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Analysis of communication alternatives in a heterogeneous network for a supervision and control system☆

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Abstract

Different communication alternatives that form an Heterogeneous Network for a Supervision and Control System of the purification network of a large city are evaluated in order to determine their viability for the supervision and control of the system. In addition there is a study of which offers the best services and costs for different scenarios. Four communication alternatives (which assure a 100% geographic cover of the stations) for the interconnection of the Remote Station and the Central Station are analysed, all of which are situated in the metropolitan area of a large city: point-to-point connections over ISDN (Integrated Services Digital Network), Virtual Private Networks VPNs/IP over ISDN, VPN over ADSL (Asymmetric Digital Subscriber Line) and wireless link 802.11. For the communication between the Central Station and the mobile remote clients, the connection via GPRS (General Packet Radio Service) and the connection by means of UMTS (Universal Mobile Telecommunication System) are evaluated. For the measurements and posterior analysis, control information and images have been transmitted. The viability of these types of solutions in the proposed scenarios is shown and the costs involved in each solution are analysed.

Keywords: ISDN; ADSL; GPRS; UMTS; Images Transport; Virtual private networks; Supervision and control systems

1. Introduction

At the moment the Public Networks are giving more and more communications support to companies, for that reason, the study of the performance of a Control and Supervision system in whose operation different public networks of communication that create an Heterogeneous Network [1] has been considered important. The organizations need to be equipped with remote access infrastructures that allow them to guarantee confidentiality and control of access, protecting the resources of the organization. This opening to Internet of the information systems means implicitly a reduction of costs in communications because of using Public Networks instead of Private Networks, which are more expensive and difficult to manage. In spite of the advantages of the Public Networks, it is necessary to study if these offer the QoS needed and if the objectives for a supervision and control system are achieved.

The objective of the study is to find out under which conditions the technologies are suitable. The real bandwidth of the different interconnection networks, response time (time when there is a state change in the equipment of the Remote Station and an operator receives this in the Central Station) number of images per second, reliability, security and costs are evaluated. With the bandwidth, the number of images per second that the Remote Station can transmit to the Central Station has been calculated.

In previous works, the architecture of the system was analyzed in detail [2,3] and some alternatives were tested [4]. In [2], the improvements achieved were described, complementing the system in use until the moment that it operates with 'polling' [5,6] by radio frequency for the communication between the Central and the Remote Station.

With the current system, it is possible to exchange control information from whichever control equipment

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(PLC, terminal, etc), and to obtain images from critical zones within the installation and transmit them to a station which functions as a supervision and processing centre, as well as allowing access to all the information obtained in remote form through the different access networks to Internet. The paper is structured in the following way: In Section 2, the architecture of the system is described. In Section 3, the operation and in Section 4 the advantages and disadvantages of the interconnection alternatives are described. For the connection of the different stations of the system, the wired connectivity is provided by ISDN (Integrated Services Digital Network) and ADSL (Asymmetric Digital Subscriber Line), and the wireless connectivity is provided by IEEE (Institute of Electrical and Electronic Engineers) 802.11 [7]. GPRS (General Packet Radio Service) as well as UMTS (Universal Mobile Telecommunication System) are used for the connection of remote clients to the system. The measurements are shown in Section 5. In this the monthly costs of the Central and Remote Stations are evaluated for the different communication alternatives and the analysis of results has also been made. The conclusions are presented in Section 6.

2. Architecture of the system

The system is made up of four fundamental parts, see Fig. 1: Central Station, Remote Stations, Communication Networks and Remote clients.

2.1. Central station

This schedules the information, which passes through the whole installation, and controls the communication between Central and Remote Stations. The slow cycles of polling by radio are eliminated now that it communicates simultaneously (using various TCP/IP connections) with the Remote Stations, and is now a redundant communication medium that works as a backup system.

The Central Station counts on equipment which operates like SCADA [8] in the new network and which houses the database of images and control information. A batch process is charged with maintaining coherence between the old database (updated by polling) and the new one to avoid incoherences. The Central also houses a Web Server, which allows consultation of information on the Remote Stations by Internet.

2.2. Remote stations

In each of the Remote Stations to be governed there is a PC that acts as a gateway between the communication network and the local control system of each Remote Station. It is able to communicate bidirectionally with any PLC on the market (in this case the protocol used is a Simatic S5/S7) and map in a simple way the variables of the process. The Remote Station process determines when variations susceptible to being sent to the Central Station have been produced, executing an automatic update. The parameterization is completely done from the Central Station, with this the PLC memory zones for orders and states are defined. The Remote Station captures information from different cameras, encodes it and then transmits it to the Central Station by the communication medium available.

2.3. Communications network

This gives communication support in concurrent form to all the Remote Stations, allowing the incorporation of new real time services such as image transport, states and orders transmission. The current system of polling by means of radio frequency is a redundant system acting as backup to operate in case of failure of minimum services.

After a detailed study of the diverse possibilities four possible alternatives for the interconnection of the stations have been studied:

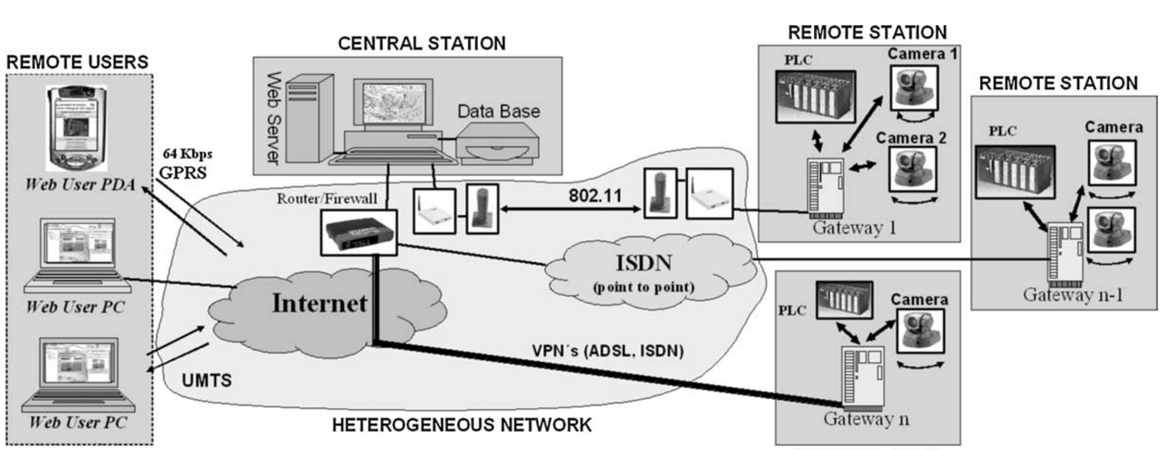

Fig. 1. Architecture of the system.

