计算机网络

8. LONG-DISTANCE DIGITAL CONNECTION

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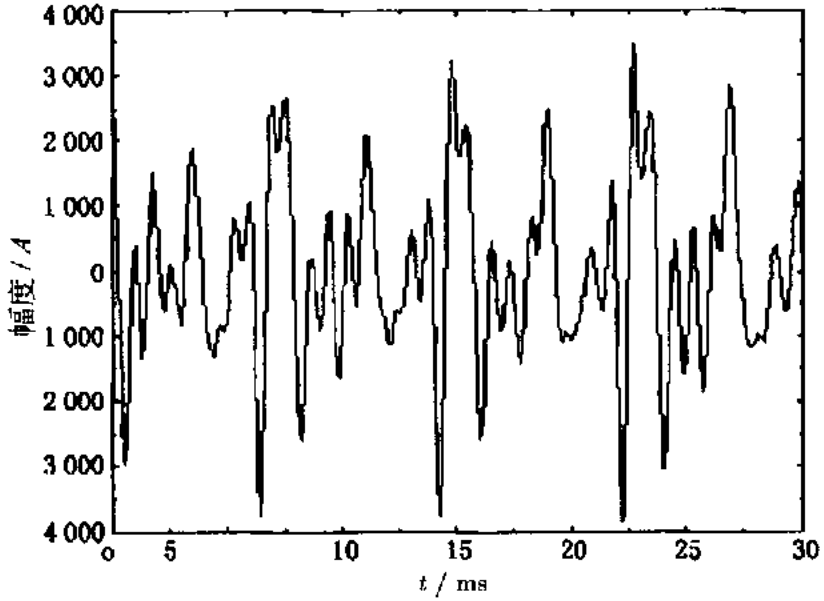
PART II Packet Transmission

Ch 12 Long-Distance Digital Connection Technologies

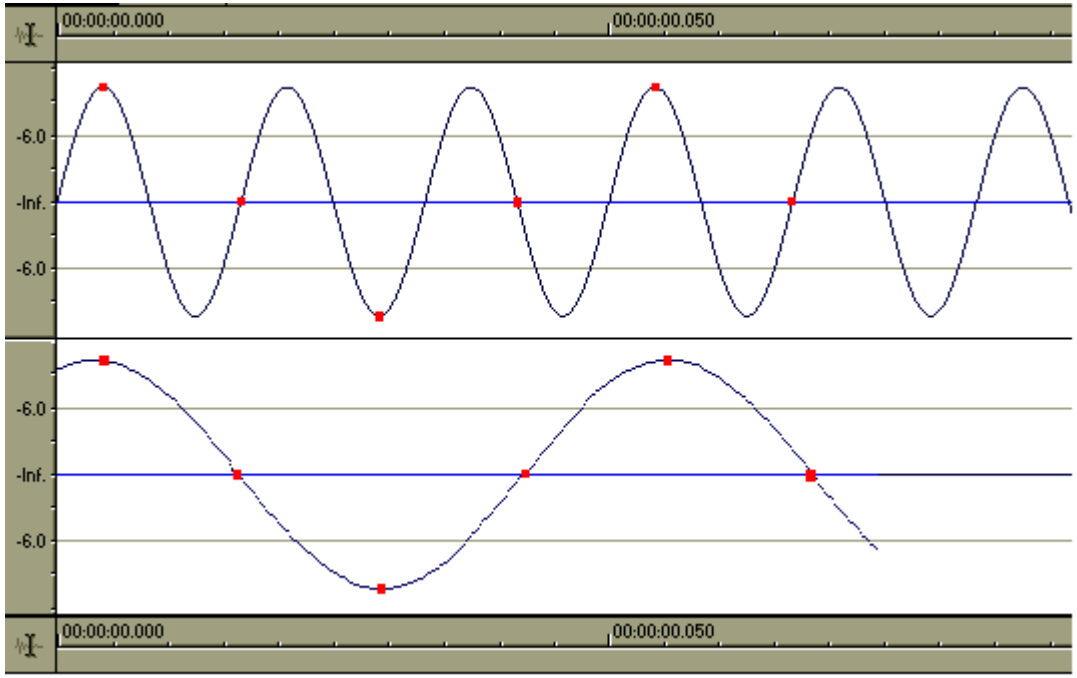
远程数字连接技术

12.2 Digital Telephony 数字电话

- **The motivation for studying digital communication**
  - **Digital communication avoids the problem of noise.**
- **Digital audio: the digital version of an analog audio signal.**
  - **The process of converting an analog signal to digital form is called digitization (数字化).**



Sampling Rate (采样频率)



Pulse Code Modulation (PCM)

- Nyquist's sampling theorem (采样定理) states that
  - if a continuous signal is sampled at a rate greater than twice the highest significant frequency, the original signal can be reconstructed from the samples (样本).
- The tradeoff is between accuracy and data size.
- Pulse Code Modulation (PCM)
  - PCM samples a signal once every 125 μs (微秒) and converts each sample into a integer between 0 and 255.

