“3G WIRELESS COMMUNICATIONS FOR MOBILE ROBOTIC TELE-ULTRASONOGRAPHY SYSTEMS”

Project submitted to Vinayaka Missions University in
Partial Fulfillment for the award of Degree
of

POST GRADUATE DIPLOMA IN ULTRA SONAGRAPHY

By

AMIT KOCHAR

APPLICATION NO.: 345295

REG. NO- 306051110019

Under the Guidance of

Dr. Anjali S. Malik

VINAYAKA MISSIONS UNIVERSITY
SALEM, TAMILNADU, INDIA.
JANUARY 2011

CERTIFICATE

This is to certify that the project entitled **“3G WIRELESS COMMUNICATIONS FOR MOBILE ROBOTIC TELE-ULTRASONOGRAPHY SYSTEMS”** is a bonafide record of independent work done by **AMIT KOCHAR** REG. NO- **306051110019** under my supervision during Year **2011**, submitted to the Directorate of Distance Education, Vinayaka Missions University in partial fulfillment for the award of the Degree of **PGDUS** and that the project has not previously formed the basis for the award of any other degree, Diploma, Associate ship, Fellowship or other title.

Signature of the supervisor

(With Seal)

DECLARATION

I **AMIT KOCHAR,** hereby declare that the project entitled **“3G WIRELESS COMMUNICATIONS FOR MOBILE ROBOTIC TELE-ULTRASONOGRAPHY SYSTEMS”** submitted to the Directorate of Distance Education, Vinayaka Missions University in partial fulfillment for the award of the Degree of **PGDUS** and that the project has not previously formed the basis for the award of any other degree, Diploma, Associate ship, Fellowship or other title.

Place :

Date : Signature of the candidate.

FORMAT FOR EVALUATION OF PROJECT

1. Name of the Candidate : AMIT KOCHAR

2. Session : JAN-2011

3. Application no. : 345295

4. Registration Number : 306051110019

5. Name of the Programme : PGDUS

6. Title of the Project : "3G WIRELESS COMMUNICATIONS FOR MOBILE ROBOTIC TELE-ULTRASONOGRAPHY SYSTEMS"

7.

Evaluation for Project	Maximum 100 Marks
Awarded	

Signature of the Supervisor

(With Seal**)**

DIRECTORATE OF DISTANCE EDUCATION
SUPERVISOR'S CONSENT FORMAT

1. Name of the Student : AMIT KOCHAR
2. Name of the Programme : PGDUS
3. Session : JAN-2011
4. Application no. : 345295
5. Enrolment No. : 306051110019
6. Name of the Supervisor : Dr. Anjali S. Malik
7. Official address : Vaishali, Ghazibad. U.P.
8. Approval No. : MMB113

I declare that the above particulars are true to the best of my knowledge and willing to Supervisor of **AMIT KOCHAR** Rules and regulations of the University for the concerned programmed will be strictly abided.

Signature of the Supervisor

(With Seal)

CONTENTS

CHAPTER 1: INTRODUCTION

CHAPTER 2: 3G WIRELESS COMMUNICATIONS FOR MOBILE ROBOTIC TELE-ULTRASONOGRAPHY SYSTEMS

CHAPTER 3: CONCLUSION

REFERENCES

CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION TO THE ULTRASONOGRAPHY

The terms **Ultrasonography** and Sonography are used interchangeably. This diagnostic technique makes use of high frequency sound waves, aimed at areas in the body in order to produce visual images of anatomical structures. **Ultrasonography** is also known as diagnostic sonography and echocardiography when used in imaging the heart.

Ultrasonography makes use of generated sound waves to produces visible images of soft body tissues. Sonic waves, as a form of energy, are known as longitudinal pressure waves. These waves result when molecules are pushed together, becoming less dense (rarified). As a wave passes through molecules, they are not transported by the wave but merely vibrate back and forth (around a neutral position). A molecule will be moved through the compression and rarification cycle a specific number of times per second and this is called the frequency of the wave. The unit of measurement for sound wave frequency is termed Hertz (Hz). The human ear is capable of detecting frequencies ranging between 20Hz and 20,000Hz. Frequencies beyond 20,000Hz are inaudible to the human ear and are called ultrasonic. **Ultrasonography** utilizes sound waves between one million and 15 million Hz.

Typically, an ultrasound machine comprises of four major components: Transducer (allows for the machine to body interface); Electronic signal processing unit (controls the power output to the transducer); Display unit (normally a computer monitor screen); and some device for recording and storing the images produced (usually video or film equipment).

Ultrasonography has wide application in the field of medical diagnostics. It is best suited for obtaining images of solid, or uniform soft tissue and fluid-filled tissue. Performance is limited when imaging calcified structures (like bone) or air-filled objects (like the bowel). **Ultrasonography** is most commonly used for imaging fetus development during pregnancy, gallbladder disease diagnosis, certain forms of cancer, scrotum and prostate abnormality evaluation, heart and thyroid examination as well as breast examinations. Doppler imaging sonography is a technique developed to view the flow of blood in blood vessels as well as to guide needles through bodily structures when obtaining biopsy specimens. Detailed images of the fetus in the uterus may be viewed using three-dimensional ultrasounds.

Most ultrasonic examinations are performed externally by moving a transducer over the skin surface. Normally, a gel would be applied to the skin. This allows the transducer to glide smoothly as well as to eliminate the formation of air pockets between the skin and transducer (this would interfere with the imaging obtained). Where necessary, a probe is inserted into a bodily orifice. Examples are: Trans-esophogal cardiogram, which requires a specialiized transducer placed in the esophogus to obtain a clearer image of the heart; Trans-rectal examinations require a transducer to be inserted into a male patient's rectum in order to obtain images of the prostate; Trans-vaginal ultrasound examinations are used to obtain images of the ovaries and uterus and of the fetus during the early weeks of pregnancy.

Types of Ultrasonography

A. Diagnostic sonography

Diagnostic sonography is an ultrasound-based diagnostic imaging technique used for visualizing subcutaneous body structures including tendons, muscles, joints, vessels and internal organs for possible pathology or lesions. Obstetric sonography is commonly used during pregnancy and is widely recognized by the public.

In physics, the term "ultrasound" applies to all sound waves with a frequency above the audible range of human hearing, about 20,000 Hz. The frequencies used in diagnostic ultrasound are typically between 2 and 18 MHz.

1. Diagnostic applications

Typical diagnostic sonographic scanners operate in the frequency range of 2 to 18 megahertz, though frequencies up to 50-100 megahertz has been used experimentally in a technique known as biomicroscopy in special regions, such as the anterior chamber of eye. The choice of frequency is a trade-off between spatial resolution of the image and imaging depth: lower frequencies produce less resolution but image deeper into the body. Higher frequency sound waves have a smaller wavelength and thus are capable of reflecting or scattering from smaller structures. Higher frequency sound waves also have a larger attenuation coefficient and thus are more readily absorbed in tissue, limiting the depth of penetration of the sound wave into the body.

Sonography (ultrasonography) is widely used in medicine. It is possible to perform both diagnosis and therapeutic procedures, using ultrasound to guide interventional procedures (for instance biopsies or drainage of fluid collections). Sonographers are medical professionals who perform scans which are then typically interpreted by Radiologists, physicians who specialize in the application and interpretation of a wide variety of medical imaging modalities, or by Cardiologists in the case of cardiac ultrasonography (echocardiography). Sonographers typically use a hand-held probe (called a transducer) that is placed directly on and moved over the patient.

Sonography is effective for imaging soft tissues of the body. Superficial structures such as muscles, tendons, testes, breast and the neonatal brain are imaged at a higher frequency (7-18 MHz), which provides better axial and lateral resolution. Deeper structures such as liver and kidney are imaged at a lower frequency 1-6 MHz with lower axial and lateral resolution but greater penetration.

Medical sonography is used in the study of many different systems:

System	**Description**
Anesthesiology	Ultrasound is commonly used by anesthesiologists (Anaesthetists) to guide injecting needles when placing local anaesthetic solutions near nerves
Cardiology	Echocardiography is an essential tool in cardiology, to diagnose e.g. dilatation of parts of the heart and function of heart ventricles and valves
Emergency Medicine	Point of care ultrasound has many applications in the Emergency Department, including the Focused Assessment with Sonography for Trauma (FAST) exam for

	assessing significant hemoperitoneum or pericardial tamponade after trauma. Ultrasound is routinely used in the Emergency Department to expedite the care of patients with right upper quadrant abdominal pain who may have gallstones or cholecystitis.
Gastroenterology	In abdominal sonography, the solid organs of the abdomen such as the pancreas, aorta, inferior vena cava, liver, gall bladder, bile ducts, kidneys, and spleen are imaged. Sound waves are blocked by gas in the bowel and attenuated in different degree by fat, therefore there are limited diagnostic capabilities in this area. The appendix can sometimes be seen when inflamed (as in e.g.: appendicitis).
Neonatology	for basic assessment of intracerebral structural abnormalities, bleeds, ventriculomegaly or hydrocephalus and anoxic insults (Periventricular leukomalacia). The ultrasound can be performed through the soft spots in the skull of a newborn infant (Fontanelle) until these completely close at about 1 year of age and

	form a virtually impenetrable acoustic barrier for the ultrasound. The most common site for cranial ultrasound is the anterior fontanelle. The smaller the fontanelle, the poorer the quality of the picture.
Neurology	for assessing blood flow and stenoses in the carotid arteries (Carotid ultrasonography) and the big intracerebral arteries
Obstetrics	Obstetrical sonography is commonly used during pregnancy to check on the development of the fetus.
Urology	In a pelvic sonogram, organs of the pelvic region are imaged. This includes the uterus and ovaries or urinary bladder. Males are sometimes given a pelvic sonogram to check on the health of their bladder, the prostate, or their testicles (for example to distinguish epididymitis from testicular torsion). In young males, it is used to distinguish more benign testicular masses (varicocele or hydrocele) from testicular cancer, which is still very highly curable but which must be treated to preserve health and fertility. There are two methods of performing a pelvic

	sonography - externally or internally. The internal pelvic sonogram is performed either transvaginally (in a woman) or transrectally (in a man). Sonographic imaging of the pelvic floor can produce important diagnostic information regarding the precise relationship of abnormal structures with other pelvic organs and it represents a useful hint to treat patients with symptoms related to pelvic prolapse, double incontinence and obstructed defecation. It is used to diagnose and, at higher frequencies, to treat (break up) kidney stones or kidney crystals (nephrolithiasis).
Musculoskeletal	tendons, muscles, nerves, ligaments, soft tissue masses, and bone surfaces
Cardiovascular system	To assess patency and possible obstruction of arteries Arterial sonography, diagnose DVT (Thrombosonography) and determine extent and severity of venous insufficiency (venosonography)

Other types of uses include:

- Intervenional; biopsy, emptying fluids, intrauterine transfusion (Hemolytic disease of the newborn)
- Contrast-enhanced ultrasound

A general-purpose sonographic machine may be used for most imaging purposes. Usually specialty applications may be served only by use of a specialty transducer. Most ultrasound procedures are done using a transducer on the surface of the body, but improved diagnostic confidence is often possible if a transducer can be placed inside the body. For this purpose, specialty transducers, including endovaginal, endorectal, and transesophageal transducers are commonly employed. At the extreme of this, very small transducers can be mounted on small diameter catheters and placed into blood vessels to image the walls and disease of those vessels.

