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Industrial Ethernet Protocols IPv6 enabling approach

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ABSTRACT

The current Internet Protocol (IPv4) made Ethernet with TCP/IP find application in industrial automation environment via Industrial Ethernet Protocols. The question "Can things go smooth in Internet Protocol next generation (IPv6)?” This paper answers the question by proposing solutions and proofing via simulation using OPNET Modeler simulator that IPv6 introduction in industrial automation environment introduces very small (negligible) delay relative to IPv4. Measured delays include: global Ethernet delay, IP node end-to-end delay and delay variation for 72, 520 and 1500 bytes transported packet size. Results showed that IPv6 introduces very small delay relative to IPv4, the various delays increase with increased packet size and IPv6 can be used in industrial automation environment.

Keywords: Ethernet, Industrial Automation, IPv4 / IPv6 performance

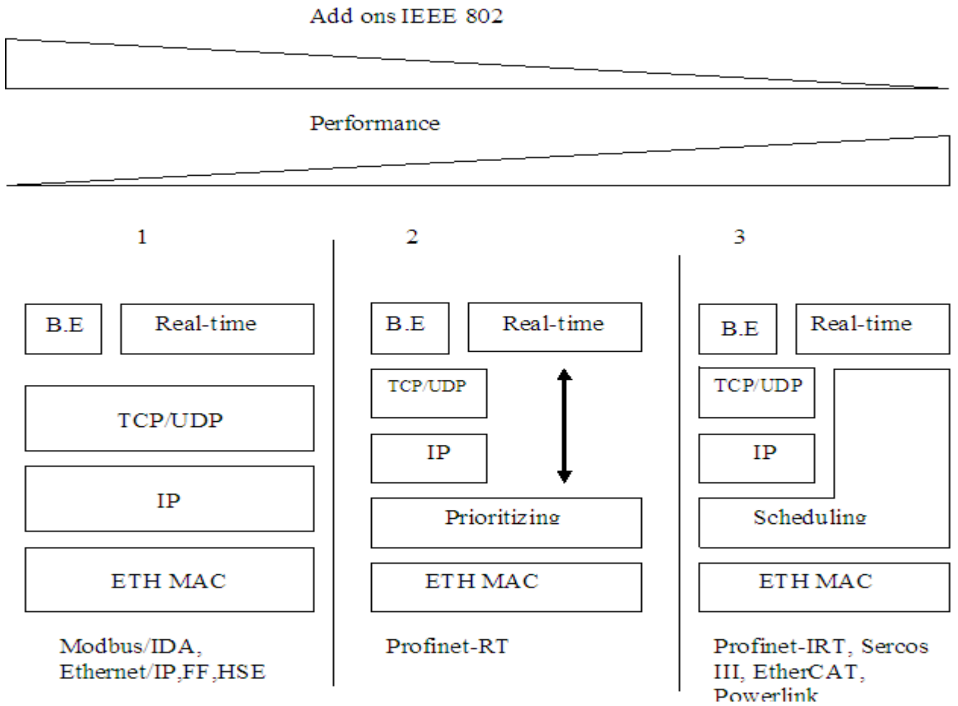
INTRODUCTION

The Ethernet protocol was developed in the 1970s by the Xerox Palo Alto Research center and standardized by IEEE as IEEE 802.3 standard [IEEE, 1998]. Ethernet builds either shared or switched networks based on the communication media. For shared Ethernet networks, Ethernet uses Carrier Sense Multiple Access/Collision Detection (CSMA/CD) protocol and binary exponential back-off algorithm as a media access method [IEEE, 1998]. Advances in Ethernet technology such as micro-segmentation, fast/gigabit Ethernet, full-duplex operation mode [IEEE, 1998], traffic prioritizat-ion using IEEE 802.1p [IEEE, 1998b], network segmentation using IEEE 802.1Q [IEEE, 1998c] and loops free networking using IEEE 802.1w [IEEE, 2004] made a shift to switched Ethernet adoption in industrial automation environment with completely information collection elimination (deterministic operation).

