Graduate School ETD Form 9
(Revised 12/07)

PURDUE UNIVERSITY
GRADUATE SCHOOL
Thesis/Dissertation Acceptance

This is to certify that the thesis/dissertation prepared

By Birhan Payli

Entitled

SCALABLE AND QoS NETWORKING SOLUTIONS FOR TELEMEDICINE

For the degree of Master of Science

Is approved by the final examining committee:

Dr. Arjan Durresi
Chair

Dr. Mihran Tuceryan

Dr. Yuni Xia

To the best of my knowledge and as understood by the student in the *Research Integrity and Copyright Disclaimer (Graduate School Form 20)*, this thesis/dissertation adheres to the provisions of Purdue University's "Policy on Integrity in Research" and the use of copyrighted material.

Approved by Major Professor(s): Dr. Arjan Durresi

Approved by: Dr. Shiaofen Fang 07/28/2010
Head of the Graduate Program Date

Graduate School Form 20
(Revised 1/10)

PURDUE UNIVERSITY
GRADUATE SCHOOL

Research Integrity and Copyright Disclaimer

Title of Thesis/Dissertation:

SCALABLE AND QoS NETWORKING SOLUTIONS FOR TELEMEDICINE

For the degree of Master of Science

I certify that in the preparation of this thesis, I have observed the provisions of *Purdue University Teaching, Research, and Outreach Policy on Research Misconduct (VIII.3.1)*, October 1, 2008.*

Further, I certify that this work is free of plagiarism and all materials appearing in this thesis/dissertation have been properly quoted and attributed.

I certify that all copyrighted material incorporated into this thesis/dissertation is in compliance with the United States' copyright law and that I have received written permission from the copyright owners for my use of their work, which is beyond the scope of the law. I agree to indemnify and save harmless Purdue University from any and all claims that may be asserted or that may arise from any copyright violation.

Birhan Payli

Printed Name and Signature of Candidate

07/28/2010

Date (month/day/year)

*Located at http://www.purdue.edu/policies/pages/teach_res_outreach/viii_3_1.html

SCALABLE AND QoS NETWORKING SOLUTIONS FOR TELEMEDICINE

A Thesis

Submitted to the Faculty

of

Purdue University

by

Birhan Payli

In Partial Fulfillment of the

Requirements for the Degree

of

Master of Science

August 2010

Purdue University

Indianapolis, Indiana

For RUP

who, miraculously, never gave up hope on me.

ACKNOWLEDGMENTS

I am extremely thankful to my supervisor, Professor Arjan Durresi, whose encouragement, guidance, and support from the initial to the final level enabled me to develop a deeper understanding of the subject.

I would like to thank my committee members, Professor Yuni Xia and Professor Mihran Tuceryan for agreeing to be on my committee and devoting their time.

I would also like to thank the staff of the TCM Writing Center for their hours of assistance in the creation of this work, especially Ellen Harley.

TABLE OF CONTENTS

Page

Page

ABSTRACT

Payli, Birhan M.S., Purdue University, August 2010. Scalable and QoS Networking Solutions for Telemedicine. Major Professor: Arjan Durresi.

Retrieving data from a patient in real-time is a challenging operation, especially when requiring information from the network to support the patient's health. A real-time healthcare system process is conducted with a continual input, processing, and output of data. It needs to have the ability to provide different priorities to different applications, users, or data flows, or to guarantee a certain level of performance to a data flow.

The current Internet does not allow applications to request any special treatment. Every packet, including delay-sensitive audio and video packets, is treated equally at the routers. This simplest type service of network is often referred to as best effort, a network service in which the network does not provide any guarantees that data is delivered or that a user is given a guaranteed QoS level or a certain priority.

Providing guaranteed services requires routers to manage per-flow states and perform per-flow operations. Such network architecture requires each router to maintain and manage per-flow state on the control path, and to perform per-flow classification, scheduling, and buffer management on the data path. This complicated and expensive network architecture is less scalable and robust than today's modern stateless network architectures such as Random Early Dropping (RED) for congestion control, DiffServ for QoS, and the original IP network.

This thesis introduces a new DiffServ-based scheme of IP bandwidth allocation during congestion, called Proportional Allocation of Bandwidth (PAB) which can be used in all networks. In PAB scheme, the bandwidth is allocated in proportion to Subscripted Information Rate (SIR) of the competing flows. PAB implementation uses multiple token buckets to label the packets at the edge of the network and multilevel threshold queue at the IP routers to discard packets during congestion.

CHAPTER 1 INTRODUCTION

Medical patients today face a variety of conditions that are both difficult and costly to diagnose and treat. With the cost of getting treatment from medical experts or healthcare facilities, the use of information technology is urgent in helping control and potentially reduces medical costs.

However, telemedicine or more precisely, communications and information technologies for the delivery of the clinical care, healthcare information system technology also comes with its own costs. Creating healthcare systems are complicated works and require expert system configurations and applications. Although these sophisticated system architectures can guarantee end-to-end QoS on networks, they come with a high price. For example, the Integrated Service (IntServ) model of Internet is one of the guaranteed delivery architectures already set up in almost every computer in use today. However, it is expensive to construct due to its per-flow-state requirement.

IntServ network architecture requires each router to maintain and manage per-flow state on the control path, and to perform per-flow classification, scheduling, and buffer management on the data path. Also, the nature of its structure makes this service model of Internet less scalable and robust than today's modern stateless network architectures, such as Random Early Dropping (RED) for congestion control, Differentiated Service (DiffServ) for QoS, and the original IP network.

The current Internet does not allow applications to request any special treatment. Every packet, including delay-sensitive audio and video packets, is treated equally at the routers. This simplest type of network service is often referred to as best-effort, a network service in which the network does not provide any guarantees that data is delivered or that a user is given a guaranteed QoS level or a certain priority.

Healthcare systems are real-time processes conducted with a continual input, processing, and output of data. Health data retrieving from a source has to be processed in a small specific time period; otherwise, it creates problems for the system and along with danger for the source if it is a living subject. These characteristic of real-time data retrieving over the Internet is the main reason real-time applications are extremely challenging processes. Additionally, these types of applications also need to have the ability to provide different priorities to different applications, users, or data flows, or to guarantee a certain level of performance to a data flow. Under these requirements of real-time healthcare systems, the DiffServ service model has been developed.

To provide simple best-effort service, core routers do not need to maintain state information of the flow of packets. However, as mentioned above, in the IntServ model, state information must be maintained for per core routers on the path from source to destination. DiffServ lies on between these two extreme service models. DiffServ maintains only a constant amount of state per router; it provides a simple, scalable, and coarse-grained mechanism for classifying, managing network traffic, and providing QoS guarantees on IP networks [18] [19] [20].

In general, Internet service providers (ISPs) are expected to make service guarantees to their clients. In some cases, such as a real-time healthcare system, the clients have a specific application that requires such service and they buy a package from the ISP that meets the needs of the application.

Since different users can ask for different service requirements, a user may pay more for a subscription with high privilege than a user with a lower rate subscription. In the case of congestion, a user with the higher privilege will be allocated more bandwidth and will be allowed through before lower rate customers of the ISP. For some healthcare system applications this might be fair, but for a real time healthcare system it is not acceptable. For fair behavior, a different method of bandwidth allocation during congestion on the network, Promotional Allocation of Bandwidth (PAB), is proposed in this thesis study.

The bandwidth allocations and dropping mechanism of network communication are mostly based on the max-min fairness principle, especially if the sizes of the jobs or tasks vary. The bandwidth resources are allocated to data rates in order of increasing demand. No data rate receives more than its required rate capacity. Data rate with large sources split the remaining resource. In other words, small data rate sources get all their required bandwidth resource, and the remaining bandwidth is equally split between the large resources. This is a fair way not to allow large sources to be favored over other sources.

PAB creates a new method of bandwidth allocation in which bandwidth must be allocated in proportion to the Subscripted Information Rate (SIR) of the competing flows. Storing the state of the flow in the interior of the network is not necessary in PAB implementation. Instead, the ratio of a flow’s data rate to its SIR is encoded in the form of a label on its packets at the first network element. This would be a boundary (edge) router as ingress of a wireless network. At the interior of the network, these labels are used by the routers for differentiating between packets during congestion. A wireless router drops packets based on these labels and the current level of threshold in the router. PAB, like DiffServ, also lies on the middle of the service model scale between the best-effort model and the IntServ model of the Internet; however, it has different congestion control strategy as ratio of a flow’s data rate to its SIR.

In a real-time healthcare system, retrieving data strongly depends on the bandwidth allocation to the source. When multiple sources relate to a healthcare system, bandwidth allocation must be divided between sources fairly. Since PAB has the ability to provide different treatment to different priority classes, it is also able to provide fair shares of the bandwidth during the network congestion.

Sources in healthcare systems, most of the time, are living subjects; more precisely, they are patients who have different reasons for monitoring their health. Some patients have specific health issues which need to be observed very closely. However, others are routinely observed by healthcare experts in order to stay healthy. With this in mind, some common health issues the world is facing today should be examined.

According to the International Diabetes Association study, 23.6 million people or 7.8% of the population of the United States have diabetes [1]. People with diabetes should check their blood sugar daily by taking a blood sample. Most of the time blood sugar testing can be conducted at home with an over-the-counter blood test kit by the patient or caregiver. Although over-the-counter blood test kits give the ability of self-testing to patients, which also provides the freedom of making their own decision about whether they need professional help, most of the time people with certain illnesses need a health expert’s help for taking a blood sample. For example, a patient with risk of stroke, heart disease, kidney disorder, or liver problem may be observed frequently by performing blood analysis and supervised carefully by health specialists [12] [13] [23] [24].

According to [2] Sudden Infant Death Syndrome (SIDS) is the third leading cause of infant death in the United States and the first leading cause of death among infants aged 1-12 months. Unfortunately, all over the world millions of babies die each year from the unknown causes of SIDS, leaving behind heartbroken parents and puzzled medical experts.

Almost all SIDS deaths occur without any warning or symptoms of health problems. During the hospital stay, all newborns' vital signs are observed to check for any health issues that are not visible immediately after delivery. However, after they leave the hospital, babies still need to be monitored carefully for the first 6-12 months.

According to Federal Interagency Form on Aging Related Statistic [3] in 2006, 37 million people aged 65 and older lived in the United States, or 12% of the total population. Over the 20th century, the older population grew from 3 million to 37 million. The oldest-old population (85 and over) grew from just over 100,000 in 1900 to 5.3 million in 2006.

Observing body energy and performance from vital signs is important for many reasons. For example, when people age, no matter how healthy they are, body muscles begin to weaken. This situation makes daily life dangerous for elderly people. Besides having difficulty lifting, pulling, pushing, or carrying things, most dangerously, they might also fall down and cause serious harm to their body, or even life-threatening injuries. As a precaution, elderly people's body performance should be checked frequently.

Evaluating body energy and performance from vital signs also helps sport scientists and coaches in almost every discipline to determine the capability of the body muscles of athletes. For example, blood lactate can be measured to evaluate the physical performance of athletes; a coach can set up the best training plan to put the athlete in the right training zones, and at the same time, collect data from every step of athlete's practice performance [4].

Additionally, this type of observation is good for military personal during their hours of training, for physical laborers such as, in the mining industry, oil and gas extraction, off shore oil rigs, or the construction industry. Depending on the patient's condition, clinic visitations for body evaluation may be difficult or, in some cases, may not be possible. Observing the chemical balance of body muscles should be conducted remotely to reduce to clinic visitations.

A number of different types of invasive or non-invasive vital sign tests monitor the conditions inside the human body. For example,

- for profiling cardiovascular risks, pulse rate, blood pressure, body temperature, and respiratory rate, are observed; also, the blood lipids, as well as glucose tests are performed [6].
- for diabetics, the blood sugar is checked on a daily basis
- for a person with kidney disease, mainly the creatinine, renin, albumin, prealbumin, phosphate, and potassium levels in the blood are observed [6].
- for liver diseases, the liver enzymes, AST and ALP, alkaline phosphatase (ALP), albumin, bilirubin, and total protein levels in the blood are measured to detect liver damage or disease [6] [14].

These are just a few of the common and well-known body health examinations that help to diagnose patients' physical health. In addition to these, in recent years, research and several studies in medicine indicate that some new kinds of blood tests are developing to diagnose mental illnesses such as depression, schizophrenia, and bi-polar disorder in their early stages, as well as Alzheimer's and Parkinson's diseases [22].

Scientists in bio-medical, computer, electric and electronic fields have seen the impact and unlimited advantages of integrated wireless technologies on people's health and living standards. Several studies have been done to address the medical sensors and remote sensory data collections to provide better healthcare systems. For example, implanted and wearable sensor applications with their monitoring capabilities have become extremely popular especially in healthcare [5] [7] [8] [11], military [15], home security, as well as monitoring environmental conditions such as planetary exploration, chemical and biological detection, or environmental monitoring in the ocean or atmosphere.

Health sensors and wireless network technologies such as WLAN, WiMAX, Ad Hoc networks, satellite, and cellular networks can be utilized to create a next generation of ubiquitous and pervasive healthcare systems [8] [11] [5] [16].

Wearable and implanted sensors can be thought of as the first level of a real-time healthcare information system. The personal and local area networks follow the sensor as the second level of healthcare hierarchy. And finally, wide area and other networks complete the list as the third level of healthcare systems.

This thesis study has seven chapters. Chapter 1 is the Introduction providing background details and supporting evidence for the study. Chapter 2 will continue with examples of common health issues and the importance of health screening tests on adults and children. Chapter 3 will introduce three tiers of a Wireless Healthcare System Network. It will introduce as the first tier several sensor applications in use today and give great detail on health sensors and their use in living subjects. Personal and local area networks will be examined as the second tier of healthcare systems. And finally, wide area and several other networking technologies will be introduced as the third tier.

Chapter 4 is about Quality of Service (QoS) of the Internet and its requirements. In this chapter will be a brief description of some techniques which are commonly in use in today's Internet, such as resource allocations, scheduling mechanisms, and policing mechanisms. Also, it will provide vivid examples and explanations about the chain of QoS. Additionally, it will compare different service models of Internet, examine their scalable abilities, and look at their business aspects. Chapter 4 will also give detailed information about DiffServ architecture and its routers.

Chapter 5 will focus on Scalable Proportional Allocation of Bandwidth (PAB), discussing its structure, implementation, and packet labeling methodology. Additionally in this chapter, brief instructions on PAB's multiple token buckets usage with a graphic composition will be given.

Moreover, the packet dropping mechanism at core routers, as well as three sets of label fractions, will be stated in this chapter.

The contents of chapter 6 include a section where the simulation results will be provided. In this section, PAB will be compared with Random Early Dropping (RED) in a set of source experiments: UDP and TCP. These two different sources will be run for single congested link and for multiple congested links. Experiment results will be introduced graphically in this chapter.

The conclusion, Chapter 7, is the last chapter of the thesis; it will be followed by the references.

CHAPTER 2 COMMON HEALTH ISSUES

Blood (Screening) Test

Blood in the human body gives several clues that lead the medical doctors on the right path about physiological and biochemical health, or about health risks. Blood tests help individuals and health professionals to learn more about the body and detect potential problems in early stages when treatment or changes in personal habits can be most effective. The goal of the blood testing for diseases is to control symptoms, reduce complications, and slow the progression of the disease. Blood components and their analysis can vary from person to person for several reasons [13] [25] [26].

- Sex, age, and race are the main factors that make individuals differ internally and externally from each other.
- Dietetic preference, including alcohol intake, creates changes in the blood components from person to person.
- Prescription drugs or over-the-counter drugs display different outcomes in the blood [13] [14].
- The degree of physical activity affects the blood results. For example, athletes' blood lactate can be measured to evaluate the physical performance while exercising [5].

Blood Tests for Certain Illnesses

Diabetes: One of the most common diseases that continually need to be monitored by blood testing is diabetes. People with diabetes, either type-1 or type-2, cannot balance insulin production in their body. When the insulin level of the body is imbalanced, the body can produce too little or too much insulin. The glucose in the blood cannot move into the cells and glucose collects in the blood. Over time, these high glucose levels can cause serious complications such as blindness, neuropathy, microangiopathy, macroangiopathy, kidney damage, cardiac complications, ulcers, or uncontrollable heart rate and blood pressure, which can lead to heart failure, coronary artery disease, myocardial infarction, or stroke. This life threatening illness requires frequent testing for blood sugar (blood glucose) levels sometimes twice a day, and in some advanced cases, as frequently as every hour or more [6] [12] [14] [23] [24].

Heart Diseases*:* The frequency of blood tests increases depending on the severity of a patient's illness. People living with any type of heart diseases are at greater risk of stroke and sudden death. "As of 2007, cardiovascular disease is the leading cause of death in the United States, England, Canada, and Wales, killing one person every 34 seconds in the United states alone [20]."

Cardiovascular diseases need to be followed very closely. Patients' vital signs sometimes should be monitored every second of their lives. Their body responses to certain medicines also require close observation by healthcare professionals [6].

Some cardiovascular patients are able to monitor their own vital signs using several non-invasive and easy-use devices by themselves without any health professionals' help, for example, a blood pressure device, hand carried electrocardiography or hand carried cardiac ultrasound. However, they may fail to indicate specific cardiac abnormalities that provide a conclusive diagnosis for emergency care.

For example: Blood lipids such as cholesterol, HDL-C, LDL-C, triglycerides, or VLDL-C are often ordered to determine risk of coronary heart disease. They are tests that have been shown to be good indicators of whether someone is likely have a heart attack or stroke caused by atherosclerosis. Pre-diabetic metabolic syndrome as well as diabetes can also cause cardiovascular complications. For that reason, blood glucose and insulin levels also need to be checked at certain intervals in at-risk patient groups. Blood electrolytes levels also can affect cardiac conductivity [6].

Potassium is one of the components in cardiac functions that even a slight decrease of its level in the blood can cause abnormal electrical activity in the heart. On the other hand, excessive potassium in the blood usually indicates poor kidney function that also may cause abnormal and even fatal abnormalities in the heart rhythm [10] [20].

