



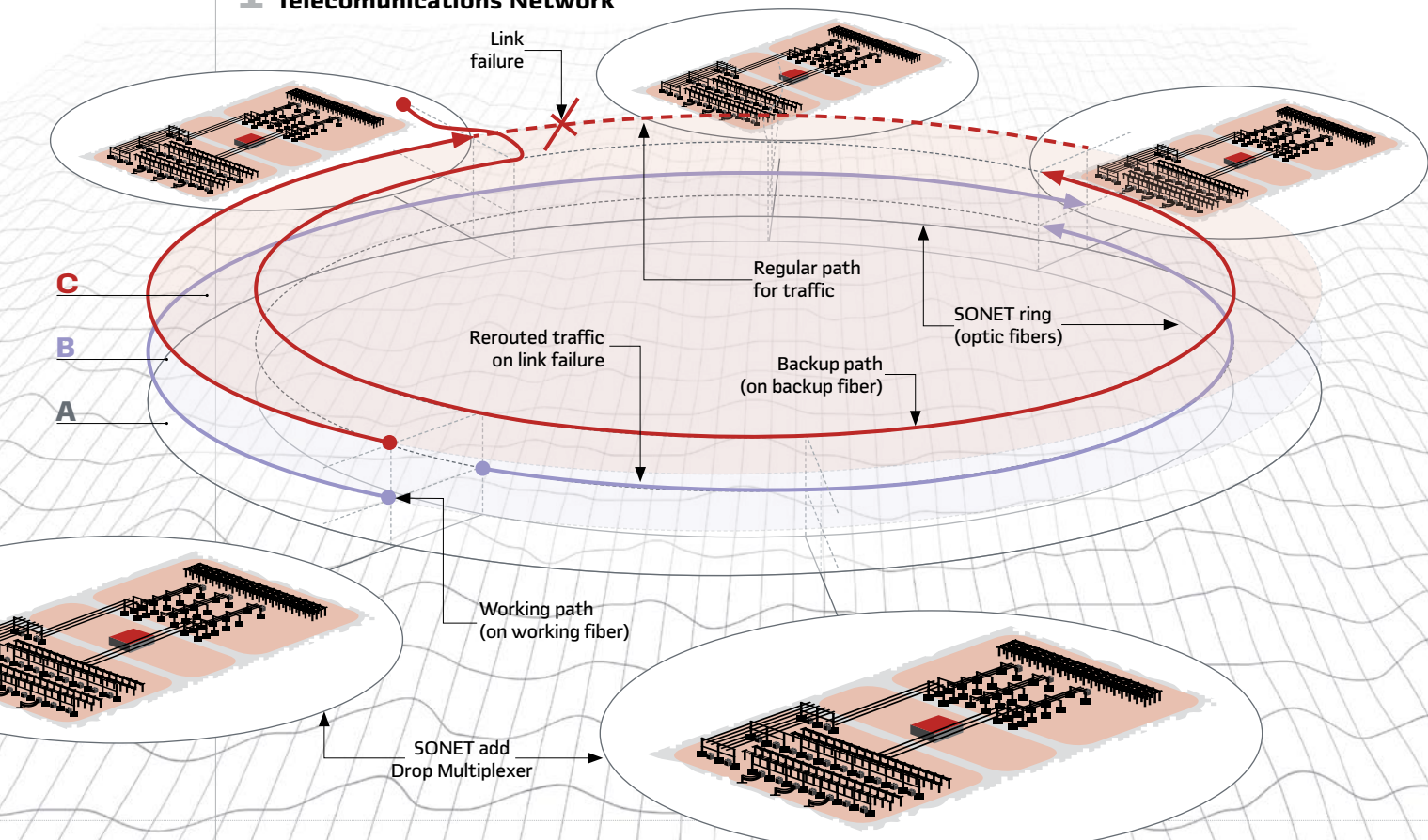
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Communication CHANNEL Requirements for Pilot Protection

provide much higher data transfer rate but reliability and security performance criteria developed for the telecommunications industry are not easily translated to teleprotection applications.

Pilot relaying has been applied for transmission line protection since the 30's. The well known communication channels (pilot wire or Power Line Carrier) are increasingly being replaced by digital channels. Dark fiber (dedicated fiber optic cable), multiplexed fiber optic systems (T1 and SONET) and 56 kbps phone lines are now made available for pilot protection purposes. The new channels

1 Telecommunications Network



The demand for Information Technology and Telecommunications has grown exponentially over the last decade. Industries with critical infrastructure organizations, including electric utilities, are working to integrate their IT and telecom strategies in order to reduce costs, improve efficiency, and strengthen the information backbones.

