Wireless Telemedicine as Part of an Integrated System for E-Medicine

Ivan Chorbev, Gjorgji Madzarov, Dragan Mihajlov

Introduction

Telemedicine and related healthcare technologies aim to provide efficient healthcare remotely. It ought to improve the well-being of patients and bring medical expertise at a lower cost to people in need at the right time. Telemedicine has various potential uses such as clinical, educational and administrative. Telemedicine can bring high quality medical service to under-served areas. Perspectives show that telemedicine can provide a solution to various problems such as: access to care for large segments of the population, reduce healthcare cost, bring experience and expertise closer to patients, and solve uneven geographic distribution of service quality. It can improve quality as a result of providing coordinated and continuous care for patients, targeted and highly effective continuous education for providers, and highly effective tools for decision support.

Wireless telemedicine is a rather new emerging area. The low bandwidth or high costs of previous wireless technologies discouraged advanced telemedicine services. The new wireless broadband technologies enabled creation of telemedicine services previously only possible via cable connections. Advanced medical services can be provided to rural areas or areas stricken with disasters otherwise unreachable by cable connections, very quickly and with fraction of the previous cost. Wireless telemedicine is especially suitable for areas lacking proper cable connections or places where installing cable links is difficult, economically unavailable or simply impossible. For instance, in cases of natural disasters such as earthquakes, hurricanes, tsunami, installing WiMAX wireless links is the only possible way to establish communication and provide medical service.

Our project consisted of implementing several wireless telemedicine components of an integrated system for e-medicine. WiMAX (IEEE 802.16) and Wi-Fi (IEEE 802.11) are the technologies that we used to implement our telemedicine functionalities compatible with IEEE 11073 Standards for Health Informatics. The proposed system consists of medical information systems (MIS), telemedicine functionalities and decision support functionalities. The system is modular and therefore easily upgradeable.

Background and evolution of Telemedicine

The evolution and growth of telemedicine is highly correlated with the developments in communication technology and IT software development. This dependency is evident if we review the history of telemedicine technologies. Researches categorize the telemedicine history into three eras [Bashshur 2000],[Tulu 2005]. All the definitions during the first era of telemedicine focused in medical care as the only function of telemedicine. The first era can be named as telecommunications era of the 1970s [Bashshur 2000]. Applications in this era were dependent on broadcast and television technologies where telemedicine application was not integrated with any other clinical data.

The second era of telemedicine, dedicated era, started during the late 1980s as a result of digitalization in telecommunications and it grew during 1990s [Bashshur 2000]. The transmission of data was supported by various communication mediums ranging from telephone lines to Integrated Service Digital Network (ISDN) lines. The high costs attached to the communication mediums that can provide higher bandwidth became an important bottleneck for telemedicine.

Dedicated era has turned into an Internet era where more complex networks are supporting the telemedicine. The third era of telemedicine is supported by the technology that is cheaper and accessible to an increasing user population [Bashshur 2000]. The enhanced speed and quality offered by Internet or 3G mobile telephony [Yamauchi 2004] is providing new opportunities in telemedicine.

Certain recent research projects include the use of satellite-based Telemedicine solutions. The Healthware project (http://healthware.alcasat.net/), among others, has tested various scenarios where satellite-based telemedicine services are used to solve tele-consultation, tele-education, home care, second opinion and other medical problems. However, the high costs of quality satellite connections discourage the use of this technology in a developing country like the R. of Macedonia. Cheaper and robust wireless technologies like WiMAX enable provision of similar or same functionalities.

During the evolution of telemedicine, new technologies were developed and the applications and delivery options increased in variety. Application areas expanded to almost all the fields medicine can cover [Zielinski 2006].

