

# Ethernet: How fast is it really?

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With the popularity and low cost of Ethernet hardware, industrial control systems are evolving toward this platform. Users be aware; proper network design and implementation is critical to fast reliable network throughput.

## Introduction

Considerable confusion exists as to the actual capacity, reliability, and usability of Ethernet networks in the industrial control arena. There are many varieties of Ethernet hardware and media types, ranging from the traditional half-duplex 10Mbps/Second coax (10Base5) to the latest 1000Mbps/Second full-duplex Fiber Optic (1000Base-LX). The speed and throughput of an Ethernet network will vary among the different types. To complicate things further, the use of switches, routers, and repeaters change the timing characteristics and performance of Ethernet networks. This article will cover the question of how fast it's possible to communicate via the various types and configurations of Ethernet networks. It will also describe the effects on reliability and determinism due to system loading.

## Half Duplex Ethernet Overview

Traditional half-duplex Ethernet is based on the IEEE 802.3 standards. Ethernet uses only the lower 2 layers of the ISO networking model, the Physical layer and the Data Link layer. Ethernet does not define any specific Network Layer protocol (e.g. TCP/IP). Ethernet incorporates the use of CSMA/CD (Carrier Sense Multiple Access with Collision Detection) as the "who gets to talk" means of media access to the network.

- **Carrier Sense** defines that all stations must listen for no traffic on the network for a predefined period of time (Inter-frame Gap) before transmitting data.
- **Multiple Access** defines that all stations on the network have equal access to transmit data. Also, any station is allowed to repeat the transmit sequence without waiting for other stations to transmit their data. This is unlike Token-Ring or Token-Bus networks that guarantee every other station an opportunity to transmit before a second packet can be sent.
- **Collision Detection** defines that a transmitting station must detect a collision of data with any other transmitting stations data. This occurs when 2 stations attempt to simultaneously transmit data.

Ethernet performance depends on multiple parameters both fixed by the specification and variable due to the network usage and architecture.

Parameters include:

- **Bit Rate:** Current Ethernet bit rates are 10, 100, and 1000Mbps/Second.
- **Propagation Delay:** Maximum round trip delay between any two stations.
- **Jam Time:** When a transmitter detects a collision it continues to transmit for 32 extra bit times to ensure all stations reliably detect the collision.
- **Slot Time:** Longest acquisition time. This must be longer than Maximum Propagation Delay + Maximum Jam Time.
- **Packet Length:** Minimum is 64 Bytes, Maximum is 1518 Bytes.

- **Number of Stations:** Maximum depends on media type.
- **Cable Length:** Maximum depends on media type.
- **Number of Repeaters:** Maximum depends on media type.

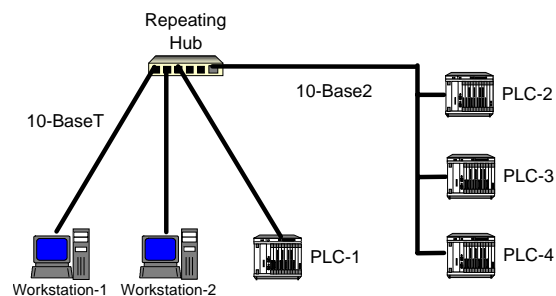
The sequence for a station to transmit data is:

- 1.) The station monitors network for activity. If there is no activity for a duration greater than or equal to the Interframe Gap time then the station will immediately begin transmission of the data packet.
- 2.) During transmission the station monitors the network for a collision (abnormal voltage on the wire). If a collision is detected, the station transmits at a minimum the frame preamble plus a 32 bit Jam Sequence to ensure that other stations can reliably detect the collision.
- 3.) The station then waits a random period of time, increments a collision counter then repeats the sequence starting from step 1. This process known as “backoff” and is designed to reduce the probability of repeated collisions.
- 4.) If another collision is detected, the “backoff” process is repeated with the random time being increased for each collision.

