Master's Thesis
Electrical Engineering
September 2012

Literature review on Energy Efficiency of Base Stations and Improving Energy Efficiency of a network through Cognitive Radio

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This thesis is submitted to the School of Computing at Blekinge Institute of Technology in partial fulfillment of the requirements for the degree of Master of Science in Electrical Engineering. The thesis is equivalent to 20 weeks of full time studies

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ABSTRACT

Context: The usage of cellular devices has been advanced in recent years and expected to increase rapidly in the coming years. Thanks to rapid development of technologies which is making us comfortable in the field of communications. The rapid development in technology is causing many serious hazards to the environment and also the mobile operators are facing problems with increasing energy costs and regulatory pressures to reduce carbon footprint to operate Green networks.

Objectives: This research provides a study on the problems pertaining to energy efficiency and remedies to overcome issues in decreasing energy efficiency of networks, this research also concentrates on various approaches for energy efficiency in base stations, the goal is to identify the best technologies that best suits the base station platform in terms of energy efficiency.

Methods: Two different methods are carried out throughout our research

- Literature Review

  In this literature review problems pertaining to energy efficiency of base stations are studied and reported, there by different technologies which helps to increase energy efficiency of base stations are analysed and best technologies are reported.

- Experimentation

  This section describes the concept of cognitive radio. It helps in energy efficiency in a cognitive network through analysis of two routing protocols AODV and OLSR using NS2 simulator.

Results:

- From the literature review we look at the energy consumptions issues of base stations (RQ1).
- For RQ2, the remedies to reduce energy consumption are studied and the best suitable technologies for energy efficiency are suggested.
- For answering RQ3, experimentation is carried out concentrating on achieving energy efficiency through cognitive radio network.

Conclusions: Thus, Problems pertaining to energy efficiency of base stations are studied, and best technologies to reduce energy consumption of base stations are reported. Comparison of two routing protocols OLSR and AODV under cognitive radio is also studied proposing the best routing protocol.

Keywords: Base stations, Cognitive radio, Energy efficiency, Green networks, AODV and OLSR.

ACKNOWLEDGEMENT

We would like to express our sincere gratitude to our supervisor Prof. Adrian Popescu, who gave us the opportunity and courage to complete this work; it is a matter of great privilege to carry out our thesis under his supervision. He always inspired and guided us in the right direction throughout the way. We also thank him for sharing his ideas in completing this work.

We would like to extend our gratitude to the examiner Dr. Patrik Arlos for supporting us.

We also thank all the members of the Blekinge Institute of Technology for providing us an opportunity to have quality education and research exposure in the field of Green Networking.

Last but not least, we would like to thank our Parents, families and friends who helped us with their valuable suggestions and encouraging us at every moment. Their motivation helped us to overcome all the problems we encountered throughout the study.

Regards,
Shashank Reddy Nalapatla
Sreedhar Reddy Mamidala

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LIST OF ABBREVATIONS

ICT	Information and Communication Technology
PC	Personal Computer
NS2	Network Simulator 2
LR	Literature Review
IT	Information Technology
EU	European Union
ECR	Energy Consumption Ratio
TEER	Telecommunications Energy Efficiency Ratio
MIMO	Multiple Input Multiple Output
SON	Self Organizing and Networks
LTE	Long Term Evolution
OFDM	Orthogonal Frequency Division Multiplexing
BER	Bit Error Rate
SNR	Signal to Noise Ratio
BS	Base Station
UE	User Equipment
SCF	Store and Carry information received before Forwarding
RF	Radio Frequency
PAR	Peak-to-Average Power ratio
UMTS	Universal Mobile Telecommunication Systems
WiMAX	Worldwide Interoperability for Microwave Access
IBO and OBO	Input and Output Back-off regions
SPPP	Homogeneous Spatial Poisson Point Process
MS	Mobile Stations
ET	Envelope Tracking
WCDMA	Wideband Code Division Multiple Access
PA	Power Amplifier
BBU	Base Band Unit
DSP	Digital signal processors
FPGAs	Field Programmable Gate Arrays
ASICS	Application Specific Integrated Circuits
DRX	Discontinuous Reception
DTX	Discontinuous Transmission
RBS	Radio Base Stations
OPEX	Operational Expenditure
MT	Mobile Terminals
UL	Uplink
GS	Green Spots
GSM	Global System for Mobile Communications
SDR	Software Defined Radio
CRN	Cognitive Radio Network
CR	Cognitive Radio
SPEAR	SPEctrum-Aware Routing
OSPF	Open Shortest Path First

SORP	Spectrum aware On demand routing protocol
AODV	Ad-hoc On Demand Distance vector
OLSR	Optimized Link State Routing
MAC	Medium Access Control
SPR	Shortest Path Routing
NAM	Network Animator
CBR	Constant bit rate

1 INTRODUCTION

1.1 Overview

This section gives detailed information on “Energy consumption and reduction issues” and explains why this has got much importance to study not just because of operational costs and financial reasons but also environmental reasons. Energy consumption of cellular networks is a growing concern for all cellular operators. Across this development, wireless communications has proven its necessity. The exponential rise in users and data demand is not only the reason for the crises but also the energy cost may rise three fold over next seven years [69]. With the introduction of iPhone and other software driven smart phones, the Internet is now available from mobile platform, which will place even greater demand for broadband. To everyones notice every year 120,000 new basestations are being deployed serving 400 million new mobile subscribers around the world[10]. We are aware that information and communication technology infrastructure accounts for about 3%-4% of the world wide energy [app 1.5 -2% by wireless]. Every telecom industry looks for minimal usage of power and deliver energy efficient results, with less effect on environment. This is what we call as “Green Communication or Green networking”. To overcome the above hurdles and to attain green communications the cognitive radio technology can be studied and implemented, where Cognitive radio can be defined as a system which is aware of its surroundings and able to intelligently adapt as operating parameteres to

a. Improve spectrum efficiency.
b. More reliable communication.
c. Afford new paradigm for green communication.

Routing challenges in cognitive radio [75] is almost similar to that of traditional multi-channel multi hop networks, the additional challenge of having to deal with simultaneous transmissions of PU’s which dynamically change network topology. The major challenges are

- In CRN’s the communication frequencies affect connectivity of network, where distance between nodes is the only parameter that effects.
- Channel availability in CRN’s varying with time according to PU’s activity at its position.

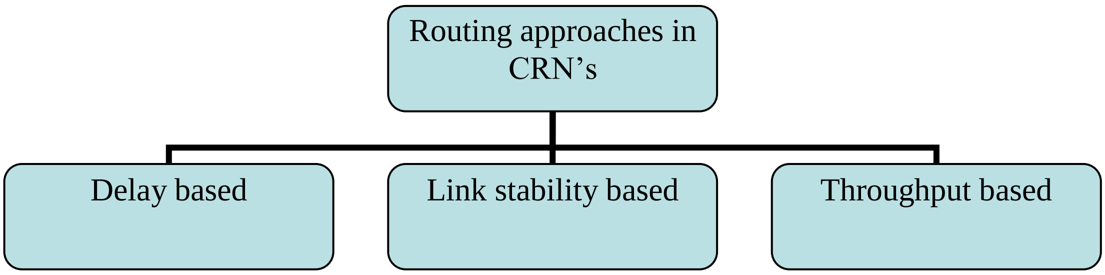


Figure 1-1: Routing Classification of CRN’s

Delay based routing deals with the routing approaches that measure the quality of routing in terms of delay, while link based in CRAHN’s (Cognitive Radio Ad Hoc Network) deals with the connectivity that has to be changed because of Secondary Users experience spectrum heterogeneity. For two nodes to be in connectivity, the nodes should be in same radio visibility and have at least one available channel and Throughput based can be defined as the average rate where successful packet delivery per second.

Need for Green Communication:

ICT usage has grown at a staggering rate worldwide with an estimated 6 billion susbscriptions in 2010 [12]. The developing regions are increasing their infrastructure and mobile subscriptions by a factor of ten. From the year 2000 to 2010 the mobile subscriptions in developing regions is about 200%, where as in developing areas it is 1300% [13]. This growth obviously shows an effect on carbon usage and energy costs due to ineffcient energy resources. A low power urban cell cite requires 3kw of power and generates 11 tons of carbon [71].

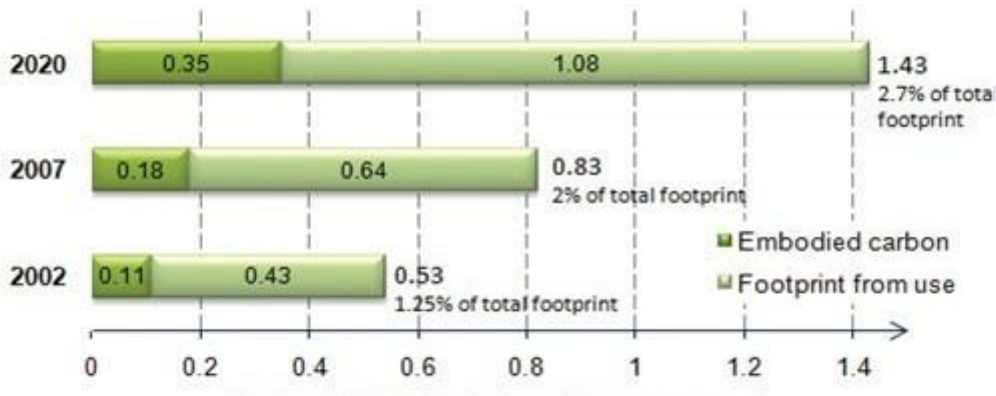


Figure 1-2: Estimated CO2 Emissions [Gtons per year] [5]

Figure shows the Estimate of the global carbon footprint of ICT (including PCs, Telco’s networks and devices, printers and datacenters). Source: Smart 2020 report by GeSI [14].

1.2 Aims and Objectives

1.2.1 Aim

- The aim of this research is to survey existing and emerging technologies that can be used in energy saving, due to the increased environmental pollution that has resulted from the rapid increase of the number of base stations.

1.2.2 Objectives

- To map the various approaches for energy efficiency in base stations.
- To identify the best technology that suits the base station platform in terms of energy efficiency and power consumption.
- To study energy efficient protocols that could be achieved through Cognitive Radio.

1.3 Research Questions:

1. What are the problems associated with energy efficiency of Base stations?
2. What are the recently emerged technologies to study the energy efficiency in Green Networks?
3. How energy efficiency in a network can be achieved through cognitive radio through study of routing protocols?

1.4 Research Methodology:

The first approach will be to develop a literature review of relevant materials. Literature review basically helps to build on what others have done [8]. Use of keywords in generating information from peer referenced articles and journals will be applied. Since information gathered will be wide, the literature is going to be classified by assessing relationship between features. This classification is important in order to ensure familiarity with key concepts and methods that other researches use in the field [9].

Figure 1-3: Research Methodology

The second approach will focus on technologies which help in energy efficiency of base stations that will be selected through literature study shall be examined and then reported. And in the third approach a simulation experiment is conducted where simulations shall be done on Ad Hoc routing protocols with NS2 simulator [73] to evaluate energy efficiency in cognitive radio networks by adding new features to NS2, like installing CRCN patch and improving it.

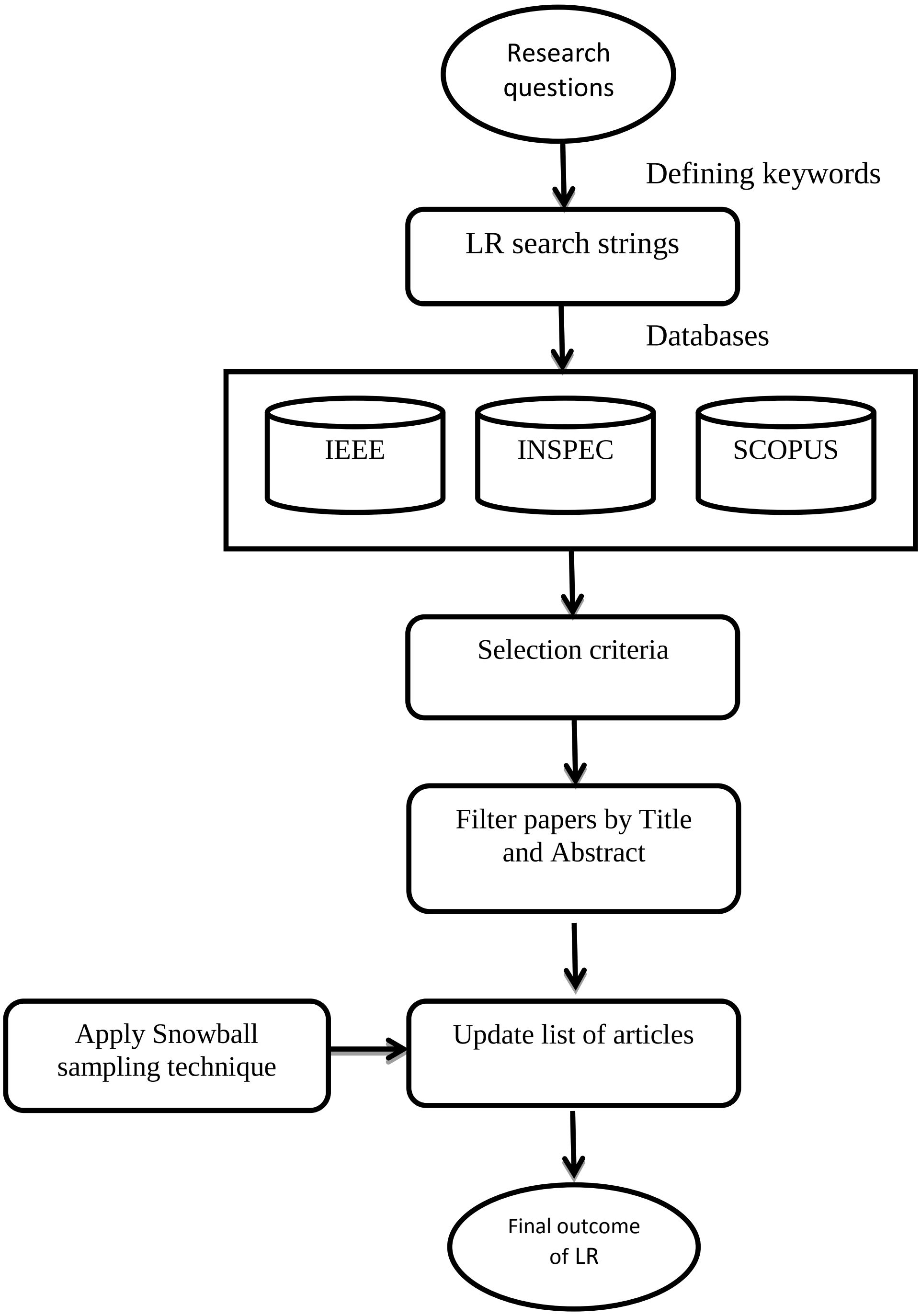


Figure 1-4: Structure of Literature Review

Literature review is done considering different sources of information such as IEEE Xplore, Engineering Village (Inspec) and Scopus and the university library at BTH.

Defining Keywords & Search String:

The below given keywords are defined for building a string, which helps to find the research articles from different databases.
"Base stations or Radio Base stations, Energy Efficiency or Energy Consumption, Green networks"

The search string is formulated by using these keywords. The below table defines the search string by searching different related articles from different databases for research papers.

Table 1-1: Search String for Literature Review

((((((((cellular networks) WN ALL) AND ((energy efficiency OR energy consumption OR power consumption) WN ALL)) AND ((base stations OR radio base stations) WN ALL))) AND (({energy efficiency} OR {energy utilization} OR {base stations}) WN CV)) AND ((2012 OR 2011 OR 2010) WN YR)) AND ({network architecture} WN CV)), Week 201242
((((((green communications) WN ALL) AND ((energy efficiency) WN ALL)) AND ((base stations) WN ALL))) AND (((({energy efficiency} OR {energy utilization} OR {wireless networks} OR {energy conservation} OR {cellular radio} OR {power amplifiers} OR {energy consumption} OR {algorithms}) WN CV) AND ({english} WN LA))), Week 201242

Paper selection criteria:

The articles thus obtained are too filtered based on inclusion and exclusion selection criteria techniques.

Inclusion criteria:

* Studies covering research on energy efficiency of networks
* Studies covering research on green networks
* Studies focusing on different techniques on energy efficiency

Exclusion Criteria:

* Articles which are not related to energy efficiency of networks
* Removing the duplicate articles
*Articles which are not peer reviewed

Snowball Sampling Method:

Snowball sampling which is defined by K.D Bailey [76] is "*a non-probabilistic form of sampling in which persons initially chosen for the sample are used as informants to locate other persons having necessary characteristics making them eligible for sampler*". In this thesis snowball sampling played an important role in finding the reference among the papers found in the literature review.

