Tele-operated Vehicles System Using WLAN and Industrial Ethernet Techniques

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Abstract

Tele-operated vehicles have been used in different applications and environments. This paper studies the case in which a Tele-operated vehicle is guided through city streets. OPNET package is used to simulate the behavior of the system. Industrial Ethernet is assumed to be the field bus network of the vehicle and WLAN technique (IEEE802.11b) is assumed to be the communication link between the vehicle and the control center. The real time performance of the system is investigated during changing some important parameters. Then , image compressing technique is used to enhance the real time behavior of the system.

Keywords: Tele-operated Vehicle, Industrial Ethernet , WLAN , Image Compression

تقييم أداء الشبكات المحلية اللاسلكية و شبكة أثرنيت الصناعية في

أنظمة المركبات المسيطر عليها عن بعد

قتيبة ابراهيم علي

قسم هندسة الحاسبات/جامعة الموصل

الخلاصة

يتناول هذا البحث دراسة خواص الزمن الحقيقي لمركبة ذات نظام سيطرة ذاتي (باستخدام شبكة ايثرنيت الصناعية) و مسيطر عليها عن بعد باستخدام شبكة محلية لاسلكية. استخدمت حزمة المحاكاة البرمجية (OPNET) لبناء نموذج للنظام و تمت دراسة تأثير تغيير العوامل المختلفة(مثل جودة الصورة المنقولة، معدل توليد الصور ,البعد بين مركز السيطرة و المركبة) على أداء النظام. بعد ذلك، تم استخدام تقنية كبس الصور من اجل تحسين أداء الزمن الحقيقي للنظام.

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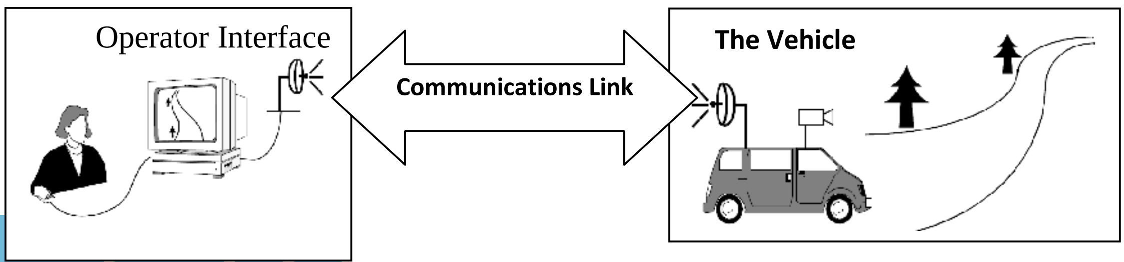
1. Introduction:

Tele-operated Vehicles (or unmanned vehicles) have, in recent years, come to prominence in a number of esoteric spheres of application, notably, in Space, in Underwater Exploration, in Military Aerospace, and in robot-assisted Surgery[1]. Tele-operated vehicles, describes the class of vehicles that are remotely operated by human beings. The three main elements that define a Tele-operated vehicle system are[2] (see Figure 1):

· The Operator Interface

· The Communications Link

· The Vehicle



Figure(1): Tel-operated Vehicle System's Elements

In-turn we can break down each of these three elements into their essential components.

The Operator Interface: this will generally consist of one or more *displays* for the video from the vehicle's onboard camera(s) and other sensor or status information. In addition the interface will require *input devices* to allow the operator to enter commands (via a keyboard), or execute manual control of the vehicle (via a joystick, for instance).

The Communications Link: this might utilize a wireless connection for mobile vehicles. This link will need to be full duplex so that command data can be transferred from the Operator Interface to the Vehicle, and at the same time vision, sensor and status information can be conveyed back from the Vehicle to the Operator Interface. Often, the communications requirements are diverse, requiring both digital and analogue channels and high bandwidths, especially for real time video from the Vehicle back to the operator.

The Vehicle: the Tele-operated vehicle will integrate mechanical and electronic components. Its design will vary enormously over different applications and operating environments. However, the vehicle is likely to require:

· Onboard power and energy management sub-systems.

· Communications transceivers to interface with the Operator Interface via the Communications Link.

· Embedded computation and program storage for local control systems, and to interpret commands from the Operator Interface and translate these into signals for motors or actuators.

