APPLICATION OF TELEPROTECTION EQUIPMENT OVER DIGITAL NETWORKS

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ABSTRACT

Over time, communications equipment manufacturers have developed highly specialized "teleprotection equipment." This equipment provides power utilities with very secure and reliable signaling between power substations for the remote operation of power system circuit breakers. The evolution of this equipment understandably has lagged behind the evolutions in the telecommunications field. As new communications systems have become available new types of teleprotection equipment have followed. Up until the introduction and acceptance of high-speed digital networks by power utilities, teleprotection has consisted almost exclusively of analog based systems.

Today, however, these teleprotection systems are taking advantage of higher speeds and bandwidths that were not available using older analog communications networks. Because the telecommunications industry and the teleprotection industries have evolved separately (with different focus on performance criteria), some overall operational discrepancies now exist. These issues are not insurmountable; however, there are application concerns that need to be addressed.

A BRIEF INTRODUCTION TO TELEPROTECTION

The following list depicts some typical protective relaying schemes that use teleprotection:

1. Transfer trip
2. Current differential
3. Phase comparison

In each of these three categories, several application types can exist. However, the overall communications performance requirements can be grouped in this manner. Until the advent of digital communications networks, the primary communications media for these systems has been powerline carrier, dedicated pilot wires, dedicated fiber optics, and audio tones applied over leased services or analog microwave.

Transfer Trip

In most applications, this form of teleprotection involves the transfer of information in the form of a contact closure between two ends of a protected power line. Most systems of this type operate in about 3 ms to 15 ms, depending on the application and not including propagation delays.

Current Differential

Two vintages of current differential relays are in use today: electromechanical, and numerical (or digital).

Electromechanical relays are the oldest type. They were designed for use over dedicated copper pairs. Communication consists of a composite 60-Hz signal that is used for comparison at the remote end.

Numerical or digital relays are the newer types. These relays use more conventional audio tone or digital communications systems. These relays have propagation delay limits, and most cannot compensate for dynamic changes in this delay.

Phase Comparison

Phase comparison systems use tone or digital communications systems. Depending on the vintage, some of these relays have propagation delay limits of 8 ms maximum, and cannot compensate for dynamic changes in this delay.

A BRIEF T1 OVERVIEW

T1 multiplexers and channel banks use time division multiplexing (TDM) techniques to combine twenty-four 64-Kbps channels (or DS0s) onto a single 1.544-Mbps aggregate signal. (See Figure 1.) This aggregate signal is called a "DS1," or Digital Signal Level 1.

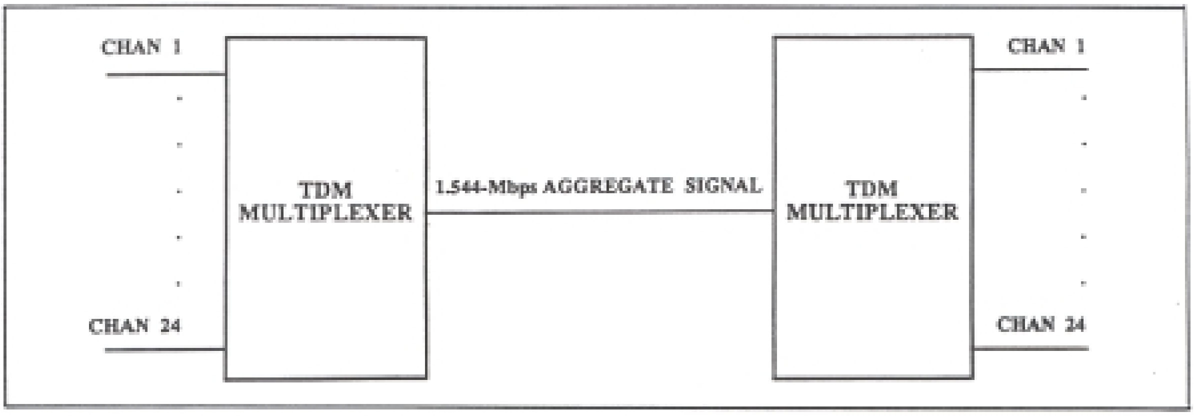


Figure 1. Time Division Multiplexer (TDM)

Each channel or DS0 contains eight bits. When the twenty-four DS0s are combined, they make up 192 of the 193 bits in the T1 aggregate. The 193rd bit is the framing bit (F-bit) and is inserted by the multiplexer for synchronization. Synchronization keeps the multiplexers at each end of the link locked with each other; what goes in on one end on a specific channel comes out the other end on the same channel. The combination of the twenty-four DS0 time slots and the framing bit are also called a "D4 frame." (See Figure 2.)