Kidney Diseases: Creatinine, renin, albumin, prealbumin, phosphate and potassium levels need to be monitored regularly by a medical doctor. These parameters could reflect kidney function and disease. These tests also help to monitor kidney function and the effectiveness of the treatments in these patient groups if they are under certain drug therapies. [6] [21] [27].

For example creatinine is a waste product in the blood created in muscle cells during physical activities. A healthy kidney does not let the creatinine build up in the blood but separates creatinine from blood and transfers it into the urine. However, if the kidneys cannot work properly the creatinine level in the blood elevates and indicates that the kidneys are not working at full strength [27].

More chronic illnesses also require regular blood testing to observe the body’s health. For example, depending on the severity of the individual’s case, all Hepatitis, (A, B, and C), hemochromatosis (genetic defect), cirrhosis patients, as well as fatty liver patients require blood tests to check the condition of the liver [6].

Blood tests are one of the major medical applications that help medical doctors to detect potential problems in one's body. Performing blood tests lets the medical doctors indicate the symptoms of certain illnesses and take necessary precautions to minimize the risks.

Newborn Blood (Screening) Test

All newborns will have a simple blood test to check for disorders that are not visible immediately after delivery. These disorders can be genetic, metabolic, blood-related, or hormone-related. Also, disorders can vary from baby to baby depending on the baby's sex, race, and geographical area where the baby lives. Some disorders are more common in some regions of the world, which makes testing more important.

Possible newborn disorders may include:

Phenylketonuria (PKU) is an inherited disease in which the body cannot metabolize a protein called phenylalanine, "essential" amino acids. Without treatment, PKU can cause mental retardation [28].

Congenital hypothyroidism is a condition in which the baby is born with too little thyroid hormone. Low thyroid hormone levels can lead to cognitive development problems and poor physical growth.

Galactosemia, is an inherited disorder. The baby is unable to metabolize galactose, a milk sugar. Without treatment, galactosemia can be life threatening. Symptoms may begin in the first two weeks of life.

Sickle cell anemia is a hereditary anemia marked by abnormal crescent-shaped red blood cells which are deficient in oxygen [29]. Early diagnosis of sickle cell anemia can help lower some of the risks which include severe infections, blood clots, and stroke [30].

Maple syrup urine disease is another inherited disorder which is caused by an inability of the body to properly process certain parts of protein called amino acids. The name comes from the characteristic odor of maple syrup in the baby's urine [28]. It is life-threatening as early as the first two weeks of life. Even with treatment, severe disability and paralysis can occur.

Homocystinuria this inherited disorder causes mental retardation, bone disease, and blood clots. It is caused by a deficiency of an enzyme necessary to digest an amino acid called methionine.

Biotinidase enzyme deficiency disorder is characterized by a deficiency of the biotinidase enzyme. This enzyme is important in metabolizing biotin, a B vitamin. Lack of the enzyme can lead to severe acid build up in the blood, organs, and body systems.

Congenital adrenal hyperplasia is an inherited disease of the adrenal glands. Babies born with congenital adrenal hyperplasia (CAH) cannot make enough of the hormone cortisol, which helps control energy, sugar levels, blood pressure, and how the body responds to the stress of injury or illness. CAH may also affect the development of the genitals and the hormones of puberty.

Medium chain acyl-CoA dehydrogenase (MCAD) deficiency is a disorder of fatty acid oxidation which can cause sudden death in infancy and serious disabilities in survivors, such as mental retardation. Moreover, newborns must be screened *for congenital toxoplasmosis* and cystic fibrosis [28] [31] [30].

Sudden Infant Death Syndrome (SIDS)

SIDS deaths occur in children between two months and four months of age. Sudden infant death syndrome rarely occurs before one month of age or after six months.

Newborns are safe and protected while they are in the healthcare facilities. However, how safe will the baby be at home? What could be more painful than new parents facing the sudden death of their baby from undefined causes? How would a healthcare giver feel after letting a healthy baby go home, and then finding out it has died?

A well-conducted a real time monitoring healthcare system can help the parents have less worry for their new born. The system can also reduce institutionalization, and cost Figure 1.

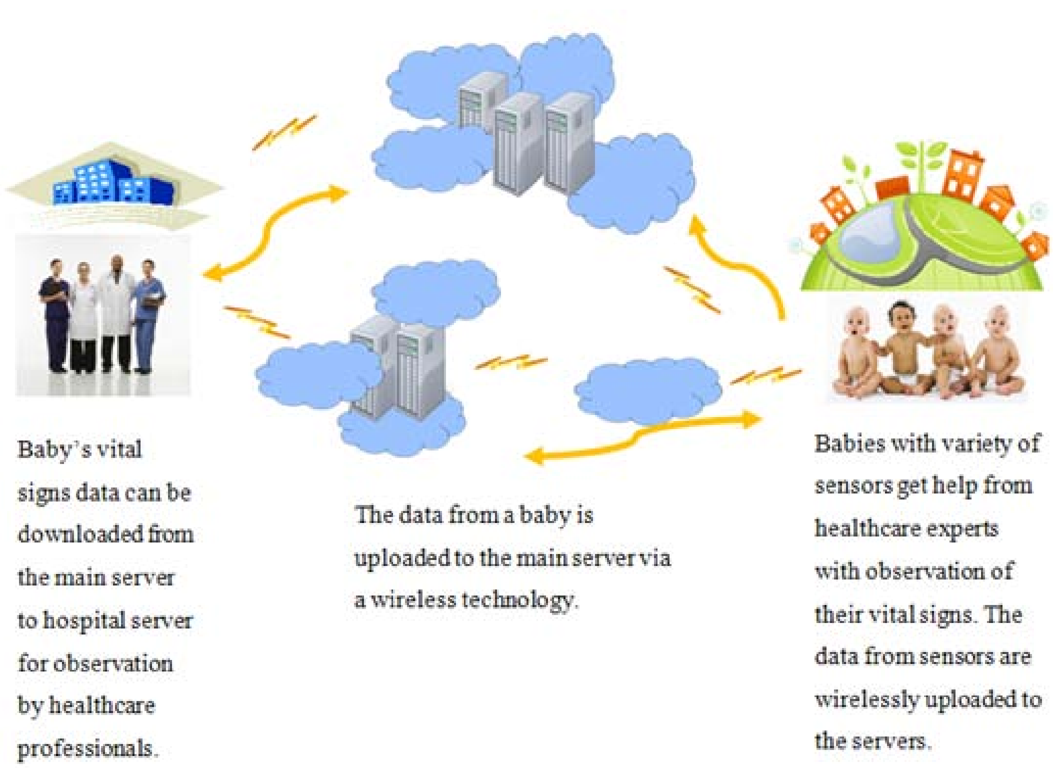

Figure 1: An abstract composition of Real-Time Observation Home System.

Newborn Observation System (NOHS) can read the vital signs properties from a body sensor and transfer the data to a remote health facility to diagnose a newborn's health values and, if necessary, warn the parents to take action while medical help is on the way.

Wireless real-time healthcare systems provide a sense of security, independence, and, to some degree, peace of mind from the worry of SIDS.

Blood Test for Evaluating Body Performance

Analyses of blood concentrations for performance are also important in healthcare and medicine; it is important for people who have lost their muscle or bone health, and most importantly, the people who are losing their movement ability because of age.

When people age, no matter how healthy they are, body muscles begin to weaken. This situation makes daily life dangerous for elderly people. Besides having difficulty lifting, pulling, pushing, or carrying things, most dangerously, they might also fall down and cause serious harm to their body, or even life threatening injuries. Lactate testing for body energy can be useful:

- for athletes during exercise
- for soldiers during their hours of training
- for workers who have to work long hours with body power at the places such as the mining industry, oil and gas extraction, or off shore oil rigs
- for individuals who have movement difficulties
- for the elderly who lose the body energy by aging

Blood properties, especially blood lactate measurement are used by sport scientists, coaches and athletes in almost every discipline to determine the capability of the muscles of an athlete. Using the wireless non-invasive real-time blood analysis, a coach can set up the best training plan to put the athlete in the right training zones, and at the same time, collect data from every step of athlete's practice performance as in Figure 2.

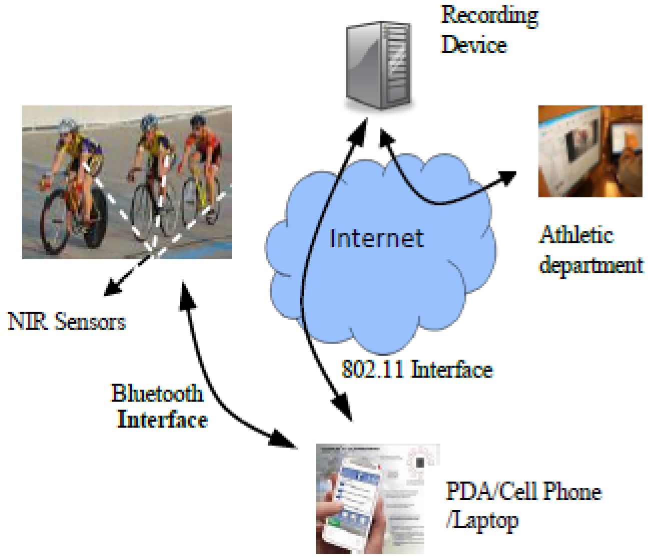

Figure 2: Using the wireless non-invasive real-time health analysis, a coach can set up the best training plan in order to put the athlete in the right training. Analyses of blood concentrations for performance are also important in healthcare and medicine.

Health care professionals can analyze, collect data, observe, and create exercises for individuals according to their muscle health with non-invasive blood testing in real time without using of heavy cables that may limit level of comfort and thus negatively influence the analysis results [4] [32] [33] [34] [35] [36].

CHAPTER 3 WIRELESS HEALTHCARE SYSTEM ARCHITECTURE

A healthcare system structure can be thought of in three tiers as seen in Figure 3. The first tier is wearable and implantable body sensors, which are the first step for providing health data from a living subject to personal or local area network traffics. The second tier represents personal and local area networks. These networks are a bridge between the health sensors and the Internet where health data can flow to a healthcare facility or a healthcare professional, anywhere around the world with the help of the wide area and other networks.

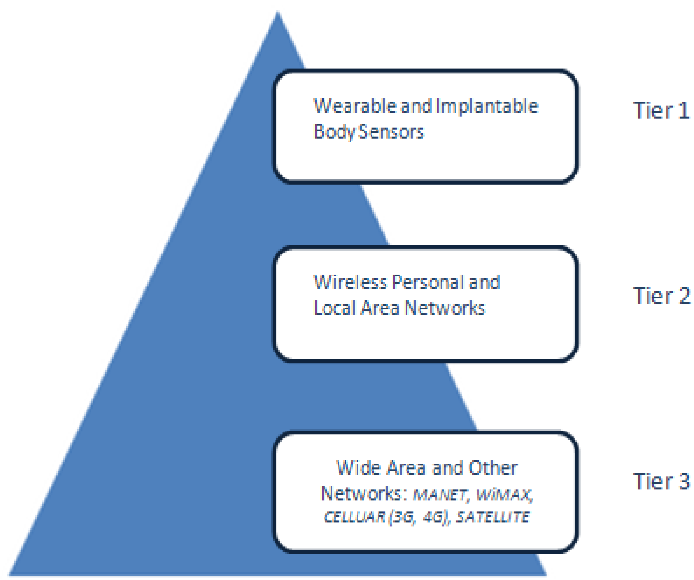

Figure 3: Three tiers of a healthcare network system show different wireless network technologies that can structure a wireless healthcare system when combined properly.

Wearable/Implanted Wireless Body Sensors

Tier 1 indicates a number of wireless health sensor technologies that help in many life-threatening environments such as chronically ill patients, military personnel, or miners. It can be applied to a variety of different disciplines such as healthcare, security, sports, entertainment, military, or industry. For example, analyses of blood concentrations for clinical condition are important in healthcare and medicine. People with certain illnesses require going to a laboratory environment where their blood can be analyzed. These clinical visitations are important for people who have illnesses such as diabetes, cardiovascular, liver, or lung diseases. Athletes who need to frequently evaluate their body performance.

Clinical visitations are also important for people who have lost their muscle flexibility, bone density or mobility because of illness or age [11]. However, frequent visitation to a medical clinic for blood tests is exhausting and expensive. This periodical process leads the patients to being depressed and, over time, careless about their health.

Several studies have been conducted by engineers and scientists about wireless sensors and networking in healthcare to help the frequent visitation struggles of people who live with certain health conditions. Most importantly, through these studies scientists hope to be able to give them a sense of security, independence, and, to some degree, give them the peace of mind which comes from being free from the worry of their illnesses.

Current Wireless Health Sensor Applications

Reading and observing vital signs with wireless sensors is the one of the most important and promising studies in last two decades. Healthcare systems are quite aware of recent advances in implanted and wearable wireless sensors. Many different types of sensor-equipped devices, noninvasive or invasive, can collect data from individuals, display them in real-time, store, analyze or send them to distance destinations with the help of wireless technology Figure 4.

Some of the sensor-equipped health devices are

- LUCAS (lenses ultra-wide-field cell monitoring array).
- Dark field microscopy.
- Defibrillator or pacemaker.
- Glucometers.
- NIRI (Near Infrared Imaging).
- NIRS (Near Infrared Spectroscopy).

Figure 4: Implanted/wearable sensor equipped devices such as; nano-sensor, defibrillator, dark field microscope, LUCAS imager (lenses ultra-wide-field cell monitoring array), and glucose monitoring [30] [31] [32] [42] [43] collect data patients, transmit it to a PDA, laptop, or PC where to be displayed, stored, and analyzed.

Implanted cardiovascular defibrillators (ICDs) improve survival rates and ultimately save heart patients with irregular heartbeats, especially those that could lead the heart to suddenly stop. Most defibrillators can automatically use wireless technology to send the patient's data from its transmitter, automatically to the patient's physician, nurse, or healthcare facility, using either the landline phone or the mobile network. This remote follow-up reduces or avoids unnecessary clinic visitations, and visitation costs. [37] [7].

Purdue University's Weldon School of Biomedical Engineering researchers have designed a wearable acoustic emission sensor that could be used to monitor the formation of micro-cracks that can lead to hairline stress fractures in bones. The goal of the device is to alert users when a stress fracture is imminent so that they can stop potentially damaging physical activity [5].

According to [38] Sudden Infant Death Syndrome (SIDS) is the 3rd leading cause of infant death in the United States and the 1st leading cause of death among infants aged 1-12 months. Children are generally considered to be at highest risk of dying of SIDS between birth and one year of age. Although real causes of SIDS are not precisely known, healthcare professionals consider following to be some of the causes [39]; Apnea, cessation of breathing, Hypoxia, lessening of oxygen supply, Hyperoxia, excess oxygenation, Hypopnea, shallow breathing, Hypoxemia, low oxygen content, Hypercarbia, excess carbon dioxide.

Many sensor-equipped devices have been created and several others are in development, to protect healthy newborns from sudden death for unknown reasons. One commercial application is the HiSense BabySense V CU-100/2 Baby Safe Infant Movement Monitor [40]. The device is comprised of two very sensitive sensor pads, which are placed under the baby's mattress, and a high-speed microprocessor control unit. The control unit alerts parents with a loud alarm if it does not detect any movement for 20 seconds.

The purpose of the device is to alert you when slowing or stopping of movement occurs. Moreover, the Baby Safe monitors, Angel Care-Baby and Nanny Baby-Breath monitors are also commercially available with the same features [41] [42].

Academic research and studies are also interested in SIDS. A team at the University of Texas, Arlington, has designed and built a device that monitors the carbon dioxide a child exhales, and sends an alert via RFID seconds after the infant stops breathing [43]. According to this source, the device includes an array of sensors and an RFID chip that is attached to the crib rather than to the child.

Observation of people vital signs during physical performance, more specifically, measuring the approximate values of an individual's maximum anaerobic and aerobic (maximum oxygen uptake) threshold rates. For example, sport scientists, coaches and athletes in almost every discipline should determine the capability of an athlete’s muscles to set up the best training plan and right training zone, and at the same time, collect data from every step of athlete’s practice performance [4] [44] [45].

Performance tests can be conducted in two ways: for an accurate body performance evaluation, the blood lactate level test is measured during the exercise session. This test is conducted under laboratory conditions by taking a drop of blood at a fingertip. For a practical, fast, but approximate solution, noninvasive test calculations may be applied during an activity which involves an individual’s heart rate (ECG) and speed. Through the use of a sensor equipped chest strap Hosand Heart Rate Telemetry Systems [46] monitor multiple individuals' heart rates at the same time and display them in real-time simultaneously with the help of wireless sensors and technology. Moreover, the system can transmit the wireless signals up to 200 meters (656 feet) on a PDA, laptop, or PC where information will be displayed, stored, and analyzed.

These systems can help to evaluate body performances several times, to see the results of specific training periods, response to a treatment or drug, and most importantly, collect information on the individuals' metabolic and cardiovascular strengths or weakness [20] [47] [48]. Their small, low-cost, low-powered, multifunctional sensors transmit the patient's health data with diverse networks requirements [49] [50]. Examples of health sensors and their network requirements are presented in Table 1.

Table 1: Health Sensors and their Network Requirements [67].

Wearable/Implanted Health Sensors	Voltage range (V)	Bandwidth (Hz)	Sample Rate (Hz)	Resolution Sample	Information Rate (b/s)
ECG (Electrocardiogram) monitoring heart activities	5-9	0.01-250	1250	12	15000
EEG (Electroencephalogram) monitoring brain electrical activity	20	0.5-70	350	12	4200
EMG (Electromyogram) monitoring muscle activity	2+	0-10000	50000	12	600000
Blood pressure monitoring sensors	2	0.4-5	25	24	600
Heart Sound	2-4	5-2000	10000	12	120000
Tilt sensors monitoring trunk position	3	0-500	1000	11	115200
Breathing sensors monitoring respiration	1	0.1-10	50	16	800
Motion sensors recording user's status and level of activity (accelerometers, and gyroscopes sensors)	3	0-500	1000	11	115200

Several sources, [51] [33] [34] [35] [36]indicate that wireless non-invasive real-time vital sign analysis is possible with a device, which uses a polychromatic light source LED (Light Emitting Diode) that emits a broad spectrum of light in the near infrared range. By using NIRI (Near Infrared Imaging) [33], NIRS (Near Infrared Spectroscopy) [34], inventions like [35] [36], or studies like [41] [42] [43] [44] [45] wireless non-invasive real-time health monitoring and continuous data collection from a live subject improves the quality of healthcare systems. Most importantly, this reduces the frequency of a patient's visitation to a doctor's office and consequently, the cost of medical care.

