802.11n Performance Analysis for a Real Multimedia Industrial Application

Abstract

In spite of their limitations, wireless networks are being increasingly used in industrial environments. The electromagnetic phenomena that can occur, along with the interference that may occur due to it being an open medium, mean that fluctuations in latencies are often produced. These drawbacks limit the use of wireless networks for distributed factory applications where timeliness is essential. Recent standards, such as 802.11n, offer some interesting characteristics applicable to factory automation. In particular, QoS support and a very high data rate aids their operation under non-saturation conditions, allowing their satisfactory use as an industrial network. In this paper the potential of these networks is analyzed in a real world scenario and their performance is compared with an idealized scenario. In both cases the priorities behave as expected, however, the algorithms for an auto-rate functioning perform badly in real world situations, especially in industrial scenarios such as those analyzed here, where the mobility of sources and the interference produced by other sources produce frequent rate changes, leading to a reduction in network performance.

Key words: Wireless network, Fieldbuses, Image processing

1 Introduction and related work

Over the last decade, wireless communications have been widely and successfully used in different application domains. Computers or even smartphones today have different wireless connections (WiFi, Bluetooh, NFC, 3G and recently 4G) that allow the interaction of the devices with the Internet to share and consult information with other servers, the use of in-car handsfree mobiles, or watching of educational videos. In spite of the advantages of this tecnology such as flexibility, ease of installation, low cost, maintenance, etcetera, [1][2] these networks have certain drawbacks that prevent their use in the field of factory automation. It is an open medium operating over an unlicensed ISM band (Industrial, Scientific and Medical), so interference cannot be avoided. Also, different electromagnetic phenomena, such as reflection, scattering or diffraction can increase interference, producing strong latency fluctuations or even short losses of connection [1][3][4][5][6]. In spite of these limitations, the use of wireless networks in soft real-time applications is growing [7][8]. This growth has been influenced by the standardization of IEEE 802.11e standard, its incorporation into IEEE 802.11-2007 [9] and the improvements in QoS management at the Media Access Control (MAC) level [10][11]. Also, recent standards such as 802.11n offer this QoS capacity with some interesting characteristics that can be used in factory automation processes[12][13].

At the physical level, the objective of these characteristics is to increase the data rate. In order to achieve this 802.11n adds MIMO (Multiple-input multiple-output) functionality to the typical OFDM (Orthogonal Frequency Division Multiplexing) with support for up to four spatial streams . Additionally, wider spectral bandwidth channels can be used, since 40 MHz has been added instead of the baseline 20 MHz. Other small enhacements include increasing the number of OFDM subcarriers for user data transmission from 49 to 52 in the 20 MHz bandwidth case, and also the interframe spacing is reduced. With these characteristics a high data rate can be achieved, up to 600 Mbps with four spatial streams, surpassing the previous 54 Mbps limitation of 802.11g. Concerning the link level, the advantages of the 802.11e QoS mechanism for use in industrial networks, and the drawbacks and limitations that still exist, have been analyzed in several papers. In [14] the authors analyze how the different types of industrial traffic can be mapped onto the four types of priorities provided by EDCA (Enhanced Distributed Channel Access [6]). Through OPNET simulations their behavior is analyzed in-depth, showing that this network could offer a satisfactory solution when real-time traffic does not exceed about 20%, as long as time critical requirements are not mandatory. In [6] the limitation of the highest priority level of the EDCA to support real-time communication is evaluated through a statistical analysis of deadlines and the simulation of the network through a Stochastic Petri Net. In this paper they show how the network load and the error-prone channel can produce higher delays and percentages of packet loss in real-time traffic. In [17] the behavior is analyzed with a real testbed. However this is very simplified, and only two stations are competing for the wireless medium, so the probability of collision is very low. In [18] the use of networked control systems is analyzed, however, the main issue analyzed here is the use of a hard real-time software infrastructure, and this was done in a laboratory environment, or in a simulation scenario [19]. In [20] an experimental evaluation of the service time is carried out. In this paper the delay introduced by different access points is measured, as well as the influence of each component in a controlled testbed. A relevant result is the fact that fixed low transmission rates guarantee better service times. To our knowledge, the use in a real world scenario has not been fully analyzed. There is no data on the influence of a bandwidth-intensive application on the control traffic in these kinds of scenarios.

This paper presents the results of a full experiment in a real world scenario.

A machine vision application was used as a bandwidth-intensive application. Image transmission performance was analyzed for a fixed bit rate, and for an automatic bit rate selection. In a real world scenario, this machine vision application would have to share the medium with other real-time applications, such as control applications. The experiment therefore analyzed the influence of this machine vision application on the performance of control applications, such as the influence of traffic priority on control traffic. All the experiments were also carried out in a controlled environment, free of interference from other sources, so the results from both scenarios could be compared.

