SMC Proposal for 100-Mbit/sec Ethernet Over Three Pairs With Level-Three Coding

BY ROBERT HEATON

Because it has shipped over five million 10-Mbit/sec Ethernet nodes, Standard Microsystems Corp. is focusing on 100-Mbit/sec Ethernet solutions that will be familiar to its customers and have a mass market appeal. For this reason, SMC is proposing Media Access Control (MAC) and physical-layer (PHY) protocols that are as close as possible to the familiar 10Base-T 10-Mbit/sec Ethernet 802.3 standard.

The challenge is to design a physical layer that can use the 802.3 MAC layer as it is, but scaled in timing for 100-Mbit/sec operation. The benefits of using the current 802.3 MAC are:

1. It is the most widely used MAC. Over 25 million 802.3 MAC-based nodes have been installed. Users understand it. They expect that 100-Mbit/sec Ethernet will operate the same way 10-Mbit/sec Ethernet does. Knowledge of the protocol and existing network management applications can be leveraged.
2. Only small changes are needed to adapt the 802.3 MAC to 100-Mbit/sec transmission. This will reduce the time required to agree on a standard, and will permit many silicon and system vendors to compete early in the market by leveraging 10-Mbit/sec expertise. This translates into a price benefit for users.
3. Frame format will be the same for 10-Mbit/sec and 100-Mbit/sec transmission. If the same MAC is used, bridging to 10-Mbit/sec systems will be simplified.
4. If the same MAC is used for 10-Mbit/sec and 100-Mbit/sec Ethernet, the extra complexity required to support both data rates on a single board will be reduced. This results in a price benefit for the user. It will also allow customers to install 10-to-100-Mbit/sec adapters with the intention of future upgrades.

In order to perform as well as 10-Mbit/sec 10Base-T from a user's standpoint, the following physical-layer objectives are required:

1. 100-Mbit/sec transmission over 100 meters of four-pair category 3 unshielded twisted-pair (UTP) cable. One hundred meters of UTP category 3 is a requirement of 10Base-T. Unlike 10Base-T, however, 100-Mbit/sec Ethernet cannot be carried over two pairs with a low-cost implementation. For this reason, SMC's PHY proposes four pairs.
2. Robust collision detection within scaled MAC timing
3. Error detection and conformance to IEEE 802.3 (no more than 1 bit error for every 109 bits transmitted)
4. Compliance with the FCC class B emissions requirement
5. Electromagnetic field strength. Although not specifically required by the 802.3 standard,

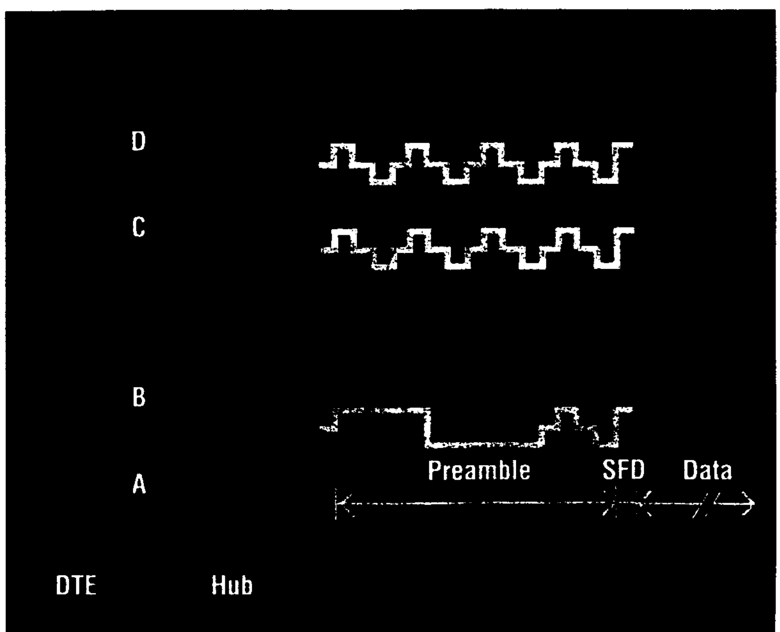

Figure 1. Under SMC's fast Ethernet specification, the hub or DTE sends data on three pairs simultaneously and listens for a signal to detect a collision on the fourth pair.

10Base-T equipment has been shown to operate in test chambers with up to 3 volts per meter of radio frequency electromagnetic field strength.

Essential Features

The basic connection scheme is shown in Figure 1. Pairs A and B are able to transmit and receive data. Pairs A and B are unidirectional. When sending data, the hub or DTE sends data on three pairs simultaneously and listens for a signal to detect a collision on the fourth pair. To compare, 10Base-T transmits on one pair, while energy is sensed on the other pair for collision detection. As in Figure 1, the hub and the DTE transmit over different pairs, or are interleaved. This makes collision detection possible. Three pairs are used to lower the required bandwidth per pair (33.3 MHz per pair).

