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DIGITAL MICROWAVE LINK DESIGN to ELECTRICAL FILTERS

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DS1 Services and Standards

Introduction

The purpose of this article is to provide a technical overview of DS1 (Digital Signal Level 1), including a description of services, applications, and relevant standards. Although the focus is on the current state of DS1 services and standards, the article puts them in the context of their evolution to date and provides an outlook toward the future.

The article begins by describing DS1 at the technical level (tutorial overview), including the characteristics of the digital signal, the position of DS1 in the digital hierarchy, differences among countries, and references to the key standards.

The article then describes services and applications made possible by DS1, including a brief historical review of their evolution. Fractional DS1 (FDS1) and Integrated Services Digital Network (ISDN) services also are addressed.

The relevant standards that make DS1 services possible are summarized to facilitate the identification of relevant standards in various parts of the world. The intent is to provide a global perspective including international and regional/national standards. Thus, the reader should be able to locate readily the standards, as required.

Finally, the article concludes with a summary and a look into the future. Since it is not possible to cover in this brief article all the details of DS1 services and standards, a comprehensive list of references (both technical papers and standards) is provided to allow the reader to pursue the subject further.

Digital Signal Level 1

Digital networks are based on standardized, hierarchical bit rates (1,2), built upon a primary level bit rate of either 1544 kilobits per second (kb/s) (e.g., United States, Canada, Japan, and Caribbean countries except Haiti) or 2048 kb/s (e.g., Europe, Africa, Australasia, Central and South America, Mexico, and Haiti). The 1544-kb/s primary level signal is referred to as the Digital Signal Level 1, or DS1. The term "DS1" is used mainly in North America. The 2048-kb/s digital signal and the corresponding systems/standards have been referred to by a variety of terms such as E-1 (3), CEPT-1 (4), DS1A (5), 2048 MHz (6), and D2048U/D2048S (7).

While DS1 refers to the signal itself, the equipment used to process and transmit/receive that signal usually is referred to as T1-carrier equipment. In the traditional sense, *T1-carrier* refers to copper-based (twisted-pair) line transmission systems. Other transmission media for DS1 may include microwave radio, communications satellite, coaxial cable, optical fiber, or even as part of community antenna television (CATV) applications (8).

DS1 and the Digital Hierarchies

The position of DS1 with respect to other bit rates used in digital networks, including the asynchronous and synchronous digital hierarchy levels, is summarized in Table 1 (1,2,5,9,10).

The left-most column in Table 1 indicates the asynchronous and synchronous International Telegraph and Telephone Consultative Committee (CCITT) digital hierarchy levels (1,2). The table also includes other bit rates used in North America, Japan, and Europe. The asynchronous bit rates are used in equipment that obtain the timing information (clock) from the signal itself and that can handle bit rates that are close but not necessarily identical. The synchronous (or isochronous) bit rates are used with equipment that have precise reference clocks.

It should be noted that the list in Table 1 of asynchronous bit rates based on 1544 kb/s contains two threads (United States and Japan). The asynchronous bit rates in North America and Japan are different at Level 3 and higher, as shown in the table.

The synchronous digital hierarchy (SDH), which starts with STM-1 at 155,520 kb/s, is common for both the 1544- and 2048-kb/s-based systems (11). The usable bit rate for information (payload) is shown in the table as multiples of 64 kb/s to indicate how the hierarchies are formed; however, other multiplexing alternatives exist and mappings of other tributary bit rates into the SDH levels are possible, giving rise to other payload capacities (e.g., Ref. 12). STS-N refers to the Synchronous Transport Signal Level N, for optical interfaces (9).

While all the bit rates in Table 1 are used in digital networks, the ones most commonly made available by telecommunications service providers to customers are DS0, DS1, and DS3.

Technical Characteristics of DS1

A summary of the most significant technical characteristics of DS1 is provided here. In particular, the DS1 format structures and line codes are described, following the American National Standards Institute (ANSI) standards. For further details, refer to the standards (e.g., Refs. 5, and 13–15) and the literature on the subject (e.g., Refs. 16–23). For a description of differences between DS1 and the 2048-kb/s-based systems refer also to Refs. 3, 4, and the applicable standards described below.