- Point to point connections between the Central Station and each of the Remote Stations through ISDN.
- VPN (Virtual Private Network) [9–11] by Internet with ISDN access.
- VPN by Internet with ADSL access.
- Wireless link 802.11.

For the connection between the Central Station and a mobile remote client, GPRS and UMTS have been used. In all the cases Telefonica S.A. has been the Spanish provider of telecommunications used.

2.4. Remote clients

This is the equipment with which an authorized user can access remotely via Web to the information of the control, to the images stored in the data base of the Central Station and can see real time images. The Web connection can be made by a remote client from fixed nodes (PC) with an ADSL or ISDN connection or mobile nodes (PDA, telephones, portables, tablet PC) using the Internet as a transport network and GPRS or UMTS as access technology.

3. Operation of the system

There are three software components which make up the system:

- Local application of the Central Station.
- Remote Station processes.
- Web application.

3.1. Local application of the central station

The SCADA principal application is composed of a map of the city in which the stations of the system are located. From the Central Station the reading and writing of the PLC variables are parameterized and the position in the memory zone which will contain the information of a given state or order is indicated. In this parameterization, with a particular state an alarm can be assigned, which signifies that if this state changes an image capture will begin automatically. Also from this application orders can be given (written in the PLC) from the Central to a Remote Station and the change occurring in the states of the equipment can be observed (by reading PLC).

It is possible to see the images in real time and control the camera (right, left, up, down, in a determined position indicating the degrees X or Y, zoom, speed of movement, brightness and backlight).

The positions that cover the angles of interest can be stored and later the camera can be situated directly in these positions. If it is considered necessary the images that are being observed in the screen can be recorded, for example in situations of alarm such as intense rain. Another form of storing the images is that done in background. In this, the parameterization where the days, the periodicity with which an image will be recorded depending on the alert state (every 1, 5, 15, 30, 45 or 60 min), the quality (high quality equivalent to 50% of compression and low quality equivalent to 90 previously done. Also, if there are prefixed positions, the background process grabbing takes images from each of these positions. The stored images can later be recovered (background or real time) in order to examine them and to be able to make technical reports that evaluate the operation of the system, see Fig. 2.

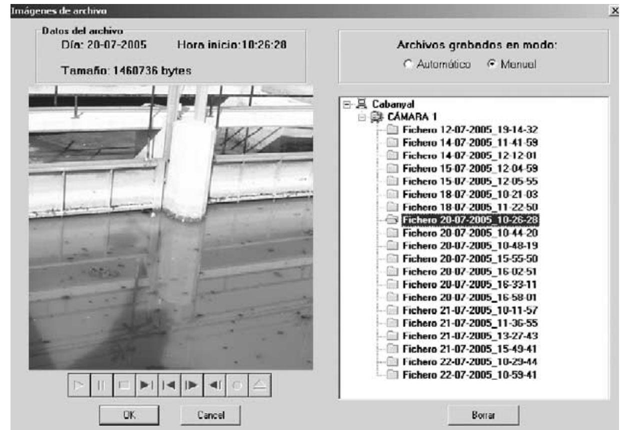

Fig. 2. Screen in the local application of the Central Station where the images stored (real time or background) are seen.

3.2. Remote stations processes

The images are transmitted compressed from the Remote Stations to the Central Station, since the bandwidth used for their transport is reduced but at the cost of losing quality. The study of the codecs is based on the variation of two parameters: quality of compression and the interval between key frames, which influence the obtained values of the following characteristics:

- Quality.
- Bandwidth necessary/available.
- Compression/decompression time.

Several codecs have been used (see Table 1), varying the values of those two parameters. In Fig. 3, the relationship between quality and size of frame for codecs with different combinations of quality and key frame is shown. That relationship has been obtained for six standard sequences.

Following this study it has been observed that three codecs provide a very good quality/size relationship when a key frame superior to one is used: LIV3 (Lingos Indeo V.3.2), LIV5 (Lingos Indeo V.5.11) and DIVX. When a key frame of one is used the codecs with which a better quality and a smaller size of frame is obtained are the following:

Table 1
Codec description

Index	Codec	Index	Codec	Index	Codec
1	C(K1)	2	L3(K1, C55)	3	L3(K1, C65)
4	L5(K1, C75)	5	L5(K1, C85)	6	M2K(C56)
7	M2K(C75)	8	M2K(C56)	9	M2K(C75)
10	I2K(C30)	11	I2K(C40)	12	I2K(C50)
13	LD(C180)	14	LD(C180)	15	LD(C190)
16	I3(C50)	17	I3(C60)	18	I3(C70)
19	DX(K1, C100)	20	DX(K10, C100)	21	L3(K30, C55)
22	L3(K30, C65)	23	L5(K30, C75)	24	L5(K30, C85)
25	C(K30)				

C, Codec Cinepak Radius; DX, DIVX; I3, Intel I.263 Video Driver; I2K, Image Power JPEG200; L3, Lingos Indeo V.3; L5, Lingos Indeo V5 LD Lead MCMP/MJPEG; M2K, Morgan Multimedia M-JPEG2000.

LIV5, LEAD, I2K (Image Power JPEG2000) and M2K (Morgan Multimedia M-JPEG0). In addition, the compression and decompression time and other parameters have been considered, and finally it has been decided to use codec M-JPEG2000, due to its good results. Furthermore, the capture of one image per minute prevents the use of codecs MPEG because no temporary redundancy exists.