Since the first formal definition of telemedicine by Bird in 1971, many researchers tried to define this term in order to clarify the boundaries of telemedicine and its use. His definition states that "telemedicine is the practice of medicine without the usual physician-patient confrontation …via an interactive audio-video communications system". A newer definition states that "Telemedicine is the use of electronic information and communications technologies to provide and support healthcare when distance separates the participants." Even though the essence of these definitions is the same, telemedicine, and hence its definition, evolved dramatically as a result of the tremendous changes experienced in the telecommunication and information technologies. Newer terms and research areas have emerged (telehealth, e-health). According to Maheu in 2001 [Bashshur 2000], E-health refers to all forms of electronic healthcare delivered over the Internet, ranging from informational, educational, and commercial "products" to direct services offered by professionals, nonprofessionals, businesses or consumer themselves. Recent applications of telemedicine include: Consultation, Diagnostic Consultation, Monitoring, Education, Disaster management [Olariu 2004], Virtual Microscopy [Fontelo 2005], Homecare, Diagnosis, Treatment and Therapy (Psychology).

The telecommunication technology we used - Wimax

Due to specific circumstances in the Republic of Macedonia, we used a WiMAX network as basis for our telemedicine services. WiMAX is a popular name for a wireless digital communications system. WiMAX is a telecommunications technology aimed at providing broadband wireless data connectivity over long distances. It is based on the IEEE 802.16 standard. The high bandwidth and increased reach of WiMAX make it suitable for providing a wireless alternative to cable and DSL for last mile broadband access. WiMAX can provide broadband wireless access (BWA) up to 30 miles (50 km) for fixed stations, and 3 - 10 miles (5 - 15 km) for mobile stations. In contrast, the WiFi/802.11 wireless local area network standard is limited in most cases to only 100 - 300 feet (30 - 100m).

With WiMAX, WiFi-like data rates are easily supported, but the issue of interference is lessened. WiMAX operates on both licensed and non-licensed frequencies, providing a regulated environment and viable economic model for wireless carriers.

WiMAX can be used for wireless networking in much the same way as the more common WiFi protocol. WiMAX is a second-generation protocol that allows for more efficient bandwidth use, interference avoidance, and is intended to allow higher data rates over longer distances.

The ETSI HiperMAN [IEEE 2006] is the European version of IEEE 802.16 addressing spectrum access in ranges under 11 GHz. There is a second European standard emerging called ETSI HIPERACCESS that will define (mostly licensed uses) above 11 GHz (approximately). The IEEE 802.16 standard covers spectrum ranges up to about 66 GHz inclusively.

The IEEE 802.16 standard and its QoS

When building telemedicine functionalities, the quality of service (QoS) of the telecommunication is essential, especially in critical services. The IEEE 802.16 standard includes features like integrated QoS and mobility support. The IEEE 802.16-2004 (also known as IEEE 802.16d) [IEEE 2004] and IEEE 802.16e are the most popular versions of the standard. They define various functionalities, such as: operation in line of sight (LOS) and in non line of sight (NLOS) conditions, integrated support for different scheduling services, mobility, and extended coverage. The scheduling services supported include:

- Unsolicited Grant Service (UGS) for VoIP applications with constant bit rates;
- Real Time Polling Service (rtPS) for video applications with variable bit rates;
- Extended rtPS (ertPS), for VoIP applications with silence suppression features;
- Non Real Time Polling Service (nrtPS) for file transfer applications;
- Best Effort (BE) service for web browsing applications.

In the IEEE 802.16 QoS model, each packet caries a particular set of QoS parameters, such as: traffic priority, maximum sustained traffic rate, maximum traffic burst, minimum reserved traffic rate, minimum tolerable traffic rate, tolerated jitter range, maximum delay, vendor-specific QoS parameters, and request/transmission policy. There are different types of service flows: Provisioned, Admitted and Active.

The functional entities defined in the standard are the Subscriber Station (SS), or Mobile Station (MS) in IEEE 802.16e, and the Base Station (BS). The BS is responsible for the centralized QoS scheduling inside its cell based on QoS parameters configured by the management system and the active bandwidth requests received from the SS. The SS or MS must identify a BS, acquire physical synchronization, obtain MAC parameters, and attach to the network. In IEEE 802.16, connections are identified by a Connection Identifier (CID) and not by the MAC address of the host as in other IEEE 802 standards (IEEE 802.11 for example). The SS MAC address is only used in initial authentication.