Teleprotection, or relaying, channels conventionally reside with the Utility Relaying group, as a relaying communications channel forms part of the Protection System. Relaying channels have traditionally been point-to-point connections but it seems logical and cost effective to use an existing digital communications network instead of installing or replacing a dedicated relay communications channel. The relaying demands, at first glance, seem to easily fit into the telecommunications network that generally provides high redundancy and high bandwidth. However, due to a lack of understanding between the relaying group and the telecommunications group, the special requirements for teleprotection are not always clearly stated and, as a result, not fully considered in the communications network's design. At the same time, the relay engineer does not have a clear picture of how the relay's data is transported from the local relay to the remote, receiving relay. Consequently, any problems relating to the communications link can be hard to resolve due to lack of understanding of the entire teleprotection system, including both relays and communications.

Several working groups are active in this area. The new IEEE C37.94 "Standard for N times 64 kilobit per second Optical Fiber Interface between Tele-protection and Multiplexer Equipment" addresses connectivity between relays and multiplexers on an optical level. PSCC (Power System Communications Committee) as well as WECC have groups working on guides to provide communications system designers with basic performance criteria for communication circuits carrying protective relaying applications. The need for these guides was precipitated by the recognition of potential relay problems due to channel timing delays arising from the application of digital communications and switching technologies.

Digital Communication Channels

Media transporting relay data in digital form are: dedicated optic fiber, multiplexed networks using 64 kbps interfaces (T1 multiplexing, SONET, digital microwave and radio links), and CSU (Channel Service Unit) providing 56 kbps or 64 kbps service over copper phone lines. There is also Power Line Carrier available with the ability of transmitting up to 64 kbps but this bandwidth over a power line is presently not sufficiently reliable to be used for other than SCADA or other slower-speed data.

T1 Multiplexing T1 is a term for a digital carrier facility used to transmit a digital signal at 1.544 megabits per second. T1 was developed by AT&T in 1957 and implemented in the early 1960's to support long-haul pulse-code modulation (PCM) voice transmission. The primary innovation of T1 was to introduce digitized voice and to create a network fully ca-

The effect of asymmetrical delay, if not eliminated in the communications network design, should be taken into account for relay scheme selection.

pable of digitally representing what was up until then a fully analog telephone system.

T1 is used for a wide variety of voice and data applications embedded in the network distribution architecture as a convenient means of reducing cable pair counts by carrying 24 voice channels in one 4-wire circuit. T1 multiplexers are also used to provide DS0 access to higher order 'transport' multiplexers such as SONET.

T1 Frame A T1 frame consists of 24 eight-bit words plus a framing bit. Each timeslot of the frame contains 8-bits of binary information. Each timeslot is called a Digital Signal Zero (DS0) which is sampled 8000 times per second. This sampling rate can adequately represent voice characteristics of a human speaker when using Pulse Code Modulation (PCM). Each DS0 contains 64kbps (8k samples/sec x 8 bits/sample) of user information. Time Division Multiplexing (TDM) is used to combine 24 DS0's into one T1 frame, giving an effective data rate of 1.536 megabits per second. In addition, each frame contains one framing bit, which is used primarily for frame synchronization. This bit adds an additional 8kbps of overhead to the frame, increasing the information rate from 1.536 Mbps to 1.544 Mbps. This 1.544 Mbps is commonly referred to as a Digital Signal One or DS1. Note that the word T1 and DS1 are used interchangeably, however this is not really accurate. A T1 refers to the digital transmission system which operates at DS1 rates.

Framing Framing is used on T1 circuits to synchronize individual frames without the need for external clocking devices. D1 framing was the first framing pattern to be used for transmission of T1 signals. Within a D1 frame, each timeslot contained seven-bits of digitized voice and one-bit used for signaling (call setup and routing). The framing bit identified the boundary between frames. As T1 networks evolved, other framing and signaling methods needed to be developed. The SuperFrame (SF) or D4 framing was the first one introduced.