The fore mentioned technologies with TCP/IP [Reynders. and Wright, 2003] which provides addressing, transport type and interoperability were used in developing Ethernet industrial automation protocols. The protocols include: Ethernet/IP [Ethernet/IP, 2007], Modbus/IDA [Modbus, 2007], Profinet [Profinet, 2007], EtherCAT [EtherCAT, 2007], Powerlink [Powerlink, 2007], Sercos III [Sercos III, 2005] and others. This paper describes industrial Ethernet protocols categories, proposes methods for making them IPv6 enabled and showing with simulation using OPNET Modeler simulator [OPNET, 2009] that IPv6 [Deering and Hinden, 1998] introduction has a negligible Ethernet delay relative to IPv4 [Postel, 1981] for an industrial automation Local Area Network (LAN). The rest of the paper is organized as follows; section 2 describes the industrial Ethernet protocols categories and IPv6, section 3 is about network modeling, simulation collected results, result discussion and conclusion.

2.0 Industrial Ethernet Protocols Categories

Industrial Ethernet protocols can be classified into three main categories according to real-time fulfillment [Jasperneite et al, 2007] using TCP [Postel, 1981b] for non-real-time message transport and either UDP [Postel, 1980] or customized Ethernet device driver for real-time message transport as shown in figure 1. The first category provides soft-real-time guarantees only with Ethernet usage as it is, refer to figure 2 for message encapsulation in Ethernet frame. Protocols in this category include Ethernet/IP and Modbus/IDA. The second category provides hard-real-time guarantees via prioritization scheme at the Ethernet MAC layer according to IEEE 802.1D/Q with further enhancement by passing layer 3 and layer 4 of TCP/IP reference model. A variant of Profinet named Profinet-RT is an example of the second category protocols. The third category provides hard real-time guarantees via changing the scheduling procedure of the MAC layer and by passing layer 3 and layer 4 of TCP/IP reference model. Protocols in this category include Profinet-IRT (Profinet variant), EtherCAT, Powerlink and SERCOS III.



B.E = Best Effort, ETH MAC = Ethernet Media Access Control

Fig. 1 Industrial Ethernet Protocol Categories [Jasperneite *et. al*, 2007]

Ethernet Header	IP Header	TCP/UDP Header	Encapsulation Header	Encapsulation Data	Ethernet Trailer

Fig. 2 Message encapsulation in Ethernet frame

2.1 Industrial Ethernet Protocols and IPv6

The current Internet Protocol, which is IPv4, successes in accommodating changes in hardware technologies and heterogeneous networks with limitation in address space. The limitation in address space becomes the driving motivation for adoption of a new version of the Internet Protocol named IPv6. The IPv6 specification provides for several significant enhancements over IPv4 that are expected to promote the development of advanced Internet communications and services. These enhancements are: beside increased IP address space, simplified IP header, improved routing, enhanced mobility features, easier configuration, improved Quality of Service (QoS), extensibility, and integrated Internet

Protocol security (IPsec) [Kent and Seo, 2005]. IPv6 is made available since 2004 by the effort of Internet Engineering Task Force (IETF). IETF formed working groups to deploy, test and develop IPv6. The working groups include: 6Bone (testing), Moonv6 (interoperability and application demonstration), 6net and Euro6IX (research) [Hagen, 2004]. IETF also defined mechanism such dual stack, tunneling and translation for IPv4 to IPv6 migration and the two protocols coexistence [Hagen, 2006].