The mobility support introduced in the IEEE 802.16e standard includes power-saving specifications and handover procedures. With respect to power-saving, two modes of operation are specified: Sleep and Idle. The Idle mode is more power conserving than the Sleep mode, as the MS can turn off completely and become periodically available for downlink broadcast messages without being registered with any BS. With respect to mobility, although different handover types are supported in the standard, such as Hard Handover (HHO), Fast Base Station Switching (FBSS) and Macro Diversity Handover (MDHO), only HHO is mandated to be supported by all equipment. With HHOs, transfer interruptions are possible when a mobile node switches from one BS to another. The handover decision can be taken by the BS, MS or by another network entity. The MS gets knowledge of existing neighbors via management messages transmitted periodically by the BSs. Using this information the MS can perform scan and association procedures. Once the handover decision has been made, the MS begins the synchronization process with the target BS.

BreezeMAX

The infrastructure of the provider that we used in the experiments consists of BreezeMAX antennas and client devices, manufactured by the company Alvarion. BreezeMAX TDD (BreezeMAX) is Alvarion's WiMAX compatible platform operating in Time Division Duplex (TDD) mode.

The BreezeMAX equipment is based on the IEEE 802.16/ETSI HIPERMAN standards. It is designed to meet the requirements of the wireless Metropolitan Area Network (MAN) environment and to deliver broadband access services to a wide range of customers, including residential, SOHO, SME and multi-tenant customers. Its Media Access Control (MAC) protocol is designed for point-to-multipoint broadband wireless access applications, providing efficient use of the wireless spectrum. The access and bandwidth allocation mechanisms accommodate hundreds of subscriber units per channel, with subscriber units that may support different services to multiple end users.

The system uses OFDM radio technology, which is robust in adverse channel conditions and enables operation in non line of sight links. This allows easy installation and improves coverage, while maintaining a high level of spectral efficiency. In the uplink the system uses OFDMA-16, supporting N x Subscriber Units per Symbol (N=1 to 16). Modulation and coding can be adapted per burst, ever striving to achieve a balance between robustness and efficiency in accordance with prevailing link conditions.

BreezeMAX supports a wide range of network services, including Internet access (via IP or PPPoE tunneling), VPNs and Voice over IP. Service recognition and multiple classifiers that can be used for generating various service profiles enable operators to offer differentiated SLAs with committed QoS for each service profile.

The system supports also IP CS Switching Mode that is compatible with the infrastructure of next generation WiMAX systems or DSL systems. IP CS Switching Mode provides smooth upgrade to systems that fully support the IEEE 802.16e standard, with the same “Look and Feel” of service provisioning. It also enables operators working with BRAS that supports DHCP option 82 for already deployed DSL systems to add a wireless access solution in areas where DSL is not available using the same provisioning equipment.

BreezeMAX supports service recognition and multiple classifiers that can be used for generating various service profiles for defining various QoS for each service profile. When using VoIP devices that do not support the DRAP protocol, the required QoS service can be provided through a Data (L2) service with a CG QoS that is defined in accordance with the estimated bandwidth required for the service. The required bandwidth depends on several parameters, such as codec type, sample rate and T.38 Fax Relay support.

BreezeMAX Client Premise Equipment (CPE)

The WiMAX-compatible PRO-S CPE and Si CPE Subscriber Units (SUs) are powered by Intel's WiMAX Connection 2250 chip. BreezeMAX CPEs serve as an efficient platform for a wide range of services, providing bridge functionality and supporting up to 512 MAC addresses.

BreezeMAX CPEs are currently available in the 2.3 GHz (WCS), 2.5 GHz (MMDS and MCS), 3.3 GHz, 3.5 GHz and 3.6 GHz frequency bands.

BreezeMAX CPEs support dual operation modes, enabling detection of the protocol used in the wireless link (APD) and automatic switching between FDD and TDD operation modes provided they hold the appropriate SW versions. In addition, the Intel's WiMAX Connection 2250 chip is ready for future support of IEEE 802.16e (mobile WiMAX) through simple over the air software upgrade.

