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Using 3G links to develop a teleconsultation system between a moving ambulance and an A&E base station

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Summary
Minimising the time required for a patient to receive primary care has always been the concern of the Accidents and Emergency units. Ambulances are usually the first to arrive on the scene and to administer first aid. However, as the time that it takes to transfer the patient to the hospital increases, so does the fatality rate.
In this paper, a mobile teleconsultation system is presented, based on third generation mobile links. This system can be installed inside an ambulance and will permit high resolution videoconferencing between the moving vehicle and a doctor or a consultant within a base station (usually a hospital). In addition to video and voice, high quality still images and screenshots from medical equipment can also be sent.
The system was tested and validated by both engineers and doctors. The statistical results of these tests are also included. The test was carried out in Athens, Greece where a 3G system was recently deployed by Vodafone. The results show that the system can perform satisfactory in most conditions and can effectively increase the patient's quality of service, while having a modest cost.

Introduction
One of the most important factors when trying to improve the healthcare delivery in emergency situations is the minimisation of time required to provide primary care (and most importantly consultation) to the patient. In most cases an ambulance has to respond to an emergency call, administer first aid and in many cases carry the patient to an Accident and Emergency ward in a close by hospital. In Greece there are an average of 461000 ambulance calls every year. In the general area of Athens alone, an average of 730 ambulance calls take place each day with 27% of those patients in need to rush into an A&E department (category A responses). The average time it takes for an ambulance to reach its destination in the city of Athens, is 17 minutes.[1]
Patients transferred that are in critical condition, would benefit by a faster access to medical expertise (that cannot by provided by staff operating the ambulance) and more specifically, direct interaction with either a doctor or a consultant.
Emergency 112 was one of the projects that tried to improve the above situation.[2] However, as the system was using a second generation mobile telephony link (2G) it was limited to a speed of 9.6 Kbps so only low resolution static images and text-like patient data could be sent over the air.
A similar approach (including slow frame video) was followed by another research project that took place in Lancashire in 1996-97. It allowed the transmission of images at a rate of 15 frames per minute over a slow GSM link.[3] An alternative would be to directly use satellite communication to establish a high-speed wireless channel. [4,5] However, such solutions are limited by both the requirement for expert installation and their high running cost.

As the situation in mobile telephony improved General Packet Radio Service (GPRS) came into use (2.5G) and allowed for a bandwidth of about 50 Kbps, permitting users to send static images of modest quality.[6]
The deployment of the third generation of mobile telephony (3G) has opened up many new possibilities for over-the-air communication and more specifically for distant health care delivery. 3G systems can support higher data rates thus allowing for a range of new applications.[7]
3G systems utilise the Universal Mobile Telecommunication Services (UMTS) technology. When conventional 2G mobile terminals move from one cell to another, they have to disassociate from the old cell and associate to a new cell. This process of "handover" (HO) introduces small gaps in communication that can severely affect time sensitive processes like videoconferencing. In contrast with 2G, UMTS uses "soft hand-over" where a mobile terminal switches from one cell to another in such a way that there is a point in time that it communicates with both cells. That translates to a more stable flow of data, essential in real time applications.[7]
As the number of 3G cells is lower than those supporting 2.5G when a mobile terminal gets out of the 3G coverage area it will have to fallback into GPRS speed, until it regains a 3G signal. The whole operation of disassociating with 3G and registering in a 2.5G network introduces considerable delays in communication and data transfer.
In the remaining of this article there will be a presentation of a system that can be installed in a moving ambulance and by taking advantage of a 3G communication link, can establish a video / audio / image link with a base hospital so doctors or consultants can offer their expert opinion to a patient in need, from the time this patient enters the ambulance. There will be an investigation as to what extent this kind of communication can be useful, what is the quality of the results it produces and whether it can replace or supplement existing telemedical technologies.

