Scientific Research and Essays Vol. 5(14), pp. 1845-1851, 18 July, 2010
Available online at http://www.academicjournals.org/SRE
ISSN 1992-2248 ©2010 Academic Journals

*Full Length Research Paper*

# Interconnections of WorldFIP, CAN and PROFIBUS fieldbuses over an ATM backbone

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Accepted 6 July, 2010

**Manufacturing automation systems are widespread and becoming more common across the world. Therefore, fieldbuses of automation systems in a factory plant becomes distant and dissimilar technologies from one another. Realtime interconnection between these fieldbuses is essential for the sustainability of automation. This study designs a system that provides a realtime, remote communication among WorldFIP, CAN, PROFIBUS fieldbuses over ATM backbone. Fieldbuses are connected to backbone with bridges. Using network simulation software under various message traffic, the designed system's performance is investigated and the obtained results from the simulations are discussed. The results showed that fieldbuses can communicate with each other based on realtime requirements over ATM.**

**Key words:** ATM backbone, fieldbuses, internetworking, heterogeneous networks.

## INTRODUCTION

The computer integrated manufacturing (CIM) model in Figure 1 shows hierarchical architecture of communication connections in a factory plant automation system. The CIM model is divided into five layers. The level 1 is a wide area network that includes mainframes and the level 5 is fieldbus network that includes sensors and actuators (Schickhuber and McCarthy, 1997). Communication network structures at every level differ considerably from one another. For instance, while general-purpose networks are used in the higher layers, fieldbuses are utilized at the lower levels since real time requirements increase at the lower levels.

Nowadays, globally distributed CIM systems are used across geographical boundaries, whereas CIM is an integration of localized manufacturing facilities (Nagalingam and Lin, 2008). Future scenarios of distributed automation also lead to desired mechanisms for geographically distributed automation functions due to various reasons that include (Neumann, 2007):

1. Centralized supervisory and control of (many) decentralized (small) technological plants.
2. Remote control, commissioning, parameterization and maintenance of distributed automation systems.
3. Remote experts or external machine-readable knowledge for the plant operation and maintenance.

Consequently, as shown in Figure 1, the communication scenario on the CIM automation system is expanded both vertically and horizontally (Treytl et al., 2004; Cseh et al., 1999). Modern industrial enterprise and environments usually adopt a few different types of fieldbus technologies in their control systems simultaneously (Yanjun and Jun, 2005; Carvalho et al., 1996; Lin and Jeng, 2006). And the adoption of multiple fieldbus technologies is defined as heterogen communication type.

It is inevitable to share data and information among all heterogen networks. Integration and interoperability of them are also required (Nagalingam and Lin, 2008).

In recent years, vertical expands trend is Internet Protocol (IP)-based networks (Treytl et al., 2004). In horizontal, on the other hand, there are many scientific researches with different viewpoint as transmission

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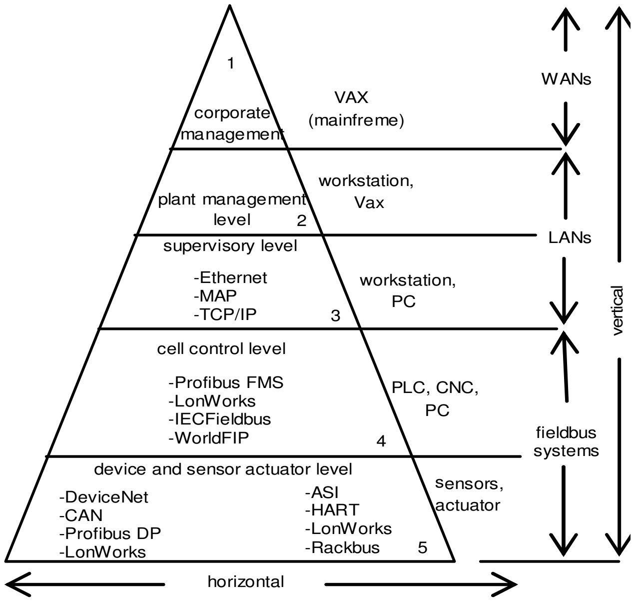


**Figure 1.** CIM model.

technologies of backbone and converter devices among fieldbuses.