The paper is organized in the following way. After a briew review of the 802.11 MAC, a short introduction to the application is given. Then, the real world industrial scenario (denominated **IS**) and the controlled environment scenario (denominated **CS**) are presented. Finally, the measurements obtained are shown, and the conclusions are presented.

2 802.11 Medium access control

Medium access control in the first IEEE 802.11 standard is provided by Distributed Coordination Function (DCF), as there is no Point Coordination Function (PCF) implementations. In DCF, a random access system is provided by a *carrier sense multiple access with collision avoidance* CSMA/CA. Stations have to monitor the medium before access into the channel. If this channel is idle for a period of time (DIFS: *Distributed Interframe Space*) then the message is transmitted immediately. If the channel is busy it is monitored until it is sensed as being idle by a DIFS. The stations then wait for a random backoff interval before transmition, thereby reducing the likehood of collision. Other frames, mainly control frames, such as acknowledgement control frames, use SIFS (*Short Interframe Space*). As SIFS is shorter that DIFS, these control frames are more likely to be transmitted than data frames. 802.11e and its enhanced distributed channel access (EDCA), which was incorporated into IEEE 802.11-2007 standard, and which is therefore included in 802.11n, provides four different priorities to offer service differentiation. Frames are classified in different access categories (**AC**) from higher to lower priority, as follows: voice (VO), video (VI), best-effort (BE) and background (BK). Each AC define different arbitration interframe spaces (AIFS), and different maximum and minimum contention windows ($CW_{max}[i]$ & $CW_{min}[i]$) (see Fig. 1). The interframe space duration of each AC is calculated according to the following equation:

$$T_{AIFS[i]} = T_{SIFS} + T_{slot} AIFSN[i] \qquad (1)$$

using $AIFSN[i] \geq 2$, or $AIFSN[i] \geq 1$ for access points, and T_{slot} is the slot duration. In EDCA, the backoff procedure is initialized in the range $[0, CW_{min}[i]]$, and this range is doubled until $CW_{max}[i]$ is reached. Using this rules the higher priotity traffic has a higher probability of accessing the medium than other sources with traffic with a lower priority.

3 Experiments

The objectives of the experiments were to analyze the

- Influence of a fixed versus a variable bit rate in the performance of traffic sources.
- Influence of a bandwidth-intensive application (machine vision application) over the control applications.
- Differences between a interference free scenario, and a real world scenario with uncontrolled environment sources.
- Influence of EDCA priorities on the above.

Some of the parameters of the experiments (see Table 1) were defined by the possibilities of the real world industrial scenario, and they were also limited by the number of devices that could be used. However, the results can be extrapolated to other scenarios with other requiments and capacities.

3.1 System description

The system task used as a testbed was the quality control prototype that is being developed for a textile process through image processing. The machines that open, clean and blend the fibers from a bale of raw material include a header that runs over the bale of raw material, delivering fibers to the subsequent process in the correct quantities and quality. Contaminated fibers may be present in the bale. At present there is no way to detect this contamination so the header system of the prototype is being designed to detect and evaluate this on-line. Detection of contamination will result two different actions. If it is serious contamination, the process has to be stopped and fibers inspected by operators. If the contamination is slight, the machine does not need to stop, but the information is compiled to produce a final report.
The computer vision system was composed of eight cameras mounted on a head that is moved over the fibers (see Fig. 2) and which communicated the images to an *industrial PC* through IEEE-1394a [22]. A *multicore PC* is neces-

sary because the algorithm that detects the contamination is computationally demanding, so the use of COTS computers (Commercially available Off-The-Shelf) is needed. However the vibrations of the process are too strong for this kind of equipment, so an *industrial PC* is needed. The use of *industrial PC* to process the received images is too expensive if it has to have the computational power needed to process the received images.

The solution selected for the prototype was the use of a *multicore PC* to process the images, which receive them from the *industrial PC* using 802.11n. Some communications properties of the system used can be seen in Table 1. With this equipment, the system was configured to a maximum data rate (that is, the bit rate at the physical level) of 108 Mbps, in order to produce a certain level of saturation with a low number of devices. Throughput at this data rate depends on many parameters, such as noise or packet size. In contrast to wired technologies, the efficiency is significantly lower, and values of around 50% of the data rate are quite usual [23] due to an inefficient MAC overhead [24] and retransmissions due to channel errors. Therefore, for a network running at 108 Mbps, the useful bandwidth could be around 54 Mbps. The transmission of images from the *industrial PC* to the MultiCore PC can be considered to be a bandwidth-intensive application in this type of system. In order to fulfill its role as a control application, the *MultiCore PC* sometimes had to transmit a stop order to the *Industrial PC*, which had to stop the process immediately.