There are four processes charged with image and camera control: '*CapturaImag*', '*ClienteImag*', '*ComprImag*' and '*ControlCam*'. These share a common memory zone in which they exchange information. The first captures the images and passes them to '*ComprImag*' which compresses them. '*ClienteImag*' is in charge of transmitting them to the Central as well as receiving parameterization information and the camera movement requests from the Central. These requests together with the parameters are transmitted to '*ControlCam*' which manages the camera. In Fig. 4, the operation scheme for these processes is shown. When a request is made from the Central Station to start or stop receiving images, that request reaches the Remote station through the application '*ClienteImag*', which indicates to

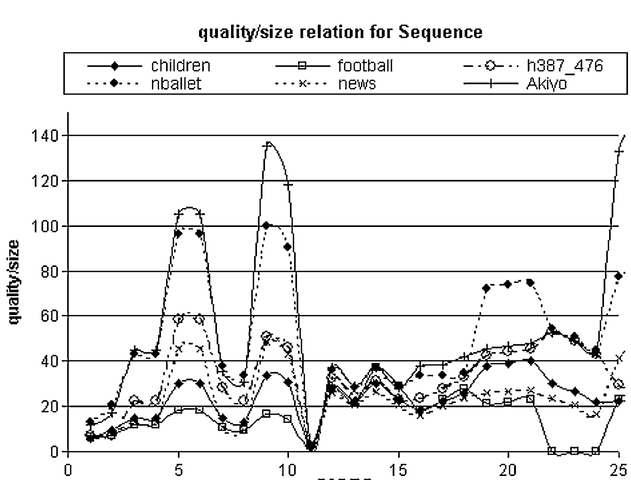

Fig. 3. Relation quality/size from different sequences.

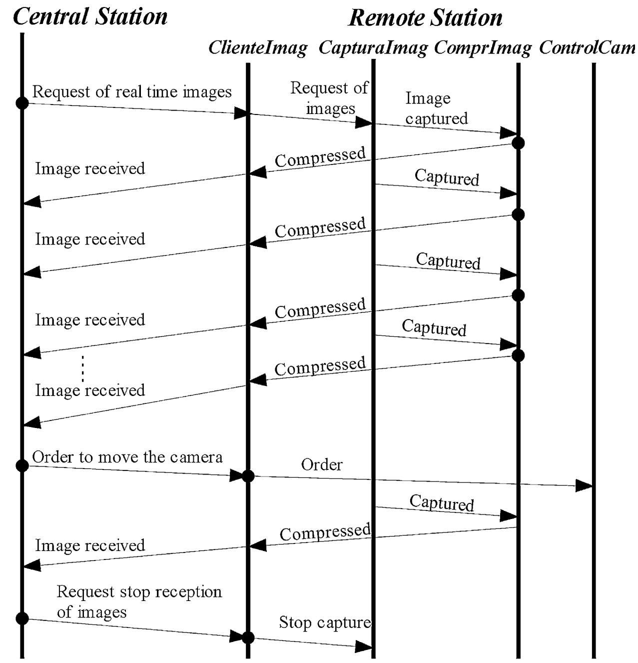

Fig. 4. Request protocol and transmission of images.

'*CapturaImag*' whether to pass or not pass images to '*ComprImag*' until there is a new order.

The Remote Station communication with the PLC (Simatic S5/S7) is made by means of an ActiveX Control that uses the protocol of the PLC by a serial connection. Any change that is detected by the remote application '*ControlPLC*' is sent to the Central Station and stored in the database. The control information travels in IP packages independently of the images, the state variability is not elevated and only 7/8 bytes are transmitted, then this traffic does not affect the system throughput significantly.

In Fig. 5, the protocol of the data control process is showed. Initially, the parameterization of the zones of

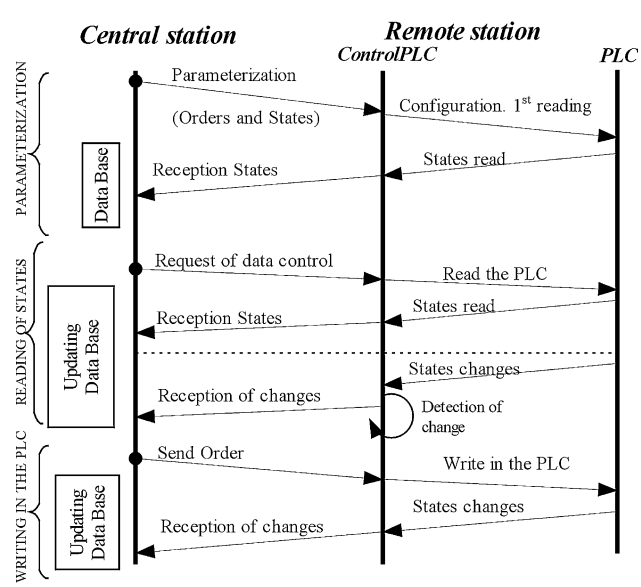

Fig. 5. Protocol of the data control process.

memory to read and to write in the PLC and the first reading is made, with this, recent information arrives at the Central Station and is stored in the database. After that, a request to see the situation of the equipments in real time (reading of states) can be made from the Central Station. In the scheme, the possibility that a user from the Central Station gives an order (writing in the PLC) appears too, which implies writing in a zone of memory of the PLC and it implies as well, a change of state of the corresponding equipment. In the scheme the possibility has been considered that the application '*ControlPLC*' detects a change and sends it to the Central Station to update the data base where the states are stored.

3.3. Web application

The security of a System that can be acceded via Web is an important aspect and as such has a system of authorized users, which restricts open access to it. Moreover a Web user can only consult information and doesn't have control over the system.

If the client is connected from a remote client with a fixed PC, he is permitted to see control data, real time images and archive images of each camera placed in the station. The option of control information shows the state of the equipment, which makes up each station. If access is made through a PDA type client the images can be seen in real time (see Fig. 6), the same as states information.

Fig. 6. Real time images in the PDA Web.

When a remote client requests images or wants to know the states in real time from the Web page, the protocol is very similar to that shown in Figs. 4 and 5, but considering that in the first place a request is made to the Central Station by the client Web. The Central Station makes the gateway between the remote Web clients and the Remote Stations that offer the information of their control equipment and the images from their cameras. Once the Central Station receives the request of images or states, the protocol between the Central Station and the Remote is the same as when the request is made from the local application of the Central Station.

4. Interconnection alternatives

4.1. ISDN

ISDN is an integrated solution for providing basic telephone and data services [12]. It permits point to point connection between two equipments or to be used as an access network for the creation of Virtual Private Networks through Internet [13]. The advantages of this technology are shown in point to point connections:

- Presents bandwidth guaranteed at 100%.
- The bandwidth is symmetrical.
- Increased security, only two pieces of equipment can take part in the communication.

In contrast it provides various disadvantages:

- A high price of the equipment, the admission of the service and the monthly cost which can be invoiced by time or flat rate in permanent connections.
- A basic ISDN access has a bandwidth of 128 Kbits/s divided in two channels of 64 Kbits/s, and so if it is necessary to increase the bandwidth, more channels must be contracted.

