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Building a Wireless Telemedicine Network within a WiMax based Networking Infrastructure

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***Abstract*— In this paper we propose an implementation of a WiMAX-based integrated system for e-medicine in the Republic of Macedonia. We present developed telemedicine multimedia services and their related QoS. We also present the problems and challenges for using a public wireless IP network for setting up the system.**

I. INTRODUCTION

The World Health Organisation (WHO) describes telemedicine as: "...Practising of medical care by using interactive audiovisual and data communication, including medical care, diagnosis, consultations and medical treatment, as well as education and transmission of medical data."[20] In shorthand, the term telemedicine can be defined as the application of medicine over distance. Although other descriptions of the term exist, this can be accepted as a solid base for further discussion.

In the past decade, technological developments have made the delivery of health services, including medical diagnosis and patient care possible from a distance. Consequently, wireless telemedicine has received high attention from health care providers and recipients, governments, industry, and researchers. As telemedicine has become a growing new interdisciplinary field it is expected to contribute to the improvement of health care quality for everyone. Nevertheless, although various ideas have been tested and implemented, the practical realization of telemedicine depends highly on advances in computing and networking techniques.

Due to the low bandwidth and high costs of previous wireless technologies, advanced telemedicine services could not be efficiently instigated. Since the deployment of second generation mobile networks (2G) and Global System for Mobile communication (GSM) researchers have been attempting to transmit medical data over wireless and mobile links, however with bandwidth limited to around 10Kbps for most applications. In recent years, 2.5G or General Package Radio Service (GPRS) has been used, followed by the current 3G and 3.5G High Speed Downlink Packet Access (HSDPA). Higher bandwidth has been achieved with WiFi 802.11, with the limitations of deployment to very short distances.

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Recently, the establishment of broadband wireless standards like WiMAX (IEEE 802.16) enabled implementation of telemedicine functionalities that were previously possible only with cable links. Wireless telemedicine is especially suitable for areas lacking proper cable connections or places where installing cable links is expensive, difficult, economically unviable or simply impossible. For instance, in cases of natural disasters [4], [13], installing wireless links is the only possible way to establish communication and provide sufficient medical services.

The result of the fast development in telecommunication technologies as well as the growing interest in telemedicine, has been the development and deployment of many telemedicine applications in the recent years [1],[2],[3],[4],[5],[7]. With various potential uses such as clinical, educational and administrative, telemedicine can bring high quality medical service to under-served areas.

In an example of how IT can reduce the cost and increase quality [9], telemedicine provides a solution to various problems such as: access to care for large segments of the population, reducing healthcare cost, bringing experience and expertise closer to patients and solving uneven geographic distribution of service quality. As a result it is possible to provide: coordinated and continuous care for patients, targeted and highly effective continuous education for providers, and highly effective tools for decision support.

Telemedicine is a specific field where different services need varied and often extremely high levels of reliability and robustness. Therefore the applied communication technology must support different QoS guarantees. For example, wireless telemedicine/eHealth applications may require transmission of huge volume of non-real-time diagnostic data (e.g., images) and real-time video or audio data simultaneously. Several QoS parameters (like throughput, timeliness, reliability, security, and cost) must be taken into account when designing an integrated system for E-Medicine. QoS support should be provided in different mobility scenarios (e.g., in a mobile ambulance environment as well as in a static in-hospital environment). High-speed wireless transmission with QoS support would be required for video and voice communications between injured patients and physicians during prehospital service. Any transmission of real time diagnostic multimedia data must be efficient and its quality must be constant and guarantee.

As this paper proposes an implementation of a WiMAX-based integrated system for e-medicine it is organized as follows: After the introduction in section 1, a short overview of the work by other authors is presented in section 2. A short overview of the WiMax IEEE 802.16 standard is given in section 3, followed by a description of the network infrastructure we used in the project, in section 4. Section 5 presents our implementation of the QoS requirements in the telemedicine system under development. An overview of our medical information system is given in section 6 and the developed multimedia services in our system are presented in section 7, followed by the concluding remarks in section 8.