Wireless infrastructure

The telecommunication market in Macedonia is growing quickly and de-monopolizing. Currently there are several statewide backbone networks operated by various data communication providers. In order to implement our telemedicine system we used the backbone network of a fast growing privately owned data communication provider. The backbone network consists of some fiber optic connections in the city limits of Skopje and mostly 802.16 (WiMAX) base stations throughout the country. The optic fiber connections are used for provision of fast bandwidth services where possible. The WiMAX antennas are used for connecting hospitals where the optic fiber has not reached yet and 802.11 hotspots are used for wireless devices (PDAs, notebook PCs etc.) Other providers operate totally fiber optical backbone networks throughout the country, but due to lower costs of WiMAX based systems and other advantages, we decided to use the network in question.

Due to the sufficient bandwidth of WiMAX, it is used to cover most of the needs of our telemedicine system. WiMAX is a telecommunications technology aimed at providing broadband wireless data connectivity over long distances. It is based on the IEEE 802.16 standard. The high bandwidth and increased reach of WiMAX make it suitable for providing a wireless alternative to cable and DSL for last mile broadband access. We tested the performance of both fixed outdoor and fixed indoor WiMAX antennas and the results are very promising, since both provided robust connections. Latest systems built using 802.16e-2005 and the OFDMA PHY as the air interface technology are called "Mobile WiMAX" and are expected to provide broadband connections while the client is moving.

Within the city limits of the capital Skopje there is a functional fiber optic Metro Ethernet network. Hospitals in the city are (or will be) connected to the network. The fiber optical connection enables fast and robust connectivity for provision of advanced telemedicine services like high quality video streaming of surgical procedures, medical visualization etc. Even when the fiber optical lines are used for communication, the WiMAX wireless lines could be used for backup in case of interrupted cable communication. While cables can be physically cut, the WiMAX connections are stable even in severe weather conditions.

A wireless backbone network is established throughout the country, and hospitals in different cities are (or will be) connected to the network. Antennas are placed on hills overseeing cities, and coverage with the radio signal is good and robust. The backbone network is depicted in Figure 1, while one antenna in Skopje and two pilot hospitals included in the system are shown in Figure 2.