4.2. ADSL

The ADSL technology is oriented toward Internet access. ADSL [14] only permits the interconnection of equipment through VPNs, which consists of sending the information by Internet, previously encrypting it, so that it cannot be deciphered by third parties. The advantages of this solution are (see [15]):

- Reduced cost using flat monthly rates.
- More Remote Stations can be added without modifying the router in the Central.

On the other hand there are various disadvantages:

- Asymmetric bandwidth, the channel for sending data is less than that for reception, and so a Remote Station will be able to send as a maximum 128 Kbps with an ADSL access of 256 Kbps.
- Only 10% of the bandwidth is guaranteed which could give transmission of only 128 Kbps which is insufficient for video transmission.
- Lower security, the equipment is connected to Internet, which is a public network and is exposed to attacks by third parties.

4.3. Wireless link 802.11

802.11 is the family of IEEE specifications that address wireless networking [16,17]. The basic purpose of wireless networking is to translate digital signals into an analogue radio signal, then to receive that signal and convert it back into digital.

The favourable characteristics of this solution are:

- The great advantage that the monthly cost is nil.
- Bandwidth greater than ADSL and ISDN.

The great disadvantage of this system is that the two stations to communicate must have direct vision between them.

4.4. GPRS

GPRS is an access technology for the wireless transfer of information. It is an extension of GSM (General System for Mobile Communications) technology and has been designed for applications which go further than voice transmission, where it is necessary to transmit and receive data (see [18]). In [19], a study detailed of the transmission of images and states in real time using GPRS to access at the information by means the PDA has been made. The PDA, Compaq iPAQ 3970 has been used.

The advantages of this technology are:

- Mobility, it permits wireless access from anywhere with mobile coverage.
- Internet access from mobile devices whether they are telephones or PDA, which facilitate access to images and data via Web.
- Suitable for access by the Web now that tariffs are by data and not time.

On the other hand there are some disadvantages:

- Low access speeds.
- High access costs, the tariffs are higher.

4.5. UMTS

It is a technology pertaining to the family IMT-2000 of the system of mobile communications of 'third generation' (3G) of ITU (International Telecommunication Union). The objectives of the 3G are: to provide a system of global communication and the integration of networks and services. With these it tries to provide (see [20–22]):

- Global roaming.
- Internet access with broadband.
- Connection to the network at any moment.
- Voice communication.
- Multimedia services in real time.
- Information according to the location.
- Video conference.
- Unloading of applications…

The European Telecommunications Standards Institute (ETSI) has defined the interface or radio access for UMTS, the UTRA (UMTS Terrestrial Radio Access), that is based on the technology W-CDMA (Wideband Code Division Multiple Access) which supports two ways of operation: FDD (Frequency Division Duplex) and TDD (Time Division duplex). With the access radio W-CDMA a greater number of users by MHz are obtained and in addition the quality of the information transmission is increased, meaning speeds of transmission can be obtained from 384 Kbps for full coverage to 2 Mbps for local coverage. At the moment, service UMTS uses W-CDMA in operation FDD (Frequency Division Duplex) and allows 384 Kbps of velocity (see [23]).

5. Experiments and results

The experiments have been done in the real heterogeneous system that has been presented in section 2. In Fig. 1, the different technologies that are going to be analyzed are shown.

The results are presented in two parts:

(1) The measurements of the interconnection alternatives between the Central and the Remote Station gateway (see Section 5.1).
(2) The measurements of the access networks technologies that can be used by a mobile user that connect to the system remotely by means a Web page (see Section 5.2) .

5.1. Measurements of the communication Central Station-Gateway

To obtain the measurements of ISDN, ADSL and 802.11, all the tests were done with three video sequences stored on

Table 2
Test sequences

Sequence	Size (KB)	Duration (min)
C2	341.192	2.34
C3	364.450	2.36
C4	472.302	3.16

disc (see Table 2) to thus analyze a same test set. Two important parameters were used: 'Forced Quality' (FQ) and 'Constant Bit Rate' (CBR), which influence the compression quality (PSNR), the size, the compression time (CT) and the decompression time (DT) of each image decisively. For each sequence four quality levels were used, obtained with different values from FQ (87, 56, 30 and 18). With the size of the frames of these three sequences in their different qualities and the transference rate obtained for every one of the technologies with the software IPERF (see [24]), the *number of images per second* that the system can offer in every case has been calculated. It is necessary to reach a compromise between quality and compression level, due to it being a monitoring application, where a very high quality is not necessary. In the experiments, it has been observed that the MorganFQ30 compression (PSNR of 34.38 dB) offers an acceptable quality for the monitoring and control application. Diverse experiments were taken in different hours trips during different days, taking samples every 15 min to obtain the channel speed.

Furthermore, for these three types of interconnection, measurements were taken to obtain the *response time*, that is, the time from when a request is made to a Remote Station from the Central Station and it is received, processed, the state is modified and notification of this change is sent back to the Central Station. For the system that is being evaluated, a response time of 1 s is considered sufficient to receive the warning of alarm. In the experiments, each day 40 orders were executed (changes of state) randomly.

5.1.1. Point to point connection through ISDN

For this connection, it was observed that the obtained speed values of the channel were practically constant, with very small variation and without cuts. For the MorganFQ30 compression almost 6 *images per second* can be transmitted, (see Fig. 7).

Measurements to the *response time* are shown in Fig. 8 and the values obtained are inferior to 1 s, then the goal is achieved.

5.1.2. Connection by VPN/IP on ISDN

A greater speed variation was observed than in the point-to-point connection, since the speed of the connection depends on: the speed that the ISP (Internet Service Provider) offers and the state of the Internet. There were moments in which the communication was interrupted and then reinitiated after a few seconds. This creates a decrease in the average value of the speed of the channel and its reliability. For each of the compression levels the *number of images per second* which can be transmitted was always smaller than with the point to point connection, as can be seen in Fig. 9. There were also reliability problems that could cause instability in the channel speed.

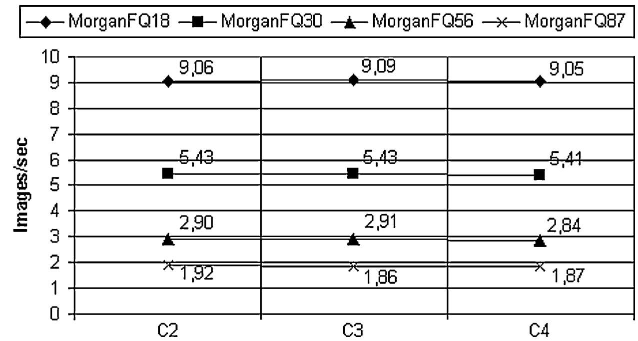

Fig. 7. Number of images per second for the interconnection by means ISDN point to point.