Studies on invasive reading of vital signs also have several valuable applications. For example, one of the most common diseases that continually need to be monitored by blood testing is diabetes. This life-threatening illness requires frequent testing for blood sugar (blood glucose) levels sometimes twice a day, and in some advanced cases, as frequently as every hour or more. In summer 2005 the FDA improved a glucose monitoring system, Guardian RT (also, in 2006 MiniMed Paradigm REAL-Time) which has the capability for 24-hour glucose monitoring. The system uses a disposable sensor that is inserted into the abdominal area to measure blood glucose levels. Sensor readings are relayed via a radio frequency (RF) transmitter to a monitor and displayed in real-time every five minutes. Preset alarm thresholds alert patients to potentially dangerous glucose levels, and trend reports/charts can be analyzed after data are downloaded to a computer using therapy management software and a docking system [52] [53].

Current Wireless Sensor Applications

A number of wireless sensor applications have been created and their effectiveness has been tested in many areas that relate to humanity, such as

- Health applications; Smart medicine cabinet, Body implanted health devices, Monitoring clinical conditions, Evaluating body energy and performance, Tracking doctors and patients in medical facilities.
- Military applications; Battlefield surveillance, Nuclear biological chemical attack detection, Battle damage assessment.
- Environmental applications; Fire detection, Agricultural monitoring and mapping, Flood detection.
- Home applications; Smart home environment, Home automation.

In addition to these, several commercial applications have been created for better everyday living, for example, environmental control in offices, and homes, or car security. The main purpose of these studies is to provide a better quality for life for people, making lives easier, more comfortable, and most importantly, more secure.

Wireless Personal Area Networks

Tier 2 indicates wireless personal area networks (WPANs). A WPAN is a network structure for interconnecting information technology devices within the range of an individual person, typically within a range of 10 meters, which is defined by IEEE standard 802.15. A WPAN could serve to interconnect all the ordinary computing and communicating devices, stationary or mobile, or it could serve more specialized purposes such as in a healthcare facility or in a surgery room, allowing the surgeons and other team members to communicate during an operation.

The best features of WPAN technology are known as *plugging in* and the ability of each device to lock out other devices selectively. For example, when any two WPAN-equipped devices come into close proximity or within a few kilometers of a central server, they can communicate as if connected by a cable and, with the lock out ability, prevent interference or unauthorized access to their information.

Bluetooth is one of the most-widely used WPANs under the IEEE protocol 802.15.1 today. It uses a radio technology called frequency-hopping spread spectrum (FHSS) which transmits radio signals, by rapidly switching a carrier among many frequency channels, through 2.4 GHz short-range radio frequency with data rate of 1 Mbps. It exchanges information between devices such as mobile phones, telephones, labtops, PCs, printers, Global Positioning System (GPS) receivers, and digital cameras.

ZigBee is another common WPAN based on the IEEE 802.15.4 standard with a low-cost, low-power wireless mesh networking structure. It is a general-purpose, inexpensive self-organizing network that can be shared by industrial controls, medical devices, smoke and intruder alarms, building and home automation. The low cost and low power-usage of ZigBee makes it widely deployed in wireless controlling monitoring applications, which are commonly used in healthcare systems. Very small amount of power requirement of ZigBee provides longer battery life, which is ideal for use in small medical devices; and because of mesh networking structure, systems in the network can communicate within a larger range.

WPAN technologies include Bluetooth, IrDA, UWB, Z-wave, and ZigBee, which all permit communication within about ten meters [20]. The most common WPAN device today is PDAs (Personal Digital Assistant). The vast majority of all PDAs are smart phones, such as RIM Blackberry, Apple i-Phone, and Nokia N-Series [20] [54] [60].

Wireless Local /Wide Area and Other Networks

Tier 3 indicates method for accessing the Internet. Many PDAs can reach server(s) such as, hospital information servers, emergency servers, healthcare provider servers, healthcare facility servers, by accessing the Internet, intranets, or extranets via either one of Wireless Personal Area Networks (WPAN), Wireless Local Network (WLAN), Mobile Ad Hoc Network (MANET), Celular Network (3G, 4G), Satellite Techonologies, or integration of all of these. Table 2 summarizes major features of wireless local, wide and other network technologies.

Table 2: Major Features of Different Wireless Technologies [61] [62] [67] [68].

WIRELESS NETWORKS	**Radio Coverage**	**End-to-End Delay**	**Data Transmission (Bandwidth) Rate**	**Applications**	**Allowable Patient Mobility**	**Deployment Cost**
Radio Frequency Identification (RFID)	1 m- 10m	Very low	100 Kbps	-EMR management -Patient monitoring and management -Medical inventory	Low	High/Very High
Wireless Personal Networks (WPAN)	1m ~100m	Low	>3 Mbps	-Patient tracking	Low	Low
Wireless Local Area Networks (WLAN)	50 m -300 m	Very Low	1 – 54 Mbps	- Patient monitoring and management - Medical inventory	Medium	Medium
Mobile Ad Hoc Networks (MANET)	< 1 km	Low/Medium	300 Kbps - 2 Mbps	Patient monitoring and management	Medium	Low
Worldwide Interoperability for Microwave Access (WiMAX)	~20 km	Low	~10 Mbps	Patient monitoring	Very High	Medium/High
Cellular (3G,4G)	~35 km.	Medium/High	144 kbps - 1 Mbps	-EMR management -Patient monitoring and management -Medical inventory	High	High/Very High
Satellite	World	Very High	< 144 Kbps	Mobile Healthcare	High	Very High

Radio Frequency Identification (RFID)

RFID is a wireless identification system that can wirelessly identify an object or a person with a tag. Most RFID tags contain at least two parts. One is an integrated circuit for storing and processing information, also modulating and demodulating a radio-frequency (RF) signal, and other specialized functions. The second is an antenna which is linked to each element and allows power to be transferred between the reader/writer and remotely sited tag through inductive coupling. Since this is a bi-directional process, data is transferred in both directions. The data transferring range capability of RFID is up to 1 meter with 100 Kbps data rate.

RFID tags are currently used in healthcare system applications such as patient tracking and information, recording blood pressure and heart beat rate, and patient's prescriptions and drug tracking. RFID tags are also used in applications that allow tagging of patients, beds, and expensive hospital equipment. They can work well even in harsh environments with significantly high speed without any reading error. Multiple RFID tags can be read at the same time— a bulk of 10 to 100 tags at a time—and since it is RF technology, physical contact between the tags and the reader is not required. However, this technology also has some disadvantages, such as high cost. The cost and size may increase depending on the design for specific applications. Related to requested designs, the signals from different types of tags may be affected when they are near to some chemical combinations, metals or liquids, which may cause false reading of data.

Active tags contain their own power source, usually an on-board battery. Depending on an application's read range and memory requirements, they operate at higher frequencies, 455 MHz, 2.45 GHz, or 5.8 GHz. In contrast, passive tags obtain power from the signal of an external reader and typically operate at frequencies of 128 kHz, 13.6 MHz, 915 MHz, or 2.45 GHz with the ranges of a few centimeters to 10 meters. Properly implanted and carefully conducted RFID can significantly aid the healthcare systems in performing their duties. [55] [56] [60].

Wireless Local Area Networks (WLAN)

Today, large portions of health care information and management systems rely on the WLAN technologies. Healthcare professionals carry personal digital assistants (PDAs) and laptops that are used either to view or to submit information via WLAN connections within their facilities. WLANs are attractive, both for consumers and businesses, because they do not require expensive cabling and they enhance mobility and accessibility to the network.

The Institute of Electrical and Electronics Engineers (IEEE) governs most of the popular WLAN standards in use today. In 1997 IEEE created the first WLAN standard and called it 802.11. During the years, gradually, 802.11 have been expanded and the 802.11 family, a, b, g, n, e and a few more in processes, created. Today, IEEE 802.11a/b/g/n WLAN standards collectively are known as WiFi (also called as 802.11X) technologies, Table 3. The full names of the acronyms of different transmission protocols in the 802.11 family listed in Table 3 are provided in Table 4.

Table 3: Major Features of Different Wireless Technologies [61] [62] [67] [68].

Wi-Fi Characteristics	Spectrum Used (GHz)	Data Rate (Mbps)	Transmission Protocol	Backward Compatibility	Advantages	Disadvantages	Current Status
802.11	2.4 GHz	2	FHSS/DSSS		Higher range	Minimum bit rate	Phased out
802.11b	2.4 GHz	11	DSSS only	802.11	>Inexpensive >Widely deployed high range	>Slowest max. speed >Bit rate is not enough for emerging applications	Widely used
802.11a	5.25, 5.6, 5.8 GHz	54	OFDM		>Higher bit rate in a less crowded spectrum	>Expensive >Smallest range of 802.11 standards >Short range signals are easily obstructed	Limited use
802.11g	2.4 GHz	54	OFDM	802.11 802.11b	>Higher bit rate in 2.4 GHz >Signal range is good and not easily obstructed	>Limited number of co-located WLANs >Expensive than 802.11b >Applications may interfere on the unregulated signal frequency	Widely used
802.11n	2.4 GHz	100	MIMO	802.11g	>Fast and best signal range >Resistant to signal inference from outside sources	>More expensive than 802.11g >Multiple signals may interfere with nearby 802.11b/g networks	Not finalized yet
802.11e	2.3, 2.5, 3.5, 3.7, 5.8 GHz	70	EDCA HCCA	802.11b 802.11a	>Enhanced QoS features and multimedia support		In process

Table 4: Full name of Different Transmission Protocols of 802.11 Family.

Acronym	Full Name
FHSS	Frequency Hopping Spread Spectrum
DSSS	Direct Sequence Spread Spectrum
OFDM	Orthogonal Frequency Division Multiplexing
MIMO	Multiple-Input and Multiple-Output
EDCA	Enhanced Distributed Channel Access
HCCA	High Speed Controlled Channel Access

IEEE 802.11b is backward compatible with original standard, 802.11. It uses same CSMA/CA media access method and it is a direct extension of the DSSS (Direct-sequence spread spectrum) modulation technique defined in 802.11. 802.11b has 11 Mbps data rate and uses 2.4 GHz spectrum. In practice, an application can achieve the maximum 5.9Mbps 802.11b throughput using TCP and 7.1 Mbps UDP [20]. Its lower cost and substantiality of obstructions makes it widely used. However, devices operating in the same frequency, 2.4 GHz range, such as Bluetooth, baby monitors or cordless telephones may interfere with each other on the unregulated frequency band.

IEEE 802.11a was created as a second extension to the original 802.11 standard at the same time with 802.11b. Since both standards utilize different frequencies, the two technologies are not compatible with each other.

The higher cost of 802.11a makes it better for use at hospitals, healthcare facilities, and businesses network. 802.11a supports bandwidth up to 54 Mbps and signals in a regulated frequency spectrum around 5 GHz. Supporting high bandwidth and high frequency are advantage of 802.11a due to preventing signal interference from other devices. However, high frequency creates also some problems such as lower range of the network and difficulty to penetrate obstructions, such as walls, tall buildings, and hills.

802.11g was created with a combination of the best features of both 802.11a and 802.11b in mind. However, it is backwards compatible only with 802.11b. It supports bandwidth up to 54 Mbps, and it uses the 2.4 GHz frequency for greater range. 802.11g is fast, high frequency and penetrates for obstructions. However, it costs more than 802.11b and devices operating in the same frequency may interfere on the unregulated signal frequency.

IEEE 802.11n is the new standard in the WiFi category and still in process. It was developed to improve network throughput over two previous standards, 802.11a and 802.11g.

The bandwidth improvement in the 802.11n is supported by multiple wireless signals, four spatial streams at a channel width of 40 MHz, and multiple antennas instead of one. The technique of using multiple antennas at both the transmitter and receiver for improving communication performance is called Multiple-Input and Multiple-Output (MIMO) technology. MIMO offers significant increases in data throughput and link range without additional bandwidth or transmit power. 802.11n has the fastest maximum speed and the best signal range with more resistance to inference from other sources. As mentioned, this standard is still in development. It is expensive and using multiple signals may greatly interfere with 802.11b/g based networks [20] [57] [60].

IEEE 802.11e standard defines a set of Quality of Service enhancements for WLAN applications, especially for WiFi. It defines QoS mechanisms for wireless gear that gives support to bandwidth-sensitive applications such as voice and video. 802.11e enhances QoS applications with modifications to the Media Access Control (MAC) layer. Two of the original 802.11 MAC protocols, Distributed Coordination Function (DCF), and PCF do not differentiate between traffic types or sources, the IEEE developed enhancements in 802.11e to both coordination modes to facilitate QoS. Its development is very important in delay-sensitive applications, which are widely used, in healthcare systems [20] [57] [59] [60].

Other than these common WiFi standards, more IEEE 802.11 standards exist or are in development to support the creation of technologies for wireless local area networking:

- 802.11d - worldwide compliance with regulations for use of wireless signal spectrum (2001).
- 802.11i - security improvements for the 802.11 family (2004).
- 802.11k - WLAN system management (in progress).
- 802.11m - maintenance of 802.11 family documentations.
- 802.11p - wireless access for the vehicular environment.

- 802.11T - wireless performance prediction recommendation for testing standards and metrics.
- 802.11u - internetworking with 3G / cellular and other forms of external networks.
- 802.11v - wireless network management / device configuration [57].

Mobile Ad Hoc Networks (MANET)

A wireless ad hoc (or self-organizing) network is a decentralized 802.11-based WLAN network where wireless devices directly communicate with each other. Operating in ad-hoc mode allows all wireless devices within range of each other to discover and communicate in peer-to-peer fashion without involving central access points (including those built to in broadband wireless routers). With an ad hoc network, topology may be changing all the time without warning. The decentralized nature of wireless ad hoc networks makes them quite flexible, scalable, and suitable for a variety of applications, especially in healthcare systems.

A mobile ad hoc network (MANETs) is one of the applications of wireless ad hoc networks. It is a self-configuring network of mobile devices connected by wireless links. Each node in a MANET moves independently in any direction by frequently changing its links to other devices. These networks tend to feature a small group of devices all in very close proximity to each other. It even offers unrestricted mobility, but the routing becomes very complex due to the lack of centralized infrastructure. Performance suffers as the number of devices grows, and a large ad hoc network quickly becomes difficult to manage. Due to user mobility, many routes become unusable, resulting in discovery of new routes or rerouting of old routes.

Several different types of routing schemes can be used in Ad Hoc wireless networks for health monitoring. Some of the basic schemes are shown in the Table 5.

Table 5: shows different types of routing schemes of Ad Hoc networks [61] [62] [67].

Unicast Routing	Anycast	Multicast	Broadcasting
The most efficient routing schema. The communication is routed between one patient and only one healthcare professional.	Routing is conducted from one patient to multiple healthcare professionals.	Patient information is multicast to multiple healthcare professionals.	Broadcasting Patient information is sent in all directions

Each scheme has its own complexity, overhead and performance in terms of reliability of message delivery and end-to-end delays. For example, unicast routing will provide the worst performance if an intermediate device has failed, moved or is simply not co-operative due to one to one communication. On the other hand, multicast and broadcast routing provide better reliability of message delivery. However, the amount of network traffic and monitoring delays will be high due to multiple communication directions [62] [60] [59] [20] [57].

Worldwide Interoperability for Microwave Access (WiMAX)

WiMAX is based on the IEEE 802.16e standard (also called Broadband wireless access), which evolved from 802.16a, using advanced physical layer techniques to support non-line-of-sight communication. It is a scalable wireless access technology specially designed to provide high throughput over long distances. It has the capability to deliver high-speed Internet access up to 10 Mbps broadband speed with 10 to 66GHz to rural areas and other locations without the need for cable or DSL technology.

WiMAX provides transmission of data using a variety of transmission modes, from point to multipoint links to portable and mobile Internet access. The healthcare sector is one of the potential customers of WiMAX. This technology had a great impact on the healthcare systems due to wireless broadband connectivity from the local vicinity to a wider scale. WiMAX technology improves mobile communication for information exchange while users are traveling from one place to another or while they are in a café, a restaurant, or an airport [20] [59] [57].

Cellular Technologies, 3G, 4G

Integration of a variety of advanced wireless communication technologies and many diverse cellular (mobile) environments, such as 3G or 3^{rd} Generation and 4G or 4^{rd} Generation (successor of 3G and still in process), are the major driving force for today’s and tomorrow’s developments in health care systems.

3G technology is actively used by it’s a growing number of subscribers since 2007. 3G is a family of standards for mobile telecommunications. These standards include GSM EDGE, UMTS, CDMA2000 and also DECT and WiMAX with the services of wide area wireless voice telephone, video calls, and wireless data. Technology is capable of simultaneous use of speech and data services with the data rates up to 14.0Mbps on the downlink and 5.8 Mbps on the uplink with HSPA+ [59] [20].

The ability to unify existing cellular standards under one mobile environment is the best feature of 3G. According to [61] this is one of the reasons over 85% of the world’s network experts have chosen 3G as the underlying technology platform to deliver their third generation services (GSM-Information).

4G technology is still in the development stages and when more readily available, the integrated wireless access technologies will provide high-speed multimedia communications services to mobile users with wide range data rates up to approximately 100 Mbps for high mobility such as mobile access; up to approximately 1 Gbps for low mobility such as nomadic/local. Achieving such wide data rates will provide capability of accessing multiple wireless networks simultaneously for mobile or stationary users. In such a heterogeneous wireless access environment, a mobile connection will achieve high data rates through load balancing, global mobility through seamless handoff, and quality-of-service (QoS) support through strong integration of network services with applications in the higher layers. In this way, wireless services can be provided anytime, anywhere, regardless of the type of wireless access available to a mobile user.

