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Performance of a wireless telemedicine system: MedLAN

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Abstract:

Until recently, teleconsultation was performed by transferring the patient from the Accidents and Emergency department, to a specially equipped room, or by moving large and heavy machinery to the patient trolley. Both these solutions were impractical if not impossible in the majors or resuscitation areas of the department. Recently, performance indicators of dealing with 90% of patients within four hours were introduced for A&E departments in the UK, so the pressure is on to rapidly deal with patients in the majors or trolley area of the department.

This paper presents an integrated system called MedLAN dedicated for use inside the A&E department. Its purpose is to wirelessly support high-quality live video, audio, high-resolution still images and networks support from anywhere there is WLAN coverage. It is capable of transmitting all of the above to a consultant sitting at a computer terminal either inside or outside the hospital. To implement this, it makes use of the existing IEEE 802.11b/g wireless technology.

This paper shows that the new system is capable of delivering telemedicine with a small light trolley without any trailing wires in the all important trolley area of the department, which now needs a lot of consultant input to meet UK regulations of 90% of all patients to be discharged or admitted within four hours. The equipment is safe to use and can easily move from one area of the department to the other.

Introduction

Teleconsultation accounts for a third of the use of telemedical networks and usually defines the procedure of using communication links to provide an audio / video link between a generalist at the patient's side and a place where a consultant sits, usually his office[1,2,3]. Teleconsultation systems used in hospitals today usually consist of a heavy trolley that includes a TV monitor (usually CRT), a codec

supported by UPS with keyboard and mouse, an ISDN modem supporting a triple ISDN line (3x128=384Kbps), a camera and a set of microphone and speakers.[4] The same equipment has to be present on both sites. The whole system weighs about 70kg and has to be powered by the mains and has to be plugged into ISDN sockets. Due to its volume, weight and delicate nature, it is usually kept in a special room close to the consultant's office and at the generalist's end in a room into which the patient can be wheeled.
The need was therefore, for a small trolley without any wires that can be wheeled next to any trolley to conduct a telemedical consultation. That need became more obvious when taking into account the recent UK regulations that demand 90% of Accident & Emergency department patients must be treated and discharged or admitted in four hours.[5]

Material & Methods

Funding:

Approximately £3000 each was provided by North West London Hospital NHS Trust and Brunel University to support the building of a prototype.

Permissions:

The main and subsidiary projects were approved by the Ethics Committee. If patients, their images, or any other information was used for transmission, permission was sought from the patient.

General description of MedLAN:

MedLAN consists of two main parts: A mobile trolley that stays in the Accident & Emergency area (A&E) and a consultation point, within the hospital [Fig. 1]. The mobile trolley uses a wireless LAN to connect to the hospital's network through an Access point in the ceiling and can be freely moved to anyplace within the hospital, as long as there is coverage by the WLAN. It can also seamlessly roam from cell to cell without significantly interrupting the teleconference procedure. Within the mobile trolley, there is a high-end laptop computer and a camcorder capable of transmitting both video and still images. The doctor/nurse that operates the system can either point the camera directly to the patient, or to any medical information (ECG, hardcopy outputs, films, CRT screens, details of the patient, etc) available at the time. The system can also be connected to various medical equipment (digital stethoscope, otoscope, dermascope, endoscope, etc) that produce video or audio (digital or analogue) convert and forward their output into the network.
[Fig. 1]

A consultant either sits in another part of the hospital or in another hospital connected to the NHSnet.[6] There is also the option of establishing a WLAN in the consultant's site to allow the consultant to freely move around his or her hospital while giving advice. The overall system is very light and flexible. In its initial version, the contents of the trolley weigh just 3Kg. [Fig. 2]

The trolley and equipment

Below is a summary of the basic system components of MedLAN:

- A light laptop computer is heart of the system. Most laptops available in the market today have sufficient computational power to accommodate the needs of a videoconferencing session.
- A digital camcorder performing a two-fold function: it can be used as a camera for the general teleconference setting plus it is capable of taking high-resolution photographs and sending them to the consultant. The most important characteristics of the camera are: the quality of the camera lens, the ability of focusing to distances close to zero (macro lens), the automatic reduction of hard tremor ("steady shot") the fast and automatic white-balance and the ability to perform under poor lighting conditions. The camcorder also includes a video / audio-in port to connect third-party medical equipment while being able to perform real-time analogue to digital conversion of their signals.
- A video encoder (hardware) stands between the camcorder and the laptop. A very light USB device accelerates the compression procedure and alleviates that task from being performed by the computer.
- The data to be transmitted are processed by the mobile computer and fed into the network path. A WLAN card transmits the data into an infrastructure WLAN. The optimum speed is 54Mbps that falls down as the MT (mobile trolley) moves away from the AP (Access Point). About 40% of the nominal speed is actually available to the MedLAN system with the rest being used by the controlling mechanisms of the WLAN system.
- APs (Access points) are strategically placed in the Accident & Emergency department [Fig. 3] (and to anywhere else deemed necessary), pick up the signals from the MTs and forward them to the wired hospital network. From then on and depending on the location of the receiving station the data are routed either to a computer within the same domain or to any other computer in the NHSnet.

The receiving points

The consultant's computer will receive / transmit the video, audio and other medical information having no need of any special software. The system was tested from any of the offices in the A&E department at Central Middlesex Hospital or from any office at Northwick Park Hospital using the hospital's network [Fig. 4] and the NHSnet[6].

Images:

The following were used:

a. macro detail of patient x 5 images
b. camera pointing on a TFT ECG screen x 1 image
c. chest x-ray x 3 images

d. Computed Tomography x 2 series
e. Magnetic Resonance x 1 series
f. Ultra sound film x 4 images

Video:
About four hours of video-conferencing were used for judging suitability.

Sounds:
Four different types of heart sounds and four breath sounds were used.

Results

Tables

Table 1 represents the audio quality, Table 2 shows the quality of the still images, Table 3 shows the operational comparison between different hospitals. and Table 4 the lack of interference on medical equipment in A&E.

Testing phase commentary

Doctors in the A&E department

The two consultants seemed to be the most enthusiastic group; one more so than the other. As they were the ones working in the A&E department, they looked at the system as something that has the potential to alleviate some of the burden of the A&E procedures since mobility leads to effectiveness and better time utilisation.

As some of these doctors had basic computer training and experience, they were eager to try the system out and to provide all necessary sources for the test. They were, however, anxious about issues of confidentiality and took the patient's permission after explaining what was being done.

Consultants were very positive in their initial comments. After some of the glitches were corrected, they continuously requested for system improvements, as they understood that the potential of the system was greater than initially planned. Some of their requests include the transmission of the MedLAN's output at their home through the use of DSL lines, being able to use 3G mobile device to view video and having access to the MedLAN system from outside the NHSnet.

Nurses / healthcare personnel

Most of the nurses did not seem to grasp the potential of the system and remained sceptical of its use. They were more active in providing initial care for the patients in the A&E, rather than investing time to learn about a system that would be used in the future.

Patients

Patients were slightly anxious about the use MedLAN to transmit their data into a distant point. This was for several reasons: Initially, being in the A&E majors area as patients inclined them to worry more about their current health (different from minor injuries), rather than the potential of the system. Additionally, when explaining to them that their images and video will be transmitted in a distant location there was concern about the overall security of the system and about the possibility of others viewing their personal data. All the above were made even worst when dealing with older people. Of course, many patients were enthusiastic on the possibility that a technologically advanced system will be used for their own benefit.