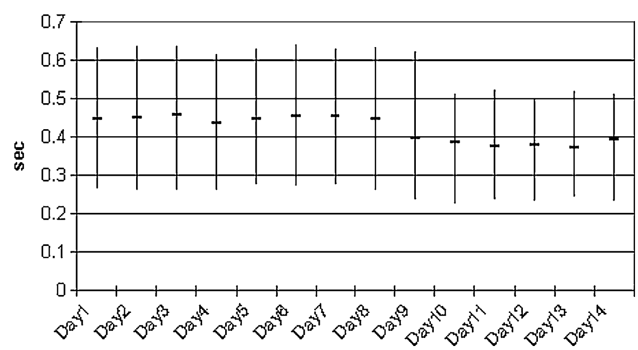

Fig. 8. Response time for interconnection through ISDN point to point.

As regards the measurements of the *response time*, the values obtained are shown in Fig. 10. Over 14 days the response time was inferior to 1 s; therefore, this interconnection provides a good value.

5.1.3. ADSL measurements

The average velocity of reception over the period studied was 99.52 Kbps, the maximum 102 Kbps and the minimum

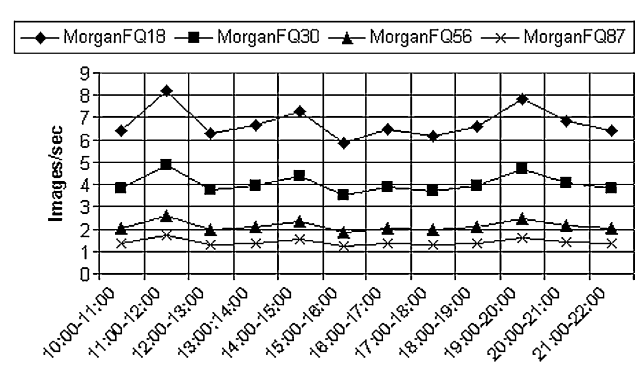

Fig. 9. Number of images per second for the interconnection by means VPN through ISDN.

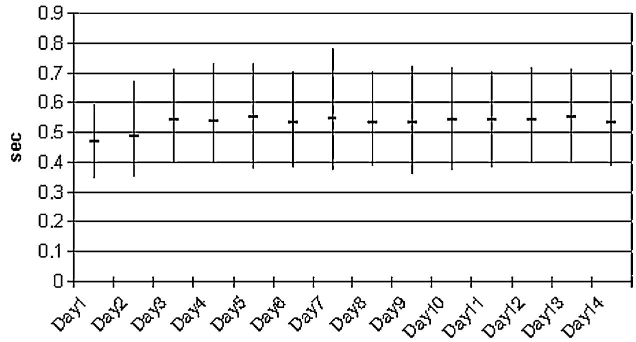

Fig. 10. Response time for the interconnection by VPN ISDN.

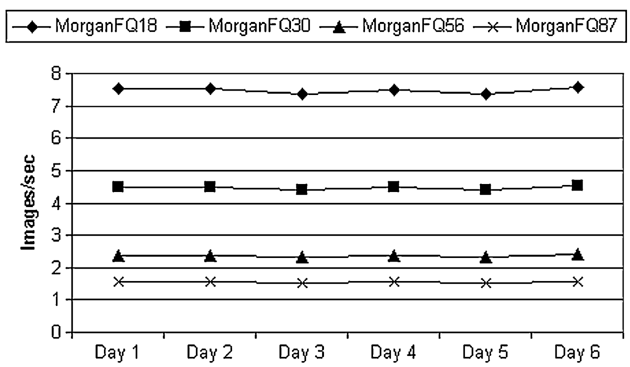

Fig. 11. Number of images per second in the connection via VPN with ADSL access.

93.5 Kbps. During the recording of measurements, it was observed that the speed on some occasions was irregular, sometimes pronounced drops in transmission being seen. In any case, in the majority of the tests that have been made, the bandwidth has been quite regular although always below 128 theoretical Kbps of reception (download). The *number of images per second* which can be transmitted in a second is shown in Fig. 11. The *response time* for the VPN interconnection on ADSL is shown in Fig. 12.

5.1.4. 802.11 measurements

The distance between the two stations that have direct vision and have been used to make the measurements is of 2.5 Km, as can be seen in Fig. 13.

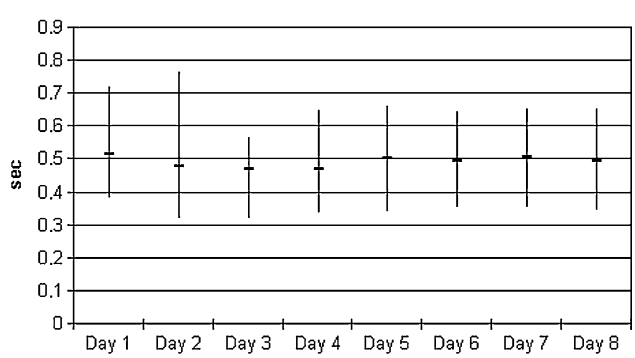

Fig. 12. Response time with ADSL connection.

Fig. 13. Distance between the Central Station and the Remote Station that has direct vision.

In the first place measurements of the different channels were made to see the operation in each of them, and to use this to provide better performance. Some cuts in transmission were observed in the channels. The useful bandwidth in the 13 channels available oscillates between 1.98 and 2.99 Mbps (channel 10). During the tests of the different channels, changes in the bandwidth have been observed. According to the measurements, the theoretical values of the *number of images per second* that can be reached with this type of interconnection is very high (between 35 and 230 images/s), independent of the degree of compression of the images, as can be observed in Fig. 14.