Industrial Ethernet automation protocols were designed based on IPv4. For the protocols to benefit from IPv6 benefits such as large address space, address auto-configuration, performance enhancement features and security using IPsec, they must be IPv6 enabled. Although the protocols can be encapsulated in IPv6 on IPv6 environment as a short term solution with some IPv6 benefits, protocols modification to support IPv6 is needed as a long term solution with all IPv6 benefits. Looking into the protocols, it is found that they are object oriented application layer protocols with some of them using middleware on top of layer 4 of TCP/IP reference model. Ethernet/IP as an example of object oriented application layer protocol, Ethernet/IP uses the Control and Information Protocol (CIP) [ODVA, 2006] at the application layer to provide connections between field instruments (sensors and actuators) and controllers. CIP makes use of abstract object modeling for describing communication services, externally visible behavior of a CIP node and information routing. Object oriented application layer protocols using middleware use one of three technical middleware solutions, for example Modbus/IDA uses Message Oriented Middleware (MOM) middleware solution based on Real-time Publish-Subscribe Wire Protocol [OMG, 2008]. Today many software vendors provide operating system platforms and development tools that were IPv6 enabled, fore an example Microsoft [Microsoft, 2010] provides Windows XP, Windows 2003 server and Windows 2008 server platforms and development tools such as Visual studio .NET (provides IPv6 enabled middleware) that support IPv6. Thus due to IPv6 enabled tools and platforms availability and object oriented nature of Industrial Ethernet protocols, making the protocols IPv6 enabled is possible. The protocols need IPv6 structure, IPv6 aware procedures/functions and algorithms being added to be IPv6 enabled.

IPv6 introduces extra processing delay, due to its large header (40 bytes) relative to IPv4 header (20 bytes). The extra processing delay is reduced by enhanced IPv6 features such as fixed size header with streamline structure that allows extremely fast switching without having to recalculate header check sum values as in IPv4, no packet fragmentation in intermediate nodes, enhanced routing, QoS and IPsec [VAN, 2006].

3.0 Network Modeling, Results Discussion and Conclusion

The paper's work use OPNET Modeler to model and simulate a switched Ethernet 100BaseT LAN that can represent a manufacturing cell, a substation or any automated application field. The network consists of a server that represent a controller, ten workstations that represent smart field instruments (sensors and actuators) and 16 ports Ethernet switch. The server and workstations were connected to the switch using 100BaseT links. The server is modeled using OPNET Modeler's ethernet_server_adv node model, while the workstations are modeled using work_stn_adv node model. Six of the workstations represent sensors, while four of them represent actuators. The controller accepts data from sensors and commands actuators, in addition to receiving messages from actuators. The network traffic is modeled using the OPNET Modeler's default applications, where FTP application (TCP traffic) is used to model non real-time traffic and Voice over IP application (UDP traffic) is used to model real-time traffic. OPNET Modeler's Application Config and Profiles Config node models were used to characterize the network traffic. Refer to figure 3 for the network model.