2. Therapeutic applications

Therapeutic applications use ultrasound to bring heat or agitation into the body. Therefore much higher energies are used than in diagnostic ultrasound. In many cases the range of frequencies used are also very different.

- Ultrasound is sometimes used to clean teeth in dental hygiene.
- Ultrasound sources may be used to generate regional heating and mechanical changes in biological tissue, e.g. in occupational therapy, physical therapy and cancer treatment. However the use of ultrasound in the treatment of musculoskeletal conditions has fallen out of favor.

- Focused ultrasound may be used to generate highly localized heating to treat cysts and tumors (benign or malignant), This is known as Focused Ultrasound Surgery (FUS) or High Intensity Focused Ultrasound (HIFU). These procedures generally use lower frequencies than medical diagnostic ultrasound (from 250 kHz to 2000 kHz), but significantly higher energies. HIFU treatment is often guided by MRI.
- Focused ultrasound may be used to break up kidney stones by lithotripsy.
- Ultrasound may be used for cataract treatment by phacoemulsification.
- Additional physiological effects of low-intensity ultrasound have recently been discovered, e.g. its ability to stimulate bone-growth and its potential to disrupt the blood-brain barrier for drug delivery.
- Procoagulant at 5-12 MHz,

3. From sound to image

The creation of an image from sound is done in three steps - producing a sound wave, receiving echoes, and interpreting those echoes.

Producing a sound wave

A sound wave is typically produced by a piezoelectric transducer encased in a housing which can take a number of forms. Strong, short electrical pulses from the ultrasound machine make the transducer ring at the desired frequency. The frequencies can be anywhere between 2 and 18 MHz. The sound is focused either by the shape of the transducer, a lens in front of the transducer, or a complex set of control pulses from the ultrasound scanner machine (Beamforming). This focusing produces an arc-shaped sound wave from the face of the transducer. The wave travels into the body and comes into focus at a desired depth.

Older technology transducers focus their beam with physical lenses. Newer technology transducers use phased array techniques to enable the sonographic machine to change the direction and depth of focus. Almost all piezoelectric transducers are made of ceramic.

Materials on the face of the transducer enable the sound to be transmitted efficiently into the body (usually seeming to be a rubbery coating, a form of impedance matching). In addition, a water-based gel is placed between the patient's skin and the probe.

The sound wave is partially reflected from the layers between different tissues. Specifically, sound is reflected anywhere there are density changes in the body: e.g. blood cells in blood plasma, small structures in organs, etc. Some of the reflections return to the transducer.

a. Receiving the echoes

The return of the sound wave to the transducer results in the same process that it took to send the sound wave, except in reverse. The return sound wave vibrates the transducer; the transducer turns the vibrations into electrical pulses that travel to the ultrasonic scanner where they are processed and transformed into a digital image.

b. Forming the image

The sonographic scanner must determine three things from each received echo:

1. How long it took the echo to be received from when the sound was transmitted.
2. From this the focal length for the phased array is deduced, enabling a sharp image of that echo at that depth (this is not possible while producing a sound wave).
3. How strong the echo was. It could be noted that sound wave is not a click, but a pulse with a specific carrier frequency. Moving objects change this frequency on reflection, so that it is only a matter of electronics to have simultaneous Doppler sonography.

Once the ultrasonic scanner determines these three things, it can locate which pixel in the image to light up and to what intensity and at what hue if frequency is processed.

Transforming the received signal into a digital image may be explained by using a blank spreadsheet as an analogy. First picture a long, flat transducer at the top of the sheet. Send pulses down the 'columns' of the spreadsheet (A, B, C, etc.). Listen at each column for any return echoes. When an echo is heard, note how long it took for the echo to return. The longer the wait, the deeper the row (1,2,3, etc.). The strength of the echo determines the brightness setting for that cell (white for a strong echo, black for a weak echo, and varying shades of grey for everything in between.) When all the echoes are recorded on the sheet, we have a greyscale image.

c. Displaying the image

Images from the sonographic scanner can be displayed, captured, and broadcast through a computer using a frame grabber to capture and digitize the analog video signal. The captured signal can then be post-processed on the computer itself.

4. Sound in the body

Ultrasonography (sonography) uses a probe containing multiple acoustic transducers to send pulses of sound into a material. Whenever a sound wave encounters a material with a different density (acoustical impedance), part of the sound wave is reflected back to the probe and is detected as an echo. The time it takes for the echo to travel back to the probe is measured and used to calculate the depth of the tissue interface causing the echo. The greater the difference between acoustic impedances, the larger the echo is. If the pulse hits gases or solids, the density difference is so great that most of the acoustic energy is reflected and it becomes impossible to see deeper.

The frequencies used for medical imaging are generally in the range of 1 to 18 MHz. Higher frequencies have a correspondingly smaller wavelength, and can be used to make sonograms with smaller details. However, the attenuation of the sound wave is increased at higher frequencies, so in order to have better penetration of deeper tissues, a lower frequency (3-5 MHz) is used.

Seeing deep into the body with sonography is very difficult. Some acoustic energy is lost every time an echo is formed, but most of it (approximately $0.5\frac{\mathrm{dB}}{\mathrm{cm\ depth}\cdot\mathrm{MHz}}$) is lost from acoustic absorption.

The speed of sound varies as it travels through different materials, and is dependent on the acoustical impedance of the material. However, the sonographic instrument assumes that the acoustic velocity is constant at 1540 m/s. An effect of this assumption is that in a real body with non-uniform tissues, the beam becomes somewhat de-focused and image resolution is reduced.

To generate a 2D-image, the ultrasonic beam is swept. A transducer may be swept mechanically by rotating or swinging. Or a 1D phased array transducer may be use to sweep the beam electronically. The received data is processed and used to construct the image. The image is then a 2D representation of the slice into the body.

3D images can be generated by acquiring a series of adjacent 2D images. Commonly a specialized probe that mechanically scans a conventional 2D-image transducer is used. However, since the mechanical scanning is slow, it is difficult to make 3D images of moving tissues. Recently, 2D phased array transducers that can sweep the beam in 3D have been developed. These can image faster and can even be used to make live 3D images of a beating heart.

Doppler ultrasonography is used to study blood flow and muscle motion. The different detected speeds are represented in color for ease of interpretation, for example leaky heart valves: the leak shows up as a flash of unique color. Colors may alternatively be used to represent the amplitudes of the received echoes.

5. Modes of sonography

Several different modes of ultrasound are used in medical imaging. These are:

- **A-mode**: A-mode is the simplest type of ultrasound. A single transducer scans a line through the body with the echoes plotted on screen as a function of depth. Therapeutic ultrasound aimed at a specific tumor or calculus is also A-mode, to allow for pinpoint accurate focus of the destructive wave energy.
- **B-mode**: In B-mode ultrasound, a linear array of transducers simultaneously scans a plane through the body that can be viewed as a two-dimensional image on screen.
- **C-mode**: A C-mode image is formed in a plane normal to a B-mode image. A gate that selects data from a specific depth from an A-mode line is used; then the transducer is moved in the 2D plane to sample the entire region at this fixed depth. When the transducer traverses the area in a spiral, an area of 100 cm^2 can be scanned in around 10 seconds.
- **M-mode**: M stands for motion. Ultrasound pulses are emitted in quick succession - each time, either an A-mode or B-mode image is taken. Over time, this is analogous to recording a video in ultrasound. As the organ boundaries that produce reflections move relative

to the probe, this can be used to determine the velocity of specific organ structures.

- **Doppler mode**: This mode makes use of the Doppler effect in measuring and visualizing blood flow
    - **Color doppler**: Velocity information is presented as a color coded overlay on top of a B-mode image
    - **Continuous doppler**: Doppler information is sampled along a line through the body, and all velocities detected at each time point is presented (on a time line)
    - **Pulsed wave (PW) doppler**: Doppler information is sampled from only a small sample volume (defined in 2D image), and presented on a timeline
    - **Duplex**: a common name for the simultaneous presentation of 2D and (usually) PW doppler information. (Using modern ultrasound machines color doppler is almost always also used, hence the alternative name **Triplex**.)
- **Pulse inversion mode**: In this mode two successive pulses with opposite sign are emitted and then subtracted from each other. This implies that any linearly responding constituent will disappear while gases with non-linear compressibility stand out.
- **Harmonic mode**: In this mode a deep penetrating fundamental frequency is emitted into the body and a harmonic overtone is detected. In this way depth

penetration can be gained with improved lateral resolution.