Table 1
Communication properties

Description	**Value**
linux kernel	2.6.32-32
driver	iwlagn
TxPower	15 dBm
Retry limit	7
antennas	2
ISM Band	2.4 GHz
Bandwidth	20 MHz
SIFS	$10\mu s$
DIFS	$28\mu s$
Slot time	$10\mu s$
Transmission rates for 1 antenna (Mbps)	6, 9, 12, 18, 24, 36,48,54
Modulation and Coding Schemes	0-23, 32

3.2 Controlled scenario (CS)

The CS had 6 nodes (selected details for the laptops used are shown in Figs. 3 and 4) and two access points forming networks on the same channel, implementing the industrial scenario described in Section 3.3 below, but in a 3x3 metre area without other 2.4GHz sources (Fig. 3). Two nodes implement the transmission of images from one node to another using a period of T = 1000ms. This transmission was made with two different bit rate configurations: using a 54 Mbps fixed bit rate; and also configured in auto bit rate mode. A special program was developed for this with a frame size based on real traces of the application, whose size distribution for 300 images (5 min at 1 image per second) can be seen in Fig. 5. Over the same channel, another four nodes were used (see pair 1 and pair 2 in Fig. 3) to implement control traffic. These nodes communicated between each other through a separate Access Point (AP2 in Fig. 3) using a fixed bit rate of 11 Mbps. Control traffic was implemented using a modified version of the standard *ping* command, which sends echo request packets of 200 bytes every 50 msec and waits for the response. Both parameters are inside the range of typical industrial applications [20][21]. In the experiment the behavior of the control traffic in coexistence with the image burst was analyzed, using the lowest and the highest EDCA priorities.

3.3 Industrial scenario (IS)

The overall architecture for the industrial scenario is shown in Fig. 4. The *Industrial PC* communicated through asynchronous serial communication RS-485 with a programmable logic controller (*PLC*) that operated the vision system header machine. In the experiment this link allowed the head position to be continuously monitored and the head to be stopped if there was serious contamination. An 802.11n Access Point (AP1 in Fig. 4) communicated with the *Industrial PC* through the wireless network, whereas FastEthernet was used for communication between this access point with the *multicore PC* and this automation island and the management area. Each image had a resolution of 640x480 pixels, using three bytes for each one in a RGB codification. With this resolution and with the head movement, images had to be sent every second, that is, with a period T of 1000 ms. This represents a network data load of 58.9 Mbps (without headers, interframe spacing, and retransmissions) which could have overloaded our 802.11n channel, which was limited to a useful bandwidth of 54 Mbps as mentioned previously. To reduce this load a compression and decompression stage was used, using JPEG with a quantification factor of 85 to obtain sufficient quality and a low compression latency. The images had to be processed in the *multicore PC*. If there was serious contamination, a stop order had to be returned to stop the vision system header. So the deadline available for the overall process was:

$$T = T_{1394} + T_C + T_{11n}^1 + T_{eth}^1 + T_D + T_{proc} + T_{eth}^2 + T_{11n}^2 + T_{RS485} \tag{2}$$

where T_{1394} is the time needed for the transmission of images from IEEE 1394 cameras to the *Industrial PC*; T_C is the time needed for image compression; T_{11n}^1 is the time needed for their transmission from the *Industrial PC* to AP1 through 802.11n, including transmission and access medium; T_{eth}^1 is the time needed for the transmission from AP1 to the *Multicore PC*; T_D is the time needed for image decompression; and T_{proc} is the time used by the computer vision algorithm in the *multicore PC*. If serious contamination was found and the machine had to be stopped, sufficient time was required to send the stop order from the *multicore PC* to the PLC. That is, the time needed to send the order from the *multicore PC* to AP1, T_{eth}^2, the time needed to send this order in 802.11n from AP1 to the *Industrial PC*, T_{11n}^2, and for the order to be sent from the *industrial PC* to the PLC T_{RS485}. The nondeterminism times are T_{11n}^1 and T_{11n}^2. To the wireless nondeterminism, in the case of T_{11n}^1, was also necessary to consider that the compression process does not always produce the same quantity of bytes. In our testbed T_{11n}^i and T_{eth}^i could not be measured separately, so $T_{net}^i = T_{11n}^i + T_{eth}^i$ were measured while the ethernet network was disconnected from the factory management area to avoid the possibility of saturation in the AP. The real equipment had the following high bounds:

T_{1394}= 50ms; T_C= 200ms; T_U= 50ms;
T_{proc}= 100ms; T_{485}=20ms

To avoid interference with production, while the real world system was working on channel 1, the same equipment used in the CS was used in the industrial scenario on channel 11. Thus, the same program and traces were used in the CS. Then, the images were read from the disk and there was no need to process the images. As in the CS, to implement control traffic on the same channel, four nodes were used (see pair 1 and pair 2 in Fig. 4). They also used a separate Access Point, a fixel bit rate of 11 Mbps, and a modified *ping* which sent 200 bytes every 50 ms.