2 BACKGROUND AND RELATED WORK

Environmental concern has become a dominant issue in 21st century. The concept of green computing has been defined as the practice and study of efficient computer use. The common belief that humanity is behaving in environmentally sound manner is a prerequisite for a sustainable future. However, in the absence of efforts to reduce toxic wastes like carbon dioxide that are emitted into air, this goal cannot be achieved. Recent reports indicate that the Earth is actually warming. These are signals telling us that efforts to reduce greenhouse gases must be made to save the future. One of the various approaches that can be used to ensure the sustainability of environment is through green computing. This is about practice and study of efficient computer use that aims to reduce environmental pollution. Green computing is very vital because the modern society is dependent on the use of IT to perform operations [1]. Further, cellular operations are paying little attention to energy efficiency, but instead are focusing on variety, capacity and stability of communication services. There are currently more than 4 million base stations serving the mobile users, each consuming average of 25MWh per year. Although concern on energy efficiency is still at blossoming stage, it can be beneficial to cellular operators both in terms of profitability and environment effects [2].

In paper [3], the authors provide an up-to-date survey on the current state-of-the-art in green computing. To this aim, authors introduce the concept of green computing. Subsequently, they provide a detailed survey on some key issues of green computing, including the modeling and evaluation of energy efficiency, energy-awareness and green networking. In paper [4], the authors present an Open Source low power router that supports renewable energy by using an ultra-capacitor based energy compatibility module. Concerning the consumption of energy in different networks, the authors describe the energy efficiency classification in form of questions.

Various researches have been conducted in this line of green computing. In paper [5], the authors contribute by assessing existent technologies in power consumption that can influence direction of next generation networks. In addition, they also examine developing technologies, work in progress, and projects that can be used in networks and development of infrastructures to minimize carbon emission. In paper [6], the authors take a similar approach aimed at shaping the future of green computing. They also identify salient issues in green computing such as energy awareness, evaluation and modeling of energy efficiency and examine approaches being used to solve them. In paper [7], the authors identify a specific solution to reduce power consumption in networks. They examine an open source low power router that uses renewable energy based on its energy compatibility module, which has an ultra-capacitor.

These results posit great breakthroughs towards green computing in network efficiency. However, cellular networks have tremendously increased in last few decades. Energy consumption has got more important to study because resultant increase in the rate of data access has raised power consumption in the base station. According to paper [2], the authors state that carbon emission by Information and Communication Technology (ICT) totals 2% to 4% out of which 0.2% in energy consumption. As a result, there is need for further research to establish approaches that can lead to energy savings in base stations as they contribute 60% to 70 % of the whole network energy [6]. The authors in [60] deals with the rough set approach to comprehensive performance evaluation of routing protocols in Cognitive Radio Networks, states the importance of cognitive radio that has to be studied for spectrum scarcity and challenges that are being faced in multi hop wireless cognitive radio networks. The authors on the other hand also points out that evaluation approach of routing protocols is still an unexplored area in the field of CRCN. The authors [63] in this paper shortly describes the CR routing protocol i.e. CRP which makes the contributions on protection for primary Users (PU), multiple classes of routing based on service differentiation in CR networks and joint route spectrum allocation. Furthermore the authors describe the ongoing research on spectrum sharing, and scheduling for single-hop communication in CR networks. In the last decade many of the researchers mainly focused on the physical and MAC layer issues for energy efficiency in Cognitive radio networks, and states that routing is one of the most important issues when applied to CR technology to the mobile ad-hoc networks [64].

Cognitive Radio has become new paradigm proposed to manage with the spectrum scarcity due to enormous increase in data access. A CR can sense the radio spectrum, locate spectrum holes and access them as long as the primary uses do not use the band. Nodes that are coupled with these cognitive functionalities which are thereby called as cognitive nodes can increase network performance by self-aware operation capabilities. The routing of data through routing protocols in a cognitive radio network plays an important role in achieving energy efficiency. Performance evaluation approach of routing is still an unexplored area in CRN and efficient Criterion to assess the performance of routing protocols is still an open issue [60].

3 ORGANIZATIONS INVOLVED IN STUDY OF GREEN NETWORKS:

The energy consumption of mobile cellular networks has become an important criterion to study for future development; being known that already 4 billion has already surpassed the exponential increase of data traffic carried over mobile networks continues to increase in coming decades. Thus mobile network operators are facing problems with rapidly increasing energy costs and regulatory pressures to reduce their carbon footprint to operate more green networks.

These are the most relevant, recent and ongoing "Green Radio" research initiatives.

- Earth – Energy Aware Radio and Network technologies [31]

Partners Involved: Ericson, Teleco Italia, NTT DoCoMo
Objective: The objective is to raise the importance of energy efficiency considerations in the standardization process while seeking solutions using a holistic approach to energy efficiency.

- OPERA-Net–Optimising Power Efficiency in mobile Radio Networks [32]

Partners Involved: France Telecom and other academic researchers
Objective: Consolidating the response of the mobile telecommunications industry to Climate change trends and meeting the relevant EU.

- Objectives for improving energy efficiency by 20% before 2020.

- Green Touch [33]

Partners Involved: Alcatel Lucent Bell Labs and researchers of Dublin City University.
Objective: The stated goal of Green Touch is to deliver the architecture, specifications and roadmap required to reduce energy consumption per user by a factor of 1000 from the current levels by 2015.

- Virtual Centre of Excellence in Mobile and Personal Communications - Mobile VCE -Green Radio [34]

Partners Involved: Vodafone, Nokia Siemens Networks and Huawei
Objective: Mobile VCE set the goal of achieving a100 fold reduction in power consumption compared to current mobile networks without decreasing the provided QoS or having any negative impacts on network operations.

3.1 Energy Consumption and Efficiency Metrics

3.1.1 Energy Consumption in Base stations:

A cellular mobile network consists of three elements, a core network that takes care of switching, base stations providing radio frequency interface and mobile terminals in order to make voice and data connections, of these base station alone contributes 60% to 80% of the whole network energy consumption [2, 19], Of these cellular networks the energy consumed by the base station components, power amplifier is one of the components which utilizes 65% of energy, based on the literature review on the problems pertaining to energy consumption of base stations, base station consumes its energy on [2].

- Power supply (7%)
- Power amplifier (65%)
- Air conditioning (18%)
- Signal processing (10%)

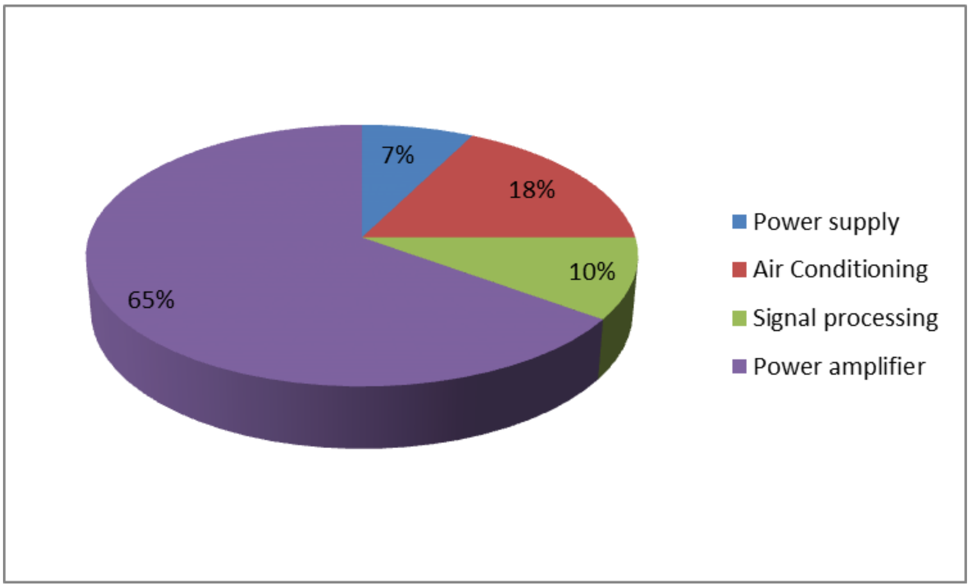


Figure 3-1: Energy consumption distribution in Base stations

This section describes relevant energy efficiency and consumption metrics along with discussing power consumption models that are required to understand, characterize and contrast the challenges, opportunities and benefits associated with various techniques and relevant research initiatives in the "Green Radio" arena.

3.1.2 The standardized energy metrics:

The Energy Consumption Ratio (ECR) is presented in [48] and the Telecommunications Energy Efficiency Ratio (TEER) is presented in [49]. The ECR metric is defined as the ratio of the peak power (measured in Watts) to the peak data throughput rate in bits per seconds and therefore can measure the consumed energy per bit of information transported, which is then expressed in units of joules per bit.

The energy efficiency metrics [11] generally in a telecommunication system can be classified into

a. *Facility level*: It relates to high level systems where equipment is deployed.
b. *Equipment level*: It relates to evaluation of performance of individual equipment.
c. *Network Level*: It relates to the features and properties related to capacity and coverage of the network.

$$\mathrm{ECR} = \frac{\mathrm{POWER}}{\mathrm{DATA\ RATE}} = \frac{\mathrm{Watt}}{\mathrm{Bps}} = \frac{\mathrm{Joule}}{\mathrm{bit}}$$

Table 3-1: Energy Efficiency Metrics

Metric	Type	Units	Description
PUE (Power Usage Efficiency)	Facility-Level	Ratio (>=1)	Defined as ratio of total facility power c onsumption to total equipment power consumption.
DCE (Data Center Efficiency)	Facility-Level	Percentage	Defined as reciprocal of PUE.
Telecommunications Energy Efficiency Ratio (TEER)	Equipment-Level	Gbps/Watt	Ratio of useful work to power consumption
Telecommunications Equipment Energy Efficiency Rating(TEEER)	Equipment-Level	$-\log\left(\frac{Gbps}{Watt}\right)$	$-\log\left(\frac{\text{Ptotal}}{Throughput}\right)$, Where P_{total} is given by equation
Energy Consumption Rating (ECR)	Equipment-Level	Watt/Gbps	Ratio of energy consumption over effective system Capacity
ECR-Weighted (ECRW)	Equipment-Level	Watt/Gbps	Calculated the same way as ECR except energy consumption is now calculated as $0.35E_f + 0.4\, Ef + 0.25E_i$, where each term corresponds to energy consumption in full load, half load and idle modes.
ECR-variable-load metric (ECR-VL)	Equipment-Level	Watt/Gbps	Average energy rating in a reference network described by an array of utilization weights
ECR-extended-idle metric (ECR-EX)	Equipment-Level	Watt/Gbps	Average energy rating in a reference network, where extended energy savings capabilities are enabled
Performance Indicator in rural areas(PI_{rural})	Network-level	Km^2/Watt	Ratio of total coverage area to power consumed
Performance Indicator in urban areas(PI_{urban})	Network-level	Users/Watt	Ratio of number of subscribers to power consumed

3.2 Energy Consumption Reduction Techniques

This section contains the main architectures and techniques which have been considered in various “Green Radio” research projects which go this way.

- Multiple Input Multiple Output MIMO Resource allocation strategies
- Self-Organizing and Optimising Networks SON [39]
- Relaying and Multi-hop cellular[58, 59]
- Efficient power amplifiers and RF power delivery [43]
- Two Tier Femto Macro Technology
- Other ways to reduce energy consumption

3.2.1 MIMO (Multiple Input Multiple Outputs):

Research by 3GPP Technical Specification Group Radio Access Network team [52] and Gesbert [53] suggest that Multiple Input Multiple Outputs (MIMO) is a sure mode that uses receiving antenna and multiple transmissions to enhance efficiency. MIMO has the qualities of enhancing efficiency in a manner to handle essential characteristics of Quality, Spectral efficiency and Throughput.

With technology like OFDM radio access of the 3GPP LTE network authors [54] identifies 3 essential types of MIMO that are, Array gain, Diversity gain and spatial multiplexing. The Diversity gain is further divided into two; Single user which is characterized by many one UE antennae that receive data across several diverse paths and Multi user that enable information transfer and reception by various users over several diversity paths. The two MIMO techniques [35] as space frequency block and space-time block coding where a signal is sent over more than one antenna, however, this is at different time and frequency. When the signals are received, a higher quality is obtained by combining the streams leading to a better Signal to Noise ratio and lower Bit Error Rate (BER). For maximum signal quality and strength at the receiver, the Array Gain MIMO is used to send the same signal from each transmitter, but this is at a set phase and gain (time and amplitude) shift (also called coding) over the transmission path. The receiver also constructively combines the various multipath environments by the array gain to increase signal strength. A constructive and dynamic Array Gain can be obtained in the pre-coding feedback process to transmit from the receiver. These give relevant data a significance signal quality for adjustment of transmitter and improve the “beam” in the user’s direction [40]. This result finds support from the authors of [53], [35], [37] and [40]. Spatial multiplexing is characterized by splitting of high bit rate streams to several lower bit rate streams and each bit is then transmitted via a different transmitter antenna but on the same frequency channel. In case multiple signals arrive at the receiver with a large spatial difference, it is orthogonally separated.

The significance of spatial multiplexing as proposed [53, 35, 37] and [40] is to increase the channel capacity and improved SNR for a greater spectral efficiency.

3.2.2 SON (Self Organizing/Optimizing Networks):

In this paper the authors [38] argue that LTE standard development, use of SON method offers a technique to reduce energy consumption. The method entails intelligent and automatic technique to alter procedure characteristics of the eNodeB's that are possible to reduce consumption of energy.

3.2.3 Relay Node and Multi-hop Cellular

The UE communicates like the traditional cellular networks that are links directly to eNodeB in regard to relay cellular networks and links directly with dominant eNodeB or through a transitional relay station. The relay stations [36] between eNodeB and UE of significance in saving energy and enhancing performance [42] and also suggests that the Relaying method splits longer paths into shorter segments, thus reducing the sum of path loss that might occur as a result of non-linear association of path distance and path loss. Moreover, Using sophisticated shorter radio links instead of longer ones has an economic effect on power budget. For mechanical and human-based relaying method in wireless access network, there is a need to focus on ways to minimize overall energy used, a fact investigated [41]. This form of scenario, mechanical relaying involves Store-and –Carry Forward, the received information before forwarding (SCF). This is perfect for an elastic service.

3.2.4 Efficient power amplifiers and RF power delivery:

A radio modem needs a high linearity from the RF (radio frequency) that will isolate the RF design and the digital signal processing design. Class AB amplifiers are useful in forming RF envelope waveforms towards peak power. However, most of the time power amplifiers operate in the less efficient range as a result of waveforms having a high peak to average. By this mean [49], ETSI TS (2009) notes that only15-25% of the waveform can be determined for modems using LTE, UMITS and WiMAX. Further clarifies [70] that RF power increase is only to a certain threshold. It is also difficult to get a rise in power output when input power is also on the rise. In addition, the output gain compresses with input increase toward saturation point of an RF amplifier.

3.2.5 Two tier femto macro technology:

Consider a two-tier network with Femtocell and Macrocell as shown in the Fig3.2. With regard to the OFDMA (orthogonal frequency division multiple access), the network is a fundamental technology in the 4^{th} generation of networks like LTE and WiMAX. In the orthogonal frequency division multiple access system, the bandwidth is separated into several orthogonal sub-channels. Thus, macro and Femtocell users via an exclusive sub-channel can evade intracellular interference. N and WHz are mostly used to describe the quantity of sub-channels and the total bandwidth of the system. With the definition as a short-range data access point, lower power, base stations using Femtocells are stationed in highly dense hotspot points supporting stationary and low mobile users.

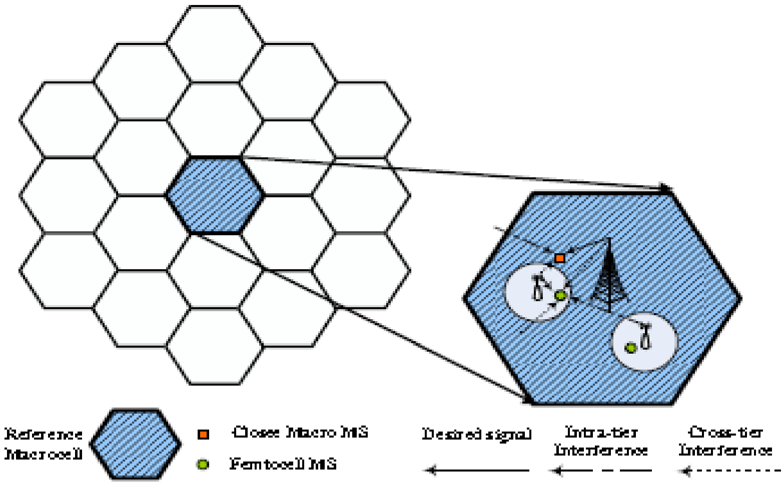


Figure 3-2: Macro-Femto TWO tier Network [61]

Also notes that Macrocell coverage [15] is larger compared to radio, it enables lower power transmission to base stations and better signal reception. In essence, a two-tier Femtocell has both Femtocells and Macrocells that enable high spectral efficiency and low power consumption. One of the networks has an NC hexagonal standard macro BSs that uniform distribution of macros MSs. The other overlaid tier network has Femto (base station) BSs redistributed in accordance with Homogeneous Spatial Possion Point Process (SPPP) on the intensity plane λf on each Macrocell. Moreover, all Femto mobile stations are uniformly distributed. Let's also assume Rf and Rc to be the radius of Femto BS and macro BS, respectively, such that, (Rc>>Rf). Rd is the distance from Femto BS to macro BS. The mean number of Femtocells BSs on each Macrocell can be calculated as Nf = λfS(Rc), with S(Rc) being Macrocell area. Two access policies exist in deploying Femntocell network that is open access and closed access. In the first case, users including Femto MSs and macro MSs in the operator network have rights to access Femtocell. In the second scenario, macro MSs can't access the Femto BS even if received macro MSs Signals from the Femto BS is stronger. It is therefore essential to use open access in public areas and hot spots. However, closed access can be implemented for small office and home environments. Overall, open access has an advantage over closed; closed access has problems of cross tier macros MSs in the downlink transmission if located near a Femto BS. Contrary to these, closed access Femtocell networks are used by majority of operators due to security issues.