1 T1 Frame



Biography

Solveig M. Ward received her M.S.E.E. from the Royal Institute of Technology, Sweden in 1977. The same year she joined ABB Relays. She has held many positions in Marketing, Application, and Product Management. Assignments include a six-month period in Montreal, Canada and two years in Mexico. When Ms. Ward returned to Sweden, she was application responsible for the development of a numerical distance protection relay and in charge of marketing the product. After transferring to ABB in the US 1992, she was involved in numerical distance protection application design, and was Product Manager for ABB's line of current differential and phase comparison relays. Solveig has written, co-authored and presented several technical papers at Protective Relaying Conferences. She is a member of IEEE and holds one patent, "High Speed Single Pole Trip Logic". In June 2002, Solveig joined RFL Electronics Inc. as Director of Product Marketing.

A SuperFrame consists of 12 individual T1 frames. The framing bit in every odd frame is used for terminal framing while the framing bit in every even frame is used for signaling framing. Terminal framing and signal framing are used to form a 12-digit word (100011011100). Notice that the even bits used to identify signaling frames are sequenced as XOXOX1X1X1X0. Signaling information is marked by the change in the bit pattern. Frame six transitioned to a one and frame twelve transitioned to a zero. Signaling information is contained within frames six and twelve of a SuperFrame. The sixth and twelfth frames are used the same in D1 framing. Only two of the 12 frames contain signaling information within each timeslot.

Most T1 facilities today use a framing technique called Extended SuperFrame (ESF). ESF consists of 24 individual T1 frames. The 24 framing bits are classified into three different categories; alignment or terminal framing (2kbps), CRC (2kbps), and data link (4kbps). The terminal framing bits are used to identify frame boundaries and positions of other framing-bits. The CRC (cyclic redundancy check) is used to monitor the performance of the ESF and the data link is used to send performance information as well as other messages between multiplexers.

Line Coding A T1 signal is transmitted on the link in a binary format (ones and zeros). This binary format is encoded onto the link using a technique known as alternate mark inversion (AMI). The format is alternating pulses (+3/-3 V) denoting a one and no-pulse denoting a zero. The benefit of this encoding is that it has a built-in method of error detection. Whenever consecutive pulses are detected of the same polarity, a bipolar violation (BPV) is indicated. Therefore, we know that the frame experienced some type of error. A disadvantage to this encoding is the transmission of an all zero's pattern.

To correctly identify DS1 input, the multiplexer must know when to sample the bipolar signal to determine whether a "0" or a "1" is being transmitted at any given time. To ensure proper sampling, the multiplexer relies on a timing method that uses the binary pulses (ones) to maintain synchronization with the network equipment that is transmitting the DS1 signal.

Since pulses are critical to maintain signal timing, all DS-1 signals are required to meet specific one's density standards. These standards require that at least one pulse be transmitted within any eight-bit sequence (12.5% ones density). Further, since long strings of consecutive zeros between digital values can also hinder signal timing, ones density standards prohibit the transmission of more than 15 zeros in succession.

Success in meeting ones density requirements can vary based on application. For example, since the size and content of the bit patterns that represent human speech are consistent, acceptable ones density in voice applications is a virtual certainty. But since digital data is highly variable in size and content, conformance to ones density standards cannot always be guaranteed. This technical problem is why a coding technique known as bipolar with 8-zero substitution (B8ZS) has gained in popularity.

Digital communications networks can provide reliable and interference-free relaying channels if some fundamental requirements are taken into account

B8ZS uses intentional bipolar violations (BPVs) to break up long strings of zeros, allowing their transmission through the T1 link without violating the ones density standard. With B8ZS, network equipment replaces any string of eight consecutive zeros with two intentional BPVs before the DS1 signal is transmitted over the T1 link: the first BPV replaces the fourth zero, the second replaces the fifth and seventh zeros. Additionally, the eight-zero bit which normally would be coded as a zero is assigned a pulse value. Using this format, the DS1 signal can pass through the multiplexer on the T1 link with an acceptable level of pulse density. When the signal arrives at the receiving network equipment, the pattern is recognized as the B8ZS substitute for eight consecutive zeros; the equipment then replaces the international BPVs with their zero value.

Network Timing T1 networks are designed to be synchronous networks. Data clocked in at one point in the network at which the data is clocked out. Technically, the speeds at both points are the same, and there is a fixed frequency relationship between the clocks which strobe the data in and out. This condition is referred to as frequency locked.

