VAN Applied to Control of Utilities Networks. Requirements and Capabilities.

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1. Introduction

Industrial communication networks have played a key part in the success and evolution in the concept of CIM (*Computer-Integrated Manufacturing*) and in their more recent evolution MES (*Manufacturing Execution System*) and ERP (*Enterprise* Resource Planning). These systems provide a means of communication for industrial applications of a distributed nature, through the use of sensors, controllers and intelligent devices capable of exchanging and processing information. Although there were precursors to current industrial networks in the area of instrumentation such as CAMAC (*Computer Automated Measurement and Control*) or GPIB (*General Purpose Instrumentation Bus*), these types of networks really began to appear in the 1980s, with MAP (*Manufacturing Automation Protocol*) and its variants can generally be considered as the first industrial networks. MAP appeared in the manufacturing plants of General Motors as a consequence of the growing cost and complexity of interconnection between machines. This difficulty arose principally because of the incompatibility between the many different proprietary systems in use at the time, and led to the development of standards designed to eliminate this incompatibility problem (See (Sauter, 2005a) for a more detailed description of the history of fieldbuses and the evolution of their standardization process).
The introduction of these networks led to a change of paradigm in the development of automated industrial systems, allowing the development of systems that were both distributed and decentralized. The use of these networks has also had a great influence on what is called the "automation pyramid". Although various proposals and numbers of levels are given today (Sauter, 2005b), initially within the CIM hierarchy at the network level, there were considered to be three: factory networks, cell networks, and fieldbuses. Of these, only the last was expected to have special capabilities, different from what was traditionally expected of office networks; that is, the capability to perform in harsh environments, and that users of this exchange of information were processes and not humans (Decotignie & Pleineveaux, 1993). However, from a network point of view, the most significant differences are in:

- The time requirements, which become stricter as we go lower on the pyramid.
- The volume of information exchanged, which becomes less as we go lower on the pyramid.
- The frequency of information exchange, which becomes greater as we get closer to the process.

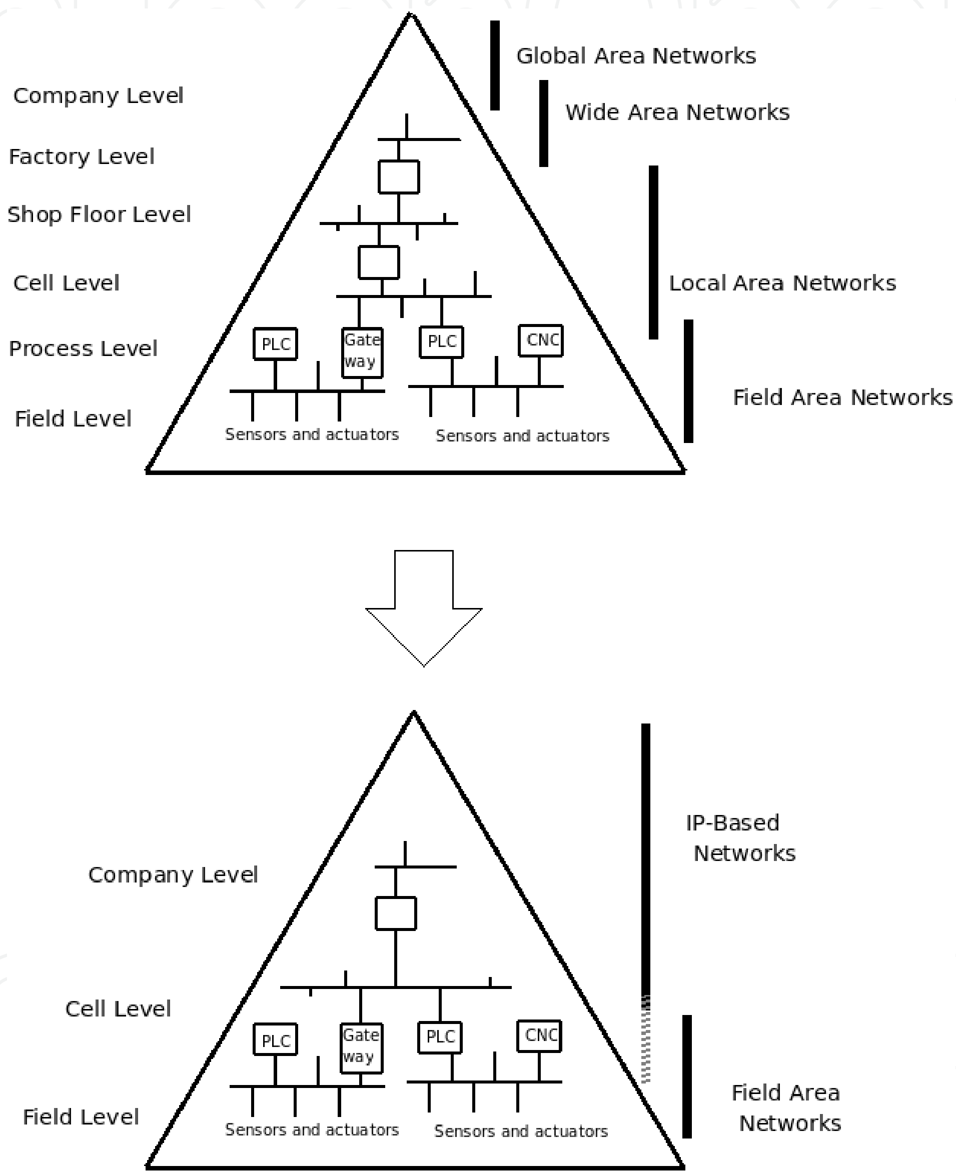

Fig. 1. Evolution of the CIM pyramid

However, this distinction corresponds with the initial concept of the CIM pyramid. Currently, the introduction of Ethernet in the different levels of the pyramid (even the lower level) and the use of internet have reduced the number of layers to only three (Sauter, 2007), as can be seen in Fig 1. This has affected the design of new networks and applications, which now offer new types of services. From the point of view of the application domain, although industrial networks were initially only applied in the lower levels of the pyramid, fieldbus technology influenced all applications domains. Currently, these networks are classified into six different categories (Thomesse, 2005), whose principal characteristics are shown in table 1.