4 Measurements

In wireless communications it is assumed that it is not possible to avoid some loss of packets, so the evaluation of worst-case latency is mostly pointless [14].

In this case the statistical distribution of response times is sometimes used as a performance index. However, when tests show a high dispersion, the mean and standard deviarion are not very useful. In these cases the use of percentiles as a better way to characterize the behavior in wireless communications [14][15][16] is assumed. A percentile is the value of a variable below which a certain fraction of observations falls.
In this paper, the mean and standard deviation of Round Trip Time (RTT) [17][18] is calculated on the 99^{th} percentiles (denominated $\mu_{99^{th}}$ & $\sigma_{99^{th}}$ in the results tables). Also the max RTT obtained on 99^{th} percentiles ($\max_{99^{th}}$) and the global RTT maximum (max) are presented.

4.1 Measurement in a controlled environment (CS)

Firstly, the control traffic was introduced between each pair of nodes, without any other source, and the mean RTT obtained in a longer test (30 min) was around 2.80 ms. After that, four experiments of 5 minutes duration on image transmission were carried out. Firstly, without control traffic (denominated **test 0**), secondly, with two sources without priorities (**test 1**), thirdly, with one of the sources with voice priority (**test 2**), and finally, one with voice priority and the other with video priority (**test 3**). The mean and standard deviation throughput obtained by image transmission in each case at different network bit rate configurations can be seen in Table 2, while the same information for T_{net}^{1} is shown in Table 3. Thus, the introduction of two sources, which represents 64 kbps at 11 Mbps (test 0 versus test 1, test 2 and test 3),

Table 2
Image throughput average and deviation (Mbps) in CS

	CS	**test 0**	**test 1**	**test 2**	**test 3**
Average	54Mbps	22.87	22.29	21.42	21.19
	auto	60.45	47.59	48.89	50.45
Deviation	54Mbps	1.32	1.37	2.26	1.25
	auto	11.99	14.01	5.79	6.95

Table 3
Image T_{net}^{1} average and deviation (msec) in CS

	CS	**test 0**	**test 1**	**test 2**	**test 3**
average	54Mbps	257.3	265.6	274.2	268.9
	auto	98.9	130.7	120.8	117.6
deviation	54Mbps	103.8	108.6	104.0	108.3
	auto	39.5	59.8	48.2	48.23

Table 4
Control Round Trip Time in CS

			54Mbps		
test 1	QoS	$\mu_{99^{th}}$	$\sigma_{99^{th}}$	$\max_{99^{th}}$	max.
1º pair	none	3,30	2,82	20,48	70,16
2º pair	none	3,25	2,18	20,74	64,50
test 2	QoS	$\mu_{99^{th}}$	$\sigma_{99^{th}}$	$\max_{99^{th}}$	max.
1º pair	voice	2,65	1,91	17,5	54,40
2º pair	none	3,38	2,23	21,42	56,42
test 3	QoS	$\mu_{99^{th}}$	$\sigma_{99^{th}}$	$\max_{99^{th}}$	max.
1º pair	voice	2.40	1,67	14.24	51.10
2º pair	video	3.24	2,04	18.19	53.32
			auto		
test 1	QoS	$\mu_{99^{th}}$	$\sigma_{99^{th}}$	$\max_{99^{th}}$	max.
1º pair	none	13,29	20,37	118,67	232,49
2º pair	none	11,07	18,60	114,07	295,28
test 2	QoS	$\mu_{99^{th}}$	$\sigma_{99^{th}}$	$\max_{99^{th}}$	max.
1º pair	voice	6,42	7,71	42,01	62,7
2º pair	none	8,08	12,31	77,50	194,3
test 3	QoS	$\mu_{99^{th}}$	$\sigma_{99^{th}}$	$\max_{99^{th}}$	max.
1º pair	voice	6,39	7,56	41.34	95.30
2º pair	video	8,38	17,3	82.97	176.59

produced a throughput degradation of the images for 54 Mbps and for the auto configuration of around 600 kbps and 13 Mbps respectively. For the fixed 54 Mbps configuration, the introduction of priorities in the control traffic produces a slight decrease in the throughput whereas for the auto configuration the throughput is improved. This can be explained since the use of priorities in control traffic increases their likelihood of being transmitted and also a reduction of collisions with image traffic. For a fixed configuration, the increase in the likelihood of traffic control implies a reduction in the likelihood of image traffic, so the throughput is then reduced. For the auto configuration, the behavior is different, since this likely reduction also implies a collision reduction that can be exploited by image traffic through an increase in the bit rate assigned.