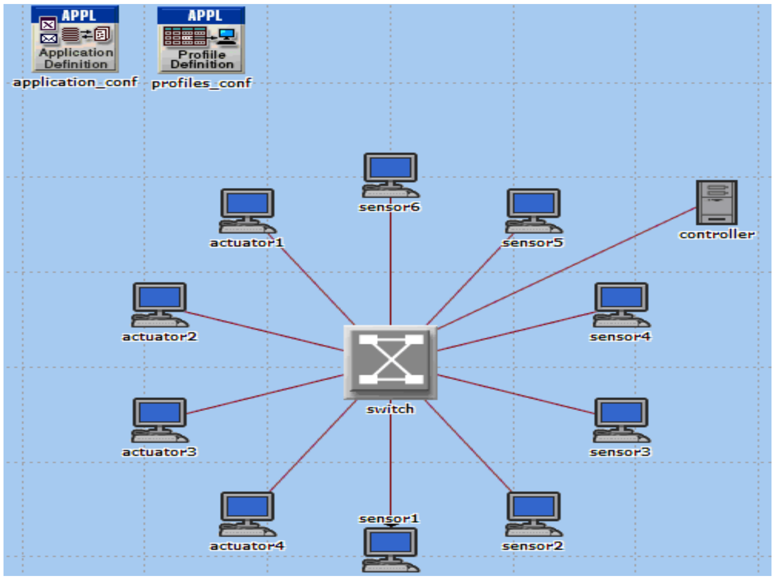


Fig. 3 Network Model

In this work, simulation scenarios were conducted for IPv4 and IPv6 environments with 72, 520 and 1500 bytes packet size. Different packet sizes were used to investigate the effect of transported packet size on performance. IPv4 environment is used as a baseline for IPv6 study. The simulations collected results with the highest value of the intended statistic being reported. The result statistics include: global Ethernet delay, IP node end to end delay, IP node end to end delay variation and link point-to-point throughput and utilization. Table 1 shows the global Ethernet delay, table 2 shows IP node end to end delay, table 3 shows IP node (Field instruments to controller) end-to-end delay and table 4 shows IP node (Field instruments to controller) end-to-end delay variation. Figure 4 compares the global IPv4/IPv6 Ethernet delay for 72, 520 and 1500 bytes transported packet size.

Table 1 Global Ethernet delay

Packet size (bytes)	IPv4 Ethernet delay (milliseconds)	IPv6 Ethernet delay (milliseconds)
72	0.055180	0.058104
520	0.135450	0.141030
1500	0.347980	0.349620

Table 2 IP node end-to-end delay

Object name	Packet size (bytes)	IPv4 Ethernet delay (milliseconds)	IPv6 Ethernet delay (milliseconds)
Sensor2	72	0.07145	0.09238
Actuator4	520	0.18222	0.20652
Actuator3	1500	0.38142	0.40058

Table 3 IP node (Field instruments to controller) end-to-end delay

Object name	Packet size (bytes)	IPv4 Ethernet end-to end delay (milliseco-nds)	IPv6 Ethernet end-to end delay (millisec-onds)
Actuator3	72	0.000.07128	0.088138
Actuator1	520	0.000.16691	0.21806
Sensor2	1500	0.000.46348	0.46956

Table 4 IP node (Field instruments to controller) end-to-end delay variation

Object name	Packet size (bytes)	IPv4 Ethernet end-to end delay variation (sec)	IPv6 Ethernet end-to end delay variation (sec)
Sensor2	72	0.09152	0.08828
Actuator4	520	0.11933	0.16447
Actuator3	1500	0.14477	0.16415