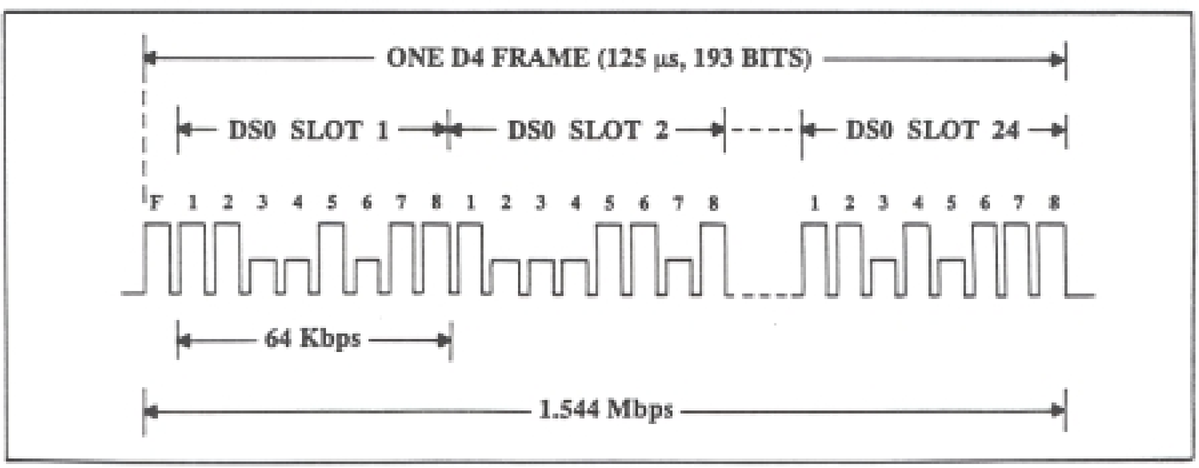


Figure 2. D4 frame

SUPERFRAME

It takes twelve D4 frames to make up what is called a "superframe." (See Figure 3.) The resultant 12 F-bits of the superframe are split into two groups that are used for terminal framing (F_t) bits and signal framing (F_s) bits. The F_t bits identify the framing boundaries while the F_s bits are used to identify the robbed-bit signaling frames (6 and 12) and the associated signaling channels (A and B).

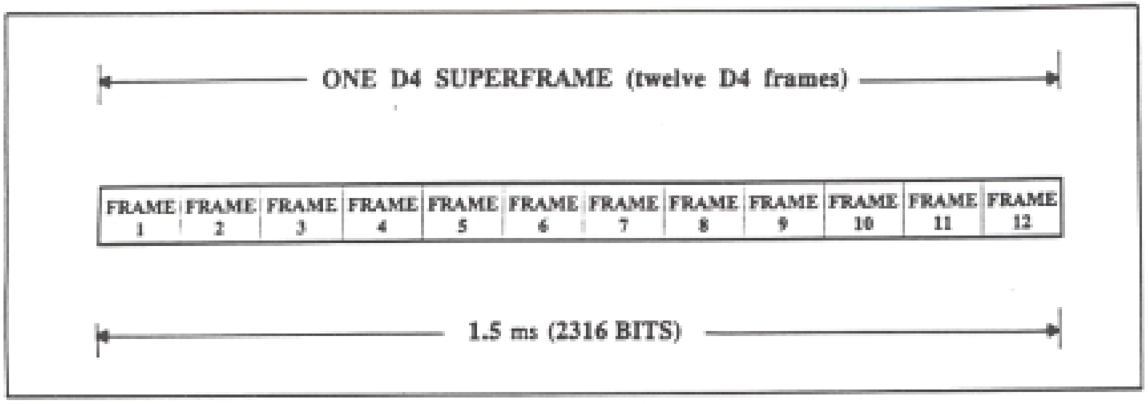


Figure 3. D4 superframe

EXTENDED SUPERFRAME (ESF)