6. Expansions

An additional expansion or additional technique of ultrasound is **biplanar ultrasound**, in which the probe has two 2D planes that are perpendicular to each other, providing more efficient localization and detection. Furthermore, an **omniplane** probe is one that can rotate 180° to obtain multiple images. In 3D ultrasound, many 2D planes are digitally added together to create a 3-dimensional image of the object. In contrast-enhanced ultrasound, microbubble contrast agents enhance the ultrasound waves, resulting in increased contrast.

a. Doppler sonography

Sonography can be enhanced with Doppler measurements, which employ the Doppler Effect to assess whether structures (usually blood) are moving towards or away from the probe, and its relative velocity. By calculating the frequency shift of a particular sample volume, for example flow in an artery or a jet of blood flow over a heart valve, its speed and direction can be determined and visualised. This is particularly useful in cardiovascular studies (sonography of the vascular system and heart) and essential in many areas such as determining reverse blood flow in the liver vasculature in portal hypertension. The Doppler information is displayed graphically using spectral Doppler, or as an image using color Doppler (directional Doppler) or power Doppler (non directional Doppler). This Doppler shift falls in the audible range and is often presented audibly using stereo speakers: this produces a very distinctive, although synthetic, pulsating sound.

Most modern sonographic machines use pulsed Doppler to measure velocity. Pulsed wave machines transmit and receive series of pulses. The frequency shift of each pulse is ignored, however the relative phase changes of the pulses are used to obtain the frequency shift (since frequency is the rate of change of phase). The major advantages of pulsed Doppler over continuous wave is that distance information is obtained (the time between the transmitted and received pulses can be converted into a distance with knowledge of the speed of sound) and gain correction is applied. The disadvantage of pulsed Doppler is that the measurements can suffer from aliasing. The terminology "Doppler ultrasound" or "Doppler sonography.” has been accepted to apply to both pulsed and continuous Doppler systems despite the different mechanisms by which the velocity is measured.

It should be noted here that there are no standards for the display of color Doppler. Some laboratories show arteries as red and veins as blue, as medical illustrators usually show them, even though some vessels may have portions flowing towards and portions flowing away from the transducer. This results in the illogical appearance of a vessel being partly a vein and partly an artery. Other laboratories use red to indicate flow toward the transducer and blue away from the transducer. Still other laboratories prefer to display the sonographic Doppler color map more in accord with the prior published physics with the red shift representing longer waves of echoes (scattered) from blood flowing away from the transducer; and with blue representing the shorter waves of echoes reflecting from blood flowing toward the transducer. Because of this confusion and lack of standards in the various laboratories, the sonographer must understand the underlying acoustic physics of color Doppler and the physiology of normal and abnormal blood flow in the human body.

b. Contrast media

The use of microbubble contrast media in medical sonography to improve ultrasound signal backscatter is known as contrast-enhanced ultrasound. This technique is currently used in echocardiography, and may have future applications in molecular imaging and drug delivery.

Contrast-enhanced ultrasound (CEUS) is the application of ultrasound contrast medium to traditional medical sonography. Ultrasound contrast agents rely on the different ways in which sound waves are reflected from interfaces between substances. This may be the surface of a small air bubble or a more complex structure. Commercially available contrast media are gas-filled microbubbles that are administered intravenously to the systemic circulation. Microbubbles have a high degree of echogenicity, which is the ability of an object to reflect the ultrasound waves. The echogenicity difference between the gas in the microbubbles and the soft tissue surroundings of the body is immense. Thus, ultrasonic imaging using microbubble contrast agents enhances the ultrasound backscatter, or reflection of the ultrasound waves, to produce a unique sonogram with increased contrast due to the high echogenicity difference. Contrast-enhanced ultrasound can be used to image blood perfusion in organs, measure blood flow rate in the heart and other organs, and has other applications as well.

Targeting ligands that bind to receptors characteristic of intravascular diseases can be conjugated to microbubbles, enabling the microbubble complex to accumulate selectively in areas of interest, such as diseased or abnormal tissues. This form of molecular imaging, known as targeted contrast-enhanced ultrasound, will only generate a strong ultrasound signal if targeted microbubbles bind in the area of interest. Targeted contrast-enhanced ultrasound can potentially have many applications in both medical diagnostics and medical therapeutics. However, the targeted technique has not yet been approved for clinical use; it is currently under preclinical research and development.

1. How it works

There are two forms of contrast-enhanced ultrasound, untargeted (used in the clinic today) and targeted (under preclinical development). The two methods slightly differ from each other.

a. Untargeted CEUS

Untargeted microbubbles, such as the aforementioned Optison or Levovist, are injected intravenously into the systemic circulation in a small bolus. The microbubbles will remain in the systemic circulation for a certain period of time. During that time, ultrasound waves are directed on the area of interest. When microbubbles in the blood flow past the imaging window, the microbubbles' compressible gas cores oscillate in response to the high frequency sonic energy field, as described in the ultrasound article. The microbubbles reflect a unique echo that stands in stark contrast to the surrounding tissue due to the orders of magnitude mismatch between microbubble and tissue echogenicity. The ultrasound system converts the strong echogenicity into a contrast-enhanced image of the area of interest. In this way, the bloodstream's echo is enhanced, thus allowing the clinician to distinguish blood from surrounding tissues.

b. Targeted CEUS

Targeted contrast-enhanced ultrasound works in a similar fashion, with a few alterations. Microbubbles targeted with ligands that bind certain molecular markers that are expressed by the area of imaging interest are still injected systemically in a small bolus. Microbubbles theoretically travel through the circulatory system, eventually finding their respective targets and binding specifically. Ultrasound waves can then be directed on the area of interest. If a sufficient number of microbubbles have bound in the area, their compressible gas cores oscillate in response to the high frequency sonic energy field, as described in the ultrasound article. The targeted microbubbles also reflect a unique echo that stands in stark contrast to the surrounding tissue due to the orders of magnitude mismatch between microbubble and tissue echogenicity. The ultrasound system converts the strong echogenicity into a contrast-enhanced image of the area of interest, revealing the location of the bound microbubbles.[6] Detection of bound microbubbles may then show that the area of interest is expressing that particular molecular, which can be indicative of a certain disease state, or identify particular cells in the area of interest.

2. Applications

Untargeted contrast-enhanced ultrasound is currently applied in echocardiography. Targeted contrast-enhanced ultrasound is being developed for a variety of medical applications.

a. Untargeted CEUS

Untargeted microbubbles like Optison and Levovist are currently used in echocardiography.

- **Organ Edge Delineation**: microbubbles can enhance the contrast at the interface between the tissue and blood. A clearer picture of this interface gives the clinician a better picture of the structure of an organ. Tissue structure is crucial in echocardiograms, where a thinning, thickening, or irregularity in the heart wall indicates a serious heart condition that requires either monitoring or treatment.
- **Blood Volume and Perfusion**: contrast-enhanced ultrasound holds the promise for (1) evaluating the degree of blood perfusion in an organ or area of interest and (2) evaluating the blood volume in an organ or area of interest. When used in conjunction with Doppler ultrasound, microbubbles can measure myocardial flow rate to diagnose valve problems. And the relative intensity of the microbubble echoes can also provide a quantitative estimate on blood volume.

b. Targeted CEUS

- **Inflammation**: Contrast agents may be designed to bind to certain proteins that become expressed in inflammatory diseases such as Crohn's disease, atherosclerosis, and even heart attacks. Cells of interest in such cases are endothelial cells of blood vessels, and leukocytes:
    - The inflamed blood vessels specifically express certain receptors, functioning as cell adhesion molecules, like VCAM-1, ICAM-1, E-selectin. If microbubbles are targeted with ligands that bind these molecules, they can be used in contrast echocardiography to detect the onset of inflammation. Early detection allows the design of better treatments. Attempts have been made to outfit microbubbles with monoclonal antibodies that bind P-selectin, ICAM-1, and VCAM-1, but the adhesion to the molecular target was poor and a large fraction of microbubbles that bound to the target rapidly detached, especially at high shear stresses of physiological relevance.
    - Leukocytes possess high adhesion efficiencies, partly due to a dual-ligand selectin-integrin cell arrest system. One ligand:receptor pair has a fast bond on-rate to slow the leukocyte and allows the second pair (integrin:immunoglobulin superfamily),

which has a slower on-rate but slow off-rate to arrest the leukocyte, kinetically enhancing adhesion. Attempts have been made to make contrast agents bind to such ligands, with techniques such as dual-ligand targeting of distinct receptors to polymer microspheres, and biomimcry of the leukocyte’s selectin-integrin cell arrest system, having shown an increased adhesion efficiency, but yet not efficient enough to allow clinical use of targeted contrast-enhanced ultrasound for inflammation.

- **Cancer**: cancer cells also express a specific set of receptors, mainly receptors that encourage angiogenesis, or the growth of new blood vessels. If microbubbles are targeted with ligands that bind receptors like VEGF, they can non-invasively and specifically identify areas of cancers.
- **Gene Delivery**: Vector DNA can be conjugated to the microbubbles. Microbubbles can be targeted with ligands that bind to receptors expressed by the cell type of interest. When the targeted microbubble accumulates at the cell surface with its DNA payload, ultrasound can be used to burst the microbubble. The force associated with the bursting may temporarily permeablize surrounding tissues and allow the DNA to more easily enter the cells.

- **Drug Delivery**: drugs can be incorporated into the microbubble's lipid shell. The microbubble's large size relative to other drug delivery vehicles like liposomes may allow a greater amount of drug to be delivered per vehicle. By targeted the drug-loaded microbubble with ligands that bind to a specific cell type, microbubble will not only deliver the drug specifically, but can also provide verification that the drug is delivered if the area is imaged using ultrasound.

3. Advantages

On top of the strengths mentioned in the medical sonography entry, contrast-enhanced ultrasound adds these additional advantages:

- The body is 73% water, and therefore, acoustically homogeneous. Blood and surrounding tissues have similar echogenicities, so it is also difficult to clearly discern the degree of blood flow, perfusion, or the interface between the tissue and blood using traditional ultrasound.
- Ultrasound imaging allows real-time evaluation of blood flow.
- Ultrasonic molecular imaging is safer than molecular imaging modalities such as radionuclide imaging because it does not involve radiation.