Methods
A series of 17 trial runs were conducted in the city of Athens. This city was chosen for two distinct reasons: First, the traffic within the centre of the city is quite high thus the average time needed for the ambulances to reach their destination is above average so, patients would benefit more by the deployment of such a telemedical system. Secondly, 3G mobile telephony was recently deployed by Vodafone thus presenting system developers with an advantage as the spectrum had a very low utilisation rate.
An ambulance was equipped with the following [Fig. 1, Fig. 2]:

- A high end, light, laptop computer.
- A quality camcorder connected to the above laptop, that could focus and white balance under various lighting conditions. It could also support for high resolution still imaging.
- Either a PCMCIA card that supports 3G communication between a laptop and a 3G network or a 3G phone that acted as a modem (wired using a USB port or wireless using bluetooth).

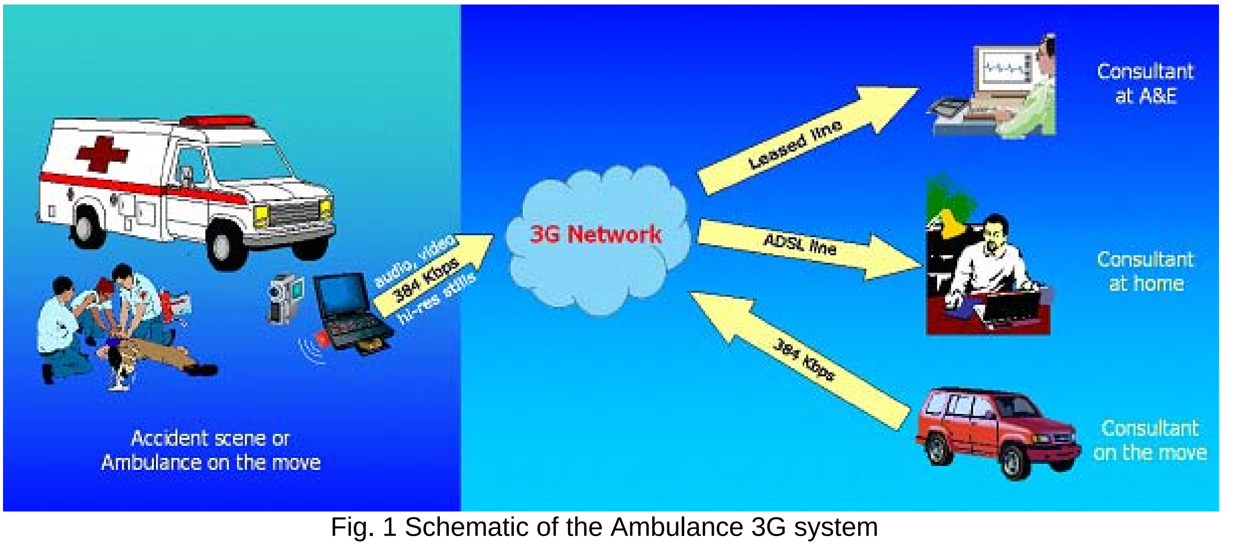

Fig. 1 Schematic of the Ambulance 3G system

Within the laptop a standard videoconferencing programme (Microsoft NetMeeting) was running allowing for point-to-point communication to the base station. The base station resided in a hospital where either a doctor or a consultant could use a standard computer to establish a link with the moving ambulance [Fig. 1]. The specifications of the base station computer need not to be high. Any communication link can be used on the hospital side, but it is obvious that at least 384 Kbps should be available to the base computer, to match the maximum speed of the roaming one. An average quality web camera was installed on the base computer and allowed for two-way videoconferencing. That was not an essential requirement of the test but improved the feeling of the users and especially the patients, as they tend to be calmer viewing the image of a doctor. It also allowed for the consultant to visually demonstrate a method to the treating personnel. However, two-way videoconferencing posed an extra strain to the communication channel and lowered the quality of the ambulance-to-base station link.