Cellular technologies provide mobile patients with the choices that will be the best fit for their lifestyle and make it easier for them to interactively get the medical attention and advice they need, when and where it is required, and how they want it regardless of any geographical barriers or mobility constraints [59] [20].

Satellite

Communication via satellite introduces a number of healthcare-related opportunities for health information systems. According to [69], “Satellite Healthcare, one of the nation’s first and leading providers of kidney dialysis services and a major sponsor of nephrology research.”

Besides healthcare systems, satellites are used for a large number of purposes. Common types include military and civilian earth observation satellites, communications, and navigation satellites, weather, and research satellites. Also, services such as, Fixed Satellite Services, Mobile Satellite System and Scientific Research Satellites are non-military satellite services:

Fixed satellites handle hundreds of billions of voice, data, and video transmission tasks across all countries and continents between certain points on the earth's surface.

Mobile satellite systems help connect remote regions, vehicles, ships, people, and aircraft to other parts of the world and/or other mobile or stationary communications units, in addition to serving as navigation systems.

Scientific research satellites provide meteorological information, land survey data (e.g., remote sensing), Amateur (HAM) Radio, and other different scientific research applications such as earth science, marine science, and atmospheric research.

Combinations of all these technologies provide patients the freedom to navigate all over the world without restriction [20].

A Global Wireless Healthcare Abstract System Composition

Monitoring vital signs in the human body gives several clues that lead medical doctors on the right path about physiological and biochemical health, or about health risks. Health screening of helps individuals and health professionals to learn more about the body and detect potential problems in early stages when treatment or changes in personal habits can be most effective [8] [14] [45]. The goal of examining the body's health for diseases is to control symptoms, reduce complications, and slow the progression of the disease.

Body vital components and their analysis can vary from person to person, but requirements for trusted, and well designed global wireless health monitoring systems should

- Be able to sense early signs of health problems for particular signs in the body and alert health care professionals in emergency situations.
- Reduce frequent visits to the healthcare facilities and create a more independent lifestyle for a patient or elderly person; help them to handle their fears, insecurities, and loneliness associated with their illness.

- Create multi-source, real-time, physiological data for the individual's health records; following up on the patients' conditions from the beginning to the present will be an enormous help to the healthcare professions.
- Collect data and create a collection that provides scientific benefits to medical scientists all over the world for their research, and at the same time, allow more study participants to enroll, communicate, and discuss more specific health cases [7] [8]. Figure 5 presents an abstract composition of a wireless healthcare system.

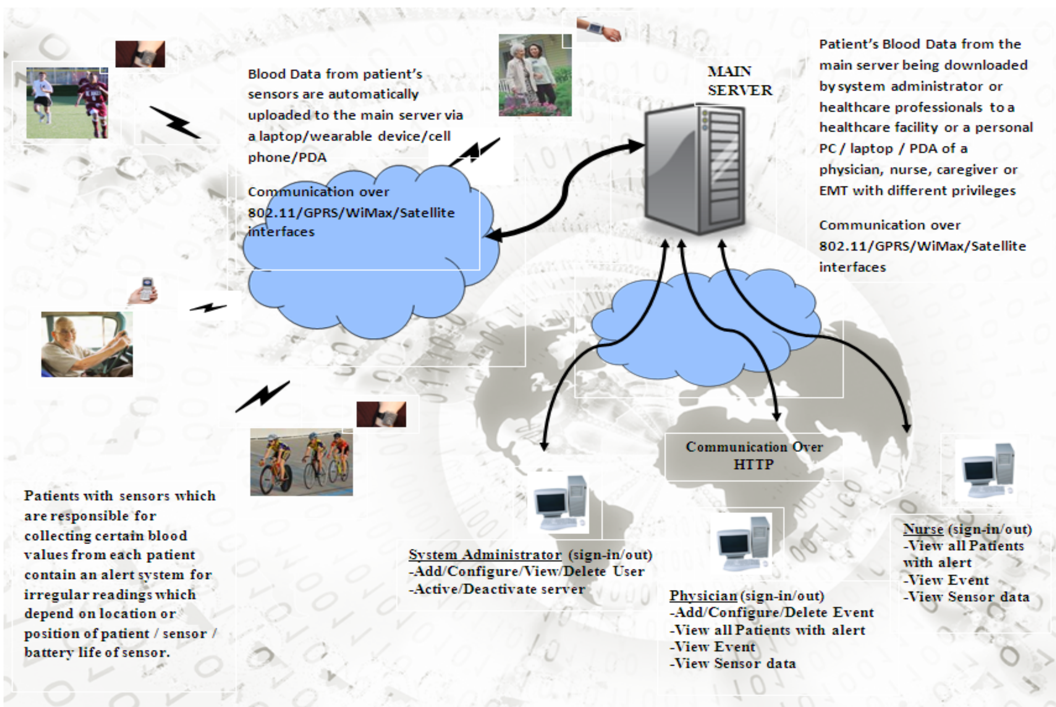

Figure 5: An abstract presentation of a wireless healthcare system. It shows some outlines how to transmit the patient's data via Internet to the main server and downloaded from server by the healthcare professionals and indicating their data view priorities.

CHAPTER 4 QUALITY OF SERVICE (QoS) OF INTERNET AND REQURIMENTS

Monitoring vital signs for diseases allows the medical doctors to recognize the symptoms of certain illnesses and take necessary precautions to minimize the risks. The different chemical values of vital signs imply particular quality requirements that need to be analyzed in order to make correct diagnoses. For example, regularly testing insulin levels in blood is very important for a person with diabetes; on the other hand, the importance of insulin levels might have secondary priority on a cardiovascular patient's blood values.

This is exactly the same for different computer systems. Each computer system has its own service qualifications that differ from another; the different structure of the services implies particular quality requirements that need to be executed in order to keep the end-users happy. For example, listening to the radio or talking on the phone through the Internet requires a lower delay; an e-mail or a file transfer service requires higher reliability. Each data flow network can have different requirements and need to be treated according to their differences. These different requirements for different computer services are constructed as the principles of Quality of Services (QoS).

Resource Allocation

In the current Internet many problems come down to the issue of resource allocation due to massive network traffic demands. Today's Internet does not support any active resource allocation and it serves all packets in the same way on a first in first out (FIFO) technique without admission control.

In contrast, a network that supports QoS needs to take an active role in the resource allocation process of Internet services as well as having the decision-making ability of who should receive it, and how much resource allocation should be made available to certain applications. For example, real time applications such as patient monitoring, security monitoring, or space shuttle launches refer to a group of applications that have minimum delay requirements. These types of applications should inject packets into the network as fast as possible without any delay or packet lost.

The Internet currently relies on the TCP protocol in the hosts for detecting network congestion, and if it detects a lost packet, first it reduces, throttles, the transmission rate then increases it gradually as more bandwidth becomes available. The throttling of the transmission rate can have very harmful effects on real-time applications that have minimum throughput requirements. Since real-time applications are known as loss-tolerant and do not need reliable connections, they usually choose to run over UDP by the developers. However, a reduced transmission rate is not tolerable for some real-time systems such as healthcare. These applications typically cannot tolerate large fluctuations in the transmission rate [59] [60] [58].

The current Internet does not allow applications to request any special treatment. Every packet, including delay-sensitive audio and video packets, is treated equally at the routers. When a link is congested, packets are simply pushed out as the queue overflows.

This simplest type service of network is often referred to as best-effort, a network service in which the network does not provide any guarantees that data is delivered or that a user is given a guaranteed QoS level or a certain priority. Although the best-effort model is adequate for some applications that can tolerate large delay variations such as file transfer and e-mail, it clearly does not satisfy the needs the needs of many new applications and their users.

To satisfy the requirements of new applications, especially real-time applications, two types of service model architectures were created to introduce a number of new concepts and primitives that are important to QoS support in the Internet: Integrated Service architecture (IntServ) is an architecture that specifies the elements to guarantee QoS on network, and Differentiated Services architecture (DiffServ) is an architecture that specifies a simple, scalable and coarse-grained mechanism for classifying, managing network traffic and providing QoS guarantees on modern IP networks.

These three different architectures of Internet are work in different ways: the best-effort model works on a per-packet basis, whereas the IntServ architecture deals with individual flows, and DiffServ Internet architecture lies somewhere in between these two and offers a “better than best-effort” service.

To provide a service model that is better than best-effort service, a simple approach is to divide network traffic into classes, and provide different levels of service to these different classes of traffic. Network traffic classification allows a router to distinguish among packets belonging to different classes of traffic, isolates classes and flows that are not harmfully affected by each other’s fluctuations, and allows the use of resources, such as link buffers and bandwidth, as efficiently as possible.

Two important mechanisms, scheduling mechanism and policing mechanism, provide a degree of isolation among traffic classes or flows.

Scheduling Mechanism

(Link-scheduling discipline: Queued packets selection for transmission)

Packets belonging to various network flows are multiplexed and queued for transmission at the output buffers associated with a link. This association of selected queued packets and a link is known as link scheduling discipline. Link scheduling discipline is responsible for enforcing resource allocation to individual packets. The purpose of the scheduler is to decide which queued packets should be selected for transmission or get the network resources. Some of the popular link-scheduler disciplines are Simple Priority, which is also known as Priority Queuing, Round Robin Queuing, and Weighted Fair Queuing.

Priority (Simple) Queuing

In a simple priority, packets arriving at the output link are classified into priority classes at the output queue. A packet’s priority class may depend on an explicit marking it carries in its packet header, its source address or destination IP address, its destination port address, or other criteria. Each priority level has its own queue. When the outgoing link becomes available for transmission, the priority scheduler selects packets from the queue with the highest priority. If there are no packets with higher priory in the queue or the higher priority packet queue is empty, then packets with lower priority are transmitted. The choice among packets in the same priority class is done in FIFO manner.

Round Robin (RR) Queuing

In Round Robin Queuing (RR), packets are sorted into classes as in priority queuing. However, an RR scheduler alternates service among the classes instead of being a strict priority of service among classes.

In the simplest explanation of its logic, assuming packets are sorted in 3 classes, a class 1 packet is followed by a class 2 packet, a class 2 packet is followed by a class 3 packet, then a class 3 packet is followed by a class 1 packet, class 2 packet, and so on. The process repeats until all packets have been transmitted. RR is a work-conserving queuing discipline. This means that it will never allow the link to remain idle if there are queued packets of any class for transmission. A work-conserving scheduler that looks for a packet of a given class but finds none will immediately check the next class in the sequence. In the case of equally sized data packets, RR is max-min fair.

Max-Min Fairness

The bandwidth must be allocated fairly to competing flows to satisfy all traffic demands. One form of fair sharing policy is called max-min fairness or max-min fair sharing. The max-min fair sharing tries to maximize the minimum share of a flow whose demand is not fully satisfied. It can be calculated as:

1- Calculate the initial fair share = $\dfrac{\text{(total capacity)}}{\text{(total number of flow)}}$.

2- For all flows that have a demand equal to or less than the fair share, allocate the flow's actual demands.

3- Remove the satisfied flows and subtract the allocated capacities from the total available capacity.

4- Repeat steps 2 and 3 for the remaining flows with the current fair share.

Remaining fair share = $\dfrac{\text{(remaining capacity)}}{\text{(remaining number of flow)}}$.

In this way, all flows with demands less than fair share will be satisfied. The unused resources from those flows are allocated according to the same principle for the remaining flows with demands larger than the fair share.

A generalized abstraction of RR is called as Weighted Fair Queuing (WFQ) that has found considerable use in QoS architectures.

Weighted Fair Queuing

In the fair-queuing approach, the share of bandwidth by a flow is represented by a real number which is referred to as a weight. Each active flow is allocated bandwidth proportion based on its weight. According to assigned weight, each class may receive a differential amount of service in any interval of time. Incoming packets are classified and queued according to their classes and a WFQ scheduler serves classes in a circular manner as in round robin scheduling.

The formula of WFQ is: $$x_i = \frac{R\, w_i}{\sum w_j}$$

An idealized description of WFQ is:

- Each class i, is assigned a weight, w_i.
- During any interval of time there are class i packets to send, class i will then be guaranteed to receive a fraction of service equal to $w_i / (\sum w_j)$.
- In the worst case, even if all classes have queued packets, class i will still be guaranteed to receive a fraction of service equal to $w_i / (\sum w_j)$ of the bandwidth.
- Thus, for a link with transmission rate R, class i will always achieve a throughput of at least $R \cdot w_i / (\sum w_j)$.

WFQ, like RR, is a work-conserving queuing discipline, whose scheduler is idle only when there are no packets waiting to be transmitted. It supports bandwidth allocation and delay bounds and it is widely implemented in routers for supporting QoS.

Policing Mechanism

(Regulation packets per time Interval)

The regulation of the rate at which a data flow is allowed to insert packets into the network is an important QoS mechanism. For this purpose, three important time scales over the packet flow are policed:

- Average rate regulates the limitation of long-term average rate, packets per time interval, at which flow's packets can be sent into the network. It is the policing of the interval of time over the transmission rate. The average rate can be calculated in many ways and results can be quite different.
- Peak rate is the limitation of the maximum number of packets that can be sent over a short period of time. For example, a flow can be policed at an average rate of 6,000 packets per minute, while policing the flow's peak rate 1,500 packets per second.
- Burst size is limitation of the maximum number of packets, the burst of packets, which can be sent into the network over an extremely short interval of time. For example, the burst size limits the number of packets flow into the network as interval length approaches the zero.

These three important criteria of rate regulations can be policed or shaped the existing traffic by two predominant methods, a leaky bucket and token bucket implementations. Although these two mechanisms have the same purpose as controlling the burst of packets that are injected into a network they behave according to a different principle. The leaky bucket imposes a hard limit on the data transmission rate to provide a steady stream, smooth, of traffic to the network.

On the other hand, the token bucket allows a certain amount of burst packets while imposing a limit on the average data transmission rate.

<u>Leaky Bucket Mechanism</u>

A leaky bucket is a popular class of traffic regulators that can be used to characterize these policing limits. It has two parameters: the token arrival rate r and the bucket depth b. In this mechanism, tokes are being generated at a constant rate r tokens per any unit of time, such as second. If the bucket is filled with less than b tokens, the newly generated token is added to the bucket; otherwise the new token is ignored and the token bucket remains full with b tokens. For example; before a packet is transmitted into the network, it must first remove a token from the token bucket, if token bucket is empty, the packet must wait for a token. The leaky bucket mechanism has a number of interesting properties:

- The total number of packets that a leaky bucket allows a source to send to the network is bounded by a liners function. For example, if $P(t)$ is the amount of packets transmitted any interval of time of length, then $P(t) \leq rt + b$.
- The token-generation rate, r, corresponds to the long-term average rate of the traffic. It serves to limit the long-term average rate at which packets can enter the network.
- The maximum burst size cannot be larger than b tokens since there can be at most b tokens in a bucket.

A flow might be comprised of traffic from a single end-to-end connection or a collection of many such connections.

Service Models

Best-Effort Service

The Internet's single service, known as best-effort service provides logical communications between hosts that makes no guarantees regarding the speed with which data will be transmitted to the recipient or that the data will even be delivered entirely. More specifically, with best-effort service, timing between packets is not guarantee to be served, or to be received in the order in which they were sent, and no guarantee the eventual delivery of transmitted packets.

Integration Services (IntServ)

IntServ architecture was developed by IETF to provide individualized QoS guarantees to individual applications, especially real-time application, in the Internet. It is based on per-flow resource reservation with the goal of preserving the datagram model of IP-based networks and at the same time support reservation for real-time applications. The main flow-based architecture is Resource Reservation Protocol (RSVP). Algorithm allows multiple sources to transmit to multiple destinations. It gives ability to individual destinations to switch channels freely. Additionally optimizes bandwidth while eliminating congestion [58] [59] [60]. To receive performance assurance from the network, an application must set up the resource reservation along its path, in advance, before starting to transmit packets Figure 6.

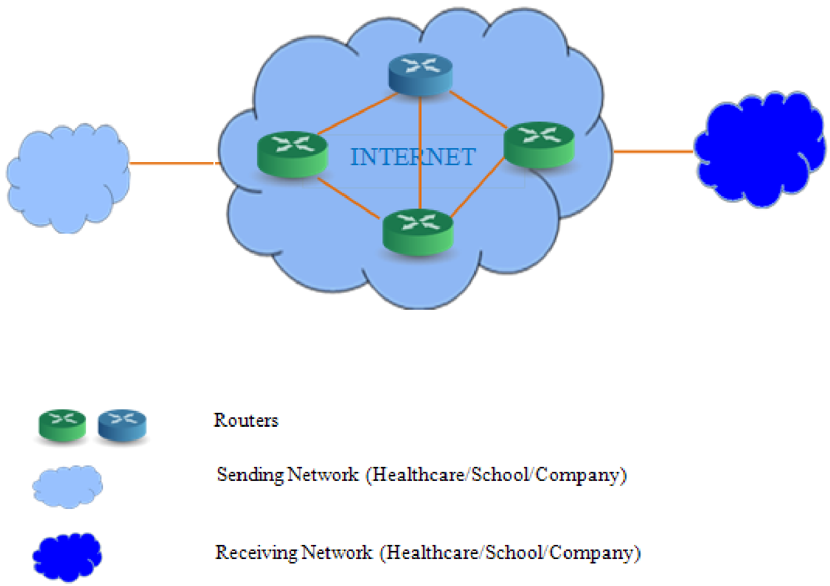

Figure 6: An IntServ infrastructure abstract: an application making a reservation with description characteristics of the flow and resource requirements to the network.

The process is start with setting up a reservation. The source application characterizes its traffics source and resources, QoS, requirements to the network by leaky bucket mechanism. When a router receives the request, first, interacts with the routing module to determine next hop to which reservation request should be forwarded. Second, it coordinates with the admission control to check whether there are sufficient resources to meet the requested resources. For example, if an application needs to reserve a path of 25 Mbps bandwidth to a particular destination, it is important that the selected path should meet this requirement. At each node the network must determine which path to use for setting up the resource reservation. A reservation protocol goes hop by hop along the path to install the reservation state in the routers.