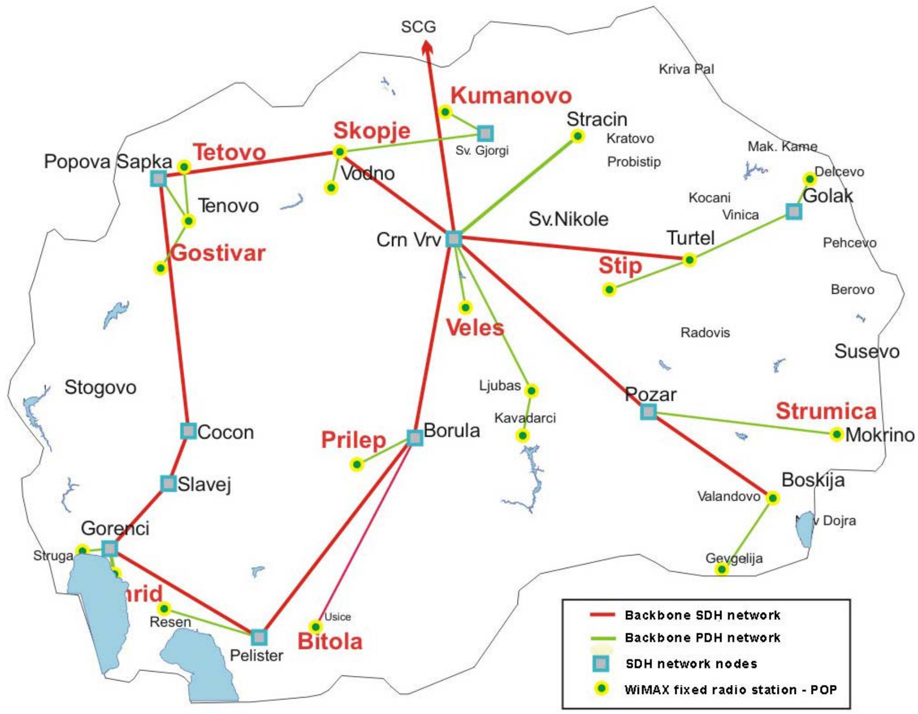

Fig. 1. Scheme of the wireless backbone network in the Republic of Macedonia

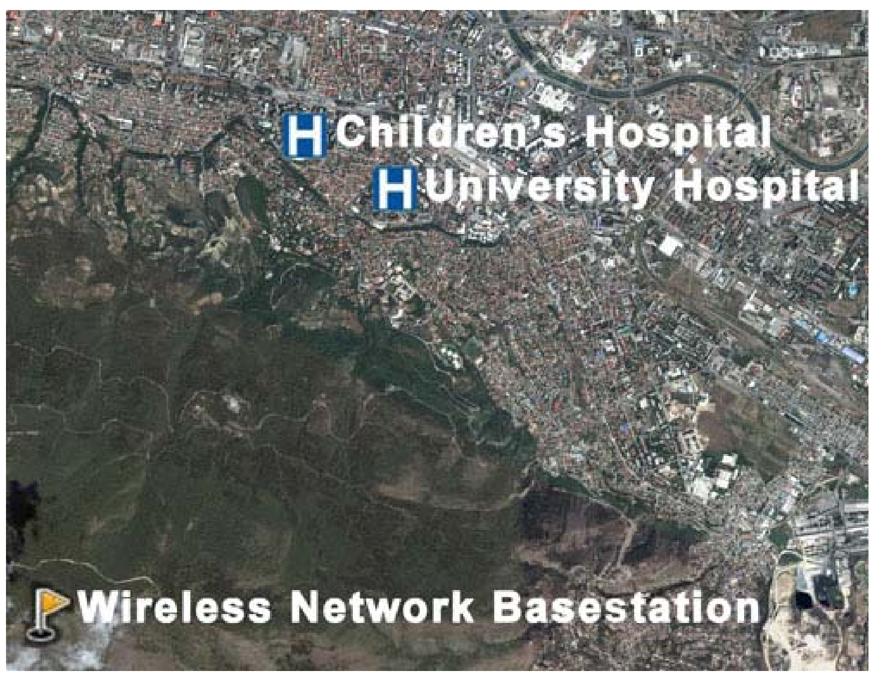

Fig. 2. Image of the WiMAX antenna on a hill overseeing Skopje and the hospitals included in the pilot project (Original image from Google Images)

Figure 3 shows the geographical distribution of major healthcare facilities within the Republic of Macedonia. They are all within reach of the WiMAX base stations, and several of them were actually connected to the network as part of the pilot project and the experiments. Some of the hospitals, especially in the capital could also be connected using fiber-optical cables for better communication quality. However, the current tested wireless links seemed sufficient for most of the basic telemedicine functionalities.

Fig. 3. Map showing the geographical distribution of major healthcare facilities within the Republic of Macedonia

Software modules

While researchers in developed countries can have different goals, our objectives have to be scalable, ranging from establishment of basic telemedicine services up to advanced up to date functionalities. The main concepts of the main integrated system include:

1) Creation of necessary basic Medical Information Systems (MISs) for hospitals;
2) Creating a framework and interfaces where various multiplatform MISs could interconnect in an integrated MIS;
3) Using modern telecommunication technologies for connecting parts of the integrated MIS and provision of advanced medical services at remote locations.
4) Using the integrated MIS for various telemedicine applications (sharing knowledge, experience and expertise among physicians in different hospitals, consultations, video streaming, enabling better remote patient-doctor communication, and better access to medical information).

Since various software modules were developed, or legacy modules had to be integrated, XML and web services were widely used for system integration. Due to the standardized format of XML, and the support of Simple Object Access Protocol (SOAP) in all platforms, web services were always used for data exchange.

The initial stages of the project included a couple of hospitals: The Institute for Respiratory Diseases in children-Kozle and the University Clinical Center in Skopje. Due to the lack of a modern Medical Information Systems (MIS) in the hospitals, the project has to start from scratch. We developed the initial Web based MIS to be used by the staff at the Kozle children's hospital (figure 4). Since the hospital cannot afford to maintain an IT department, the MIS is hosted on the Internet Service Provider's servers. Since connectivity speeds are high enough when using WiMAX, there is no need to host the MIS locally at the hospital. The MIS is developed as a web application that can be accessed by a common Internet browser. The staff at the hospital can browse the MIS, log in using their username and password and access patient's data.

