Deployment of Digital Video and Audio Over Electrical SCADA Networks

J. I. Escudero, J. A. Rodríguez, M. C. Romero, and S. Díaz

***Abstract*—With the arrival of new hardware and software technologies, supervisory control and data acquisition human-machine interfaces (SCADA/HMI), usually text-based, can now benefit from the advantages the inclusion of multimedia information brings. However, due to the special requirements imposed by such systems, integrating audio and video data into the SCADA interfaces is not a trivial task. In this document we analyze those special characteristics and propose solutions so this integration is possible in power systems communication.**

***Index Terms*—Audio coding, digital communication, multimedia communication, power systems communication, supervisory control and data acquisition (SCADA) systems, video codecs.**

I. Introduction

TRADITIONALLY, supervisory control and data acquisition/human-machine interface (SCADA/HMI) systems have limited the display scope of status information and alarms logs to simple text characters.

This was mainly caused by the status of hardware technology at that time:

— systems were proprietary ones as there were not widespread hardware or software platforms;
— the early stage of development of the networking technologies;
— video and audio compression techniques were not efficient enough to be used on systems other than scientific mainframes.

Proprietary systems meant there was a strong dependence between the software and hardware parts, so only those who built the hardware systems had the knowledge to develop software applications that could be executed over those systems. That leaded to expensive and incompatible platforms where the original manufacturer could only do any improvement.

The relatively low processing power of those systems, together with the low bandwidth offered by the besides custom network technologies, prevented SCADA/HMI systems from using audiovisual information. Video and, to a lesser extent, audio information needed too much bandwidth to be transmitted over the existing networks, and even if that was the case, it would end up being too expensive to be used.

Throughout the last two decades, at a greater or lesser level, all these technologies (computer hardware and software, networking and audiovisual processing and analysis) have steadily been improved, while the cost of acquiring them has decreased.

1) The hardware side has benefited from a raising level of semiconductors integration, which has lead, among other improvements, to more powerful processors and faster and larger memory subsystems. Now, thanks to the new standard hardware architectures that have arisen, and along with new cost-effective widespread software platforms, we have at our disposal interoperable and hardware-independent systems.
2) Networking has also evolved over the years, and as a result from this, we can make use of many different transmission technologies, both affordable and powerful.
3) Audio and video processing has also been dramatically improved. Standard compression technologies such as MP3 and MPEG-4 allow comprising a huge amount of information in a relative small space.

In few words: we now have systems capable of processing huge amounts of audiovisual information and transmitting it to remote locations [1], all at an affordable cost.

In the case of SCADA systems, they have progressively adopted these new technologies, but, due to their special characteristics, at a slower rate. SCADA systems are typically huge systems, so the cost of upgrading them is greater than other typical systems.

They are targeted to supervise critical processes. In such processes, fails on the system could have adverse side effects, so only those technologies that have been tested enough are taken into consideration.

II. Physical and Data Link Layers on SCADA Systems

Classic SCADA systems were centralized systems. But modern SCADA systems are distributed ones, what means different nodes do the processing, instead of performing it in a single, centralized, machine.

Although the division of the existing buses on a SCADA system differs depending on the author, it is widely accepted there are at least three different types of them, in function of their temporal requirements [2], (Fig. 1).

Data that comes from the sensors and is sent to actuators, due to the special temporal requirements needed, is transmitted over the so-called **field buses**. These are buses where operation is done in real time, and are designed to support a high traffic of limited messages in the form of orders and status data. They are buses with low transmission rate and cable length [3].

These buses are typically proprietary ones, but in the last years some open buses have been developed. The most used are CAN Open, DeviceNet and AS-i.

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The authors are with the Departamento de Tecnología Electrónica, E.T.S.I. Informática Universidad de Sevilla., Avda., Reina Mercedes s/n 41012, Sevilla, Spain (e-mail: ignacio@us.es).

