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Abstract

The first hour following the trauma is of crucial importance in trauma care. The sooner treatment begins, the better the ultimate outcome for the patient. Generally the initial treatment is handled by paramedical personnel arriving at the site of the accident with an ambulance. There is evidence to show that if the expertise of the on-site paramedic team can be supported by immediate and continuous access to and communication with the expert medical team at the hospital, patient outcomes can be improved.

After care also influences the ultimate recovery of the patient. After-treatment follow up often occurs in-hospital in spite of the fact that care at home can offer more advantages and can accelerate recovery.

Based on emerging and future wireless communication technologies, in a previous paper [1] we presented an initial vision of two future healthcare settings, supported by applications which we call *Virtual Trauma Team* and *Virtual Homecare Team*.

The Virtual Trauma Team application involves high quality wireless multimedia communications between ambulance paramedics and the hospital facilitated by paramedic *Body Area Networks* (BANs) [2] and an ambulance-based *Vehicle Area Network* (VAN). The VAN supports bi-directional streaming audio and video communication between the ambulance and the hospital even when moving at speed. The clinical motivation for Virtual Trauma Team is to increase survival rates in trauma care.

The Virtual Homecare Team application enables homecare coordinated by home nursing services and supported by the patient's PAN which consists of a patient BAN in combination with an ambient intelligent home environment. The homecare PAN provides intelligent monitoring and support functions and the possibility to ad hoc network to the visiting health professionals' own BANs as well as high quality multimedia communication links to remote members of the virtual team. The motivation for Virtual Homecare Team is to improve quality of life and independence for patients by supporting care at home; the economic motivation is to replace expensive hospital-based care with homecare by virtual teams using wireless technology to support the patient and the carers.

In this paper we develop the vision further and focus in particular on the concepts of personal and body area networks.

Key words

Healthcare, wireless, broadband, video, trauma, homecare.

1. Introduction

Accidents Happen. It is an unfortunate fact of life that the majority of accidents happen inconveniently not only outside of hospitals but also quite far from them and at random hours. The first treatment received by the trauma victim is usually administered by paramedics who are specifically trained to perform emergency first aid treatment at the accident site in those vital first moments.

Paramedics must usually perform these (life-saving) interventions in the absence of all the relevant medical knowledge and the specific patient information required to give optimal treatment to each individual accident case. Normally communication between the paramedics and the hospital is limited to a brief report (eg. via two-way radio or cell phone) from the paramedics to hospital administrative staff giving basic information about the casualty's injuries and condition and their ETA. In certain circumstances, for example in very serious accidents or where a patient is trapped, the patient must be treated (possibly even operated) at the scene, and a mobile trauma team (a traumatologist and an anaesthetist) are dispatched to the scene. In the interim the paramedics may also be in direct (audio) contact with hospital medical staff. In these cases the on-site paramedics need to administer first-aid, communicate with the medical base, exchanginging information orally and wait for the mobile trauma team to arrive. Any delay means that precious minutes are lost, vital information might not be communicated and it is difficult for the hospital-based medical specialists to follow the rapid evolution of the casualty.

The situation becomes more complicated when the accident involves more than one victim, each of whom needs special treatment (for example at the site of a fire, one victim might be suffering burns, another fractures and a third may be suffering from smoke inhalation). Where there is more than one casualty a separate trauma team is dispatched to attend each patient. Air ambulances may also be deployed to deliver members of the mobile trauma team an and/or to transport patients to the hospital. Coordination between several on-site trauma teams and the trauma unit and trauma theatre in the hospital is vital. Problems of communication and coordination are scaled up in the case of major accidents and disaster scenarios, where a large number of emergency teams from different emergency services, and possibly more than one receiving hospital, are involved. This was the case with the disaster in Enschede in May 2000, when nearly 1000 casualties were treated, some in the regional trauma centre in Enschede (Medisch Spectrum Twente) and others in other hospitals including trauma centres across the border in Germany. After the event, the evaluation showed that the biggest problem for the medical services was communication and coordination between the teams involved [3].