DS1 Frame Format

In digital telephony, the analog speech signal is sampled and digitized at the rate of 8000 samples per second and 8 bits per sample. This results in a digital

TABLE 1 Bit Rates and Digital Hierarchies

CCITT Digital Hierarchy Level	U.S. ANSI	Japan TTC	Based on 1544 kb/s: Usable ($n \times 64$ kb/s) $n =$	Based on 1544 kb/s: Total bit rate (kb/s)	Based on 2048 kb/s: Usable ($n \times 64$ kb/s) $n =$	Based on 2048 kb/s: Total bit rate (kb/s)
Asynchronous						
0	DS0	0	1	64	1	64
1	DS1	1	24	1,544	30	2,048
	DS1C		2 × 24	3,152		
2	DS2	2	4 × 24	6,312	4 × 30	8,448
3		3	5 × 4 × 24	32,064	4 × 4 × 30	34,368
3	DS3		7 × 4 × 24	44,736		
4		4	3 × 5 × 4 × 24	97,728	4 × 4 × 4 × 30	139,264
	DS4NA		3 × 7 × 4 × 24	139,264		
	DS4		6 × 7 × 4 × 24	274,176*		
		5	4 × 3 × 5 × 4 × 24	397,200	4 × 4 × 4 × 4 × 30	564,992*
Synchronous						
	STS-1	0	7 × 4 × 24	51,840		
STM-1	STS-3	1	3 × 7 × 4 × 24	155,520	4 × 4 × 4 × 30	155,520
	STS-9		3 × 3 × 7 × 4 × 24	466,560		
STM-4	STS-12	4	4 × 3 × 7 × 4 × 24	622,080	4 × 4 × 4 × 4 × 30	622,080
	STS-18		6 × 3 × 7 × 4 × 24	933,120		
	STS-24		8 × 3 × 7 × 4 × 24	1,244,160		
	STS-36		12 × 3 × 7 × 4 × 24	1,866,240		
STM-16	STS-48	16	16 × 3 × 7 × 4 × 24	2,488,320	16 × 4 × 4 × 4 × 30	2,488,320

*These bit rates are in use, but they have not been standardized in the digital hierarchies.

rate of 64 kb/s and a time interval per sample of 125 microseconds (μs). The sampling rate is based on the Nyquist rate of twice the bandwidth in the analog signal. Since the nominal band of telephone speech is 300 hertz (Hz) to 3400 Hz, there is a 900-Hz guard band when the band-limited analog signal is sampled at 8000 Hz. This must accommodate the transition band of the filters in the transmission system (24). This technique of transmitting analog information in a digital form is referred to as pulse code modulation (PCM) (16).

The basic timing parameters of the 64-kb/s signal must be maintained when several channels are multiplexed. The definition of DS1 is based on multiplexing 24 64-kb/s channels: 24 8-bit words in series (1 per channel) are preceded by 1 framing bit and are coded into 193 time slots in a 125-μs time interval, which is referred to as a *frame*. This establishes the first-level bit rate of 1.544 megabits per second (Mb/s) (DS1).

The framing bits identify the beginning of a new frame and multiple frames are associated to form a multiframe structure, referred to as the *DS1 frame structure*. The channel formed by the framing bits (one every 125 μs, i.e., 8 kb/s) is referred to as the *frame overhead*. The frame overhead can be encoded as a frame alignment signal and as maintenance channels to transmit information relating to alarms, signal quality, and other networks' operations data.

Over the years, DS1 has had different applications, in which the significance of certain bits and the coding have changed and the standards may offer options. Hence, implementations must ensure that each part of the equipment supports the same options in the standards.

The information payload may be structured into channels of 64 kb/s or other bit rates. Unchannelized structures are also possible, in which the total number of payload bits is available as one channel (1536 kb/s). The payload structure also may contain overhead channels carrying information necessary for a specific network use, depending on the application.

In telephony applications, such signaling information as setting up a connection and supervising its completion is included in the digital bit stream by robbing the least significant digit from each codeword in every sixth frame (see Fig. 1). This provides 24 bits every sixth frame (i.e., 32 kb/s) that can be used

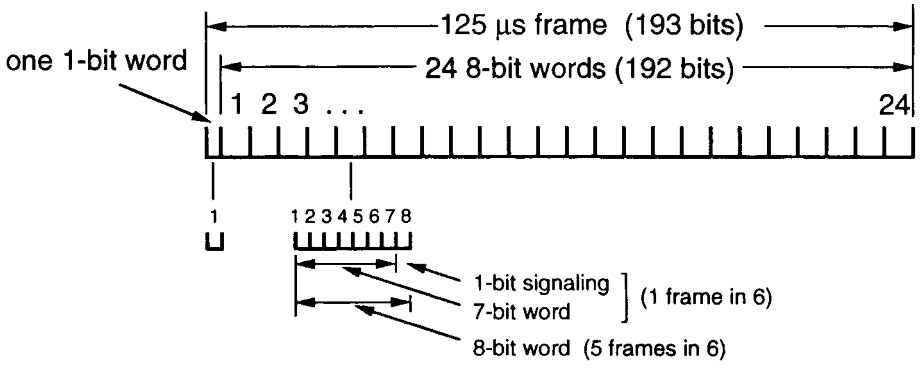

FIG. 1 DS1 frame format: Bit robbing.

