Secure Multimedia Streaming over Wireless Ad-Hoc Networks for Telehealth Systems

Bernhard Hohmann
Graz University of Technology
Institute for Technical Informatics
Inffeldgasse 16, 8010 Graz, Austria
hohmann@iti.tugraz.at

Mérouane Debbah
Institut Eurecom
Mobile Communications Group
2229 Route des Cretes, B.P. 193, 06904 Sophia Antipolis Cedex, France
merouane.debbah@eurecom.fr

Christian Leistner
Graz University of Technology
Institute for Computer Graphics and Vision
Inffeldgasse 16, 8010 Graz, Austria
leistner@icg.tugraz.at

Andreas Kröpfl
Zydacron GmbH
Teslastrasse 4, 8074 Grambach, Austria
A.Kroepfl@zydacron.com

Abstract: In this paper we give a detailed state-of-the-art review for the design and implementation of embedded wireless ad-hoc systems as they are applied for multimedia data transmission. More precisely, this paper focuses on eHealth applications with specific quality of service (QoS) constraints which have to be treated differently compared to other, already standardized systems. Different techniques to secure as well as enhance the reliability of the transmission will be discussed.

Furthermore, we present the design of an embedded interactive system for distributed multimedia processing for telehealth. In this interactive home care system, speech recognition is used to enable easy user control. Additionally, the system consists of several wireless network cameras to perform full indoor patient surveillance.[1]

1 Introduction

In recent years telehealth systems have become more and more important and will gain further attention in the future. This is the case for example in the western world where

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the population is aging and telehealth can provide a cheap alternative to traditional care solutions. Such telehealth systems already find application in hospitals [bARCAF05] and home care environments [KTA06], [WXO$^+$06].
In general, it is hard to deploy proper infrastructures due to financial reasons or time constraints. Wireless systems provide, from this point of view, interesting features. Especially ad-hoc networks can be deployed easily and fast. This leads to higher flexibility and offers higher reliability because data packets can be easily transmitted over different routes if some nodes fail. Additionally, there is no need for further networking hardware, e.g. access points.
With increasing computational power and reduced hardware costs, embedded systems are gaining attention in modern industrial applications. Such systems are cheaper and more flexible due to their small size compared to standard PC systems. However, most embedded systems provide limited system resources such as memory, computational power and energy, i.e. battery powered systems. Therefore, there has to be more emphasis on a lightweight system design.
Interaction is an other important issue in telehealth systems. It must be possible to interactively communicate with the patient and vice versa. Speech recognition might enable new possibilities in interaction, e.g., speech-to-text for deaf persons or for controlling a local telehealth system.
To meet these demands for telehealth while still employing ad-hoc networking multi-route streaming or network coding techniques can be employed to enhance the reliability of the received signals. The remainder of this paper is organized as follows: In Section 2 we will give a detailed overview of the current state-of-the-art in the field of multimedia data transmission in wireless ad-hoc networks. Additionally, we focus on telehealth applications and their special demands such as data reliability and security. The conclusions of Section 2 are presented and merged in Section 3, where we present our system design proposal and platform for future interactive telehealth systems. Finally, we will conclude this paper in Section 4.

2 State-of-the-Art and Related Work

In order to transmit reliable and confidential data over mobile wireless ad-hoc networks (MANETs, Mobile Ad-hoc Networks), many features have to be considered. The design depends heavily on the type of traffic to be considered (audio, video) and will therefore guide us in the selection of the protocol. In our system audio and video will be routed from several carestations to a central carestation, connected to the internet. In Section 2.1 an overview of the most important protocols for MANETs is given. Succeeding, in Section 2.2 issues such as QoS, rate control, multi path or cross-layer transmission are discussed. Finally, in Section 2.3 security issues are addressed and in Section 2.4 a presentation of current telehealth systems is given.

2.1 Protocols

For mobile ad-hoc networks, many routing protocols exist. The most popular protocols, however, are AODV, DSR, DSDV and OLSR. In general MANET protocols can be divided into two groups, namely proactive and reactive. Proactive are table driven e.g. OLSR or DSDV and reactive are on-demand e.g. AODV or DSR.