		requirements		
Application Domain	**Distances**	**Time**	**Safety**	**Dependability**
discrete manufacturing	LAN	High/medium	Not specified	
process control	LAN	Very high	Not specified	
Embedded	PAN	Higher/lower	Major constraint-none	
Transportation	MAN-WAN		Very high	
Building Automation	LAN,MAN	low	high	
Control of Utilities Networks	MAN, WAN	medium	Medium	

PAN: Personal Area Networks
MAN: Metropolitan Area Networks
LAN: Local Area Networks
WAN: Wide Area Networks

Table 1. Fieldbus Applications Domains

In each of them, there are different requirements and constraints in terms of time, synchronization, distances, safety and dependability. However, although there may be principles in common between application domains, each individual application can have its own particular requirements. For example, in embedded systems domains the requirements are completely different for the control of a motor or a vehicle's brakes from those of a coffee machine; or in Transportation systems, where there are also important requirement differences between the management of a railway network, and highway monitoring applications.

The first three categories, due to similarity in distances covered, are considered to belong to the LAN/PAN domain. The first application domain (*discrete manufacturing*) is characterized by the existence of a stable state of products between two operations, which allows a process to be divided into various subprocesses independent from each other. Dependability is connected with productivity. The temporal requirements for a machine or process are quite high, but the traffic between different processes can be considered to be asynchronous. The second application domain (*process control*) involves continuous processes, so there are not stable states between two processes. The temporal requirements are greater than the requirements in the same machine of the previous domain, and also cover a wider area, since these requirements must also be satisfied between different machines. Safety is usually more stringently controlled (for example in the chemical industry), and dependability usually demand redundancy. In the third (*embedded systems*) the distances are very short, and so must be considered as PANs. When used in vehicles of some type, they have the greater requirements, but for many other types of embedded system these requirements are very relaxed.

The other application domains, belong to the MAN/WAN domain. The *Transportation systems* domain covers (still following the Thomesse classification) the management of railway networks, remote control of urban traffic, the monitoring of railways, etc., and therefore safety, dependability and availability are crucial. In the *building automation* area the applications are more relevant to data acquisition and supervision than to control, this being often very simple. There is more extended use here, with the typical state information, of multimedia streams. Another difference is the use of a higher number of devices and controllers, which makes them very complex systems. Reliability is also required, but with lower demand. In the ***control of utilities networks*** the applications consist of remote monitoring and control of very large networks for the distribution of water, gas, or electricity. The networks are no longer really LANs, as the operators are in ***central control rooms*** (CCR) for operation and maintenance organization. The traffic consists of status variables and events, the data rate depending on the complexity of the system considered. The networks have the same dependability roles as a fieldbus in a factory, the difference being in the distances covered. For example, power line protocols are used in electrical networks, radio waves are often used to connect very remote stations, and it is also now a preferred domain for Internet use.

The necessities when working with geographically distributed plants require the use of ***heterogeneous networks***, consisting of local and wide area, and wired and wireless communication systems operated by different authorities. (Sempere et al., 2006). In an automation environment, these heterogeneous networks are denominated ***Virtual Automation Network*** (VAN) (Neuman, 2003a)(Neumann, 2007) since the classical requirements demanded of fieldbuses must be satisfied by a network that is currently composed of many different networks. A VAN is "a heterogeneous network consisting of wired and wireless local area network, the internet, and wired or/and wireless telecommunications systems" (Neuman, 2003b). However, it is usually only applied to discrete manufacturing applications (Balzer et al., 2008), and not to other fieldbus application domains which are type MAN/WAN.

In Fig. 2 we can see a typical VAN network for control of utilities in a big city. There are a wide range of remote nodes: remote stations for environment, for control (pumps, gates, levels), for control/monitoring by multimedia, mobile stations, etc. Each remote station can be considered as an autonomous entity that controls a particular aspect of the application. This entity uses fieldbuses with more or less strict real time requirements depending on the type of station, in order to perform the service desired in each area (automation islands). However, to improve the working and use of the system, facilitate maintenance, improve responses in situations of risk and alerts, increase the quantity of information available in the control center etc., VAN must provide the capacity to communicate information between nodes and the central using a wide range of solutions.

In this chapter, the requirements that this type of applications make on VAN networks, the different type of technologies that are normally employed and the capacities that they can offer are analyzed. Public networks and Global Wireless networks are analysed in (Sempere et al., 2003) and in (Sempere et al., 2004; Albero et al., 2005) respectively, so in this chapter an special focus is done in WiMAX networks, since they have enormous potential in this area, an area which up to now has been studied very little. Also, the real implementation of a VAN network for the purification network of Valencia City is presented and a video can be seen in extension 1, which shows the real capabilities of this kind of network.

This chapter is organized as follows. In section II the services supported by the VAN infrastructure for control of utilities networks is analyzed. In section III we review the networks employed in factory automation, putting special emphasis on MAN networks and their use in a VAN environment. In section 4, we present results obtained using WiMAX 802.16-2004 networks as a VAN infrastructure in a utilities network control application.