for voice channel signaling information. This procedure causes every sixth frame to use 7-bit words to encode the voice channels. This technique is referred to as *bit robbing*. Although the effect of bit robbing on the overall quantization distortion of the voice is not significant, it prevents the use of the full 24 × 64 kb/s in data communications applications. Other schemes of bit robbing are possible. The signaling channel(s) created by the bit-robbing technique form part of the payload overhead.

As indicated above, multiple DS1 frames are associated to form a structure. Two DS1 frame structures have been standardized (13): superframe (SF) (12-frame multiframe) and extended superframe (ESF) (24-frame multiframe).

The SF structure consists of 12 DS1 frames (12 × 193 = 2316 bits). The 12 framing bits in each SF are used for frame and signaling phase alignment, depending on their position in the SF. An SF alignment channel is formed by the 6 framing bits contained in the odd-numbered frames of the 12 framing bits, referred to as S1, S2, S3, S4, S5, and S6. The other six framing bits (contained in the even-numbered frames) of the SF form a frame alignment channel and are referred to as F1, F2, F3, F4, F5, and F6. The SF alignment channel signal (S1 = 0, S2 = 0, S3 = 1, S4 = 1, S5 = 1, and S6 = 0) is used to locate all 12 frames. The frame alignment channel signal (F1 = 1, F2 = 0, F3 = 1, F4 = 0, F5 = 1, and F6 = 0) is used to locate all 24 payload channels.

The ESF structure consists of 24 DS1 frames (24 × 193 = 4632 bits). The 24 framing bits are shared among an ESF alignment signal, a cyclic redundancy check (CRC), and an operations channel data link (DL). The ESF format provides additional operations and maintenance capabilities in DS1 facilities. It was developed when advancements in technology permitted the establishment and maintenance of framing with fewer overhead bits than the 1 in 193 used in the 12-frame SF format. Hence, there was spare capacity in the frame overhead and the SF was extended to 24 frames with the 24 framing bits allocated as follows:

Framing alignment signal: 6 bits (Frames 4, 8, 12, 16, 20, and 24) (referred to as F1, F2, F3, F4, F5, F6), 2 kb/s

CRC of previous SF: 6 bits (Frames 2, 6, 10, 14, 18, 22) (referred to as C1, C2, C3, C4, C5, C6), 2 kb/s

Operations channel DL: 12 bits (odd-numbered frames) (referred to as M1, M2, M3, . . . , M12), 4 kb/s

In this configuration (i.e., ESF), each 3 bits provide a data rate of 1 kilobit per second (kb/s).

The standardized signals and functions for ESF include only the minimum essential subset of functionality needed for all applications. Additional functionality can be accommodated within the ESF for specific applications (25).

The 2048-Mb/s frame format is quite different (26). Each frame has 256 bits (32 8-bit words in series) and the frame alignment signal is carried in the first 8-bit word in alternate frames. The frames that do not contain the frame alignment signal carry operational messages in the first 8 bits of the frame. The remaining 31 8-bit words in each frame carry speech/data or signaling information. The 8-bit word in Time Slot 16 usually is reserved for signaling. Bit-robbing techniques are not used and 30 64-kb/s channels are available for payload. Frames are grouped into multiframes of 16 frames each.

DS1 Line Codes

In order to make efficient use of the transmission media, the line code for DS1 is a bipolar code known as alternate mark inversion (AMI). The zeros correspond to zero volts and successive ones are coded as pulses that alternate between positive and negative voltages (nominally ± 3 volts). This is done to remove very low frequency energy from the digital signal in order to allow transformer coupling of repeaters and cable pairs. The direct current (DC) powering for the line repeaters also is carried on the same pairs of wires as the digital signals. With AMI, two or more successive pulses of the same polarity are termed *bipolar violations*. Unless introduced intentionally by the coding system in a predetermined manner under certain conditions (see below), bipolar violations indicate an error in the signal.

The bipolar code requires that sufficient ones are transmitted so that the transmitter clock rate can be recovered effectively at each receiver. The pulse density requirements are that no more than 15 consecutive zeros are present and there are at least N ones in each and every time window of $8(N + 1)$ digit time slots (where N can equal 1 to 23); that is, the average density of ones has to be at least 1 in 8.