· Video camera(s) and other distal sensing devices.

Tele-operated vehicles has been the subject of many studies for the last few years. Attempts have been made to design such a system in different manners to satisfy the working conditions in the different environments. The subjects of the studies cover different issues to optimize the performance of the mentioned system elements.

Jennifer et.al. [3] studied the case of Guiding a remote vehicle when real time image transmission is not possible (data rate is in the range of ten's kilo bit per second and latency is in the range of few seconds). Many methods for accurate semi-autonomous Tele-operation using monocular image data have been suggested. In semi-autonomous Tele-operation, an operator designates the path that the vehicle should follow in an image of the scene transmitted from the vehicle, and the vehicle autonomously follows this path.

Many papers focused on the design of Tele-operated robots [4-6]. The main characteristic of such a system is the low speed of the vehicle carrying the robot and the relatively limited distance between the Tele-control center and the vehicle. Image compression technique (to minimize the video data size) and WLAN technique (IEEE 802.11) (as the communication link)were used in such a systems.

Other studies [7] use Tele-operated vehicles in the military applications to guide tanks and other vehicles in the battle fields. The operation range of such a vehicles is in the range of few kilometers and video link uses selectable RF carrier frequencies ranging from 4.4 to 4.6 GHz as the video link.

Other field of study is the Unmanned Aerial Vehicle (UAV)[8,9]. This system has been studied and implemented using different communication links such as WLAN and FM radio channels.

2. Description on the Current Work:

This paper studies real time performance of a *ground* Tele-operated vehicle. A simulation model is built using OPNET package to test the performance of the network under different conditions. The current work differs from the previous studies in different aspects:

1.The current system consists of a Tele-operated vehicle (*a Car*) which is guided through city streets.

2.The vehicle consists of seven subsystems as described by the Society of Automotive Engineers (SAE) report[10].These subsystems are: the batteries, the vehicle controller (VC) ,the inverter/motor controller(IMC) , the instrument panel display(Ins.) ,driver inputs (located at the Tele-control center) ,brakes and the transmission control. The field bus network connecting these subsystems is required to handle a total of 53 messages, some of which contain sporadic signals, and some of which contain control data sent periodically. In addition to these subsystems, a Camera node(s) is added to the vehicle. Industrial Ethernet is used to connect these subsystems.

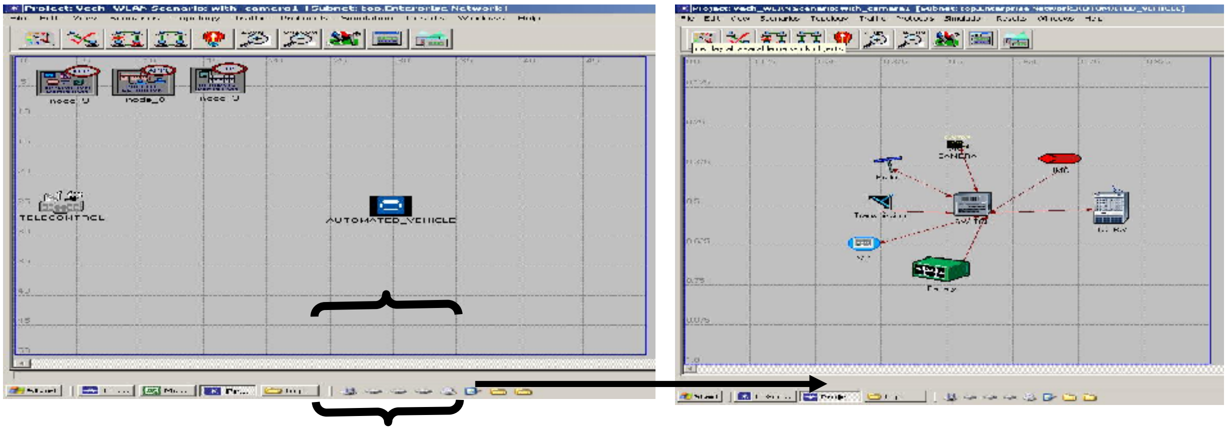
3.A single channel wireless LAN link (IEEE 802.11b) is used to connect both the control center and the vehicle.