The protocol also carries the information about traffic characterization and resource requirements that at each node along the path it can be determined whether the new reservation request can be accepted or not. The set up protocol also deals with changes in the network topology. For example, a link dropping in the network causes a sudden change at the network topology. In this case, the reservation protocol should tear down the current reservation and setting up a new one for recovery.

Since IntServ is an architecture that specifies the elements to guarantee end-to-end QoS on networks, it comes with high price. For example, resource reservation set up usually involves the issues related to authorization, authentication, and billing that they indicates the financial transactions. The users who can effort to put some weight on their packets for queuing scheduling get the guaranteed and controlled-load services.

Differentiated Services (DiffServ)

As wireless medical applications are expected to provide vital aid for healthcare systems, wireless network technologies have to be able to provide much better connectivity than commercial networks, which often suffer from congestion, packet dropping and increased errors.

The diversity in network resources needed for different telemedicine applications, as well as the various levels of emergency in medical situations, make the DiffServ model an appropriate architecture for creating a scalable and QoS solution in wireless medical networks.

The IETF defined DiffServ Internet architecture has the ability to handle different service requirements in different ways with a scalable and flexible behavior. Service and forwarding treatment are two important concepts in this architecture. Their functionality is quite different than each other. In DiffServ context, forwarding treatment is an externally controllable specific application that it is implemented in a node. Conversely, service of DiffServ context refers to the overall performance of a customer’s traffic receiving.

Architectural Model

The key elements for building DiffServ lays under its nodes. Two types of DiffServ nodes are used for different responsibilities by this architecture. Each type of nodes has different responsibilities. The nodes at the boundary of the network are called Boundary nodes or Edge nodes and according to their functionality at the edge of network they also called as ingress nodes, incoming, or egress nodes, outgoing.

Boundary nodes or Edge nodes serve at the edge of the network and consist of a set of functions needed to interconnect a DiffServ domain to another DiffServ domain as well as a non-DiffServ-capable domain. Basically, when they handle the incoming traffic streams, they become ingress node to a DiffServ domain. If they handle outgoing traffic streams, they became egress node to domain. In particular, a real boundary node can contain all these functions: The same node can be a boundary node for some traffic stream and an interior node for some other streams. Moreover, any interior node can have part of the functions of boundary nodes in the case of having a limited capacity of traffic conditioning.

Interior nodes or Core nodes serve inside of the network and consist of a set of functions needed if a node is connected only to other DiffServ capable nodes. Within the Interior of the network, packets are forwarded based on the forwarding classes in the packet header which determines the treatment of the packets. At a DiffServ-capable router, the packet is forwarded onto its next hop according to the Per-Hop Behavior (PHB), which influences how a router’s buffers and link bandwidth are shared among the competing classes of traffic. In DiffServ architecture, a router’s PHB will be based merely on the class of traffic to which the packet belongs.

Ingress and Egress are also the term of the DiffServ architectures. An ingress node is a collection of functions needed to handle incoming traffic stream to a DiffServ domain. On the other hand, an egress node is a collection of functions needed to handle outgoing traffic streams from a DiffServ domain.

The nodes at the edge of the network can be either a DiffServ-capable host that generate traffic or a DiffServ-capable router that the traffic passes through, Figure 7.

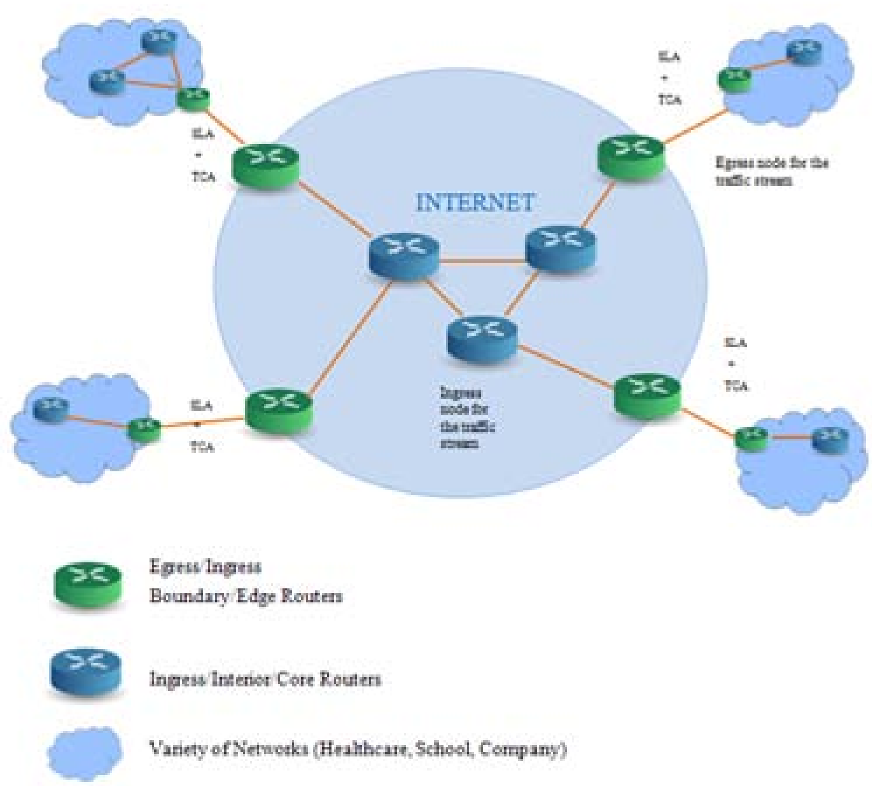

Figure 7: A DiffServ infrastructure abstract; the nodes at the boundary of the network: egress/boundary/edge routers, the nodes inside of the network: ingress/interior/core routers. Two level of agreements between nodes: Service Level Agreement (SLA) and Traffic Conditioning Agreement (TCA).

Two levels of agreements between nodes:

- Service-level agreement (SLA): A contract between a customer and a service provider that specifies the forwarding service.
- Traffic-conditioning agreement (TCA): Defines the rules used to realize the service, such as metering, marking, and discharging.

Traffic Classification and Conditioning

DiffServ architecture is composed of a number of functional elements implemented in network nodes, including a small set of per-hop forwarding behaviors, packet classification functions, and traffic conditioning functions including classifying, metering, marking, and shaping, shown in Figure 8.

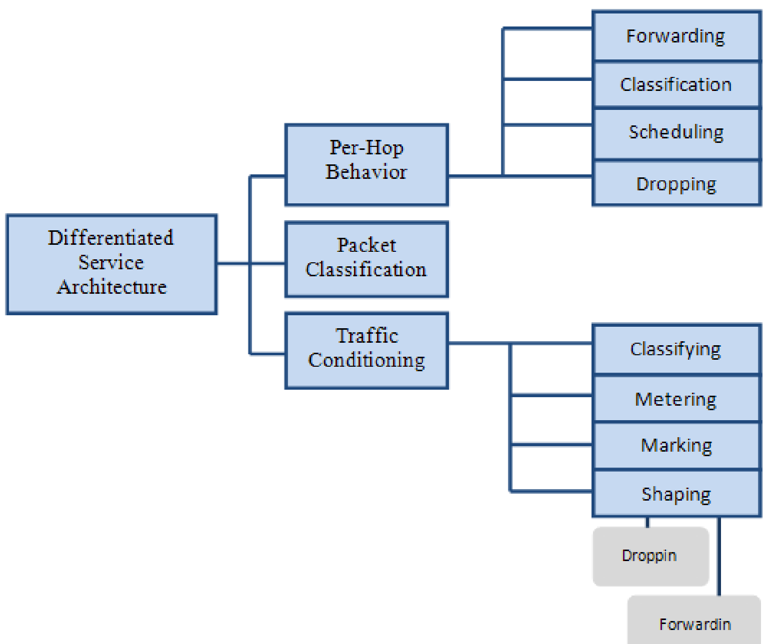

Figure 8: DiffServ system components.

When traffic arrives at the boundary of the administrative domains, the boundary node performs the tasks of packet classification and traffic conditioning. These two tasks of boundary (edge) router include mapping packets to different forwarding classes, checking to see if the traffic flow meets the service agreements, and dropping nonconforming packets. Packets arriving at the edge router are first classified. The classifier selects packets based on one or more packet header values, such as source address, destination address, source port, destination port, and protocol ID and leads them to the marking function to be marked properly.

Differentiated Service architecture achieves scalability by implementing complex classification and conditioning functions only at network boundary nodes and by applying per-hop behaviors to aggregates of traffic which have been appropriately marked using the DS field in the IP headers.

PHB are defined to permit a reasonably granular means of allocating buffer and bandwidth resources at each node among competing traffic streams. Per-application flow or per-customer forwarding state need not be maintained within the core of the network.

The current IP packet header includes an eight-bit field called the Internet Protocol-Type of Service (IP-ToS) field as in Figure 9. The three precedence bits have a value from 0 to 7 and represent the properties for the traffic. The following three-bit ToS indicate delay (D), throughput (T), and reliability (R). Default for bits are 0. The last two bits are reserved for future use.

DiffServ redefines the existing IP-ToS field and renames it as DiffServ field to indicate forwarding behaviors. The first six bits of the DiffServ field are used as a Differentiated Services Code Point (DSCP) to encode the PHB for a packet at each DiffServ node. The last two bits are currently unused, as seen in Figure 10.

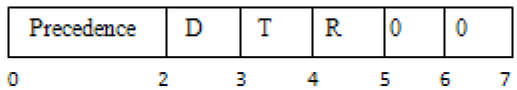

Figure 9: Format of IP header: 3-bits ToS indicate delay (D), throughput (T), and reliability (R). Default for bits is 0. The last 2-bits are reserve for future use.

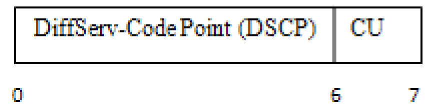

Figure 10: The first 6 bits of the DiffServ field are used as a Differentiated Services Code Point and the last 2 bits are currently unused.

Per-Hop Behaviors (PHBs)

PHB defines the policy and priority applied to a packet at a single node when traversing a hop (such as a router) in a DiffServ network [20] [58]. On the other hand, it is defined as “a description of the externally observable forwarding behavior of a DiffServ node applied to a particular DiffServ behavior aggregate” [RFC 2475]. This description is related to “a PHB can result in different classes of traffic receiving different performance” [59].

For example, an end user may have limits on its packet-sending rate or burstiness of the packet flow. As long as externally observable performance criteria are met, any implementation mechanism and any buffer/bandwidth allocation policy can be used.

Two PHBs have been defined currently, an expedited forwarding (EF) and an assured forwarding (AF):

Expedited Forwarding (EF): EF type of PHB specifies that the departure rate of a class of traffic from a router must equal or surpass a configured rate. It means during any interval of time, the class of traffic can be guaranteed to receive enough bandwidth to make the output rate of the traffic equal or surpass this minimum configuration rate.

EF implies some form of isolation among traffic classes. Even if the other classes of traffic are overwhelming router and link resources, with EF isolation, required resources will be still available to the class to receive its minimum rate guaranteed link bandwidth. EF PHB provides a low loss, low jitter, low delay service.

Assured Forwarding (AF): AF PHB is more complex than EF. It divides traffic into four classes, where each class is guaranteed to be provided with some minimum amount of bandwidth and buffering. Within each class, packets are classified into one of three drop priorities in the case of congestion concurrency. When congestion within an AF class occurs, a router can then drop packets based on their drop priority values. Class AF1 has the highest priority and resources, and AF4 has the lowest. Within each class AF, 1-4, the subclass with DP 1 will have the lowest dropping probability while the one with DP 3 will have the highest [59] [63].

At a DiffServ-capable router, a marked packet is forwarded onto its next hop according to its traffic class. Forwarding is conducted according to the Per Hop Behavior (PHB) that influences how a router's buffers and link bandwidth are shared among the competing classes of traffic. A router's PHB is based strictly on packet marking, the class of traffic to which a packet belongs. The DiffServ technique takes place somewhere between the best-effort model and the IntServ.

Fairness of Network Congestion

The current Internet best-effort service and end-to-end congestion control with TCP mechanisms are successful in preventing network collapse. However, that does not mean these two services guarantee fairness among users during network congestion. For example, if a router is handling multiple flows, the potential exists that one of them will be more aggressive and cause starvation for others [60].

Most existing routing algorithms for packet dropping techniques are usually based on the min-max fairness principal for achieving a fair dropping. These techniques usually store per-flow state information by using Resource Reservation Setup Protocol (RSVP) along their paths, such as the IntServ model.

A few queuing techniques, such as Core-Stateless Fair Queuing (CSFQ), are also based on a min-max principal technique. However, these types of queuing techniques do not store per-flow state information on competing flows, as in the DiffServ model.

The Internet's best-effort service does not maintain state information at the core routers and does not need to maintain state information for the flow of packets. It does not provide any guarantees that data is delivered or that a user is given a guaranteed QoS level or a certain priority. In the case of congestion, flows cannot have fair treatment; an aggressive flow will cause starvation for other flows. In this type of network infrastructure, all users obtain best-effort service. This means that they obtain unspecified variable bit rate and delivery time, depending on the current traffic load. Since the best-effort service model does not support the features, such as recovery of lost or corrupted data and pre-allocation of resources, it can be operated efficiently. More than this, since it is simple, it is inexpensive [20].

The flow-based IntServ model, on the other hand, provides a one hundred percent guarantee of service in the network. This specification of IntServ comes with a high price; in the IntServ model, state information must be maintained for per core routers on the path from source to destination, which disables the model's scalability. Additionally, establishing such network architecture is highly complex, and more than that, it is very expensive. Its cost and complexity affect its preference as a network model today.

Class-based DiffServ, which does not need to store per-flow state on the routers at the interior of the network, lies between these two extreme service models. DiffServ maintains only a constant amount of state per router; it provides a simple, scalable, and coarse-grained mechanism for classifying, managing network traffic, and providing QoS guarantees on IP networks [18] [19] [20]. These characteristics make it highly favorable in real-time healthcare systems. Figure 11 summarizes these three service models of network features and their differences.

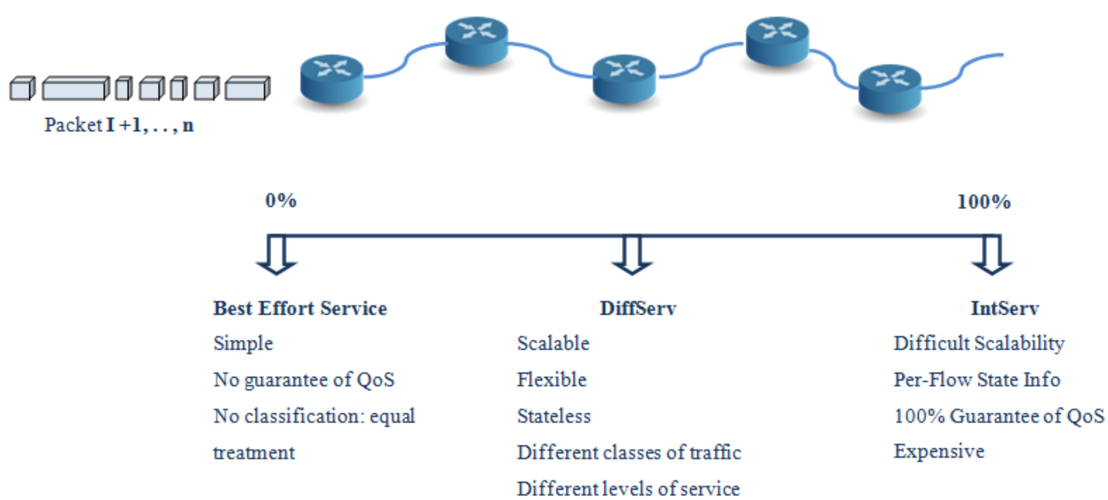

Figure 11: IntServ requires each router to maintain and manage per-flow state on the control path. Best-Effort is highly popular due to its simplicity and cost.
DiffServ has the ability to handle different service requirements in different ways with a scalable and flexible behavior.

DiffServ aims to provide scalable service differentiation in the Internet that can be used to permit differentiated pricing of Internet service [58] [59] [60] [63]. This thesis presents a new technique, Proportional Bandwidth Allocation (PAB), in which, during congestion IP bandwidth is allocated in proportion to the users' negotiated bandwidth agreement. In the PAB technique, bandwidth is allocated in proportion to the Subscripted Information Rate (SIR) of the flows. The ratio of a flow's data rate is encoded to its SIR as a label on its packets at the edge of the network. With this structure, PAB provides a more scalable, affordable, stateless, and fair network service than the two extreme network service models, best-effort and IntServ, as well as a different strategy than the DiffServ model during network congestion. Figure 12 shows where PAB stands as a network service model among the other three models.