### Throughput, Traffic, and ‘Collision Domains’

After examining the sequence for a station to transmit data in a half-duplex Ethernet network, it becomes evident that “network traffic” is the key to performance within the system. The greater the number of nodes and/or the greater the number of transmissions, the higher the probability of collisions and the longer a station will have to wait for “no activity” on the network. These traffic issues are only relevant within a “Collision Domain” which is defined as any network segment in which there will be a collision if two devices transmit at the same time. Bus type networks such as 10-Base5 and 10-Base2 coaxial networks are examples of a single collision domain type system. Star type networks such as 10-BaseT and 100-BaseT using repeater hubs are also examples of single collision domains.

#### Single Collision Domain



**Figure 1**

The network in figure 1 is an example of a single collision domain. Even though the stations on the 10-BaseT portion of the network are on individual wires, because they are connected to a repeating hub they are considered to be on a single network segment. Assuming no “network traffic,” it is possible to calculate the time it takes to transmit a packet of given length from any station to any other station within the network. The IEEE 802.3 specifications provide in excruciating detail, the complex methods for calculating delay times for each component within a network. It is beyond the scope of this document to define these. However, the specifications state “Carrier Sense” requires 96 bit times and the minimum “Slot Time” is 512 bit times. Using these numbers, it is theoretically possible to send a 64 Byte packet onto a 10 Mbit/second system network with no other traffic every 60.8 microseconds. In reality, most devices are only

capable of processing several hundred packets per second. This type of Ethernet network, while perfectly fine in a business environment, is not particularly well suited for use within the industrial control environment where deterministic and reliable communications are required. There are several reasons why this is true. There is a phenomenon known as a “Jabbering Node”. This occurs when a node starts transmitting a continuous stream of data onto the network. This phenomenon normally results from faulty hardware within a network interface card. Since CSMA/CD requires 96 bit times of quiet before allowing transmission onto the network, the Jabbering Node disables all other nodes on the network from sending their data and essentially stops the network.

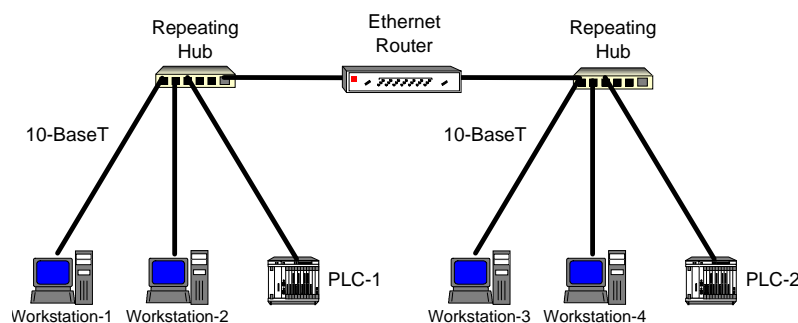
### Worst Case Throughput

Another issue is being able to determine the guaranteed worst-case time it will take for a packet to get from point A to point B within a network. A network with many nodes and large amounts of traffic make it impossible to predict how long it will take for a given node to get its data onto the network. Collisions cause retries that increase the number of packets being sent that cause more collisions that cause more “backoff” delays. Increasing the Bit Rate of the network decreases the impact of collisions proportional to the increase in speed. For example, on a 100 Mbit/second network the packet is only on the wire for one tenth the amount of time as on a 10 Mbit/second network. The carrier sense time and the “backoff” time are also reduced by a factor of 10. If the application is a “Master/Slave” type, as in the use of Ethernet I/O modules, the problems with collisions and traffic are eliminated. Since there is only one master node polling each of the slaves, and the slaves do not generate unsolicited packets, there is no problem with collisions.