In practice, however, very little testing has been performed on real MANETs. Most research is on very special and sometimes unrealistic cases. Networks with hundreds of nodes which are moving at very high speeds are examined and therefore only tested with software simulators e.g. ns-2 [NS2]. The problem of unrealistic simulations is addressed by Feeley et al. in [FHR04]. According to them, the first problem is that most of the time, the random walk model is used although humans usually do not just randomly walk. The second problem is that often random speeds with a very high maximum value are used. However, typically one wants to simulate situations where humans either walk or bike. In their paper, a generator for realistic scenarios which can be used in e.g. ns-2 is presented. Furthermore, no practical implementation for everyday use for the average user is yet available. Additionally, as stated by Tschudin et al. [TGLN05], the advantages of current ad-hoc technology vanish beyond 10-20 nodes and three hops. However, for specialized networks these numbers might be higher. In 2004 the IETF MANET working group, proposed four protocols for experimental RFC status, namely AODV, DSR, OLSR and TBRPF. In [TGLN05], intense testing in real MANETs was performed. The tested protocols were OLSR, LUNAR [TGRW04] and AODV. LUNAR, in particular, is described in Section 2.2. In order to test them, APE (Ad-hoc Protocol Evaluation) was developed. It was shown that AODV performs poor above 2 hops and 11 nodes when using TCP. Other experiments showed the inaccuracy of some simulations, e.g., the gray zone problem or how implementations based on simulations fail in the real world. Another comparison of AODV and OLSR [Bor05] based on indoor and outdoor testing, showed that OLSR outperforms AODV in terms of response time and packet delivery at just a small protocol overhead. Another ns-2 based comparison of AODV, DSR and DSDV can be found in [CPP04]. It states that none of the three protocols is suited for MPEG-4 [MPE] streaming in highly mobile ad-hoc networks. However, the speeds chosen are very high. Two secure implementations of AODV are discussed in Section 2.3. Concluding our discussion about protocols, OLSR performs well in most cases e.g. multimedia and LUNAR might be a good lightweight solution to consider.

2.2 Improved Transmission

As in multimedia streaming much data has to be transfered over the network, bandwidth is limited and links may break, it is necessary to employ improved transmission techniques. Especially when it comes to telemedicine where lives may be at risk.

QoS plays an important role here. There is much research going on in that field e.g. in [CCMM05] different QoS algorithms are presented which are based on 802.11e [IEE]. However, only simulations have been performed, using ns-2. Another example is [ZCF06]

where a novel call administration and rate control scheme is proposed. The call administration regulates the real-time and streaming traffic whereas the rate control fills the rest of the channel capacity with the best effort traffic. It is based on DCF (Distributed Coordination Function), the standard access mode of 802.11 and thus does not require special hardware. However, again just ns-2 simulations have been performed.
As already pointed out in [TGLN05] it is hard to clearly separate link, network and transport layer in MANETs. There are many different cross-layer approaches proposed to perform e.g. rate control. However, they involve the danger, of implementing specific solutions which just work with certain technologies. In [YSZ+04] a cross-layer approach is proposed. This approach goes down to the physical layer where transmission rates are adjusted according to adaptive link layer techniques. Furthermore, the link's energy efficiency is considered in contrast to the ordinary fixed capacity scheme. Simulations were performed using ns-2. In [SAB04] a combined routing and MAC protocol for MANETs is proposed. It is based on geographic routing and chooses in a multi hop scenario the node with the shortest time-to-respond for relaying packets. However, in this work just the constraints of the physical layer and delay are analyzed.
In [TGRW04] the LUNAR (Lightweight Underlay Network Ad-hoc Routing) protocol is presented. It is suited between layer 2 and 3 at the underlay layer 2.5. It presents itself as a network interface attached to a LAN and makes all nodes in the LUNAR network appear to be one IP hop away. It is very simple and aimed on network sizes of 10-15 nodes and 3 hops. Furthermore, it is multi platform and there exist many versions for e.g Linux, Windows or embedded systems. As stated in [LJ06] schemes for multimedia data delivery in wired networks, below the application layer can not be used without modification in wireless networks due to time constraints, fairness problems and unstable links. In their work a hop-by-hop rate control algorithm for maximizing the throughput and fairness is proposed. Furthermore, it is a cross-layer design which operates at transport and MAC layer. In simulations they showed the good performance of their algorithm. Another cross-layer rate adaption scheme is proposed in [QPM+05]. Again just simulations are performed.
The topology of MANETs opens the possibility of using multi path transmission. This is especially interesting for multimedia streaming applications where multiple routes can fight interruption and allow higher data rates. However, there is the danger of bottleneck connections which limit the transmission to a single path. In [RYZ+05] AMTP, a protocol for such an approach is proposed. Furthermore, they state that in MANETs the different reasons for packet loss, i.e. congestion, transmission errors or change/break of routes, should be treated suitably. AMTP tries to accomplish all that and furthermore to find maximally disjointed paths. It was compared against two other rate controlled streaming protocols and performed well in most cases. However, in case of a bottleneck route, signaling overhead yields worse performance. Simulations have been performed using ns-2. Another approach to multi path streaming can be found in [MLW+05] where the advantages of multi path streaming were not only showed by simulations but also tests in a real 4 node ad-hoc network were performed.
Furthermore, in [ACLY00] network coding is proposed to utilize transmission channels more efficiently and enhance reliability. In order to achieve more reliability the traffic can be routed over several different routes.