Every effort was made to acquire the permission of the patient in sending his / her details over the wireless channel. Most patients were reluctant at the beginning (due to the higher priority of their current problems) but later on seemed to be at ease with the whole operation, as they felt that they were treated by experts.

The routes followed by the ambulance, consisted by a mixture of UMTS and GPRS covered areas: Only a relatively low percentage of the geographical area of Athens is covered by 3G cells, centred close to the main routes and highways. For the remaining area the system had to fallback to GPRS thus considerably lowering the available speed. Several road speeds were tested, from a standstill position to a top speed of 120 Km/h. Finally, alternative routes were followed, that included four road tunnels, three times travelling sideways to a mountain and several urban canyons.

Various scenarios were run mostly in relation with videoconferencing and included the actual trauma, real-time ECG signals, supervision of the actions of the ambulance personnel, etc. Also, a number of different still images were transmitted that included patient and trauma details, paper printed information, screenshots of medical equipment and other patient details. The simplest of the methods was used to transmit the above: the user just pointed the camera to the information to be transmitted, including CRT or TFT displays (ECG, etc). That way the overall procedure was simplified and there were no wireless channel collisions due to multiple streams of data sent.

As there had to be some kind of network performance indicator, on the mobile side of the system, two network monitoring programmes were running continuously: one was provided with the PCMCIA card and indicated the network connection (UMTS or 3G) and the speed connected, while the other displayed information on channel utilisation, packet size, protocol usage and specific speed on every instant.

Fig. 2 Operation of the system: the camera is transmitting video to the laptop computer that in its turn uses the PCMCIA card to transmit through a 3G link.

Results

Regardless of some specific problems, the overall system performance has met or even exceeded the expectations of both the engineers and the medical personnel and showed that the system can be effectively deployed on a larger scale.

Engineering

The videoconferencing sessions produced relatively clear video in general. The algorithm used with most videoconferencing programmes is H.263 (a simplified version of MPEG-4 algorithm)[8]. Fortunately the bandwidth was high enough for a satisfactory video of 10-15 frames per second (fps) and a choice of resolution between 160x120, 320x240 and 640x480 pixels. Windows NetMeeting videoconferencing software was proven to be sufficient for the task. Apart from audio and video, it also supported file transfer (FTP) including images and patient data. It also allowed changing into any of the above mentioned resolutions "on the fly" to adapt to the changing environment: as the bandwidth become limited or even fluctuated heavily, changing into a lower resolution required a smaller portion of the bandwidth and thus kept a minimum quality (5 fps at 160x120 pixels with a connection speed of 64-128 Kbps).

The initial speed of connection reported by the PCMCIA utility was usually 384 Kbps, reflecting a 3G coverage area. The speed was stable with very little margin of fluctuation. When connected to a 2.5G cell, the speed dropped to about 40 Kbps but with relatively heavy fluctuations. As the system handed over from one 3G cell to another, the transaction was very smooth and literally undetectable to the user, as the mobile terminal was connected to both cells during the HO period.

When the system handed-over from a 3G cell into a 2.5G, there were some inevitable delays as the terminal had to reregister to another cell. Delays varied from 5-15 seconds and there was an instance where communication was lost for more than one minute and the whole session had to be re-established [Fig. 3]. For a total period of 23 hours and an area of about 180 square kilometres, there were 9 recorded instances where the communication fall back from 3G to 2.G and for a total of 17 minutes.

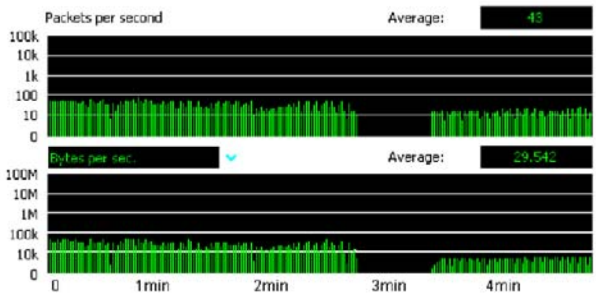

Fig. 3. Network reported throughput: left section indicates 3G communication, right section is the fallback into GPRS while the gap in the middle is the hand-over time.