A solution commonly employed in complex accident situations is to equip paramedics with a wireless headset communications device [4]. Although this solution greatly improves coordination and communication between the on-site and on-base medical teams, emerging technologies can offer more that just audio communication. A number of trials using (limited) visual (audio/video) communication between ambulances and hospital have already been conducted (eg. [5], [6]). However current wireless technologies do not yet support high quality real time streaming video from fast moving vehicles. Nevertheless the use of even limited visual communication (eg slow scan video, short video segments, with 10 or 15 seconds end-to-end delay) [7], has shown the value of visual information conveyed to hospital medical staff in aiding early diagnosis and enabling early administration of drug therapy. Reduction of morbidity in ischaemic stroke patients was demonstrated in trials [8]. Future advances in wireless broadband technologies, supporting seamless high quality multimedia communication, promise a further evolution such that remote members of the (virtual) trauma team (whether based at the hospital or while in transit to the scene) can be fully and continuously involved in the treatment of the patient by means of telepresence from the first moment that the paramedics reach the patient. We envisage the on-site paramedics relaying not only audio but also video, vital signs and test results, and receiving the EMR, with telepresence further enhanced by the use of virtual or augmented reality systems.

Homecare is another area where emerging technologies can offer dramatic improvements in quality of care. It is a well established fact that, due to the psychological effect of being in a familiar environment, long term patients in homecare have a better chance of recovery than long term hospital patients. Furthermore the cost per day of care at home is a fraction of that of a hospital stay.

One current development is to separate 'hoteling' and nursing functions from core hospital medical functions by providing rehabilitation care in *Care Hotels*. A further step is to provide comprehensive services and functions in the patient's own home (which could be a private home or, for example, sheltered housing).

There are a number of demonstration projects involving *smart homes* for the elderly or for people with health problems, providing for example assistive technologies and aids such as video-intercom systems and motion sensors for lighting control [9], emergency buttons for elderly and disabled, and pulse monitoring. However due to the need for continuous observation of the patient's vital signs and control of his environment, homecare treatment is currently restricted to patients in a relatively stable condition.

One trial involving home-based management of tuberculosis patients, coordinated by nurses equipped with mobile devices and wireless communications, proved to be a successful alternative to detention of persistently non-compliant patients in secure hospitals [10], [11]. Another trial involving virtual medical teams coordinated by nurses and facilitated by wireless communications involves homecare for cancer patients [12]. In future we envisage more patients (and patients with acute conditions) being cared for at home by virtual homecare teams supported by intelligent care systems based on wireless and nano technologies, body area networks and ambient intelligent environments.

2. The Application Scenario

The following fictional application scenario illustrates the applications. The 'chain of care' begins in the community with the emergency services attending a road accident. The patient is treated at the scene of the accident by the ambulance paramedics assisted by telepresent members of the Virtual Trauma Team, is taken to hospital where he receives treatment and later returns home to continuing support centered on the home.

While driving in the country Vic loses concentration and collides with a tree. His smart car detects the collision and calls an ambulance. On reaching the scene the paramedics begin to treat the patient and they also identify him using biometric techniques. Once identified they can call up Vic's EMR to check the history, problem list, current medication and any drug allergies or sensitivities. The paramedics are at the same time talking to the specialist in the hospital emergency room (ER), who can see and hear what is going on. The paramedic is wearing a trauma team BAN which includes a video camera, an audio system and a wireless communications link to the ambulance network. The ambulance network (a Vehicle Area Network or VAN) relays the audio and video to the hospital via wireless links so that the hospital specialists can view and talk to the patient and talk to the paramedics. At the same time sensors monitor Vic's vital signs and these are displayed simultaneously to the paramedics at the scene (via augmented reality glasses), on screens in the ambulance and to the ER and surgical teams in the hospital. The sensor network is a specialised trauma patient BAN. In the ambulance Vic can see the ER specialist and the surgeon on the screens and they can talk directly to him as well as to the paramedics during the journey to the hospital. The journey to the hospital takes them back along the country lane and then they speed along the highway, then into the city and to the hospital. During the journey they pass from one wireless cell to the next, and move between areas (rural, highway and urban) covered by different wireless technologies, creating tough challenges in terms of maintenance of Quality of Service and seamless horizontal and vertical handover.

Whilst the ambulance is in transit the ER is prepared to receive the patient and the operating theatre is also made ready. Vic is prepped for surgery whilst still in the ambulance and within minutes of admission is undergoing surgery.