2.3 Security

In wireless networks security is an important issue. In the realm of wireless transmissions, everybody can listen to the communication as well as insert fake packets. Especially in telehealth systems where fake data could trigger or prevent the triggering of an alarm, this has to be considered. Furthermore, privacy is another concern which has to be treated carefully. In [YLSC05] a secure video surveillance system is proposed. The system is based on the SAODV [GZ06] routing protocol, a secure version of the above mentioned AODV protocol. A lightweight encryption scheme along with watermarks containing encryption keys is applied. Neighbors' authentication is also performed to reduce the risk of e.g. man-in-the-middle attacks. As well, a key distribution scheme is proposed. Tests showed satisfactory results using a MPEG-4 encoded video stream with a resolution of 640x480 at 20fps. However, tests were not performed in large scale wireless networks. Problems might occur if network traffic converges in nodes at key positions.

An alternative to the SAODV routing protocol, which is also based on AODV, the Token Routing Protocol (TRP), is proposed in [LC06]. It employs the hash algorithm instead of public key cryptography used in SAODV. That way it reduces power consumption and delay while still providing comparable security. However, the supremacy of TRP over SAODV results from the chosen model as the comparison is just performed in ns-2. Furthermore, it is stated that in a very stable topology energy efficiency might be worsened due to the extra overhead of this approach.

In [SK05] a QoS analysis is performed to analyze the impact of using WEP security in 802.11b. The main result is that WEP increases the delay significantly and that the QoS degradation is a nonlinear function of the packet sizes of each user stream and the number of users attached.

2.4 Telehealth

There is intense research going on in the field of telehealth. In [KTA06] a fall detection based on a user badge with accelerometers and video analysis is proposed. The work is based on [TKA06] where parts are described in more detail. If the accelerometers indicate a fall, the system tries to locate the user employing signal strength analysis. This triggers the video analysis. A posture and head detection are performed and fed into a reasoning module which then decides if the person really has fallen or not. In case of a fall a telephone connection between the user badge and a third party is initiated. Multi frame analysis of the body centroid is also discussed in the paper.

A system purely based on video analysis is presented in [WXO+06]. The system relies on hardwired infrastructure. It performs fall detection and implements an object finder application. Both tasks are based on machine learning algorithms. If an alert is triggered, a video call between one of the terminals located in each room and a third party is initiated.

In [HHW+06] Husni et al. describe a telemedicine system based upon mobile ad-hoc networking. The proposed network design employs the AODV+ routing protocol, an extension of AODV. Three VoIP codecs are tested using ns-2. Furthermore, mobile IPv6 is proposed as underlying network address scheme. A real-time medical data acquisition system employing wireless ad-hoc networking is presented in [bARCAF05]. As underlying protocol, AODV is used.

3 System Design

As already discussed in Section 2 there are many things to consider when designing a telehealth system and there exist a great variety of different methods. Our approach, however, differs from others in (i) that we employ ad-hoc wireless connectivity on an embedded system and (ii) take care of the special demands needed for multimedia data transmission with respect to telehealth applications employing speech recognition.
The proposed system design is split into three parts: how speech recognition could help to improve such systems, the embedded carestation design and the network system topology.