Discussion

System services and performance

Video

Several commercially available software packages suitable for video-conferencing, were tested and evaluated. Among those were Microsoft NetMeeting, CUSeeMe, TeVeo and several videoconferencing tools designed for chatting solutions. Below is a comparison of the most commonly used software, each having its set of advantages and disadvantages:

- The most standard videoconferencing solution today is Microsoft NetMeeting. It comes free and is embedded to any Microsoft Windows operating system. The system is capable of sending and receiving video in three different resolutions: 160x120, 320x240 and 640x480 pixels. The highest resolution (640x480) is the most suitable for medical applications. Within the available resolutions, the compression factor of the video can be adjusted to increase the quality of the video.
- An alternative to the MNM is the TeVeo Vidio Suite. Unlike MNM this program does not offer a complete videoconferencing solution as it can only handle video and not audio. By using Java scripts, live video can be transmitted to any computer running an Internet browser by just knowing the transmitter’s IP. The major advantage of this alternative is that a basic teleconsultation procedure can be initiated very quickly, without the receiving side having to have any special software or needed to install or configure any applications (like MNM).

As the bandwidth available by the WLAN usually fluctuates due to the movement of the mobile trolley, the number of frames per second (fps) change and both users experience this as a temporary “freezing” of the video. This is more apparent when the mobile trolley roams from one cell to another (disassociating from one AP and associating with another) although there is very little need for that. In normal operation, this freezing effect is less than 100-200ms for the former case but can reach up to 10 sec while roaming from cell to cell. Generally, the system displays an average of 13-18 fps when a single MT is used inside each AP. The delay is usually below 500ms, which is more or less expected by any wireless videoconferencing system: enough frames have to be buffered and compressed (find similarities

between proceeding and succeeding frames) before the videostream is transmitted over the air.
Overall, the delay is considered very low and presented no major problems to the videoconferencing procedure. Frame rate fluctuation is always expected in a wireless system. However, by limiting the bandwidth requested from the wireless link (around 250-350kbps out of 2500 kbps), the fluctuation due to bandwidth shortage is also minimised.

Audio

The audio of the MedLAN system is usually transmitted alongside the video when software like MNM is used. From the available sound codecs, G.723 is a standard audio compressor sampling a single sound channel at 8KHz and output 6.4Kbps of sound data. This compression algorithm was proven sufficient for common applications when the two doctors needed only to verbally communicate to discuss a case.

In the case that an external sound source was connected to the system (electronic stethoscope, ultra sound monitor, etc), alternative compressors performed better (ADPCM and CCITT's A-law and u-law).

The results for the clinical sounds are shown in Table 1

Still images

One of the most highly used functions of the MedLAN system is its ability to send high quality still images to the consultant. These images can be films (x-ray, MRI, CT), images directly taken from a patient (skin, injury, various details) or images pointing at an object (ECG monitor, hardcopy results, patient records, etc

By having a quality digital camera (1 to 4 Mpixels) to take snapshots of images and transmit them to the consultant, he or she can deliver easier, faster and safer diagnosis in comparison with the 720x576=0.4 Mega pixels used so far in the conventional videoconferencing systems.

The system uses a high quality Carl-Zeiss lens capable of auto focusing from actual zero to infinity and auto white balancing in all lightening conditions. It has a CCD with a maximum resolution of one Mega pixel and can optically zoom 6x (independently of the 4x digital zoom). Its output is compressed as a JPEG with the user having the choice of three alternative compression levels and two available resolutions. Its maximum file size is 0.5 to 1.5 MB.

Generally, the quality of the images was very satisfactory. The worst-case scenario was when capturing x-ray films it was often better to adjust the brightness of the camera manually, to bring out the details of the film as the camera tend to get "fooled" by any remaining light from the x-ray viewing box.

The results for the images are shown in Table 2

Connecting to an external device

The MedLAN system also has the ability to connect to an external medical device and transfer video, audio and still images from that device to anywhere in the network.

These kinds of devices were usually ultra sound monitors, endoscopes, electronic stethoscopes, etc. With the exception of the latter (being small and mobile), the remaining devices could output a video signal either through a RCA (coaxial) video cable or through a S-Video cable. Two sound channels (stereo) can also be carried through a RCA coaxial cable.

The overall performance of the system while connected to an external device followed precisely that of when the system was operating on its own

Wireless network access

In addition to the above services, MedLAN also permits the user to wirelessly access the hospital network and perform any task that would require the use of a computer connected to the wired part of the network (file transfer, print, amend record, access the Internet, etc). This presents a significant advantage, especially in the A&E department where the computer access sometimes becomes a problem.