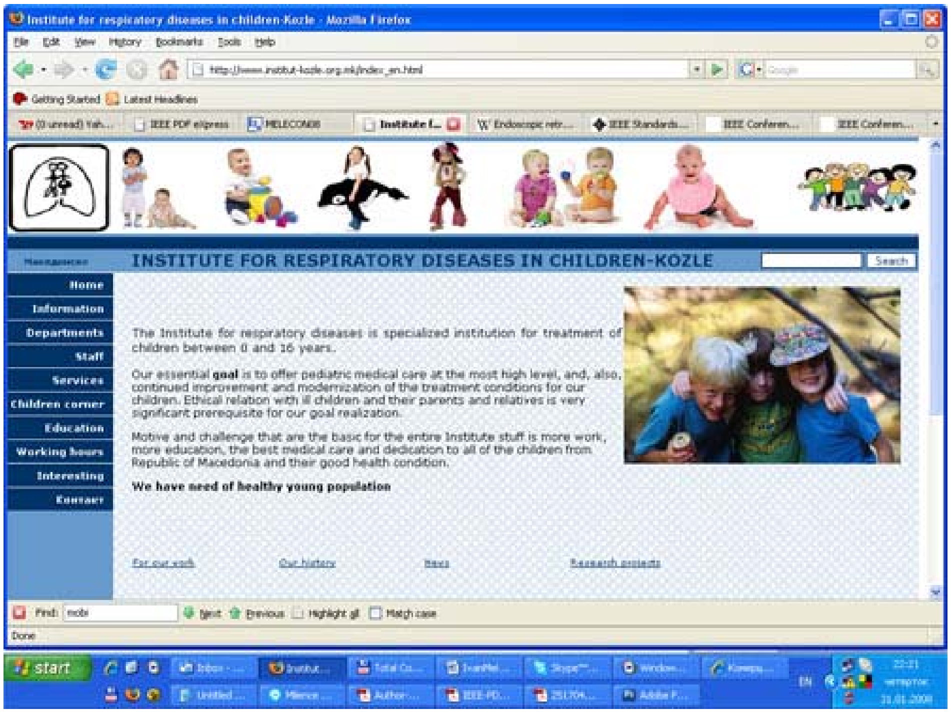

Fig. 4. The web based medical information system in the Institute for respiratory diseases in children-Kozle.

Querying data in the web based MIS is possible using multiple criteria. Data can be searched from other patients with similar symptoms in order to learn from other previous experiences. Entire patient history is accessible online, with strong regard to privacy issues. While patient identity details are available to the physician in charge of the particular case, for other medical personnel with lower access privileges, only medical information is available, without disclosing the identity of the particular patient.

A vital part of a telemedicine system is the sharing of knowledge, experience and expertise. The initial MIS includes a forum and a virtual chat room where physicians can consult each other. Since the children's hospital and the university hospital are connected to the same system, consultations are possible among physicians from both hospitals. The system has an Internet interface toward the outside world where advices can be gathered or given from and to physicians anywhere in the world.

The developed system includes software components specialized for use by PDA devices. Both patients and staff can wirelessly access different software modules. Physicians can access patient's data, results from laboratory analyses, forums and chats, web sites with medical scientific papers. Patients can access their results from different analyses, make appointments, and check the availability of certain physicians. We paid great attention to the usability of the user interface in the PDA applications. Due to the resolution and dimension limitations, significant effort was made to maximize the utilization of the given space on the small screens and to enable easy navigation through the user interface. We adopted a policy of gradual increase of details presented on demand, since scrolling and navigating large texts is unpleasant on a PDA device.

Initially telemedicine was defined as provision of medical services at remote locations without direct physical contact between the physician and the patient. Our system incorporates modules that enable laboratory results and other analyses to be submitted for review to the specialists. Physicians working in smaller towns could access the system using their accounts and could submit questions along with supporting materials electronically. Special web application software modules are developed for submitting images (MRI, X-Ray, CAT scan) from remote hospitals in the country to the specialist working in the capital. Also results from blood analysis are filled in online forms. Specialists review the results and can post their reply to the sender. This system enables reduction of transport costs, response times are drastically smaller and patients do not have to suffer through long trips to the specialist.

