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Introduction to Industrial Ethernet, Part 4.

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MULTI-SEGMENT ETHERNET NETWORKS

Using Repeaters to Increase Network Diameter

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INTRODUCTION

In our very first article on Ethernet we discussed the basics of its operation. We mentioned that multi-segment Ethernet networks can be constructed by using repeaters and hubs. A segment is defined as a length of cable consisting of one or more cable sections and associated connectors with each end terminating in its characteristic impedance. For example with 10BASE5, the segment represents the complete end to end length of thick coaxial cable even though several medium attachment units (MAUs) are clamped onto the cable. The maximum length of a 10BASE5 segment is 500 m and this would represent the network diameter of the Ethernet network if no repeaters were used. However, Ethernet can be expanded to a larger network diameter by using repeaters as long as the network diameter does not exceed the collision domain of Ethernet. This article will discuss those restrictions.

For this article, we will limit discussions to 10 Mbps, shared Ethernet. With shared Ethernet, all nodes participate in media arbitration and must reside within one collision domain. Another characteristic of shared Ethernet is that communication is half-duplex. Although all nodes can send and receive, there cannot be any simultaneous sending or receiving. This would result in collisions and it is this detection of collisions that is used to arbitrate media access. Repeaters must not interfere with this arbitration method by favoring one node over another.

REPEATER REQUIREMENTS

The requirements for repeaters are stated in IEEE 802.3. The standard uses the term repeater set which consists of a repeater with two or more attached MAUs. These MAUs may also have an AUI cable connecting the repeater to its attached MAU but with modern repeaters this is not usually the case. We will use the terms repeater and repeater set interchangeably. A repeater is usually viewed as a two-port device, while a repeating hub has more than two ports. Their operation is the same. A valid signal on one port is retransmitted to all other ports. Regardless if we are using DIX V2.0 or IEEE 802.3 frame format, the expansion issues are the same. Adding a repeater should be transparent to the network by not causing any disruption of Ethernet's basic operation or impacting media arbitration. Repeaters are commonly viewed as a device that restores the amplitude of the signal in order to correct the effects of cable attenuation. However, Ethernet repeaters are required to do more. Repeaters must do the following:

- Restore the amplitude of the signal
- Restore the symmetry of the signal
- Retime the signal
- Rebuild the preamble
- Enforce collisions on all segments
- Extend fragments

As a signal propagates down a cable it suffers loss of signal strength, symbol symmetry and jitter is introduced due to effects identified as inter-symbol interference. These effects must not accumulate through the use of repeaters. Repeaters must restore the integrity of the signals which includes retiming.

The preamble of an Ethernet frame consists of 64 bits and it is possible that all bits are not present due to transceiver startup delays. The repeater must count the bits in the incoming preamble and insert bits if any are missing. This means that the repeater must have a first-in-first out (FIFO) buffer in order to accomplish this. All repeated ports will have the proper 64-bit preamble.

Preamble regeneration should not be confused with packet store and forwarding. According to the standard, repeaters are not allowed to store and forward. Bridges and routers provide this functionality, not repeaters.

Ethernet relies upon collision sensing as it arbitrates access to the cable. Repeaters must reinforce the detection of a collision by asserting the same collision signal on all ports. It does this by sending out a 32-bit jam signal. If the collision was sensed during the 64-bit preamble, the preamble is still repeated but a 32-bit jam signal is appended in order that all ports see a minimum of 96 bits for proper collision detection by devices connected to the ports. This is called fragment extension.

NETWORK DIAMETER LIMITATION

Repeaters can be connected in series (cascaded) in order to increase the network diameter but there are restrictions. As mentioned before, repeaters must reinforce collision detection but if the network diameter exceeds a single collision domain, unreliable operation will result. The maximum collision diameter is determined by the round-trip time of a signal propagating between the two furthest nodes. This time cannot exceed 575 bits (57.5μs at 10 Mbps).

Repeaters impact the maximum collision diameter since they contribute data latency due to their electronics. The IEEE 802.3 standard does an exhaustive study on all contributors of data latency including cables, transceivers and the like. These values formulate the rules that govern the number of repeaters that can be cascaded.

APPROACH 1

There are two approaches that can be used to calculate the number of repeaters. Approach 1 is more of the "cookbook" approach while approach 2 is the more analytical. It would be nice to have simple cabling rules for expanding an Ethernet network but unfortunately that is not the case. Here are the rules for approach 1:

- The transmission path permitted between any two DTEs may consist of up to five segments, four repeater sets (including optional AUIs), two MAUs, and two AUIs.