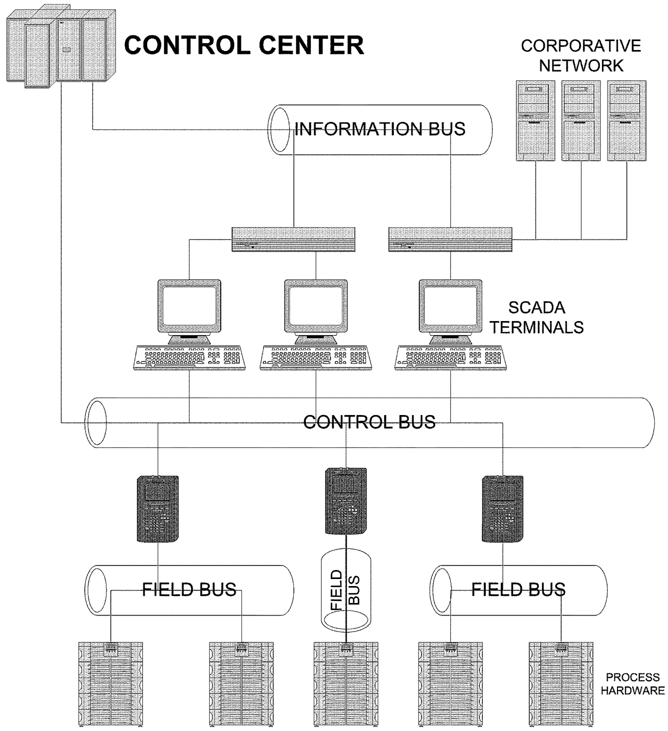

Fig. 1. Typical buses on SCADA systems.

The communication between process control devices and/or between personal computers with SCADA/HMI applications is usually performed over another type of bus, known as **control bus** [4].

Control buses have higher transmission rates and more relaxed temporal restrictions than field buses; the network reach is also wider than on field buses. In example, ControlNet reaches 5 Mb/s and allows links with a length of up to 30 Km if optical fiber is used. A segment of a Modbus Plus bus has a maximum length of 500 meters while transmitting at up to 122 Mb/s.

The rise of personal computers (PCs) introduced the need of interconnecting a set of PCs in the same subnet, so they could share information. These systems work on environments less tough than the former ones, whilst at the same time they need to deal with a greater data load. These buses are known as **information buses**.

Internet and the TCP/IP protocol have imposed a fact standard, Ethernet, which is widely used on this type of buses.

We have focused on studying the topology of the electrical distribution networks. These networks are usually wider than those used on industrial applications.

From this study, the following considerations can be taken into account.

- Remote stations can be located at far distances from the control center.
- Transmission between remote stations and the control center(s) is performed over medium voltage electrical lines or using radio signals, at slow rates.
- Only new stations use to have another type of physical links, usually fiber optic.
- Equipment within the remote stations are exposed to high intensity electromagnetic distortions.
- The bandwidth offered by the typical field buses is not enough to room audiovisual information with a decent quality. It should not be forgotten that the information must be detailed enough to give extra details that could not be obtained with the usual text displays.

Depending on the links available on the control and information buses (if existing), it will be more or less likely multimedia information can be transmitted over them.

Information buses are designed to support a high load of information, but control buses are more sensitive to such floods of data, as status and control messages arrival cannot be delayed too much.

It is recommended not to share the physical medium between the audiovisual information and the SCADA real-time information, but in the event it is, multimedia data should be transmitted on different channels than those used by supervision information so it does not interfere with the latter.

A study of the different available transmission technologies has been made, analyzing their advantages and drawbacks with regard to their possible use as communication channels.

A. Electrical Links

Power line communication (PLC) refers to the transmission of signals over electrical lines, at frequencies other than the $50/60$ Hz of the alternating current. This technology turns any electrical plug into a potential connection to all telecommunication services.

Although it has been widely used on SCADA systems from the beginning, the bandwidth was quite limited. In example, the CENELEC EN 50065 standard specifies 148.5 kHz as the highest usable frequency.

Nevertheless, further research done over the last years has brought this technology to the front. The use of coding methods such as ODFM allows the transmission of information over low-tension electrical links at speeds of up to 45 Mb/s.

With regard to electric utilities, remote stations are usually linked to the medium voltage distribution systems, using medium to low voltage transformers to feed the stations.

Tests have been made over medium voltage links showing further improvements must be done in order to take profit of them as a transmission medium to multimedia information. The main problem lies in the distribution transformers, which limit the effective transmission reach of communication signals to a few hundred of meters. Anyway, although high speed PLC transmission is still under development, it is the recommended solution as it allows enterprises to cut down on expenses in infrastructures, and it is also an alternative to other technologies in case their use is not profitable, or not possible.

B. Telephonic Lines

Can also be taken under consideration when choosing from the different available options.