- Alternative molecular imaging modalities, such as MRI, PET, and SPECT are very costly. Ultrasound, on the other hand, is very cost-efficient and widely available.
- Since microbubbles can generate such strong signals, a lower intravenous dosage is needed; micrograms of microbubbles are needed compared to milligrams for other molecular imaging modalities such as MRI contrast agents.
- Targeting strategies for microbubbles are versatile and modular. Targeting a new area only entails conjugating a new ligand.

4. Disadvantages

In addition to the weaknesses mentioned in the medical sonography entry, contrast-enhanced ultrasound suffers from the following disadvantages:

- Microbubbles don't last very long in circulation. They have low circulation residence times because they either get taken up by immune system cells or get taken up by the liver or spleen even when they are coated with PEG.
- Ultrasound produces more heat as the frequency increases, so the ultrasonic frequency must be carefully monitored.
- Microbubbles burst at low ultrasound frequencies and at high mechanical indices (MI), which is the measure of the

acoustic power output of the ultrasound imaging system. Increasing MI increases image quality, but there are tradeoffs with microbubble destruction. Microbubble destruction could cause local microvasculature ruptures and hemolysis.

- Targeting ligands can be immunogenic, since current targeting ligands used in preclinical experiments are derived from animal culture.
- Low targeted microbubble adhesion efficiency, which means a small fraction of injected microbubbles bind to the area of interest. This is one of the main reasons that targeted contrast-enhanced ultrasound remains in the preclinical development stages.

7. Attributes

As with all imaging modalities, ultrasonography has its list of positive and negative attributes.

Strengths

- It images muscle, soft tissue, and bone surfaces very well and is particularly useful for delineating the interfaces between solid and fluid-filled spaces.
- It renders "live" images, where the operator can dynamically select the most useful section for diagnosing and documenting changes, often enabling rapid diagnoses. Live images also allow for ultrasound-guided

biopsies or injections, which can be cumbersome with other imaging modalities.

- It shows the structure of organs.
- It has no known long-term side effects and rarely causes any discomfort to the patient.
- Equipment is widely available and comparatively flexible.
- Small, easily carried scanners are available; examinations can be performed at the bedside.
- Relatively inexpensive compared to other modes of investigation, such as computed X-ray tomography, DEXA or magnetic resonance imaging.
- Spatial resolution is better in high frequency ultrasound transducers than it is in most other imaging modalities.
- Through the use of an Ultrasound research interface, an ultrasound device can offer a relatively inexpensive, real-time, and flexible method for capturing data required for special research purposes for tissue characterization and development of new image processing techniques

Weaknesses

- Sonographic devices have trouble penetrating bone. For example, sonography of the adult brain is very limited though improvements are being made in transcranial ultrasonography.
- Sonography performs very poorly when there is a gas between the transducer and the organ of interest, due to

the extreme differences in acoustic impedance. For example, overlying gas in the gastrointestinal tract often makes ultrasound scanning of the pancreas difficult, and lung imaging is not possible (apart from demarcating pleural effusions).

- Even in the absence of bone or air, the depth penetration of ultrasound may be limited depending on the frequency of imaging. Consequently, there might be difficulties imaging structures deep in the body, especially in obese patients.
- Body habitus has a large influence on image quality, image quality and accuracy of diagnosis is limited with obese patients, overlying subcutaneous fat attenuates the sound beam and a lower frequency tranducer is required (with lower resolution)
- The method is operator-dependent. A high level of skill and experience is needed to acquire good-quality images and make accurate diagnoses.
- There is no scout image as there is with CT and MRI. Once an image has been acquired there is no exact way to tell which part of the body was imaged.

8. Risks and side-effects

Ultrasonography is generally considered a safe imaging modality, although there is relatively little data available.

Diagnostic ultrasound studies of the fetus are generally considered to be safe during pregnancy. This diagnostic procedure should be performed only when there is a valid medical indication, and the lowest possible ultrasonic exposure setting should be used to gain the necessary diagnostic information under the "as low as reasonably achievable" or ALARA principle.

World Health Organizations technical report series 875(1998). supports that ultrasound is harmless: "Diagnostic ultrasound is recognized as a safe, effective, and highly flexible imaging modality capable of providing clinically relevant information about most parts of the body in a rapid and cost-effective fashion". Although there is no evidence ultrasound could be harmful for the fetus, US Food and Drug Administration views promotion, selling, or leasing of ultrasound equipment for making "keepsake fetal videos" to be an unapproved use of a medical device.

Studies on the safety of ultrasound

- A meta-analysis of several ultrasonography studies published in 2000 found no statistically significant harmful effects from ultrasonography, but mentioned that there was a lack of data on long-term substantive outcomes such as neurodevelopment.

- A study at the Yale School of Medicine published in 2006 found a small but significant correlation between prolonged and frequent use of ultrasound and abnormal neuronal migration in mice.

9. Regulation

Diagnostic and therapeutic ultrasound equipment is regulated in the USA by the FDA, and worldwide by other national regulatory agencies. The FDA limits acoustic output using several metrics. Generally other regulatory agencies around the world accept the FDA-established guidelines.

Currently New Mexico is the only state in the USA which regulates diagnostic medical sonographers. Certification examinations for sonographers are available in the US from three organizations: The American Registry of Diagnostic Medical Sonography, Cardiovascular Credentialing International and the American Registry of Radiological Technologists.

The primary regulated metrics are MI (Mechanical Index) a metric associated with the cavitation bio-effect, and TI (Thermal Index) a metric associated with the tissue heating bio-effect. The FDA requires that the machine not exceed limits that they have established. This requires self-regulation on the part of the manufacturer in terms of the calibration of the machine. The established limits are reasonably conservative so as to maintain diagnostic ultrasound as a safe imaging modality.

In India, lack of social security and consequent preference for a male child has popularized the use of ultrasound technology to identify and abort female fetuses. India's Antenatal (US: Prenatal) Diagnostic Techniques act makes use of ultrasound for sex selection illegal, but unscrupulous Indian doctors and would-be parents continue to discriminate against the girl child.

B. Obstetric ultrasonography

Obstetric sonography (ultrasonography) is the application of medical ultrasonography to obstetrics, in which sonography is used to visualize the embryo or foetus in its mother's uterus (womb). The procedure is often a standard part of prenatal care, as it yields a variety of information regarding the health of the mother and of the fetus, as well as regarding the progress of the pregnancy.

Types of Obstetric sonography

Traditional obstetric sonograms are done by placing a transducer (a device that converts one type of energy into another) on the abdomen of the pregnant woman. One variant, a *transvaginal sonography,* is done with a probe placed in the woman's vagina. Transvaginal scans usually provide clearer pictures during early pregnancy and in obese women. Also used is *Doppler sonography* which detects the heartbeat of the fetus. Doppler sonography can be used to evaluate the pulsations in the fetal heart and bloods vessels for signs of abnormalities.

Early pregnancy

The gestational sac can sometimes be visualized as early as four and a half weeks of gestation (approximately two and a half weeks after ovulation) and the yolk sac at about five weeks gestation. The embryo can be observed and measured by about five and a half weeks. The heartbeat may be seen as early as 6 weeks, and is usually visible by 7 weeks gestation.

Dating and growth monitoring

Gestational age is usually determined by the date of the woman's last menstrual period, and assuming ovulation occurred on day fourteen of the menstrual cycle. Sometimes a woman may be uncertain of the date of her last menstrual period, or there may be reason to suspect ovulation occurred significantly earlier or later than the fourteenth day of her cycle. Ultrasound scans offer an alternative method of estimating gestational age. The most accurate measurement for dating is the crown-rump length of the fetus, which can be done between 7 and 13 weeks of gestation. After 13 weeks gestation, the fetal age may be estimated by the biparietal diameter (the transverse diameter of the head), the head circumference, the length of the femur (the longest bone in the body), and the many more fetal parameters that have been measured and correlated with age over the last 30 years. Dating is more accurate when done earlier in the pregnancy; if a later scan gives a different estimate of gestational age, the estimated age is not normally changed but rather it is assumed the fetus is not growing at the expected rate.

Not useful for dating, the abdominal circumference of the fetus may also be measured. This gives an estimate of the weight and size of the fetus and is important when doing serial ultrasounds to monitor fetal growth.

Fetal sex determination

The sex of the baby can usually be determined by ultrasound at any time after 16 weeks, often at the dating scan around 20 weeks into the pregnancy depending upon the quality of the sonographic machine and skill of the operator. This is also the best time to have an ultrasound done as most infants are the same size at this stage of development. Depending on the skill of the sonographer, ultrasound may suffer from a high rate of false negatives and false positives. This means care has to be taken in interpreting the accuracy of the scan.

Ultrasonography of the cervix

Obstetric sonography has become useful in the assessment of the cervix in women at risk for premature birth. A short cervix preterm is undesirable: At 24 weeks gestation a cervix length of less than 25 mm defines a risk group for preterm birth, further, the shorter the cervix the greater the risk. It also has been helpful to use ultrasonography in women with preterm contractions, as those whose cervix length exceeds 30 mm are unlikely to deliver within the next week.

Abnormality screening

In some countries, routine pregnancy sonographic scans are performed to detect developmental defects before birth. This includes checking the status of the limbs and vital organs, as well as (sometimes) specific tests for abnormalities. Some abnormalities detected by ultrasound can be addressed by medical treatment in utero or by perinatal care, though indications of other abnormalities can lead to a decision regarding abortion.

Perhaps the most common such test uses a measurement of the nuchal translucency thickness ("NT-test", or "Nuchal Scan"). Although 91% of fetuses affected by Down syndrome exhibit this defect, 5% of fetuses flagged by the test do not have Down syndrome.

Ultrasound may also detect fetal organ anomaly. Usually scans for this type of detection are done around 18 to 20 weeks of gestational age.