A DTE is data terminal equipment which is either the source or destination of the traffic. A repeater set is actually a repeater with two attached medium attachment units (MAUs). An AUI is an attachment unit interface which is required if external MAUs are being used. With this rule the two MAUs and the two AUIs are reserved for the DTEs. The repeater sets, by definition, have their own MAUs.

- When a transmission path consists of four repeaters and five segments, up to three of the segments may be mixing and the remainder must be link segments. When five segments are present, each fiber optic link segment shall not exceed 500m.

A mixing segment is actually a bus segment such as 10BASE2 or 10BASE5. A link segment consists of only two MAUs and is capable of full-duplex operation (10BASE-FL and 10BASE-T qualify). Notice that although 10BASE-FL is capable of achieving a 2km segment length, it is limited to 500m under the above conditions. Figure 1 shows this situation. Notice that the maximum segment length for 10BASE2, 10BASE5 and 10BASE-T can be achieved. Only the 10BASE-FL segment length is restricted. This rule says that you cannot have an all coaxial system when using four repeaters; however, an all fiber or all twisted-pair network is possible using four repeaters.

- When a transmission path consists of three repeater sets and four segments, the following restrictions apply:
  - The inter-repeater fiber segment can now be 1000m.
  - The end fiber segments (connected to DTEs) can be 400m.
  - All segments can be mixing.

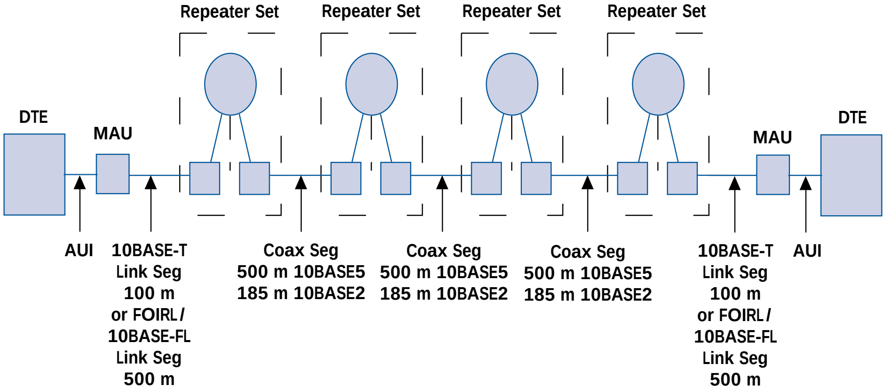

Figure 1. *Good example of 5-4-3 rule. Notice the distance limitation on the fiber segments.*

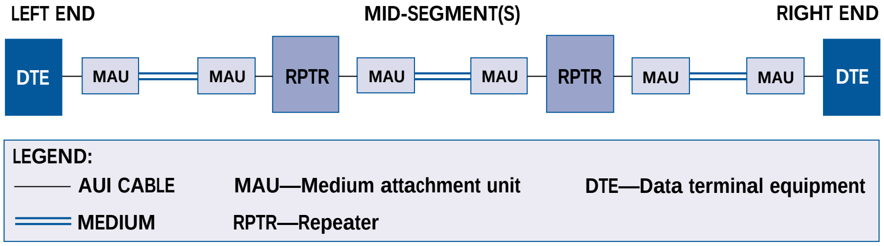

Figure 2. *Approach 2 uses this path model.*

An all coaxial network can be created when using three repeaters, and it appears that an all fiber system can extend to 2800 meters.

5-4-3 Rule

The above rules have lead to a simplified procedure for creating multi-segment Ethernet networks called the 5-4-3 rule. In the 5-4-3 rule, a total of five segments can exist connected by four repeaters as long as no more than three are bus segments. This is a very simple rule and it does not address the three, two or one repeater configuration. The rule also does not address the maximum allowable segment length under the varying conditions. In general, fiber segments are limited when using multiple repeaters. For these special situations, approach 2 should be used to determine if the proposed expansion method will not exceed the limit of the collision domain.