The North American T1 network is derived from a series of higher-order network multiplexer with unsynchronized

clocks, using a technique called pulse stuffing to overcome clock inaccuracies and fluctuations. The use of unsynchronized clocks for higher-level TDM networks does not preclude network-synchronized clocks for higher level T1 or DS1 signals. Synchronization of the network at the DS1 level is achieved by framing the data streams and frequency locking the node and network clocks. Loss of synchronization or unlocked clocks results in frame slips. A frame slip is a condition in which framing is momentarily lost, as well as network timing information, typically resulting in data loss.

SONET

SONET (Synchronous Optical Network) is the American National Standards standard for synchronous data transmission on optical media. The international equivalent of SONET is SDH, Synchronous Digital Hierarchy. Together they ensure that digital networks can interconnect internationally and that existing conventional transmission systems can take advantage of optical media through so called "tributary" interfaces.

One of the main drivers behind SONET is the Multi-Vendor interoperability. Standards existed for the electrical level only and to connect to another manufacturer's equipment back-to-back connected devices were required. With SONET establishing standards for the optical signal levels, a change of equipment can be made mid-span; one vendor's multiplexer can be connected to the fiber network at one terminal and another vendor's multiplexer connects to the same fiber at the other end.

Some of the most common SONET (and SDH) applications include transport for all voice services, Internet access, frame relay access, ATM transport, cellular/PCS cell site transport, inter-office trunking, private backbone networks, metropolitan area networks and more. SONET operates as the backbone for most, if not all, interoffice trunking as well as trans-national, and trans-continental communications.

Figure 5 illustrates the levels (bandwidths) in the SONET standard and how these relate to the North American Digital Hierarchy. STSn is the Synchronous Transport Level where 'n' signifies the level (or bandwidth). STS is the electrical signal rate used within SONET prior to its optical

conversion. OCn is Optical Carrier Level where, again, 'n' is the bandwidth level. OC is the optical signal. DS stands for Digital Signal Level. DS0 is one voice channel and occupies 64 kbps. DS1, also called T1, is 24 DS0's or 1.544 Mbps.

Asynchronous and Synchronous Multiplexing

Transmission hierarchies in the past have been built using asynchronous multiplexing systems. In asynchronous systems, each terminal in the network runs on its own clock. In digital transmission, clocking is one of the most important considerations. Clocking means using a series of repetitive pulses to keep the bit rate of data constant and to indicate where the ones and zeroes are located in a data stream.

Because these clocks are totally free-running and not synchronized, large variations occur in the clock rate and thus the signal bit rate. For example, a signal specified at 44.736 Mbps +20 parts per million (ppm) can produce a variation of up to 1,789 bps between one incoming signal and another.

Asynchronous multiplexing uses multiple stages. Signals such as asynchronous DS1's are multiplexed, and extra bits are added (bit-stuffing) to account for the variations of each individual stream and combined to form a DS2 stream. Bit-stuffing is used again to multiplex up to DS3.

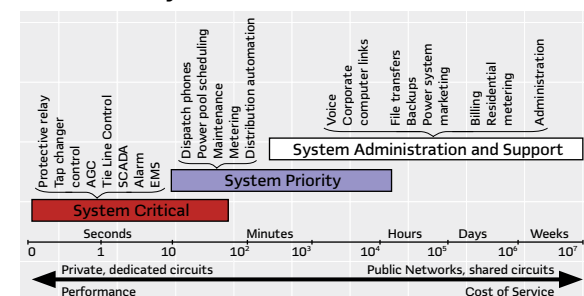
The lower multiplexed levels can not be accessed without de-multiplexing the entire signal. To add or drop a signal, the optical DS3 needs to be converted to copper DS3 and then de-multiplexed into individual DS1 signals before the required signal can be dropped. To add a signal, the reverse process has to take place.

In the synchronous SONET system, adding and dropping signals are much easier. The frequency of all clocks will be the same (synchronous) or nearly the same (plesiochronous). The STS1 rate remains at a nominal 51.84 Mbps, allowing many STS1's to be stacked together without any bit stuffing. The multiplexing is made by byte interleaving.