Paper examples for transmission technologies of backbone are over Transmission Control Protocol (TCP)/IP (Kaiser and Brudna, 2002; Carvalho et al., 1996; Cena et al., 2001), over Ethernet (Park and Kim, 2005; Cuong and Kim, 2007; Jasperneite and Feld, 2005) and Asynchronous Transfer Mode (ATM) (Cseh et al., 1999; Lauckner et al., 1999; Noh and Lee, 1997; Nasri and Maaref, 2000; Kunert, 1997; Kunert, 2000; Maaref and Nasri, 1997; Erturk, 2005; Ozcelik and Ekiz, 2007; Ozcelik and Ekiz, 2004; Ozcelik and Ekiz, 2008). Also, there is a study that used the solution of Iskefiyeli and Ozcelik (2007), with a wireless metropolitan area network (MAN) based on the Institute of Electrical and Electronics Engineers (IEEE) 802.16 standard as a backbone system.

Earlier studies use Gateway (Lauckner et al., 1999; Kaiser and Brudna, 2002; Yanjun and Jun, 2005; Noh and Lee, 1997; Park and Kim, 2005), Bridge (Yong et al., 2004; Cuong and Kim, 2007; Thomesse, 2005; Kunert, 1997; Kunert, 2000; Yinghong and Hongfang, 2007; Ozcelik and Ekiz, 2007; Ozcelik and Ekiz, 2004; Ozcelik and Ekiz, 2008; Iskefiyeli and Ozcelik, 2007) as interworking devices. Some alternative studies propose and implement Interoperability Unit (IU) (Hadellis et al., 2002), the proxy represents a gateway (Jasperneite and Feld, 2005), a new communication system architecture called Manufacturing Message Specification (MMS)-ATM (Maaref and Nasri, 1997), a gateway application between MMS and TCP/IP was developed to interface the PCs (Carvalho et al., 1996), propose over Wireless ATM (Erturk, 2005).

This article focuses on horizontal expands of the field area integration. Unlike previous researches, internetworking of factory instrumentation protocol (WorldFIP), controller area network (CAN) and process field bus (PROFIBUS) fieldbuses over ATM backbone by bridges are studied. Hence, the integration of heterogeneous fieldbus systems is presented from a different viewpoint. For this purpose, a system that consists of WorldFIP, CAN, PROFIBUS fieldbuses, and ATM backbone and bridges is designed and implemented.

The remainder of the article contains information about fieldbuses and backbone. It also contains information about bridge specifications and analysis of simulation of the internet worked system.

## WorldFIP, CAN, PROFIBUS and ATM

Industrial applications have used many fieldbus automation systems. WorldFIP, CAN and PROFIBUS are the most widely used three fieldbuses (Thomesse, 2005). These fieldbuses are preferred because they are commercial-off-the-shelf (COTS), standardized and open systems (Arjmandi and Moshiri, 2007; Baribaud et al., 1997; Aydogan, 2005).

WorldFIP (factory instrumentation protocol) is a fieldbus used in the areas of industry, power, process and transport. It is described in volume 3 of EN50170, which is the first international industrial communication standard that will also become a standard in each of the member countries of the European Union. WorldFIP has three layered fieldbus architecture. WorldFIP physical layer provides data transmission at S1 (31.25 Kbit/s), S2 (1 Mbit/s), S3 (2.5 Mbit/s) on STP and at 5 Mbit/s on FO. Data link layer provides transmission services of variables and messages. Application layer provides periodic/aperiodic message transmission services (Thomesse, 2005; Tovar and Vasques, 2000).

CAN protocol defined by BOSCH is not only used in mobile systems but also in other fields of application. Aside from its application in all kinds of mobile systems, it also predominates the data communication within embedded systems or factory automation because of being described in layers 1 and 2 of the OSI reference model. Its main features are described by ISO [ISO99-1, ISO99-2]. At 1_Mbit/s, a network extension of 40 m is possible. At 80 Kbit/s, a network length of 1000 m is possible. The CAN protocol is not based on the exchange of messages by addressing the message receiver. Instead, it is based on the identification of a transmitted message via mess-age identifiers (Etschberger, 2001).

