Chapter 6
Conclusions and Future Work

In this chapter we will review the entire research thesis objectives and results. We will emphasis on the scientific contributions that this research work made. At the end we will give some prospective points for the future work of this research.

6.1. Review of the Research Objectives.

Currently, the fieldbus networks are widely used as communication support for the Integrated Communication and Control Systems (ICCS). Usually there are many control loops that are attached to the fieldbus common bus. The applications of the fieldbuses have a wide range from the process control to the discrete manufacturing. There are real-time constraints that are imposed by the ICCS onto its communication network (i.e. bus), which means that the traffic of the ICCS (both periodic and aperiodic) must be bounded within a well-defined time interval; otherwise a timing fault occurs, which in turn may lead to critical situations.

WorldFIP fieldbus network is a broadcast network, where several network nodes share a common communication medium (bus). The FIP protocol depends on the producer/consumer model, in which the data packets are transmitted from the producer node to the consumer node(s) via this shared communication medium. As a consequence, the packets to be transmitted by any network node may experience some delay. This delay is not only resulting from the contention between packets requests from the same node, but also the contention with other packet requests coming from the other network nodes.

One of our main objectives in this thesis was to analysis the appropriate scheduling algorithms to guarantee that the real-time constraints of the FIP's ICCS are easily verified. This verification was made before to the run-time (off-line); so that we need not to formulate the complexity of this scheduling algorithm.

In this thesis we addressed an important measure of the overall latencies of the communicating tasks along the shared bus; namely the Worst Case Response Time (WCRT). We calculated the WCRT of both types of the FIP's aperiodic variables (i.e. the urgent and normal aperiodic variables) by using a theoretical model.

In order to guarantee that the timing requirements (deadlines) of the ICCS are met, the communication delay between a sending task queuing a variable value, and the related receiving task being able to access that value, must have an upper bound (i.e. WCRT). This bounding is considered one sort of the schedulability analysis.

The periodic traffic of the WorldFIP end-to-end deadline, and hence the schedulability analysis, can be easily guaranteed. This is of course due to the Bus Arbitrator of the WorldFIP implements a pre-defined static schedule (i.e. the WorldFIP BAT) for these periodic variables.

However for the aperiodic traffic, the response time is not easily bounded and need more schedulability analysis. We assume that the bound of the WCRT of the aperiodic variables can be guaranteed provided that there is at least one microcycle with an aperiodic window length that is suitable for processing aperiodic requests.

Another important objective of this thesis is the study of the performance metrics of the closed-loop control systems that are attached to the FIP system. The satisfactory performance can not be easily guaranteed as the data packets of the control loops encounter delay when accessing the shared communication medium. This delay problem can make these loops instable. For this reason we chose to address the stability of these control loops as a performance metric. As we saw in chapter three, there are two main methods to address the stability problem. One method was to find the maximum delay that each closed-loop control system can tolerate. The other solution was to find new values of the sampling times of all control loops taking into account the delay that each control loop face.

6.3. The Main Research Contribution of this Thesis.

As we have just seen in the previous section; we have two main objectives in this thesis. In this thesis we have made some important contributions to the real-time analysis of the WorldFIP protocol. Now, we will summarize our main contributions below.

For the WorldFIP periodic traffic, we saw that the data packets deadlines can be easily guaranteed, since the bus arbitrator implements a static schedule for the periodic variables. Therefore, the real-time guarantees for periodic traffic rely on the scheduling algorithm that is used for building the WorldFIP BAT. In chapter three of this research we reviewed many scheduling strategies for building build the FIP BAT that were proposed by other researchers and we commented on each algorithm.

In chapter four we studied the analysis of the WCRT for both the aperiodic urgent variables, and the aperiodic normal variables. This work is the first to introduce the calculation of WCRT of other aperiodic traffic of FIP systems rather that the urgent aperiodic variables. Despite the importance of all the aperiodic traffic, no effort was made before to calculate the WCRT of both the normal aperiodic variables, and/or the aperiodic messages.