Safety issues

Current evidence indicates that diagnostic ultrasound is safe for the unborn child, unlike radiographs, which employ ionizing radiation. However, no randomized controlled trials have been undertaken to test the safety of the technology, and thus ultrasound procedures are generally not done repeatedly unless medically indicated.

A 2006 study on mice exposed to ultrasound showed neurological changes in the exposed fetuses. Some of the rodent brain cells failed to migrate to their proper position and remained scattered in incorrect parts of the brain.

It has been shown that Low Intensity Pulsed Ultrasound does have a localized effect on growth in human beings. The 1985 maximum power allowed by the U.S. Food and Drug Administration (FDA) of 180 milliwatts per square cm is well under the levels used in therapeutic ultrasound, but still higher than the 30-80 milliwatts per square cm range of the Statison V veterinary LIPUS device. LIPUS has been shown to affect tissue growth in as little as 20 minutes of time with repeated daily applications. Adding to the similarity, LIPUS and medical ultrasound both operate in the 1 to 10 MHz range.

While the benefits of medical ultrasound probably outweigh any risks, vanity uses such as making 3D ultrasound movies without a doctor's order present an obviously unnecessary, but unknown risk to a developing fetus. The FDA discourages its use for non-medical purposes such as fetal keepsake videos and photos, even though it is the same technology used in hospitals. The demand for keepsake ultrasound products in medical environments has prompted commercial solutions such as self-serve software that allows the patient to create a "keepsake" from the ultrasound imagery recorded during a medical ultrasound procedure

1.2. 3 G Wireless Communication Systems

3rd Generation Wireless, or 3G, is the generic term used for the next generation of mobile communications systems. 3G systems aim to provide enhanced voice, text and data services to user. The main benefit of the 3G technologies will be substantially enhanced capacity, quality and data rates than are currently available.3G Mobile will enable the provision of advanced services transparently to the end user and will bridge the gap between the wireless world and the computing/Internet world, making inter-operation apparently seamless. The third generation networks should be in a position to support real-time video, high-speed multimedia and mobile Internet access. All this should be possible by means of highly evolved air interfaces, packet core networks, and increased availability of spectrum. The ability to provide high-speed data is one of the key features of third generation networks, the real strength of these networks will be providing enhanced capacity for high quality voice services. The need for landline quality voice capacity is increasing more rapidly than the current 2nd generation networks will be able to support. High data capacities will open new revenue sources for the operators and bring the Internet more closely to the mobile customer. The use of all-ATM or all-IP based communications between the network elements will also bring down the operational costs of handling both voice and data, in addition to adding flexibility. The drive for 3G is the need for higher capacities and higher data rates. Whereas higher capacities can basically be obtained by having a greater chunk of spectrum or by using new evolved air interfaces, the data requirements can be served to a certain extent by overlaying 2.5G technologies on the existing networks. In many cases it is possible to provide higher speed packet data by adding few network elements and software. The 3rd Generation Mobile System will most likely grow out of the convergence of enhanced 2nd generation mobile systems with greater data transfer speed and capacity and 1st generation satellite mobile systems. Evolution to the current generation mobile networks to 3G doesn't necessarily mean seamless up gradation to the existing infrastructure to the 3G.

3G or **3rd generation mobile telecommunications** is a generation of standards for mobile phones and mobile telecommunication services fulfilling the **International Mobile Telecommunications-2000 (IMT-2000)** specifications by the International Telecommunication Union. Application services include wide-area wireless voice telephone, mobile Internet access, video calls and mobile TV, all in a mobile environment. To meet the IMT-2000 standards, a system is required to provide peak data rates of at least 200 kbit/s. Recent 3G releases, often denoted 3.5G and 3.75G, also provide mobile broadband access of several Mbit/s to smartphones and mobile modems in laptop computers.

The following standards are typically branded 3G:

- the UMTS system, first offered in 2001, standardized by 3GPP, used primarily in Europe, Japan, China (however with a different radio interface) and other regions predominated by GSM 2G system infrastructure. The cell phones are typically UMTS and GSM hybrids. Several radio interfaces are offered, sharing the same infrastructure:
  - The original and most widespread radio interface is called W-CDMA.

    - The TD-SCDMA radio interface was commercialised in 2009 and is only offered in China.
    - The latest UMTS release, HSPA+, can provide peak data rates up to 56 Mbit/s in the downlink in theory (28 Mbit/s in existing services) and 22 Mbit/s in the uplink.

- the CDMA2000 system, first offered in 2002, standardized by 3GPP2, used especially in North America and South Korea, sharing infrastructure with the IS-95 2G standard. The cell phones are typically CDMA2000 and IS-95 hybrids. The latest release EVDO Rev B offers peak rates of 14.7 Mbit/s downstream.

The above systems and radio interfaces are based on kindred spread spectrum radio transmission technology. While the GSM EDGE standard ("2.9G"), DECT cordless phones and Mobile WiMAX standards formally also fulfill the IMT-2000 requirements and are approved as 3G standards by ITU, these are typically not branded 3G, and are based on completely different technologies.

A new generation of cellular standards has appeared approximately every tenth year since 1G systems were introduced in 1981/1982. Each generation is characterized by new frequency bands, higher data rates and non backwards compatible transmission technology. The first release of the

3GPP Long Term Evolution (LTE) standard does not completely fulfill the ITU 4G requirements called IMT-Advanced. First release LTE is not backwards compatible with 3G, but is a pre-4G or 3.9G technology, however sometimes branded "4G" by the service providers. Its evolution LTE Advanced is a 4G technology. WiMAX is another technology verging on or marketed as 4G.

A. WOKS FOR 3 G WIRELESS COMMUNICATIONS

1. cdma 2000 Simulation

NIST and Cadence Design Systems, Inc. have jointly developed simulation models for the cdma2000 system based on Cadence's SPW communication system design/simulation tool. An extension of the IS-95 standard for cellular phone systems based on mostly Qualcomm's technology, cdma2000 is one of the major systems proposed to the International Telecommunication Union (ITU) for the IMT-2000 standard for third-generation wireless systems.

SPW is an object-oriented language for software development and testing of communication systems. SPW includes models for many basic building blocks in a communication system. The joint work by NIST and Cadence combines and extends these building blocks to yield models for the cdma2000 system, based on the proposed standard specifications. These models will allow communication engineers to measure the performance of the physical layer of cdma2000 systems over a range of communication channel conditions, e.g., whether the cellular phone user is mobile or stationary, the type of environment the user is in (urban/ suburban/countryside), and how much interference the user is getting from other cellular users. This makes it possible to characterize the performance of a cdma2000 system prior to hardware prototyping and expensive field tests.

2. W-CDMA Simulation

Two former guest researchers at NIST, Maarit Melvasalo, from VTT, Finland, and Tommi Makelainen from Nokia Research Center, Finland, built a simulation of the 3GPP FDD proposal for 3G wireless. The simulation can run on Simulink or as a stand alone C-coded program. It includes the channel encoding, interleaving, rate matching, modulation, spreading (channelization), a channel model, a RAKE receiver, and the corresponding decoding functions. Both the downlink and uplink have been modelled.

3. W-CDMA Applications

The wireless telecommunications industry is now planning the deployment of a third-generation of mobile systems in anticipation of growing demands for voice and multimedia services. In particular, visually based services such as video conferencing, medical emergency consultation, wireless web access, and remote site surveys might dominate future services offered to subscribers in future third-generation mobile systems. Unfortunately, existing video compression standards, developed for relatively benign, nearly error-free environments, cannot be directly applied in the more hostile communication environments experienced by mobile systems. As part of the evaluation of the CDMA-based 3G systems, NIST has been working to assist industry to enable efficient use of radio bandwidth to support audio-visual services. The work has been based on the performance testing and evaluation of the W-CDMA for transmission of ITU-T H.263 compressed video bitstream. In collaboration with Cadence Design Systems, a compatible dual-priority transmission system has been developed. The end-to-end transmission system consists of a robust video partitioning scheme and a flexible 3G W-CDMA model. A demo system has been developed and implemented in the SPW model, which provides a subjective assessment of the transmitted video over IMT-2000 channels.

4. Performance Analysis and Dynamic Resource Allocation in Multi-Service DS-CDMA Networks

The main force driving evolution of wired networking technology is the need to handle multimedia traffic with widely varying statistical characteristics and with specific requirements for Quality of Service (QoS). While this trend will continue, future network infrastructures will be a mixture of both wired and wireless networks. In fact, wireless access to the Internet will probably become much more common than wired access. To prevent waste of resources in the wired backbone, the wireless access network must have the same or comparable capabilities to handle multimedia traffic. Today, wireless technology lags far behind wired technology in its ability to serve multimedia traffic. The effectiveness of wireless technology is restricted by wireless channel impairments and by severe limitations on wireless bandwidth and on transmission power by mobiles. To overcome these restrictions, system designers have a finite but complex set of techniques to employ. Such techniques include error-correction and error-detection coding, source coding, medium access protocols, smart antennas, power control algorithms, and retransmissions.

Recently, Direct-Sequence Code Division Multiple Access (DS-CDMA) has emerged as a technology for 3G wireless communication systems. DS-CDMA allocates the wireless bandwidth on demand: all users share the same wireless bandwidth and simultaneous transmissions affect each other through an increase in the random noise. However, in DS-CDMA a user bit-service rate is a complex non-linear function of various intrinsic parameters, such as transmission power and processing gain, as well as various extrinsic parameters, such as interference from other users and conditions on the wireless channel. To provide guaranteed QoS for multimedia traffic DS-CDMA requires fast, closed-loop control of system parameters based on real-time information about the intrinsic and extrinsic parameters, and about the performance of the system. For a closed-loop system to operate successfully, accurate and timely measures of appropriate parameters must be fed into the control algorithm. Our work includes identifying the system parameters, besides transmission power, having the greatest effect on the provision and maintenance of the QoS for multimedia traffic, developing control algorithms based on the parameters identified, and comparison of the performance of the proposed algorithms against the theoretical limits.