The efficiency of High power Amplifiers is a result of reducing peak to average power ratio (PAR) of the transmitted signal. The peak and average values of a power amplifier should be as close as possible to maximize on the efficiency of the power amplifier. However, use of Envelope tracking (ET) can improve on efficiency of the power amplifier. An ET has a dynamic system to change supplied voltage to the final RF stage power transistor, which synchronizes with transmitted RF signals via the device. This enables the output to be kept in a saturation region that is very efficient in operation. In a contemporary study [53], with respect to PA effectiveness for BS, 50% efficiency has been reported for WCDMA (Wideband Code Division Multiple Access) waveforms for ET based PA. In other research, accuracies close to 60% have been obtained. If power amplification efficiencies can be radically raised to between15-25%, then almost 60% of energy used on cooling fans can be reduced.

Typically, in multi-antenna (for example MIMO) systems, amplifiers are located on the antenna. When the system load is low, transmit antennas that switch the energy on and off are used. An example is a UMITS that supports 2 transmitting antennas. For a non_MIMO supported system terminal, the base station may switch off to the next regular pilot channel broadcasted over the next antenna to minimize on energy. A base band unit of the station is further utilized by the power save modes to subunits, like Digital signal processors (DSPs) and channel cards, Application specific integrated circuits (ASICS), Field programmable gate arrays (FPGA) and clocks that can be turned on and off with regard to the base load station. In addition, phase modulation techniques can reduce PAR. By doing so, also high efficiency can be obtained in the User Equipment (UE) or Mobile Station transmitter, which will as well increase efficiency in the network.

3.2.6 Other Ways to reduce Base stations Energy consumption

The different other ways to reduce energy consumption of base stations of mobile networks [2] that are shown below

- Efforts to reduce BTS energy consumption
- Minimize number of base station sites
- Maximum usage of renewable energy resources
- Improving base station energy efficiency

- Using system level features
- Site solutions for base stations
- Intra Base station Energy saving
- Inter Base station Energy saving

Improving base stations energy efficiency is more effectively dominated by power amplifier in a transmitter as studied in above chapters, the energy efficiency of power amplifier depends upon the required modulation, operating environment and frequency. The ways to improve power amplifier energy efficiency is to use different kinds of linearization methods like digital pre-distortion Cartesian feedback and feed forward.

Another feature to decrease energy consumption of base station is to shut down complete base station whenever there is no load on the network. It is important not only to study the energy efficiency which can be achieved through improving hardware infrastructure but also BTS solution sites which can make it possible to save energy, the possible site solutions [2] are

- *Outdoor sites*: BTS can be used over wider range of temperature and thereby less cooling/or heating is required.
- *Indoor sites*: in case of indoor sites possible energy save is done by avoiding the air-conditioning.
- *RF head and Modular BTS*: in this case the RF transmitter is located close to the antenna thereby the important powerless parameter can be reduced which surely improves the network performance.

Usually the normal base stations are manufactured which try to allocate the radio resources rather than caring about the channel condition. In order [72] to reduce the power consumption of a base station data scheduler may queue the data in a packet buffer until varying channel gain becomes good. Therefore the required amount of energy to send the same packet decreases as channel gain increases. If the base station power allocation resources have to be studied efficiently one should note that there should be relationship between the multiple base stations that are to be considered appropriately, which allow the coordination of base stations to optimize energy savings by knowing the capacity and coverage demand. The coordination involves sharing loads, coverage, interference and collective decision for energy saving state of particular network elements.

Two important parameters are to be considered to minimize energy consumption of base stations. One of them is number of base station sites and energy consumption of single base station. Several features could to balance between base station cell size and base station capacity in order to minimize the base stations number. Some of them are [62].

- Extended cell
- Smart antenna

- RF head and modular BTS
- 6-sector site
- 2-way and 4-way diversity

Effective usage of renewable energy resources may also help in energy efficiency of a base station. The most important energy resources are solar and wind, which can be used for several reasons [67] like

- Reduce amount of Co2
- Unreliable grid
- Long distance to electricity grid

Due to rapid growing demand for mobile communication technology, the number of worldwide cellular base stations has increased to millions. With the advent of data intensive cellular standards power consumption for each base station can increase up to 1400W and energy costs per base stations can reach to $3200 per annum with carbon footprint of 11 tons [16].

A base station has three parts: the baseband unit, the radio and the feeder network. Of these elements, the radio consumes more than 80% of a base station's energy needs, 50% of which is consumed by the power amplifier (PA) [17, 18].

3.3 Minimizing energy consumption of base stations

Base Station hardware improvement is one way to reduce energy consumption. This is achieved by addressing the part that consumes more power in a base station, that is, the power amplifier. The radio consumes about 80% of base station power consumption. Deloite (2010) studies [16] reveal that the PA consumes 50% of which about 80-90% goes to waste due to the PA requiring operational cost and additional energy [20], gives the solution to this by using a switch mode power amplifier for higher operating frequencies on wireless mobile systems [21]. He also suggests the use of laterally diffused metal oxide semiconductor (LDMOS) technology and Multi Storage Doherty Power amplifier that a power efficiency of about 70% under the Rayleigh envelope signal analysis [22].

Another significant technique to be improved on is the increase of output power to maintain signal quality as constant as signal fluctuations result is more power consumption. However, the process of low traffic load leads to a lot of energy losses. It is therefore essential to obtain a flexible PA architectural design capabilities to adapt to desired outputs. In recent architecture, mobile terminals and base stations continuously transmit pilot signals while newer ones like LTE and LTE-Advanced transmit data at higher rates. When there is no signal for transmission, then switching off the transceiver is a way to save power. The LTE standards utilized this by a power saving protocol like discontinuous transmission (DTX) and discontinuous reception (DRX) modes in mobile handsets. DTX and DRX save power by temporarily powering off the device while maintaining connection with little throughput. Base stations with fixed cellular networks, there are lots of activities linked to reducing energy wastages

Edler and Lundberg (2004) propose Ericson's idea of innovative methodologies for environmental energy saving [23]. They also describe on how to improve RBS efficiency and reduce site cooling costs. Electrical power consumption of radio access network has a direct impact on cost and the environment. There are suggestions to study and understand network performance in order to reduce operational costs. This includes determining power consumed by various parts of the network. Also the knowledge of the relationship between environment and climate is essential to assist in cooling of the base station.

For a number of years, there has been interest in an efficient design of wireless network with prolonged battery lifespan for mobile terminals and sensor nodes. Environmental impacts due to emissions of warming have changed the focus of energy efficient wireless networks. Energy reduction also has an economic effect on revenue. It is estimated that in the recent past, over $10B of electricity were spent on wireless network operation, which is a huge fraction of the expenditure. There is a 15-20% rise of energy consumption for IT sectors and is expected to double every 5 years. These results have forced major operators to to begin finding ways to improve energy efficiency in their operation.

The BSs consumes about 60-80% of the total power [54]. This section aims to reduce power consumption in the BSs unit. This has been spurred by the interest by a cellular industry desire to increase efficiency in wireless communication. The cellular industry accounts for most power consumption in the communication industry. This is a result of enhancing data rates for broadband access to 3td generation mobile systems. Data from other companies [65, 66] and cellular operators studied [45, 46, 48 and 51] and ranks the cellular operators high in energy consumption in networks. With growth predictions, there are fears of increase costs to other relevant players in the same field. Therefore reducing base station costs is of primary interest.

The green cellular architecture, at no radiation, aims to reduce mobile station emission. The design utilizes the transceiver base station to receive only devices that are deployed within the proximity of the mobile station. For ETSI TS (2009) study [49], in this architecture, both 3G and 4G (modern cellular and wireless networks) have a classic power control system able to control transmission (TX) power of macros BS and BSs. With a focus on the uplink, the distance from BS determines received MS Tx power. Majority of cellular and wireless networks use transceiver BSs architecture, however, the green cellular design proposes argumentation of the

BSs transceiver and receive-only-device. A schematic of the Green Cellular architecture is given in the fig. 3.3 [67].

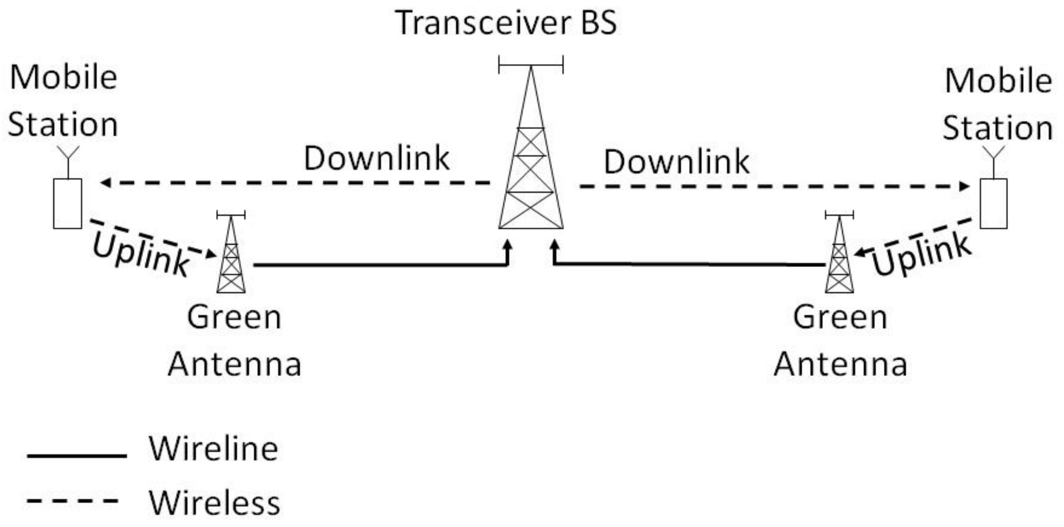


Figure 3-3: Transceivers augmented as green antenna [67]

To have reduced cellular radiation exposure, the green antenna is connected to the network infrastructure via direct point-to-point microwave or wire connection. Currently, green antenna can be set on a sufficient grid and decreasing the mean Tx power for MS to any desired value supported by MS, with no additional source of radiation. Keeping in mind the importance of cellular indoor use, an ordinary embodiment of green cellular is defined as strengthening outdoor BS with regard to indoor antenna, denoted as Green Spots (GSs). As a result of moderate MS Tx indoor power, the GSs are of important significance in this architecture. GSs can be installed in school buildings where radiation is a key issue. An outdoor BS can be positioned anywhere outdoors and still allow access. On achieving Green antenna, MSs transmits low TX power (and vice versa), reducing user interference to both the neighboring BSs and the same BS. This is because majority of communication systems is restricted by interference, resulting in decrease in need Tx power of the other MSs. For this discussion, it is assumed that the Green antenna decodes uplink (UL) transmission and is linked to all leading neighboring BSs. The serving BS respective to each MS is determined by the green antenna and forwards the MS UL information to the serving BS. On the other hand, this configuration can be utilized in IP based networks between the neighboring BSs and the Green Antenna as suggested by ETSI TS [49]. In other terms, consumed power is in two parts; energy to run the system and energy to be created and installed in the system. In this case, embodied energy is not directly linked to the communication itself. Embodied energy is also a factor to be considered in the design of a new generation of wireless network systems.

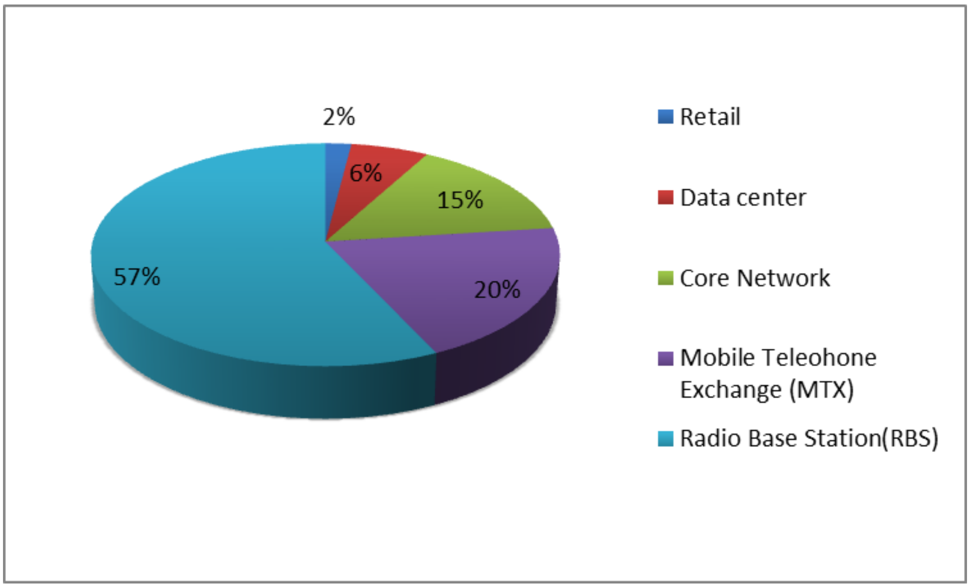


Figure 3-4: Energy consumption composition in Vodafone: source Vodafone [68].

In accordance to statistical data, the BS is a key source of energy consumption for mobile operations, hence a key factor to deal on. BS loses most of its power during conversion by power amplifiers that consume most of the power. Other energy loses as a result of cabling, AC/DC current converting, and energy for cooling can also be reduced. For example, for a global mobile communication BS system to supply 1.2kW to an antenna [44], and calculates a 3802Watts input with a 3.1% overall efficiency. Other studies are underway on improving energy efficiency of the BS at the various perspectives like using energy efficient backhaul solutions, Increasing PA efficiency, using non-active cooling techniques, improving protocols for energy efficiency, applying energy efficient deployment strategies and using the masthead PA to reduce feeder loss.