The results for the control traffic in Table 4 are shown. These results are as expected for both bit rates, taking into account the EDCA QoS of each source, and they show how this parameter can improve the behavior of one network stream in a non-saturated network. An unexpected result was the large increase in the RTT for control traffic for all the experiments in auto configuration compared to the 54Mbps configuration. As images are delivered faster, we would expect interference with control traffic to be lower, however the behavior was worse. As image and control traffic are not a synchronous process, the increase in bandwidth on image sources also has some influence on the ocupation of the channel. Thus, within a period of one second many of the control messages with 50msec period are transmitted without competing with image source, but also some of these **face** stronger competition until the image transmission is finished, which can be seen in the *max* for test 1. With the introducction of priorities, this effect is reduced, but still exists. In Fig. 6 the variability in bit rate for the auto configuration with respect to fixed 54 Mbps, even in a controlled scenario, can be seen. The impact of this variability in the RTT can be seen on the righthand side of Fig. 7. In test 1 where the control traffic sources have no priority with respect to image transmission, this variability, and the influence of image size (see Fig. 5) had a significant impact. The use of higher priorities in control traffic reduced this impact, but it was still substantial when compare with fixed 54 Mbps, as shown on the lefthand side of Fig. 7.

Table 5
Image throughput average and deviation (Mbps) in IS

	IS	**test 0**	**test 1**	**test 2**	**test 3**
average	54Mbps	19.14	18.53	18.69	18.83
	auto	35.7	33.23	39.21	36.36
deviation	54Mbps	3.54	3.36	3.32	3.11
	auto	18.93	17.13	13.17	10.16

Table 6
Image T^1_{net} average and deviation (msec) in IS

	IS	**test 0**	**test 1**	**test 2**	**test 3**
average	54Mbps	319.4	330.2	327.3	323.9
	auto	227.4	250.34	212.5	177.56
deviation	54Mbps	144.3	149.6	151.0	147.7
	auto	173.9	204.3	190.5	100.3

Table 7
Control Round Trip Time in IS

	54Mbps				
test 1	QoS	$\mu_{99^{th}}$	$\sigma_{99^{th}}$	$\max_{99^{th}}$	max.
1° pair	none	4,53	4,74	40,25	262,73
2° pair	none	4,98	4,43	38,87	256,08
test 2	QoS	$\mu_{99^{th}}$	$\sigma_{99^{th}}$	$\max_{99^{th}}$	max.
1° pair	voice	2,41	1,68	13,28	56,46
2° pair	none	4,55	3,77	32,63	272,91
test 3	QoS	$\mu_{99^{th}}$	$\sigma_{99^{th}}$	$\max_{99^{th}}$	max.
1° pair	voice	2,47	1,95	18,04	54,58
2° pair	video	4,66	3,89	33,79	272,13
	auto				
test 1	QoS	$\mu_{99^{th}}$	$\sigma_{99^{th}}$	$\max_{99^{th}}$	max.
1° pair	none	11,13	16,74	119,18	335,36
2° pair	none	10,21	16,50	117,0	252,54
test 2	QoS	$\mu_{99^{th}}$	$\sigma_{99^{th}}$	$\max_{99^{th}}$	max.
1° pair	voice	5,50	5,97	34,20	55,79
2° pair	none	10,35	17,50	149,71	454,47
test 3	QoS	$\mu_{99^{th}}$	$\sigma_{99^{th}}$	$\max_{99^{th}}$	max.
1° pair	voice	5,59	6,44	38,29	61,84
2° pair	video	12.40	22,60	160,1	287,27

4.2 Measurement in the industrial scenario (IS)

The same experiments were performed in a real industrial plant using the prototype. Exactly the same computing and network equipment were used as for the controlled environment. The real image transmission was on channel 1, while the camera source worked on channel 11, and it was located in the header machine so as to represent the same conditions as the real cameras and *industrial PC* source. The other equipment was located in the real plant as can be seen in Fig. 4. The mean and standard deviation throughput obtained for image transmission in each case at different network bit rates can be seen in Table 5, while the same information for T^1_{net} is shown in Table 6. The behavior is slightly different from the CS. The introduction of traffic control implies a reduction in image throughput, although this reduction is lower than in the previous case. Here, the introduction of priorities has a positive impact on image throughput for both configurations, fixed and at 54 Mbps. That is because the effect of traffic priority and collision reduction have a high positive impact in noisy environments. Also, it is necessary to consider that a real industrial scenario is an uncontrolled environment. Thus, as can be seen in Fig. 8.b, in test 2 and test 3 there were some periods when the conditions allowed some stability in a high bit rate mode, whereas this was not obtained in test 0 and test 1, so the continuous bit rate changes produced a degradation in the mean image throughput, and a higher standard deviation with respect to other experiments, as can be seen in Tables 5 and 6. This variability in some test also has some impact on control traffic. While the general behavior is similar to the 54 Mbps configuration, only in test 1 for 54 Mbps the figures are worse in IS than in CS, whereas in the other cases the behavior is worse in CS, as also can be appreciated in Figs. 7 and 9. This could be due to the high peaks in image throughput obtanined in IS, which can reduce the influence on the asynchronous process of the control traffic.