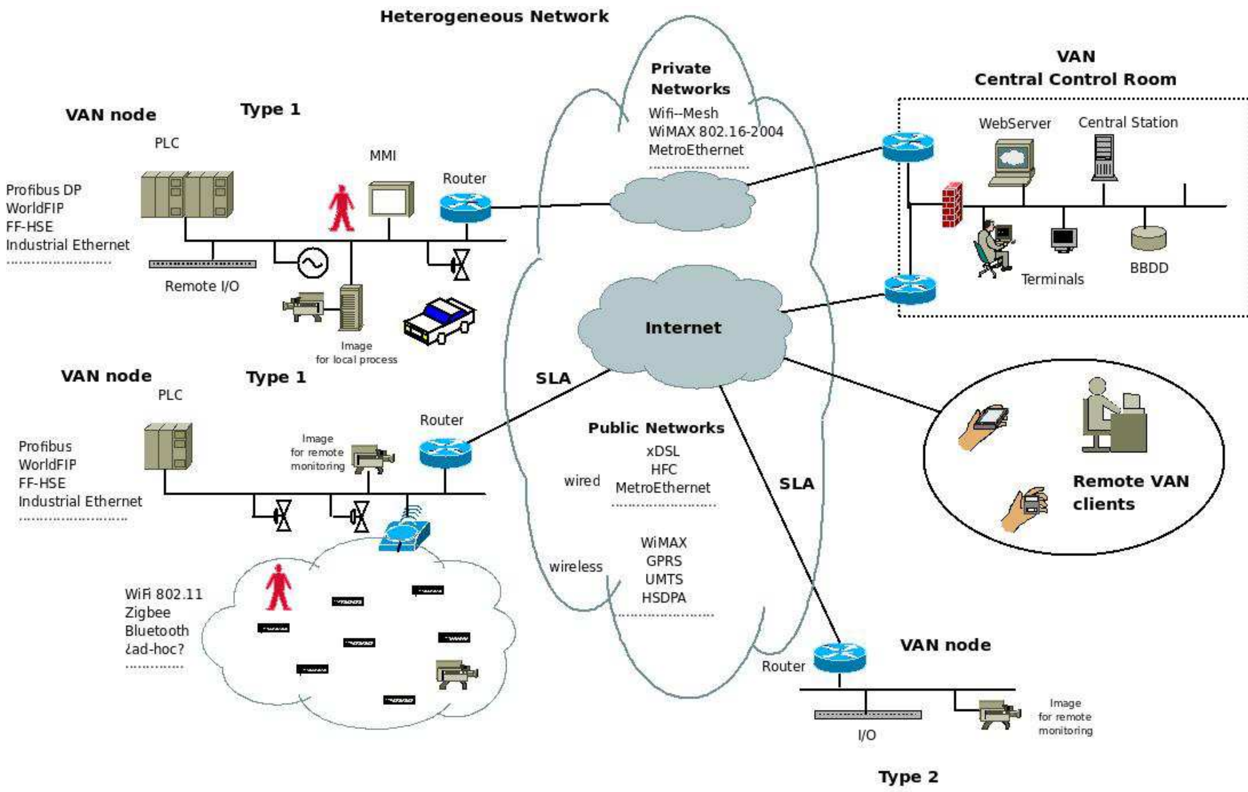

Fig. 2. Architecture of a Classical Control of Utility Network

2. Services

As previously mentioned, in each of the fieldbus application domains, there are a wide variety of requirements generally, and control of utilities network and in particular the VAN concept are no exception. One important difference is in the function of the services destinations; basically users and processes.

The services offered to a user of a VAN are divided into media services and alert services. In the opposite direction, it is the sending of orders by the client in order to gain information or to act on the process. In the case of alert services the volume of information is very low. Normally we are dealing with a few octets which give information on a particular state or alarm in the installation. The user receives the alarm because he is subscribed to this type of alarm service. In the case of alert services, the source of the alert will always be control equipment in a VAN node. The receiver may be in the central control room, in a VAN node or in a remote VAN client. The maximum delay between production and reception of the alarm is 1s. The media services typically offered will be images or video streaming for the supervision of the installation. The source is a camera installed in a VAN node (see Fig.1 image for remote monitoring). Images or streaming are offered by camera and sent to a client located in the VAN node itself, in another VAN node, in the VAN central control room or may even be sent to a remote VAN client. The maximum delay for receiving supervision images or video streaming is 3s.

A user can send requests or orders to obtain information or to act on a process. The user requests to receive images or video streaming, but not alerts, as this is a service that the user is subscribed to and does not need to request. If the user is located in the VAN central control room, he will make the request through an image order from the CCR. On the other hand, if the user is a remote VAN client, the information will be offered via a web page. In this last case, there must be access security guarantees. Another type of order is those that allow a user to parameterize the installation. These orders do not allow a user to change the state, and furthermore, remote orders are not permitted for security reasons. Safety of personnel must be guaranteed (functional safety), an operator who is not in the VAN itself will not be able to execute an order because it is not known whether it could affect the safety of the personnel working in this VAN node.

The services offered in a VAN network are divided into alert and control services, and media services. For media services, in the case that the source is a camera installed in a VAN node offering images of local processes (see Fig.1), these images are not offered to a user but to a process. The requirements here are different those of supervision. The maximum delay permitted for supervision images is 3s. Concerning alert and control services, this type of traffic has traditionally been divided into four groups:

- Best effort service: allows basic connectivity without QoS guarantees. There is no difference between traffic flows.
- Soft Real Time (RT) service: also called differentiated service or soft QoS. To offer this service, some traffic has preferential treatment over other traffic, being offered greater bandwidth, a lower loss rate, greater speed, etc. This achieved by classifying the traffic along with the use of QoS tools. The reaction time permitted is between 10 ms and 100 ms.
- Hard Real Time service: denominated guaranteed service or hard QoS. To offer this type of service, all the resources of the network are reserved for particular traffic. The reaction time permitted is 10 ms.
- Isochronous: these services are used when there are strict bandwidth requirements as occurs with particular audio and video services. That is to say that there are applications that require the continuous sending of information at defined intervals. The reaction time permitted is 1 ms.