4. The distance between the control center and the vehicle ranges between 100m to 25km.

The purpose of the current study is to explore the possibility of guiding (in real time) a Tele-operated vehicle through crowded city streets using the above control and communication tools.

3. Simulation Model assumptions:

As mentioned earlier, OPNET package is used to simulate the operation of the Tele-operated vehicle, see Figure 2.



Figure(2): OPNET Simulation Model of a Tele-operated Vehicle

The following assumptions is considered during building the simulation model:

1.The IEEE802.11b WLAN link is set to use frequency hopping modulation technique because it is more resistance to noise and attenuation [11].

2. IEEE802.11b is set to work at (11 Mbps) data rate. This gives a wider bandwidth to handle the video transmission operation with a minimum effect on the control data transmission operation and hence, on latency. The WLAN OPNET model assumes sending an acknowledgment frame after sending each packet with a (1 Mbps) data rate[12].

3.It is assumed that both the control center and the Tele-operated vehicle are supplied with a properly designed NIC's(to handle multi path effect[11]), Suitable amplifiers and high gain antennas in order to extend the coverage area of the WLAN and to resist noise and attenuation phenomena[13].

4.The Industrial Ethernet used in the vehicle is a (100Mbps) fast Ethernet. The characteristics of the different nodes are as follows: The packet processing rate for the vehicle controller and the inverter/motor controller is set to be (5000 and 1000 packet/sec.) respectively. The rest of the nodes have a packet processing rate of (500 packet/sec.)[14]. The control center node has a packet processing rate of (200000 packet/sec.) and the *Camera node* rate is (50000 packet/sec.).

5.The traffic pattern (as reported by SAE [10]) listed in table (1),is adopted to represent the different control activities among the vehicle's nodes and between the control center and the Tele-operated vehicle. The shadowed fields represent the control signals sent between the control center and the Tele-operated vehicle through the WLAN link.

Table(1): Traffic Pattern of the Vehicle

Signal Number	*From*	*To*	*Latency /msec.*	*Period /msec.*	*Size /bits*
1	Battery	V/C	100.0	100.0	8
2	Battery	V/C	100.0	100.0	8
3	Battery	V/C	1000.0	1000.0	8
4	Battery	V/C	100.0	100.0	8
5	Battery	V/C	1000.0	1000.0	8
6	Battery	V/C	100.0	100.0	8
7	Driver	V/C	5.0	5.0	8
8	Brakes	V/C	5.0	5.0	8
9	Brakes	V/C	5.0	5.0	8
10	Trans	V/C	100.0	100.0	8
11	Trans	V/C	5.0	5.0	8
12	Brakes	V/C	100.0	100.0	8
13	Battery	V/C	1000.0	1000.0	1

14	Battery	V/C	5.0	50.0	4
15	Driver	V/C	20.0	50.0	1
16	Driver	V/C	20.0	50.0	1
17	Driver	V/C	20.0	50.0	2
18	Brakes	V/C	20.0	20.0	1
19	Driver	V/C	20.0	50.0	1
20	Driver	V/C	20.0	50.0	3
21	Trans	V/C	1000.0	1000.0	2
22	Driver	V/C	20.0	50.0	3
23	Battery	V/C	20.0	50.0	1
24	Battery	V/C	20.0	50.0	1
25	Battery	V/C	20.0	50.0	1
26	Driver	V/C	20.0	50.0	1
27	Driver	V/C	20.0	50.0	1
28	Battery	V/C	20.0	50.0	1
29	V/C	Battery	10.0	10.0	8
30	V/C	Battery	10.0	10.0	8
31	V/C	Trans	20.0	50.0	2
32	V/C	Battery	5.0	5.0	8
33	V/C	Battery	1000.0	1000.0	1
34	V/C	Battery	20.0	50.0	8
35	V/C	Battery	20.0	50.0	1
36	V/C	Brakes	1000.0	1000.0	2
37	V/C	Brakes	20.0	50.0	1
38	V/C	Brakes	20.0	50.0	1
39	V/C	Ins.	20.0	50.0	7
40	V/C	I/M C	20.0	50.0	1
41	I/M C	V/C	20.0	50.0	1
42	V/C	I/M C	5.0	5.0	8
43	I/M C	V/C	5.0	5.0	8
44	V/C	I/M C	20.0	50.0	1
45	I/M C	V/C	20.0	50.0	1
46	V/C	I/M C	20.0	50.0	1
47	I/M C	V/C	20.0	50.0	1
48	V/C	I/M C	20.0	50.0	1
49	I/M C	V/C	5.0	5.0	8
50	I/M C	V/C	20.0	50.0	2
51	I/M C	V/C	20.0	50.0	1
52	I/M C	V/C	20.0	50.0	8
53	V/C	I/M C	20.0	50.0	1

6.User Datagram Protocol (UDP) is used to handle the transmission operations of control data and video streams.