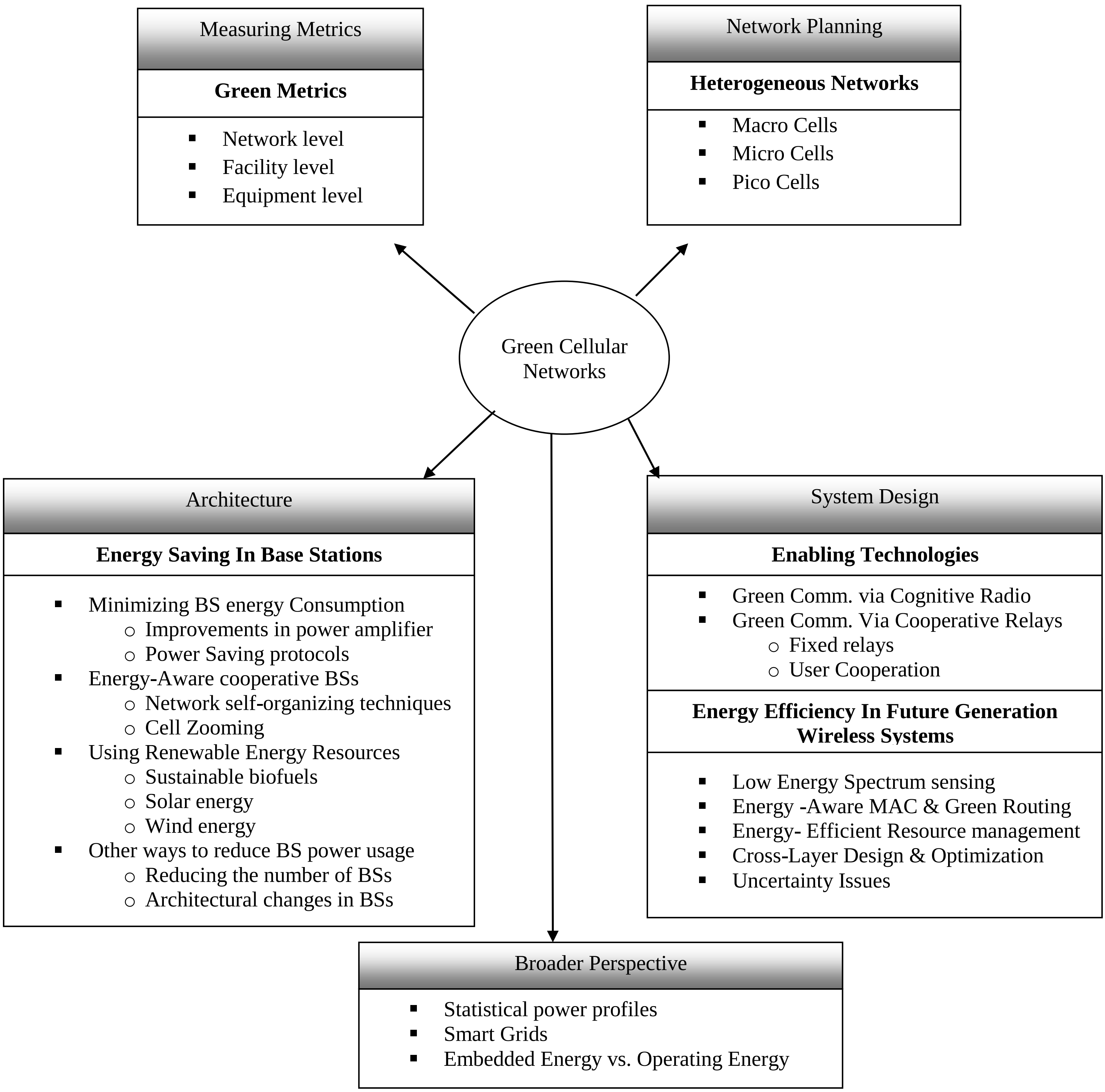


Figure 3-5: Approach for Green Communications [2]

4 EXPERIMENTATION

Exponential growth in radio technology and software design has been added to rapid growth of software defined radio (SDR). Now a day's SDR finds much importance in military radio communication and satellite communication. The term cognitive radio was coined by Joseph Mitola III. According to him Cognitive radio is a radio that employs model based reasoning to achieve specified level of competence in radio related domains [26]. It is very difficult to define cognitive radio due to its scope and complexity. Let us consider some of the definitions attributed to cognitive radio proposed by renowned researchers and regulatory authorities. Several works have tried to define cognitive radio by correlating several works contributed by industry, research groups and academia [28] [29]. Paper [30] describes the efforts being made to attain a standardized definition for cognitive radio. In paper [27] Simon Hawkin defines cognitive radio as intelligent wireless communication system that is aware of its environmental conditions. CR has achieved its own importance by

a) High reliable communication whatever and whenever necessary
b) Efficient utilisation of radio spectrum

The Virginia Tech Cognitive research group (CWG) defines CRCN as a network with a process that can perceive current network conditions and then plan and act according to the environmental conditions Cognitive radio is achieved by OODA loop [25]. This type of methodology is primarily developed by military but later founded by several, ranging from commerce to robotics [25].

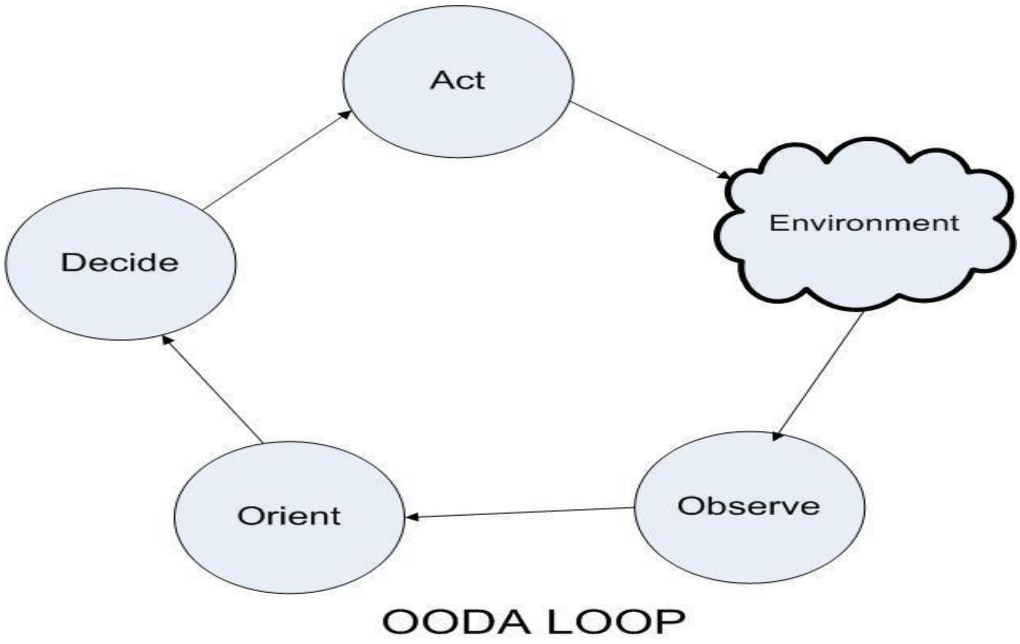


Figure 4-1: OODA LOOP [24]

4.1 Ad Hoc Routing in Cognitive Radio

Ad hoc network are the temporary network which are created when device uses the same protocol which are designed based on multi-channel and single channel communication. It's a local area network where instead of a message relaying on a base station, it flows from one node to another i.e. the individual network nodes forward packets to and from each other.

Since operation time is the most critical limiting factor, providing energy efficient routes is a challenging goal. The flexibility of cellular networks is highly improved by the utilization of mobile Ad hoc nodes as relay for calls designated to base stations. Ad hoc routing increases the overall system capacity by bypassing blocked base station. Consequently, with sufficient resources, Ad hoc routing for coverage extension allows connection to the nearest base station, in order to utilize battery efficiently, energy management techniques are required [56]. A precise estimate of energy consumption and high-level insight into protocol behavior are required so as to evaluate the energy consumption of network protocols.

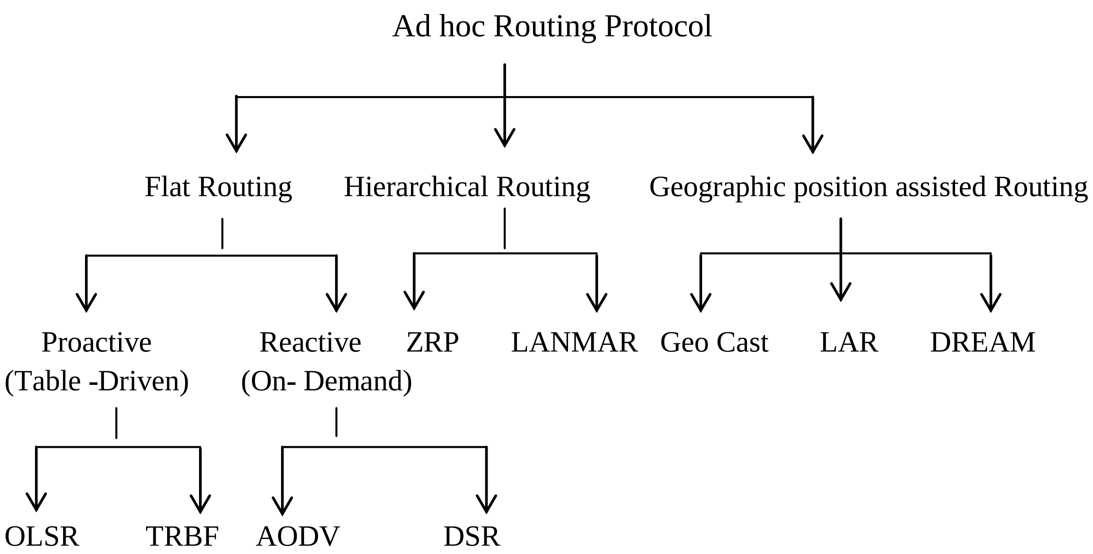
The huge channelization leads to high energy consumption by the small packets, just like the degeneration mode of operation. Reduction in the rate of data transmission and reception has affected the per packet energy consumption. This is due to the high fixed over – head. This reduction in the rate of data transmission and reception leads to decrease in transmission range, which is involved with high rates of data, and also in a reduction in the number of neighboring nodes [55].

Opportunistic use of licensed frequency bands that are vacant are enabled by the cognitive radio. An ad Hoc network, also referred to as radio networks, has the ability to predict data channel or route stability's mobility. A distributed cognitive radio routing protocol for ad hoc networks is proposed by incurring a trade-off in the cognitive radio network performance. Radio network with high power efficiency results from combination of spectrum awareness in a cognitive radio network and node mobility prediction of an Ad Hoc radio network. Modern radio networks have the cognitive radio capability which means the radio network has the ability to sense important information from the radio or wireless network [56]. This means it will take more time to detect weaker signals and so it has a weakness because it depends on the noise in the signal which is not dependable on.

Mobile hosts using the basic service set mode should be within BS transmission range. A base station ensures the mobile traffic is buffered and forwarded efficiently between the available mobile hosts. In return, the mobile hosts channel the leaving traffic to the BS and also prepare the BS for traffic reception. The interface is in sleep mode during the time spent from transmission to reception and vice versa. This facilitates energy efficiency [56] since a cognitive radio is a transceiver i.e. it transmits and receives signals; it's capable of monitoring its own performance continuously and can adjust the radio settings so as to deliver the required quality service. If the noise power is known, energy detector is optimal to detect the unknown signal. Based on the energy of the received signals, a Cognitive radio user senses the presence and or absence of the PU.

Cognitive radio presents the possibility of numerous revolutionary application arising from a software radio control processes. Cognitive radio has control that processes situational knowledge towards achieving some goal related to the need of a network and intelligent processing. By employing many base stations, performance of a network is significantly improved. Based on interaction with the environment in which it operates, a cognitive radio can change its transmitter parameters. The cognitive radio is energy efficient in the manner that it is designed to utilize the licensed spectrum when not used by the primary users who are licensed. The ability of routes to reach depends on network topology and spectrum availability in a cognitive radio ad hoc routing [57]. A cognitive radio user senses multiple channels and the optimal transmission duration is determined and power allocation too.

Table 4-2: Structural diagram ad hoc Routing protocols



From the above mentioned routing protocols, AODV and OLSR are two important popular routing protocols and therefore this thesis will now concentrate on these two. There are many evaluations that are available on these two protocols but there are no enough studies on the software implementation of these protocols on real network test beds to study their functionality and performance in Cognitive radio.

4.1.1 Optimized Link State Routing Protocol (OLSR):

The Optimized Link State Routing Protocol (OLSR) is developed for mobile ad hoc networks. It operates as a table driven and proactive protocol, thus exchanging topology information with other nodes of the network regularly. The nodes are selected as a multi-point relay (MPR) by some neighbor nodes announcing this information periodically in their control messages. Thereby, a node announces to the network, that it has reach ability to the nodes which have selected it as MPR. In route calculation, the MPRs are used to form the route from a given node to any destination in the network [47]. The main advantage is that it reduces control information and efficiently minimizes broadcast traffic usage and disadvantage is that OLSR also has routing delays and bandwidth overhead at the MPR nodes as they act as localized forwarding routers.

OLSR functions on three processes

a. Neighbor or Link sensing
b. Efficient control flooding using MPR
c. Path calculation using shortest path algorithm

Nodes which participate in the routing of packets exchange HELLO messages which consist of link information and neighbor node information, i.e. two hop neighbors MPRs and MPR selector. HELLO messages perform link sensing, neighbor detection and MPR selection signaling. As the nature of OLSR is proactive each node maintains topology graph of the network. As a routing table is maintained by each node, when a new route is detected then the table is refreshed, to fill out the routing table shortest path algorithm is used.

4.1.2 Ad hoc On-Demand Distance Vector (AODV):

It uses route discovery to dynamically build new route on an as need basis. It creates route request packets and broadcasts it to the neighbors. The advantage is that it creates routes only on demand, which greatly reduces the periodic control message overhead associated with proactive routing protocols. The disadvantage is that there is route setup latency when a new route is needed, because ADOV [50] queues data packets while discovering new routes and the queued packets are sent out only when new routes are found. This situation causes throughput loss in high mobility scenarios, because the packets get dropped quickly due to unstable route selection.

1. AODV defines three types of messages Route request (RREQ), Route reply (RREP), Route error(RERR)
2. When route has to be discovered, node sends RREQ message to find the route.

3. The route is confirmed, when RREP message is sent back to source from destination.
4. If there is a link breakage RRER message is initiated and broadcasted to notify all nodes about loss of link, the purpose of RRER is to notify the source that link has failed and there is no link to transfer the data.

4.2 Experiment

The aim of this research is to analyze the energy efficiency parameter of a cognitive radio network by varying number of nodes from 20, 30, and 40 and study two different routing protocols OLSR and AODV. The MAC layer protocol that is chosen is Macng. The specified parameters are shown below. In this report the main concentration is on the reactive based routing where we apply Shortest Path Routing (SPR) with Dijkstra algorithm to compute the route.

4.2.1 WHY only NS2

As cognitive radio research is emerging many researchers are looking forward for a better simulator, many algorithms are implemented for CR on existing network simulator such as NS2, OPNET, QualNet, not all algorithms are implemented successfully in all simulators, therefore there is a demand to extend existing simulators to support CR simulator, hence we make use of NS2.
We have chosen NS2 as our simulator because

- It is open source software.
- It consists of different topology and traffic generators which helps users to create different scenarios.
- NS2 provides an interface to users to configure different network protocols to each network layer.
- It provides different radio models such as 802.11, 802.16, 802.15.3, 802.15.4.

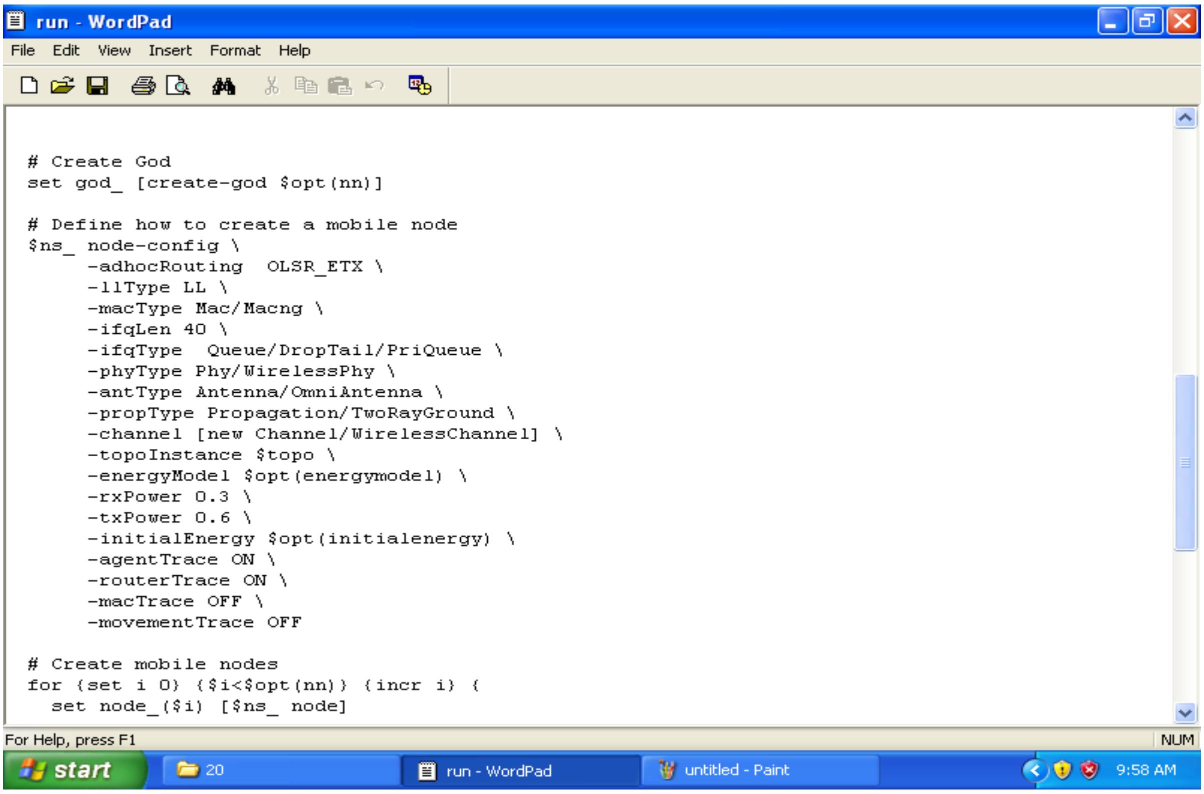
4.2.2 NS2 installation

1. The prerequisite to install NS2 is to have a C++ compiler. A windows XP platform is virtualized over WINDOWS 7 using Oracle VM virtual box Manager.
2. CYGWIN is installed to get a look of Linux.
3. All packages are installed that are required for available for NS2

As soon as NS2 is installed configuration of nodes and a setup for communication is done.