II. Recent Work

The authors in [15] present the architecture and implementation of telemedicine via Internet for heart sounds and hearing screening diagnosis. Web-based application are used as a medium for interaction between patients and doctors as several wireless telemedicine multimedia services are presented in [2], [5], [6], [7], [9], [16] and [19]. As it is essential to provide sufficient QoS required by real time traffic such as interactive video and audio applications when commercial IP based networks are used for telemedicine systems, the authors in [14] analyse the quality of service requirements for a typical rural telemedicine applications and then propose proper scheduling, traffic engineering and fast-rerouting as mechanisms that can compensate for IP's best effort debilities. Authors in [17] and [18] present a QoS framework for telemedicine applications.

III. The IEEE 802.16 Standard and its QoS

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).

The ETSI HiperMAN [12] 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.

When building telemedicine functionalities, the quality of service (QoS) of the communication is essential, especially in critical services like life video streaming of surgeries or other diagnostic signals. The IEEE 802.16 standard includes features like integrated QoS and mobility support. The IEEE 802.16-2004 (also known as IEEE 802.16d) [10] and IEEE 802.16e are the most popular versions of the standard. The standards define several 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 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) for web browsing applications.

In the IEEE 802.16 QoS model, each packet contains a 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.

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 neighbours 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.

IV. Wireless Infrastructure

A WiMAX network is used as a basis for our telemedicine services due to the specific circumstances in the Republic of Macedonia. There are several state-wide backbone networks operated by various data communication providers in the Republic of Macedonia. 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 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, while the WiMAX antennas are used for connecting hospitals where there is no fiber optic connections. At the end, service point 802.11 hotspots are used for wireless devices such as PDAs, notebook PCs etc. Although there are other providers in the country with a complete fiber optic backbone network throughout the country, due to lower costs of WiMAX based systems and additional advantages explained in the following sections of this paper we decided to use the network in question.

Within the city limits of the capital, Skopje, there is a functional fiber optic Metro Ethernet network. Hospitals in the city are or will soon be connected to this network. The fiber optic 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 are utilized as backup in case of disrupted cable communication. While cables can be physically cut, the WiMAX connections are stable even in severe weather conditions.

Since a wireless backbone network is established throughout the country, 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. The geographical distribution of hospitals in the country is presented in Figure 2.

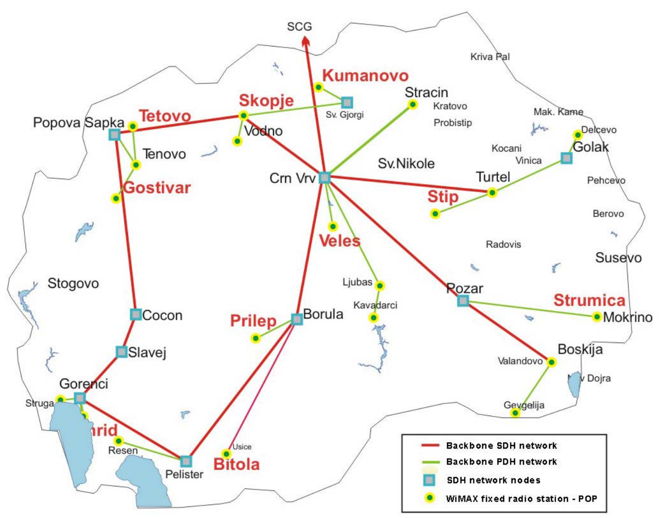

Fig. 1. Scheme of the wireless backbone network in the Republic of Macedonia

Within the hospital premises, a process of placement of Wi-Fi access points is under way. The wireless connectivity should be used by both medical personnel and patients.

Fig. 2. Distribution of hospitals in towns across the Republic of Macedonia

The WiMAX infrastructure is developed mostly with products from Alvarion, especially the BreezeMax product line. The network also includes devices from Cisco and Alcatel. BreezeMAX supports a wide range of network services, including Internet access (via IP or PPPoE tunneling), VPNs and Voice over IP. BreezeMAX also 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. The required bandwidth depends on several parameters, such as codec type, sample rate and T.38 Fax Relay support.