7.The Camera node consists of four cameras : front, back, left and right. These cameras offer different scenes to the operator. In order to minimize the video stream traffic, the operator can switch to one of these cameras at any time.

8.The video stream performance mentioned in references[15,16] is considered in the simulation model. Frame rate is assumed to have one of two values (10 or 15 frame/sec) and the selection is based on the vehicle speed which is assumed to have a maximum value of (25 km/hr.)[17].

9.Sounds of the surrounding environment of the vehicle is assumed to be transmitted as indication data signals with each video packet. These data signals could be recreated at the control center to produce a sound equivalent to the source.

10.The metrics used to evaluate the real time performance of the system are:

♦**Vehicle Controller Latency:** As listed in table (1),the worst case latency value is (5 msec.),so that, the network must be able to deal with this condition.

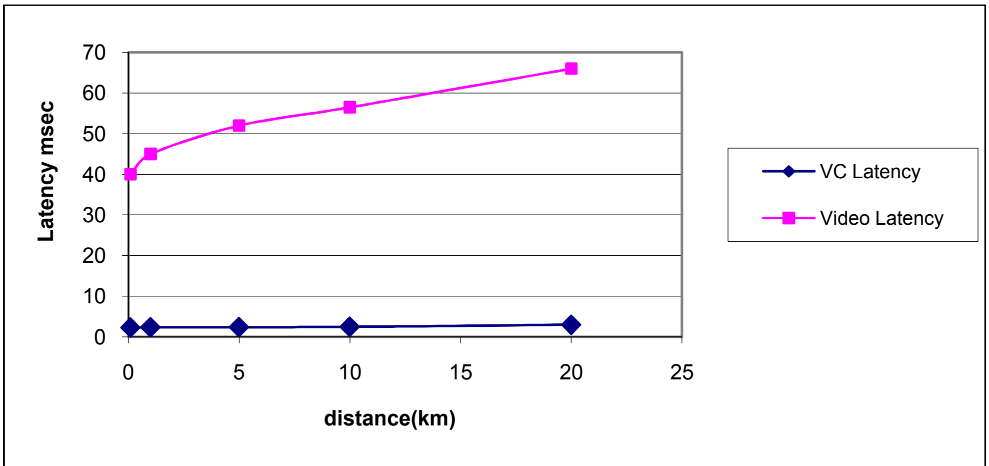
♦**Video Stream Latency:** In order to get an acceptable operator response, this latency value should not exceed (170 msec.)[18].