4.3 Controlled versus industrial scenarios

For the image source, using a configuration of 54 Mbps, changing from an interference free scenario to an industrial scenario caused a significant loss of throughput. This throughput fell to 83% of the clean scenario for test 0. This throughput reduction is considerably bigger for auto configuration since the reduction fell to 59%. The standard deviation in IS is at least double that of all the other experiments, as also can be appreciated in Figs. 6.a and 8.a. These differences were due to the fact that in order to increase the bit rate it is necessary to use sophisticated modulation mechanisms that are more sensitive to the noise and interference that is prevalent in a real industrial scenario. Differences between each test (from test 0 to test 3 for the different cases) are more difficult to analyze due to the system itself, since even in a controlled scenario there are some strong bit rate changes, whereas in the industrial scenario the header is an autonomous system, that can be freely moving or stopped inside a test. The image throughput increase in test 2 and test 3 against test 0 was not due to the EDCA priorities but to the bit rate stability periods produced in these tests. However, the use of EDCA priorities in the control traffic clearly have a positive impact in the overall system function.

5 Conclusions

In this paper we have evaluated experimentally the timing behavior of 802.11n in a real industrial scenario, analyzing the influence of EDCA and bit rate algorithm on a bandwidth intensive application. The priorities given by EDCA are very effective in improving performance in non-saturation situations when each source has a different type of priority. However, the number of EDCA priorities is very low which means that the effectiveness of this improvement is highly dependent on the number of sources necessary in each of the priorities, and on the volume of traffic for each of these sources. In a clean scenario the use of EDCA has a very positive impact on the RTT of control traffic, but their effect in a non-priority bandwidth intensive application is negative, reducing the performance. However, in a noisy and more realistic scenario, the positive effect on RTT of control traffic is maintained but also a slightly positive impact can be seen in the non-priority bandwidth intensive application. The configuration of the bit rate may have a significant influence on the overall behavior of the system, but this improvement is not always directly proportional to the increase in bit rate and may even have negative repercussions on other traffic sources sharing the channel. Thus, in a non-noisy environment, the use of a variable bit rate could produce a considerable improvement in the performance of bandwidth-intensive applications, of around x3, but the control traffic has an equivalent reduction in their RTT values. In a noisy environment, the improvement is reduced below 2x, and the impact on control traffic RTT is reduced equivalently. Therefore, the difference between IS and CS were as expected. Although the increase in the $\text{max}_{99^{th}}$ values in IS are reasonable and manageable, the real RTT maximum values are very high, reaching around 500 ms. in the tests of 5 min. duration. Therefore, in real world situations these values could be even higher. Therefore, the use of EDCA priorities could have a positive effect on industrial applications, but considering this as a noisy environment, the existence of bandwidth intensive applications and the selection of fixed versus variable bit rate operations could have even more impact, so this should be balanced. The most important conclusion is the influence of bit rate algorithms in the performance of the overall system. Even an increase in the performance could be obtained for the multimedia application, which is lower than 2x, and this also has a negative influence in the RTT of control traffic, giving worse figures for $\text{max}_{99^{th}}$ and max, so the likelihood of missed deadlines is increased.

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List of Figures

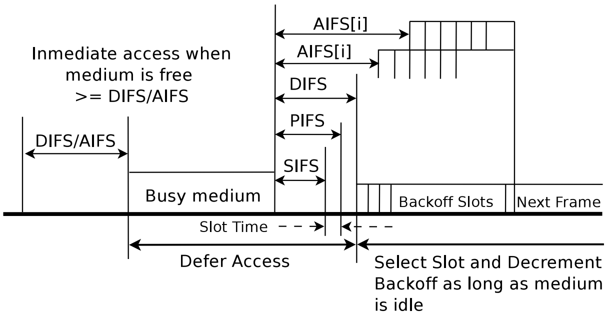


Figure 1. Interframe spaces in EDCA ([9])