### Using Routers to Improve Throughput

A common way of reducing collision problems and improving throughput on half-duplex Ethernet network is to use Ethernet Routers or Bridges to break a large “Collision Domain” into groups of smaller segments or subnets. These devices limit traffic to their individual subnets either by the MAC address or by network address as in IP routing. Using Figure 2 as an example, network traffic between Workstations 1, 2, and PLC-1 is a single “Collision Domain”. The same is true for Workstations 2, 3, and PLC-2. The Ethernet Router only passes packets to other segments when the destination address requires it to. The end result is that each segment is only seeing half the traffic of one large segment. However, Ethernet Routers are generally much more expensive than repeating hubs and require programming to define routing paths.

### Ethernet Routing

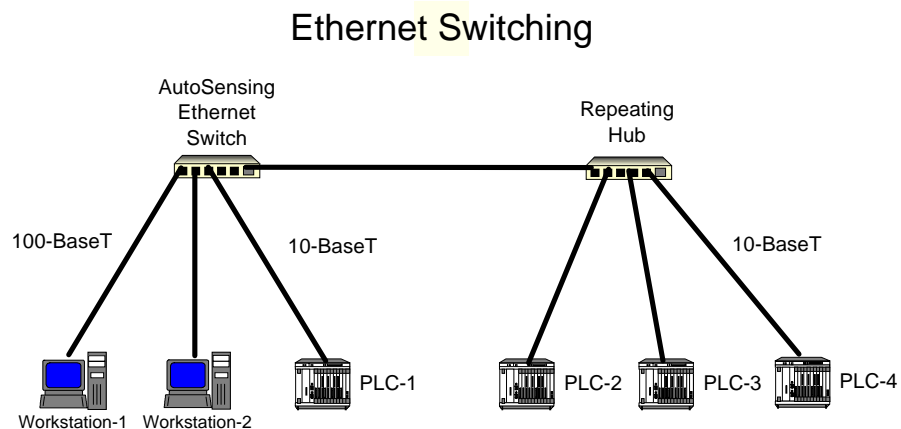


### Full Duplex/Switching Ethernet Overview

Recently a new mode of Ethernet operation called “Full-Duplex” was defined in the IEEE 803.3x specification. In this mode, all connections must provide independent transmit and receive paths allowing stations to transmit and receive simultaneously. This effectively doubles the throughput of the network. However, it also limits connections to a point-to-point mode. In point-

to-point mode only two devices can be on the same segment, thus limiting a network to two nodes or incorporate the use of an Ethernet Switch. Since the transmit lines of one station are tied to the receive lines of the other station and visa versa, there is no longer a possibility of collisions. CSMA/CD protocol is not longer needed and the only restriction for transmitting packets is the "Interframe Delay" period.

Ethernet Switches allow "Micro-Segmentation" which essentially puts each device on its own segment connected to a unique port on the switch. Ethernet Switches are extremely fast and eliminate all of the problems encountered with CSMA/CD type networks. This is ideal for applications that require high-speed deterministic throughput. Auto-Sensing 10/100 Ethernet Switches allow for the mixing of 10 and 100Mbit/Second devices as well as full and half duplex devices. The example in figure 3 shows an Ethernet Switch connecting 100-BaseT, 10-BaseT discreet devices as well as a repeating hub of 10-BaseT devices. In this example, devices requiring high-speed deterministic data transfers would be isolated on individual switch ports, and devices where timing is not as critical can be placed on a repeating hub. This configuration allows flexible, performance based, and cost conscience networking. Significant changes in network traffic will have minimal effect on the system.



**Figure 3**

## Conclusion

Although the performance of Ethernet networks will vary among the different types and configurations, a properly planned and installed Ethernet network should be capable of providing fast, reliable, and deterministic performance for industrial control applications.

## About the Author

Jeff Nowling is an Industrial Automation Engineering Consultant with Omron Electronics LLC. He specializes in industrial automation, especially communications and networking applications. He joined Omron in 1986, and has more than 20 years of experience in the industrial automation industry.

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