PROFIBUS can be used at three levels including, fieldbus message specification (FMS), decentral periphery (DP) or process automation (PA) to better match the application. It is well-developed and supported by large companies such as SIEMENS. It complies with the DIN 19245 standard, parts 1 and 2. It already has a wide acceptance in European and American industries.

PROFIBUS can work in multimaster or in master/slave

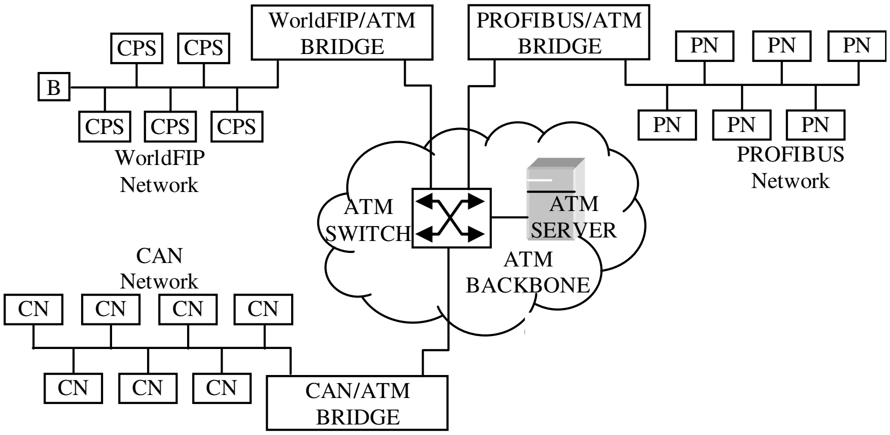


**Figure 2.** The communication system of fieldbuses over ATM backbone.

mode. PROFIBUS is suitable for communication between intelligent stations (e.g., Programmable Logic Controller-PLCs or Programmable Controller-PCs). It is also optimized for fast and efficient data transmission between controllers and the decentralized periphery (e.g., sensors). Baud rates can be selected from 9.6 kBits/s up to 12 MBits/s (Baribaud et al., 1997).

ATM is an innovative high speed, real-time data transfer technology. ATM standards were defined by the International Telecommunications Union (ITU) and the ATM Forum. ATM, as a connection-oriented technology, establishes a virtual circuit between the two endpoints before the actual data exchange begins. ATM is a cell relay, packet switching protocol, which provides data link layer services. This differs from other technologies based on packet-switched networks (such as the IP or Ethernet), in which variable sized packets are used. ATM exposes properties from both circuit and small packet switched networking, making it suitable for wide area data networking as well as real-time media transport. It is a core protocol used in the Synchronous Optical Network/Synchronous Digital Hierarchy (SONET/SDH) back-bone of the public switched telephone network.

The results by the previous scientific research presented in Lauckner et al. (1999), Cseh et al. (1999), Nasri and Maaref (2000), Kunert (1997), Maaref and Nasri (1997), Erturk (2005), Ozcelik and Ekiz (2007), Ozcelik and Ekiz (2004) and Ozcelik and Ekiz (2008), show that ATM is a proper network technology for the sensor/actuator level, where stringent real-time requirements have to be met.

## MATERIALS AND METHODS

### Designing

Figure 2 shows the communication system of fieldbuses over ATM backbone designed for the study. In this research, fieldbuses are connected to ATM backbone with bridges not with gateway. This is because gateway provides connection among all seven layers of dissimilar networks. For fieldbuses communications, on the other hand, three layers are sufficient. Hence, when bridges are used, the data transmission delays decreases in comparison to the data transmission delays when gateway are used. Bridges in this system are designed and implemented beforehand as WorldFIP/ATM, CAN/ATM and PROFIBUS/ATM Local Bridges. And their performances are simulated and found peer-to-peer delays by Ozcelik and Ekiz (2004), Ozcelik and Ekiz (2008) and Aydogan (2005).