To ensure that DS1 can provide 64-kb/s clear channels for ISDN and other applications, modifications of the bipolar line code have been devised to ensure that long strings of zeros could be transported. DS1 standards offer two alternatives for line codes that support clear channels: bipolar 8-zero substitution (B8ZS) and zero-byte time-slot interchanger (ZBTSI). B8ZS is considered the long-term method of providing clear-channel capability in DS1, and ZBTSI is considered as one alternative interim method for providing it in the short term.

The B8ZS code uses an algorithm that replaces occurrences of eight consecutive zeros (00000000) with exactly defined bipolar violation pairs in the fourth- and seventh-bit position of the inserted code ($000VB0VB$) where B represents a normal bipolar pulse and V represents a pulse violating the bipolar rule, that is, V has the same polarity as the preceding pulse. The receiving equipment monitors the incoming DS1 signal for B8ZS codewords and replaces them with eight zeros. B8ZS is transparent to format and framing structures, treating all bits equally, and maintains the density requirements.

ZBTSI is a technique in which zero octets are replaced by an address chain that is decoded by the receiving terminal. It operates by buffering multiple frames prior to transmission, scanning the buffered data for all-zero patterns and replacing them with other bit patterns. The ZBTSI algorithm requires 2 kb/s of overhead information carried within the ESF DL. The ZBTSI overhead bits are referred to as Z-bits and each one is associated with the 96 octets that immediately follow it. The other frame bits between Z-bits also are present in the 96-octet group but they are not involved in the ZBTSI process in any way. The frame bits are buffered to experience the same delay as the information bits so that the original SF may be restored at the decoder. The ZBTSI algorithm is specified in T1.107 (13).

Other schemes of zero-code substitution are possible that maintain the pulse density requirements and do not introduce DC components. For example, the 2048-kb/s signal uses HDB3 (high-density bipolar of order 3) (27). Each block of four successive zeros (0000) is replaced by either 000*V* or *B*00*V* so that the number of *B* pulses between consecutive *V* pulses is odd. That is, successive *V* pulses are of alternate polarity and no DC component is introduced.

DS1 Performance Aspects

Although the performance aspects of DS1 are outside the scope of this article, Refs. 22, 23, and 28–40 may be consulted. For network configurations, refer to Ref. 41.

Applications of DS1

Some of the different ways in which DS1 can be used include the following (13):

Unchannelized: The 1536-kb/s information payload is available to the user. One of the techniques available to provide a clear-channel capability (e.g., B8ZS or ZBTSI) may be used to allow for an unrestricted number of zeros in the payload.

Twenty-four channels at 64 kb/s: Each DS1 frame carries 24 octet-interleaved channel time slots.

Twenty-four channels with bit-robbing signaling channel: This is the traditional application with channel banks in digital telephony. Eight bits are available for payload in 5 out of 6 of the DS1 frames.

ISDN Primary Rate Access (PRA): The DS1 frame carries 24 octet-interleaved channel time slots. The channel time slot may be used for a variety of applications. If there is a D channel, it is assigned Time Slot 24.

Twenty-four channels with ISDN basic access signal.

Forty-four or 48 channels using 32-kb/s adaptive differential pulse code modulation (ADPCM): With ADPCM, the usual 24-channel capacity of DS1 is doubled. In the 44-channel format, 4 channels are designated for signaling, maintenance, and a DL. In the 48-channel format, signaling is provided either outside the DS1 signal or inside (e.g., using bit-robbing techniques).

Twenty-three channels at 64 kb/s with overhead channel: Channels 1–23 are used for payload and Channel 24 is used as a payload overhead channel.

DS1 facilities are built into systems to provide services that end users will use for their own applications. This is the subject of the next section.

DS1 Services

Evolution of DS1 Services

DS1 transmission systems were first introduced into telecommunications networks by the early 1960s (16,17). However, initially they were used exclusively by telephone companies for interconnections between digital channel banks, primary rate multiplexers, and switching centers. DS1 facilities were made available to commercial customers for the first time in the late 1970s on a special assembly basis for point-to-point private lines. A typical application was circuit consolidation by means of multiplexers for voice, data, and video applications. By the early 1980s, as a result of an increasing demand by customers to have access to these facilities, they eventually were tariffed and made available on a wider scale. Thus, DS1 traditionally has been used to implement private-network backbones and to provide access from customer premises equipment (CPE) to public networks. The evolution of DS1 service capabilities may be assessed by comparing the literature on the subject over the years (e.g., Refs. 42–57).

