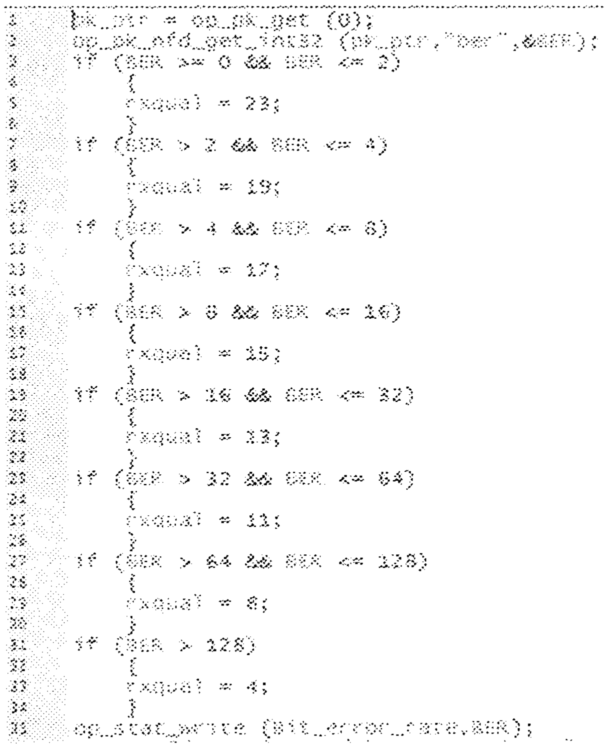
Experiment three

Code5. Initializing parameter



```
nodes = 30;
ones = 14;
beta = 0.5;
alpha = 0.5;
Bit_error_rate = op_stat_reg ("Bit_error",OPC_STAT_INDEX_NONE,OPC_STAT_LOCAL);
Drain_value_BS = op_stat_reg ("Drain_Base Station",OPC_STAT_INDEX_NONE,OPC_STAT_LOCAL)
Power_change_pu = op_stat_reg ("power_change_BS",OPC_STAT_INDEX_NONE,OPC_STAT_LOCAL);
new_drain_value = op_stat_reg ("Drain_value_new",OPC_STAT_INDEX_NONE,OPC_STAT_LOCAL);
power_compare = 50;
```

Code6. Dynamic algorithm



```
pk_ptr = op_pk_get (0);
op_pk_nfd_get_int32 (pk_ptr,"ber",&BER);
if (BER >= 0 && BER <= 2)
     {
     rxqual = 23;
     }
if (BER > 2 && BER <= 4)
     {
     rxqual = 19;
     }
if (BER > 4 && BER <= 8)
     {
     rxqual = 17;
     }
if (BER > 8 && BER <= 16)
     {
     rxqual = 15;
     }
if (BER > 16 && BER <= 32)
     {
     rxqual = 13;
     }
if (BER > 32 && BER <= 64)
     {
     rxqual = 11;
     }
if (BER > 64 && BER <= 128)
     {
     rxqual = 8;
     }
if (BER > 128)
     {
     rxqual = 4;
     }
op_stat_write (Bit_error_rate,BER);
```

```
op_stat_write (Bit_error_rate,BER);
op_pk_nfd_get_int32 (pk_ptr,"drain_value",&drain_value);
if (drain_value >= 0 && drain_value <= 1)
        {
        rxlev = 30;
        }
if (drain_value > 1 && drain_value <= 2)
        {
        rxlev = 33;
        }
if (drain_value > 2 && drain_value <= 3)
        {
        rxlev = 34.8;
        }
if (drain_value > 3 && drain_value <= 4)
        {
        rxlev = 36;
        }
if (drain_value > 4 && drain_value <= 5)
        {
        rxlev = 36.7;
        }
if (drain_value > 5 && drain_value <= 6)
        {
        rxlev = 37.8;
        }
if (drain_value > 6 && drain_value <= 7)
        {
        rxlev = 38.5;
        }
if (drain_value > 7 && drain_value <= 8)
        {
        rxlev = 39;
        }
op_stat_write (Drain_Value_BS,drain_value);
Pmax = 39;
if (rxlev <= power_compare)
        {
pu = alpha*(ssdes - rxlev) + beta*(qdes - rxqual);
pl = (-pu/2);
op_stat_write (Power_change_pu,pl);
BTS_output_power = Pmax - 2*pl;
power_compare = BTS_output_power;
        }
if (rxlev > power_compare)
        {
        BTS_output_power = rxlev - 2;
        }
op_stat_write (new_drain_value,rxlev);

if (BTS_output_power <= 30)
        {
        drain_value = 1;
        }
if (BTS_output_power > 30 && BTS_output_power <= 33)
        {
        drain_value = 2;
        }
```

```
        drain_value = 2;
        }
if (BTS_output_power > 33 && BTS_output_power <= 34.8)
        {
        drain_value = 3;
        }
if (BTS_output_power > 34.8 && BTS_output_power <= 36)
        {
        drain_value = 4;
        }
if (BTS_output_power > 36 && BTS_output_power <= 36.7)
        {
        drain_value = 5;
        }
if (BTS_output_power > 36.7 && BTS_output_power <= 37.8)
        {
        drain_value = 6;
        }
if (BTS_output_power > 37.8 && BTS_output_power <= 38.5)
        {
        drain_value = 7;
        }
if (BTS_output_power > 38.5 && BTS_output_power <= 39)
        {
        drain_value = 8;
        }
op_pk_nfd_set_int32 (pk_ptr, "drain_value",drain_value);
op_pk_send (pk_ptr,0);
```

```
        drain_value = 2;
        }
if (BTS_output_power > 33 && BTS_output_power <= 34.8)
        {
        drain_value = 3;
        }
if (BTS_output_power > 34.8 && BTS_output_power <= 36)
        {
        drain_value = 4;
        }
if (BTS_output_power > 36 && BTS_output_power <= 36.7)
        {
        drain_value = 5;
        }
if (BTS_output_power > 36.7 && BTS_output_power <= 37.8)
        {
        drain_value = 6;
        }
if (BTS_output_power > 37.8 && BTS_output_power <= 38.5)
        {
        drain_value = 7;
        }
if (BTS_output_power > 38.5 && BTS_output_power <= 39)
        {
        drain_value = 8;
        }
op_pk_nfd_set_int32 (pk_ptr, "drain_value",drain_value);
op_pk_send (pk_ptr,0);
```