These temporal requirements are satisfied by different types of fieldbuses in PAN and LAN type applications that can be found in VAN nodes, but in VAN applications the requirements must be at least one order of magnitude greater or even completely discarded, as with isochronous services. In applications supported by VAN infrastructures, and in particular in the domain of utilities network control, each VAN node will use local control systems in order to be able to guarantee isochronous and/or hard real time behavior, but can use the VAN infrastructure to communicate events, receive orders (such as changes in control policies, etc.) and synchronize actions with other VAN nodes.

3. Networks

The communication between control devices inside each VAN node is outside the scope of this chapter. However, there are solutions which provide isochronous Real-Time between the distributed processes inside. An interesting review can be found in (Thomesse, 2005), and based on Ethernet solutions in (Decotignie, 2009). In this section, there is a brief description of the most interesting technology making up heterogeneous networks which form part of the VAN infrastructures in a metropolitan installation such as that found in Control of Utilities Networks.

3.1 Public Networks
Public networks are defined as networks which are publicly owned, however, the infrastructure is usually operated, in part or completely, by private companies. (service providers). Public administration owns the network of infrastructures, and as such must guarantee access to the communication network at high speed to the whole population. Nowadays, the most common internet access technologies are xDSL (Digital Subscriber Line), both asymmetrical (ADSL) and symmetrical (SDSL). The formal agreement between Internet provider and the client is commonly denominated the Service Level Agreement (SLA), specifying the level of service, mainly the bandwidth and availability guarantee. However, IPv4 networks are only capable of offering best effort services, for which reason their use in factory automation is fairly limited. Networks of this type have been used for monitoring systems (Sempere et al., 2003) and there are various proposals for using them with real time services (Torrisi et al. 2007) (Balzer et al. 2008).

3.2 Wired Networks
The management and operation of distributed installations metropolitan environment are based on a collection of heterogeneous networks, mobile networks, fixed wire, coaxial and fiber-optic networks, etc. which operate in in a MAN environment. There is evidence of the growing use of METRO ETHERNET and CARRIER ETHERNET as technologies in telecommunications networks on the part of providers and operators. The reason for the growing use of this technology is clearly that when generating and receiving information in extreme formats, using Ethernet means the transport has the same format, the benefits of which are evident: efficiency and simplicity.
Metro Ethernet Forum (MEF. See http://metroethernetforum.org) defined the attributes that Metro and Carrier Ethernet must have independently of the solution system used: SDH (Synchronous Digital Hierarchy), OTN (Open Transport Network), HFC (Hybrid Fiber Coaxial), OF (Optical Fiber), WDM (Wavelength Division Multiplexing), WiMAX, Bridging, MPLS (Multiprotocol Label Switching), etc. These attributes defined by the MEF are: standardized services, scalability, security and robustness, quality of service and management (MEF, 2006). Two connectivity services were initially defined, E-Line and E-LAN (MEF, 2004) which were later broadened with E-Tree (MEF, 2008). All Ethernet services can be defined within these categories. E-Line is that which provide Ethernet Virtual Connection (EVC) point to point between two UNIs (Unit Network Interface). An E-Line service can provide a symmetric bandwidth to send information in whatever direction and without any type of quality of service (best effort) at 10 Mbps between two UNIs. An E-LAN provides multipoint to multipoint connectivity connecting two or more UNIs. E-Tree services provide Ethernet Virtual Connection (EVC) point-to-multipoint. In all cases, best effort services are provided, but if it were necessary to offer more sophisticated services, communications could be carried out with certain guarantees, offering different speeds depending on the direction of transmission. To achieve this, it would be possible to combine two of four Traffic parameters defined in a Bandwidth Profile service attribute (Kasim, 2008).

3.3 Wireless Networks

Wireless networks have received a great deal of attention in recent years, and their use today is fairly widespread in PAN y LAN environments. In the area of factory automation, the mobility and flexibility of these types of networks offer interesting advantages and applications, and a great deal of effort has recently gone into solving the various problems inherent in an open, unstable medium such as this (Willing et al. 2005; Matkurvanov et al., 2006; Cena et al. 2008). It is now common to see these networks incorporated in different standards, although several proprietary solutions have also been developed, such as the ABB wireless sensor, denominated WISE (Scheible et al. 2007).

Within wireless networks, there are also PAN, LAN, MAN and WAN classifications. The principal characteristics and difficulties in this type of network when compared to wired networks are:

- Problems related to security are accentuated in wireless networks. This is a shared communication medium which can be accessed by anyone. The privacy of information must be guaranteed, and for this the most common solution is information encryption (Crow et al. 1997).
- Interference and reliability. Interference in wireless communications is common due to being a shared medium. A typical problem is that of hidden terminals, which occurs when there are two nodes within communication range of a third node but not of each other. The typical solution for this is coordination of terminals for the transmission of information (RTS/CTS, Request to Send/Clear to Send).
- Frequency allocation. So that the different nodes in a network can communicate with each other, they must operate on the same frequency.
- Mobility. One of the principal advantages of wireless networks is mobility. However, this often means a network topology that is changing, and where links between nodes are created and lost dynamically.
- Throughput. Due to physical limitations and the fact that the bandwidth available in a wireless interface is less than with a wired interface, transmission rates are lower than in wired networks. To support multiple transmissions simultaneously, spread spectrum techniques are frequently employed.

Another important characteristic leading to significant differences in this type of network is whether there is the need for a Line of Sight (LOS) between the entities that establish a wireless communication, or not (NLOS).