Range and scalability of the MedLAN system

As mentioned previously, IEEE 802.11b/g allows clients to roam from one AP to another while retaining their connection to the network. This means that multiple APs can be placed in strategic locations around a hospital's wards to cover the entire hospital, so MTs can roam around seamlessly while running real-time applications. It was also mentioned that 802.11b/g supports for three independent channels.

This introduces the concept of site survey and frequency planning: before any WLAN installation, specific tools that reveal the signal strength in the region of interest have to be used. The site survey was the first action to take place in the Central Middlesex Hospital A&E department especially majors and resuscitation areas, when tried to install a WLAN. Fig. 3 illustrates the range of two APs (marked in black circles), one installed in the majors and one in the minors area of the A&E. The ranges overlap each other but without causing any interference as the lower user channel 6 and the higher (minors) uses channel 11.

Both the APs are connected to the wired network of the CMH hospital and from then on, to the network of North West London Hospitals (NWLH) that includes Northwick Park Hospital (NPH), Wembley MATS and Willesden Hospital [Fig. 4].

Any teleconsultation operation that can take place within one of these hospitals using WLANs, can also be performed between any other two, as they all belong to the same network. All experiments (site survey, frequency planning, videoconferencing, etc) that were performed in CMH were also tested in NPH and Wembley MATS. The results were the same (if not better) as in the CMH case, yielding that the MedLAN system performs adequately regardless of the environment [Table 3]

Interference with medical equipment

Several studies so far have dealt with this issue, both in the practical and theoretical aspect. It is however, clear that unless practical measurements are taken in the actual hospital environment, one cannot be certain on the effects that these electromagnetic frequencies might have in the medical hardware.[7-13]

Electro-Magnetic Interference (EMI) caused by narrow band transmission (mobile phones, radio transmitters, etc) is very different from the case when WLANs operate. WLANs use a spread spectrum technique (usually DSSS) to spread their signal to the entire available frequency band. As they continuously transmit a low power signal, the chance of interfering with any device (medical or not) is minimal.

Nevertheless, the US FDA developed a set of rules recommending that non life supporting medical electrical equipment should be resistant to background electric fields in the frequency range of 80MHz to 2.5GHz of 3 V/m (130 dBuV/m), increasing to 10 V/m (140 dBuV/m) for life supporting medical equipment.[8] An extensive study of the possible effects of 2.4GHz WLAN operation into the hospital environment took place during 2003 in two US hospitals[9.] The results indicate that the worst-case emissions of WLANs are far below the levels of resistance proposed by the FDA (the curve found in the 2.44GHz frequency is due to the often operation of a microwave oven).

A past study in the John Hopkins Hospital performed in 1999, also dealt with the same issue. This study was performed at the dawn of the WLAN revolution and investigated on the use of WLANs to fulfil patient record updates, while on the move. Several APs were placed inside the hospital and there was an emerging concern on the possible effects that these radio frequencies might have in the medical hardware.[14]

The same experiment was performed in both CMH and NPH during spring of 2002:

- Each of the devices usually found in an A&E ward or Resuscitation Room was tested with emphasis on oscilloscopes, as these tend to be the most vulnerable to EMI.
- Both the client PCMCIA card and the access point were placed in a number of different positions near or on the device in question.
- To ensure realistic conditions, all the above devices were connected to one or more patients and possible changes in their vital signs were examined both by doctors and by technicians.

No visible interference was noticed in all the medical equipment tested in CMH and NPH [Table 4].

Thus, several experiments (both practical and theoretical) indicate that the emerging concern about the possible effects that WLAN emissions might have in hospital equipment is unfounded.

The MedLAN system performs well when it is compared with conventional TV based video-conferencing systems in terms of the video performance, the quality of the still images, the clarity of sound and its ability to be connected to external devices. It does not interfere with medical equipment, more than one mobile trolley can be used at a time and the trolley can roam from one part of the department to another. The range of the WLAN is acceptable for an A&E department, even an old one like that at Central Middlesex Hospital.