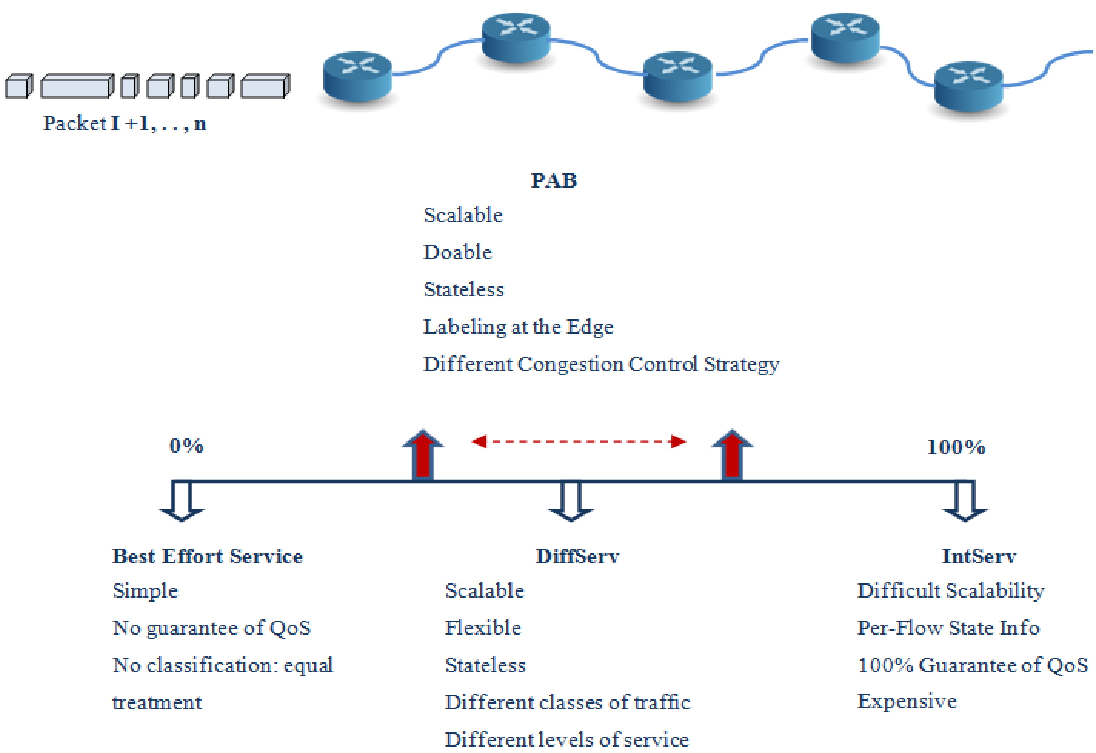

Figure 12: PAB lies in the middle of the service models scale with a different congestion strategy.

CHAPTER 5 SCALABLE PROPORTIONAL ALLOCATION OF BANDWIDTH (PAB)

In wireless networks, radio resources are limited and expensive. These two important characteristics of wireless communication lead to the requirement of appropriate resource management. With this in mind, a new method of bandwidth allocation technique, Proportional Allocation of Bandwidth (PAB) is defined in this study.

In PAB technique, bandwidth is allocated in proportion to the Subscripted Information Rate (SIR) of the flows. During the implementation of PAB, no state of the flows information is stored in the interior of the network. Instead of storing per-flow-state of information into the core, the ratio of a flow's data rate is encoded to its SIR in the form of a label on its packets. At the interior (core) of the network, the routers use these labels for differentiating between packets during congestion. All the labeling is done at either the source or the first network element, ingress (edge) routers of a wireless network, which have information about the source's SIR. The interior router drops packets based on their labels and the current level of threshold in the router. In this way, no state information is stored in the center of the network. During bandwidth allocation, two service parameters, the flow's data rate and its SIR, conduct fairness among users in the case of network congestion.

According to the definition of max-min fairness as defined in [66], each flow is allocated bandwidth as given by:

$$Alloc\ (i) = Min\{send(i), rr\} \qquad (1)$$

$$\Sigma\ Alloc\ (i) \leq Available\ Bandwidth \qquad (2)$$

send(i) → the data rate of the i^{th} flow

rr → the maximum rate that satisfies the above inequality

Any flow sending more than *rr* will have its throughput reduced to *rr*. However in this scheme, the SIR of the flow is not considered in bandwidth allocation.

On the other hand, in PAB, bandwidth will be allocated such that all flows have identical flow rate (FR) to SIR ratio. However, this requirement must be satisfied with full network utilization. Therefore, in PAB the allocation of bandwidth is given by:

$$Alloc\ (i) = Min\{\ send(i), frac * SIR(i)\ \} \qquad (3)$$

$$\Sigma \quad Alloc\ (i) \leq Available\ Bandwidth \qquad (4)$$

SIR(i) → the SIR of the i^{th} flow

frac → the maximum fractional multiplier (between 0 and 1) that satisfies the above inequality

The *frac* determines the maximum data rate of a flow as a fraction of its SIR. If the data rate of a flow is below its allowed throughput, *frac*SIR*, then it does not suffer any packet loss. Additionally, if a flow has a data rate less than its allowed fraction of SIR, then the remaining excess bandwidth is also shared among other flows in proportion to their SIR. No flow is allowed to send more than its SIR during congestion.

The throughput of any flow sending more than the allowed fraction of SIR is reduced to its maximum allowed data rate. Thus, PAB differentiates between flows and allocates bandwidth in proportion to the classes of the flows. A simple example with three sources which each try to reach three destinations will be aid to explain functionality of PAB.

Considering sources, S1, S2, S3 are sending one flow each to destinations D1, D2, and D3 respectively by traversing two congested links, L1, L2, Figure 13.

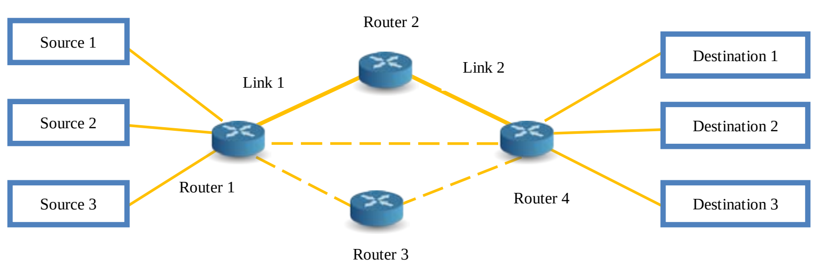

Figure 13: The network configuration of the example. Sources, S1, S2 and S3, send one flow each to destinations D1, D2 and D3 respectively. The flows traverse two congested links Link-1 and Link-2.

In the example, the original flow rate (FR) of sources, S1, S2, and S3 are 90 kbps, 120 kbps, and 200 kbps; the SIR of the individual sources are 100, 150, and 300, respectively, as shown in Table 6. The bandwidth of the 2 links, L1 and L2, are shown as 200 and 150, as in Table 7.

	Source 1	**Source 2**	**Source 3**
Original flow rate (Kbps) of Sources (FR)	90	120	200
SIR (Kbps)	100	150	300

Table 6: The original flow rate of sources, S1, S2, S3 and their Subscripted Information Rate (SIR).

The Bandwidth of the Links	
Link 1	200
Link 2	150

Table 7: The bandwidth of the links, L1 and L2.

The ratio of the SIR of the individual sources to the sum of SIRs of all sources determines the throughput of the sources during congestion. The throughput of a source is the product of the ratio of its SIR to the total SIR and the bandwidth of the bottleneck link. The sum of the throughput of the sources after link L1 and before L2 is 200 Kbps, and after that link L2 is150 Kbps, utilizing the full capacity of the network.

Table 8: Throughput calculation and values of PAB.

	Calculation	**Source 1**	**Source 2**	**Source 3**
Ratio of SIR to Σ SIR (%)	*SIR / Σ SIR*	18.18%	27.27%	54.54%
Flow Rate between Link1 and Link 2 (Kbps)	$\frac{L1 * \text{ratio of SIR}}{100}$	36.36	54.54	109.09
Flow rate after Link 2 (Kbps)	$\frac{L2 * \text{ratio of SIR}}{100}$	27.27	40.90	81.81

Table 8 shows the throughput calculation and values of PAB. According to the results, all three sources are below their allowed throughput and they do not experience packet loss.

Implementation of PAB

Implementation of PAB is based on the principles of DiffServ [58] [59] [60] [63]. To avoid per-flow state information in the core routers, PAB technique uses labels to indicate the ratio of FR to the SIR of the flow. Packets are marked with labels at the edge of the wireless network. The ratio of FR to the SIR of each flow is encoded as the label on the flow's packets. In the core (interior) of the network, bandwidth allocation is done using these labels to differentiate between packets. The wireless routers perform multilevel threshold based dropping.

Two main components of PAB, the labeling of the packets at the edge of the network and dropping of packets at the core router, guide the implementation.

Packet Labeling Methodology

Packets are labeled at the ingress (incoming) or source routers. The ingress router has knowledge of SIRs of all the sources connected to it. The labeling mechanism marks the flow's packet with different labels depending on the ratio of the FR to the SIR, *Link1 * ratio of SIR /100.* The total number of labels is fixed for all flows, but the number of label values used at any time for a source depends on its FR. As the ratio of FR to SIR increases for a flow, more and more packets will be marked with labels with low priority. Packet labeling methodology has functionality to mark the packets of two flows differently even though these two flows have identical FR with different SIR or identical SIR with different FR. Figure 14 and Figure 15 are consecutively composite these methodologies.

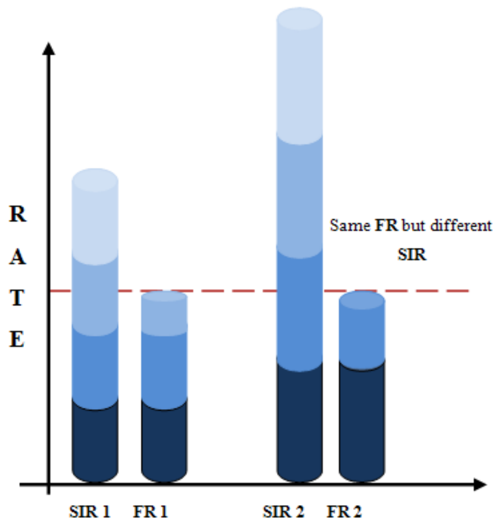

Figure 14: Packet labeling methodology of PAB marks the packets of two flows with the same FR but different SIR, differently.
The flow with lower SIR has more packets with lower priority than the flow with the higher SIR as shown in the figure.

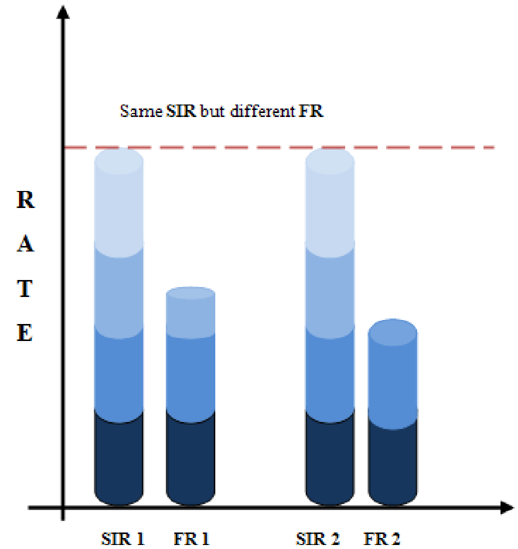

Figure 15: Packet labeling methodology of PAB marks the packets of two flows with the same SIR but different FR, differently.
The flow with the higher FR is marked with lower priority labels than the flow with the lower FR as shown in figure.

A label is not associated with a particular rate numerically. Each label is associated with only a fraction between 0 and 1. The sum of the fractions corresponding to all labels is set equal to one.

Token Bucket Usage Methodology

To label the packets, multiple token buckets are used at the ingress (edge) router, which has the knowledge about the SIR of the source. The source should be able to send data at or below its SIR, but its average data rate should not exceed its SIR. So the sum of the token rates of all the token buckets must be equal to the SIR of the source. The SIR, however, is distributed among all the token rates. Therefore, the token rate of an individual token bucket is a fraction of the source's SIR. This fraction is equal to the fraction associated with the label corresponding to that token bucket. The sum of all the fractions associated with the labels is 1. So the sum of the token rates is the SIR of the source.

$$\text{Token Rate of Bucket } j = frac(j) * SIR \qquad (5)$$

$$\Sigma\ frac(j) = 1 \qquad (6)$$

frac(j) → fraction of a individual token bucket, *j*

1 → The sum of all the fractions associated with the labels

The flow rate determines the actual label values that the packets get. As the ratio of flow rate to SIR increases, more and more packets will be labeled with lower priority. The token bucket size allows for bursts in the flow rate. However, the long term rate of the flow can never exceed its SIR. The lower the label value, the higher is the priority of that packet and the lower probability of being dropped.

A packet can remove tokens from only one bucket. If a packet has insufficient tokens to remove from any of the token buckets, then the source is sending packets at a rate greater than SIR and the available burst size. So the packet is dropped. Figure 16 is a visual presentation of multiple used of token buckets at the ingress (incoming) router of wireless network.

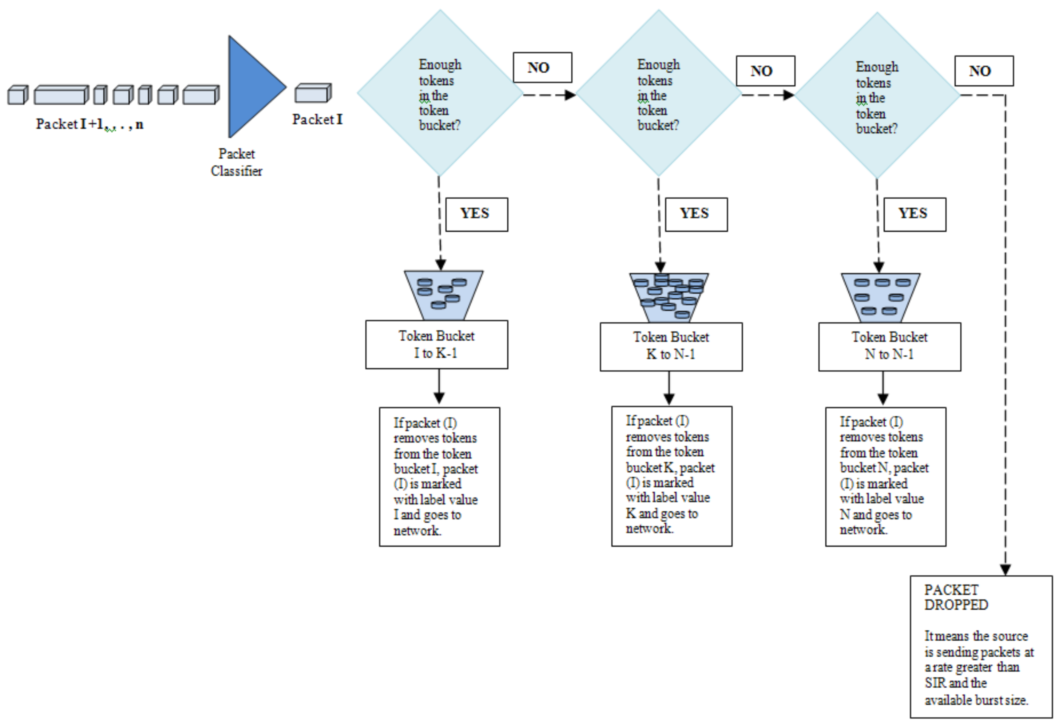

Figure 16: Visual presentation of multiple used of token buckets at the ingress (incoming) router of wireless network.

An incoming packet, *I* in the presentation above, first examines the first bucket, *I*, to determine whether it has sufficient tokens to remove. If *bucket I* has sufficient tokens in its bucket, *packet-I* is marked with a label value of *bucket I* and goes to the network. However, if token *bucket-I* does not have the sufficient tokens required by *packet-I*, then *packet-I* moves to the *bucket-K* to see if *bucket-K* has enough tokens. If *bucket-K* satisfies the *packet-I* requirement, it is marked with a label *K* and goes on its way. If *bucket-K* has insufficient tokens for the *packet-I* requirement, *packet-I* moves to next bucket. However, if a packet has insufficient tokens to remove from any buckets it shows that packet has a rate greater than its SIR and burst size then that packet must drop.

Packet Dropping at the Core Routers

Packet dropping mechanisms help identify which packets should be dropped when queues exceed a certain threshold. It is possible to place packets in one queue or multiple queues depending on their priority class or flow type. The process is similar for threshold. It is possible to keep a single threshold on packets in all queues or to keep multiple thresholds on packets in one queue. In summary, queues and thresholds could be single or multiple.

One of four types of classes of packet dropping techniques can be use for dropping management:

- Single Accounting (queue), Single Threshold (SAST).
- Single Accounting (queue), Multiple Thresholds (SAMT).
- Multiple Accounting (queues), Single Threshold (MAST).
- Multiple Accounting (queues), Multiple Threshold (MAMT).

The active queuing mechanism used in this study, the Multilevel Threshold Based Queuing (MLTQ), is similar to SAMT. In MLTQ, multilevel drop thresholds are established at the core routers and the drop probability of a packet is calculated based on its label value and the average queue length. The average queue size is monitored using an exponential weighted moving average technique, as in Random Early Dropping (RED), or a modified version of RED, Fair Random Early Dropping (FRED) [64].

A single average queue length is maintained for all the packets in implementation of MLTQ. There are *n* label values. *N* sets of min_{th}, max_{th}, and P_{max} exist in the core router, where:

min_{th} → indicates the minimum threshold for queue.

max_{th} →indicates the maximum threshold for queue.

P_{max} →indicates the maximum drop probability.

When a packet of label value *K* arrives in the router, the min_{th} -*K*, max_{th} -*K* and P_{max} -*K* are used to determine whether that packet has to be dropped. The values are set as shown in Figure 17. A low priority label has its thresholds such that it has high drop probability even when the average queue length is low. However, a high priority label has its thresholds such that it has a low drop probability even when the average queue length is high. The highest priority label is label 1 and the least priority label is label N. Lower priority labels have high maximum drop probabilities.

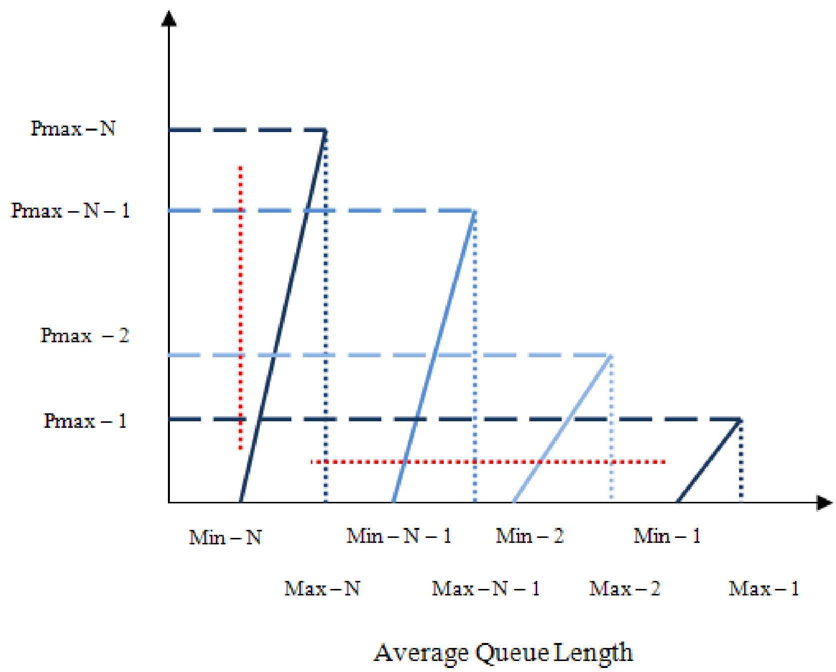

Figure 17: Core Router Mechanism for Dropping Packets.