Tests with 56-kb/s V.92 modems have showed the rate they reach is not fast enough to transmit suitable audio and video streams. ADSL technology could be a solution, but hardly any telecom provider give support to them outside urban areas.

C. Optic Fiber

One ideal solution as it both has a big bandwidth and is not affected by electromagnetic perturbations.

New construction facilities tend to use them because of the mentioned reasons; in the case of electrical companies, the optic fiber is usually laid along with the medium voltage electrical cables.

D. Non-Guided Links

The use of radio and microwave signals is also a good solution to long distance transmissions.

Solutions based on the 802.11 standard offer reach of up to several kilometers. There exists equipment that allows integrating 802.11 systems into 802.3 networks.

It must be taken under consideration that the longer the link is, the lower is the effective transmission rate that can be obtained. Also, an important investment must be done in the antenna equipment when trying to communicate two distant points.

III. Multimedia SCADA Nodes

At the network layer, IP protocol is proposed as the solution to interconnect the different subnets constituting the full SCADA network, as nowadays operating systems and SCADA/HMI suites offer full support to this protocol. It not only allows interconnecting different lower level protocols, but it also allows making use of the extensive transport protocols and applications that make use of it.

The central core of the system performs basically the management of multimedia information [5]. In consequence, we need to perform a detailed analysis of all elements that take part in the process and the technologies available to develop them.

A. Multimedia Data Acquisition

First, it is essential to analyze which hardware elements allow capturing video and audio information.

Multimedia signals must be in digital form so computers can process them, so in case they are analog they have to be previously digitized.

This is the case of analog cameras; as they need additional capture hardware to perform the analog to digital conversion of the input signal. On the contrary, digital cameras (i.e., web cams) already offer a digital flux; at worst they would need additional hardware so they can be connected to the computer.

This digital data use to be coded on the raw RGB24 or the spatially compressed YUV color spaces, although some cards offer the possibility of compressing the data with codecs such as MPEG. In the case of digital cameras, some use color-compressing methods (usually YUV variants) to reach higher pixel resolutions or frame rates.

The use of compression is highly unwished in this first phase, as it requires additional use of processor time because if data is acquired in a compressed format and an analysis of the data is needed. It would be necessary to decompress it before being able to perform any processing on the images/sounds. Also, if on a later phase we need to compress the information using another decompression technique, a previous decompression of the data would also be needed.

Once acquired, both the video and audio information are managed the same way, so from now on we will concentrate on the video side, knowing that the same is applied to audio data.

The main difference when dealing with video and audio processing consists on video data needing more resources (bandwidth, processor time, etc.) than audio to reach the same level of perceptual quality.

B. Signal Analysis

This module analyzes the input data, so abnormal situations can be detected, and warnings or alarms given on consequence.

This is a process that needs a lot of system resources, so this module could be located on a different computer or card.

In case a different computer is used, it would be needed to network it with the capture system, obtaining the multimedia data through a high-speed leased link.

C. Signal Compression

After the initial signal acquisition stage, it would be desirable to perform the compression of the captured data, so it needs less bandwidth to be transmitted [6].

There are two compression methods: **lossy** and **lossless**. With a lossless format, later decompressing/compressing operations will not alter the quality of the generated data, while when using a lossy format, those operations will mean progressive signal deterioration, and with the consequences it carries to the image fidelity.

However, the compression ratios reached by the lossy methods widely surpass those reached when using loss less algorithms. The former can reach up to 50:1 compression ratios whilst the latter hardly reach 2:1 ratios.

Because it is only needed to compress the data once, and decompression is a task that needs a relatively low amount of system resources, lossy formats are the recommended ones.

There are many lossy codec technologies available (wavelet, fractal, DCT, etc.). Those based on DCT are by far the most widely supported and they also offer a great quality/compression power relation, so if we had to choose we would use DCT based codecs.

D. Semi-Temporal Storage

As it is being generated, the multimedia stream can be stored so it is available for later use.

In such a case, only a limited period of time is usually stored, making necessary a stream trimming strategy, as the input stream is a continuous one. Note that the close, creation and deletion of the involved files can cause the loss of information during the process.

The stored data may also need to be sent to those stations that ask for it, meaning the encoder software/hardware must be able of generating multiple output streams.

As the signal analysis module, it can be located on other computer than the one where the capturing process is done. Unless a high-speed leased connection exists between the storing and the emitting stations, the use of high performance, big capacity, hard disk units is the recommended solution.