3.3.1 wPAN

Wireless Personal Area Networks (WPAN) interconnect devices in a small area. 802.15 is the wireless standard defined by IEEE for WPANs. The first version, 802.15.1, is based on the Bluetooth specifications (lower layers) and is completely compatible with Bluetooth 1.1. The standard 802.15.1 was approved in 2002 (802.15.1-2002) by IEEE and in 2005 an updated version was introduced, 802.15.1-2005. This standard allows interconnection of devices at distances of a few cm (≈ 10 cm) up to 10 meters. The IEEE Working group continued improving the Bluetooth standard. Two categories of 802.15 are currently proposed: the low rate 802.15.4 (TG4) and high rate 802.15.3 (TG3). The IEEE 802.15.4 standard (IEEE, 2003), approved in 2004 and promoted by the ZigBee Alliance, has been developed to enable applications with relaxed bandwidth and delay requirements, where the emphasis is device battery lifetime maximization. Devices can be powered by batteries for months or even

years. These applications will be run on platforms such as sensors. The IEEE 802.15.3 defines the PHY y MAC levels for high speed WPANs (15 – 55 Mbps). With the IEEE 802.15.3a standard, there was an attempt to improve the physical layer of UWB for its use in applications which work with multimedia applications; however, after several years of deadlock, the IEEE 802.15.3a task group was dissolved in 2006.
In table 2 the main properties of these networks are summarized. Although they are used as sensor networks in industrial environments, the coverage area does not allow their use as VAN networks.

Network	Band	Channels	power	Distance	Throughput	No. elements
Bluetooh – class 1	2.4MHz ISM	79	100mW	≈100m	1Mbps	7
Bluetooh – class 2	2.4MHz ISM	79	2.5mW	≈10		7
Bluetooh – class 3	2.4MHz ISM	79	1mW	≈1		7
Ultra-Wideband	3.5GHz		20-40 mW	10 m	50-480Mbps	
802.15.4	868-868.6MHz	1	200-500 µW	10-100 m	20,100,250 Kbps	65000
	902-928MHz	10		10-100 m	40-250 Kbps	65000
	2.4MHz ISM	16		10-100 m	250Kbps	65000

Table 2. Wireless PAN

The Task Group 4 (TG4), presented a wide range of applications at the 802 meeting in 2001 (Gutiérrez et al. 2001). These applications include industrial monitoring and control. It is important to highlight that industrial monitoring applications which use this protocol must not be operating with critical information, must accept high latency and do not need constant updating. However, there are now several proposals in existence which aim to support real time applications. These are based on the Guaranteed Time Slot (GTS) mechanism (JunKeun et al. 2007) and the use of low superframe orders (Koubba et al. 2006)

3.3.2 wLAN

In Wireless Local Area Networks (WLAN) there are technologies based on HiperLAN (High Performance Radio LAN) a group of the standard group ETSI (European Telecommunications Standards Institute) and Wi-Fi standardized under IEEE 802.11 series. This standard works on unlicensed ISM band, using 2.4 GHz in 802.11/b/g, and 5 GHz for 802.11/a/n. There are 11 channels (although this may vary from country to country) with a bandwidth of 22 MHz per channel for the standards IEEE 802.11 b/g and approximately 20 MHz for the standard 802.11a, and a separation value between channels higher than (5MHz). Because of this, non consecutive channels are usually used. As well as the traditional problems with wireless networks, we must also consider the possibility of multiple interference from other devices and equipment. With a transmission power of 100mW, this technology provides NLOS communication with coverage's of between 100 and 400 meters, and throughputs of between 11 (802.11b) and 300 Mbps (802.11n)[1]. The use

[1] According to the march 2009 DRAFT the standard 802.11n must work at 2.4 GHz and at 5GHz, although as the band 5GHz used by 802.11a is less used, there is a general feeling that 802.11n should not be permitted to include the option of working in the 2.4 GHz band. Regarding the Mbps, according to the DRAFT, it must be capable of working at 600 Mbps.

of this type of network in automation environments has been studied a great deal, due to the characteristics mentioned, although for the coverage range, only in LAN environments. For example, in (Rauchhaupt, 2002) and in (Willing, 2003) the use of WiFi in Profibus is analysed. In (Willing, 2005)(Willing, 2008)(De Pellegrini et al., 2006) the authors carry out a comprehensive study on the use of wireless networks in industrial applications. In (Brevi et al. 2006) the authors evaluated the use of 802.11a in a real industrial environment.

3.3.2 wMAN

When speaking of wireless networks with a MAN type coverage, we are basically speaking of trunk networks and of WiMAX. The first of these are not standardized and are based on proprietary technology. WiMAX networks, with coverage's of up to 8-50 Km (depending on whether they are LOS or NLOS), are a clear alternative for the development of networks for son tele-operation and tele-supervision (Cardeira, 2006; Silvestre et Al. 2007). WiMAX activities started in August 1998, and it was the IEEE 802 group who led the formation of the Working Group 802.16 Broadband Wireless Access (BWA) Standards in 1999. The necessity of NLOS (Non Line of Sight) links moves the frequency bands from 10-66 GHz to 2-11 GHz. The first standard, 802.16a in 2001, was improved upon by the standard 802.16d, which is normally known as 802.16-2004. The standardization of 802.16e in 2005 adds mobility support to the family (Li, 2007). Other standards that will be a choice in the future for this kind of application will be IEEE 802.22 Wireless Regional Area Network or IEEE 802.20. The current standardization process and their different characteristics are summarized in table 3. IEEE 802.16 is optimized for point to multipoint (PTMP) configurations, where there is a base station (BS) and several subscriber stations (SS). Later amendments also allow for mesh network architecture. Of the three air interfaces, the OFDM (Orthogonal-frequency division multiplexing) is suitable for NLOS and is the more extended due to a lower peak to average ratio, faster FFT (Fast Fourier Transform) calculation, and less stringent requirements for frequency synchronization compared to OFDMA (OFDM access) (Ghosh, 2005). It offers a flexible burst-type frame structure with fixed frame duration, and the duplexing is provided by means of TDD (Time Division Multiplexing).