B. FEATURES

1. Data rates

ITU has not provided a clear definition of the data rate users can expect from 3G equipment or providers. Thus users sold 3G service may not be able to point to a standard and say that the rates it specifies are not being met. While stating in commentary that "it is expected that IMT-2000 will provide higher transmission rates: a minimum data rate of 2 Mbit/s for stationary or walking users, and 384 kbit/s in a moving vehicle," the ITU does not actually clearly specify minimum or average rates or what modes of the interfaces qualify as 3G, so various rates are sold as 3G intended to meet customers expectations of broadband data.

2. Security

3G networks offer greater security than their 2G predecessors. By allowing the UE (User Equipment) to authenticate the network it is attaching to, the user can be sure the network is the intended one and not an impersonator. 3G networks use the KASUMI block crypto instead of the older A5/1 stream cipher. However, a number of serious weaknesses in the KASUMI cipher have been identified.

In addition to the 3G network infrastructure security, end-to-end security is offered when application frameworks such as IMS are accessed, although this is not strictly a 3G property.

3. Applications of 3G

The bandwidth and location information available to 3G devices gives rise to applications not previously available to mobile phone users. Some of the applications are:

- Mobile TV
- Video on demand
- Videoconferencing
- Telemedicine
- Location-based services

CHAPTER 2: 3G WIRELESS COMMUNICATIONS FOR MOBILE ROBOTIC TELE-ULTRASONOGRAPHY SYSTEMS

Mobile healthcare (m-health) is a new paradigm that brings together the evolution of emerging wireless communications and network technologies with the concept of ‘connected healthcare’ anytime and anywhere. In this article, we present the performance analysis of an end-to-end mobile Tele Echography using an ultra-Light robot (OTELO), over the third-generation (3G) mobile communications network. The experimental setup of the OTELO system over a 3G connectivity link used to measure the system performance is described. The performance of the relevant medical data and the relevant quality of service (QoS) issues defined in terms of the average throughput, delta-time packet delay, and jitter delay are investigated. The real-time 3G performance results show the successful operation of this bandwidth demand- ing robotic m-health system.

1. INTRODUCTION

M-Health has been defined as “mobile computing, medical sensor, and communications technologies for healthcare”. This emerging concept represents the evolution of e-health systems from traditional desktop “telemedicine” platforms to wireless and mobile configurations. Current and emerging developments in wireless communications integrated with developments in pervasive and wearable technologies will have a radical impact on future healthcare delivery systems. One of the new areas of advanced mobile healthcare applications that has not been explored and investigated in detail is the wireless robotic tele-ultrasonography (U.S.) system.

It is well known clinically that ultrasound scanning is a well-established noninvasive method that is easy to use and very well adapted for routine clinical examinations in specialist medical centres and hospitals. However, most of the available portable ultrasonography and exist ing ultrasonography systems require the expert to carry out the examination on site. Although these systems offer quick and reliable noninvasive diagnosis in many clinical scenarios, the major drawback of these portable ultrasound systems is that they are not available in small medical centres, isolated sites, and rescue vehicles in emergency cases. Their usefulness is dependent on the operator’s (expert) skills. In such circumstances, robotic tele-ultrasonography could be useful. In addition, such robotic telemedicine systems could be very valuable for training in nonspecialist sonograph remote medical centres, and can also be valuable for expert opinion in combat and military scenarios as well.

The wider availability of 3G systems in most of the European and developing countries will inevitably allow the wider use of such wireless robotic m-health systems, especially in remote and isolated areas, which will certainly reflect on better healthcare efficiency and improved medical care in these countries.

One of the first ultrasound telemedicine studies on remote examinations was reported in the mid-1990s, where the ultrasound video images acquired by the technician at the patient's side were transmitted to a medical expert. However, these systems were not efficient enough for proper medical validation because of their 'expert dependency' on the relevant ultrasound examination.

In 1998, videoconferencing was used between two experts, with one of them was performing the echography examination. Both experts could simultaneously discuss the obtained ultrasound image, and the expert who was distant from the patient could suggest a different probe orientation to his peer for better observation and analysis of the area of interest. In 2000, the European project TeleInVivo was developed, in which the echography was performed by a clinical expert standing next to the patient then ultrasound data were sent via satellite to a data base station and processed to reconstruct a 3D representation of anatomical regions of interest.

In Japan, tele-operated robots have been set up to perform a remote ultrasound examination between two nearby sites with terrestrial communications.

All these studies have shown the necessity of a skilled ultrasound expert to drive the robotic structure holding the probe. We have developed a new generation of specific lightweight, portable, and fully integrated robotic devices for tele-ultrasound. These robotic devices have different degrees of freedom (DoFs) dedicated to special applications. The number of degrees in the robotic head or arm represents the number of movements, and a flexibility that translates as close as possible to human hand movement, for example, 6 DoF represents movements in total X, Y, Z and diagonal directions that the human hand can do.

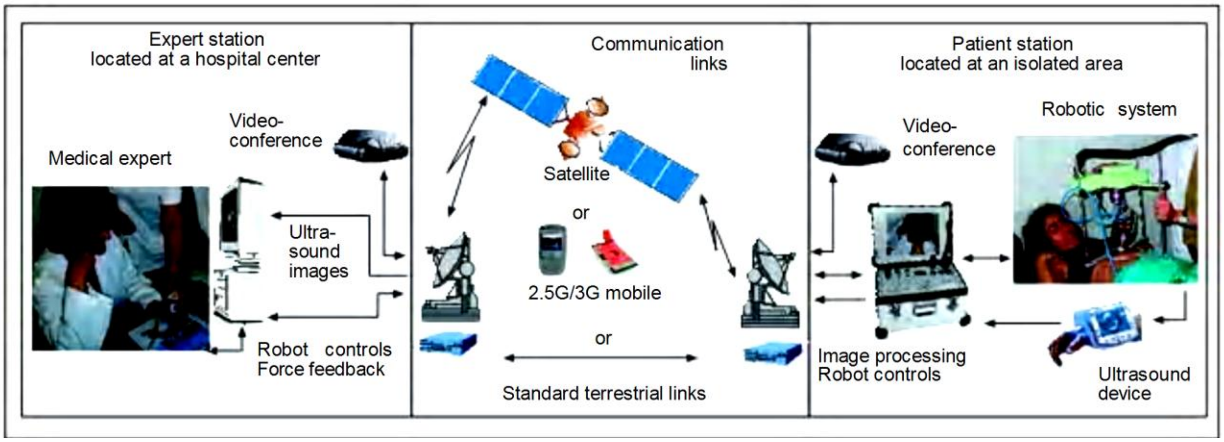

Figure 1: The OTELO mobile robotic system, general blocks diagram, and different communication links.

The article is structured as follows. The following section presents an overview of the OTELO system. Next, we outline the 3G wireless connectivity of the system and the medical data-rate requirements. The article then presents the experimental setup, and goes on to present the performance analysis and discuss the results. The final section presents the conclusions of the article.

2. 3G MOBILE ROBOTIC TELE-E CHOGRAPHY SYSTEM

The advanced medical robotic system, mobile Tele-Echography using an ultra-Light robot (OTELO), was a European Information Society Technologies (IST) funded project that developed a fully integrated end-to-end mobile tele-echography system for population groups that are not served locally, either temporarily or permanently, by medical ultrasound experts. It comprises a fully portable tele-operated robot allowing a specialist sonographer to perform a real-time robotised tele-echography (ultrasonography) to remote patients. The system comprises three main parts:

- **The expert station:** where the medical expert interacts with a dedicated patented pseudohaptic fictive probe instrumented to control the positioning of the remote robot and emulates an ultrasound probe that medical experts are used to handle, thus providing better ergonomy.

- **The communication links:** OTELO is adaptable to operate on different types of communication (satellite, 3G wireless and terrestrial) links. In this article, we address the performance of the system under 3G mobile connectivity. (The other links have been addressed elsewhere; these different communication links will allow the universal usage of the system based on the availability of these technologies in different geographical locations.)
- **The patient station:** composed of a 6 DoF lightweight robotic system and its corresponding control unit. This robot manipulates an ultrasound probe according to orders sent by the medical expert. The probe also allows the grabbing of the ultrasound images that are sent back to the expert. Figure 1 shows the general end-to-end functionality of the OTELO system.

Three types of critical data are to be transmitted over the OTELO system: robotic control data, ultrasound still images, and medical ultrasound streaming data. In this article, we only address the performance issues regarding the controlled ultrasound medical streams, since this type of medical data represents the most “demanding data-rate” requirements of such robotic telemedicine systems.

The robotic system has also a force feedback mechanism in order to allow the expert to move the fictive probe and control the distant probe holder for the remote robotic system.

We observed that the voice packet data takes priority and could cause some degradation (in terms of the packet delays and jitter) on the ultrasound reception. In addition, during the “ultrasound scan” voice is rarely needed by either the patient or the expert. Hence, we consider that both the ambient video plus the voice (videoconference) can be transmitted when such a data type is required following the reception of ultrasound data by the expert station. However, if sufficient 3G bandwidth is available, simultaneous ultrasound stream and videoconferencing data transmission can be accommodated. It is reported that at least 80 percent of these in-vivo tests have led to comparable results with a conventional ultrasound examination for the organs examined and detected.

It is well known that 3G wireless technologies present an enhanced mobile platform for many wireless telemedicine applications; in general, for:

Medical data	**Data description**	**Data rates (kb/s) and resolution (dB)**	**Data flow direction, patient-to-expert (P-to-E), expert-to-patient (E-to-P)**

Still US images	Grayscale, 512 512 pixels	14-97 kbytes	Uplink, P-to-E
Stream US images	Grayscale, CIF (R.O.I.), 200 × 200 pixels	10 frames/s, > 35 dB	Uplink, P-to-E
Stream US images	Grayscale, CIF, 352 × 288 pixels	7 frames/s, > 35 dB	Uplink, P-to-E
Robot control frequency	100-200 Hz	5-6 kb/s	Up-or downlink, E-to-P and P-to-E
Stream US images	QCIF, 176 × 144	5 frames/s, > 36 dB	Up and down, P-to-E and E-to-P
Videoconf. Option 1	QCIF, 176 × 144	7.5 frames/s	Up and down P-to-E and E-to-P
Videoconf. Option 2	CIF, 352 × 288	5 frames/s	Up and down, P-to-E and E-to-P

Table 1: OTELO medical data rate requirements.