V. Implemented QoS Requirements

Our wireless health care network consists of entities linked via the public WiMAX network. Sharing the network with other subscribers can have negative impact on the transmission of medical data. For instance, if the network is congested, the chances of packet dropping, delay, and reductions in the bandwidth can increase. Therefore strict QoS requirements had to be implemented for every multimedia service build into the system.

Based on the options provided by the used technology, we created 5 different service profiles, with various levels of priority. We distributed our multimedia services in the 5 groups according to the estimated priority for each service. The highest priority is given to services with live video and audio streaming of diagnostic data (teleconsultations). The lowest priority is given to the common use of the Internet for browsing medical scientific papers and various online chat rooms for delayed written consultations. The three middle levels of priority are given to various services performing uploads and downloads of multimedia diagnostic material (images of X-Ray, MRI, Ultra sound and similar content).

Furthermore, VoIP conversations are classified in two groups: medical consultations and common business communication, giving a higher priority to medical consultations. Separate IP phones are used for both tasks. The necessary data exchanges for non-urgent cases are mainly scheduled and performed at night when the IP traffic is minimal and the probability of causing congestion is small. Some of the typical transmission data rates required by telemedicine devices are presented in Table 1.

Other concerns about the use of public mobile networks for health care applications are security and authentication issues. These issues were avoided by using tunnelling mechanisms, i.e., establishing VPNs, as VPNs have been used traditionally in wire line networking technologies. Currently, VPN is widely used over the Internet, allowing reliable, secure remote access to the users of private networks. In the case of wireless networks, mobile VPNs (MVPNs) can be used to add extra immunity to the links.

TABLE I
SOME TYPICAL DATA RATES REQUIRED BY TELEMEDICINE DEVICES [21]

Device	Required Data Rate
Digital blood pressure monitor	<10 kbps
Digital thermometer	<10 kbps
Digital audio stethoscope with ECG	<10 kbps
Ultrasound	256 kb per image
MRI	384 kb per image
Scanned x-ray	1.8 Mb per image
Digital radiography	6 Mb per image
Mammogram	24 Mb per image
Compressed and full motion video	384 - 1544 kbps

The classification of multimedia services in different priority levels brought sufficient quality for appropriate tasks. The scheduling of non urgent communication and processing freed resources for urgent operations which often emerge in medical systems. The strain on the equipment was uniformly distributed.

VI. IMPLEMENTED INFORMATION SYSTEM FUNCTIONALITIES

Implementation of telemedicine services is a lengthy and continuous process. In the initial stages of implementation two hospitals were included in the pilot project: The Institute for Respiratory Diseases in Children – Kozle and the University Clinical Centre in Skopje. Due to the lack of a modern Medical Information Systems (MIS) in the hospitals, the project started with essential activities. We developed the initial Web based MIS to be used by the staff at the Institute for Respiratory Diseases in Children. 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. The homepage of the web application is presented in Figure 3. As the hospital cannot afford to maintain an IT department, the MIS is hosted on the Internet Service Provider's (ISP) servers. Since WiMAX connectivity speeds are high, there is no practical need to host the MIS locally at the hospital.

Fig. 3. 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 previous experiences. The 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 with the identity of the particular patient remaining undisclosed.

A vital part of a telemedicine system is the sharing of knowledge, experience and expertise. The implemented MIS includes a forum and a virtual chat room where physicians participate in mutual consultations. Since the children's hospital and the university hospital are connected to the same system, consultations are possible among physicians from both hospitals. Furthermore, the system has Internet access allowing for advices to be gathered or given to physicians anywhere in the world. A schematic overview of the wireless information system is given in Figure 4.