4.3 Model Design and Implementation

In this project we considered the simulation area to be 900*900sq. units



```
# Create God
set god_ [create-god $opt(nn)]

# Define how to create a mobile node
$ns_ node-config \
     -adhocRouting  OLSR_ETX \
     -llType LL \
     -macType Mac/Macng \
     -ifqLen 40 \
     -ifqType  Queue/DropTail/PriQueue \
     -phyType Phy/WirelessPhy \
     -antType Antenna/OmniAntenna \
     -propType Propagation/TwoRayGround \
     -channel [new Channel/WirelessChannel] \
     -topoInstance $topo \
     -energyModel $opt(energymodel) \
     -rxPower 0.3 \
     -txPower 0.6 \
     -initialEnergy $opt(initialenergy) \
     -agentTrace ON \
     -routerTrace ON \
     -macTrace OFF \
     -movementTrace OFF

# Create mobile nodes
for {set i 0} {$i<$opt(nn)} {incr i} {
  set node_($i) [$ns_ node]
```

Figure 4-2: The values which are set to run the simulation

To understand certain parameters the simulation should be conducted and concentrated on

- Mobility models.
- Traffic patterns.
- Interface queues.
- Parameters affecting radio propagation.

From the figure 4.3 the meaning of parameters are shown below

-adhocRouting OLSR_ETX \	#type of routing protocol (OLSR)
-llType LL \	#link layer
-macType Mac/Macng\	#type of Mac protocol (Macng)
-ifqLen 40 \	#queue length (buffer length)
-ifqType Queue/DropTail/PriQueue \	#type of queue (Drop type)
-phyType Phy/WirelessPhy \	#network interface type

```
-antType Antenna/OmniAntenna \              #type of antenna (Omni directional)

 -propType Propagation/TwoRayGround \    #propagation model

-channel [new Channel/WirelessChannel] \   #type of channel (wireless channel)
```

And other important parameters that are set are

```
$cbr_(0) set packetSize_512         # setting packet size to 512
$cbr_(0) set interval_1.0           # send packet for every sec
$cbr_(0) set random_1               # packet is sent randomly between 1 sec
$cbr_(0) set maxpkts_10000          # maximum number of packets to send are 10000
```

4.3.1 Mobility Models

These are movement based pattern generators that are generated to model the behavior of mobile nodes where movements are independent to each other. As the mobile nodes are moving according to prescribed random way point mode, and a destination is selected as defined in the topology and moves towards the destination at random speed. The random speed is between 0 to 20m/sec, and when the destination node is reached the mobile node pauses for pause time seconds which are defined in the script and proceeds to the destination again.

4.3.2 Node Movement Animation

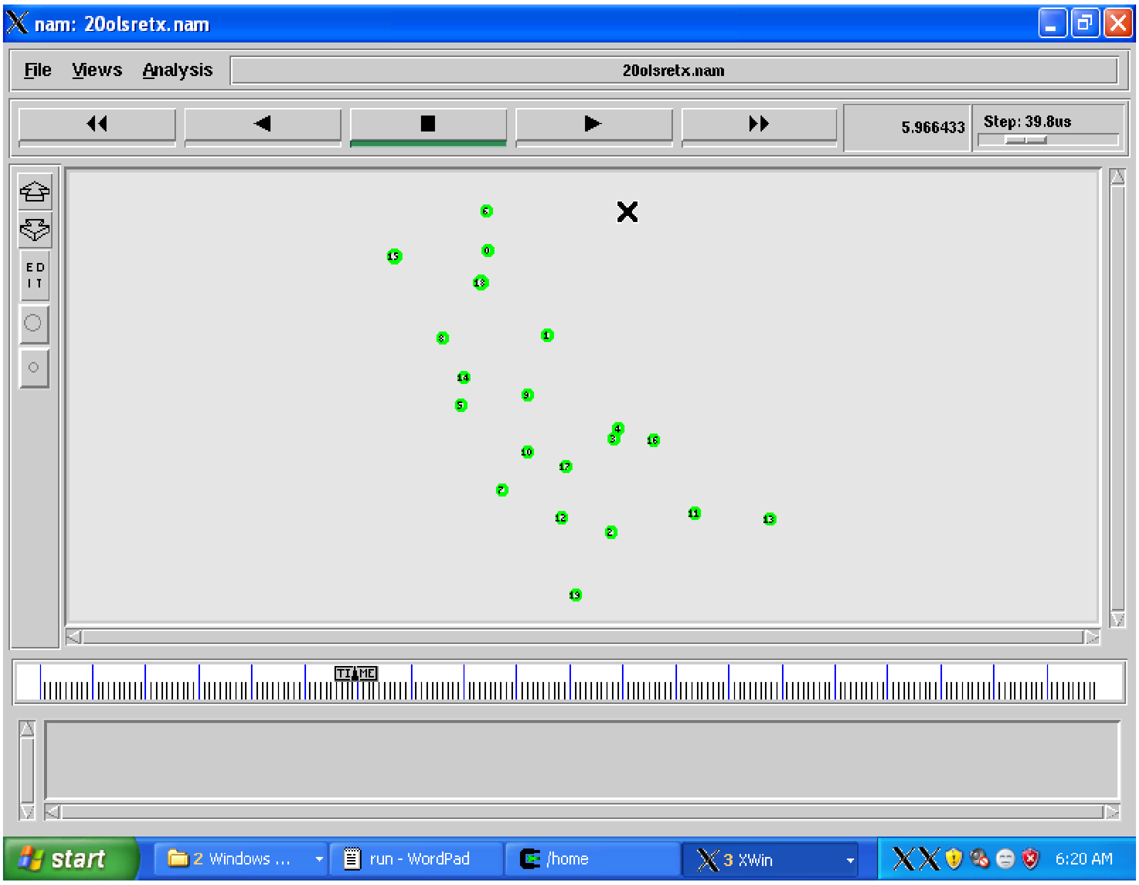
A tool is created to generate movement animation of nodes, this tool takes ns2 file to generate Network Animator (NAM). It is important to note that this generation of animation file is not a post simulation trace. The NAM file that is produced by ns2 is playable animation file.

4.3.3 Traffic Generator and scenario file

The MANET importantly uses deploying operations which involves video and voice communication applications which are mainly constant data rate datagram applications. Constant Bit Rate (CBR) is used as application traffic running over UDP connection. The generator script is available under “/indep-utils/cmu-scen-gen” directory, and the file name is cbrgen.tcl. The traffic source in NS2 is CBR traffic generating agent at source node and sink is a null agent at the destination or target node. As the experimentation is used to store all the necessary data such as traffic connections, in the same way scenario file is used to store certain parameters like initial position of nodes and their movement at different times and speed. The node movement generator is available under the path /indep-utils/cmu-scen-gen/setdest/.

4.3.4 Network Traffic

As we know that there are two kinds of traffic that can be used in the simulations one of those is TCP based traffic and the other is UDP based Constant Bit rate (CBR) traffic. Since UDP consumes much lower energy than TCP, UDP



with CBR is employed. There is no retransmission of lost packets and lost packets are simply ignored.

Figure 4-3: Animation files for 20 nodes

Table 4-1: Parameters consideration

PARAMETER	VALUE
Channel Type	Wireless Channel
Radio-propagation model	Two Ray Ground
Network interface type	Wireless Physical Layer
MAC type	Macng
Interface queue type	Drop Tail/Priority Queue
Interface queue length	40

Link layer type	Traditional Link Layer (LL)
Antenna model	Omni-directional (unity gain)
Value (x)	900
Value (y)	900

Nodes are created in a topology where the every first node i.e. 0^{th} node acts as the source node and $(N-1)^{the}$ acts as the destination node and where N represents 20, 30, 40 number of nodes.

As soon as the nodes are configured, two protocols OLSR and AODV are used; transportation is done with UDP using traffic sources CBR and selected Queuing discipline as Drop tail.

We create a cognitive scenario for 20, 30, 40 mobile nodes. As the simulation event is configured the output is stored and collected in the trace file. The simulation can be visualized using NAM.

