Real Time Ethernet I

Introduction to Real-Time Electronic Control Systems

Full & Half Duplex Ethernet

When Ethernet was standardised in 1985, all communication was half duplex. Half duplex communication restricts a node to either transmit or receive at a time but not perform both actions concurrently.

Nodes sharing a half duplex connection are operating in the same collision domain. This means that these nodes will compete for bus access, and their frames have the potential to collide with other frames on the network. Unless access to the bus is controlled at a higher level and highly synchronised across all the nodes co-existing on the collision domain, collisions can occur and real-time communication is not guaranteed.

Full duplex communication was standardised for Ethernet in the 1998 edition of 802.3 as IEEE 802.3x. With full duplex, a node can transmit and receive simultaneously. A maximum of two nodes can be connected on a single full duplex link. Typically this would be a node-to-switch or switch-to-switch configuration. (The set-up of Figure 5 is for illustration purposes, and unlikely to be implemented in a practical form). Theoretically, employing full duplex links can double the available network bandwidth taking it from 10 Mbps or 100 Mbps to 20 Mbps or 200 Mbps respectively, but in practice it is limited by the internal processing capability of each node. Full duplex communication provides every network node with a unique collision domain. This operation completely avoids collisions and does not even implement the traditional Ethernet CSMA/CD protocol.

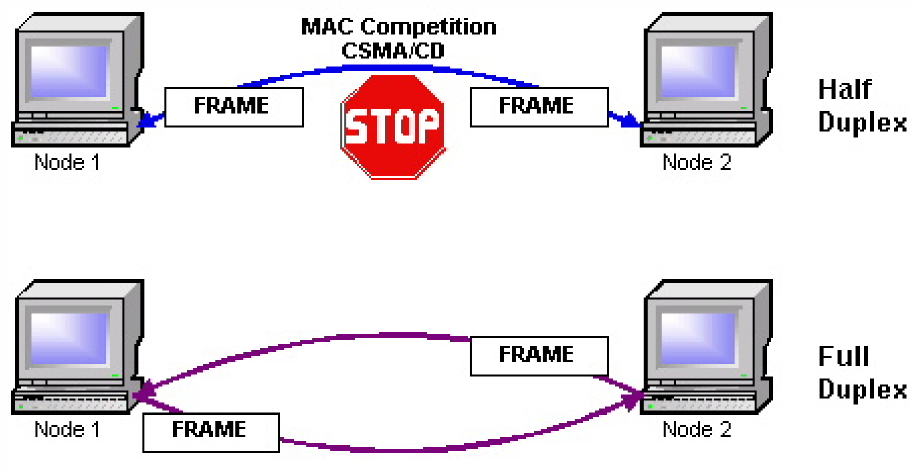


Figure 5 — Half-Duplex vs. Full-Duplex

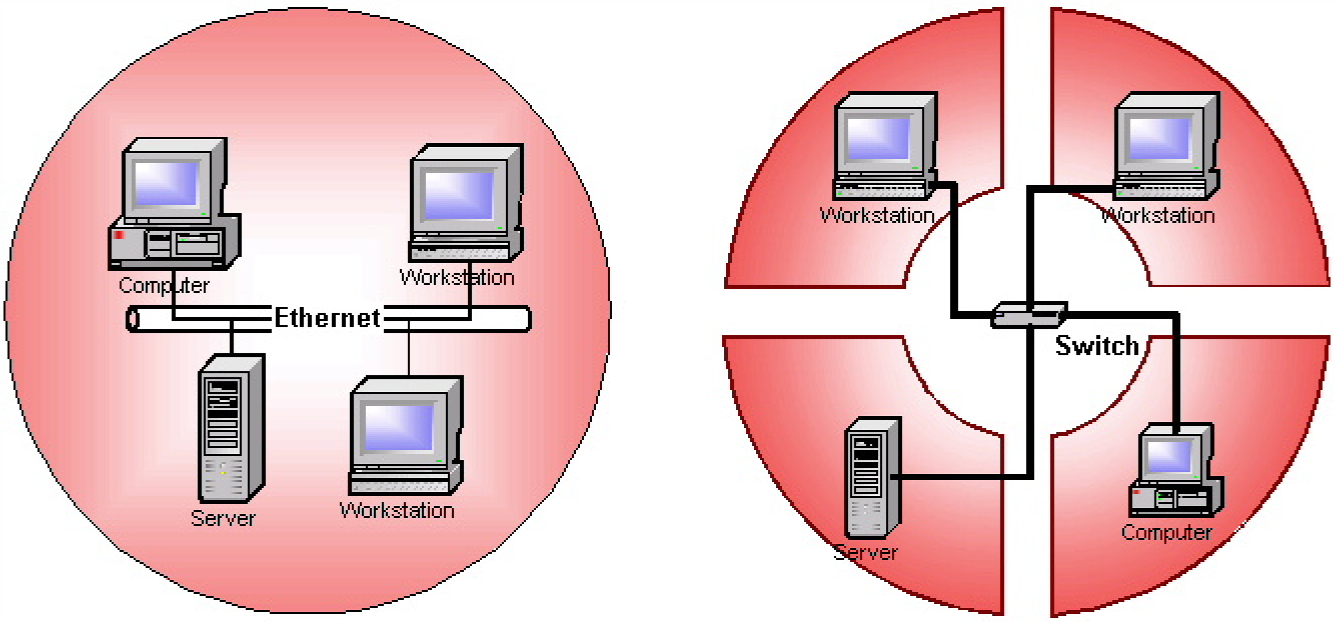
Since full duplex links can host a maximum of two nodes per link, such technology is not viable as an industrial real-time solution without the use of fast, intelligent switches capable of connecting links/segments as a network with single collision domains for each node — i.e. Switched Ethernet.