Table 1 summarises different results regarding the landscape and speed diversity. Overall, speed had a minimal effect on the output of the system as UMTS specifications support for three different bandwidth rates: 144 Kbps while moving at a maximum speed of 500 Km/h, 384 Kbps while under 120 Km/h and as high as 2 Mbps while in a stationary position[7] and there was no instance where the ambulance had travelled faster than 120 Km/h in an urban area.

Table 1 Effects on the performance of the system due to different geographical scenarios.

Telemedical

During the research of this system and for a period of 7 days, a number of doctors, patients and other personnel were involved:

- A total of 17 patients were transferred using an ambulance that the above system was installed into.
- Four consultants were asked to evaluate the results sent by the system (video, image and sound) and make a prognosis on the patient, based on this data.
- Two engineers continuously researched into the communicational properties of the system.

The table below summarises some of the specifics of the patients used to test the system:

Table 2. Summary of the cases within the testing phase of the system

All the cases presented in Table 2 produced acceptable results for the remote consultants both for videoconferencing and for still imaging. For each of the 17 patients described in Table 2, consultants were given questionnaires to evaluate the system's performance. The overall quality of the outputs was: poor 4.2%, acceptable 25.4% and good 70.2% [Table 3].
Sound was acceptable although the relatively high background noise created by the ambulance moving (especially with the use of siren) lowered the quality of videoconferencing.

Table 3. Summary of doctors' feedback regarding the Audio / Video quality of the system

Transmitting a still image was a straightforward task. The same high quality camcorder that was used for videoconferencing, could also be used as a digital camera so still images of either 1 or 2 Mpixels could be transmitted to the laptop computer and from then to the 3G network. A still image of 1Mpixel took about 10-15 seconds to be transmitted while a 2 Mpixel one required twice as much time. The quality of the images was very good, even under poor lighting conditions such as fluorescent lighting inside the ambulance. The camera could focus from actual zero to infinity making this ideal for pointing at a patient's trauma or any other body details. Even pointing the camera straight to various medical equipment within the ambulance, produced a very clear and sharp image. That included both TFT and CRT screens and monitors. Transmission of films (x-rays, CT, MRI, etc) required a suitable projector to be installed inside the ambulance and the camera taking a high resolution picture of that; a luxury that few ambulances have due to shortness of space. Although there was little need of that, this method was tested in two instances and it was proven to be rather problematic as the camera tend to be "fooled" by the high contrast of the films[9]. Finally, the system could also act as an on-line terminal to the hospital's network, thus allowing the access of information in the hospital's database (patient's history, drug prescription, etc).

Discussion

The above results constitute the initial phase of the system deployment. The general opinion formed by the doctors was that this system produced solid results that could be used for improving the quality of service to the patients.
More specifically, and for the cases described in Table 2, all prognoses made through using the system, agreed with the final diagnoses of the patients; even though further tests had to be made to justify each diagnosis.
The general idea is that using this system, small groups of consultants can be housed on one hospital and serve a wide area within a city, or an entire city itself.

In engineering terms, the system had an acceptable videoconferencing quality when the ambulance was within a 3G coverage area. Moving into a GPRS area posed a problem, as the bandwidth was not enough to accommodate the load. Sound and still imaging was very satisfactory even in GPRS conditions rendering the system useful, even in areas that do not have support for 3G communication. However, it is more than certain that the number of 3G cells within every European country will keep increasing much like 2G cells did in the past. For that reason, research like the one presented in this article is bound to have an increasingly high field of application and a guaranteed success as more and more areas are covered by UMTS.