ATM backbone is built based on an ATM switch where the speed of one of the ports (used for bridge side) is 155 Mbps. Features of an ATM Switch produced by IBM, "8285 Nways Workgroup Switch", are used (The IBM, 2010).

Figure 3 displays CAN/ATM Local Bridges port-to-port delays called mean process time at (a), PROFIBUS/ATM Local Bridges mean process time at (b) and WorldFIP/ATM Local Bridges mean process time at (c). These delays are performed under different loads as 70/30% local/remote. Delays are 170 - 200 µs in the direction of CAN to ATM, 270 - 350 µs in reverse direction, 125 µs in the direction of PROFIBUS to ATM, 11050 - 12950 µs in reverse direction, 2504 – 2937_µs in the direction of WorldFIP to ATM, and 206 - 221 µs in reverse direction.

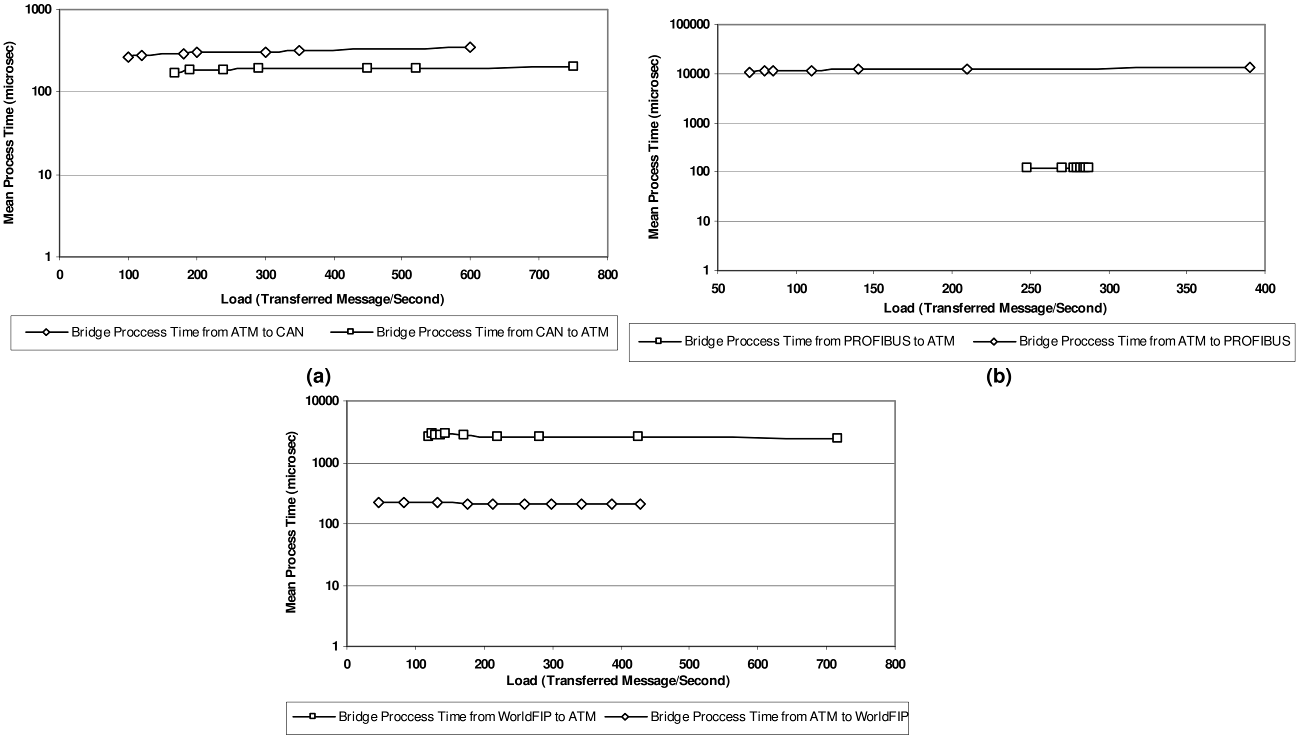
The transmission times called cycle time between nodes of WorldFIP, CAN, PROFIBUS fieldbuses and ATM appears in Figure 4. These times are delays for the system. These delays are performed under different loads as 70/30% local/remote. Delays are 200 – 600 µs in the direction of CAN to ATM, 180 - 510_µs in reverse direction, 1850 – 2300 µs in the direction of PROFIBUS to ATM, 550 - 1800 µs in reverse direction, 262 – 271 µs in the direction of WorldFIP to ATM, and 262 - 271 µs in reverse direction.