- **High mobility:** 3G offers a data rate of 144 kb/s for rural outdoor mobile use for a user traveling at a speed of more than 120 km per hour.
- **Low mobility:** 3G offers a data rate of 384 kb/s downlink for pedestrian users traveling at a speed of less than 5 km per hour (and up to 2 Mb/s indoors). These data rates enable 3G connectivity reach anyone, anywhere and transmit any kin of information in real time. 3G may provide t following services:
- **Videoconferencing:** to permit videophone- type communication between mobile terminals.
- **Video streaming:** video recording and images of various kinds can be sent and transmitted with this service. Customers will thus be able to receive real-time television programs on their 3G terminals for entertainment, cultural, or educational purposes.
- **Internet browsing:** the user can browse on the Web directly with the mobile terminals.
- **Application sharing:** applications running on the customer terminal can use processing resources resident on a remote server (e.g., one managed by the service provider).

The selected U.S. streams will be transmitted over different available 3G network data rates. These range from 56 to 384 kb/s (uplink). These rates are specifically related to the patient-station uplink that represents the specific communication bottleneck of this telemedicine 3G connectivity channel. The patient station sends ultrasound images, ultrasound streams, ambient video, sound, and robot control data, while it receives only robot control, ambient video, and sound from the expert station (i.e., expert-station uploading).

The classification of the OTELO traffic is mapped to the three major traffic classes defined by the Third Generation Partnership Project (3GPP) for Universal Mobile Telecommunication System (UMTS) quality of service (QoS) classes. The best-suited QoS class for video streaming is service class “Streaming” which preserves the time relation (variation) between information entities of the stream. However, for medical image sequences with real-time (RT) requirements, the “Conversational” class would be necessary.

The general functional modalities of the system are given in Table 1, with those addressed in this article shown in boldface letters.

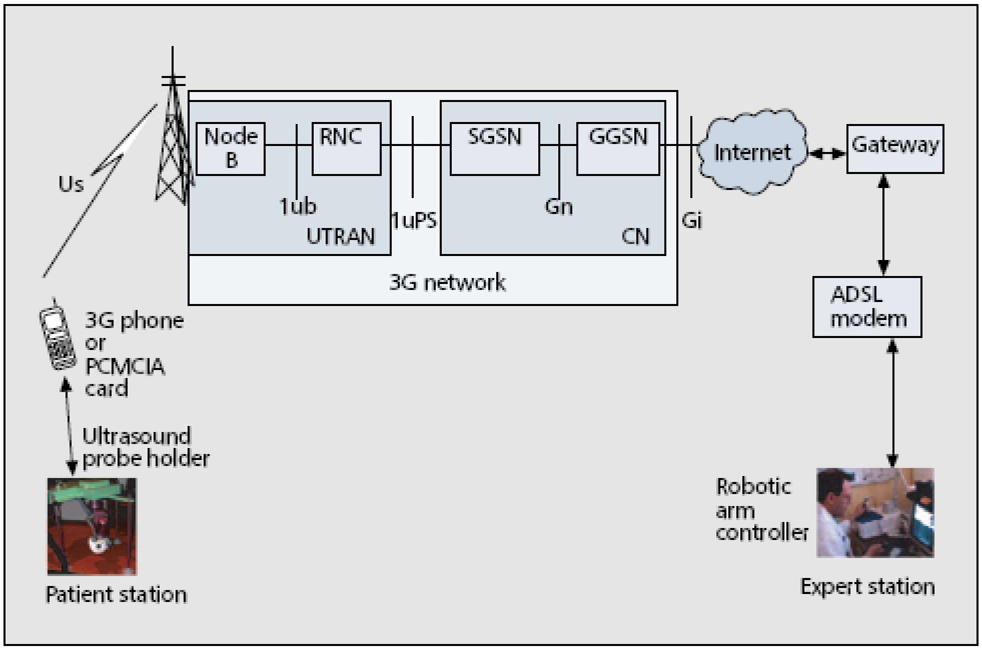

Fig 2: OTELO mobile robotic system connectivity over 3 G network

4. EXPERIMENTAL SETUP ENVIRONMENT

The experimental setup is designed to measure the end-to-end system performance over the 3G network, as shown in Fig. 2.

The following performance metrics are measured:

- Average throughput (ultrasound stream and robot control data)
- End-to-end packet delay and delay jitter.

The ultrasound scanner data is acquired at the rate of 13 frames/s, each frame with the resolution of (320 × 240) pixels for the videoconferencing format, and (176 × 144) pixels for the Quarter Common Intermediate Format (QCIF). The robotic data flow bursts from the expert station at 16 bytes payload on 70 ms time interval, and the received robot data stream from the patient station is updating the robotic head position continuously.

The patient station is connected to a 3G terminal via a wireless card connected to a laptop PC. The tests were carried out at different network loading conditions (especially at peak working hours) and the presented results reflect these network conditions.

5. IMPLEMENTATION OF THE STREAMING PROTOCOL

It is well known that protocols for streaming media are commonly designed and standardized for communications between clients and streaming servers. They are concerned with issues such as network addressing, transport, and session control. The transport protocol family for media streaming includes User Datagram Protocol (UDP), Transmission Control Protocol (TCP), Real-Time Protocol (RTP), and Real-Time Transport Control Protocol (RTCP).

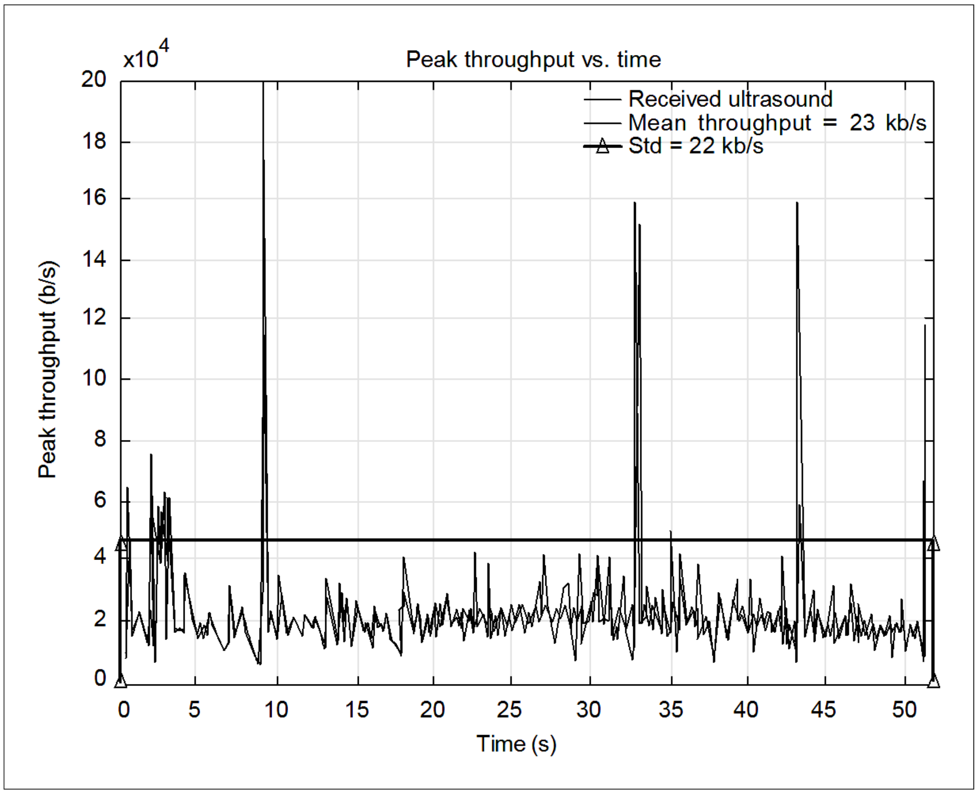

Fig 3: Sample peak throughput of received ultrasound stream by expert station

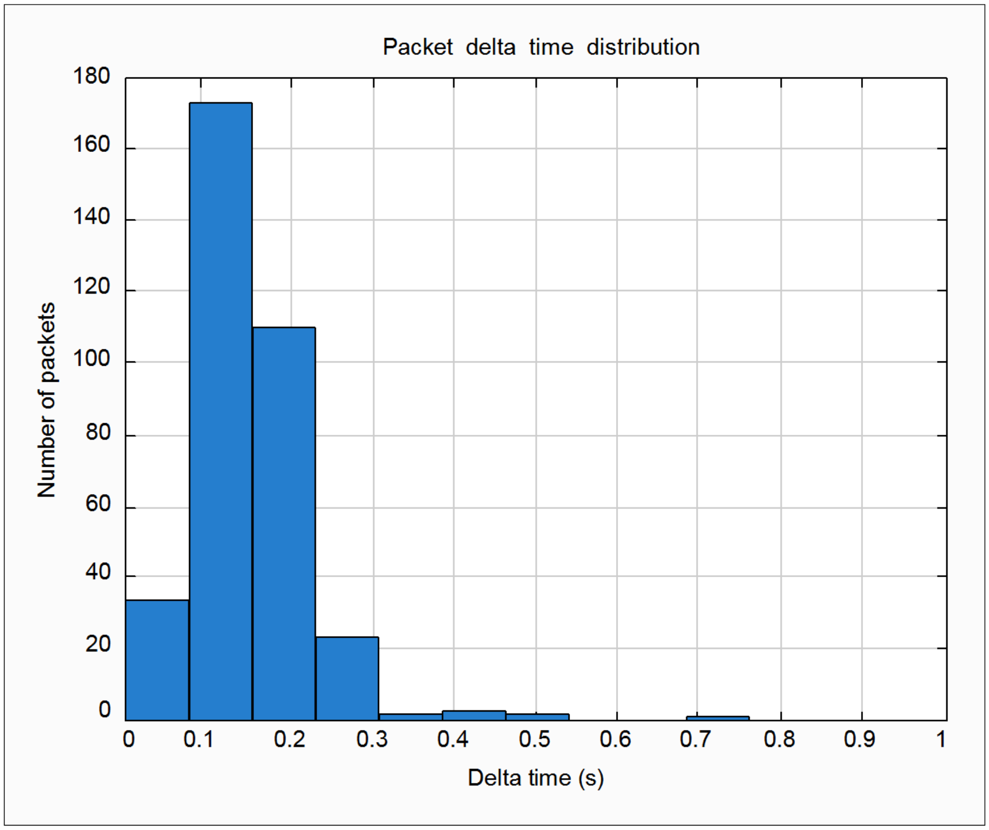

Fig 4: Distribution of delta time packet delay at the expert station

Since TCP retransmission introduces delays that are not acceptable for real-time streaming applications with stringent delay requirements, especially for transmission over fading wireless links, UDP is typically employed as the transport protocol for video streams over such fading channels.