It's inevitable that the three transmitting pairs interfere with the pair listening for energy to detect a collision. This near end cross talk (NEXT) phenomenon is very significant at frequencies required for 100-Mbit/sec transmission. Fortunately, however, it is not significant at low frequencies. Therefore, false energy, and hence false collision detection, is avoided by lowering the frequency of the appropriate transmitted preamble and providing a low-pass filter for collision detection.

Coding and Signaling

UTP cable performs poorly at frequencies over 30 MHz, so 100-Mbit/sec transmission requires a more efficient coding scheme than 10Base-T's Manchester coding. Another motivation for doing this is to keep the transmitted energy spectrum mostly below 30 MHz to make FCC class B compliance easier to achieve with low-cost implementations. Reduction in transmitted frequencies and energy peaks are achieved by:

- transmitting data on three pairs at one-third the data rate
- using a coding scheme more efficient than the Manchester scheme used in 10Base-T
- scrambling the data stream into a pseudo-random sequence

A three-level encoding scheme operating over three pairs can bring most of the transmit energy below 30 MHz. Additionally, a data scrambler spreads the transmitted energy more evenly within this band. When using a multi-level scheme, coding is required to map the binary coded data (which is coded into two levels) into three-level (ternary) symbols. The coding used is known as 7B5T since seven binary bits are coded into five three-level ternary symbols. From the constellation of 243, 128 codes are chosen that give lowest frequency content while maintaining acceptable DC balance, which is required for operation through DC blocking magnetics.

Error Detection

More efficient coding makes good error detection much more difficult. This is because an error in one ternary symbol maps (through the 7B5T coding) into as many as seven bits of binary errors. The 802.3 specification requires:

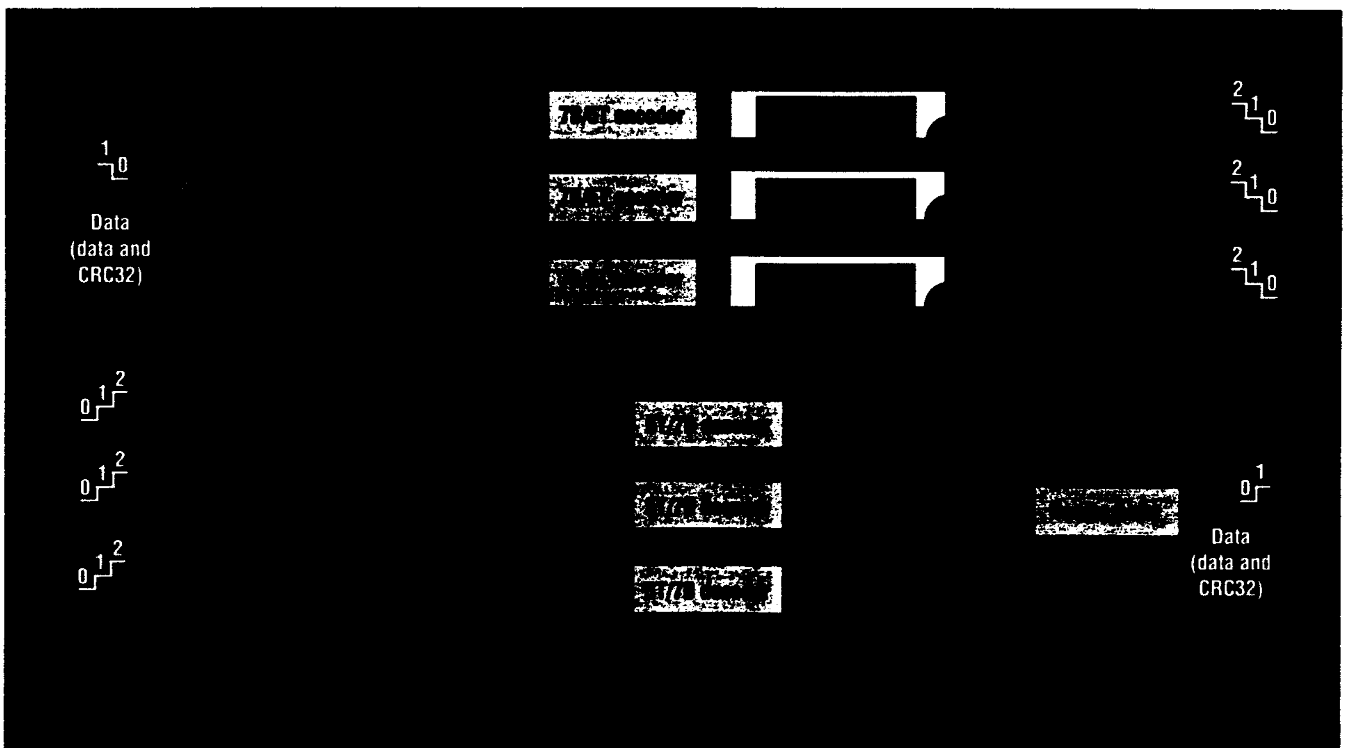

Figure 2. The data processing path for transmit and receive under SMC's proposal.