Full Duplex, Switched Ethernet

With shared Ethernet, nodes compete for access to the media in their shared collision domains. The use of a destructive non-deterministic bus access scheme, such as CSMA/CD, makes shared Ethernet unviable as a real-time network solution. The most popular method of collision-avoidance, which produces a deterministic Ethernet, is to introduce single collision domains for each node because this guarantees the node exclusive use of the medium, thereby eliminating access contention. This is achieved by implementing full duplex links as well as hardware devices such as switches and bridges. These devices have the ability to isolate collision domains through the segmentation of the network because each device port is configured as a single collision domain, see Figure 6. Although, both switches and bridges can provide this segmentation, switches are more flexible because they can cater for more segments.

Switches

Switches are data-link layer hardware devices that enable the creation of single-collision domains through network segmentation. While a bridge operates like a switch, it only contains two ports. In contrast, switches contain more than two ports, where each port is connected to a segment (collision domain). Switches can operate in half duplex or full duplex mode. When full duplex switches are used along with full duplex capable nodes, there will be no collisions on any segment. Today's switches are more intelligent and faster than previously and with careful design and implementation could be used to achieve a hard real-time communication network using IEEE 802.3.



Shared Ethernet: : 1 collision domain for multiple nodes. The possibility of collisions. Non-deterministic

Switched Full Duplex Ethernet: 1 collision domain per node. Use of switch. No possibility of collisions. Deterministic.

Figure 6 — Switched Full Duplex vs. Shared Ethernet

Although switches are data-link layer devices, today's switches are also capable of performing switching functions based on data from layers 3 and 4. Layer 3 switches can operate on information provided by IP — such as IP version, source/destination address or type of service. Layer 4 devices can switch depending on the source/destination port or even information from the higher-level application.

Further refinements to the IEEE 802 standards, specifically for switch operations, are 802.1p and 802.1Q. **IEEE 802.1p**, which was incorporated into the IEEE 802.1D [3] standard brings Quality of Service (QoS) to the MAC level and also defines how these switches should deal with prioritisation - priority determination, queue management etc. This is achieved through the introduction of a 3-bit priority field into the MAC header, which gives 8 (0–7) different priority levels decoded and upheld by switches or hubs. As defined, 802.1p can support priorities on topologies that are compatible with its prioritisation service, but to implement prioritisation on Ethernet, which does not include a prioritisation field in its frame format, it uses 802.1Q.

IEEE 802.1Q [4] defines an architecture for virtual bridged LANs, the services provided in virtual bridged LANs, and the protocols and algorithms involved in the provision of those services. 802.1Q allows Ethernet frames to support VLANs (Virtual Local Area Networks) limiting broadcast domains and thereby reducing broadcast traffic on the entire LAN. This is achieved by the insertion of 4 bytes between the source address field and the length/type field in the Ethernet frame's header, which among other identifiers, includes the identifier of the originating VLAN. Also included is a 3-bit prioritisation field required for 802.1p to implement prioritisation on Ethernet, see Figure 7.

IEEE 802.3 Frame								
56 bits	8 bits	48 bits			48 bits	16 bits	368 to 12000 bits (46 to 1500 bytes)	32 bits
Preamble	SFD	Individual/ Group Address Bit	Globally/ Locally Administered Address Bit	Destination Address	Source Address	Length	LLC/Data	Frame Check Sequence

16 bits	3 bits	1	12 bits
VLAN Protocol ID 0x8100	Priority	CFI	VLAN Identifier

Figure 7 — Extended Frame Format for IEEE 802.1Q

For a real-time Industrial Ethernet application, an 802.1p/Q implementation has certain advantages: it introduces standardised prioritisation on Ethernet, allowing control engineers to implement up to eight different user-defined priority levels for their traffic. But these standards also have drawbacks including the extra hardware costs associated with the increased Ethernet frame length (1522 bytes), which introduces compatibility issues with legacy Ethernet networks. A real-time implementation using 802.1 p/Q would require full duplex, switched Ethernet. IEEE 802.1p/Q are acceptable for certain applications of real-time Ethernet in industry when switch 'through' time is predictable and an overload situation will not result in hard deadlines being missed.

Although switches can certainly provide real-time deterministic communication on Ethernet and are the backbone of the Industrial Ethernet solutions available today, they have drawbacks. They are costly — a major influence on cost-conscious industries. They are powered devices capable of failure (an influential major factor for hard real-time control operations). And sometimes the operational predictability is not guaranteed by the manufacturer. A study on switches for real-time applications is available at [5].

TCP/UDP/IP for Real-Time Ethernet

With industrial Ethernet, the trend is to define an application layer environment along with the TCP/IP protocol, to realise an industrial automation networking solution. Although some real-time Ethernet solutions e.g. EtherNet/IP perform all their communication, real-time included, through the TCP/UDP/IP stack, most solutions although they provide compatibility with TCP/IP, do not employ this protocol for real-time communication. In a system like EtherNet/IP, TCP is used for initialisation and configuration (explicit) messages while UDP, with its reduced overhead, is used for real-time I/O (implicit messaging).

Typically, for real-time Industrial Ethernet applications it is sufficient that the solution be compatible with TCP/IP and the protocol suite is bypassed for all real-time communication. The ability of a real-time Ethernet solution to intercommunicate with an office-based system is paramount to achieve the Ethernet-technology plant of the future.

Conclusion

This module has covered a broad introduction to Ethernet for real-time. It has described concepts that will be developed upon in the follow-up module: Real-Time Ethernet II. The follow-up module will provide detail on existing real-time Ethernet solutions such as PROFInet V3, ETHERNET Powerlink and EtherNet/IP along with an important supporting technology for clock synchronisation: IEEE 1588.

References

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