4.3.5 Nodes movement before and after simulation for 20, 30 and 40 nodes

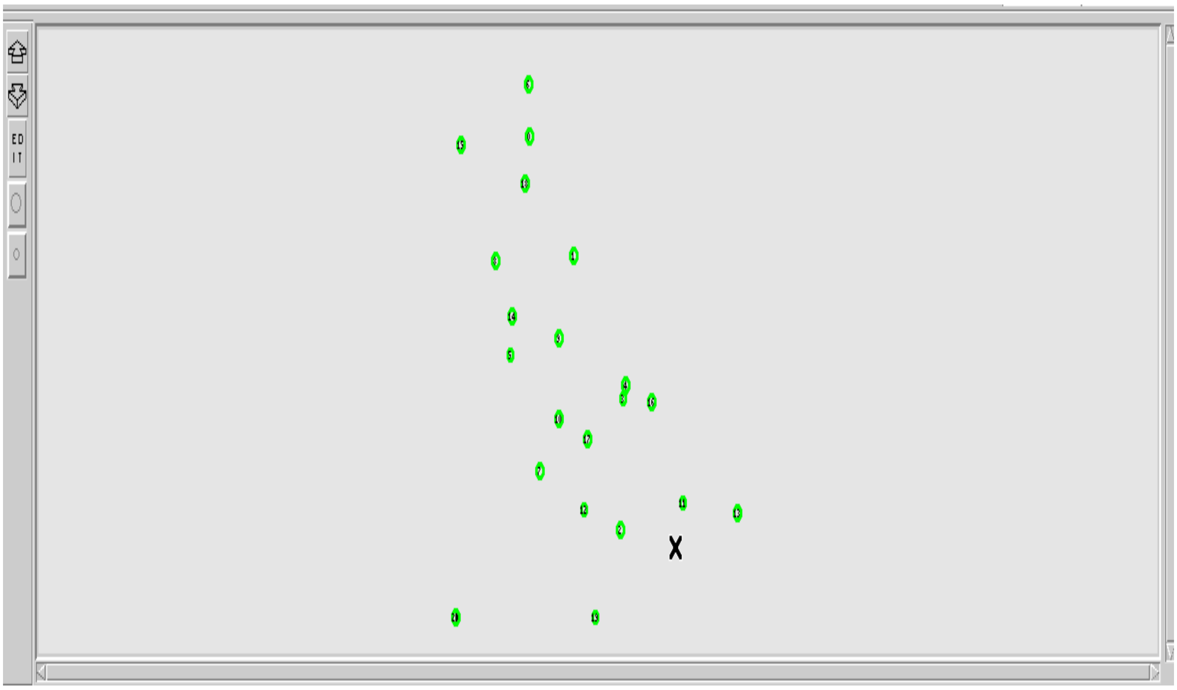


Figure 4-4: 20 Nodes before simulation

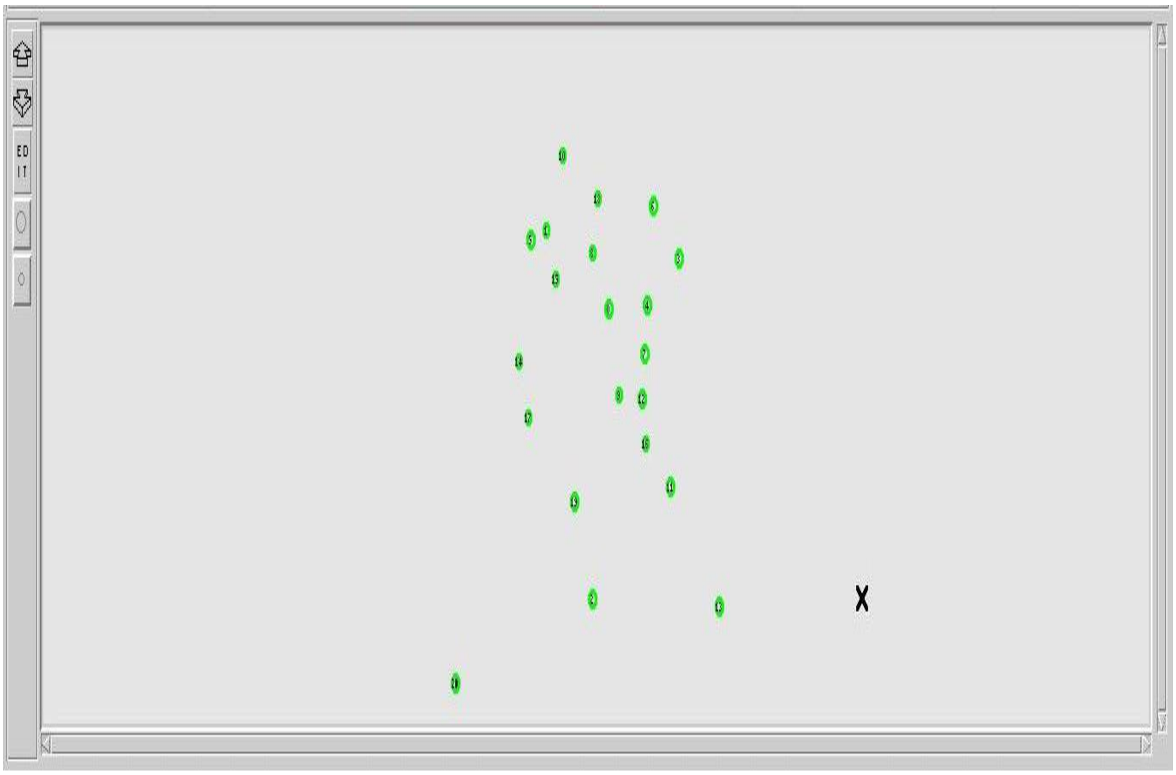


Figure 4-5: 20 Nodes after simulation

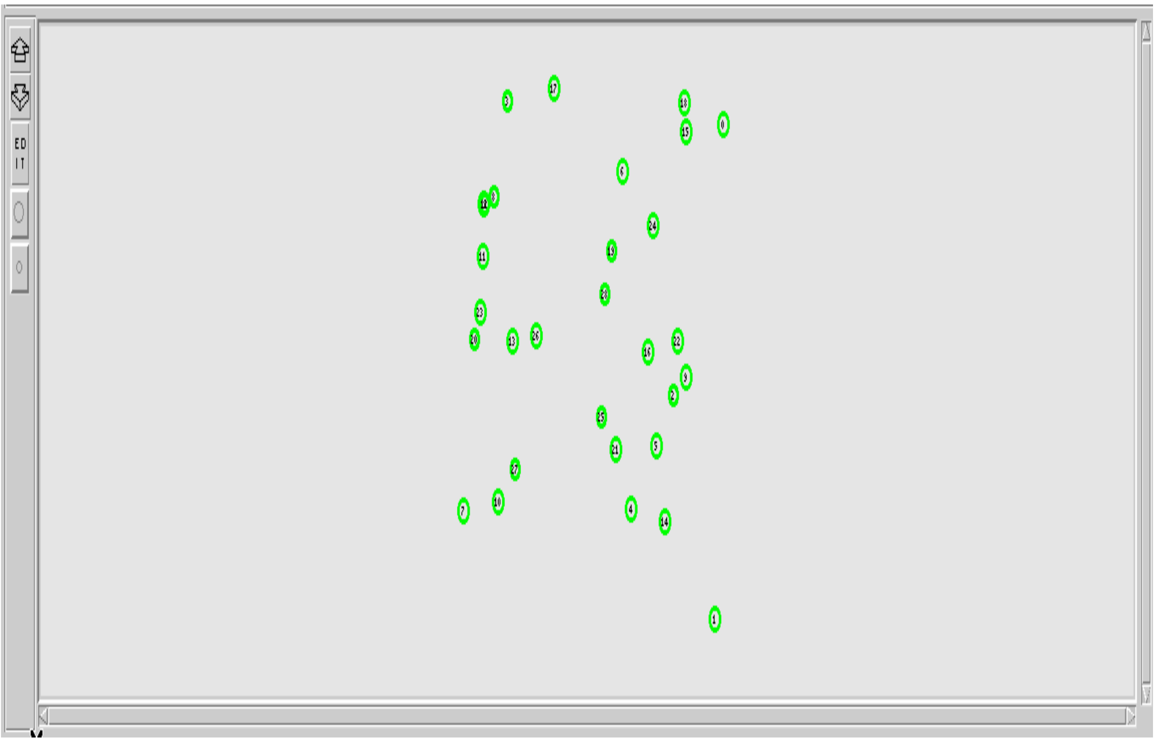


Figure 4-6: 30 nodes before simulation

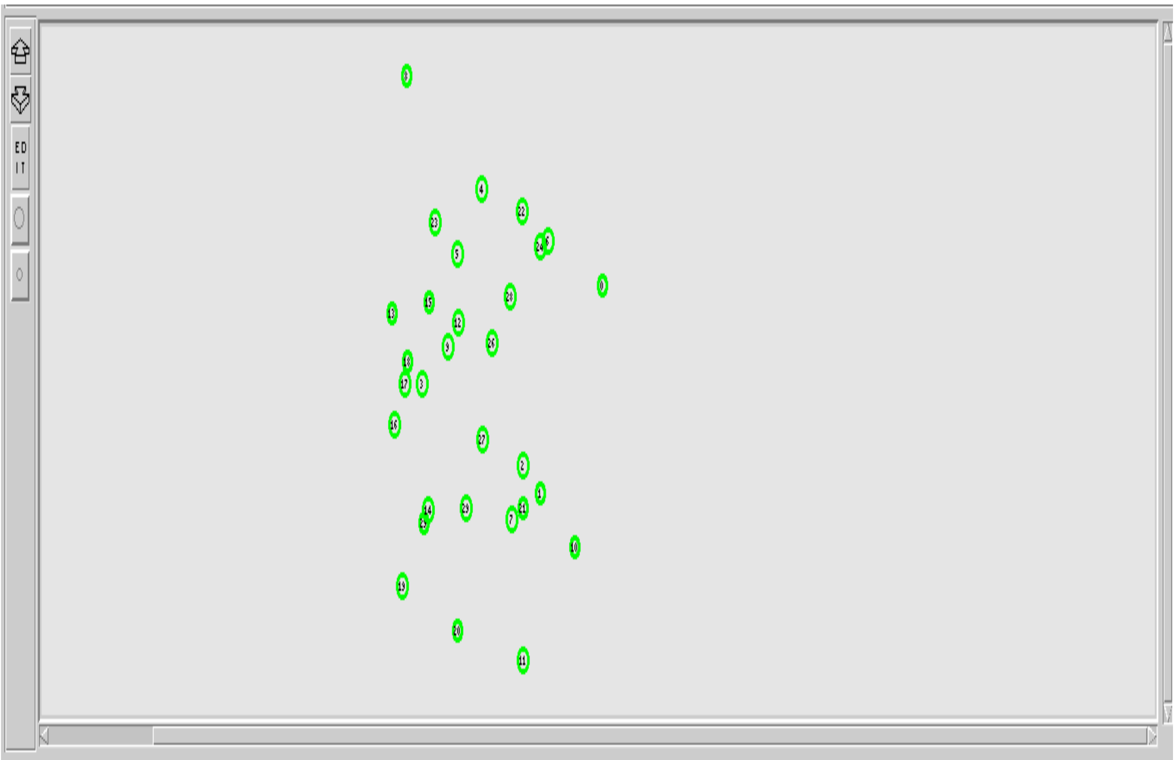


Figure 4-7: 30 nodes after simulation

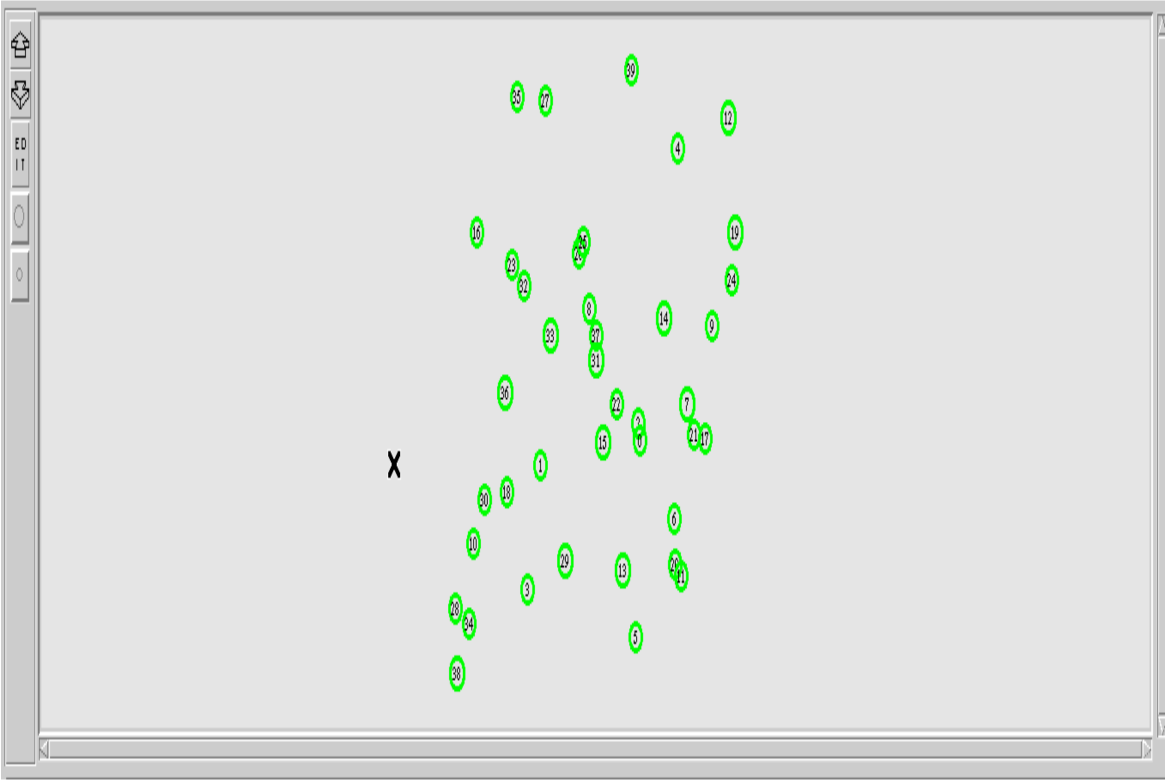


Figure 4-8: 40 nodes before simulation

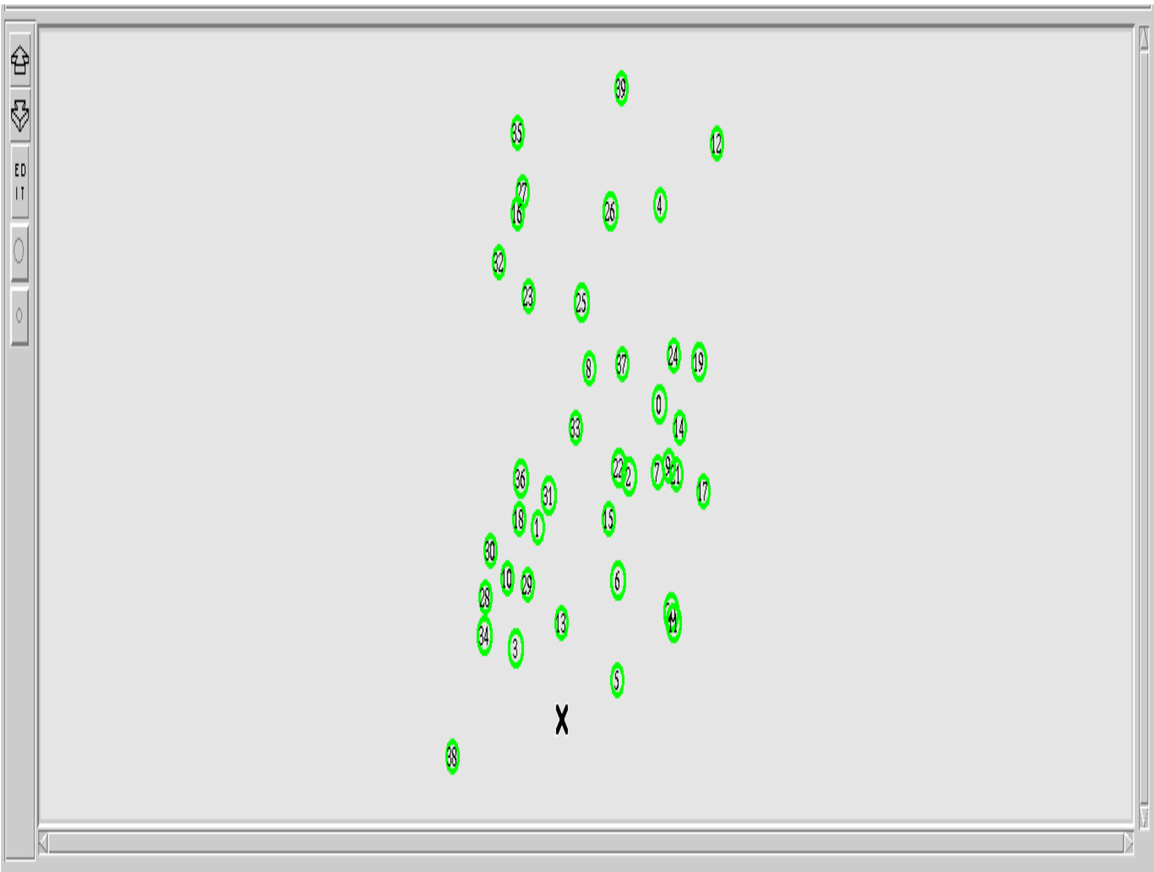


Figure 4-9: 40 nodes after simulation

5 RESULTS AND DISCUSSION

In this section we present the results of our thesis, where we conducted experimentation on NS2 platform to study the energy efficiency. The mentioned parameter have been calculated for 20, 30, 40 nodes. To get more concrete results the experiment is divided into two cases, where the simulation is carried out for single time and also for multiple times that is 10 times. These results give us the best routing protocol among OLSR and AODV.

5.1 Energy Efficiency:

As we initialized initial energy to be 100 *joules* and the total energy corresponding to 20 nodes, 30 nodes and 40 nodes, the energy in the network would be 2000 J , 3000 J and 4000 J respectively . The very first node i.e. 0^{th} node acts as the source node and *(N-1)th* node act as the destination node where N=20,30,40.

5.1.1 Case A: For a single simulation

In this section results are presented for a single run simulation

- For 20 node scenario in OLSR, the consumed energy is 0.933J and remaining energy is 1999.0963J
- For 20 node scenario in AODV, the consumed energy is 46.046J and remaining energy is 1953.953J

In the table below the energy consumption for 20, 30 and 40 nodes are shown

Table 5-1: Consumed Energy for 20, 30 and 40 nodes

Number Of Nodes	Consumed Energy in OLSR	Consumed Energy in AODV
20	**0.933J**	**46.046J**
30	**2.307J**	**79.464J**
40	**5.287J**	**126.952J**

Table 5-2: Remaining Energy for 20, 30 and 40 nodes

Number Of Nodes	Remaining Energy in OLSR	Remaining Energy in AODV
20	**1999.06J**	**1953.95J**
30	**2997.69J**	**2920.53J**
40	**3994.71J**	**3873.04J**

As we observe, as the number of nodes are increasing the OLSR routing protocol is consuming less amount of energy when compared to AODV routing protocol, which proves that OLSR performs better than AODV in terms of energy efficiency.

An example snapshot of the results is shown below:

Figure 5-1: Remaining Energy and Consumed Energy in OLSR for 20 nodes

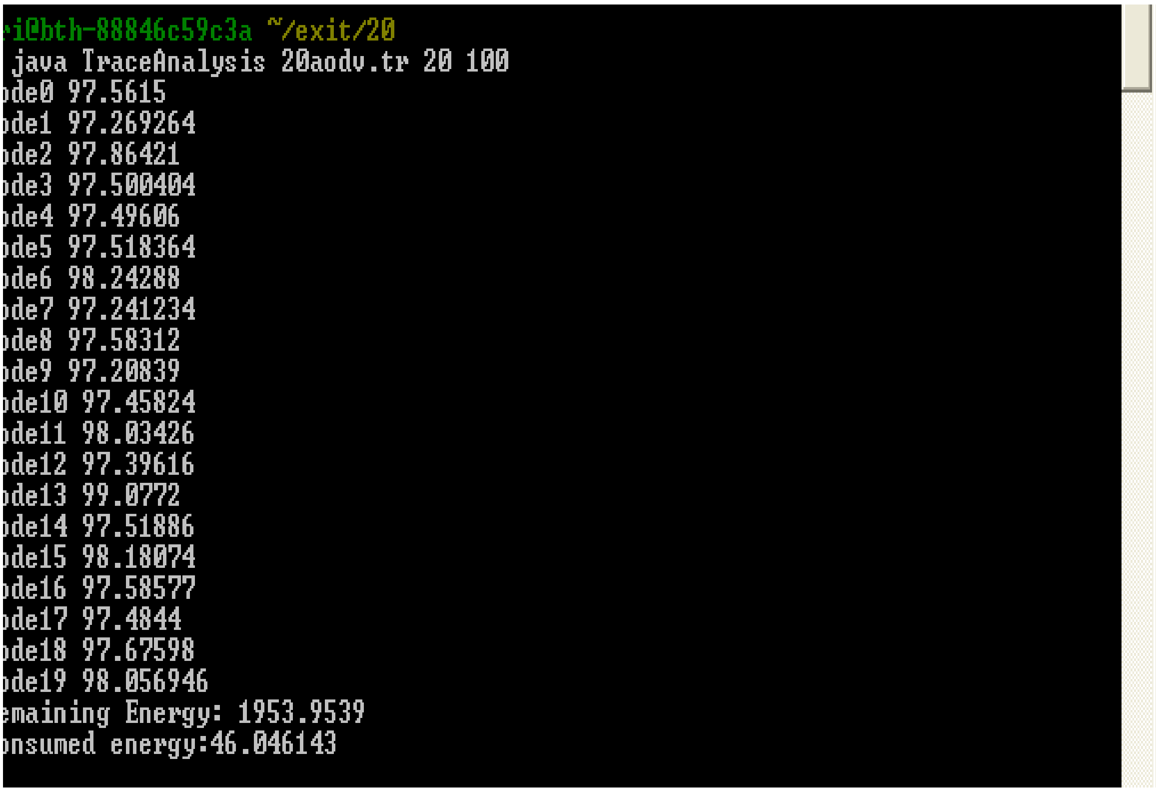
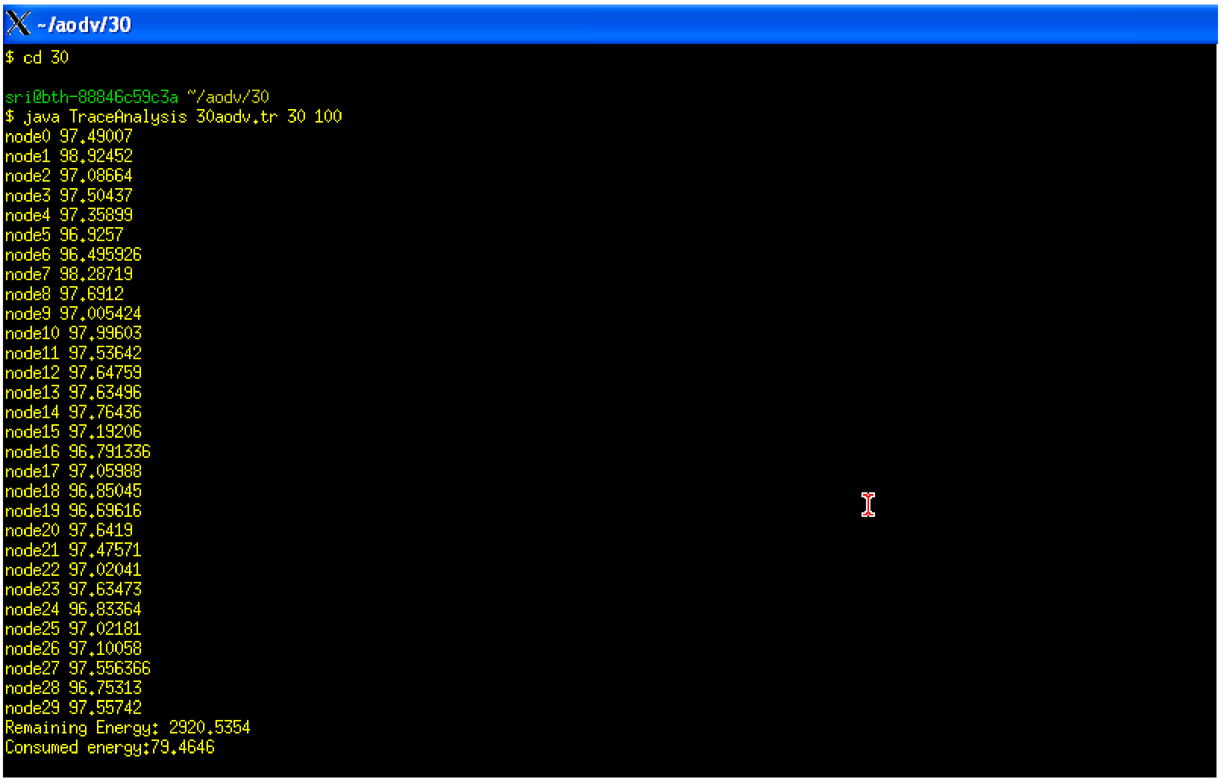
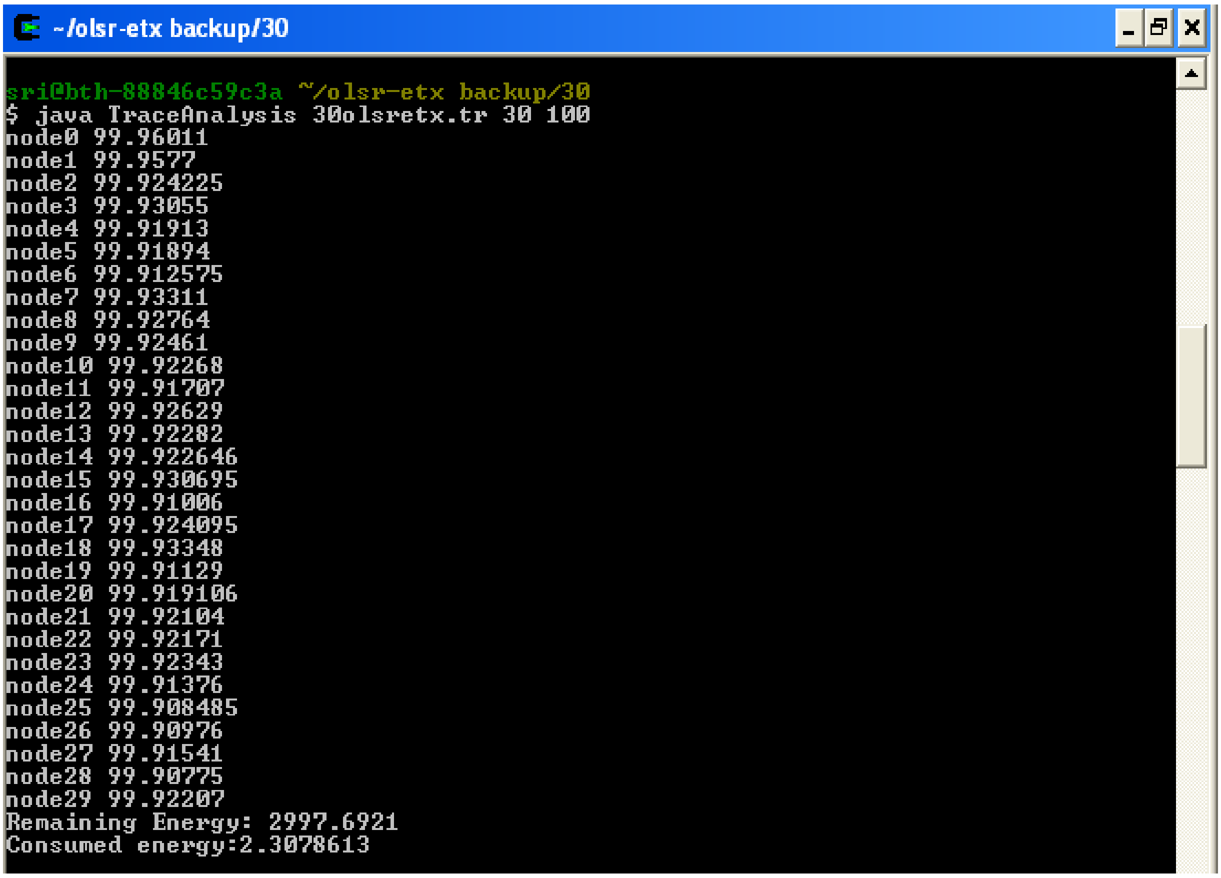