RTP is an Internet standard protocol designed to provide end-to-end transport function for supporting real-time applications. RTCP is a companion control protocol with RTP and is designed to provide QoS feedback to the participants of an RTP session; therefore, RTP/UDP/IP protocol is applied in our The UDP/IP protocol is used for the robot data that is transmitted in both directions. Although the effect of packet loss on the robotic control could affect the mechanical functionality of the robotic control system, the tests carried out on the OTELO system with an uplink of (64kb/s) have shown the reliable functioning of the robotic system in the patient station with the minimal packet loss of (< 0.5 percent).

6. ULTRASOUND STREAM CODEC

The video compression standard used in this application is H263 codec, which has a wide range of applications, including medical consultation and diagnosis at a distance. The H.263 is aimed particularly at video coding for low bit rates (typically, 20 to 30 kb/s and above). Further details on this codec design and the imaging functionality of this codec for OTELO can be found in.

7. PERFORMANCE RESULTS AND DISCUSSION

The OTELO system was tested on a live 3G network (Vodafone, U.K.). The experimental tests for the system were carried within the greater London area between Kingston University, London (patient side) and St. George's Medical School, London (expert side). The following summarize some of the performance tests carried out.

8. ULTRASOUND THROUGHPUT ANALYSIS

A sample of the instantaneous throughput of the ultrasound stream captured by the expert is shown in Fig. 3, where the average throughput obtained was 23 kb/s and the standard deviation (std) value of 22 kb/s represented the patient uplink average throughput value.

The variation in the throughput shown in the figure can be attributed to the movement of the robotic probe holder in addition to the variation the network conditions.

The number of stream packets taken for the analysis was 350. This stream length was selected based on the experimental 3G test results on OTELO, where this stream length represents a good average measure for the performance results of the system for a complete ultrasound scan session that can last, in general, between two and four minutes. These tests also indicated that approximately 82 percent of the packets received at the expert station were at rate of 18.5 kb/s, whilst the reminder of the packets were received at data rates of up to 60 kb/s.

The performance test of the system in terms of packet loss indicated that none of the 360 RTP packets captured by the expert side, in good network conditions, was lost; whereas in a different network (congested) condition test, the result indicated that only 2 out of 1192 RTP packets (0.17 percent) captured were lost.

9. DELAY DISTRIBUTION

The delta-time distribution of the stream packets is shown in Fig. 4, where the performance analysis of the stream packet delay at the expert station gives an average packet delta time (time difference between two consecutive packets) of 0.148 sec.

The delay distribution shows a maximum delay of around 0.3 sec for just about 7 percent of the received packets, while 50 percent and about 30 percent of the packets show delays of around 0.12 and 0.22 sec, respectively. There are several factors that cause this delay across the wireless link: the delay access on each ON period (variable), the delay of the multiplex process (variable), and the transmission delay. The connection between both system ends is always ON during the entire clinical session. It should also be noted that any video packet that arrives beyond its delay bound (e.g., its play-out time) is useless and can be regarded as lost.

The delay variation (jitter) across this system’s link is considered a key factor for a reliable real-time medical ultrasound stream reception at the expert station. The results also indicate that the delay jitter encountered by the received packets degrades the reliability of the ultrasound images in terms of irregular frames per second (fps) production.

10. ROUND-TRIP TIME DELAY

Generally, the network RTT can be defined as the time it takes to transmit one packet from, say, a server to a terminal plus the time it takes for the corresponding packet to be sent back from the terminal to the server. The formula for the RTT delay regarding OTELO system is represented as follows:

Expert side generates and sends robot control (Expert–Patient link delay) + Patient station responds by transmitting ultrasound stream of images (Patient–Expert link delay).

Different packet sizes of 100, 200, 300, 500, 1000, and 1400 bytes are tested to characterize various delay performances. These packet sizes are chosen to cover the possible size range of the packets generated by the H263 codec used by the system.

Internet Control Message Protocol (ICMP) is used for pinging the expert station from the patient station at 500 to 1000 ms time intervals. ICMP provides some error-detection mechanisms and it can be used to send error messages or other messages for network diagnosis. The RTT delay test is performed with patient-station data rates of 256 kb/s for downlink and up to 64 kb/s for the uplink channel. Table 2 summarizes the comparative results of the RTT values for different ultrasound packet sizes as well as the robotic control data size of 16 bytes. These results indicate the end-to-end RTT of the path defined above.

Packet sizes (bytes) Ultrasound and robot							
	100	200	**300**	500	1000	1400	16
RTT (ms)	206	257	297	360	521	638	100

Table 2: ***Comparative RTT results of different ultrasound stream and robotic packet sizes.***

The test results also show that the latencies of the 3G wireless link of the system are the highest (around 80 to 90 percent) of the total end-to-end delay.

The end-to-end delay of the system is based on the average packet delta time results, as illustrated in Table 2, which is closely correlated (RTT/2) to pinging 300 bytes (boldface results in Table 2) from the patient station to the expert station that is used as an average ultrasound transmitted packet size. Based on the above, the maximum delay of probe movement to received image (expert–patient–expert) path was found to be around 325 ms under these specific ultrasound-encoding conditions.

CHAPTER 3: CONCLUSION

The experimental test results for transmitting ultrasound streams encoded in the (QCIF) format using the H.263 codec have demonstrated successful transmission in 3G real-time environments. The quality of the received ultrasound information was 5 fps with an objective quality measure of 35 dB peak signal to noise ratio (PSNR). These values represent the minimum bounds that are clinically acceptable by the medical experts using the OTELO system for prediagnosis requirements of such 3G mobile robotic telemedicine systems. These results are achieved using 64 kb/s at the patient station uplink. Enhanced performance can be achieved using higher rates and depending on the 3G network operators channel assignments.

We have also found that network delay jitter variations were still within the acceptable boundaries of maintaining high-quality real-time interaction for the system; 297 ms compared to a maximum delay of 325 ms. In general, we can conclude that such advanced mobile robotic telemedicine systems can successfully provide clinically acceptable quality ultrasound data using commercial 3G networks.

REFERENCES

- R. S. H. Istepanian, E. Jovanov, and Y. T. Zhang, “Mhealth: Beyond Seamless Mobility for Global Wireless Healthcare Connectivity-Editorial,” IEEE Trans. Info. Tech. in Biomed. vol. 8, no. 4, Dec. 2004, pp. 405–14.
- J. Sublett, B. Dempsey, and A.C. Weaver, “Design and Implementation of a Digital Teleultrasound System for Real-Time Remote Diagnosis,” Comp.-Based Med. Sys., TX, June 1995, pp. 292–99.
- R. Ribeiro et al., “Teleconsultation for Cooperative Acquisition, Analysis and Reporting of Ultrasound Studies,” TeleMed ’98, London, U.K., 25–26 Nov. 1998.
- G. Kontaxakis, S. Walter, and G. Sakas, EU-TeleInViVo, “An Integrated Portable Telemedicine Workstation Featuring Acquisition, Processing and Transmission Over Low-Bandwidth Lines of 3D Ultrasound Volume Images,” Info. Tech. Apps. in Biomed. 2000, U.S., Nov. 2000.
  - Vilchis et al., “Robotic Tele-Ultrasound System (TER): Slave Robot Control,” 1st IFAC Conf. Telematics App. In Automation and Robotics, Weingarten, Germany, 24–26 July 2001, pp. 95–100.

- K. Masuda et al., “Development of Remote Echographic Diagnosis System by Using Probe Movable Mechanism and Transferring Echogram via High Speed Digital Network,” Proc. IX Mediterranean Conf. Med. and Biological Eng. And Comp., Pula, Croatia, June 2001, pp. 96–98.
- F. Courreges et al., “Clinical Trials and Evaluation of a Mobile, Robotic Tele-Ultrasound System,” J. Telemed. and Telecare, suppl. 1, 2005, pp. 46–49.
- S. A. Garawi et al., “Performance Analysis of a Compact Robotic Tele-Echography E-Health System over Terrestrial and Mobile Communication Links,” Proc. 5th IEE Int’l. Conf. 3G Mobile Commun. Tech., London, U.K., 18–20, Oct. 2004, pp.118–22.
- H. Holma and A. Toskala, Eds., WCDMA for UMTSs, Wiley, 2000.
- W. Dapeng et al., “Streaming Video over the Internet: Approaches and Directions,” IEEE Trans. Circuits and Sys. for Video Tech., vol. 11, no. 3, Mar. 2001.
- R. Karel, “H.263: Video Coding for Low-Bit-Rate Communication,” IEEE Commun. Mag., Dec. 1996, pp. 42–45.
- M. Taferner and E. Bonek, Wireless Internet Access over GSM and UMTS, Springer-Verlag, 2002.