Following surgery Vic is discharged from hospital into the care of the Virtual Homecare Team, his recovery is completed in his own home. Vic's home is an ambient intelligent environments which incorporates a variety of computation and communication devices linked by a home network and to the external world via a residential gateway. His care continues with home visits by members of the Virtual Homecare Team including the homecare nurse and the physiotherapist. These health professionals are also equipped with health professional BANs and can interact via wireless communications with their base whilst out and about or whilst in patients' homes. Thus they can communicate with other members of the Virtual Homecare Team who may be located in the same city or indeed anywhere in the world. Vic is also provided with a customised patient BAN - a wearable set of miniature sensors which monitor his vital signs and other physiological signals and can detect unusual situations (such as a fall or accident, or a clinical event) and which then can send alerts and summon help. The patient BAN communicates over wireless link with the smart home platform and thence to the hospital. The set of sensors and devices can be customised to the needs and health problems of any individual patient. Vic can also directly communicate with the hospital by phone and if tele-consultation is needed this is also available via the smart home video conferencing system. In many cases teleconsultation from home can replace visits to the outpatient clinic.

3. Application Requirements

The design and implementation of the systems and applications to realise the above scenario generates a set of requirements relating to the underlying mechanisms and protocols, so that the necessary quality of service can be achieved. These requirements range from security and reliability to data privacy and bandwidth availability. In the following we present a set of basic requirements that the applications need to fulfill. These requirements fall into two categories: general requirements, and requirements specific to the two applications.

3.1. General requirements

The general requirements cover the basic functionalities that the underlying mechanisms should support, so that the applications can work as intended in terms of performance, Quality of Service and security).

At the lower level we have the communications channel(s). The first basic requirement is

- *High availability and reliability of the communication resources*

Since it is not known in advance when and where an incident will happen, the communications channels should be ready at any moment to provide the required bandwidth and connections. That means that the application cannot rely on any single communication medium but have an chioce of different communications channels which can be employed at zero-time notice. These channels might range from satellite communications to GPRS or UMTS wireless links and even wired networks.

The second requirement of the communication channel is

- *QoS guarantees for bandwidth, delay, jitter and bit error rate*

The environment of the application is one requiring great precision and timely interactions. Delays and communication errors should be within strictly defined margins in order to avoid disastrous behaviour. Furthermore bandwidth unavailability and bandwidth degradation during the communications might easily result in information loss.

Medical information is governed by strict laws concerning access rights. In a system based on information exchange over open communication channels (any wireless communication is de facto an open channel), stringent security mechanisms must be employed to control access and protect the circulating information from deliberate attack. On the other hand we not only need to protect the information in transit but also to guarantee that the information does arrive and that it arrives correct and unaltered. Thus a major requirement is

- *Protection of information and control systems from unauthorised access*

Tightly related to this requirement is the need to identify and authenticate, fast and efficiently, persons who have the right to access the information. A doctor happening to be on site should be able to offer his services without delay. Thus we require

- *Fast, reliable identification and authentication of health professionals*

At the site of the accident there will be a need to identify the victim as fast possible, so that his medical records can be retrieved so that current medication and problems can be identified. A few minutes delay might prove fatal for the patient. The identification should not only be fast but also reliable so that the health professionals can use this information without reservations. Thus an important requirement is

- *Fast, reliable identification of the patient*

3.2. Virtual Trauma Team requirements

The Virtual Trauma Team application is in reality a telepresence application: the team in the ER is telepresent at the incident site and operating via the mediation of the on-site paramedical team. The basic need for this application is the provision of high quality audio/video communication between the two teams. However different levels of audio/video communication are needed at the site parts of the application.