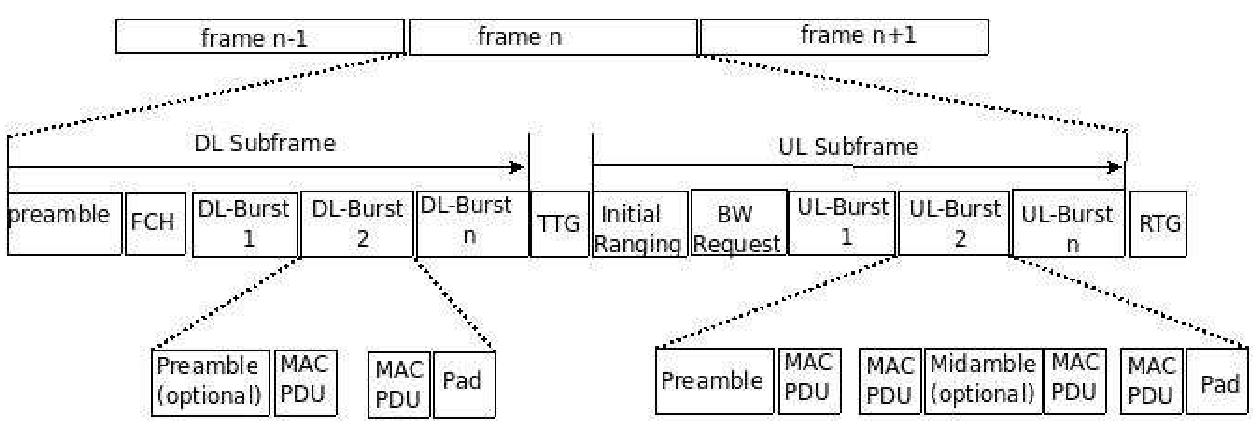

Fig. 3. IEEE 802.16 MAC frame in TDD mode (Hoymann, 2005)

In Fig. 3 the structure of an IEEE 802.16 frame is shown with Time Division Multiplexing (TDD). As can be seen, the BS has the capability for a full schedule of the traffic BS to SS, in the DL subframe. Also, in the UL subframe, there is a mechanism for bandwidth request.

However, the BS also has the possibility to schedule each burst, so it can map the QoS demands in the frame structure in a centralized way.

Network	**Band**	**Power**	**Distance**	**Throughput**	Network Architecture
802.16a	10-66GHz		50Km	32-134 Mb/s	PTP, LOS
802.16d 802.16-2004	2.5- 2.69 GHz 3.4-3.6GHz	3W (SS) 60W (BS)	50Km LOS 7.4Km NLOS	Up to 75 Mbps	PTP, PTMP, NLOS
	5.725-5.850GHz	1 W			
802.16e 802.16-2005	2-6GHz		2km	63Mb/s downlink 28Mb/uplink	PTP, PTMP, mobile

Table 3. Wireless MAN

QoS provisioning in 802.16 is based on Bandwidth grant services. For the downlink flow the BS has information for a correct scheduling. For uplink flow, the BS has to schedule the traffic based on the information provided by SS. There are different types of services (Cicconetti et al, 2006):

- UGS (Unsolicited Grant Service). This provides fixed size transmission at regular time intervals without the need for request or polls. It is adequate for constant bit rate traffic such as VoIP. (Strict delay requirements. Offset upper bounded by the tolerated jitter)
- rtPS (Real-Time polling service). This provides transmission at regular time intervals, where the BS offers the SS periodic request opportunities to indicate the required bandwidth. It is adequate for variable bit rate (VBR) traffic such as MPEG video (less strict delay requirements. Parameters: *minimum reserved traffic rate, maximum latency*
- nrtPS (Non-Real-Time polling service). This type is used for delay-tolerant data service with a minimum data rate. SS can use contention requests and unicast request opportunities will be offered to SS regularly.
- BE (Best Effort). Similar to nrtPS, does not provide bandwidth reservation or regular unicast polls.
- ErtPS (Extended Real Time polling service). This is only applicable to 802.16e (Li, 2007). Provides a service similar to UGS and rtPS. Offers unsolicited unicast grants, but with a dynamic bandwidth allocation.

4. Experiments and results

In this section, there is an analysis of the working of WiMAX networks as support for VAN communications in control of utilities networks applications. Fig. 4 shows the distribution of the stations that use WiMAX as a communications network to give support to the services that the VAN network has to offer to a Control of Utilities Networks application. The equipment works in TDD mode, with OFDM modulation, in the 5.4 GHz band (5.470-5.725 GHz), with adaptive modulation and channels of 10 MHz. As can be seen in Fig. 4, the testbed scenario presents a wide range of WiMAX scenarios, with point to point and multipoint communication, with LOS and NLOS links of between 0.5Km a 2.5Km. The fig. also shows the SNR of the links, which affects the type of modulation to be used and the maximum bit rate that can be achieved. To analyze the channel, interarrival packet time was measured (Katabi & Blake, 2002) (Varga & Kún , 2005) with different periods, message sizes and sending by unicast and multicast, obtaining also the Packet Error Rate (PER) obtained from the point of view of the application.

The first of the tests consisted of a ***multicast*** transmission from the Central Control Room (**CCR**) to the rest of messages with periods (T) of 50, 100 and 1000 ms. and payloads (C) of 100, 1000, 4000 and 10000 bytes. These values were chosen to evaluate the capacity to offer the services defined in section 2, and represent bandwidth requirements ranging from 800bps to 1.6 Mbps, which could saturate some links. The second of the tests represented a ***unicast*** transmission from the VAN nodes to the CCR with periods of 50 ms. and payloads of 100, 1000, 4000 and 10000 bytes.