Determination of the Label Fractions

Three different sets of fraction values with specific properties can be assigned to the labels:

- Fractions with equal value.
- Fractions forming arithmetic progression.
- Fractions forming geometric progression.

Equal Fractions: All the fractions are of equal value. For example, If N=89, then each label has the value 1/89. The sum of the fractions is 1.

Arithmetic Progression Fractions: The fractions form an arithmetic progression. Unlike equal fractions, the values for arithmetic progression fractions are not identical. To achieve better granularity while providing PBA, the smaller values in the arithmetic progression are associated with the higher priorities among the labels. In this sense, the fractions will have the values given by:

$$a, a + d, a + 2d, a + 3d, \ldots\ldots, a + (N\text{-}l)\, d \qquad (7)$$

Since the sum of the fraction values in the arithmetic progression must be unity, the sum of the arithmetic progression is set equal to one.

$$Sum = Na + \frac{N\,(N-1)\,d}{2} = 1 \qquad (8)$$

For simplicity purposes, assuming the "*d*" is equal the "*a*" which gives the value for the fractions,

$$d = \frac{2}{N * (N + 1)} \qquad (9)$$

For example, when *N=8,* according to *formula 9,* the value of *d* is

$$d = \frac{2}{8 * (8 + 1)} \rightarrow 2d = 72 \rightarrow d = 72/2 = 36 \rightarrow 1/36$$

Therefore, the values of fractions are for N=8 are 1/36, 2/36, 3/36, 4/36, 5/36, 6/36, 7/36, and 8/36.

Geometric Progression Fractions: The fractions can also form a geometric progression. Similar to arithmetic progression, the values of the fractions are assigned such that higher priority labels are associated with smaller values in the geometric progression.

The fractions in the geometric progression are given by

$$a, ar, ar^2, ar^3, ar^4, \ldots\ldots, ar^{(N-1)} \qquad (10)$$

Since the sum of the fractions should be 1, the value of sum is set to one:

$$Sum = \frac{a\,(1 - r^N)}{1 - r} = 1 \qquad (11)$$

For simplicity purposes, assuming the “*r*” is equal the “*a*” which gives the value for the fractions:

$$r, r^2, r^3, r^4, \ldots, r^{(N-1)} \qquad (12)$$

The value for “*r*” is given by the equation below when the sum of the fractions is unity.

$$r\,(2 - r^N) = 1 \qquad (13)$$

Assuming N is 8, $N=8$,”*r*” gets a value approximately equal to ½. According to *r* value, “$r=½$”, the rest of the fractions have 1/2, 1/4/, 1/8, 1/16, 1/32, 1/64, 1/128 and 1/128. The last two fractions are made equal so that the sum of the fractions is 1.

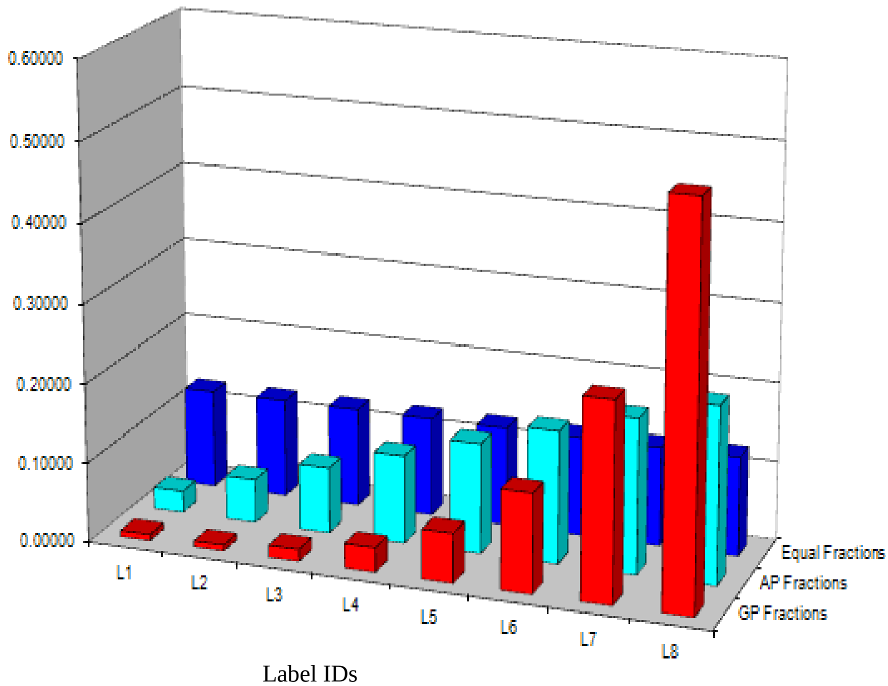

Figure 18: Values of Equal, Arithmetic, and Geometric progression fractions.

Figure 18 shows the values of fractions assigned to labels for the three types of fractions. For the same Subscripted Information Rate (SIR) and the same flow rate, the number of high priority packets is greater in equal fractions than in arithmetic fractions or in geometric progression fractions. Since equal fractions treat the packets equally, high priority packets have an advantage over low priority packets.

CHAPTER 6 SIMULATION RESULTS

With the advances of wireless technologies and ever-increasing user demands, the IP protocols suite has to extend its capability to encompass the wireless aspect. However, in reality, IP networks are heterogeneous, implying that the communication path from one end to another consists of both wired and wireless links.

TCP has congestion control for the network packets. With any delay on the packet delivery, TCP will slow down the flow and try repeatedly to deliver the packets. On the other hand, UDP does not have any control mechanism for congestion. This is the reason UDP is used for real-time audio and video streams which have no need to recover lost packets. Under these techniques of networking communication, in this simulation study the original implementation technique, PAB, is compared with that of RED in three sets of source experiments: UDP, TCP, and UDP, and TCP mixed as a Single Congested Link (SCL), as well as two sets of source experiments: UDP and TCP as the Multiple Congested Link (MCL) for IP networks.

Single Congested Link (SCL)

An ns-2 simulator [65] was used for performing the simulation. In the simulation, the packets are marked with labels at the edge routers of the network, which are the gateways to the wireless network. The wireless routers use the labels for providing service and dropping packets when congestion occurs. In the case of a single congested link, the network configuration is as shown in Figure 19.

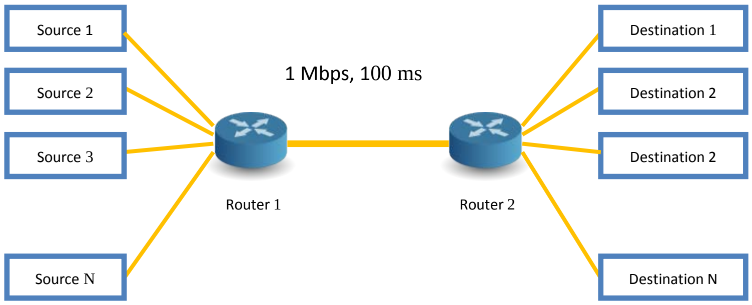

Figure 19: Single Congested Link Network Configuration.

N flows are shared in a single congested bottleneck link that stands at the core of the network. In the case of a single congested link, the setting values are as follows:

- The SIR of the i^{th} flow is → ($i / N * 500$) Kbps.
- The number of flows sharing (source) the link → varied from 3 to 32.
- The capacity of the bottleneck link is → 1 Mbps.
- The link delays between Router-1 and Router-2 → 100 ms.
- The capacity of the link buffer is → 100 packets.
- The packet size of the TCP flows → 1000 bytes.
- The packet size of the Constant Bit Rate (CBR) flows → 210 bytes.

The parameters for 8-level drop thresholds at the core router are shown in 9.

Table 9: Parameter for Core Router Dropping Mechanism.

Label	Minimum Threshold	Maximum Threshold	Max Drop Probability
1-highest priority	80	90	1/50
2	70	80	1/45
3	60	70	1/40
4	50	60	1/35
5	40	50	1/30
6	30	40	1/25
7	20	30	1/20
8-lowest priority	10	20	1/15

For the token buckets at the ingress routers, the bucket size is fixed at 80000 bytes. The token rate for each label was determined depending on the method of fractions chosen for marking the labels. The token rate for each of the eight labels is the product of the fractions associated with that label and the bucket of every label and the SIR of the source. The token rate for the bucket of every label is the product of the fraction associated with that label and the SIR of the flow.

By definition of PAB, each flow should get a share of bandwidth, which is in proportion to its SIR. The measure that has been used to calculate the effectiveness of the proportional allocation of bandwidth is obtained as shown. The throughput ratio of the i^{th} flow *[TR(i)]* is defined as the ratio of throughput of i^{th} flow to the sum of the throughputs of all flows going through the same link.

$$TR(i) = \frac{Throughput\text{-}of\text{-}Flow(i)}{\sum Throughput\text{-}of\text{-}all\text{-}Flows} \qquad (14)$$

The SIR ratio for the i^{th} flow Source Rate, *[SR(i)]*, is defined as the ratio of SIR of i^{th} flow to the sum of the SIRs of all flows going through the same link

$$SR(i) = \frac{SIR\text{-}of\text{-}Source(i)}{\sum SIR\text{-}of\text{-}Source(i)} \qquad (15)$$

The Allocation Ratio (AR) for the i^{th} flow *[AR(i)]* is defined as throughput ratio *TR(i)* to *SR(i).*

$$AR(i) = \frac{TR(i)}{SR(i)} \qquad (16)$$

The performance measure is given by:

$$\text{Proportionality Index} = \frac{\left[\sum AR(i) * \sum AR(i)\right]}{N * \sum\left[AR(i) * AR(i)\right]} \qquad (17)$$

The proportionality index is inversely related to the difference in the allocation ratios of the various sources. The more the allocation ratios of the various sources differ, the more the value of the proportionality index decreases.

Experiment of UDP flows with PAB and RED

In the first set of experiments, the entire N flows were UDP sources. Each source sends one flow into the network and the flow reaches the destination at the other end of the network. The sources sent data randomly from 10% to 200% of their SIR. Experiments were conducted with the number of flows increasing from 3 to 32 with PAB and RED bandwidth allocation techniques to observe their performances.

The performance results for the experiments are displayed in Figure 20 with the number of flows vs. the proportionality index for UDP flows.

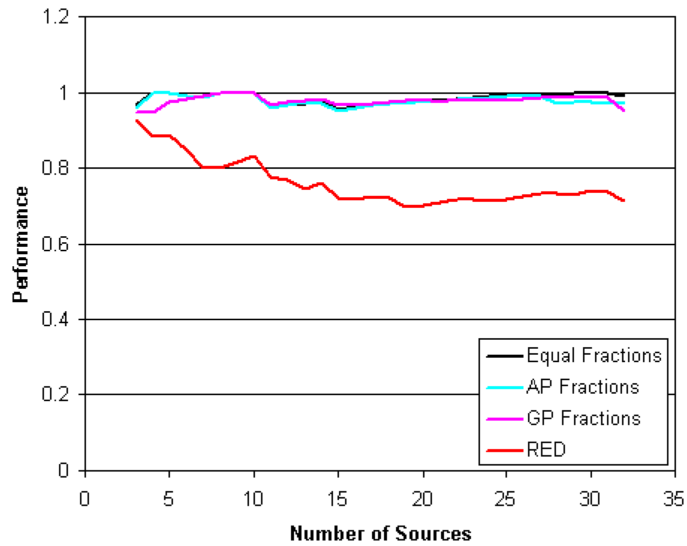

Figure 20: Performance of UDP flows with PAB and RED.

In Figure 20, it can be observed that as the number of sources increase, the performances of the three types of fractions are almost similar. However, for RED the performance drastically drops as the number of sources increases. This is due to the fact that RED has no knowledge of SIR and cannot differentiate between the flows. Thus, the bandwidth allocation by RED does not follow the principles of Proportional Allocation of Bandwidth. Actually, RED was not designed to enable sharing of resources proportional to SIR. The reason to compare PAB with RED is to show how much a PAB service would benefit users.

Experiment of TCP Flows with PAB and RED

In the second set of experiments, all the flows were TCP. The peak data rate of the TCP flows was set to their SIR. Figure 21 shows the results for the experiments. The graph shows the number of flows vs. the proportionality index for TCP flows.

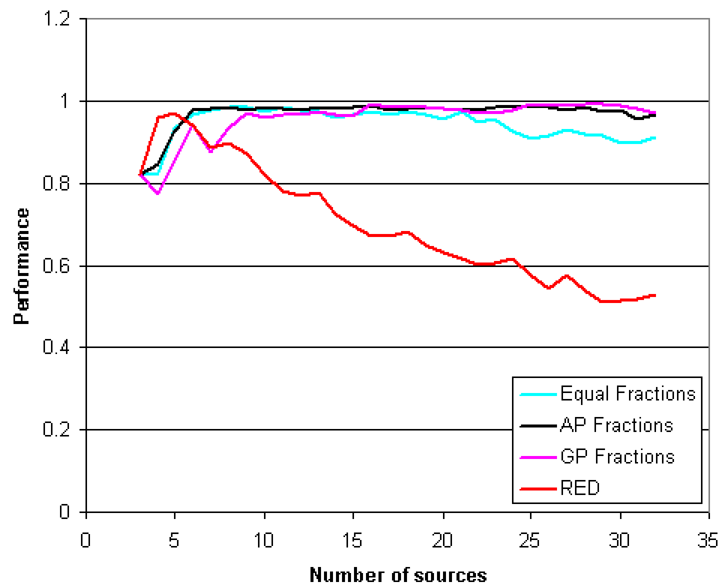

Figure 21: Performance of TCP flows with PAB and RED.

In the case of TCP sources, as the number of sources increases, the performance of the three fractions—equal, arithmetic, and geometric progression fractions—is very good. The TCP flows are congestion sensitive and when there is congestion, the TCP flows tend to share the bandwidth equally among the flows. Our technique achieves proportional bandwidth sharing by using labels and thus achieves good performance. In the case of RED, the performance has become much worse than that with UDP sources. During congestion, the TCP sources reduce the sending data rate so that the rate of all sources is equal and RED cannot distinguish between sources and thus has poor performance.

Experiment of TCP and UDP Flows with PAB and RED

In the third set of experiments, all the even flows were TCP and all the odd flows are UDP. The data rates of the UDP and TCP flows are the same as in the previous experiments. Figure 22 shows the results for the mixed experiment. As before, the number of sources varied from 3 to 32 and the experiments were done for all three types of fractions and RED.

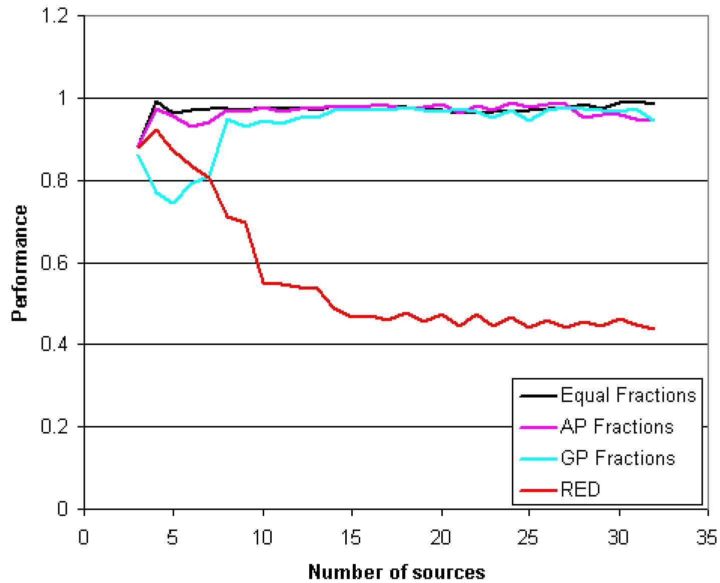

Figure 22: Performance of TCP and UDP flows with PAB and RED.

In this case, performance of the three fractions is much better than simple RED. UDP flows are congestion insensitive and TCP flows are congestion sensitive. UDP flows try to get all the bandwidth and so TCP sources get much less bandwidth. The PAB technique provides good protection of TCP flows from UDP flows and achieves excellent performance. However, for RED, TCP flows are not protected and thus RED performs poorly.

Multiple Congested Links (MCL)

In the case of multiple congested links, the network topology for the simulation is shown in Figure 23.

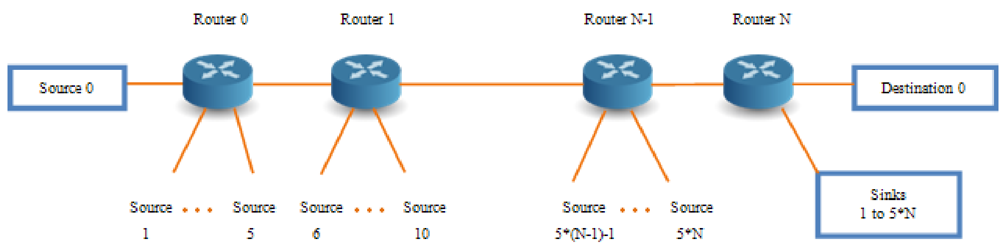

Figure 23: Multiple Congested Links Network Configuration.

This is a typical parking lot configuration. Flows travel different distances in the network which have N+ 1 routers, R0 to RN. The links connecting the routers have a bandwidth of 1.5 Mbps and a link delay of 50 ms.