The extended superframe format is made up of twenty-four D4 frames and the F-bit positions are partitioned for three separate uses. (See Figure 4.) Six of the F-bits are used for frame synchronization, and six are block check bits used as a cyclic redundancy check (CRC6) field. The remaining twelve F-bits are data link (DL) bits, used to form a 4-Kbps data channel.

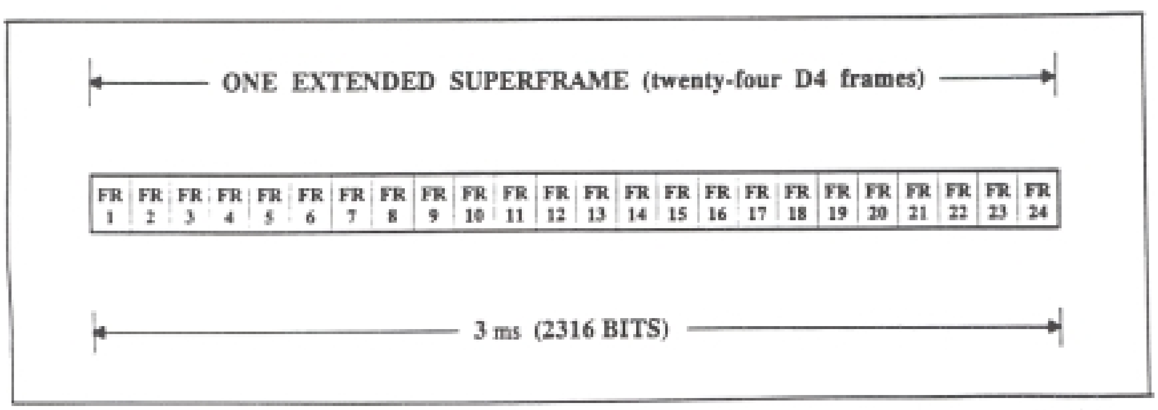


Figure 4. Extended Superframe (ESF)

A TYPICAL POWER UTILITY SYSTEM TELEPROTECTION APPLICATION

When T1 is applied as the communications medium for teleprotection applications, it is usually applied over utility-owned fiber optic cables that are routed between power substations. (See Figure 5.) This yields a serial T1 topology that is best suited for T1 add/drop multiplexers (ADM). (Add/drop multiplexers are also called "drop-and-insert" multiplexers.) Drop-and-insert capabilities allow DS0 traffic to be used between adjacent substations, while allowing re-use of the same DS0 time slot at other locations in the system.

For most teleprotection applications using this topology, the protection signals are primarily point-to-point between adjacent nodes. Other traffic (such as telephone and SCADA) are home-run to the PBX and SCADA master locations.

Timing characteristics in T1 equipment performance will vary from vendor to vendor. Some forms of teleprotection equipment will not operate properly when the teleprotection traffic needs to operate through several nodes. This will depend on the delay characteristics of the multiplexer equipment being used. Some typical delay variances are listed below:

Description	Standard Grade	Protection Grade
Data Buffering (at the channel card level)	1 ms to 2 ms	< 700 µs
Drop-And-Insert Throughtime (at the DS1 level)	125 µs to 250 µs	< 25 µs
Data Buffering (at the DS1 level)	Included above	. . .
Reframe Times	< 50 ms	3 ms to 10 ms

As far as teleprotection systems are concerned, the only types of systems that are affected by the above timing considerations are digital interfaces for the older electromechanical current differential relays. The overall system delay tolerances vary from manufacturer to manufacturer, and range from 700 µs to 1.5 ms. From this data, two facts become apparent:

1. The interface points on the network for these types of systems can affect performance.

2. The characteristics of each system component can make the difference in whether an application will actually work.

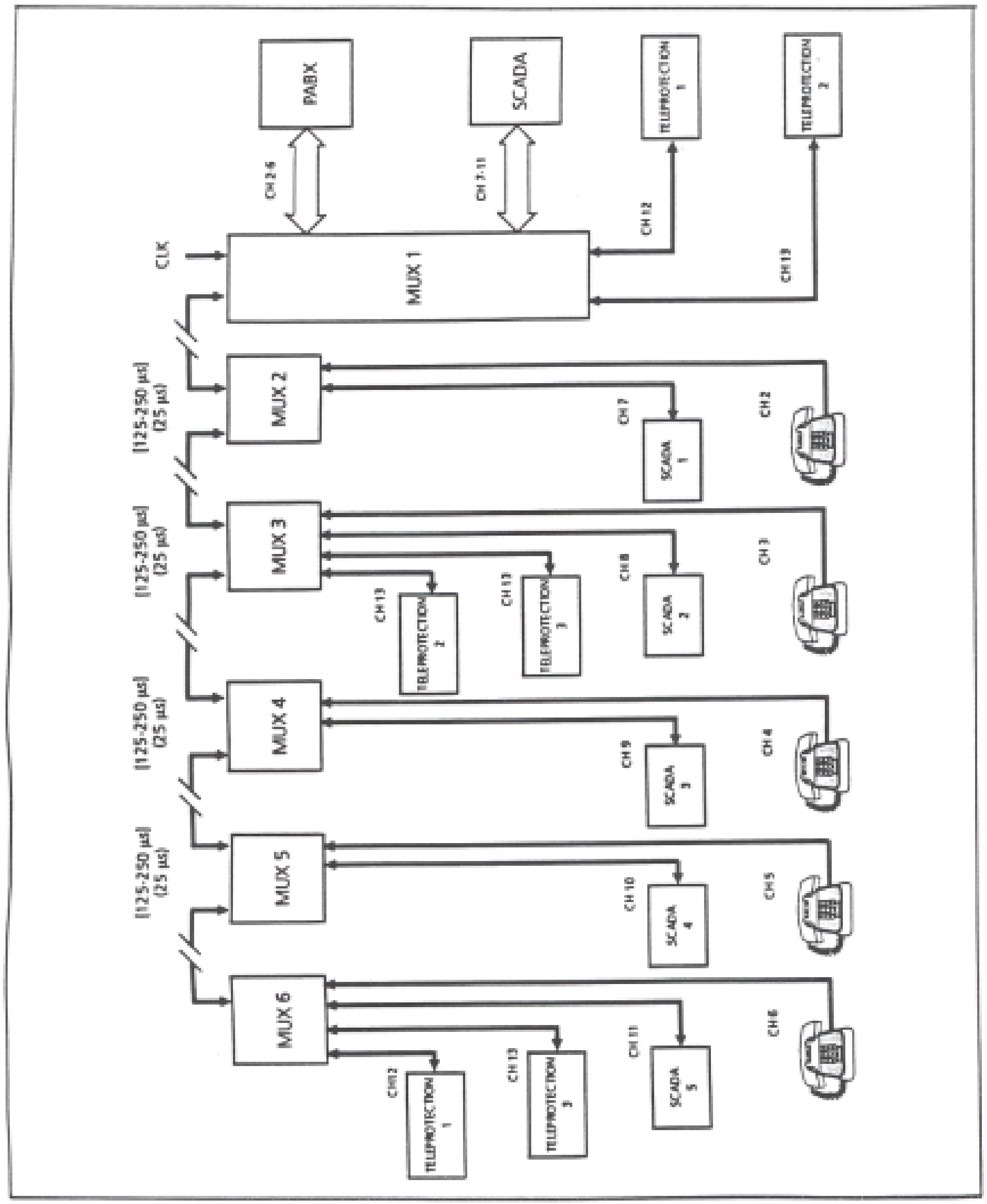
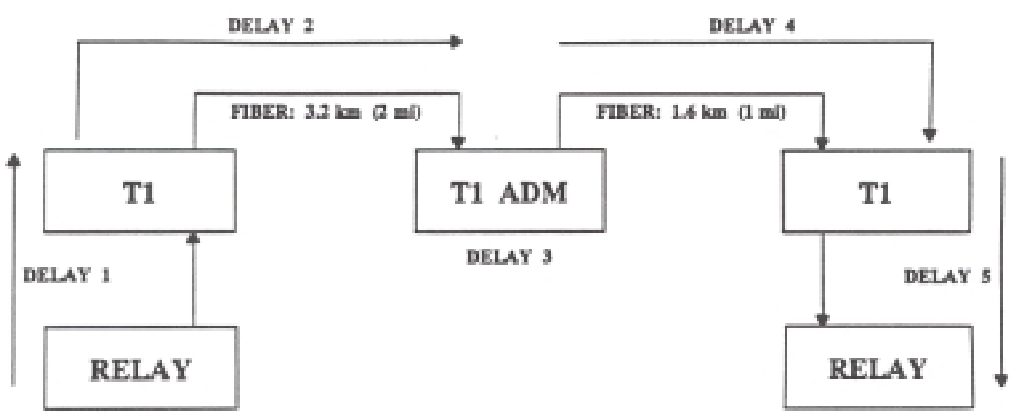