Table 4 shows the PER obtained in each of the multicast and unicast experiments. The table shows how in the majority of cases, when the bandwidth requirement is less than 640kbps, a PER less than 1% was obtained, which is acceptable for the application. However, for C=10000B, the PER obtained is excessive even for T of 1000 ms. Of these values, the greatest degradation is seen in the link between CCR and VAN node 2, reaching a PER of 55.6%. This is due to the available bandwidth that the PTMP has to share between VAN 2, 4 y 6, and the worst SNR of this link which means that it has to work with modulations that reduce the channel bandwidth. Another reason is the double traffic that VAN 2 has to carry, as it makes the link between the CCR and VAN 3. This being the most affected node, in the best cases it has double the PER rates compared to the bridging node. Of the rest of the values obtained, it is worth highlighting the good performance of the PTP link between the CCR and VAN6, as well as that of the other nodes communicating with the PTMP link, that is to say VAN 4 y VAN 5.

Concerning the communication from the VAN nodes to the CCR, it is evident that this means a higher overload of the channel, which increases congestion in the links and leads to a higher PER, although this remains acceptable for rates lower than 640Kbps. Although the PER is widely used as a measure for the characterization of channels in a wireless environment, circumstances sometimes arise that affect the channel temporarily and which affect this value and the working of the applications that use this infrastructure. The distribution of lost packets over time affects the fulfilment of deadlines the availability of the channel, as can be seen in Fig. 5. Thus, although VAN 2 has the highest PER, in no case did it record the loss of two consecutive packets, guaranteeing delivery of at least one of the two packets transmitted every 200 ms and therefore high availability. VAN 4 gave a higher PER, however, a number of small bursts of packets were lost, reaching up to 8 consecutive, meaning that there was a loss of availability in the channel of around a second. In VAN 5, there was only one burst of lost packets, but it was of 97 consecutive, at approximately the same moment in time as in VAN 4, reaching around 10 s of non availability.

Fig. 4. WiMAX station distribution in a VAN control of utilities network application

	T=50	multicast					T=100	multicast			
C	**VAN2**	**VAN3**	**VAN4**	**VAN5**	**VAN6**	**C**	**VAN2**	**VAN3**	**VAN4**	**VAN5**	**VAN6**
100	0,2%	**1,6%**	0,3%	0,2%	0, 0%	**100**	0,1%	0,4%	0,7%	0,0%	0,0%
1000	0,3%	**1,4%**	0,2%	0,2%	0,0%	**1000**	0,2%	0,4%	**1,1%**	0,0%	0,1%
4000	0,5%	**2,2%**	0,4%	0,2%	0,1%	**4000**	0,8%	**1,0%**	**1,7%**	0,8%	0,4%
10000	**55,6%**	**93,8%**	0,7%	0,0%	0,4%	**10000**	**2,6%**	**4,2%**	**1,8%**	**2,1%**	0,7%
	T=1000	multicast					T=50	unicast			
C	**VAN2**	**VAN3**	**VAN4**	**VAN5**	**VAN6**		**VAN2**	**VAN 3**	**VAN4**	**VAN5**	**VAN6**
100	0,2%	0,2%	**1,0%**	0,0%	0,2%	**100**	**1,4%**	**1,0%**	0,3%	0,55%	**1,6%**
1000	0,1%	0,1%	**0,8%**	0,0%	0,3%	**1000**	**8,2%**	0,6%	0,0%	0,0%	**1,6%**
4000	0,6%	**1,0%**	**2,8%**	0,0%	**6,1%**	**4000**	**86,2%**	**82,9%**	**83,2%**	**81,3%**	**82,0%**
10000	**1,0%**	**3,6%**	**4,3%**	1,5%	**3,8%**	**10000**	**92,8%**	**99,2%**	**99,2%**	**99,9%**	**99,4%**

Table 4. PER obtained in the different experiments.

In the following figure the histograms of the interarrival time for different stations and combinations (C, T) are shown. Fig. 5 shows the data from a PTP link between the CRC and VAN node 6. In the consequent figs. The data is shown of a PTMP link between the CRC and VAN node 4 (Fig. 6) and VAN node 2 (Fig 7). In general, one can see how in all cases for values of T=1000 a tight spike was produced (Katabi & Blake, 2002), although this spike became slightly more spread out as C becomes greater. As we approach the throughput limits of the links with values approximate to T=50, the congestion in the channel alongside the increase in the value of C causes the spike bomb to become more spread out.

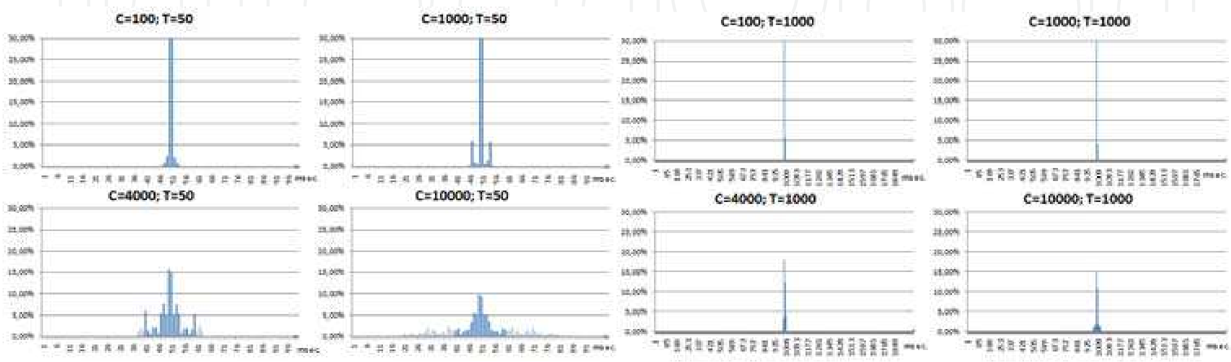

Fig. 5. Histogram of Interarrival time for station 6 and T=50 and 1000 ms.