Evidently, it is not necessary to obtain more than 25 or 30 images per second, because these values are sufficient for the human eye to have the sensation of movement. In addition, because of being an application of monitoring and control, it does not need to obtain a high number of images per second, therefore; in this case the user imposes the limit. It has been considered that a value between 5 and 10 images per second is sufficient for the utility of the system, avoiding that the transmitted and stored videos in the Central Station reach a great size, and reserving bandwidth for connecting a greater number of cameras in those remotes where it is considered necessary to have more supervision information. For example, in channel 10 where 2.99 Mbps were obtained

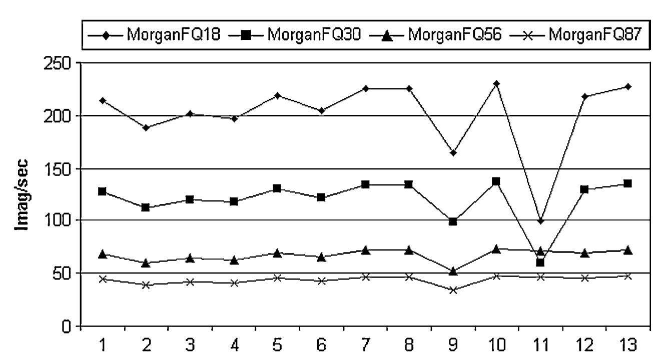

Fig. 14. Number of images per second for the interconnection by means 802.11 in different channels.

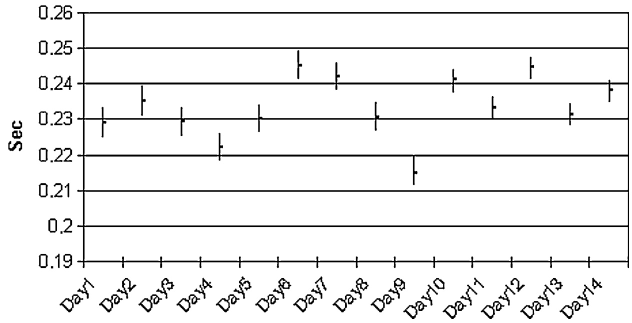

Fig. 15. Response time with 802.11 connection.

20 cameras could be connected obtaining 10 images per second.

In Fig. 15, the *response time* is shown. The variation between 1 day and another can be observed, but the value is always lower than 0.26 s. It is a very short time, very necessary for a supervision system.

5.2. Measurements web application in Central Station—remote mobile user

For UMTS and GPRS, which are the technologies that a remote client connected to a Web page would use, the *transference rate* has been measured. In this part of the system, it is important to know how long an image will take to update. Then, with the transference rate and the medium size of the images visualized in a PDA (176×144, 6 Kb) and in a PC (352×288, 17 Kb) the update time has been obtained. The measurements of the transference rate were made using two different methods. The first method used was the connection using every one of these technologies to a Web page that measures the transference speed (Kbps). The steps to carry out the measurements are the following: A primary estimation of the speed is made sending a page of a fixed size. Measuring the time taken to download the page, a primary result of the speed of download is obtained. Secondly, the real measurement is carried out by sending a page of an appropriate size at the speed calculated in the previous stage. In the second method an FTP server is used. A file of fixed size is downloaded from the FTP client, and the time and size of the download is obtained, calculating the rate in Kbps.

5.2.1. GPRS measurements

The characteristics of the PCMCIA GSM/GPRS Xacom card used are the following:

- Class 12 SW (4+4, 5 simultaneous).
- Transference velocity 67.0 Kpbs in Coding Scheme 2.

For GPRS the measurements made with the two different methods that have been explained, offer very similar results.

Measurements were also taken of the '*transference rate*' on different days. In Fig. 16, the variability of the transference rate (Kbps) over a period of 5 days is shown, where the measurements have been taken between 9:00 h and 18:00 h with intervals of 15 min in the city of Alcoy. In [19], these measurements are described in detail.

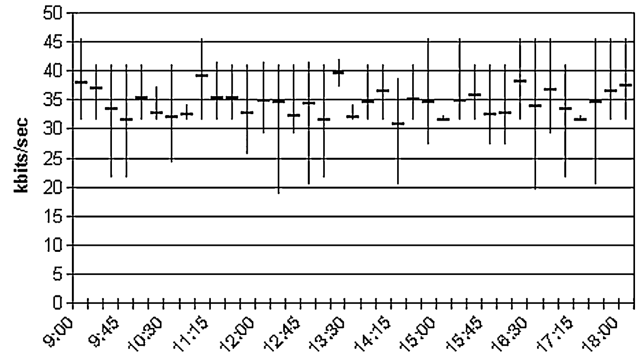

Fig. 16. Rate of transference obtained using GPRS connection over a period of 5 days. Average values, maximum and minimum.

Also, it is observed that the transference rate obtained is variable and the maximum and the minimum are very different from the average. This transference rate has been obtained in three other cities in different time zones, and similar results have been observed.

According to Fig. 16, the average speed, which is indicated in the characteristics of the card (67.0 Kbps), is not reached. To obtain the transference rate as well as the characteristics of the card, other factors have to be considered: GSM users who are using voice, the GPRS users who are connected, the geographical area, and the operator who offers the service, in the case of the tests, the Spanish company Telefonica Movistar.

Bearing in mind that the JPG image that is visualized on the PDA Web page has a size that varies between 4 and 7 Kb, the time to download the image, taking an average rate of 34.46 Kbps, varies between 0.91 and 1.63 s (T_U, unloading time). Also, there are other times to consider: internal processing time (T_{IP}, 1–1.5 s), in which the defragmentation and decompression tasks are included, T_V, visualization time, is the time that the user needs to be able to observe the image, which various observers believe should not be inferior to 3 s, and finally, a propagation delay (ΔT) is considered between 0.066 and 200 ms (see [25]).

Considering the worst case, the time (T) that must be established for the updating of the image on the PDA web page follows the expression below:

$$T = T_U + T_{IP} + T_V + \Delta T = 1.63 + 1.5 + 3 + 0.2 = 6.33 \quad (1)$$

If this same time is calculated for the best case, the result obtained in (1) is 4.91 s. However, in the tests which have been carried out with this time the image was not completely downloaded in some of the attempts. With a time of 6 s, the images are visible, therefore, this time has been established. In any case, in the Web page for the PDA,

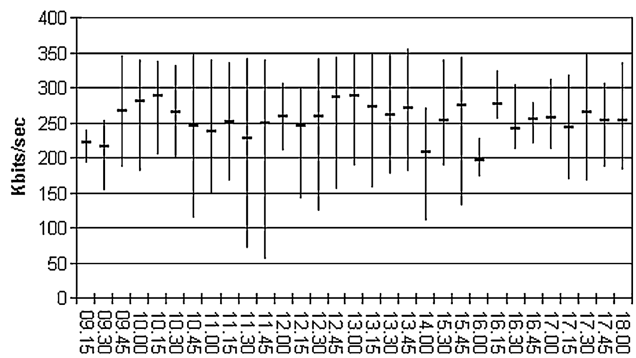

Fig. 17. Transference rate obtained using connection UMTS. Average, maximum, and minimum values.