APPROACH 2

For a detailed analysis on the restrictions for cascading hubs, approach 2 can be used. With this approach two parameters are calculated. First the worst case round trip delay is calculated. Second the interframe gap (IFG) shrinkage is calculated. The IEEE 802.3 standard provides tables for these calculations. This approach is used for situations not covered in the more generalized approach number 1.

The model used consists of two DTEs interconnected by repeaters as shown in figure 2. There is a left end DTE and a right end DTE. The middle segments are for the repeaters. The round-trip bit times for all devices can be found in the table. This calculation is done first. The total round trip delay of all devices or components cannot exceed 575 bit times. This number is based upon the 64-bit preamble followed by 511 bits of frame. You should include some margin and the standard recommends not exceeding 572. Some technical references will say the limit is actually 512 bit times since this is the slot time. This ignores the 64-bit preamble. IEEE 802.3 considers the preamble as well. For a more conservative approach, simply use 512 bit times. Table 1 provides a listing of segment delay values (SDV) for the various media.

As an example let us assume an all twisted-pair network consisting of six segments and five repeaters. Since both ends are 10BASE-T segments, there is no significance to left end and right end. If the end segments are indeed different, you would need to do the calculation twice since the left and right end delays are different. Use the worst case calculation.

For our example, we want to use the maximum allowable segment length of 100 meters. Therefore, from the chart select 26.55 and 176.3 for the ends and 53.3 for the four mid-segments. Adding them all up yields 416.05 which is less than the 572 limit. There seems to be much margin. If you do not use the maximum length of the segments in the calculation, you will need to calculate the actual delay value for a particular length of cable using the following equation: SDV = Base + [Length * (RT delay/meter)].

The next calculation is to determine the IFG shrinkage. As frames are processed through repeaters, there may be loss of bits that must be compensated for by the repeaters. The result is that the time between frames might be reduced below the minimum stated in the standard. Therefore, a path variability value (PVV) calculation

Segment type	Max length	Left end		Mid-segment		Right end		RT delay/ meter
		Base	Max	Base	Max	Base	Max	
10BASE5 Coax	500	11.75	55.05	46.5	89.8	169.5	212.8	0.0866
10BASE2 Coax	185	11.75	30.731	46.5	65.48	169.5	188.48	0.1026
FOIRL	1000	7.75	107.75	29	129	152	252	0.1
10BASE-T	100	15.25	26.55	42	53.3	165	176.3	0.113
10BASE-FP	1000	11.25	111.25	61	161	183.5	284	0.1
10BASE-FB	2000	N/A	N/A	24	224	N/A	N/A	0.1
10BASE-FL	2000	12.25	212.25	33.5	233.5	156.5	356.5	0.1
Excess length AUI	48	0	4.88	0	4.88	0	4.88	0.1026

Table 1. *Segment round-trip delay values in bit times.*

Segment Type	Transmitting End	Mid-segment
Coax	16	11
Link except 10BASE-FB	10.5	8
10BASE-FB	N/A	2
10BASE-FP	11	8

Table 2. *Segment variability values in bit times.*

must be made on the worst-case path. Table 2 provides the values. Note that you do not need to consider the receiving end. Therefore, there are only five effected segments—the transmitting segment and the four mid-segments. For the transmitting segment use 10.5 and for the mid segments use 8. The total would be 42.5 which is less than the 49 maximum. This example shows there is a situation where five repeaters can be used in a row which contradicts approach 1. However, if you want to remain conservative, limit your network to four repeaters. Notice that if we added one more repeater in our example (one more mid-segment) that the additional 8 bit times in the PVV calculation would exceed 49. Therefore, we could still pass the delay calculation but fail the IFG test.

SUMMARY

Shared Ethernet networks can be extended with repeaters as long as the network diameter does not exceed the limit of a single collision domain. The IEEE 802.3 standard mentions two approaches in determining the limit. Approach 1 provides a set of rules which has resulted in the short form 5-4-3 rule. Approach 2 is more analytical and should be used when the network topology is inconsistent with the rules. What should be remembered is that in a shared Ethernet network, repeaters should not be applied without thought.

REFERENCES

Practical Networking With Ethernet, Charles E. Spurgeon, 1997, International Thomson Computer Press

Switched and Fast Ethernet, Second Edition, Robert Breyer and Sean Riley, 1996, Macmillan Computer Publishing USA

International Standard ISO/IEC 8802-3 ANSI/IEEE Std 802.3, 1996, The Institute of Electrical and Electronic Engineers, Inc.