### Modelling

Performance of a networked system can be analyzed using network simulation programs such as Opnet, Simscritp, Omnet etc. In this paper, Network II.5 simulation package is used which can simulate computer components, especially Layer 1 and 2 of OSI model, and automated factory communications of the highest order of complexity.

The impact of ATM backbones on the performance of WorldFIP, CAN, and PROFIBUS fieldbuses was evaluated using the simulation model designed with Network II.5 as shown in Figure 5.

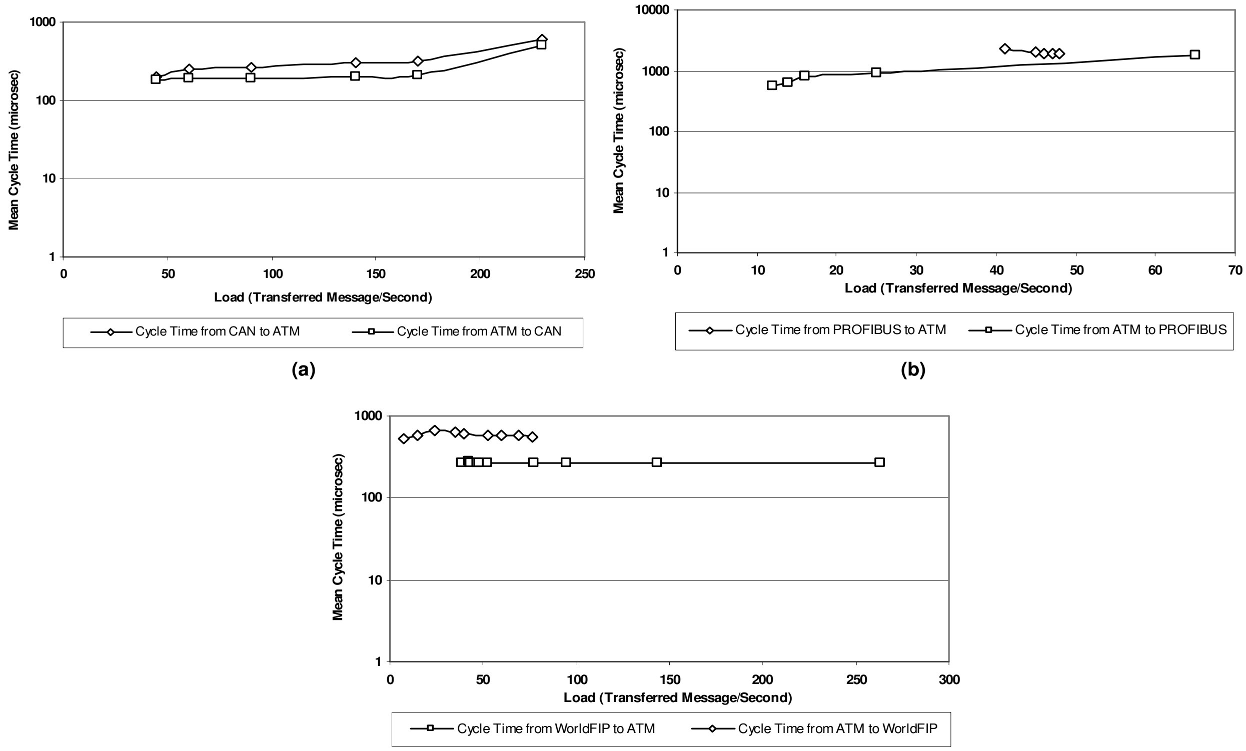
The system's end-to-end delay encountered by communication between fieldbuses results from the following components: Delay at the source fieldbus, delay at the source bridge including, bridging



**(a)** **(b)**

**(c)**

**Figure 3.** CAN/ATM, PROFIBUS/ATM and WorldFIP/ATM local bridges mean process times. (a) CAN/ATM local bridges mean process time, (b) PROFIBUS/ATM local bridges mean process time, (c) WorldFIP/ATM local bridges mean process time.