The methodology and results in this paper make it easy to replicate the system elsewhere. There are clear opportunities to be grasped in trying to speed up the throughput of patients in the majors area.

Conclusions

When evaluating a telemedical system, the objective is to prove that the healthcare data provided by telemedicine is as useful as those provided by conventional means. As the MedLAN system was developed as an improvement to existing videoconferencing systems, our task was to prove that it works as good as (or even better than) these conventional video-conferencing systems. Overall, the MedLAN system proved that it can perform satisfactory in a variety of applications and can outperform existing telemedical systems while having a relatively low cost of installing and maintenance. This, coupled by the fact that is completely open-sourced and easily upgradeable (in order to adapt to new trends in communication technology), makes the system ideal for use in a number of healthcare applications. Although the main characteristics of the system were evaluated (mostly using practical means and observations), a detailed clinical evaluation is in progress and will be presented in a future paper.

References

1. Ellis D G, and Mayrose J, The success of emergency telemedicine at the State University of New York at Buffalo Telemedicine and e-health journal 2003; 9(3): 73 -9.
2. Kim DK, Yoo S K, Kang HH, Park IC, Youn YS, Kim SH, Evaluation of compressed video images for emergency telemedicine work with trauma patients. Journal of Telemedicine and Telecaree. 2004; 10 Supplement 1: 64-6.
3. Park DG and Kim HC, Comparative study of telecommunications methods for emergency telemedicine. Journal of Telemedicine and Telecare 2003; 9(5): 300-3.
4. Tachakra S. Loane M. Uko Uche C., A follow up of remote trauma teleconsultations. Journal of Telemedicine and Telecare. 2000; 6: 330-334.
5. Performance Indicators for Acute and Specialist Trusts www.nhs.uk/England/AboutTheNhs/StarRatings/AcuteSpecialPI.cmsx, 1/5/05
6. The NHSnet www.nhsia.nhs.uk/nhsnet/, 1/5/05
7. Banitsas K A, Tachakra S, Istepanian SH: Operational Parameters of a Medical Wireless LAN: Security, Range and Interference issues, Presented at IEEE EMBS conference, vol. 3, pp. 1889-1890, Oct 2002, Houston

8. Regulatory Compliance Analysis EMC Standard, IEC (EN)60601-1-2 (2001 Edition).
9. Krishnamoorthy S, et al.: Characterization of the 2.4 GHz ISM Band Electromagnetic Interference in a Hospital Environment, IEEE EMBS conference 2003, Cancun, Mexico, vol. 4, pp. 3245-3248, Sep. 2003
10. Boivin, W.S., et al.: Measurement of Electromagnetic Field Strengths in Urban and Suburban Hospital Operating Rooms, IEEE 19th Annual International Conference on Engineering in Medicine and Biology, November 1997, vol.6, pp. 2539 -2542.
11. Vlach, P., et al.: The Electromagnetic Environment due to Portable Sources in a Typical Hospital Room, IEEE 17th Annual Engineering in Medicine and Biology Society Conference, vol.1, pp. 683 –684, September 1995
12. Phaiboon, S., and Somkuarnpanit, S., Modeling and Analysis the Effect of Radio-Frequency Fields in Hospitals to the Medical Equipment, IEEE TENCON 2000, vol.1, pp.92-95, 2000
13. Young, C., Ahmed S,, Budwill, S., EMI Levels at a ‘Patient Care Location’ in a Hospital, IEEE Canadian Conference on Electrical and Computer Engineering, May 1997, vol. 2, pp. 625-628.
14. Lombardo JS, McCarty M, Wojcik: RA. An evaluation of mobile computing for information access at the point of care, Biomedical instrumentation & technology, pp. 465-475, September / October 1997
15. Yoo SK, Park IC, Kim SH, Jo JH, Chun HJ, Jung SM, Kim DK. Evaluation of two mobile telemedicine systems in the emergency room. Journal of Telemedicine and Telecare. 2003; 9 Suppl 2:S82-4.
16. Nakamura M, et. Al., Network system for alpine ambulance using long diswtance wireless LAN and CATV LAN. Igaku butsuri. 2003; 23(1): 30-9.
17. Allen A. From early wireless to Everest. Telemedicine Today. 1998; 6(2): 16-8.