Video Streaming

Recent advances in broadband connection speeds have enabled high quality video telephony. In the context of telemedicine, we tested the use of wireless IP video telephony in communication of patients with hearing impairment. We used Leadtek IP broadband videophones (BVP8882). They use H.323 protocol for high performance and good quality video communication. The quality of the video stream was tested for the common sign language to be used and understandable by the communicating parties.

After establishing basic telemedicine functionalities within the capital – Skopje, the next step is connecting the Special Hospital for Orthopedics and Traumatology "St. Erazmo" in Ohrid, in south-western Macedonia. The hospital already operates one of the most advanced MIS in the country. One of the system challenges is integration of the current MIS in Ohrid with the newly developed in Skopje. However, with the use of XML and Web Services, helped by the fast connections of WiMAX, we expect excellent results. Since the hospital is situated about 170 km from the capital, Skopje, traveling is often a problem for patients in critical condition. We are testing streaming video through the WiMAX connections and the next step is to enable experts from Skopje to oversee complex surgical operations performed by the surgeons in Ohrid specializing in traumatology and orthopedics. Similarly, students at the University hospital in Skopje will be able to learn from the live feed from surgeries at the specialized hospital in Ohrid. On the opposite side, experts in the Ohrid hospital can offer advice to colleagues in Skopje over specific interventions performed only in Ohrid. Tested speeds promise high quality video.

We performed a video streaming experiment using a vehicle equipped with a WiMAX antenna and an MPEG coding device. We established a continual video stream that could be used to transmit live feed from the patient in the ambulance to the hospitals. The video link enables specialists to give advice to first aid workers on the scene of an accident, based on real time video feed from the patient's condition. Paramedics could be supervised by experienced medical personnel while performing necessary life support interventions. Due to current limitations of WiMAX, the ambulance must not move while being connected online. However new equipment based on Mobile WiMAX (802.16e-2005) is expected to overcome this issue. The equipment used in the experiment was SCOM MPEG-2 Digital Video Encoder/Decoder. The used WiMAX antennas support 2-10 Mbit/s. The particular experiment used 2 Mbit/s, but an acceptable video quality is achieved even with a 512 Kbit/s connection. Another experiment was conducted using a personal computer instead of a specialized MPEG coding device; however a noticeable delay was evident in the video stream. The later architecture is applicable for a smaller spectrum of services.

The small indoor antennas were also used for video telephony experiment. We tested a scenario where an older woman suffering from strong pain in the back and almost immobilized, had to communicate with her doctor for consultation. Since transportation of the patient was difficult and painful, we brought the WiMAX antennas and IP video phones at both locations (the patient's and doctor's) and established a video link that they used for consultation. We also used the video phones for establishing sign language communication for patients with impaired hearing. We used Leadtek IP broadband videophones (BVP8882). They use H.323 protocol for high performance and good quality video communication. The quality of the video stream using only 256 Kbit/s was sufficient for the common sign language to be used and understandable by the communicating parties.

The video signal that we used in most of the testing originated from a digital video camera. Another even more import feature is streaming of digitalized video signals received from analogous endoscopy equipment. We worked on digitalization of an analogous signal from a fluoroscopic camera using a Plextor MPEG encoder. The digital output from the encoder was easily streamed. The received live video could be used to consult subspecialists not present at the location where the exam is performed. Using VoIP and chat on PDA devices, the specialist could provide feedback and guidance to the person performing the exam in the field or in the remote hospital.