Starting from the remote end of the application, the patient and the paramedic, we need an asymmetric service:

- *High quality one way video and two way audio conferencing from paramedic BAN to hospital mediated by ambulance VAN.*

The ambulance serves as centralization point and the on-site operations room. The two teams will need to communicate as naturally as possible exchanging information and expressing their ideas. Since the accident can be anywhere in the world a major requirement is

- *High quality two way video and audio conferencing from ambulance to hospital no matter where the accident takes place (urban, rural, remote region…).*

After the on-site treatment the patient is transferred to hospital in the ambulance. (This may be an air ambulance; in the current paper we consider only road ambulances). During his transfer treatment continues and contact with the ER should be maintained, irrespective of the speed and position of the ambulance. Thus we need

- *High quality two way video and audio conferencing from ambulance to hospital (with ambulance moving at speeds say of up to 160kph).*

In parallel with the audio/video connection the on-site team must transmit to the ER all vital signs information of the patient. These should be sent in every detail and be viewable remotely at high resolution and in total synchronization with the audio/video signals so that meaningful and non-confusing information can be extracted. Synchronised vital signs information is superimposed as visualisation over video image.

- *Intra- and iInter- media synchronisation (audio/video/biosignals) must be preserved.*

3.3. Virtual Homecare Team requirements

We can envision the Virtual Homecare Team application being extended into a mobile intensive care unit application. The patient is monitored from anywhere in the world as if he was in a highly controlled intensive care ward in hospital. This may happen in the patient's own home or in a Care Hotel where patients undergo post-operative care and/or rehabilitation. What is needed to implement this application is both audio/visual communication and as a comprehensive set of sensors monitoring all relevant physiological measurements of the patient. To maximise the mobility of the patient, some of the sensors can be attached directly to the patient's body whilst others are integrated into the environment.
The first requirement for the application is the need for:

- *High quality two way video and audio conferencing from the Care Hotel and/or the patient's home to the hospital and to any of the (possibly roaming) members of the virtual healthcare team (ie to the health professionals' PANs or BANs).*

The audio/video will allow the patient and the care personnel to communicate in a natural way and exchange information. Using this link the expert in the hospital will able to observe the state of the patient, question him and give instructions as if he was in the hospital unit.

The most important part of this *virtual intensive care room* is the monitoring of the patient's state. In the VHT application this monitoring will be done with sensors connected directly on the body of the patient, allowing him relative mobility. We can even anticipate that in non-critical cases the patient might be able even to leave his home and walk around or travel short or long distances. Nevertheless a part of the monitoring might be also embedded in the patient's home, depending on what needs to be monitored (for example, environmental parameters such as ambient temperature and humidity, air pollution, etc). Thus further requirements can be identified:

- *Sensors monitor vital signs and other physiological signals as appropriate to the patient's condition(s). Sensors may be a mixture of patient worn and embedded in the home environment. Sensor output must be visualised and viewable by members of the virtual healthcare team in synchronisation with audio and video.*

Considering that the patient's state can change at any instant, the application should not only transmit the vital signs but also monitor them and trigger alarms when measurements exhibit abnormal patterns or exceed predefined bounds. Furthermore the patient himself should be able to trigger an alarm when he feels that something is going wrong. The application should be intelligent enough to trigger automatic alarms anticipating even cases where the patient is unable to summon help (eg. in diabetic coma or stroke). Intervention may include switching on surveillance cameras or summoning emergency services. Thus summarizing the application requires

- *Alarms and automatic triggers that initiate procedures attracting the attention of both the patient and the care team.*

It is clear that all the above requirements provide a first level approximation. Ambulance teams have served for a long time without any of the above mechanisms. One can thus anticipate that applications can be designed implementing only a part of the requirements and still provide an improvement to trauma treatment and home care. Nevertheless in the long term full implementation of the above requirements should be targetted.

Many elements and technologies are involved in the Virtual Trauma Team and Virtual Homecare Team scenarios. In the following we first outline the overall context of the Healthcare VPN and then focus on body area networks.

4. Healthcare VPN

The context of the applications can be viewed as a healthcare Virtual Private Network (VPN). The healthcare VPN simulates a private network over a public network such as the Internet. It appears as a private regional network to the hospital, but physically shares for example backbone trunks with other customers. The security level of the VPN is the same as the private network, achieved by means of a range of techniques including access control and encryption, protecting it against the threat of hacker and other attacks. The major advantages of a hospital VPN over a privately owned network are the economies of scale and built-in management facilities of large public networks.