Figure 2. Head machine with the image processing system

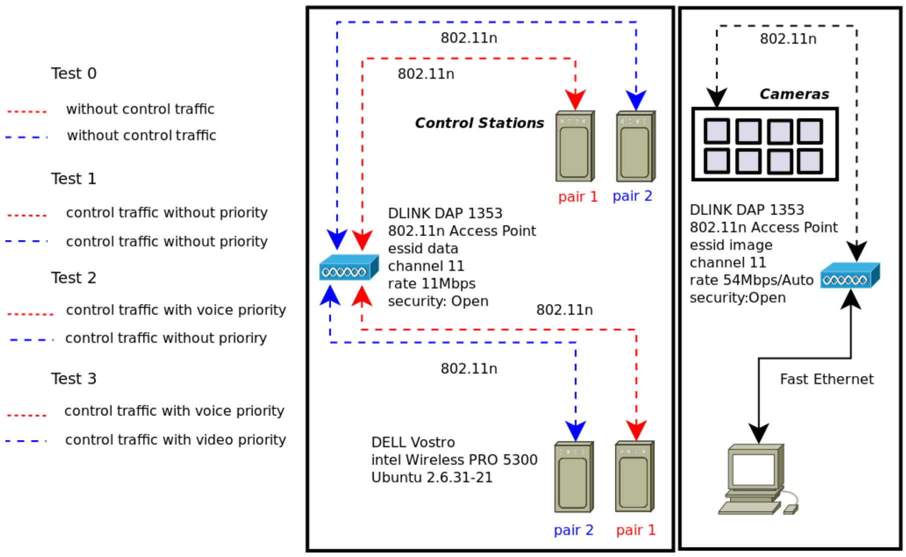


Figure 3. Controlled scenario

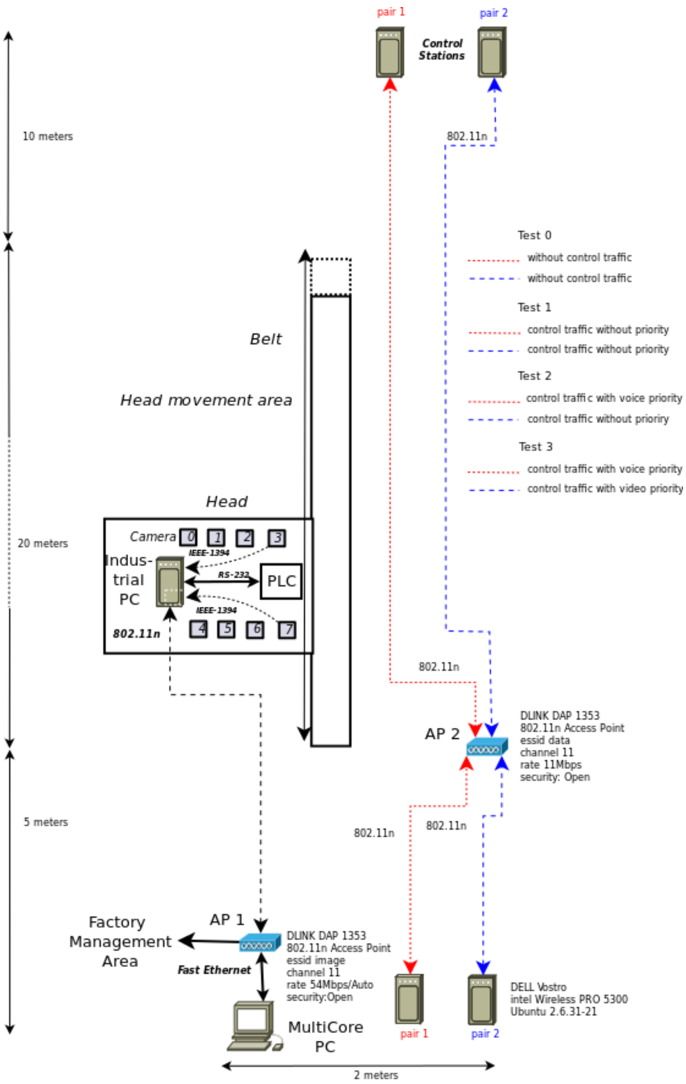


Figure 4. System architecture

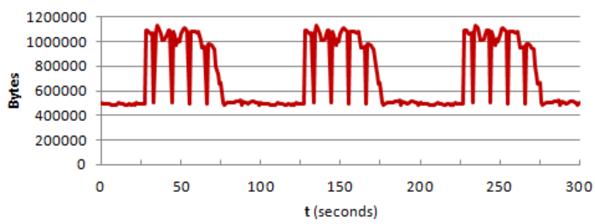
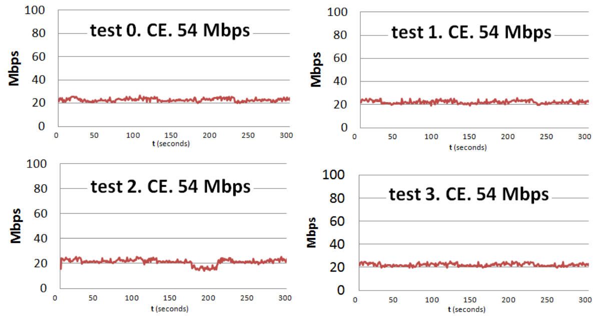
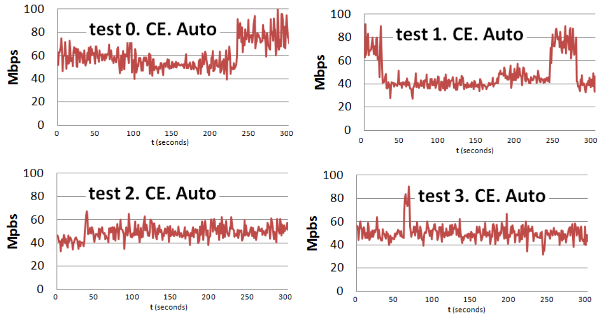


Figure 5. Image size trace used in all the experiments