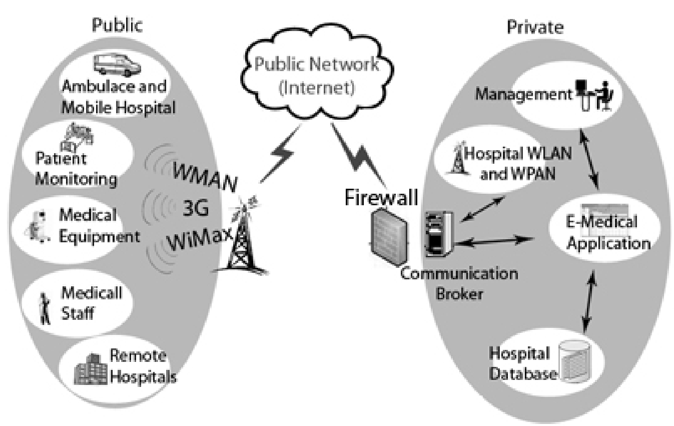

Fig. 4. A schematic overview of the wireless information system

The developed system includes software components specialized for PDA use. Both patients and staff have wireless access to different software modules. Physicians can access patient's data, results from laboratory analyses, forums, chats and 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. We adopted a policy of gradual increase of details presented on demand, since scrolling and navigating large texts is unpleasant on a PDA device.

The system includes a Short Message Service (SMS) gateway that is used for SMS notifications for both physicians and patients. Current functionalities include confirmation of appointments for patients, notification for completed laboratory analyses, SMS emergency calls for physicians, notification for the upcoming time for therapy etc.

Decision support systems are key components of contemporary MISs. Therefore we included a web based medical diagnostic expert system that performs self training using a heuristic rule induction algorithm that we developed - SA Tabu Miner [22]. The data inserted by medical personnel while using the e-medicine system is subsequently used for additional machine learning.

VII. Implemented Multimedia Services

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 can access the system using their accounts and can 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. We introduced a system of grading each submitted material giving it different priority according to the contents and level of urgency demanded by the sender. Extremely urgent submissions can even cause the SMS gateway to notify the specialist for the incoming request.

The next step is connecting the Special Hospital for Orthopaedics 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 will be 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, initial results are promising. Since the hospital is situated about 170 km from the capital, Skopje, travelling is often a problem for patients in critical condition. We already tested 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 orthopaedics. 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 (Figure 5). 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. 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. 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.

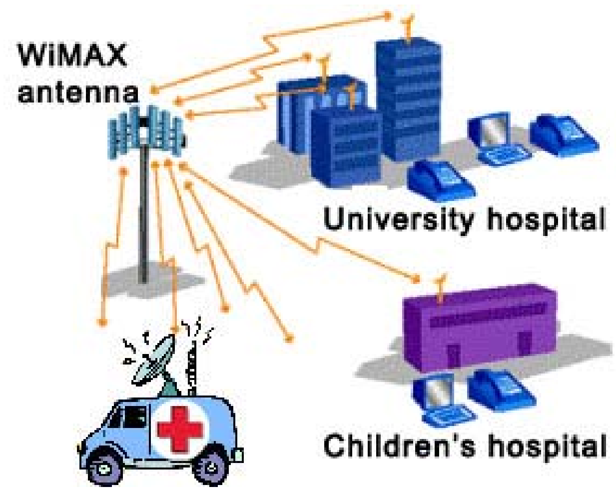

Fig. 5. Schematic view of the video streaming experiment

VIII. Conclusion

Modern wireless telecommunication technologies like WiMAX enable the provision of telemedicine services to previously unreachable places. On the other hand, web services and XML enable the integration of various geographically distributed Medical Information Systems into an Integrated System for E-Medicine. Since implementation of a nationwide network solely for e-medicine purposes is economically unviable, the only solution is the use of existing commercial networks. The use of an existing commercial telecommunication network for sensitive and demanding telemedicine services comes with several challenges regarding the quality of service and even more important - security. In this paper we presented the development of an integrated system for e-medicine, explained our approaches to meet the arising challenges and defined solutions for the problems inherent to the given network infrastructure.

Experiences gained in this project could be useful in countries or areas with similar geographical and/or economical conditions. Similar to telemedicine, other systems might also need to be implemented over existing commercial networks, and the presented experiences might provide the initial guide toward implementation and the expected challenges.

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