Figure 5-2: Remaining Energy and Consumed Energy in AODV for 20 nodes



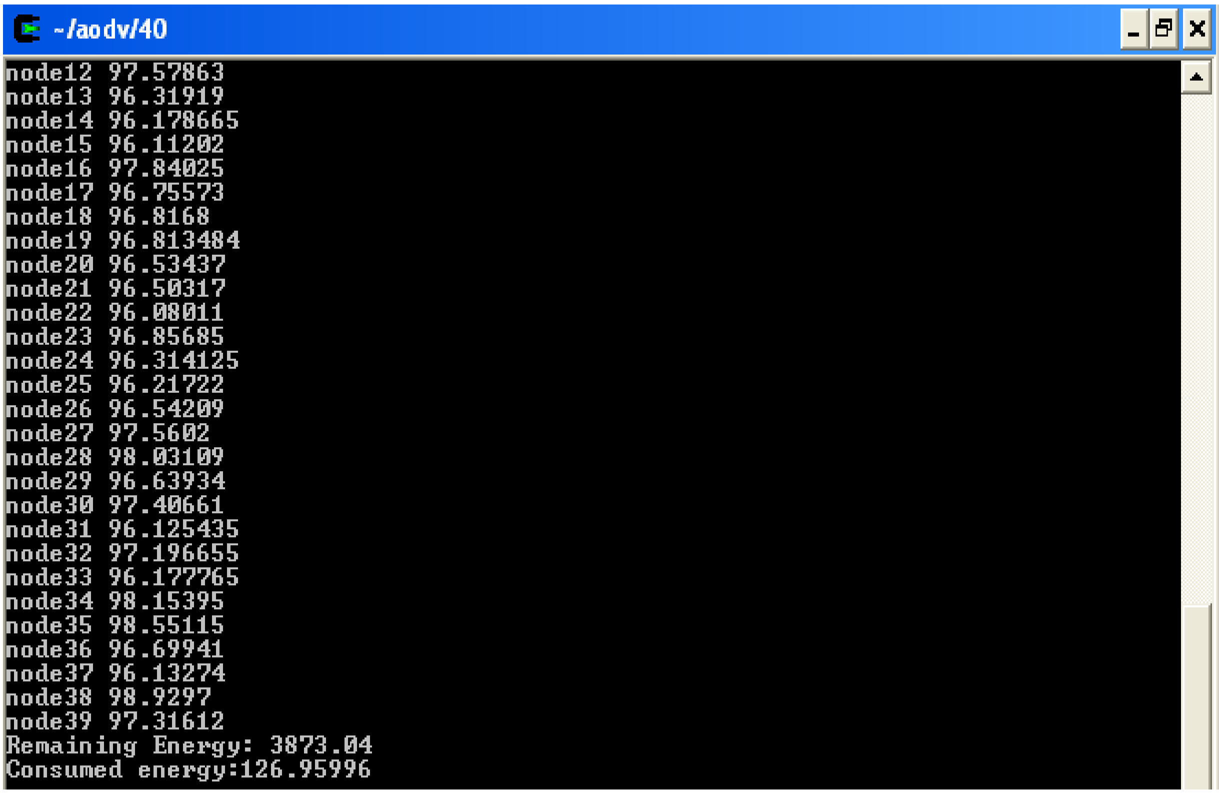
```
~/aodv/30
$ cd 30

sri@bth-88846c59c3a ~/aodv/30
$ java TraceAnalysis 30aodv.tr 30 100
node0 97.49007
node1 98.92452
node2 97.08664
node3 97.50437
node4 97.35899
node5 96.9257
node6 96.495926
node7 98.28719
node8 97.6912
node9 97.005424
node10 97.99603
node11 97.53642
node12 97.64759
node13 97.63496
node14 97.76436
node15 97.19206
node16 96.791336
node17 97.05988
node18 96.85045
node19 96.69616
node20 97.6419
node21 97.47571
node22 97.02041
node23 97.63473
node24 96.83364
node25 97.02181
node26 97.10058
node27 97.556366
node28 96.75313
node29 97.55742
Remaining Energy: 2920.5354
Consumed energy:79.4646
```

Figure 5-3: Remaining Energy and Consumed Energy in AODV for 30 nodes



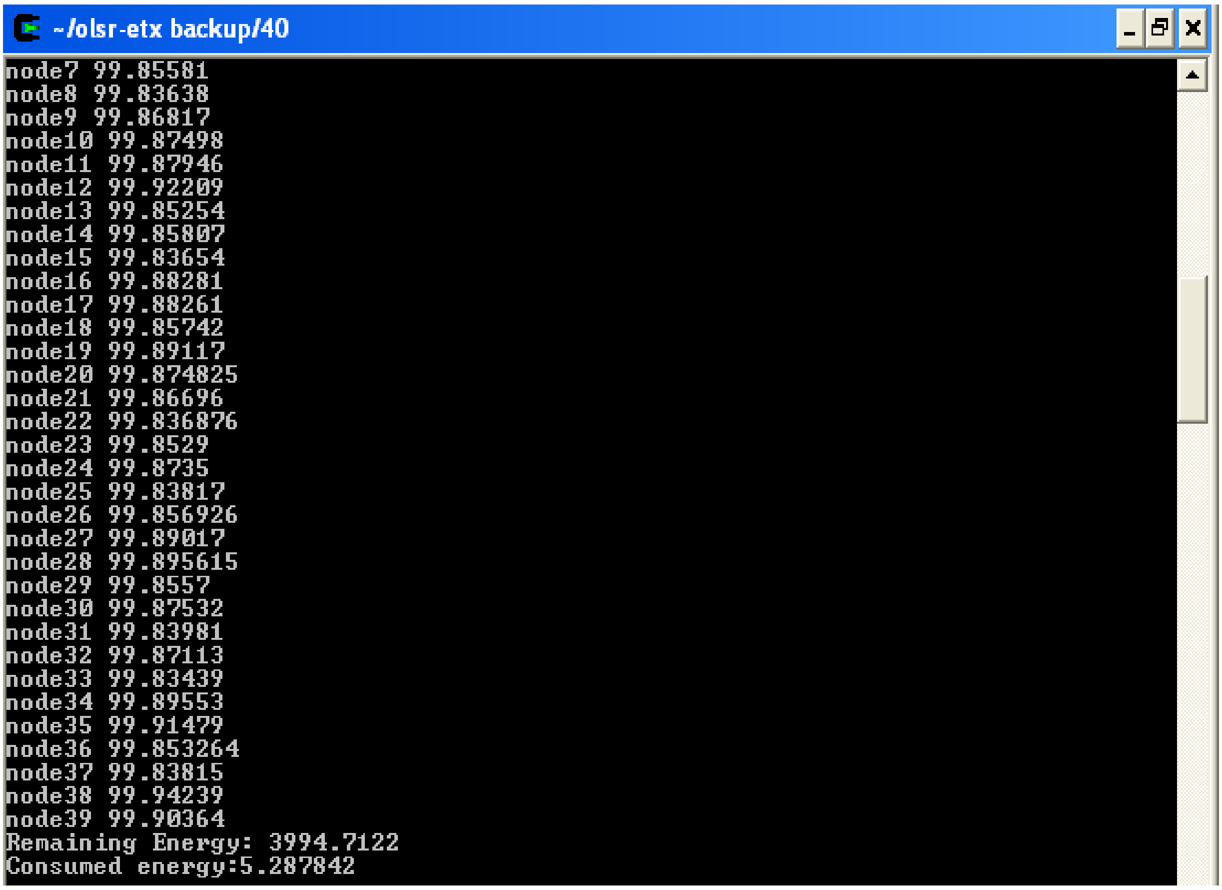
```
~/olsr-etx backup/30

sri@bth-88846c59c3a ~/olsr-etx backup/30
$ java TraceAnalysis 30olsretx.tr 30 100
node0 99.96011
node1 99.9577
node2 99.924225
node3 99.93055
node4 99.91913
node5 99.91894
node6 99.912575
node7 99.93311
node8 99.92764
node9 99.92461
node10 99.92268
node11 99.91707
node12 99.92629
node13 99.92282
node14 99.922646
node15 99.930695
node16 99.91006
node17 99.924095
node18 99.93348
node19 99.91129
node20 99.919106
node21 99.92104
node22 99.92171
node23 99.92343
node24 99.91376
node25 99.908485
node26 99.90976
node27 99.91541
node28 99.90775
node29 99.92207
Remaining Energy: 2997.6921
Consumed energy:2.3078613
```

Figure 5-4: Remaining Energy and Consumed Energy in OLSR for 30 nodes



```
~/aodv/40
node12 97.57863
node13 96.31919
node14 96.178665
node15 96.11202
node16 97.84025
node17 96.75573
node18 96.8168
node19 96.813484
node20 96.53437
node21 96.50317
node22 96.08011
node23 96.85685
node24 96.314125
node25 96.21722
node26 96.54209
node27 97.5602
node28 98.03109
node29 96.63934
node30 97.40661
node31 96.125435
node32 97.196655
node33 96.177765
node34 98.15395
node35 98.55115
node36 96.69941
node37 96.13274
node38 98.9297
node39 97.31612
Remaining Energy: 3873.04
Consumed energy:126.95996
```

Figure 5-5: Remaining Energy and Consumed Energy in AODV for 40 nodes



```
~/olsr-etx backup/40
node7 99.85581
node8 99.83638
node9 99.86817
node10 99.87498
node11 99.87946
node12 99.92209
node13 99.85254
node14 99.85807
node15 99.83654
node16 99.88281
node17 99.88261
node18 99.85742
node19 99.89117
node20 99.874825
node21 99.86696
node22 99.836876
node23 99.8529
node24 99.8735
node25 99.83817
node26 99.856926
node27 99.89017
node28 99.895615
node29 99.8557
node30 99.87532
node31 99.83981
node32 99.87113
node33 99.83439
node34 99.89553
node35 99.91479
node36 99.853264
node37 99.83815
node38 99.94239
node39 99.90364
Remaining Energy: 3994.7122
Consumed energy:5.287842
```

Figure 5-6: Remaining Energy and Consumed Energy in OLSR for 40 nodes

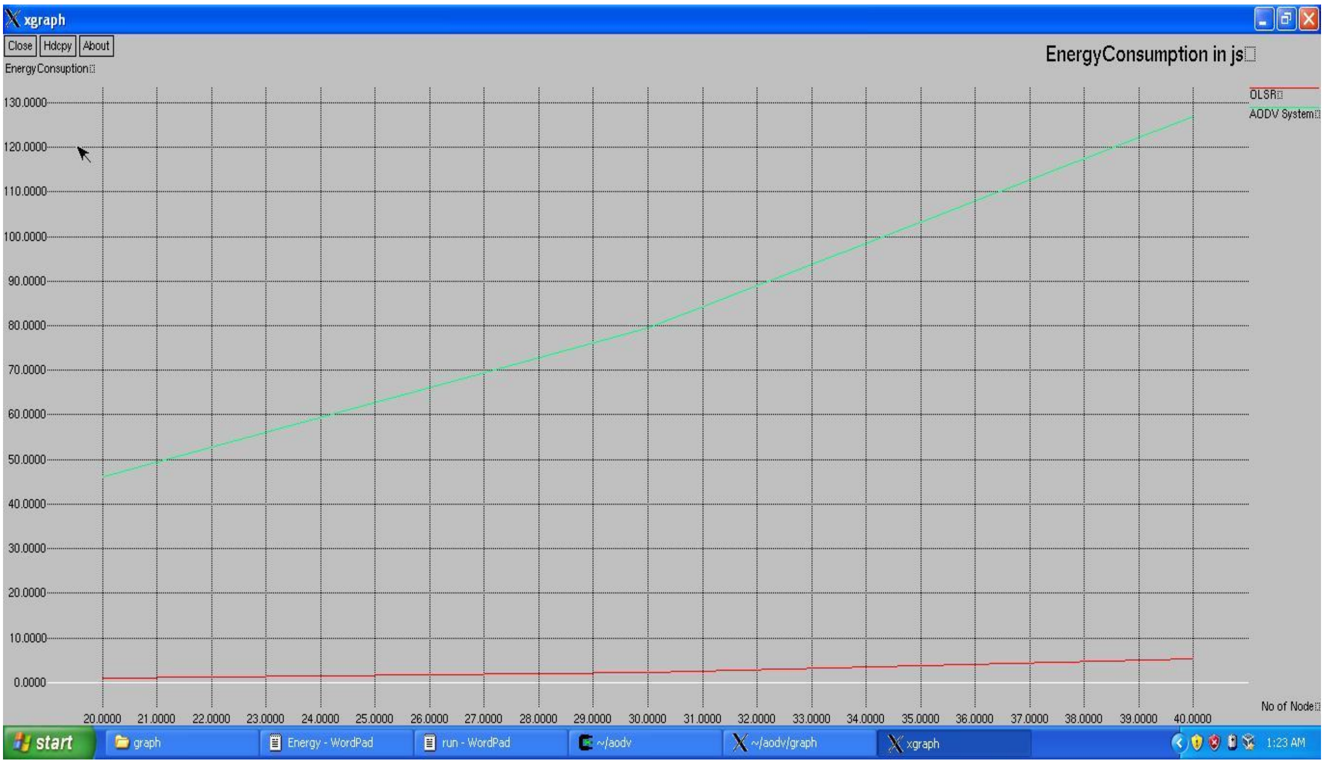


Figure 5-7: The graph showing energy efficiency comparison between OLSR and AODV protocol

5.1.2 Case B: For Multiple Simulations

As we observe, as the number of nodes are increasing in Case A the OLSR routing protocol is consuming less amount of energy when compared to AODV routing protocol, which proves that OLSR performs better than AODV in terms of energy efficiency. As said at the beginning of the discussion that we are also going to present the results for multiple simulations, the below results show the average and standard deviation of OLSR and AODV.