TABLES

Table 1 Audio quality and diagnostic ability for 4 breath and 4 heart sounds

Feature tested	Consultant 1	Consultant 2
Sound quality	Some disturbance	Some disturbance
Diagnostic ability	Good	Fair

Table 2 Quality of images

Feature tested	**Quality**	**Diagnostic ability**
5 pictures of patients	Excellent	Good
1 ECG screen shot	Good	Good
3 Chest x-rays	Fair	Fair
2 series CT images	Good	Good
1 series MRI	Good	Good
4 ultrasound images	Good	Fair

Table 3 Operational comparison between different hospitals

	CMH	NPH	Wembley MATS	Willesden
Useful bandwidth	**2500kbps**	**2700kbps**	**2750kbps**	**3000kbps**
Range	**20m**	**40m**	**45m**	**45m**
Number of AP needed	**2**	**1**	**1**	**1**
Fps	**15**	**18**	**16**	**15**
delay	**300ms**	**330ms**	**270ms**	**300ms**

Table 4. Interference of IEEE 802.11b WLAN with existing A&E medical devices in CMH and NPH

Medical equipment	**Power at 2.4GHz**	**Hospital**	**Effect**
HP 78353 BU	30 mW / 50mW	CMH A&E	No visible interference
VDU monitors	30 mW / 50mW	CMH A&E	No visible interference
HP Page Writer Xli	30 mW / 50mW	CMH A&E	No visible interference
LIFEPAK 8 cardiac monitor	30 mW / 50mW	CMH A&E	No visible interference
Agilent Page Writer 300pi	30 mW / 50mW	CMH A&E	No visible interference
Nova SI and Profig Nutra	30 mW / 50mW	CMH resuscitation	No visible interference
Passport XG Datascope	30 mW / 50mW	CMH resuscitation	No visible interference
Propaq encore	30 mW / 50mW	CMH resuscitation	No visible interference