The introduction of digital cross-connect equipment, which initially was intended to provide greater operations flexibility to carriers, introduced new capabilities in the network that were made available to customers on a reservation basis. At the DS1/DS0 level, digital cross-connect systems allow the assignment and redistribution of 64-kb/s channels among the various DS1 lines connected to them (58).

Circuit-mode services at DS1 and FDS1 rates became available from major carriers as private-line or special-services networks (47,52). These services are "slow switched" by the very nature of their implementation using digital cross-connect systems. Typical applications for these services include the creation of private networks, access to public network services, and wide-area data networks. The trend has been an increasing demand by end users for more control over the management of circuit-mode DS1 services, thus reducing channel reservation requirements, increasing connectivity, and eventually leading to the introduction of fully dialable services at DS1 and FDS1 rates.

One of the limitations in the introduction of dialable services at high bit rates has been the characteristics of the existing switched network, which has evolved from the analog network by modifying portions of it for 56-kb/s (if bit robbing is used for signaling) and 64-kb/s switched services. Although switched digital services are not yet widely available, current networks are designed for switched services at 64 kb/s. Higher bit rates may be accommodated by using multiple 64-kb/s channels; however, the original digital network implementations made no attempt to maintain any timing relationship between any two or more 64-kb/s channels that could be subject to different delays when routed through the network. In order to maintain data integrity, it is necessary that the data are delivered by the network at the destination in exactly the same order as they were received from the originating end.

Technology advancements in the digital switched network have enabled this capability (52,53,59–63). Major carriers have announced dialable services at DS1 and FDS1 rates and service-definition standards are being finalized in

CCITT within the scope of ISDN. The primary rate user-network interface offers the required capabilities to provide access to these services.

While the emphasis here has been on circuit-mode services, DS1 also can be used to transport packet-mode services, particularly frame relay services (64–66).

International Telegraph and Telephone Consultative Committee Service-Definition Standards

CCITT has a three-stage methodology for describing telecommunications services (67). The first stage is the most important because it defines the characteristics of the service from the user's point of view. It consists of a service definition and description in prose form, a static description of the service by means of attributes, and a dynamic description of the service using graphical means. Based on the Stage 1 definition (which is the responsibility of CCITT Study Group I), then the subsequent stages specify a functional model, functional entities, protocols, and the signaling required to provide the service.

CCITT has published a series of Recommendations (I.231.x) that define circuit-mode, unrestricted information transfer bearer services at various rates, including 1536 kb/s and 1920 kb/s (68). All CCITT-defined circuit-mode services allow a variety of information transfer attributes including:

Establishment of the communication: demand, reserved, permanent
Symmetry: bidirectional symmetric, bidirectional asymmetric, unidirectional
Communication configuration: point-to-point, multipoint

The latest addition to this family of circuit-mode bearer services, still under study in CCITT, is Draft Recommendation I.231.10 (69), which defines a multirate circuit-mode bearer service for an ISDN interface that allows users to request from the ISDN on a demand basis the establishment and release of circuit-mode connections supporting unrestricted information transfer rates at integer multiples of 64 kb/s up to the maximum rate of the interface.

Examples of DS1 Services/Applications

A comprehensive table of possibilities for services and their applications has been produced by CCITT in preparation for the definition of broadband services for ISDN (70).

The following descriptions may refer to services (if offered as such by a service provider) or applications (if the user is accessing a more general-purpose service). No special distinction is made here between dedicated facilities and switched facilities since these services/applications may be implemented in either environment. Furthermore, while these services may be offered at various transport bit rates, depending on CODECs (coders/decoders) utilized and other factors, they all can be offered at DS1 and FDS1 rates.

Private-Network Backup and Rapid Provisioning

Large private networks are becoming more and more complex and require dynamic means of adding circuits for disaster recovery, time-of-day alternate routing, overflow/peak-period support, network reconfiguration, and so on (45,52, 53,71,72). These applications are ideal for switched DS1 services.

Local-Area Network Interconnection

The interconnection of local-area networks (LANs) using DS1 facilities can be implemented using bridges and routers with dedicated DS1 facilities (73) or using such packet-mode services over DS1 as frame relay (66).

Videoconferencing

Videoconferencing was one of the first applications for DS1 services at their full rate (51,53,74). While desk-to-desk and some conference room videoconferencing are possible using one or two 64-kb/s channels, the higher quality provided by video CODECs at 384 kb/s and above is better suited for use in conference rooms and studios. Videoconferencing can be in point-to-point or in multipoint configurations; hence, they will require switched services. One key standard for videoconferencing applications is the CCITT Recommendation H.261, also referred to as the $p \times 64$ (p times 64) standard for videoconferencing. Recommendation H.261 specifies the coding and decoding methods for the moving picture component of audiovisual services at rates of $p \times 64$ kb/s, with p in the range of 1 to 30 (75). Other relevant CCITT Recommendations are H.221, H.230, H.242, and H.320.