Table 3
Monthly cost of the Remote station. ISDN

	Access cost ISDN (2B+D)	Cost of calls (€/month)	Total (€/month)
*ISDN*_1 with MT	22.84	MT	22.84+CCM
Permanent *ISDN*_2	22.84	120.20	143.04
*ISDN*_3 exchanged with FR	22.84	96.16	116
VPN/IP on *ISDN*_4 GQ	22.84	21.90+3.30	48.4

Mt, metropolitan tariff; CCM, cost of calls for metropolitan tariff; FR, flat rate; GQ, guaranteed quality.

the possibility of selecting the time of refreshment between 6, 8 and 12 s exists.

5.2.2. UMTS measurements

For these experiments the laptop Dell Latitude CPx with an Intel Pentium III processor to 500 MHz and 192 MB SDRAM was used. The card used is the PCMCIA UMTS/GPRS Merlin TU510 of Novatel Inc. Inside this card the USim Movistar is introduced, similar to a traditional USim but with more capacity (128 Kb) and it is associated to the Movistar Plus Datos UMTS contract which is used for the tests. According to the operator, the theoretical maximum speed that can be reached is 384 Kbps. The measurements of the transference rate throughout 5 days in a zone of the city are shown in Fig. 17.

These measurements have been made using the Web test page. The values obtained although variable are quite a bit higher, although, using the Web test page the reductions in the bandwidth of the connection have not been appreciated, due to the test obtaining the average rate in a brief period of time. On the other hand, if a FTP is used, the average transference rate is smaller to that shown in Fig. 17, due to the duration of the test being greater and the average being affected by the low values of the speed of the transference at some moments. On other occasions the tests by means of the FTP client have not been able to be finalized because the connection was cut and the file was not received.

With the tests made, considering a rate of average transference of 246.2 Kbps and a medium size of image of 17 Kbytes, 1.81 images/s could be visualized. In the tests the update of the image every 2 s has been obtained, if no cuts occur.

In this study, the measurements with UMTS have been made with the Spanish provider Telefonica Movistar but in [26] a similar study with the Vodafone provider is presented and parallel results have been obtained.

5.3. Interconnection costs

The monthly costs for ISDN, ADSL and GPRS for the Central and Remote Station are presented in different tables, disregarding the cost of setting up the service. All the costs are obtained in euros, €.

To better understand the meaning of Tables 3 and 4 some abbreviations have to be explained.

The cost of calls in metropolitan tariff depends on the hour of the day that the call is made. Then CCM (Cost of Calls for metropolitan tariff) has the following cost, Normal hour hand: 0,0240 €/min (8:00 am to 8:00 pm) and Reduced hour hand: 0,0099 €/min (8:00 pm to 8:00 am).

The Cost of Additional Lines (CAL) is the same for all the ISDN options. The cost of one additional line with two channels B is 14.77 €.

The Additional lines (AL) are the lines that we have in addition to the basic line and NL (number of lines) is the total number of lines, NL = 1 + AL.

The price of the Flate Rate (FR) with guaranteed quality is 25.20 €.

For the wireless link 802.11 in the remote stations there is no cost, if the costs are considered only for the communication between the Central Station and the Remote, the cost of the Central Station would be nil, but

Table 4
Monthly cost of the Central station. ISDN

	Access cost ISDN (2B+D)	Cost of calls (€/month)	Total (€/month)
ISDN_1 with MT	22.84	MT	$22,84 + CAL * AL + CCM$
Permanent ISDN_2	22.84	120.2*NL/2	$22.84 + 120.2 * NL/2 + CAL * (AL - 2)/2$
ISDN_3 exchanged with FR	22.84	96.16*NL	$22.84 + 96,16 * NL + CAL * AL$
VPN/IP on ISDN_4 with GQ	22.84	(21.90+3.30)*NL	$22,84 * NL + CAL * AL + NL * FR$

Mt, metropolitan tariff; CCM, cost of calls for metropolitan tariff; CAL, cost of additional lines; AL, additional lines; NL, number of lines; FR, flat rate.

Table 5
Monthly cost of the Remote station. ADSL

	Analogical line	ADSL	Fixed IP	Total (€/month)
ADSL 256 K	12.6196	39.07	12	63.6896

Table 6
Monthly cost of the Central station. ADSL

	Analogical line	ADSL	Fixed IP	Total (€/month)
ADSL 512 K	12.6196	74.98	12	99.5996

some type of interconnection for the Internet access must be considered, because the Central Station works as Web server. The flat tariff of ADSL has been considered (see Tables 5 and 6).

For GPRS, the monthly cost for the flat rate is presented in Table 7, and for every Mbyte that was consumed over the 75 Mbytes offered, the price is 0.55 €.

As far as the UMTS services are concerned, in Table 8 the costs of the operator used are presented. It is the same price as GPRS.

5.4. Analysis of results

The number of images per second that can be obtained in general in the system is an important parameter, but the costs must also be borne in mind. In order to better compare the different types of interconnection studied, in Figs. 18 and 19 the relationship between costs (€) and benefits (images/second) is shown. In Fig. 18, this relationship with the different types of interconnection for the Central Station is presented. To calculate the total cost of calls the formulas in Table 4 were used and an estimation was made, considering 4 Remote Stations (AL = 3 and NL = 4). For the calculation of the CCM in the ISDN connection with metropolitan tariff the estimation was 4 h in the normal hour hand and 2 h in the reduced hour hand.

ISDN with the metropolitan tariff (ISDN_1) has the highest costs, but an acceptable value of images per second (5.4) is achieved. ISDN with permanent connection (ISDN_2) is cheaper but a very small number of images (2.7) are obtained, owing to the fact that this connection only permits a channel of 64 Kb.