At the routers *router-0* to *router-N -1*, flows enter the network, and at the router *router-N*, all the flows leave the network. At router *router-0*, flow *source-0* enters the network. At router *router-I,* flows *source-i*5+1* to *source (i+1)*5* enter the network. In each experiment set, the number of congested links varied from 2 to 5.

The performance of PAB in multiple congested links is defined as the ratio of the throughput of flow *source-0* to its SIR divided by the ratio of the sum of the throughputs of all sources to the sum of SIRs of all flows. This measure is the allocation ratio of flow *source-0*.

$$\textit{Allocation -Ratio - AR (0)} = \frac{[\textit{Throughput (0) / SIR (0)}]}{[\sum \textit{Throughputs (0)} / \sum \textit{SIRs}\,]} \qquad (18)$$

Experiment of UDP Flow-0 with PAB and RED

The experiment for UDP is displayed in Figure 24. In the figure, the performance of RED is clearly poor with *source-0* as a UDP flow. On the other hand, the performance of the three fractions is much better. Among the three, equal fraction performance is the lowest for the allocation ratio (0) vs. the number of congested links. Other two fractions' performance is better. The reason is because the high priority labels in their cases are associated with a smaller fraction of the SIRs of the sources. Especially in the case of high levels of congestion, geometric progression fractions work better because of their higher granularity for high priority labels.

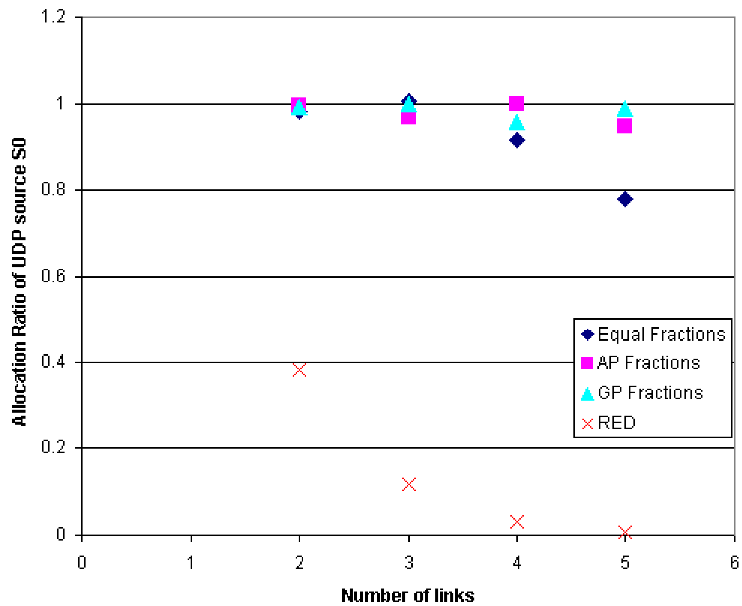

Figure 24: Allocation Ratio of UDP Flow-0 in Multiple Congested Links.

Experiment of TCP Flow-0 with PAB and RED

The experiment for TCP is displayed in the Figure 25. It can be observed that the performance of RED with TCP as flow *source-0* is very poor and almost nil. Among the three types of fractions, performance variation occurs as the number of congested links increases. This is due to the fact that this technique is an approximate implementation of PAB.

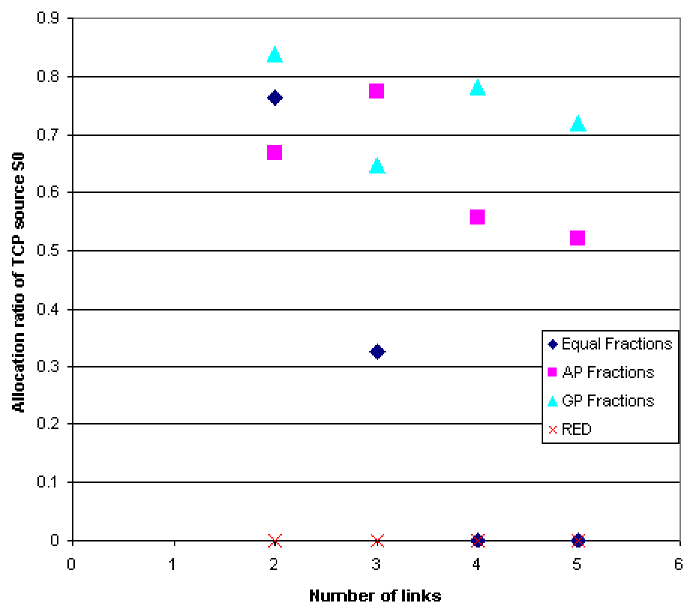

Figure 25: Allocation Ratio of TCP Flow-0 in Multiple Congested Links.

Additionally, the performance of equal fractions suffers significantly as the number of congested links increases. In equal fractions the highest priority label is associated with a fraction value that is 1/8th of SIR. So as severity of congestion increases all packets that are marked with the lower priorities are dropped. Packets of the highest priority alone survive the congestion. Since now all packets are of the same priority, it becomes difficult to achieve PAB.

CHAPTER 7 CONCLUSION

The adoption of information technology to support the delivery of healthcare data is increasingly recognized in many countries as an essential tool in improving patient care. These systems are best thought of as cost-reducing and/or quality-improving technologies. Increased demands for electronic exchange of data have been driven by the rising expense of healthcare.

This thesis proposes a new DiffServ-based scheme of IP bandwidth allocation during congestion, called proportional allocation of bandwidth (PAB) which can be used in all IP networks. In PAB scheme, bandwidth is allocated in proportion to SIR of the competing flows. PAB is implemented, without per-flow state maintenance, using multiple token buckets to label the packets at the edge of the network and multilevel threshold queue at the IP routers to discard packets during congestion. The labels are associated with fractions and each label corresponds to a fraction of the SIR of a flow.

The simulations of the study show that the performance of PAB scheme is good in both single congested link and multiple congested links in wireless networks.

The proposed PAB scheme network can handle both normal and life-critical medical applications characterized by their urgency. Assigning different priority levels according to the ratio of flow rate to its SIR causes the network to intelligently drop and/or delay the packets, in order to achieve a high service level. It is practical, doable, stateless, and its labeling process takes place at the edge routers in order to ease flowing at the interior of the network. Therefore, the proposed architecture can be considered as a survivable network that can be used under extreme traffic conditions as reliable infrastructure for telemedicine.

REFERENCES

REFERENCES

[1] American Diabetes Association, Diabetes Basics, “Diabetes Statistic”. Retrieved from http://www.diabetes.org/diabetes-statistics.jsp.

[2] NationMaster.com, (most recent). Retrieved from http://www.nationmaster.com/graph/mor_sud_inf_dea_syn-mortality-sudden-infant-death-syndrome.

[3] AgingStats.gov. Federal Interagency Form on Aging Related Statistic.Retrieved from http://www.aoa.gov/agingstatsdotnet/Main_Site/Data/2008_Documents/Population.aspx.

[4] PURE ENDURANCE, “Lactate Testing”. Retrieved from http://www.pureendurance.net/blood_lactate_test_kits.

[5] Hu, F., Celentano, L., Xiao, Y.Mobile telemedicine: a computing and networking perspective (2008), “Mobile, Secure Tele-Cardiology Based on Wireless and Sensor Networks”.

[6] Deniz U Dincer, IU School of Medicine, Principle Medical Adviser Interview by Birhan Payli and Arjan Durresi November (2008) and by Birhan Payli February, Marc (2009)

[7] Prajakta Kulkarni, Yusuf Ozturk, (2007), “mPHASIS: mobile Patient Healthcare And Sensor Information System”.

[8] Kathy J. Liszka, Malinda J. Sever, Michael E. Richter, and Sudha Bhattarai, (2008), “Issues in Personal Cardiac Health Monitoring with Sensor Networks”.

[9] Clket.Com. Router clip art. Retrieved from http://www.clker.com/clipart-10600.html.

[10] ABOUT.COM, Retrieved from http://aids.about.com/od/newlydiagnosed/qt/lytes.htm.

[11] Birhan Payli, Arjan Durresi, Deniz Dincer (2009) “Non-Invasive Real-Time Blood Observation System”.

[12] American Diabetes Association, “All About Diabetes”. Retrieved from http://www.diabetes.org/about-diabetes.jsp.

[13] Amarillo Medical Specialists, LLP, “How to interpret your blood test results”. Retrieved from http://www.amarillomed.com/howto.htm.

[14] MedlinePLUS, “Laboratory Tests” Retrieved from http://www.nlm.nih.gov/medlineplus/laboratorytests.html.

[15] TIME, (2008). “The Army's Totally Serious Mind-Control Project” Retrieved from http://www.time.com/time/nation/article/0,8599,1841108,00.html.

[16] Arjan Durresi, Arben Merkoci, Mimoza Durresi, and Leonard Barolli, (2007). “Integrated Biomedical System for Ubiquitous Health Monitoring”. Retrieved from http://www.springerlink.com/content/g657148556373586/fulltext.pdf.

[17] Ion Stoica, Hui Zhang, (1999). “Providing Guaranteed Services Without Per Flow Management”. Retrieved from http://delivery.acm.org/10.1145/320000/316208/p81-stoica.pdf?key1=316208&key2=8391354621&coll=GUIDE&dl=GUIDE&CFID=73278599&CFTOKEN=33021983.

[18] Arjan Durresi, (2002). “Scalable Proportional Allocation of Bandwidth in IP Networks”.

[19] Jorge A. Cobb, “Stabilization of Max-Min Fair Networks without Per-Flow-State”. Retrieved from http://www.utdallas.edu/~jcobb/PublishedPapers/Conf-2008/SSS2008/Max-Min-Stab-Extended.pdf .

[20] Wikipedia. Retrieved from http://en.wikipedia.org.

[21] LAB TEST ONLINE: Retrieved from http://www.labtestsonline.org/index.html.

[22] Schizophrenia.com, (2007). “Blood Tests to Diagnose Schizophrenia Moving Towards Clinical Testing”. Retrieved from http://www.schizophrenia.com/sznews/archives/005231.html.

[23] e-Medicine Help. “Diabetes Symptoms”. Retrieved from http://www.emedicinehealth.com/diabetes/page3_em.htm#Diabetes%20Symptoms.

[24] WebMD. “How to Test Your Blood Sugar With Diabetes”. Retrieved from http://diabetes.webmd.com/guide/how-test-blood-glucose.

[25] MAYO CLICK.COM. “Diseases and Conditions”. Retrieved from http://www.mayoclinic.com/.

[26] Technology Review, (2008). “Carbon-Nanotube Thread”. Retrieved from http://www.technologyreview.com/computing/21689/?a=f.

[27] NKUDIC: National Kidney and Urologic Diseases Information Clearinghouse. “The kidneys and How They Work”. Retrieved from http://kidney.niddk.nih.gov/Kudiseases/pubs/yourkidneys/#6.

[28] HelpMed. Retrieved from http://www.medhelp.org/lib/pku.htm.

[29] TheFreeDICTIONARY by FARLEX. Retrieved from http://medical-dictionary.thefreedictionary.com/sickle+cell+anemia.

[30] The New York Times, (2009). "Screening for Rare Genetic Disorders Now Routine in Newborns", by Rony Caryb Rabin. Retrieved from http://www.nytimes.com/2009/02/19/health/18screening.html.

[31] Kids Health. Retrieved from http://kidshealth.org/parent/system/medical/newborn_screening_tests.html#.

[32] SPORT COACHING. "Lactate Testing". Retrieved from http://www.jdssportcoaching.com/lactatetesting.html.

[33] OpticsInfoBase, Thomas Muehlemann, Daniel Haensse, Martin Wolf, (2008). "Wireless miniaturized in-vivo near infrared imaging". Retrieved from http://www.opticsinfobase.org/abstract.cfm?URI=oe-16- 14-10323.

[34] OpticsInfoBase, Ye Yang, Olusola Soyemi, Peter J. Scott, Michelle R. Landry, Stuart M. Lee, Leah Stroud, and Babs R. Soller, (2007). "Quantitative measurement of muscle oxygen saturation without influence from skin and fat using continuous-wave near infrared spectroscopy". Retrieved from http://www.opticsinfobase.org/abstract.cfm?uri=oe-15-21- 13715.

[35] Patent Storm, Wuori, Edward,R. (2003). "A Non-Invasive Blood Analyze Measuring System and Method Utilizing Optical Absorption". Retrieved from http://www.patentstorm.us/patents/6898451/claims.html.

[36] Patent Storm, Inventors: Hall, Jeffery W., Cadell, (1994). "Method and Device for measuring Concentration Levels of Blood Constituents Non-Invasively". Retrieved from http://www.patentstorm.us/patents/5361758.html.

[37] Ian F. Akyildiz, Ismail H. Kasimoglu, (2004). "Wireless Sensor and Actor Networks: research challenges".

[38] CDC Centers for Disease Control and Preventation, "Sudden Infand Death Syndrome (SIDS) and Sudden Unexpected Infand Death (SUID): Sudden, Unexpected Infant Death (SUID) Initiative". Retrieved from http://www.cdc.gov/SIDS/SUID.htm.

[39] e-Medicine Help, "Sudden Death Syndrome (SIDS)". Retrieved from http://www.emedicinehealth.com/sudden_infant_death_syndrome_sids/page2_em.htm.

[40] Hisense, "How BabySense V works". Retrieved from http://www.babysense.net/How-Hisense-Babysense-works.asp.

[41] Nanny Monitor UK, Nanny baby monitor. Retrieved from http://www.nannymonitor.co.uk/.

[42] Angelcare, Baby Monitors. Retrieved from http://www.angelcare-monitor.com/.

[43] RFID Journal Healthcare News. Clarie Swedberg, (2007). "Researcer Use RFID to Figth SIDS". Retrieved from http://www.rfidjournal.com/article/articleview/3252/1/1/.

[44] AIR FORCE, Human Performance Lab, Athlete Testing and Traning. Retrieved from http://www.goairforcefalcons.com/genrel/120106aag.html.

[45] Birhan Payli, Arjan Durresi, Deniz Dincer, (2008). "A Wireless Non-invasive Real-Time Monitoring Blood Lactate Test for a Moving Subject". Retrieved from http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4736791&isnumber=4736722.

[46] FaCT, "Hosand Heart Rate Telemetry Systems". Retrieved from http://www.fact-canada.com/Hosand/Hosand-heart-rate-telemetry.html.

[47] Dusit Niyato, Ekram Hossain, and Jeffrey Diamond, (2008). "Fourth Generation Heterogeneous Wireless Access Networks for eHealth Services: Architecture and Radio Resource Management".

[48] Phillip Olla, Joseph Tan, (2008). "Designing a M-Health Framework for Conceptualizing Mobile Health Systems".

[49] Dimitris Komnakos, Demosthenes Vouyioukas, Ilias Maglogiannis, Philip Constantinou, (2008). "Feasibility Study of a Joint E-Health Mobile High-Speed and Wireless Sensor System". Retrieved from
http://delivery.acm.org/10.1145/1390000/1389615/a24-komnakos.pdf?key1=1389615&key2=1664375621&coll=GUIDE&dl=GUIDE&CFID=75517223&CFTOKEN=34888062.

[50] Dimitrios J. Vergados, Dimitrios D. Vergados, Ilias Maglogiannis, (2006). "Applying Wireless DiffServ for QoS Provisioning in Mobile Emergency Telemedicine". Retrieved from http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4150890.

[51] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, (2002). "Wireless Sensor Networks".

[52] Medtronic, "Introducing the Guardian® Real-Time Continuous Glucose Monitoring system". Retrieved from http://www.minimed.com/products/guardian/.

[53] Medtronic, "MiniMed Paradigm® REAL-Time Insulin Pump and Continuous Glucose Manitoring System". Retrieved from http://www.minimed.com/products/insulinpumps/.

[54] SearchMobileComputing.com, SearchMobileComputing.com Definitions. "WPAN". Retrieved from http://searchmobilecomputing.techtarget.com/definition/WPAN.

[55] Buzzle.com, Intelligent life on the Web, RFID Technology. Retrieved from http://www.buzzle.com/articles/pros-and-cons-of-rfid-technology.html.

[56] Andrea Cangialosi, Joseph E. Monaly, Jr., Samuel C. Yang, (2007). "Application & Practise, LEVERAGINGRFID INHOSPITALS: PATIENTLIFE CYCLEANDMOBILITYPERSPECTIVES". Retrieved from http://authors.library.caltech.edu/9150/1/CANieeecm07.pdf.

[57] ABOUT.COM. Wireless/Networking. "Wireless Standards - 802.11b 802.11a 802.11g and 802.11n". Retrieved from
http://compnetworking.about.com/cs/wireless80211/a/aa80211standard.htm.

[58] Zheng Wang, (2001). “Internet QoS, Architectures and Mechanisms for Quality of Service. Integrated Service Models”. P: 15-78.

[59] James F. Kurose, Keith W. Ross, (2008). “Computer Networking. A Top-Down Approach”.

[60] Andrew S. Tanenbaum, (2003). “Computer Networks”.

[61] Editors: Yang Xiao, Hui Chen, (2008). “Mobile Telemedicine. A Computing and Networking Perspective”.

[62] Upkar Varshney, (2009). “Pervasive Healthcare Computing EMR/HER, Wireless and Health Monitoring”.

[63] Kalevi Kilkki, (1999). “Differentiated services for the Internet”.

[64] Sally Floyd and Van Jacobson, (1993).”Random Early Detection Gateways for Congestion Avoidance”.

[65] The Network Simulator - ns-2. Retrieved from http://www.isi.edu/nsnam/ns.

[66] Arjan Durresi, (2001). “Scalable Proportional Allocation of Bandwidth in IP Networks”.

[67] Joseph Tan, (2008). “Healthcare Information Systems and Informatics, Research and Practices”.

[68] Editors: G. Gomez, R. Sanchez, (2005). “End-to-End Quality of Service over Cellular Networks, Data Services Performance and Optimization in 2G/3G”.

[69] RedOrbit, (2010). “Satellite Dialysis Opens New Center in Merced”. Retrieved from http://www.redorbit.com/news/health/1832284/satellite_dialysis_opens_new_center_in_merced_ca/index.html.