FIGURES

Fig. 1 A block diagram of the MedLAN system

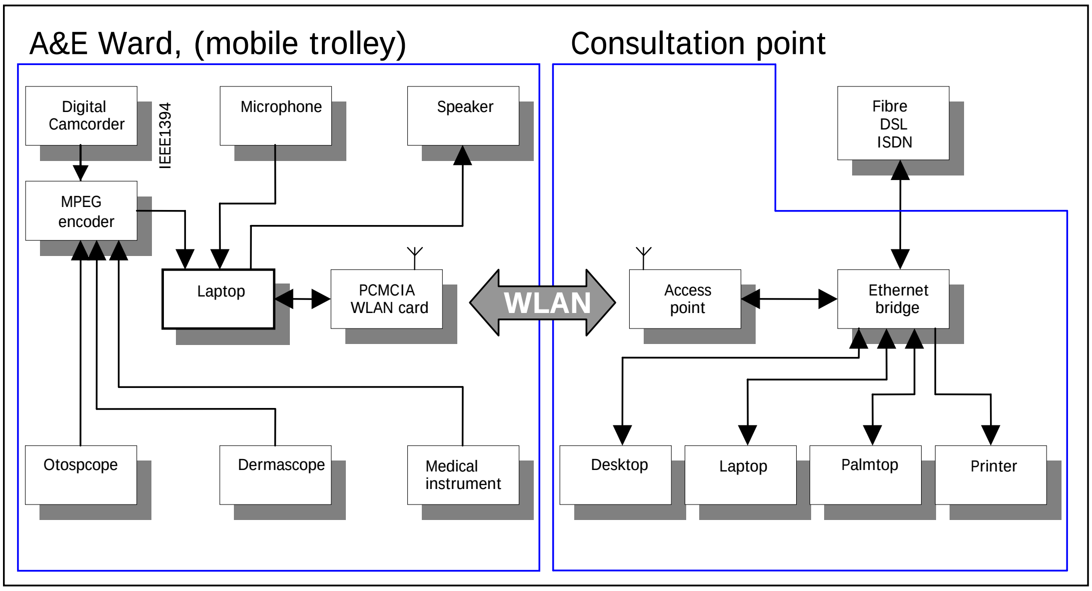

Fig. 2 The MedLAN system in trial period

Fig. 3 The range of two APs as revealed after a site survey of the CMH A&E ward. The black circles indicate the position of the APs and the grey area indicate their range at 1Mbps

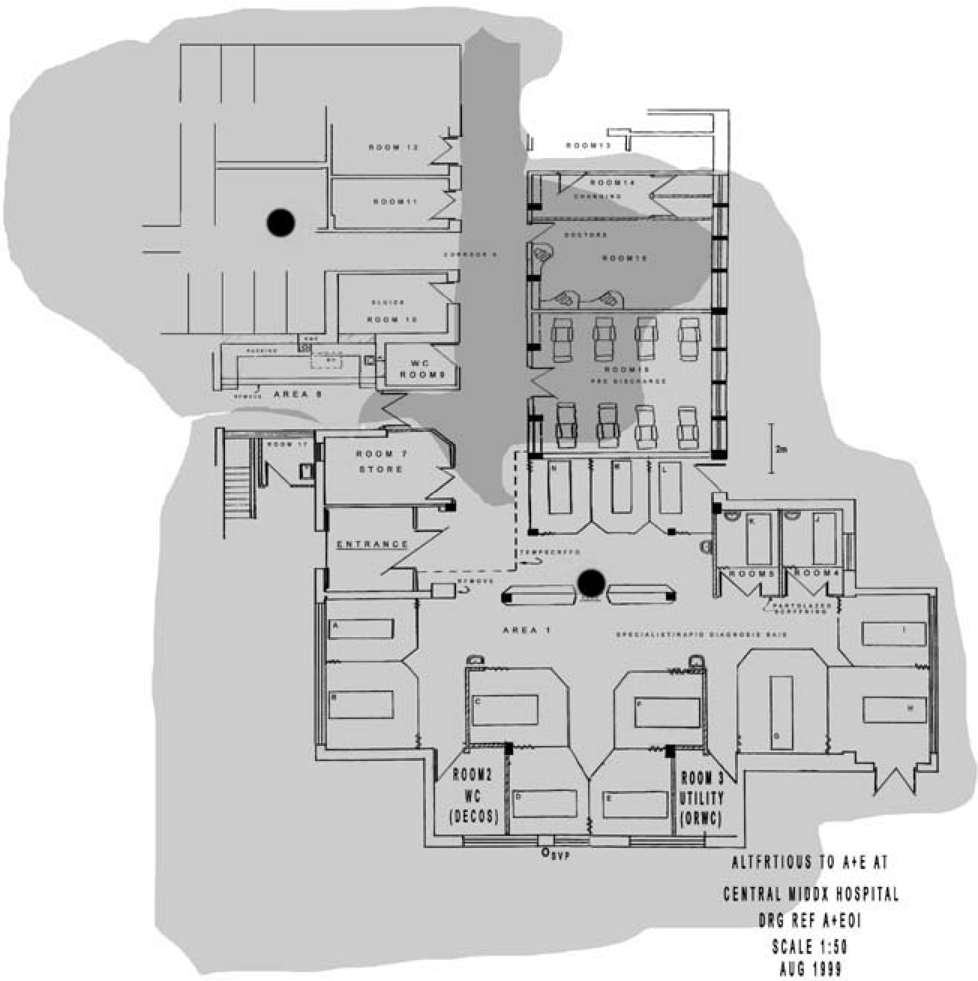

Fig. 4 Basic structure of North West London Hospital network.
The MedLAN system can directly operate between any of those two hospitals.