4. Results and Discussion:

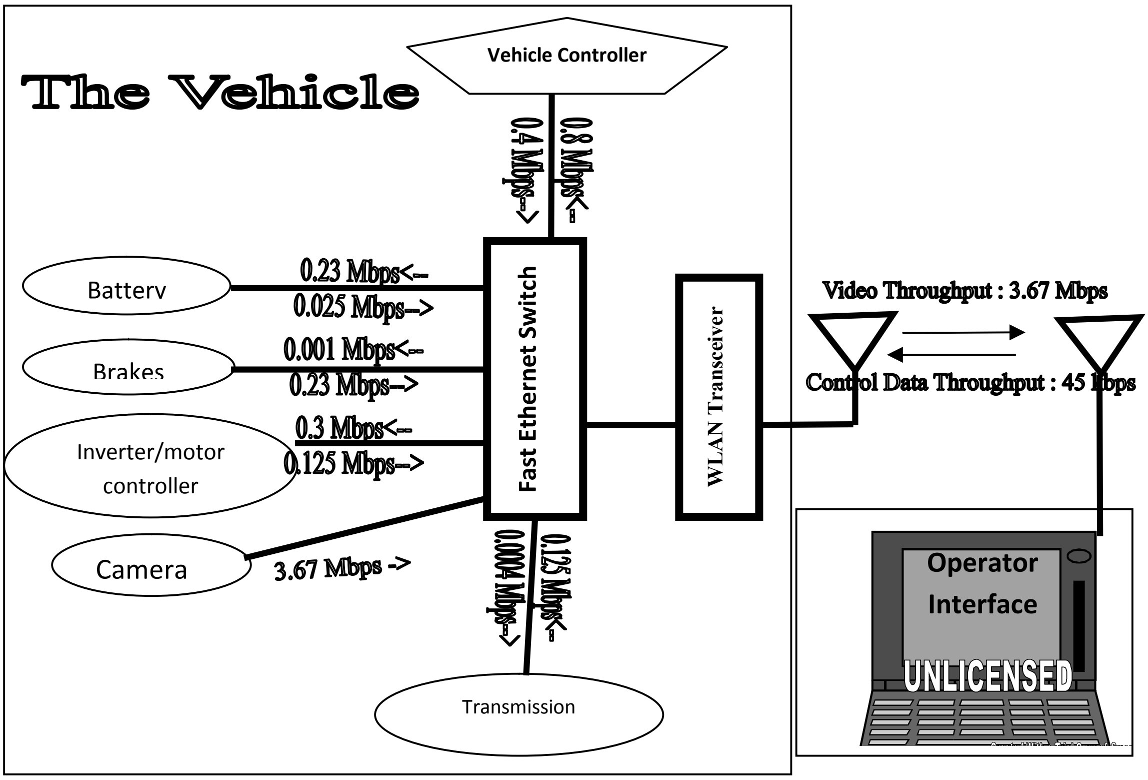
In order to test the system performance under different conditions, several simulation scenarios were built. The video stream performance was changed and its effect on different latency values is reported. Then, image compression technique is used to minimize video traffic contribution and to improve system performance.

a. Without Image Compression:

1.Scenario 1: in this case, the video performance is (300×200 pixel , 4 bits color intensity, frame rate=15 frame/sec.). The distance between the Tele-control center and the vehicle is changed from (100m to 20km). The latencies change are shown in Figure 3. The traffic map of the system is shown in Figure 4.



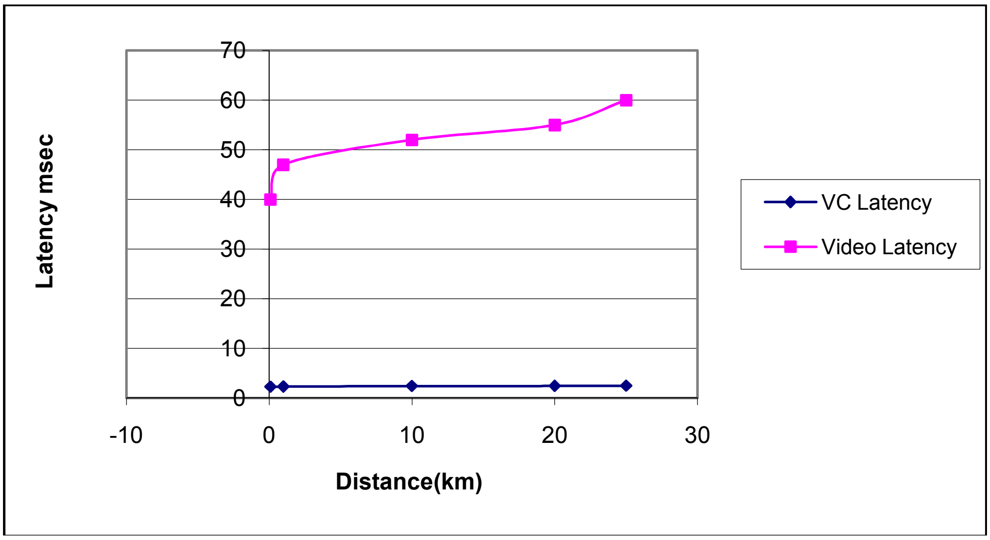
Figure(3): Latency Variation as a function of Distance in Certain Image Performance