Figure 5. Typical power utility drop/insert teleprotection application

It should be noted that the delay tolerance of some numerical current differential relays can overcome the above limitations. While applications vary, most modern current differential relays should be capable of being used for T1 multiplex systems.

One additional timing element not mentioned so far is the speed of light through the fiber. Although this is a very small number (about 8 μs per mile), it can add enough delay on very long fiber paths to affect system performance. Currently, the electromechanical current differential relay interfacing over T1 is typically the only teleprotection application that has such application restraints. (See Figure 6.)



DELAY FACTORS:

1 - INPUT (RELAY AND T1)	400 μs
2 - FIBER 1 (2 MILES @ 8 μs/MILE)	16 μs
3 - T1 ADM	25 μs
4 - FIBER 2 (1 MILE @ 8 μs/MILE)	8 μs
5 - OUTPUT (T1 AND RELAY)	400 μs
TOTAL DELAY:	849 μs

Figure 6. Electromechanical current differential relay interfacing over T1

SONET

In some applications as they exist today, T1 networks as described previously will interface into larger backbone networks, such as "SONET" (Synchronous Optical NETwork). SONET is a standard that was developed to define a synchronous digital hierarchy with sufficient flexibility to carry many different capacity signals. This was accomplished by defining a basic signal of 51.840 Mbps (OC-1) and a byte-interleaved multiplex scheme. The result is a family of standard rates and formats defined at rates that are multiples of 51.840 Mbps (OC-N). As it is a complex network to describe, only its main properties and implications for teleprotection applications are described in this paper. (The reader is referred to References 1 and 3 for more detailed information.)

A major part of SONET research has been devoted to the achievement of network resilience and survivability. This is not surprising since in 1992, fiber optic cable failure accounted for as many major communication outages in the U.S. as all exchanges with failures. (In this context, "major" refers to outages affecting more than 50,000 people.) Fifty-eight percent of these incidents were caused by dig-ups. As a consequence, a topology involving self healing rings has evolved.

SONET RINGS

Two types of SONET rings are currently defined; they are "Path Switched" and "Line Switched," as defined in TR-496 and TA-1230 (References 2 and 3). Each of these ring topologies offers pros and cons regarding different types of teleprotection applications.

Path-Switched Rings

In a path-switched ring, only the effected Virtual Tributary (VT) is switched. VTs are interfaces within the SONET multiplexer that permit the primary rate to be outputted to DS1 interfaces. An example of this is shown in Figure 7. In a unidirectional path-switched ring, VTs enter the ring at a node and are simultaneously transmitted around the ring in counter-rotating directions. This scheme uses one direction around the ring as the primary signal path, and the other direction as the protected path. If a signal path failure occurs, the affected circuit packs within the SONET multiplexer perform the switch locally. (See Figure 8.)