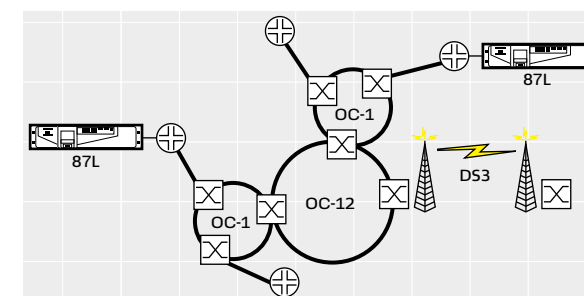
Byte interleaving makes adding and dropping signals easy as shown in Figure 6. One channel is dropped by just taking out the corresponding byte. Another signal can be added in the same way, occupying the byte freed by the dropped signal.

DS1 is transported as VT1 on SONET. VT stands for Virtual Tributary. VT1 occupies 1.7 Mbps which includes

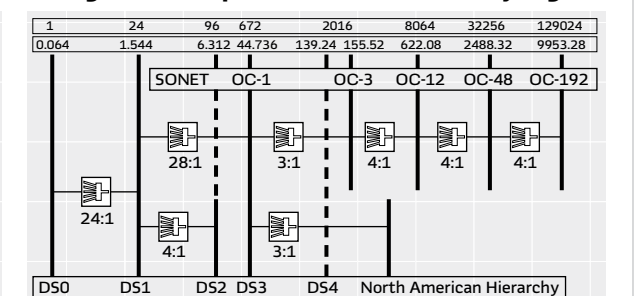
2 Power Systems Communications



3 SONET Network



4 Digital and Optical Carrier Hierarchy Signals



the DS1 1.544 Mbps and SONET overhead bits. Single-step multiplexing up to STS1 requires no bit stuffing, and VT's are easily accessed.

SONET Network Components

A typical arrangement of equipment used to interface relaying to a SONET network is shown in Figure 7.

The substation devices are connected to a T1 multiplexer which in its turn connects to a SONET multiplexer. It provides various interfaces; synchronous 64 kbps for current differential relaying, RS-232 asynchronous data ports, contact interface inputs, video, voice and data ports.

The multiplexer needs to be equipped with an interface card (channel card) that is suitable for the type of data the application device delivers.

SONET Topology Nodes, or terminals, in a SONET network are often arranged in rings to provide an alternate route or protected path in case of a fiber cut or failure of a node. Ring networks are less expensive than point-to-multipoint or star configured fiber optic networks since only two fibers (versus two for each location) are required to support all users or network elements on the ring. Traffic can be routed in either direction around the SONET ring. In case the primary path is cut, traffic is very quickly re-routed to the secondary path.

Several topologies are often combined in one network and interconnected. As the communications network does not take the same routing as the power system lines, two relays that are not physically distant might have a long communications link over the network. Delays imposed by each node the signal has to pass through need to be taken into account when checking possible channel delays.

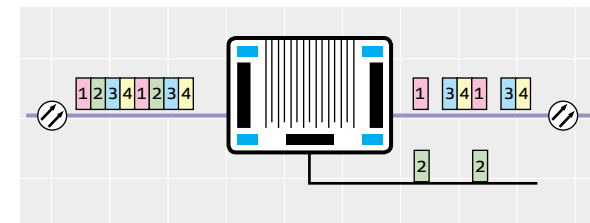
Relaying over Digital Channels

The requirement of high speed data transfer for relaying is recognized by telecoms specifications. Protective Relay service requires the shortest Process Response Time of all power system communication services. At the same time, protective relaying is just one of many services provided by the communications network, and most likely one of the smaller services with regards to amount of data transported. It might be difficult to justify optimization of the relaying channel in the same way as when a dedicated one was used.

In addition to high speed data transfer, protective relaying has very high requirements on reliability. Reliability comprises two contradictory components; dependability and security. Dependability is the ability of the relay system to trip when it is supposed to trip. Security is the ability of the relay system to refrain from tripping when not required to trip. When a digital communications system is used for teleprotection or pilot protection, the dependability and security of the communications network will have to be considered for overall protection system reliability.

A. Substation Multiplexers Several considerations must be taken into account when selecting a multiplexer for a utility's protection scheme; most which concern time delay issues.

5 SONET Add/Drop multiplexer



Reframe time is the amount of time it takes a multiplexer to re-synchronize to the network should there be an interruption in the incoming signal. This time equates to an outage of system availability during that interruption and should be kept to a minimum.

Through-channel delay is the amount of delay time incurred by a channel passing through a drop-and-insert location. Since many T1 applications are multi-point, certain channels may pass through several locations before reaching their final destination. The delay incurred may become prohibitive to certain relaying applications (current differential or directional comparison blocking).