The cost of the additional hardware needed to be installed in an ambulance, does not exceed 6000 Euros (about 4000 pounds). Airtime needed for the videoconferencing session is charged by the provider. Most test session lasted from 3-10 minutes transmitting 3-15 MB of data. It is estimated that the average cost for the airtime of each session would be about 5-20 Euros (3-13 pounds). The overall cost of the system (installation and running cost) is very low and should make the system desirable for full deployment.
As this is a telemedical application, the security of the system is always of high interest, as sensitive medical data are to be transmitted over the air. A Virtual Private Network (VPN) was used to create a secure tunnel from source to destination. Fortunately, the software that came along with the PCMCIA 3G card included such a security wizard that allowed creating such a secure connection. The data overhead of the VPN solution was minimum and remained unnoticeable to the end users.[9,10]

At this point it is important to mention that this system can be installed to work the other way around: from a base station in the hospital (possibly A&E ward) to a mobile station where a consultant may be. It is clear that consultants have to be reachable as much as possible. The above system can be installed in a mobile vehicle (the consultant's car for example) and allow for communication between the car and the A&E ward.[11]

Overall, it is clear that a high quality, low cost system like this can effectively assist on minimising the time a patient needs to get primary consultation and effectively save lives.

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Tables

1.

Scenario	Maximum speed (Kbps)	General effects
Moving fast	144-384	No visible effect
Sideways to mountain	64-128	Some loss of signal
2.5G → 3G	40-45	Freeze for 3-7 sec
3G → 2.5G	384	Freeze for 5-15 sec
Urban canyons	128	Some signal deterioration
Tunnels	384	No effect

2.

Injury	Video (min) / images sent	Parameters transmitted	Prognosis	Diagnosis
High fever	3/0	Video, temperature	Flue	Flue, high fever
Eye injury	5/3	Video, eye close-up	serious injury	Perforating injury. Surgery needed
Heart problems	11/5	Video, ECG, blood pressure	Arrhythmia	Arrhythmia corrected by IV injection
Road accident	9/4	Video, injury close-up, pressure	Broken bone	Broken bone, cast in ambulance
accident / back pain	4/0	video	Not a serious situation	Musculo-skeletal pain. Not a serious situation
Neck pain due to fall	4/1	Video, neck image	Muscular problem	Muscular problem, no bony injury medication
Skin burn	5/6	Video, skin burned close-up	2nd degree burn	2nd degree burn, Initially treated with dressings
Household accident	6/2	Video, hand close-up, existing x-ray	Broken hand	Colles' fracture, cast
Heart problems	8/5	Video, ECG, blood gas, blood pressure	Valvular Heart Disease	Valvular Heart Disease diagnosed on auscultation. More tests needed
Problem breathing / cough	7/1	Video, temperature	pneumonia	Pneumonia, oxygen in ambulance, antibiotics started, kept in hospital
unconscious	10/9	Video, facial close-up, blood data	stroke	Stroke diagnosed by paresis of face and one side of the body in ambulance
Severe bleeding due to cut	5/5	Video, injury	Bleeding contained. Not a serious situation	Bleeding, controlled by local pressure, stitches needed
Dizziness	7/3	Video, blood pressure	Low blood pressure	Low blood pressure due to heart failure heart problems
Accident / unconscious	8/4	Video, gas, injury close-up	Head injury	Head injury, diminishing consciousness internal bleeding
Heart problems / Tachycardia	10/3	Video, ECG	Mitral Valve Prolapse	Mitral Valve Prolapse, partly diagnosed by auscultation kept in hospital
Accident in workplace	15/5	Video, injury	Bleeding contained. Stitches needed	Bleeding contained. Stitches
Heart problem / pain	10/4	Video, ECG, blood gas	myocardial infarction	myocardial infarction, thrombolysis started in ambulance kept in hospital

3.

	Poor%	Acceptable%	Good%
Image clarity		35	65
Colour		20	80
Depth versatility		8	92
Sound		45	55
Audio / Video delay	10	15	75
Total delay	15	35	50
X-ray detail	5	20	75