The proposed hospital VPN consists of three basic network types: Hospital Intranet, Trauma Team Network and the ambient intelligent home environment (an evolution of the concept of eHome) (see Figure 1). The Hospital Intranet is the hospital's in house LAN, which must enforce strict access and security rules. The ambulance VAN and paramedics' BANs form a Trauma Team Network. This network is connected via a wireless link (e.g., IEEE 802.11, GPRS, UMTS) to the Hospital Intranet. The eHome network hosts, amongst others, the patient care functions, and is connected to the Hospital Intranet via a wired (e.g., ADSL, cable modem) or wireless link (e.g., IEEE 802.11, GPRS, WLL).

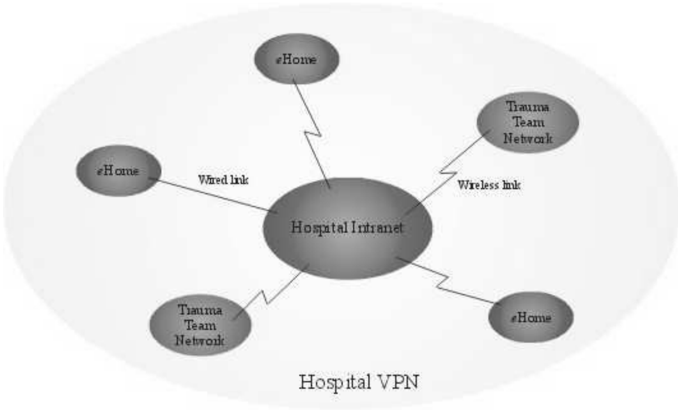

Figure 1 Healthcare VPN

The key node of the Trauma Team Network is the ambulance. It houses a VAN (Vehicle Area Network) which has connections to the Hospital Intranet and paramedic BANs. Typically the VAN interconnects a group of medical devices (e.g., active body sensors, bio-belt) equipped with wired and/or wireless network interfaces plus teleconsultation equipment. The network technology used for the VAN could be Bluetooth (version 2) or IEEE 802.11, with an appropriate gateway to interconnect to the Hospital Intranet and the paramedics BANs. If the paramedics are working outside the ambulance, their BAN has a wireless connection with the VAN. The BAN could be based on Bluetooth (version 1 or 2) devices with a Bluetooth version 2 or IEEE 802.11 link to the VAN.

Once the patient is stabilized and transported to the ambulance by the paramedics, the ambulance travels (possibly at high speed) to the hospital. The VAN to Hospital Intranet connection will be fully operational during this time. Depending on the wireless networking technology used, rapid and seamless horizontal handover from one cell to another should be supported. It is also possible that the ambulance VAN traverses different wireless networks (e.g., IEEE 802.11 to GPRS, and back to IEEE 802.11). In that case rapid and seamless vertical handover should be supported.

The patient's ambient intelligent eHome network includes a set of wired and wireless devices (e.g. digital cameras, microphones, loudspeakers) and the patient BAN. The network central device is a base station with a wired (e.g. ADSL or cable modem) or wireless link (e.g., IEEE 802.11, GPRS, WLL) from the residential gateway to the Hospital Intranet. The patient is free to move around in the eHome (premises), but his BAN stays connected.

In the case where paramedics are called to a patient in the eHome, the patient and paramedic BANs could interconnect using ad hoc networking. Here an information routing decision needs to be made: a choice between using the eHome or VAN link to the Hospital Intranet.

The overlay network should be IPv6 based. This emerging protocol provides the necessary address space for small mobile devices. It also has good support for stateless (host) configuration, IP mobility and security (e.g. IPsec).

5. BAN System Architecture

Our working definition of a BAN is simply formulated on the grounds of physical range, namely we see a BAN as a network which is literally worn on the body, as opposed to a PAN (Personal Area Network) which links devices close to the user but not necessarily (all) physically worn by him. We identify four basic functional elements of a paramedic/patient BAN : hub, sensors, audio & video and actuators (see figure 2). The "hub" includes computation and communication functions and is the main generic building block of the BAN. The hub is responsible for a) communication (intra-BAN and external e.g. inter-BAN, Base station for network access [2]) and b) program execution and data processing. The BAN is basically a heterogeneous network, where different communication media are possible (e.g. infrared light, air - radio frequency, skin, wires). The hub incorporates one or more generic interfaces to support a number of specific medium and communication technologies (e.g. Bluetooth). The hub provides the "intelligence" to autoconfigure the BAN and to route (optimize) traffic from the BAN to other BANs and to other networks. Finally, the processing unit of the hub is able to process data under control of downloadable applications.