**(a)** **(b)**

**(c)**

**Figure 4.** CAN/ATM, PROFIBUS/ATM, WorldFIP/ATM cycle times. (a) CAN/ATM cycle time, (b) PROFIBUS/ATM cycle time, (d) WorldFIP/ATM cycle time.

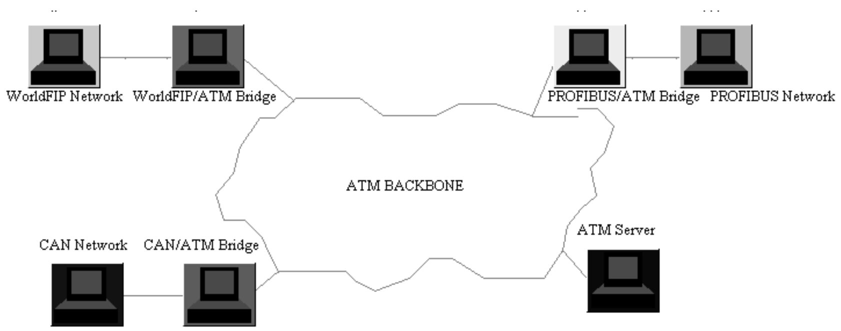


**Figure 5.** The model of system.

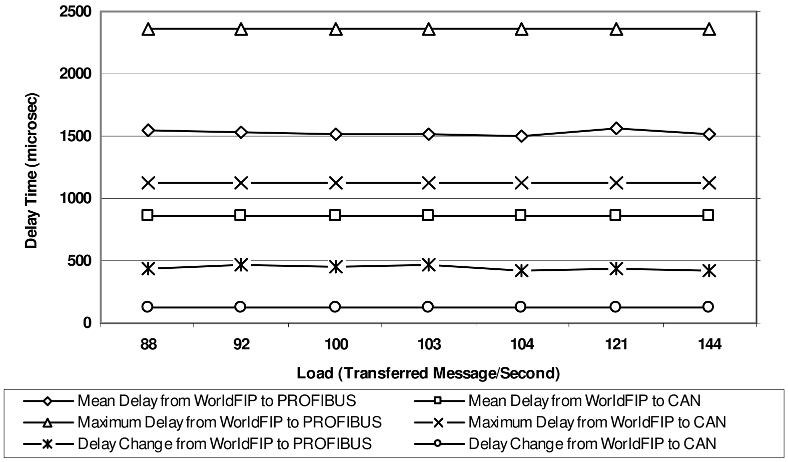


**Figure 6.** Delays of WorldFIP with CAN and PROFIBUS over ATM.

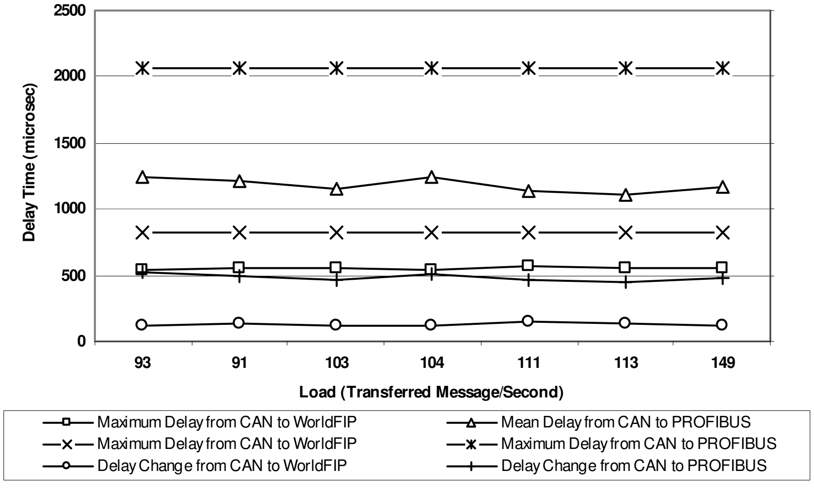


**Figure 7.** Delays of CAN with WorldFIP and PROFIBUS over ATM.

process, delays in the ATM network including, transmission delay, queuing, switching, routing, etc. delay at the destination bridge including bridging process and delay at the destination fieldbus (Bassiouni et al., 1996).