3.1 Speech Recognition in Telehealth

In order to improve their usability and performance, telehealth systems should especially be designed to additionally perform audio processing and speech recognition tasks. For better usability, telehealth systems should be able to be controlled by voice messages, which is even more important for handicapped persons. The necessary speech recognition algorithms, such as neural or baysian networks, are very sensitive to data outliers and false transmissions. Additionally, attached medical devices as e.g. electronic stethoscopes [bARCAF05] or ECGs rely on highly accurate data. Therefore, audio data has to be transmitted in a very reliable way. Scream recognition adds another safety feature to telehealth systems without handicapping persons with physical devices.

3.2 Embedded Carestation

The embedded carestation is the key component of our telehealth system. Figure 1 presents the prototype of the carestation. The corresponding block diagram is shown in Figure 2. The hardware design is based on Texas Instruments^{TM} DaVinci TMS320DM6446 Chip set. The chip set consists of an integrated ARM9 core running Monta Vista^{TM} embedded Linux, suitable for basic operating systems and networking tasks, and a signal processor running at 600MHz which is responsible for high level audio and video processing.
The carestation is designed to be an interactive speech and video terminal which is additionally able to perform basic video and audio processing tasks. Especially, we aim to implement automatic fall detection algorithms based on multi-camera data combined with scream detection. Therefore, and due to the work of [WXO^{+}06] where a minimum resolution of 128x128 for fall detection and 320x240 for object detection is suggested, we run the system at 352x288 CIF resolution. The embedded platform features several different

I/0 ports, among them six USB ports. Therefore, the 802.11g wireless card is connected on one of the internal USB ports.

Figure 1: Prototype of the Embedded Carestation.

3.3 System Topology

The system design proposed in this paper combines all aspects discussed above. It is based on a wireless network of several AXIS 207W wireless network cameras and one or more carestations. A group of cameras surveying one area e.g. a single room or place, is connected to one carestation in infrastructure mode forming one care group (CG). The communication between the carestations is performed in ad-hoc mode to be more flexible and reliable. One carestation is connected to the internet via e.g. an ADSL connection. Each carestation is equipped with a microphone, speaker and monitor for user interaction. At least one microphone per CG which must be capable of covering the whole CG area has to be installed. The carestations receive video data from the cameras of their CG. They then process the received data and take action if needed. An overview of the proposed system design is illustrated in Figure 3.3. For the ad-hoc connection we use the OLSR protocol which, compared to other standard protocols, has the advantages to be well proven in practice and suitable for audio data transmission. Additionally, we employ network coding

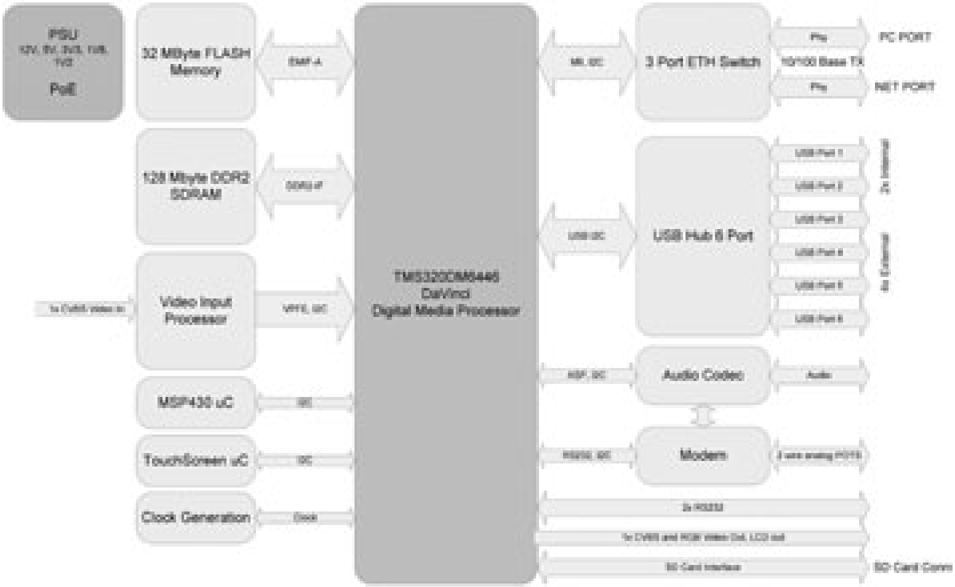

Figure 2: Embedded Carestation Platform Block Diagram.

type algorithms, e.g. [ACLY00], to reduce useless redundancies in diversity techniques while still being able to retrieve data in none reliable links to employ multi-path routing. Communication within the CGs is secured with HTTPS, the communication between the carestations is secured with AES which is a substantial part of the DaVinci platform.