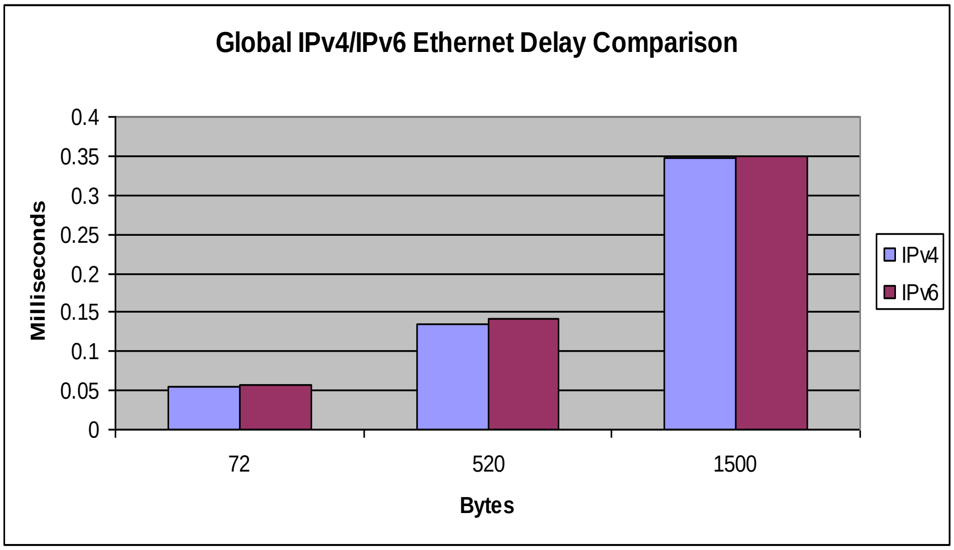


Fig. 4 Global IPv4/IPv6 Ethernet Delay Comparison

3.1 RESULT DISCUSSION

Table 1 says that the maximum Ethernet delays are 0.34798 and 0.34962 milliseconds for 1500 bytes transported packet size for IPv4 and IPv6 respectively. This result means that introducing IPv6 will result in 0.00164 milliseconds increase in global Ethernet delay time for 1500 bytes transported packet. For a small transported packet size such as 72 bytes, the global Ethernet delays are 0.055180 and 0.058104 milliseconds for IPv4 and IPv6 respectively. Thus using small sized transported packets will introduce 0.002924 milliseconds delay increase on deploying IPv6 relative to IPv4. On using 520 bytes transported packet size IPv6 introduces 0.00558 milliseconds global Ethernet delay relative to IPv4. Although the increase in global Ethernet delay difference is the smallest for 1500 bytes packet on deploying IPv6, the global Ethernet delay is the highest, so in industrial automation environment using small sized transported packets is better, since it provides the lowest Ethernet delay.

On comparing node statistic based on table 2, it is found that the highest IPv6 node Ethernet delay for 72 bytes packet size is 0.092938 milliseconds reported by sensor2 with an increase of 0.021488 milliseconds relative to IPv4. For 520 bytes packet size, the highest IPv6 Ethernet node delay is 0.20652 milliseconds reported by actuator4 with an increase of 0.0243 milliseconds relative to IPv4. For 1500 bytes packet size, the highest IPv6 Ethernet node delay is 0.40058 milliseconds reported by actuator3 with an increase of 0.01916 milliseconds relative to IPv4.

On comparing IP node end to end delay (field instruments to controller) based on results on table 3, it is found that the highest IPv6 node end to end delay for 72 bytes packet size is 0.088138 milliseconds reported by actuator3 with increase of 0.016858 milliseconds relative to IPv4. For 520 bytes packet size, the highest delay is 0.21806 milliseconds reported by actuator1 with an increase of 0.05115 milliseconds relative to IPv4. For 1500 bytes packet size, the highest IPv6 delay is 0.46956 milliseconds reported by sensor2 with an increase of 0.00608 milliseconds relative to IPv4.

On comparing IP node end to end delay variation (field instruments to controller) based on results on table 4, it is found that the highest IPv6 node end to end delay variation for 72 bytes packet size is 0.08828 milliseconds reported by sensor2 with a decrease of 0.00324 milliseconds relative to IPv4. For 520 bytes packet size, the highest IPv6 delay variation is 0.16447 milliseconds reported by actuator4 with an increase of 0.04514 milliseconds relative IPv4. For 1500 bytes packet size, the highest IPv6 delay variation is 0.16415 milliseconds reported by actuator3 with an increase of 0.01938 milliseconds relative to IPv4.

In link point-to-point throughput and utilization, the highest IPv6 throughput is 217.28 packets/s reported by controller to switch for 72 bytes packet size with an increase of 5.22 packets/s relative to IPv4, while the lowest throughput 6.917 packets/s reported by sensor5 to switch with 0.889 packets/s increase. The highest IPv6 utilization is 0.61397% reported by switch to controller for 1500 bytes packet size with a decrease of 0.00675% relative to IPv4, while the lowest IPv6 utilization is 0.04231% reported by switch to sensor2 with a decrease of 0.00387% relative to IPv4 for 520 bytes packet size. These results say that the point-to-point throughput and utilization for both protocols (IPv4 and IPv6) are very similar, thus IPv6 introduction has no major effect on point-to-point throughput and utilization.