5.1.2.1 AVERAGE FOR AODV AND OLSR RESULTS:

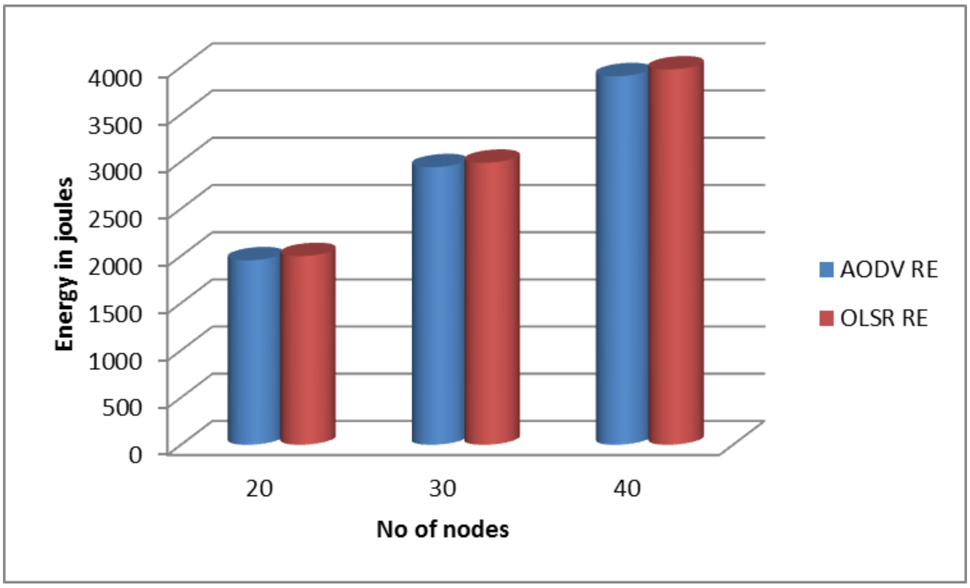


Figure 5-8: Average Remaining Energy Statistics of AODV and OLSR

The above figure 5-8 shows the Remaining Energy of AODV and OLSR protocols for 20 Nodes, 30 Nodes and 40 Nodes. Y-axis represents the Energy in Joules and X-axis represents number of Nodes. The total energy initialized in 20, 30, 40 nodes are 2000, 3000, 4000 Joules respectively, the average is calculated based on 10 simulations. For AODV protocol the remaining energy is 1953.825, 2939.915, and 3903.735. Similarly for OLSR protocol the remaining is 1998.53, 2986.524 and 3975.158. From the figure as the number of nodes in the network is increasing the remaining energy of OLSR protocol is more than AODV protocol.

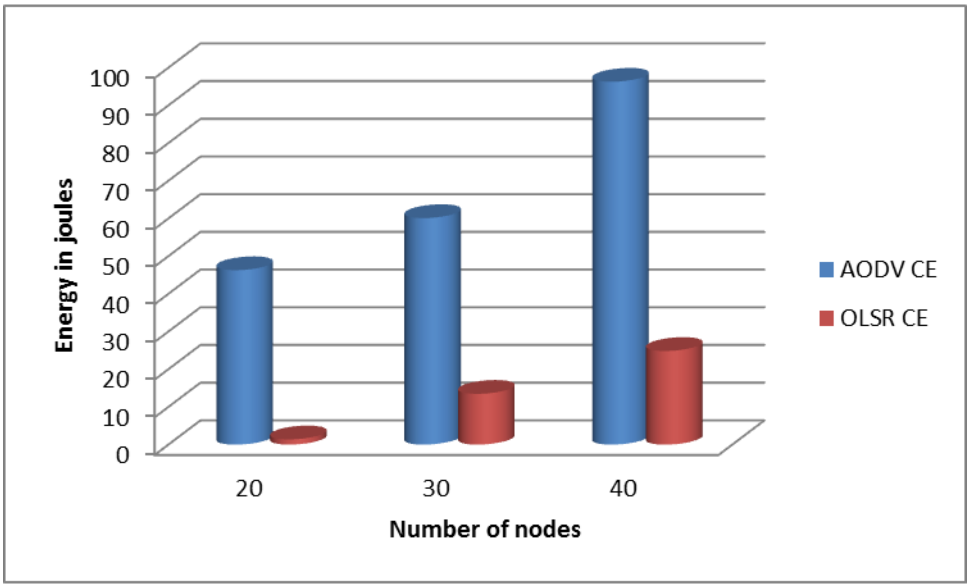


Figure 5-9: Average Consumed Energy Statistics of AODV and OLSR

The above figure5-9 show the Consumed energy of AODV and OLSR protocols for 20 Nodes, 30 Nodes and 40 Nodes. Y-axis represents the Energy in Joules and X-axis represents number of Nodes. The energy consumption in AODV protocol is more as the number of nodes is increasing in the network. As the energy consumption in AODV is 46.2748, 60.09021 and 96.26527 where as in OLSR is 1.3897, 13.4763 and 24.84176 for 20, 30, 40 nodes Scenarios respectively.

Table 5-3: Average values of AODV and OLSR Remaining Energy (RE) and Consumed Energy (CE)

No. of Nodes	AODV RE	OLSR RE	AODV CE	OLSR CE
20	1953,825	1998,53	46,2748	1,3897
30	2939,915	2986,524	60,09021	13,4763
40	3903,735	3975,158	96,26527	24,84176

5.1.2.2 STANDARD DEVIATION FOR AODV AND OLSR RESULTS:

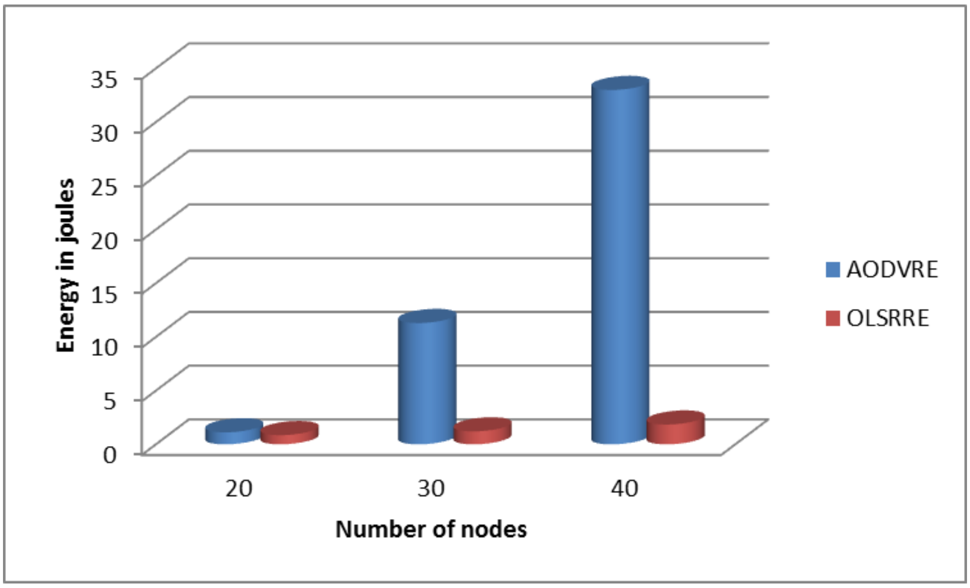


Figure 5-10: Standard Deviation for AODV and OLSR Remaining Energy

The above figure5-10 represents the standard deviation for AODV and OLSR Remaining energy based on 10 times of simulations. For the 20 Node, 30 Node and 40 Node scenarios standard deviations for AODV and OLSR are 1.115789, 11.29248, 32.98753 and 0.853853, 1.200593, 1.841714 respectively. From the values we can observe that in the case of OLSR the standard deviation is less compared to AODV, we can say that remaining energy in the case of AODV is deviating away from the average value. Where as in the case of OLSR the standard deviation is less and the values are close to the mean.

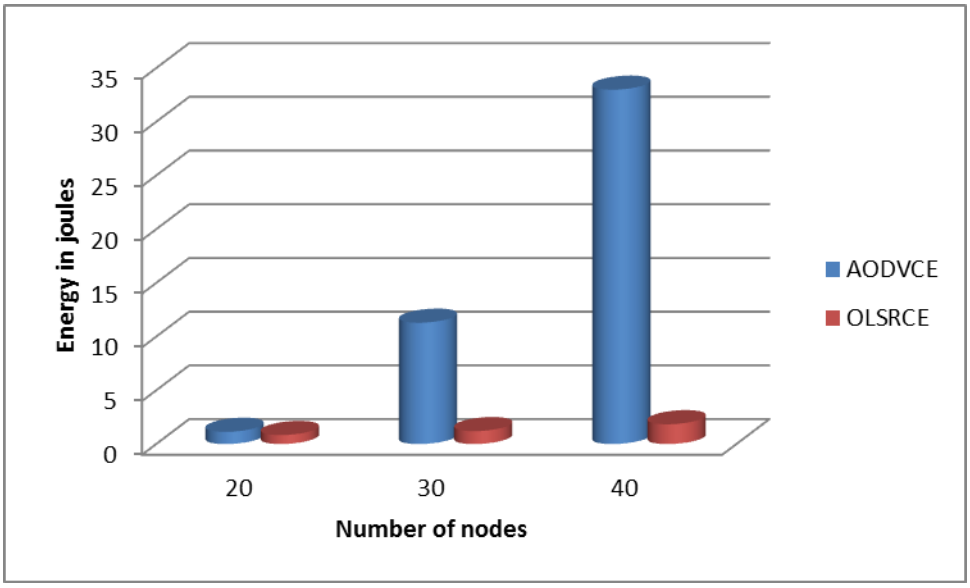


Figure 5-11: Standard Deviation for AODV and OLSR Consumed Energy

In the above figure5-11 describes the standard deviation of consumed energy for both AODV and OLSR protocols in the case of AODV the standard deviation is more compared to OLSR, as we know if the standard deviation is more the values are tending out from the average value, that means AODV protocol is having more energy consumption compared to the OLSR. The standard deviations for both AODV and OLSR for 20 Node, 30 Node and 40 Node are 1.134403, 11.29178, 32.98752 and 0.836263, 1.200446, 1.84193 respectively. In the case of OLSR the standard deviations are very less compared to AODV.

Table 5-4: Standard deviations for AODV and OLSR Remaining Energy (RE) and Consumed Energy (CE)

No. of Nodes	AODV RE	OLSR RE	AODV CE	OLSR CE
20	1.115789	0.853853	1.134403	0.836263
30	11.29248	1.200593	11.29178	1.200446
40	32.98753	1.841714	32.98752	1.84193

From the both cases, i.e. is from single simulation and from multiple simulations (average and standard deviation) we can infer that OLSR performs better when compared to that of AODV in terms of energy efficiency.

6 CONCLUSION AND FUTURE WORK

6.1 Conclusion:

The aim of this research is to tabulate the problems pertaining to energy consumption in base stations and know the emerging technologies that can be used in energy saving, due to the increased environmental pollution that has resulted from the rapid increase of the number of base stations. The literature review is done for RQ1 and RQ2, where RQ1 is focused in addressing problems related to energy consumption of base stations, where maximum amount of energy consumed at base stations are

- Power supply (7%)
- Power amplifier (65%)
- Air conditioning (18%)
- Signal processing (10%)

And RQ2 addresses the remedies to overcome the above said problems, some of the best technologies are reported and shown below which consumes less amount energy if implemented, they are

- Multiple Input Multiple Output MIMO Resource allocation strategies
- Self-Organizing and Optimising Networks SON
- Relaying and Multi-hop cellular
- Efficient power amplifiers and RF power delivery
- Two Tier Femto Macro Technology

For RQ3, we have done an experiment in NS2 to achieve energy efficiency in cognitive network by choosing routing protocols OLSR and AODV, where the experiment is done for both single and multiple simulations and deducted that OLSR is the best routing protocol compared to AODV because it consumes less amount of energy with the increasing number of nodes. The results may vary according to specified parameters and network environment.

6.2 Future Work:

As a part of future work, our evaluation process may be extended to resolve the issues pertaining to hardware design of base station, where energy is lot more consumed and also it would be interesting if new cognitive radio routing protocols are implemented on real networks and study the performance metrics of a network based on the industrial specifications.

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8 APPENDIX

8.1 APPENDIX - A

8.1.1 NS-2 Installation

1. After installing Cygwin, the first step in the installation of NS2 is to download the compressed file ns-allinone-2.31.tar.gz available on NS2 source homepage. This file contains all the libraries

- Tcl release 8.4.14
- Tk release 8.4.14
- Otcl release 1.13
- TclC release 1.19
- Ns release 2.31
- Nam release 1.13
- Xgraph version 12
- CWeb version 3.4g
- SGB version 1.0
- Gt-im gt-itm y sgb2ns 1.1
- Zlib version 1.2.3

2. Now we extract the files using the command

tar -zxvf ns-allinone-2.31

3. The installation folder ns2.31 contains the installation script which has to be installed.

cd ns-allinone-2.31 ./install

4. We install cognitive patch from the source website and we check for possible errors using the command.

. **/validate**

8.1.2 CRCN Patch to NS2:

The installation on CRCN patch to NS2, in order to integrate, one should follow these steps

1. Keep all the backup files of ns-allinone-2.31 in a folder.

2. Then from your internet trusted site download crcn.zip from Http://stuweb.ee.mtu.edu/~ljjialian/crcn.zip and then unzip it.

3. Then step into the working directory of ns-allinone-2.31/ns-2.31

4. Copy all the files in CRCN into their corresponding folders that are located in ns-allinone-2.31/ns-2.31/ and then replace them, only when if computer asks.

5. Then go to make file in ns-allinone-2.31/ns-2.31 and add the files
wcett/wcett_logs.o wcett/wcett.o\
wcett/wcerr_rtable.o wcett/wcett_rqueue.o\
mac/macng.o mac/maccon.o\
mac/macngenhanced.o\

6. Remain in ns-2.3.1 folder and run the common commands for recompiling the ns-2.31
make
make clean
sudo make install
And by the above steps one can be sure of installing crcn in ns2

7. One can check it by running the examples, folders that are present in ns-2.31
E.g-test4wcett.tcl, test4maccon.tcl

8.2 APPENDIX – B

This section of appendix gives the data regarding the average and standard deviation estimations for multiple simulations.

8.2.1 Average and Standard Deviation for AODV

Table 8-1: Average and Standard Deviation for AODV 20, 30and 40 nodes

	AODV 20Nodes		AODV 30Nodes		AODV 40Nodes	
	AODV RE	AODV CE	AODV RE	AODV CE	AODV RE	AODV CE
1	1955.954	44.046	2947.258	52.74194	3907.442	92.55786
2	1954.232	45.768	2947.187	52.81299	3899.29	100.7102
3	1953.062	46.938	2947.543	52.45703	3901.382	98.61816
4	1953.113	46.886	2936.8	63.19971	3901.773	98.22574
5	1953.693	46.307	2947.223	52.7771	3961.768	38.23169
6	1954.086	46.914	2941.371	58.68262	3961.304	38.6958
7	1954.017	45.983	2940.403	59.59668	3873.766	126.2339
8	1953.739	46.261	2911.392	88.60767	3877.754	122.2461
9	1951.686	48.314	2947.186	52.81298	3874.898	125.1016
10	1954.669	45.331	2932.787	67.21338	3877.968	122.0317
AVG	**1953.825**	**46.2748**	**2939.915**	**60.09021**	**3903.735**	**96.26527**
STD	**1.115789**	**1.134403**	**11.29248**	**11.29178**	**32.98753**	**32.98752**

8.2.2 Average and Standard Deviation for OLSR

Table 8-2: Average and Standard Deviation for OLSR 20, 30and 40 nodes

	OLSR 20Nodes		OLSR 30Nodes		OLSR 40Nodes	
	OLSR RE	OLSR CE	OLSR RE	OLSR CE	OLSR RE	OLSR CE
1	1999.933	0.067	2987.364	12.636	3977.434	22.566
2	1998.252	1.748	2986.924	13.08	3974.712	25.28784
3	1998.799	1.201	2987.442	12.558	3975.798	24.20166
4	1997.114	2.886	2988.366	11.634	3973.14	26.85962
5	1998.691	1.309	2985.409	14.591	3976.786	23.21411
6	1998.44	1.56	2986.733	13.267	3973.25	26.74976
7	1997.524	2.476	2984.101	15.899	3975.792	24.20166
8	1999.347	0.653	2986.329	13.671	3971.967	28.03296
9	1999.198	0.802	2986.817	13.183	3975.655	24.34497
10	1998.003	1.195	2985.756	14.244	3977.041	22.95898
AVG	**1998.53**	**1.3897**	**2986.524**	**13.4763**	**3975.158**	**24.84176**
STD	**0.853853**	**0.836263**	**1.200593**	**1.200446**	**1.841714**	**1.84193**