After that, we successfully verified our theoretical model that calculated the theoretical value of the WCRT of the FIP's urgent aperiodic variables by using a traffic simulator of our design. During this verification we showed that our formula is more exact than the formula that was given by [Tovar 99-1]. What is more, we introduced a new concept in calculating the WCRT of the urgent aperiodic variables for the FIP fieldbus protocol. This concept was the elimination of the number of the urgent aperiodic variables from the WCRT formula by using the queue sizes of the aperiodic variables.

The idea of using the aperiodic queues sizes instead of knowing the exact number of the aperiodic variable was inspired from [Kim 98] as the authors were talking about the memory sizes needed to implement the BAT. This idea is very good as the number of the aperiodic variables was not specified by the WorldFIP protocol standard. What is more, the number of aperiodic variable can be varied during the run-time due to critical circumstances.

This work is also the first work that used the network traffic simulator to simulate the WorldFIP protocol in order to calculate the real WCRT of the aperiodic urgent variables. The results that we got from the simulator are more close to the theoretical model results we got before from our proposed model. In this work we compare between the simulation results that we obtained from the simulation with the theoretical results. We deducted that the Gaussian curve that resulted when graphing these histograms was result from the randomness of the arrival of the aperiodic requests at the BA.

Next in chapter five, we proposed a modified scheduling algorithm which maintains the stability of each one of the control loops which are attached to the FIP's network. This was done by finding new values of the sampling periods of the control loops that are attached to the FIP shared bus. This algorithm was a modified version of the window scheduling algorithm that was given by [Halevi 88], and [Hong 95].

The author of [Hong 95] did not take into his consideration the aperiodic traffic and its great importance in the real-time systems. His algorithm maximizes the periodic utilization far may be beyond the system requirements. For this particular problem we have proposed another new modified algorithm to deal with it. In this modification we tried to reduce the worst case response time of the aperiodic traffic by finding slots for it in the BAT.

In addition to all these merits; this new modified scheduling algorithm also eliminated the communication jitter that happened to the periodic variables. in chapter three we discussed the bad effects of such phenomenon on the performance of some control systems.

6.4. The Future Work.

Although the provided analyses and methodologies are quite good and constitute a set of powerful tools to guarantee the real-time requirements of the FIP's protocol, there are some improvements that can still be made.

In this context we will survey some of the provided results which can be improved or extended further. This section also briefly describes some interesting research topics, which are worth investigating further. Here are these points:

1. The verification of the WCRT of the normal aperiodic variables by using an appropriate traffic simulator can be considered. We may enhance our traffic simulator to include the normal aperiodic variables as well as the urgent variables.
2. The extending of the theoretical WCRT model to include the aperiodic messages can be taken into account. We may also try to verify these theoretical results using the same, or other, FIP traffic simulator.
3. The enhancement of the estimation of the maximum allowable time delay (Ψ_i) of the various closed-loop control systems that are attached to the FIP fieldbus in order to maintain stability of these systems can be considered as well.
4. We will take into account the clock synchronization of the overall FIP system network in order to achieve jitter-free transmissions as we did not introduce new work for this matter.
5. We will try to apply the work of [Ryu 96], and [Hong 96] to find the appropriate task attributes of the periodic variables (i.e. periods, phases and deadlines) of the WorldFIP periodic variables. Further, we may link between this work and the work of [Halevi 88], and [Hong 95].

6. Another important observation that we must take into account is the reliability of the communication link or the bus. We will make a proposal to maintain reliable communication link. For example, we could either attach another redundant bus. Thus we may need to modify the existing protocol or use another one.

7. The extension of this real-time study to other fieldbus systems, mainly the new state-of-the art fieldbus protocols like the FlexRay, the TTP, or the FTT-CAN, is considered one of the future extensions to this work.