In Ethernet industrial automation, time requirements must be fulfilled for proper operations. According to [VAN, 2006], time requirements as shown in figure 5 must be maintained for factory floor applications; also according to [IEEE, 2004] time requirement within substations should not exceed four milliseconds.

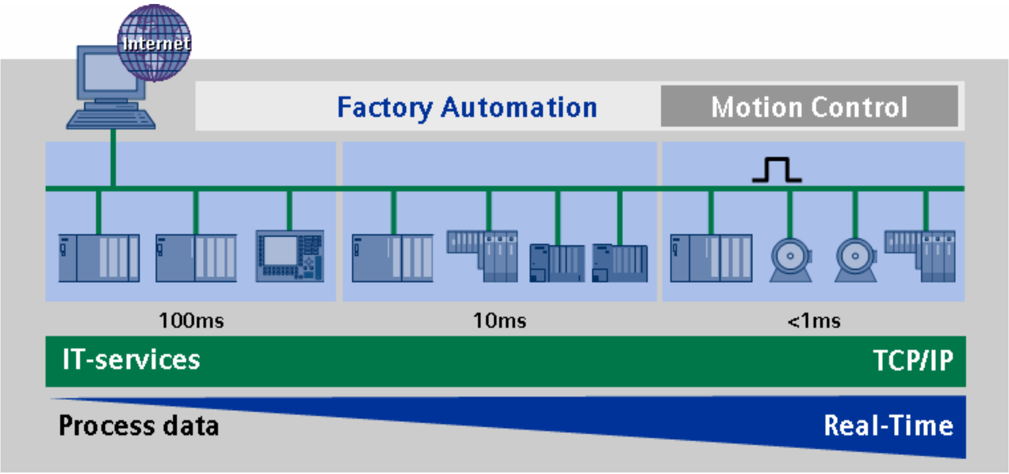


Fig. 5 Ethernet in Factory Automation [VAN, 2006]

Figure 5 says motion control applications require a time delay of < 1 millisecond. For factory automation applications, delay time requirements are up to 10 milliseconds for LANs and 100 milliseconds for WANs. Based on the simulation discussed results, it is clear that the results are more than adequate for industrial automation field application such as manufacturing cell or substation that requires a strict time requirement.

3.2 CONCLUSION

The paper showed industrial Ethernet automation protocols categories, in addition to proposing solutions for bringing IPv6 into industrial automation environment. Based on the simulation collected results, one can say that a switched Ethernet 100BaseT LAN can be used for Ethernet industrial automation applications for IPv6 with the fact that Ethernet with TCP/IP can go real, IPv6 introduction in industrial automation environment introduces negligible processing delay relative to IPv4 and the various delays increase with increased transported packet size.

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الملخص

الاصدارة الحالية من الانترنت (IPv4) أدت لجعل الايثرنت مع مجموعة بروتوكولات الانترنت أن تجد لها تطبيقات فى البيئة الصناعية عبر بروتوكولات الايثرنت الصناعية . السؤال هل تسير الامور على نحو سلس مع بروتوكول الانترنت الجيل المقبل (IPv6) . هذه الورقة تقدم الاجابة على السؤال من خلال اقتراح حلول و اثبات عن طريق النمذجة باستخدام ال (OPNET Modeler) أن استخدام ال IPv6 فى البيئة الصناعية يضيف تأخير صغير جدا (ضئيل) مقارنة بال IPv4 . التأخيرات المقاسة تشمل : تأخير ايثرنت عام ، تأخير نهاية الى نهاية العقدة بالنسبة لمرسوم الانترنت وتباين التأخير لرزم مرسلة بالاحجام 72، 520 و 1500 بايت . النتائج أظهرت أن مرسوم الانترنت الاصدارة السادسة يضيف زمن تأخير صغير جدا مقارنة بمرسوم الانترنت الاصدارة الرابعة ، ازمنة التأخير المختلفة تزداد بازدياد حجم الرزمة و يمكن استخدام IPv6 فى البيئة الصناعية .