Figure(4): Traffic Map of a Tele-operated Vehicle

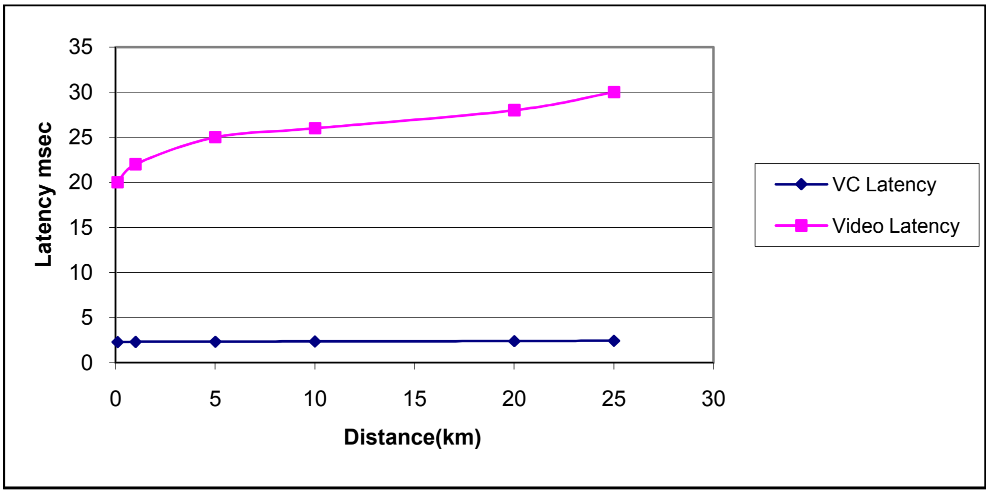
It is noted that the latency values increased with the increment of the distance because of the effect of propagation delay on the (CSMA/CA) protocol used by the WLAN[19]. However, the latency values did not exceed the acceptable values mentioned earlier. When the distance is more than(20 km), the real time performance of the system begin to deteriorate and both latency values exceed their acceptable values.

2.Scenario 2: The same video performance mentioned in (Scenario 1) is applied here, but the frame rate is reduced to (10 frame/sec). The latencies variation against distance is shown in Figure 5. It is obvious that real time performance of the system is more stable against the distance change. Changing the frame rate value cause a decrease in the video throughput from(3.67 Mbps) in Scenario 1 to (2.44 Mbps) in this Scenario**.** This reduction in video throughput frees more bandwidth to the profit of control data.



Figure(5): Latency Variation as a function of Distance in Certain Image Performance

3.Scenario 3: **T**he video performance in this scenario is (128×120 pixel , 8 bits color intensity, frame rate=15 frame/sec.). The video throughput is reduced to (1.88 Mbps) which affect positively on the latency values as shown in Figure 6.



Figure(6): Latency Variation as a function of Distance in Certain Image Performance

4.Scenario 4: This scenario describe an operation of sending back a still pictures from the vehicle to the control center (the distance between them is 25 km). The simulation is run for the following image resolutions {(640×480)pixel×16bit) , (800×600)pixel×16bit) , (1024×768)pixel×16bit) }. The effect on (VC latency) is shown in Figure 7. It is obvious that the last two cases affect negatively on the system performance.