- the detection of up to four random single bit errors
- the detection of bursts of errors up to 32 bits

In 10Base-T, error detection to this extent is achieved through the 32-bit CRC at the end of the frame. Since four random symbol errors can create up to 28 binary errors, the 32-bit CRC is no longer adequate for the deterministic detection of four errors. Therefore, a frame check sequence (FCS) is added to the transmission of each pair to improve error detection. Further, the FCS is calculated from the three-level (ternary) symbols rather than the binary data to avoid the error multiplication effect (see Figure 2).

One of the issues with three-level coding is that in order to maintain the voltage between levels (and, therefore, noise immunity), the peak-to-peak transmit voltage (5 V for 10Base-T) must be increased by 50 percent. Even though 3 volts/meter of external signal noise can represent 200 mV of noise at the end of the cable, data transmission at the 7.5 V peak can still be shown to produce bit error rates surpassing the 802.3 10-8 error rate requirement.

Collision Detection

At 100-Mbit/sec data rates, design features must be added to perform reliable and timely collision detection. The NEXT from adjacent transmit pairs may reach a peak of 400 mV. Adding 200 mV of susceptibility noise gives up to 600 mV of received noise, which may equal the true received signal level for 0-db signal-to-noise ratio. Fortunately, this scheme only transmits valid data on a half-duplex basis, so NEXT is only an issue during collision detection. Changing the preamble and jam frequency to 2.4 MHz overcomes this problem since the attenuation of the cable is low at this frequency. At 2.4 MHz, the preamble and jam received signal level is about 1.1 volts, giving a respectable collision noise margin of 500 mV (see Figure 3).

Ongoing Work

The FCS check sequence appended to the transmitted frame adds the equivalent of 96 bits of data to the end of the frame. This proposal also greatly exceeds the 802.3 requirement for error detection. Since the appended bits prevent a completely scaled 802.3 MAC from being used, work is ongoing to reduce the length of the frame check sequence by bringing the error detection capability closer to the 802.3 requirements.

In conclusion, 100-Mbit/sec data rates are feasible on 100-meter lengths of category 3 four-pair cable. The proposed three-pair, three-level signaling scheme is both robust and economical and an error detection scheme has been proposed that greatly exceeds the 802.3 requirement. Electromagnetic emission and susceptibility objectives are clearly achievable. SMC strongly believes that the use of the scaled 802.3 MAC is achievable, economical, and of the greatest benefit to both users and vendors. ■

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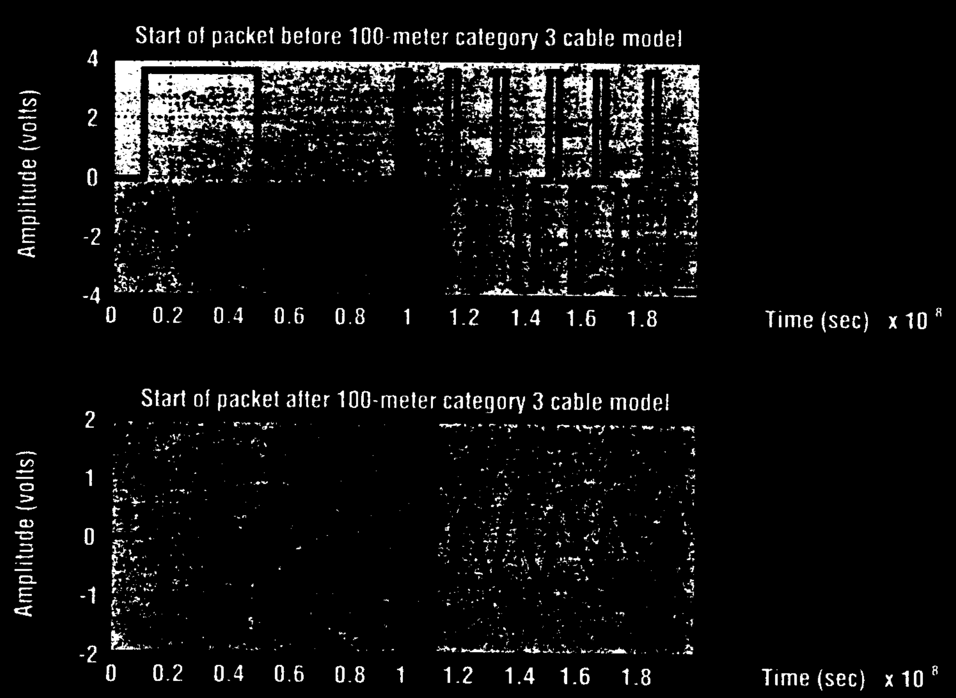

Figure 3. Changing the preamble and jam frequency to 2.4 MHz brings the received signal level to about 1.1 volts, giving a respectable collision noise margin of 500 mV.