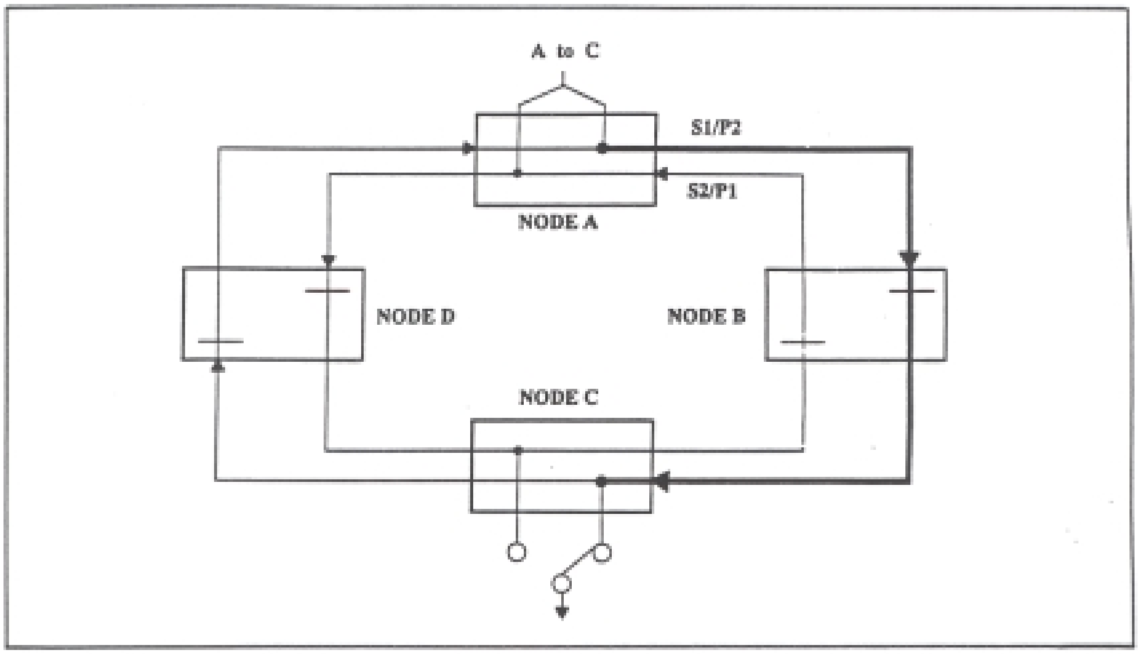


Figure 7. Unidirectional path-switched ring

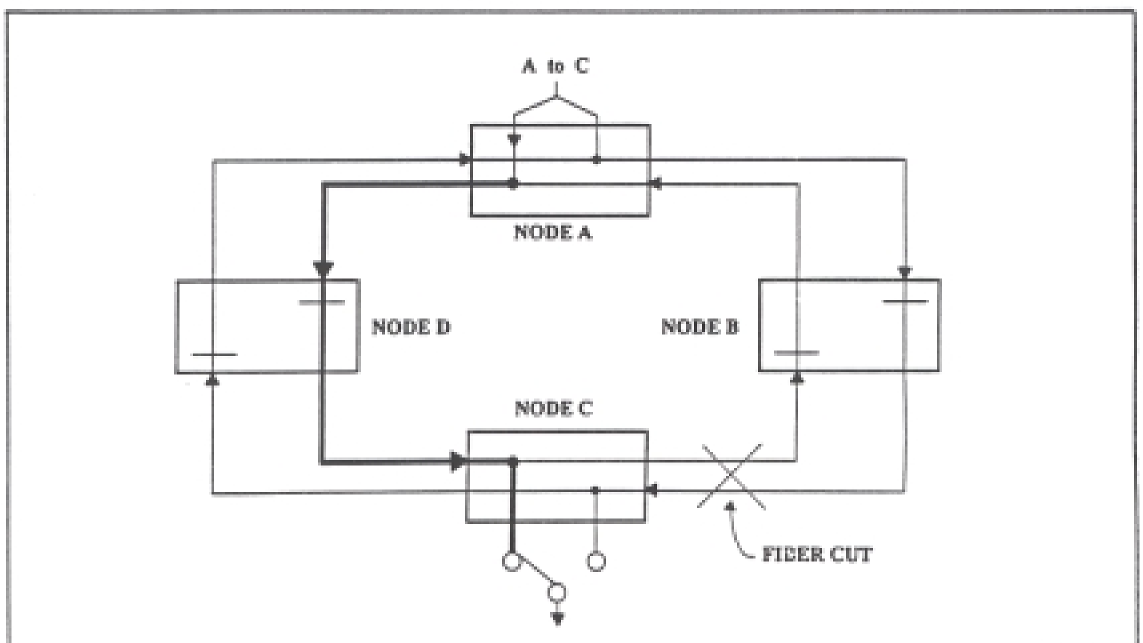


Figure 8. Protected traffic flow in unidirectional path-switched ring

When applying teleprotection over this type of ring topology, some precautions need to be taken. For example some current differential and phase comparison systems cannot compensate for unequal channel delays between the transmitter and receiver paths. These same systems have been designed with fixed propagation delay compensation. This means that substantial changes in the receive path propagation (which can occur during path switching) could result in false operations in the protection system. Modern current differential systems that can dynamically compensate for these conditions do exist, and are well-suited for these applications.

Line-Switched Rings

In the two fiber bidirectional line-switched ring (BLSR), switching occurs at the line rate (OC-N). The two fiber limitation requires that half of the available channel bandwidth be reserved to provide the protected path.

When applying teleprotection over this type of ring topology, the precautions required are slightly different than with the path-switched ring. For example, the same current differential and phase comparison systems that cannot compensate for unequal channel delays between the transmitter and receiver paths are no longer affected. The systems that have been designed with fixed propagation delay compensation could still be vulnerable to false operations, depending on the size of the network.