The implementation of the system consists of three main parts: the database, the online web applications and a standalone application that performs batch data processing and performs scheduled jobs and maintenance functionalities. Most of the applications are developed in Microsoft .NET technology, using SQL Server 2005 as a database engine. However, due to the system's modularity and the interconnections using platform independent web services, certain parts are coded in PHP and hosted on Apache servers using MySQL databases. Increased interaction and faster response times for the web applications is achieved with the use of AJAX. However, backward compatibility had to be taken in consideration due to the various older equipment found in different hospitals;

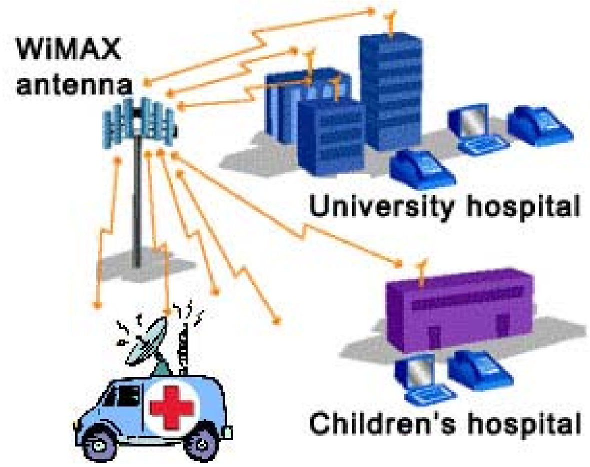

Fig. 5. The video streaming experiment.

Conclusion

Specific circumstances in the Republic of Macedonia enforce the use of wireless technologies for various applications. Modern wireless telecommunication technologies like WiMAX enable the provision of telemedicine services to places previously unreachable by landlines. New telecommunication technologies that emerge constantly and the development of software enable implementation of novel telemedicine services that were previously only imaginable. Web services and XML enable integration of various Medical Information Systems into an Integrated System for E-Medicine. High bandwidth and reliability of WiMAX helps the integration with bringing remote hospitals ever closer. Furthermore, new telemedicine services are implemented every day thanks to advances in technology.

Experiences gained in this project could be useful in countries or areas where conditions are similar. The mobility and quick deployment offered by wireless communications will help change our former views of the medical treatment in general, enabling high quality health service remotely and inexpensively.

References

- [Bashshur 2000] Bashshur R. L., Reardon T. G. , Shannon G. W., Telemedicine: A New Health Care Delivery System, Annual Review of Public Health, vol. 21, pp. 613-37, 2000.
- [Tulu 2005] Tulu B., Chatterjee S. A Taxonomy of Telemedicine Efforts with respect to Applications, Infrastructure, Delivery Tools, Type of Setting and Purpose. Proceedings of the 38th Hawaii International Conference on System Sciences, 2005, page 147.2.
- [Yamauchi 2004] Yamauchi K., Chen W., Wei D. 3G Mobile Phone Applications in Telemedicine - A Survey; Proceedings of the 2005 The Fifth International Conference on Computer and Information Technology (CIT'05). J. Mauricio Lach, Ricardo M. Vázquez. Simulation Model Of The Telemedicine Program, Proceedings of the 2004 Winter Simulation Conference, pages: 956 – 960
- [Zielinski 2006] Zielinski K., Duplaga M, Ingram D., Information Technology Solutions for Health Care, Health Informatics Series, Springer-Verlag, London Ltd 2006.
- [Olariu 2004] Olariu, S., Maly, K., Foudriat E.C., Yamany S.M. Wireless support for telemedicine in disaster management. ICPADS 2004. Proceedings. Tenth International Conference on Parallel and Distributed Systems (ICPADS 04). Volume , Issue , 7-9 July 2004, pages: 649 - 656
- [Fontelo 2005] Fontelo P., DiNino E., Johansen K., Khan A., Ackerman M. Virtual Microscopy: Potential Applications in Medical Education and Telemedicine in Countries with Developing Economies; Proc. of the 38th Hawaii Int. Conf. on System Sciences – 2005, pages: 153c - 153c.
- [IEEE 2004] IEEE 802.16-2004 Standard for Local and Metropolitan Area Networks Part 16: Air Interface to fixed and Mobile Broadband Wireless Access Systems, 2004.
- [IEEE 2005] IEEE 802.16-2005 Standard for Local and Metropolitan Area Networks Part 16: Air Interface to fixed and Mobile Broadband Wireless Access Systems,2005.
- [ETSI 2006] ETSI. Broadband Radio Access Networks (BRAN); HiperMAN; Data Link Control (DLC) layer, 2006.