Recommendation H.221 defines a frame structure for audiovisual teleservices in single or multiple 64-kb/s channels, or a single primary rate channel, by making use of the characteristics and properties of CCITT audio and video encoding algorithms and transmission frame structures (76). Recommendation H.230 provides procedures, definition of symbols, and requirements for control and indication signals in transmission frame synchronous applications (77). Recommendation H.242 specifies a scheme in which a channel accommodates speech and, optionally, video or data at several rates up to 2 Mb/s, in a number of different modes (78). Recommendation H.320 provides the system requirements for visual telephone services with channel rates up to 1920 kb/s and covers such topics as system description, terminal requirements, intercommunications, maintenance and human factor aspects (79).

Desktop Multimedia Communications

One form of videoconferencing is for desk-to-desk communications. In this application, communications are more involved than for person-to-person interactions because multimedia information will be accessed at the same time (see Refs. 80–82). The need to access multimedia databases and shared visual spaces will increase the demand for DS1 services from desktop workstations. In the residential environment, multimedia terminals and personal computers also will be used for information retrieval, teleshopping, and teleconsultation (83).

Four scenarios are likely to develop for communications in this area:

1. 64 to 128 kb/s over ISDN basic rate access
2. Multimedia information over high-speed isochronous LANs
3. ISDN PRA with $n \times 64$-kb/s circuits
4. Broadband ISDN (B-ISDN) at 155 Mb/s

Several standards activities are underway to facilitate multimedia services: audiovisual interactive services (service definition in CCITT Study Group I and protocols and terminal characteristics in Study Group VIII), multimedia and hypermedia information coding standards (International Organization for Standardization/International Electrotechnical Commission [ISO/IEC] Joint Technical Committee 1, Subcommittee 29 [JTC1/SC29]), and network capabilities to support multimedia services (CCITT Study Group XVIII).

Image Communications

There are professional groups and government departments (e.g., medical, research, earth resources, police) that have a need to communicate high-resolution images. Their requirements traditionally have been met using film-based systems that are slow, cumbersome, and expensive to handle. Possibly the most critical need for image communications is in the medical profession in which imaging is used extensively for medical diagnosis and records (84,85). Radiographs, thermographs, tomograms, ultrasound scans, and nuclear medicine images are typical examples of applications in the medical field. Depending on the application, DS1 may provide the ideal capability in terms of quality/cost tradeoffs. Image acquisition systems and image workstations distributed throughout hospitals and remote medical offices would communicate with each other and have access to databases of digital images and medical records using DS1 facilities and B-ISDN. The images in the image base would be accessed on demand from the visual workstations and desk-to-desk medical specialist consultations would take place. Digital images allow additional processing capabilities (e.g., Ref. 86).

Residential Video on Demand

Video on demand will enable residential users to access video sources and select video programs, via menus on the screens of their television sets, for entertainment, education, or other applications, offered by information providers (87–90). New coding technologies and standards now permit digital video coding at about 1.5 Mb/s with quality sufficient for many business and residential applications (89,91,92). This bit rate is well suited for compact optical disks, digital tape, magnetic disks, and DS1 facilities. Furthermore, new transport technologies permit the transmission at DS1 rates and higher over a single wire pair (93,94). Hence, a combination of these elements indicates that video on demand could be one of the mass applications for DS1 services.

High-Quality Music on Demand

Similar to on-demand video distribution, compact-disk-quality digital stereo music requires about 1.5 Mb/s, hence it is well suited for on-demand music via switched DS1 facilities. Other encoding techniques at lower bit rates (e.g., 384 kb/s) that provide equivalent quality also are possible.

Personal Computer Communications

A large range of personal computer applications is possible with switched DS1 and FDS1 services. These applications include computer-to-computer communications for the exchange of software and files, access to such remote peripheral devices as a CD-ROM (compact disk read-only memory), access to remote databases, and even to realize virtual personal computers (95). CD-ROM devices have interface bit rates of about 1.5 Mb/s, hence they are very suitable for remote access via DS1 services, referred to as *virtual CD-ROM*. A virtual CD-ROM is functionally identical to a real CD-ROM co-located with the personal computer.

