

*Synchronous protocols based on IEEE1588 can deliver workable determinism. But are they actually necessary given the faster Ethernets now cheaply available? We put the question "If I upgrade my industrial network infrastructure to 1000BaseT, will it improve the system responsiveness to the point where I may not have to implement IEEE1588 timing protocols to achieve improved network determinism?" to academic researcher Paula Doyle.*

### **How Fast is Gigabit Ethernet?**

The scope of the Ethernet (IEEE 802.3) standards lies within the physical and data-link (OSI I&II) layers. Since its standardisation, Ethernet's base rate has increased from 10Mbps, to 100Mbps in 1995, 1000Mbps (1Gbps) in 1998 and, most recently 10Gbps in 2002. So what is the significance for latency, response-time, and determinism in the network?

The latency of a network is defined as the time it takes for a packet (or a byte) to travel from source to destination. Latency is cumulative in network communication, and the total latency from source to destination does not solely depend on base rate.

Determinism describes a system whose time evolution can be predicted exactly<sup>1</sup>.

Determinism, like real-time, is not necessarily related to base rate, and a 1kbps system could be more deterministic than a 1Gbps system.

### **Base rate and latency**

At wire-level, there are two distinct delays: transmission and propagation. The propagation time is dependant on both the distance and the speed of the signal through the particular medium. For 10/100/1000 Base-T, this speed is equal ( $\sim 2 \times 10^8$  m/s) as they all employ copper. For these technologies, base rate has no bearing on propagation delay. Conversely, the transmission time is directly related to base rate. Typical Ethernet-based office installations employ half-duplex shared medium access. These nodes implement the MAC-level CSMA/CD with an exponential back-off algorithm to determine medium access. This algorithm introduces random delays along with the potential for transmission failure, making it entirely unsuitable for real-time applications requiring determinism. Along with the unsuitable medium access scheme, half-duplex communication over Gigabit Ethernet (GbE) does not offer the expected 10x speed benefits across the board.

The greater base rate reduces the maximum segment length to 20-25m, which is too short for most applications outside of the closet (Note: this segment length only applies to Base-T installations. Fibre solutions support much larger segments). The desire to retain the maximum segment length of 100m led to the introduction of the carrier extension, which gives an increased minimum slot size of 512 bytes. Comparisons with a 64-byte frame on all

three base rates gives transmission times of 51.2 $\mu$ s for 10Mbps, 5.12 $\mu$ s for 100Mbps and 4.096 $\mu$ s for 1Gbps. This gives a transmission time reduction of 20%, for a 64-byte frame when migrating from 100Mbps to 1Gbps. Packets of size equal to or greater than the 512-byte minimum will enjoy the expected 10x transmission time.

### **Switching Latency**

Switched Ethernet with full duplex links, where each node exists in a unique collision domain, is the preferred solution for real-time Ethernet. Unlike shared Ethernet, the CSMA/CD medium access scheme is not used: switched Ethernet can support shorter frames without fear of undetectable collisions. When full duplex is employed with GbE, transmission times of all frames are increased by a factor of 10, giving an improved transmission time of 0.512 $\mu$ s for a 64-byte frame.

The additional latency caused by intermediate switches along the transmission path adds to the overall latency. Switches incur both transit and buffering delays, the values of which are switch-dependant. Transit delays can be minimised with non-blocking, wire-speed switches, which provide each port with the capacity to operate simultaneously at wire-speed. The choice of switch architecture also affects transit delays with store-and-forward solutions incurring longer delays than cut-through solutions, due to the extra processing requirements. The other switching delay is the buffering delay, which increases with network congestion. Well-designed RT-systems should aim to limit congestion and hence minimise this delay. Also, the number of switches between hard real-time nodes should be minimised. (For more detailed timing information on switching, please refer to [2]).

### **Traffic prioritisation**

Prioritising traffic in terms of its real-time demands can help achieve better determinism. The priority standard for Ethernet, IEEE 802.1p, is implemented within the VLAN standard IEEE 802.1Q. IEEE 802.1p offers eight levels of priority that can be used by switches to fast-track frames through the switch. With correct configuration, switches can be deterministic and operate at wire-speed to give minimal latency increase, while eliminating the need for CSMA/CD and the extension of the minimum slot size.

### **Nodal processing delay**

Latency is a cumulative effect and in the case of Ethernet systems, the greatest part of latency is derived within the nodes. Hardware latency in the order of  $\mu$ s is no match for software latency, which can be in the order of tens of ms in a system node. Operating systems, protocol stacks, and device drivers all add to the processing time, and even finely-tuned software

applications will be a far bigger contributor to latency than hardware transmission and propagation times. Similar to the processor/memory bottleneck of the CPU, Ethernet systems developers need to concentrate on the bottleneck at the node and reduce the delay before a frame is presented at the wire. This would give the greatest improvement to system performance, and is probably the greatest cause for seemingly poor performance when migrating to GbE networks.

### **Conclusion**

Determinism is not directly related to base rate, and installation of a faster network will not guarantee deterministic behaviour. The use of priority schemes will help in achieving a deterministic solution. IEEE 1588 can also help achieve determinism if its synchronisation is used to implement distributed scheduling schemes. Base rate has a direct effect on latency and response-times. If existing 10/100Mbps systems are replaced with 1Gbps (wiring and intermediate hardware), response times will be reduced. For switched systems, transmission time will be reduced by a factor of 10, but nodal processing delays, in the order of milliseconds, will dilute this improvement.

### **References:**

[1] Definition available at <http://www.hyperdictionary.com>.

[2] Song, Y. :Time Constrained Communication over Switched Ethernet. 4th IFAC International Conference on Fieldbus Systems and their Applications - FeT'2001. 2001. Nancy, France.

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### **Source:**

*The Industrial Ethernet Book* <http://ethernet.industrial-networking.com>