In our proposal there are some important improvements over the above discussed systems, e.g. in contrast to [KTA06] no user badge has to be worn by the person. In our system, fall detection based on video analysis is performed. The microphones installed in each room of the monitored place, provide an additional alternative to detect a fall of a person. Most times a person falls, it will scream, which will be recorded by the microphones and detected by the carestation. Another advantage of our system is that it is based on a wireless ad-hoc network and does not use a fixed wired network infrastructure. In case of a detected fall a local alarm would be triggered and the person would have a certain time to disable an extern alarm. The extern alarm would then contact a third party and initiate a video call. However, the carestations are not only the central processing nodes of this wireless camera network, they also provide the possibility of remote medical check sessions with doctors especially, as it is possible to attach medical devices as e.g. electronic stethoscopes or ECGs. The user interface of the carestation works with speech recognition to improve usability especially for handicapped persons. Furthermore, it is possible to link certain data to key words. More precisely a person can store all information about its doctor in the system and then recall it by simply saying the key word ”doctor”.

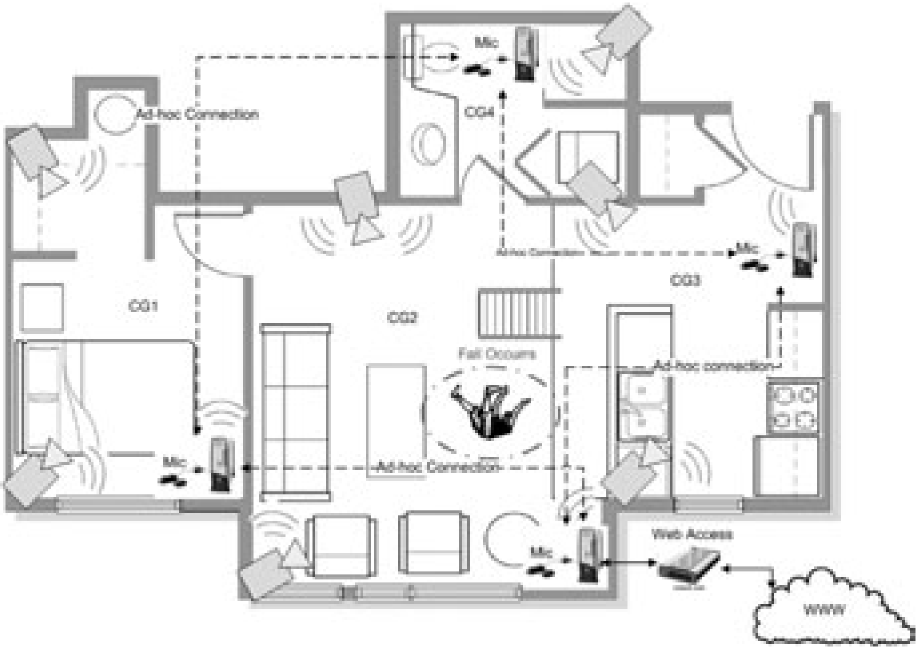

Figure 3: System Design.

4 Conclusion and Future Work

In this paper we gave a review of current state-of-the-art systems and protocols for wireless ad-hoc networks and presented a novel system design for modern embedded telehealth systems. Additionally, we presented an embedded multimedia platform (Zydacron carestation) based on Texas Instruments^{TM} DaVinci technology as the central part of our system. All wireless data transmissions in the system are secured by employing HTTPS and AES. For the ad-hoc part of the network, the well known OLSR protocol is used. To improve data reliability and to reduce useless redundancies, we proposed to employ network coding type algorithms. Future work will be concentrated on further system improvements and the development of vision and multimedia data fusion algorithms which will be ported onto the embedded platform.

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