Maximum delays, mean delays and delay changes statistics were used in the evaluations. Maximum delays show worst case. Delay changes refer to changes of mean transmission delay of messages from source to destination. In general, small delay changes are

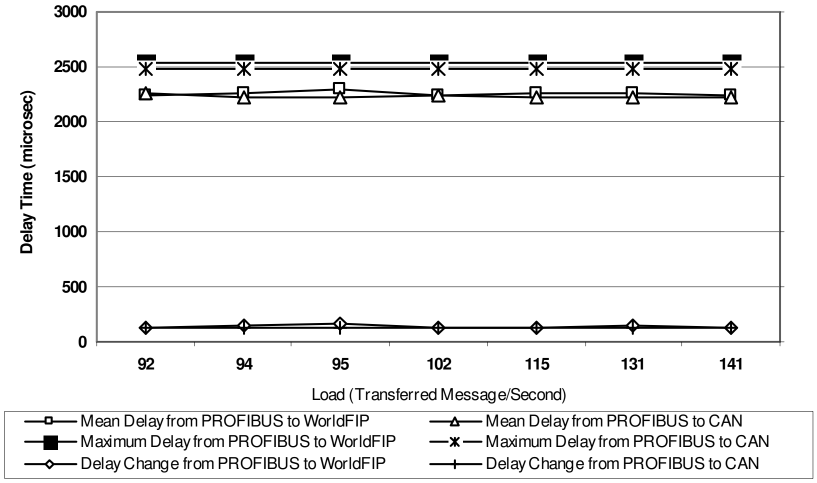


**Figure 8.** Delays of PROFIBUS with WorldFIP and CAN over ATM.

pre-ferred since they show smaller mean deviation.

## SIMULATION RESULTS AND DISCUSSION

Figure 6 shows point-to-point delays from WorldFIP to CAN and PROFIBUS over ATM. Maximum delay from WorldFIP to CAN is 1124_µs, mean delay is 864 µs and delay change is 132 µs at 144 message/s. Maximum delay from WorldFIP to PROFIBUS is 2364_µs, mean delay is 1522 µs and delay change is 426 µs at 142 message/s.

Figure 7 shows point-to-point delays from CAN to WorldFIP and PROFIBUS over ATM. Maximum delay from CAN to WorldFIP is 822_µs, mean delay is 549 µs and delay change is 126 µs at 149 message/s. Maximum delay from CAN to PROFIBUS is 2065_µs, mean delay is 1173 µs and delay change is 549 µs at 149 message/s.

Figure 8 shows point-to-point delays from PROFIBUS to WorldFIP and CAN over ATM. Maximum delay from PROFIBUS to WorldFIP is 2531_µs, mean delay is 2248 µs and delay change is 135 µs at 141 message/s. Maximum delay from PROFIBUS to CAN is 2490_µs, mean delay is 2224 µs and delay change is 132 µs at 132 message/s.

The results of the study are statistically evaluated by maximum delays, mean delays and delay changes. According to the result, maximum delay is 2531_µs at 132 message/s and maximum mean delay is 2248 µs at 141 message/s from PROFIBUS to WorldFIP. Minimum delay change is 126 µs at 149 message/s from CAN to WorldFIP.

These delays ensure latency times as 1 - 10 ms at drive systems (Etschberger, 2001) and response times as 10 ms at 34% of fieldbus (Lawrenz, 1997). In this manner, WorldFIP, CAN, and PROFIBUS fieldbuses can be remote realtime connections between each other over ATM.

This study has provided interconnection among three different fieldbuses, WorldFIP, CAN, and PROFIBUS, using bridges over ATM. That is to say, fieldbus/ATM bridges are original contribution to interoperability of heterogen fieldbuses in a CIM system.

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