Fallback timing guarantees that system clock is available should there be a loss of the incoming clock source. This ensures the remainder of the system will continue to operate from that new clock source.

DS0 Synchronization and De-synchronization delay in/out of T1 payload is the amount of delay that it takes to input and extract the DS0 signal into and out of the T1. The longer the delay the greater the effect on the relaying circuit.

The ability to intermix voice and data and preserve the transmission characteristics of each is a primary requirement of T1 multiplexers. Voice transmission, for example, can tolerate a few bit errors and not affect the quality of the voice at the receiving end. Speed of delivery is important as any delay is noticeable in voice conversations. In telephone

Avoid any intermediate devices in the channel path between the relays that may introduce unacceptable delays. Make it as much of a point-to-point connection as possible.

company channel banks, multiplexers data transmission is treated just the opposite. Error free transmission is a higher priority than speed of delivery. It is this practice that makes most Telco grade T1 systems unusable for critical real-time applications such as current differential and phase comparison relaying.

SONET requirements are to detect signal failure within 10 ms and to switch over to a healthy channel in less than 50 ms. During the 10 ms fault detection interval, the multiplexer may deliver erroneous data to the receiving device.

The relay securely needs to detect this and block its operation, and discard the faulty data. Delay times for devices used in SONET networks are given in Table I and Table II.

To establish the total channel delay from one relay terminal to the other, the delays for each possible node (drop and insert) between the locations and the signal delay through the fiber itself (8 μs/mile) need to be considered. In the example below, the primary path adds up to 591 μs and the back-up path to 787 μs.

Typical SONET ring delays are in the order of 1-2 ms. However, depending on the network's size, topology and distances, an alternate path might add several ms transmission time between relays. Still, even the worst case delay should not be a problem for a teleprotection or pilot relay scheme, with the exception of pilot wire relaying which can not accept longer delays than 1 or 2 ms.

One concern is if communications network switching result in unequal transmit and receive delays. If there is a risk that the relays can be subjected to asymmetrical delays, the relay performance for this condition should be evaluated.

Change in delays following a path switch is handled by most modern relays as they automatically measure and adjust for actual channel delay. Relays that do not have this ability will suffer degraded performance and might even misoperate as a result of the current from the remote relay being time shifted with respect to the local current.

Table 1 T1 Delay Times

	Channel Bank	Substation T1 multiplexer
Reframe time	<50 ms	<1 ms
Drop and Insert through time	125 to 250 μs	<25 μs
Data buffering at the DS1 level	Included above	Included above
Data buffering at the DS0 level	>1 ms	<375 μs

Table 2 SONET Delay Times

DS1 synchronization delay	<100 μs
DS1 de-synchronization delay	<100 μs
DS1 through-path delay	<50 μs
SONET ring switch transfer time	<50 ms (100 ms for digital microwave)
Signal failure detection time	<10 ms

B. Sources of Interference Optical fibers are near to perfect as they are unaffected by electrical interference, ground potential rise or weather conditions. However, long distances, causing too high attenuation, might cause excessive bit errors. However, very often a communications network is not all fiber optic; there might be metallic cable links or microwave links in the relay paths.

Possible sources of noise in a digital communications network are: noise, signal attenuation, jitter and wander and atmospheric interference on microwave links.

■ Noise on electrical wires where there are copper links as part of the SONET system or as a spur connecting the relay to the network. The C37.94 standard for fiber connection between relay and multiplexer eliminates the possibility of electrical interference on metallic wires in the substation.

■ Signal attenuation when fiber attenuation is too high for transmitted power available will cause signal degradation that result in bit errors.

■ Jitter is a short term variation of a digital signal's significant instants from their ideal positions in time. It is the time difference between when a pre-defined event should have occurred and when it actually did occur. Jitter may be caused by vibration or control voltage variations and is more of a problem in asynchronous communication where clocks are not synchronized. Wander is a long term variation.

■ Atmospheric interference on microwave signal. Attenuation or loss-of-signal may be caused by inclement weather. This is undesirable for relay communications as systems faults are more likely to occur during these conditions. Reliability can be improved by having two receivers using different paths or by using a ring topology with alternative routes around the ring.

Even though the risk of data corruption due to interference is much smaller in a digital communications system than over conventional media, each device using data for critical operation decisions has to be able to detect and disregard erroneous data.

6 SONET Delay Calculations