Table 7
Monthly cost GPRS flat rate

	Flat rate	Monthly cost	Additional cost
GPRS	75 Mb	35 €	0.55 €/Mb

Table 8
Monthly cost UMTS flat rate

	Flat rate	Monthly cost	Additional cost
UMTS	75 Mb	35 €	0.55 €/Mb

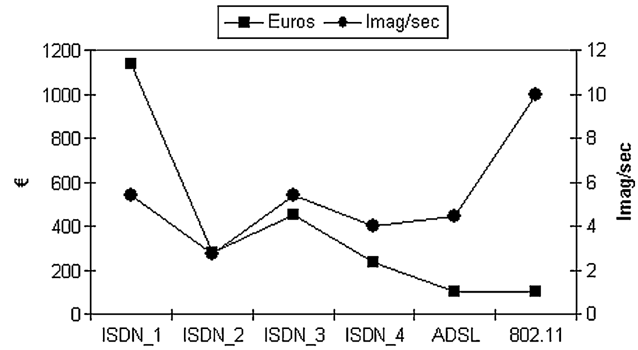

Fig. 18. Relationship between the costs and benefits of each type of interconnection in the Central Station.

For the ISDN_3 option (flat rate), the number of images per second is the same as that for the connection with the metropolitan tariff, and this has the advantage that it is cheaper. However, it is difficult to compare these two options because of the cost calculation of metropolitan calls depends on the hours of connection considered, that is, if fewer hours were considered the cost was lower.

For the connection using ISDN via VPN (ISDN_4) the costs are lower, but the number of images and the quality are lower too.

Using ADSL, the costs are lower than any ISDN option and with a number of images per second (4.46) which is acceptable for a remote control system.

Finally, the best relation between costs and number of images per second is presented by the wireless connection, because the costs are very low, being able to reach the greater value of images per second (10 images/s have been considered because as has been explained, a higher number is not necessary and the bandwidth can be reserved for other information).

In Fig. 19, the relationship between costs and images per second in the Remote Station is shown. To obtain the cost for the Remote Stations, Table 3 has been used. For ISDN with a metropolitan tariff (ISDN_1) the costs are reduced

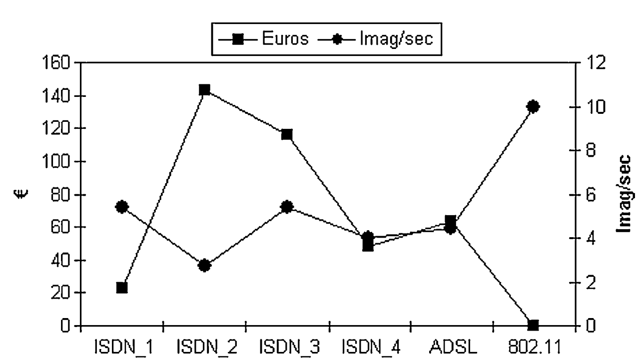

Fig. 19. Relationship between the costs and benefits of each type of interconnection in each Remote Station.

taking into account that the Central always will make the calls (CCM has been considered 0 €), the Remote could call to send the changes of state, but as the connection time will be very short it was considered to be nil. If the permanent connection is chosen (ISDN_2), the costs could be high and possibly few images could be supplied, since a single channel of 64 Kb would be counted on. For the ISDN_3 option, the number of images per second is the same as that for the connection with the metropolitan tariff. For the connection using VPN (ISDN_4), the number of images per second is the lowest of the four connections, which uses 128 Kb, although the cost is also lower. As in the Central Station the smaller cost in the Remote Stations presents the wireless connection.

As regards the response time, the tunnel over ISDN offers the worst results, with average values (0.53 s) greater than point-to-point ISDN (0.42 s), ADSL (0.49 s) and 802.11 (0.23 s). Therefore, all the types of interconnection present an average value inferior of 1 s. 802.11 on the other hand, presents the best response times, followed by Point-to-point ISDN closely followed by ADSL with similar results. Nevertheless, it should be said that the delay introduced by the channel has been studied in ADSL and ISDN and it has been confirmed that the delay is less in a point-to-point connection by ISDN since only one path exists with two jumps for the IP packets and these always arrive in order. The VPN by ADSL delay is greater since the IP packets have to cross a greater number of routers. So, although in the measurements made the response times have been very similar, due to the fact that the quantity of information transmitted is very small (5 bytes), if the reception of the states is made simultaneously with the reception of the images, the response times in ADSL would be greater than those obtained with point-to-point ISDN.

6. Conclusions

As regards performance, with ISDN, it has been proved that the bandwidth is guaranteed. Therefore, if a guaranteed number of images per second are needed (5.43 with average quality, 2.90 with good quality and 1.92 with maximum quality) ISDN is a good solution, but the costs must be borne in mind. On the other hand, the tunnel on ISDN presents the worst performance given that the bandwidth is irregular and there could even be cuts in transmission. This solution is rejected for a supervision and control system.

With regard to ADSL we are only guaranteed 10% as in certain circumstances the situation could arise where the speed of transmission would be notably reduced. Nevertheless, in the measurements taken, it has been observed that the ADSL bandwidth remains quite regular in the region and furthermore it has been confirmed with a network monitoring program that the variations are minimal except on rare occasions. So ADSL is a good solution because it is cheap, a good value of images per second acceptable for remote control is received, (4.5 with average quality, 2 with good quality and 1 with maximum quality) and the response time is not very long.

Nevertheless, in those Remote Stations where there is direct vision with the Central Station, the wireless link 802.11 due to its benefits will be used, since the cost is minimum and the number of images per second that can be reached is greater (10 images/s with any quality) than with the interconnection by means of ISDN or ADSL. But always it needs direct vision, and so its application is only for point to point links.

In conclusion, we can say that technologies studied in this paper to connect the Central and the Remote Stations are good solutions, and each one is appropriate to a specific situation, depending on the requirements. If a guaranteed flow is required the better option is a symmetrical technology with guaranteed QoS but we have to consider that it is more expensive than an asymmetrical. If the requirements are lower this is a good option.

Finally, the performance measurements for GPRS have shown that the bandwidth is quite irregular, but adequate for web use, despite the delay in transmission of images being greater than with a cable connection. As regards the cost, the prices are quite high, flat rate 75 Mb being the most appropriate. However, it is sufficient for the transmission of data and images. So, GPRS and UMTS currently are accesses for occasional consultations, but not for a continual supervision of the system.

With regard to UMTS, in recent years the characteristics of this system and its coexistence with GPRS and GSM have been studied as is possible to observe in articles [27–30] published by the operators' own department of research to improve their service where it was implanted definitively, for that reason the results will improve quickly. At the moment, in the zones where the coverage allows it, an acceptable update time of images in the Web is reached: 1 image every 2 s.

In the future, other technologies such as Wimax 802.16 will demand special attention as economic transport systems in Metropolitan Area Networks (MAN) for supervision and control applications.

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