a) 54 Mbps



b) Auto

Figure 6. Image throughput obtained in CE

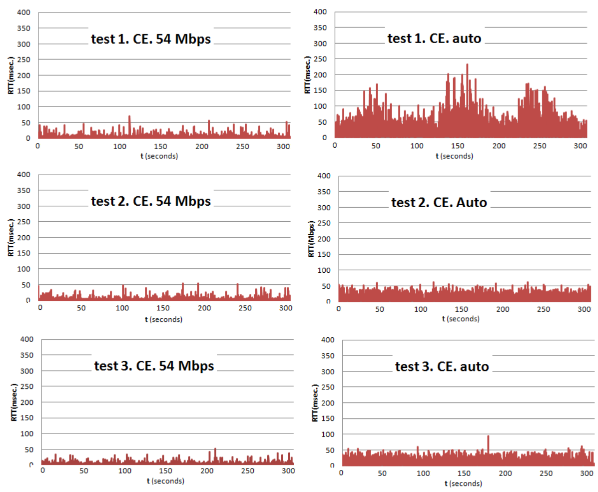
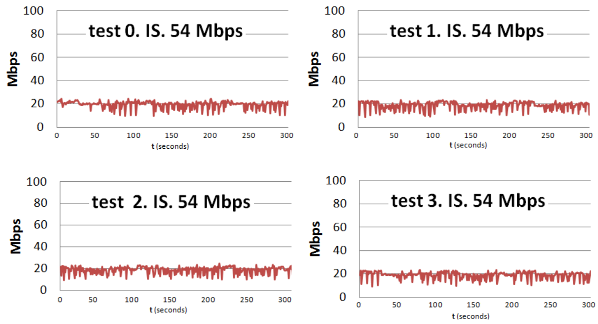
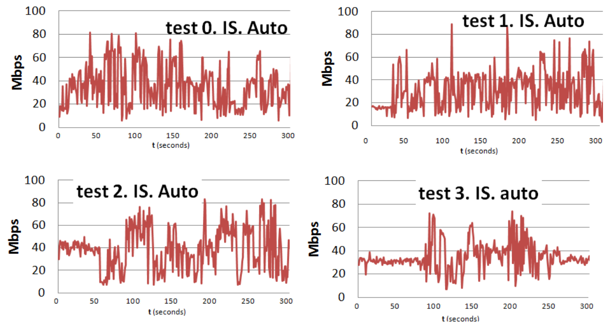


Figure 7. Rount Trip Time for pair 1 in CE



a) 54 Mbps



b) Auto

Figure 8. Image throughput obtained in IS

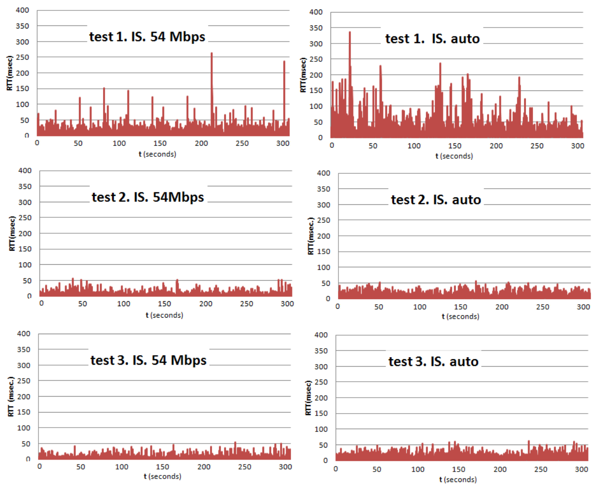


Figure 9. Rount Trip Time for pair 1 in IS