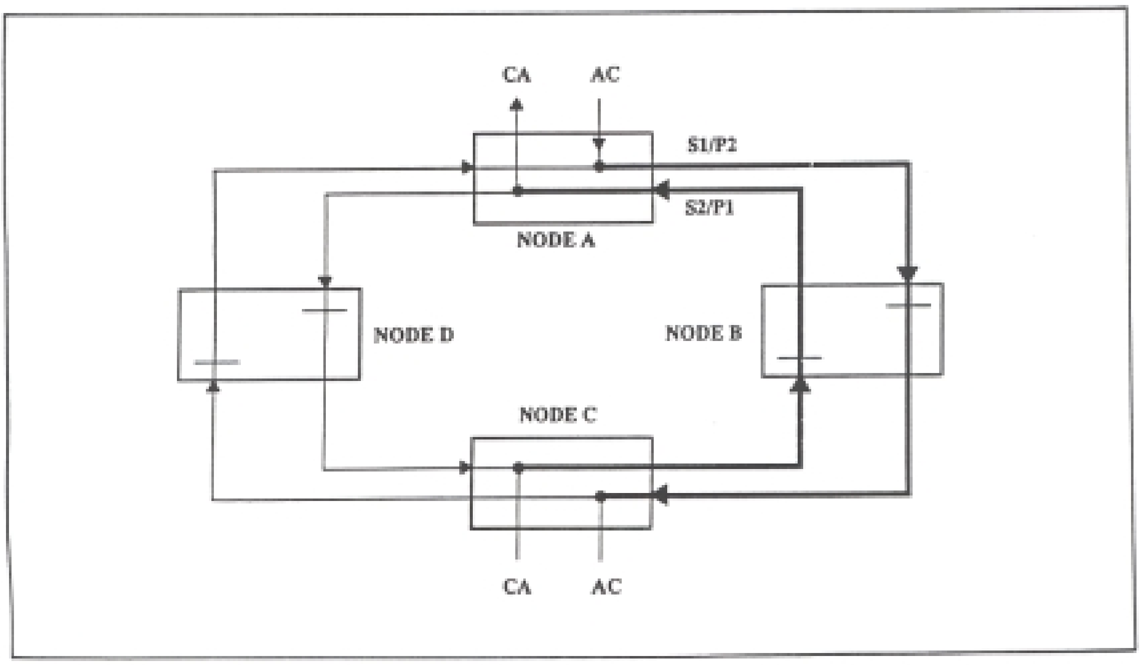


Figure 9. Normal traffic flow in two-fiber bidirectional line-switched ring

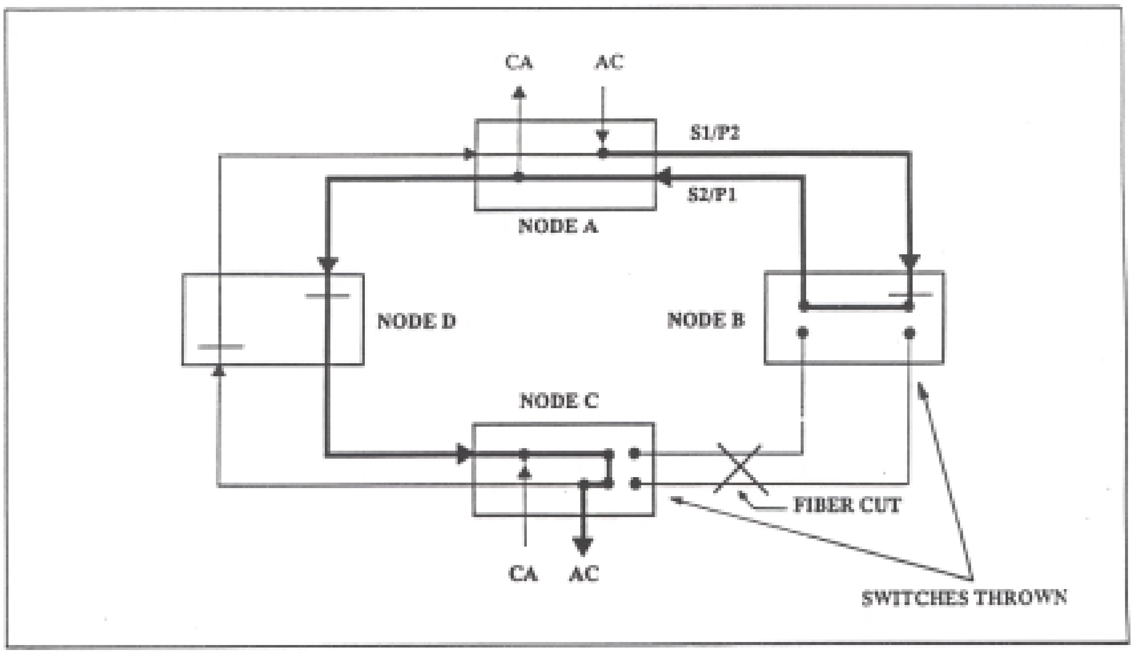


Figure 10. Protected traffic flow in two-fiber bidirectional line-switched ring

RELAYING ON SONET

While SONET offers many capabilities (including network management and self-healing rings), there are delay issues that must be considered when SONET traffic is re-routed due to breaks in the fiber or equipment failures. Like T1, timing characteristics vary from vendor to vendor. Some representative delay characteristics are as follows:

Description	Delay
Transfer Switch Time	< 60 ms
DS1 Synchronization Delay	< 100 μs
DS1 Through-Delay	< 50 μs
SONET Ring Delay (around the ring)	1 ms to 6 ms

In certain ring topologies, the received delays of the two terminal ends will be different, especially when the path is switched. While this is not a problem with transfer trip schemes, all electromechanical and most numeric current differential relays will not be able to handle this situation. Only numeric relays that can compensate for changing delays can be successfully applied.

CONCLUSIONS

Although digital networks have been in existence for many years, the use of teleprotection and digital relaying over these networks is relatively new. The overall advantages offered by these digital networks to the utilities in the area of reliability is tremendous. Teleprotection technology designed to take optimum advantage of these networks and the increased reliability exists today. However as with most things the upgrading of backbone communications systems is not tied to the upgrading of teleprotection systems so the issues discussed in this paper need to be considered.

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NOTES

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