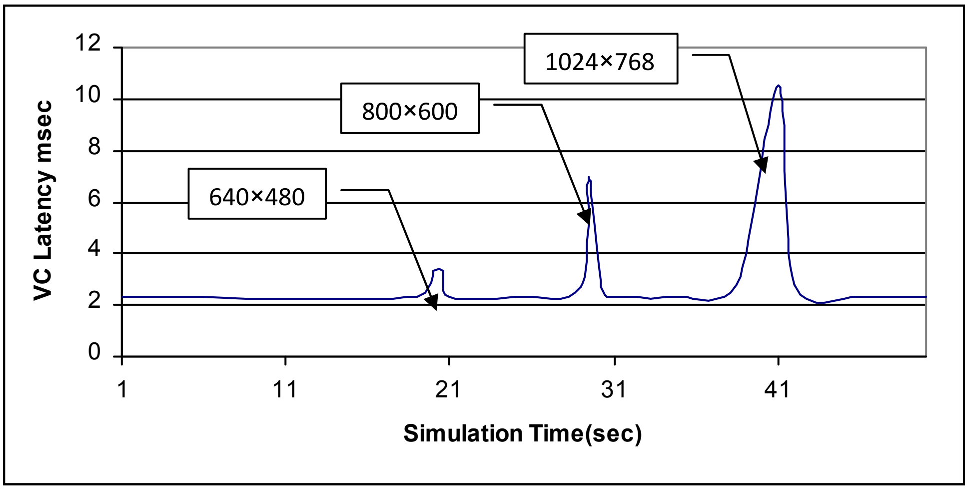


Figure (7): Latency Variation as a function of Different Image Performance

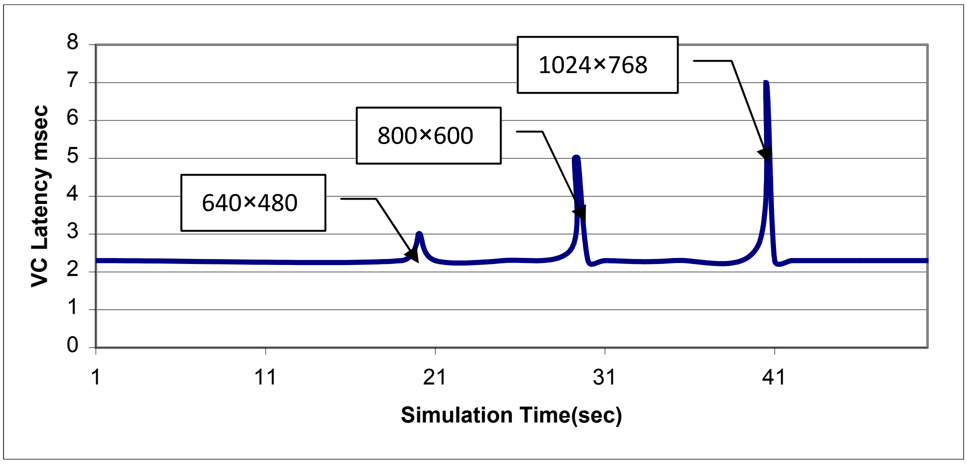
b. With Image compression:

In this case image compression technique is applied on the video stream transferred from the vehicle to the control center(the distance between them is 25 km). This technique allows to decrease the amount of the video data and hence its contribution in the shared WLAN bandwidth. The adoption of this

Image resolution(pixel)	Color intensity(bit)	Frame rate(frame/sec)	Video Throughput(Mbps)	Average VC Latency(msec)	Average Video Latency(msec)

technique would enhance the latency of the control data.

The image compression property built in the OPNET package is used in this work. It has a normally distributed compression ratio's between(50%-80%) with a compression delay of (3×10^{-9} sec/bit) and decompression delay of (1×10^{-9} sec/bit). Table 2 summarize the system performance after considering image compression technique. The effect of compression when sending a still pictures is shown in Figure 8. It is obvious that compression technique has a clear positive effect on the system performance which can be better enhanced using higher compression ratio.



Figure(8): Latency Variation as a function of Different Compressed Image Performance

Table (2): Tele-operated Vehicle Performance Using Image Compression Technique

300×200	4	15	2.25	2.5	15
300×200	5	15	3	3.5	25
300×200	8	10	3	4	50

5. Conclusions and Suggestions for Future Work:

This paper studies real time performance of a tele-operated vehicle. The following conclusions could be extracted from the current work:

1. WLAN technique (IEEE 802.11b, 11 Mbps) together with Industrial Ethernet (Fast Ethernet) could be used safely in Tele-operated vehicle system.

2. Video performance has a great effect on the overall system performance. In order to get an acceptable response, the video throughput should not exceed (3.67 Mbps).

3. The distance between the Tele-operated vehicle and the control center could affect seriously on the system performance, especially when it synchronized with bandwidth congestion problem.

4. In order to get an acceptable picture update rate, video frame rate could be changed according to vehicle speed.

5. High resolution still images could be transferred between the vehicle and the control center.

6. The key element in enhancing the system response is the use of image compression technology. High compression ratio would optimize the system performance.

As a future work, the following suggestions could be adopted:

1. Using two separate WLAN channels (one for the video stream and the other for the control data) between the vehicle and the control center.

2. Using higher wireless link bandwidth. This could be achieved using other WLAN versions such as (IEEE 802.11a or IEEE 802.11g).

3. Investigation the use of various image compression techniques and their effect on system performance.

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