DS1 Standards

While many standards are applicable to DS1 systems and services, some of which are mentioned in the previous sections, the emphasis in this section is on the digital hierarchy and the physical-layer standards for 1544- and 2048-kb/s transmission systems. The major standards organizations considered here are CCITT (96), ANSI (97), European Telecommunications Standards Institute (ETSI) (98,99), and Telecommunication Technology Committee (TTC) (48, 100).

The main standards for the DS1 physical layer are summarized in Table 2. More complete lists of references based on what is available currently in published or draft form are given in each section. Since standards organizations are updating and upgrading the standards constantly, the reader should consult the corresponding standards organizations to ascertain the status of any given standard or possible new standards.

Table 2 indicates how international, regional, and national standards ad-

TABLE 2 Relevant DS1 Standards

	International	Regional/National		
	CCITT Rec.	U.S. ANSI	Europe ETS	Japan TTC
Digital hierarchy				
Asynchronous	G.702	T1.102	300 166	JT-G702
Synchronous	G.707	T1.105	300 147	JT-G707
Physical/electrical interface characteristics	G.703	T1.102 T1.403	300 166	JT-G703
Frame structure	G.704	T1.107	300 167	JT-G704
Frame alignment	G.706	T1.107	300 167	JT-G706
Timing requirements	G.811 G.812	T1.101	(DI/BT-2006)	JT-G811
ISDN PRA Layer 1	I.431	T1.408	300 011	JT-I431

dressing similar aspects compare; however, that does not mean that there is a one-to-one correspondence between the standards, let alone equivalency, since there are significant differences in scope and content among them. Furthermore, many other standards are applicable (e.g., those pertaining to signaling, performance, management, electromagnetic compatibility [EMC] requirements, connectors, safety and protection, etc.) that are outside the scope of this article, but should not be difficult to locate with Table 2 and the list of references below as a basis.

International Telegraph and Telephone Consultative Committee

The CCITT is one of five permanent organs (another is the International Radio Consultative Committee [CCIR]) of the International Telecommunication Union (ITU). CCITT was formed in 1956 and its mandate is to study and issue recommendations on technical, operating, and tariff questions relating to worldwide standardization of telecommunications, except for radio communications. For background on CCITT, see Ref. 96.

The G-series recommendations contain the digital hierarchies (1,2), and the key DS1 standards at the physical layer (27,26,101–103). The ISDN PRA is specified in the I-series recommendations on ISDN (104).

Other relevant standards are the service-definition recommendations (64,67–70) and the video-coding and transmission recommendations (75–79).

American National Standards Institute

ANSI was founded in 1918 to coordinate voluntary standards activities in the United States. ANSI approves American National Standards (ANSs). For background on ANSI, see Ref. 97. For an overview of the development of DS1 standards in the United States, including evolution considerations in the light of divestiture considerations, refer to Ref. 19.

The relevant ANSI standards for DS1 include those for digital hierarchies (5,9), the physical layer (5,6,13–15,25,105), and ISDN PRA (106). The following are the key DS1 standards at the physical layer:

T1.102 describes the digital hierarchy in the United States and the electrical and physical characteristics for signals appearing at the appropriate level digital interface, including DS1 (5).

T1.107 describes the formats at each level of the digital hierarchy, including DS1, and identifies selected frame and payload structures, including channelization (13).

T1.403 describes the metallic interface between a carrier and customer installation, referred to as the network interface, at the DS1 rate (14).

Electronic Industries Association/Telecommunications Industry Association 547 (EIA/TIA-547) establishes performance and technical criteria for interfacing and connecting the network channel terminating equipment with various elements of the public telecommunications network (15).

T1.101 specifies the synchronization performance of references passed between networks and the synchronization performance of primary reference sources used to control synchronous networks to ensure that slip performance will be acceptable (6).

T1.408 establishes performance and technical criteria for interfacing and interconnecting the various functional groups in the ISDN primary rate functional reference configuration (106).

With regard to evolving technologies and standards, ANSI Committee T1 (Technical Subcommittee T1E1) is investigating the standardization of new digital subscriber-line technologies that will enable the transmission of DS1 on existing, nonrepeatered copper loops (19,93,94,107–109). Two such technologies are high-rate digital subscriber line (HDSL) and asymmetric digital subscriber line (ADSL).

HDSL is a symmetric capability using two copper pairs without repeaters and is limited to a range of 12,000 feet from the central office. ADSL is an asymmetric capability intended to transport a DS1 (or a DS3) bit stream from the telephone network toward the customer without repeaters, while simultaneously providing a 16-kb/s control channel from the customer to the network. ADSL has a design goal of 18,000 feet on one copper pair for DS1 and somewhat less for DS3 (94). ADSL can coexist with the basic telephone service (or basic rate ISDN) on the same copper pair because the two systems are independent and transparent to each other even though they use the same copper pair.