E. Multimedia Data Streaming

This module is dedicated to the distribution of the multimedia information so it is available to remote stations.

Basically, the streaming process consists in trimming the continuous input data and distributes it over the network. This job is mainly done at transport level where the usual **transport protocols** used when streaming are as follows.

1) UDP (User Datagram Protocol): It is a connectionless transport protocol, perfect for the distribution of real-time information, as it does not guarantee the delivery.

It may seem, as a drawback instead of being an advantage, but it is particularly beneficial when doing real-time streaming. Unlike data as files or e-mails, which need to be entirely delivered without regard to the time taken in transmitting them, the value of real-time multimedia data decreases as time goes. So, if a frame is lost in its way, it is not worth the effort of re-sending it, as it is more than probable later frames are already being played. The retransmission of lost frames would suppose a waste of bandwidth.

It must be noted multimedia streams must have additional synchronization information in order to be able to play the data. The lost of the sync information will probably lead to a lost of the synchrony during the playback, what supposes a problem when using only UDP to transmit the data.

Another drawback of UDP is that, due to security reasons, it is possible UDP packets cannot pass through firewalls.

2) TCP (Transmission Control Protocol): This is a connection-oriented protocol, and the dominant one in Internet.

The drawback of TCP when dealing with real-time data is it retransmits the nondelivered data, so it supposes a waste of bandwidth. Anyway, if the need of keeping the integrity of the multimedia data exists, it is the recommended protocol. It solves the problems related to the lost of synchronization data.

As with UDP, it can also happen TCP packets cannot pass through certain firewalls.

3) RTP (Real-Time Transport Protocol): It has been designed to be used on real-time applications.

Usually placed on top of UDP, it may be used along with other transport, or even network layer, protocols.

Occasionally, packets can be lost or they may be received disordered at the destination, what can be very harmful to the stream sync. To solve those deficiencies, the RTP header holds temporal information and a sequence number that allows the receiver side to rebuild the media information.

Additionally, and based on the previously described transport protocols, some **solutions at application level** are commonly used to the delivery of multimedia information:

a) HTTP (Hyper-Text Transfer Protocol): Based on TCP, and not specifically designed to deal with real-time data, the advantage of using HTTP is data sent using this protocol is able to pass through firewalls on most occasions.

Even though it introduces extra data and additional delays when transmitting multimedia information, it is a valid solution on most occasions.

b) RTSP (Real-Time Streaming Protocol): Taken directly from the protocol memo [7]: *"The Real Time Streaming Protocol, or RTSP, is an application-level protocol for control over the delivery of data with real-time properties. RTSP provides an extensible framework to enable controlled, on-demand delivery of real-time data, such as audio and video."*

It can be used over any transport protocol, usually RTP.

F. Remote Control of Devices

In case it is required to have advanced control functions over the capturing device, a module implementing a control interface will be needed.

This is especially useful when working with cameras; with a remote control module, their position, zoom and focus state can be managed. The bandwidth requirements to such operations are minimal.

It is only left to say that, to this purpose, it is recommended to use a standard protocol to send the commands to the cameras and receive their status. Sony's VISCA, a device-and platform-independent protocol for synchronized control of multiple video devices, is widely used on these applications.

IV. Integrating the Multimedia System With SCADA/HMI Suites

The integration of third-parties applications on SCADA software systems has historically been a difficult task.

Over the last years the effort of the developers of the most known SCADA/HMI suites (Intellution's iFIX, WonderWare's Factory Suite, etc.,) have focused on adopting the latest software technologies.

Modern suites run over mass operating systems, such as Windows (usually only on professional, more stable versions such as Windows NT or 2000) and, to a lesser extent, Linux. In our research project, we have selected Intellution's iFIX as our testing platform, a SCADA/HMI suite that works on Windows 2000 and Windows XP Professional operating systems.

iFIX, as most latest SCADA suites, support the latest technologies developed by Microsoft. Apart from supporting Visual Basic for Applications, which allows the use of VB inside the HMI application, it is being built as an ActiveX container. This allows integrating third-parties applications designed as ActiveX controls.

As ActiveX controls can be built using most important programming languages, this opens the door to the use of many external APIs.

Therefore, we've designed the multimedia system as an ActiveX control that uses the Windows Media [8] multimedia suite to deal with multimedia data. This suite offers APIs for C++ and VisualBasic languages.