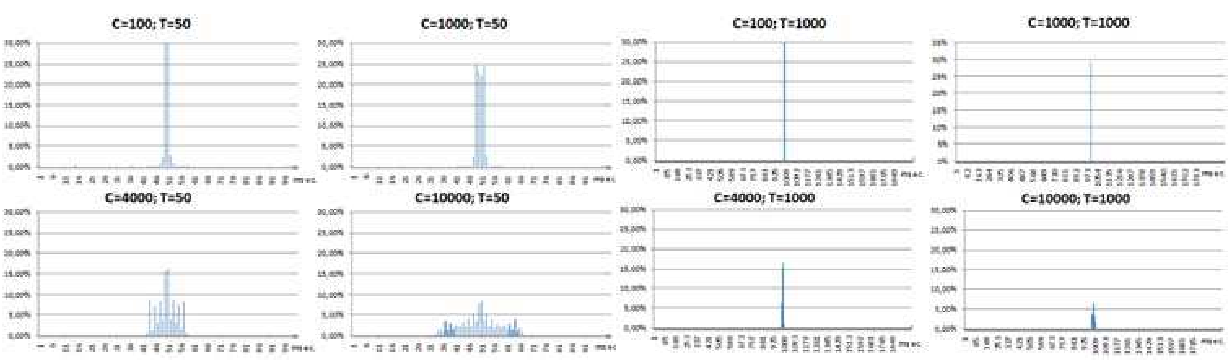

Fig. 6. Histogram of Interarrival time for station 4 and T=50 and 1000 ms.

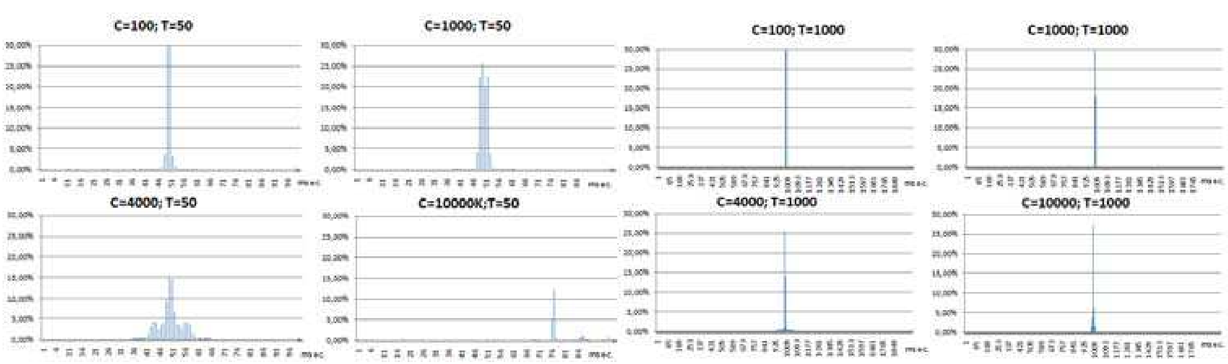

Fig. 7. Histogram of Interarrival time for station 2 and T=50 and 1000 ms.

7. Conclusions

The use of VAN infrastructures to give support to applications in the traditional areas of industrial networks , and in particular in applications with MAN requirements, as can be found in building automation, or the case studied here; utilities network control, is viable but with limitations. The use of wireless networks such as WiMAX allows proprietary networks to be quickly set up at low cost. In spite of this potential, the burst behavior they sometimes display means that the applications must take this into consideration. Thus, the control links in the VAN nodes must be based only on local information within the VAN node, using the VAN infrastructure to improve the working of a global system. Although WiMAX can form part of this VAN infrastructure in a utilities network control application and satisfy the requirements of these applications, it is important to take into consideration the interference produced in the ISM spectrum, such as the fading effects produced in wireless communication, which may produce breaks and lack of availability. These possible problems must be foreseen and considered for the higher levels of the applications so that they do not affect the performance of the system. The need to avoid congestion in the channels and the fact that the channel bandwidths change at times due to variations of the SNR mean that it is necessary to use dynamic bandwidth management mechanisms. The mechanisms must avoid congestion in the cannel, both in the normal working of the system, as well as during moments when there is degradation in the cannel and the consequent loss of bandwidth that this degradation causes.

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9. Index to multimedia Extensions

The multimedia extensions to this publication can be found online by following the hyperlinks from www.intechweb.org

1. ControlVision. Video. Description of the purification network of Valencia city, and their automation properties and heterogeneous networks used.

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Factory automation has evolved significantly in the last few decades, and is today a complex, interdisciplinary, scientific area. In this book a selection of papers on topics related to factory automation is presented, covering a broad spectrum, so that the reader may become familiar with the various fields, and also study them in more depth where required. Within various chapters in this book, special attention is given to distributed applications and their use of networks, since it is one of the most relevant subjects in the evolution of factory automation. Different Medium Access Control and networks are analyzed, while Ethernet and Wireless networks are looked at in more detail, since they are among the hottest topics in recent research. Another important subject is everything concerning the increase in the complexity of factory automation, and the need for flexibility and interoperability. Finally the use of multi-agent systems, advanced control, formal methods, or the application in this field of RFID, are additional examples of the ideas and disciplines that experts around the world have analyzed in their work.