European Telecommunications Standards Institute

ETSI was founded in March 1988 by the member administrations of the CEPT with the mandate to develop technical specifications for European Telecommunication Standards (ETSs) (98,99). In some instances, ETSs replace CEPT recommendations that were previously in use.

In the area of DS1 standards, the relevant ETSs correspond to CCITT recommendations as indicated in Table 2. The ETSs in Table 2 specify what parts or options of the CCITT recommendations are normative, informative or not relevant, and may specify other modifications as appropriate (110–114).

ETSI has a comprehensive plan for the development of standards for Open Network Provision (ONP) of leased lines (7). ONP refers to the open and efficient access to public telecommunications networks and, where applicable, public telecommunications services and the efficient use of those networks and services. The first phase of the study assessed the situation and concluded that the currently available standards do not cover the requirements for ONP leased lines adequately. For example, work will be required to supplement ETS 300 166, which in itself does not provide a complete interface specification. Hence, a detailed plan for the development of the necessary standards has been developed (7).

Telecommunication Technology Committee (Japan)

In Japan, the TTC was established on October 25, 1985, with the mandate to develop standards related to the interconnection of telecommunications networks (100). In the area of DS1 standards, TTC standards correspond to CCITT recommendations as indicated in Table 2. The differences between them are summarized in Ref. 100.

Summary

This article provides a technical overview of DS1, including a description of services, applications, and relevant standards. DS1 is one of the two primary building blocks for digital hierarchies. In terms of bandwidth capabilities, DS1 is proving to be a stepping stone in the evolution of digital networks. Indeed, while it began for grouping 64-kb/s channels into a single transmission system, and that is how it was devised originally, it then became a suitable mode of transmission for high-quality audio, video, and multimedia information services in its own right. It is expected that DS1 services will stimulate the demand for broadband services within ISDN.

In terms of functionality, DS1 services and applications have evolved from dedicated lines, through private DS1 networks managed by end users, including FDS1, to fully dialable switched services providing clear-channel flexible bandwidth allocation between 64 kb/s and 1536 kb/s on demand.

It is expected that higher and higher digital access rates will be used as new applications and services are developed. The power of personal computers in general, and more specifically multimedia desktop communications in the workplace and intelligent video in the home, including music, compact disk interactive (CDI), video on demand, and so on, will see a growth of DS1 services and eventually even higher bit rates. Standards, both existing and under development, will be a key enabler for the orderly mass-market introduction of DS1 and subsequent developments.

It is now possible to deliver DS1 and FDS1 services to every desk and to every home. Even with B-ISDN, which will provide access capabilities up to 155 Mb/s, DS1 will continue to play an important role. The relative price/performance of the various technologies and the driving need for services from the user's point of view will determine the competitive technologies. In the meantime, DS1 provides at least a good stepping stone toward the higher bit rates. Eventually, B-ISDN will phase out DS1 services at some point in the future; however, only time will tell what will be the relative significance of DS1 in years to come and the role it will play in the introduction of broadband networks.

List of Acronyms

ADPCM	adaptive pulse code modulation
ADSL	asymmetric digital subscriber line
AMI	alternate mark inversion
ANS	American National Standard
ANSI	American National Standards Institute
B-ISDN	Broadband ISDN
B8ZS	bipolar 8-zero substitution
CATV	community antenna television
CCIR	International Radio Consultative Committee
CCITT	International Telegraph and Telephone Consultative Committee
CD-ROM	compact disk read-only memory
CDI	compact disk interactive
CEPT	European Conference of Postal and Telecommunications Administrations
CPE	customer premises equipment
CRC	cyclic redundancy check
DC	direct current
DL	data link
DS1	Digital Signal Level 1
EMC	electromagnetic compatibility
ESF	extended superframe
ETS	European Telecommunication Standard
ETSI	European Telecommunications Standards Institute
FDS1	fractional DS1
HDB3	high-density bipolar of order 3
HDSL	high-rate digital subscriber line
IEC	International Electrotechnical Commission
ISDN	Integrated Services Digital Network

ISO	International Organization for Standardization
ITU	International Telecommunication Union
JTC1	Joint Technical Committee 1
LAN	local-area network
NTT	Nippon Telegraph and Telephone
ONP	Open Network Provision
PCM	pulse code modulation
PRA	Primary Rate Access
SDH	synchronous digital hierarchy
SF	superframe
STS	Synchronous Transport Signal
TTC	Telecommunication Technology Committee
ZBTSI	zero-byte time-slot interchanger

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