Windows Media Encoder API allows capturing image/audio from nearly any DirectX compatible device, compressing the captured data and streaming it over HTTP.

Using HTTP protocol should be enough in most occasions, as SCADA networks are usually static ones and do not have the high traffic peaks Internet has. In case it the use of RTP or UDP is required, the Windows Media Services component is a good solution.

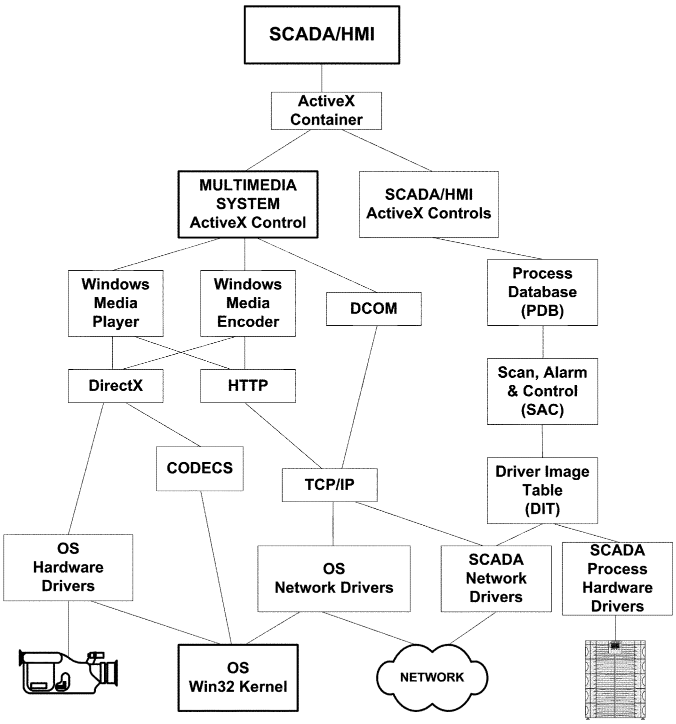

Fig. 2. Example of multimedia enabled SCADA/HMI system.

To play the multimedia content, the Windows Media Player component can be used. Apart from having an API, it has been implemented as an ActiveX control.

Remote access to the multimedia system is needed in order to configure it. The DCOM technology deals with the security issues related to remote accesses.

Fig. 2 shows an SCADA/HMI system using the previously commented technologies. Note the PDB, SAC, and DIT parts can differ if using another SCADA/HMI system other than iFIX [9].

V. Conclusions

Now, integration of multimedia information in SCADA systems is closer to reality. More and more frequently, electric utilities are equipped with an underlying data network (usually one of optic fiber) whose bandwidth is suitable for video, audio and data transport. Also innovations on communications technologies like power-line communications and wireless networks are important factors to take into account for this integration.

From a technical approach, this integration is feasible, such as we have described in this paper, and we are still working on the implementation of a specific system and researching about transmission of multimedia and telecontrol information. From a functional approach, this integration greatly extends the functionality of SCADA system, so it enriches existing telecontrol functions adding new operation, maintenance support, and operators training functions.

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J. I. Escudero received the physics degree in 1979 and the Doctorate in physics in 1995 from the University of Seville, Seville, Spain.

He has held several teaching positions. He has been Professor of Electronic Engineering at the University of Seville since 1989. Dr. Escudero has focused his research activity on the study of computer network performance, power systems telecontrol, and the use of multimedia in power systems control.

J. A. Rodríguez received the degree in computer engineering in 2003 from the University of Seville, Seville, Spain. At present he is working in several projects about multimedia in the operation of large industrial networks.

His principal study is focused on the use of multimedia in power systems telecommunication networks.

M. C. Romero received the computer engineering degree from the University of Seville, Seville, Spain, in 1999. At present she is working on her Ph.D. thesis in multimedia control of power systems.

Since 1999 she has worked on several research projects focused on telecommunications network management and power systems telecontrol at the University of Seville. In 2001 she became Associate Professor and began her teaching work in the School of Computer Engineering, University of Seville.

S. Díaz received the degree in computer engineering in 1999 from the University of Seville, Seville, Spain. At present he is working on his Ph.D. thesis in Power System Control.

Since 1999 he has worked in several research projects focused on computer network management at the University of Seville. In 2000 he became Associate Professor and began his teaching work in the School of Computer Engineering, University of Seville.