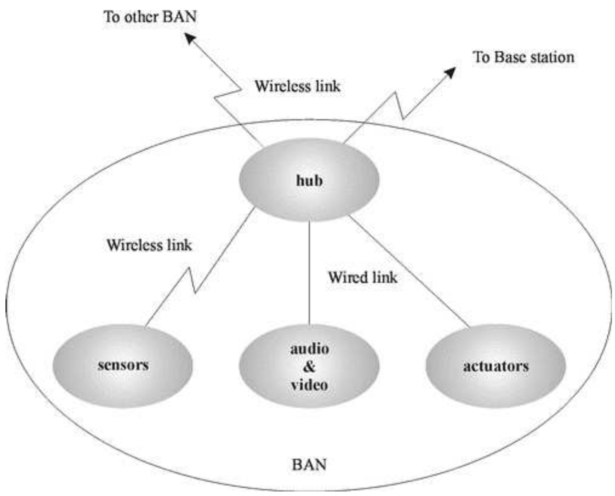

Figure 2 BAN System architecture

The hub and the devices are worn on the body, perhaps embedded in clothing, jewellery, glasses, headsets or helmets, perhaps attached directly to the body (eg. a cardiac monitor).

Specific BANS are created around the generic BAN by adding a specific set of devices as appropriate to a role (eg paramedic BAN) or for a certain (set of) needs. For instance a diabetic patient BAN would include sensors to monitor blood sugar and insulin, plus possibly a micro insulin pump. A cardiology BAN would include sensors to monitor pulse, oxygen saturation, BP and ECG.

A particular patient, say a diabetic patient, may acquire another chronic illness, or have a temporary problem (eg require cardiac monitoring for a period of time) and his (diabetic) BAN can then be extended to incorporate further functions as appropriate (eg. cardiac monitoring) by addition of another (set of) device(s) and the associated embedded and non-embedded software components .

The BAN is therefore intended to be an open, extensible platform which can be customised not only to a class of patients (eg. diabetic patients) but also to the particular set of (chronic and acute) problems of the individual person/patient.

Such a BAN system could also be used in other areas and applications, ranging for example from fire-fighting to sports training, in sports medicine and for physiotherapy in rehabilitation medicine. In the same way that we can measure vital signs we can also monitor environmental parameters such as temperature, humidity, pressure, air composition, visibility etc. The actual system infrastructure remains the same; only the interpretation of the measurements changes. For example in the case of fire-fighters temperature and air composition sensors can be connected both inside and outside the uniform and the firefighter will be informed by the operations centre to leave the area when the external temperature has risen above a certain level or the air composition is such that an explosive combustion might occur.

Another area where a BAN system could provide help is psychology research. By equipping the “patient” with a set of sensors we will be able to measure body functions and data in different life situations and achieve a better understanding of how the body reacts in stress situations. Research in new pharmaceutical products could also be assisted with a BAN system applied both to human and animal subjects. The advantage would be that more parameters could be measured for longer periods in a natural environment. Thus the results and side effects of a product will be easier to identify.

6. Discussion

The vision of the future outlined above anticipates advances in a range of technologies, including the development of new non-intrusive, non-invasive physiological measurement techniques, nanothechnology (miniaturisiation of medical equipment and sensors), ad hoc and self-organising networks, (fast roaming) broadband wireless access, new security mechanisms for wireless communications, dynamic quality of service management strategies, biometric techniques for identification and authentication, development of new generation short range, low power devices, and other technologies needed to realise the vision of (mobile) ambient intelligence.

Apart from the technology considerations, the systems should assist and support, and not hinder, the user's process(es), and be easy and natural to use. We believe that all categories of users should be involved in the design process, and that a thorough understanding of the domain and the users' and the organisations' systems and ways of working is on eof the prerequisite to success. Systems for patients and for the public in general should not require any complex setup or training (the owner of a 'smart home' or a patient BAN should not be required to be a system manager!). For professional users training is essential and can be facilitated by use of advanced training techniques involving for example virtual and augmented realities.

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