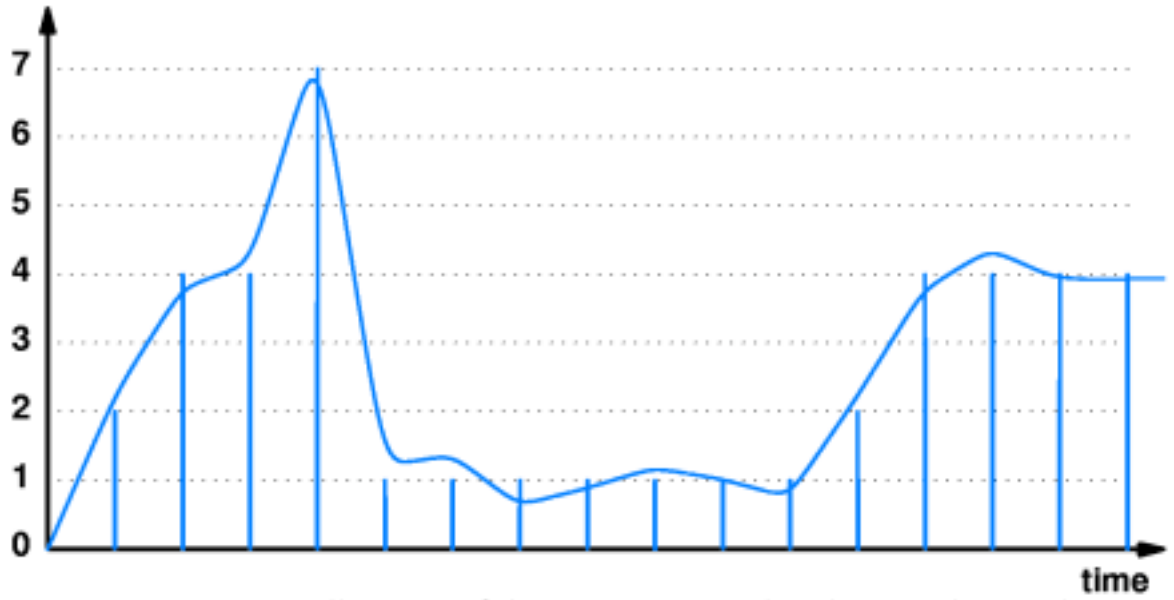


Figure 12.1 An illustration of digitization using eight values. Each vertical line represents an integer value chosen for one sample.

12.3 Synchronous Communication 同步通信

- **The facilities used for digitized voice and data**
  - **Voice systems use synchronous or clocked technology.**
  - **Most data networks use asynchronous technology.**
- **A synchronous network consists of a system designed to move data at a precise rate.**
  - **The telephone system is carefully designed to transmit additional information along with the digitized data and to ensure continuous transmission.**
  - **Receiving equipment uses the additional information to synchronize its clock and ensure that data leaves the network at exactly the same rate as it entered.**

12.4 Digital Circuits and DSU/CSUs

- **Digital circuits leased from common carriers.**
- **The standards for telephone system digital circuits differ from those used in the computer industry.**
- **DSU: Data Service Unit; CSU: Channel Service Unit.**

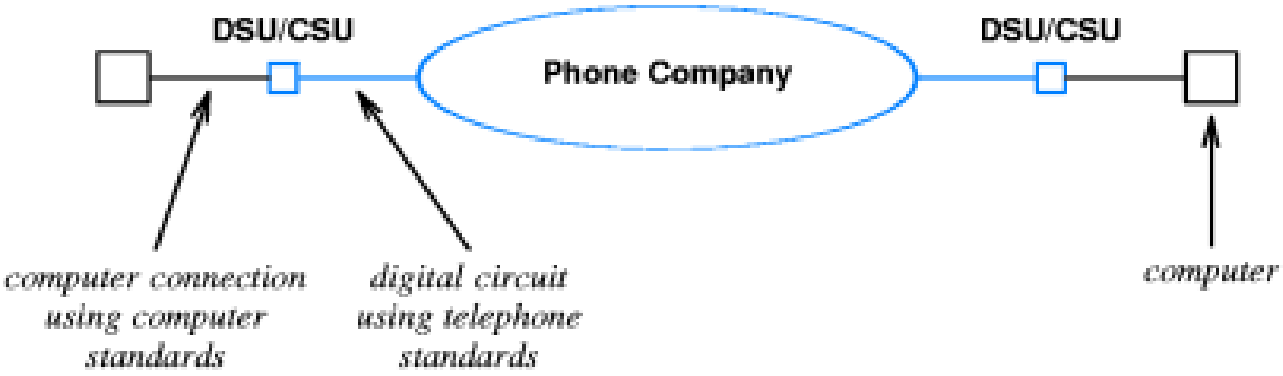


Figure 12.2 Illustration of a digital circuit with a DSU/CSU on each end. The DSU/CSU converts between the digital standards used in the telephone system and those used by computer vendors.

12.17 Circuit Termination, DSU/CSU, and NIU

- To use a leased digital circuit, one must agree to follow the rules of the telephone system
  - including adhering to the standards that were designed for transmitting digitized voice
- Computer industry and the telephone industry developed independently
  - Standards for telephone system digital circuits differ from those used in the computer industry

12.17 Circuit Termination, DSU/CSU, and NIU

- **Computer industry and the telephone industry (*con't*)**
  - **A special piece of hardware is needed to interface a computer to a digital circuit provided by a telephone company**
  - **a Data Service Unit/Channel Service Unit (DSU/CSU)**
    - **Device contains two functional parts, usually combined into a single chassis**
  - **The CSU portion of the DSU/CSU device handles line termination and diagnostics**

12.17 Circuit Termination, DSU/CSU, and NIU

- A CSU also contains a loopback test facility
  - that allows the CSU to transmit a copy of all data that arrives across the circuit back to the sender without further processing
- We need to prevent excessive 1s
  - having too many contiguous 1 bits would mean excessive current on the cable
  - To prevent problems, a CSU can either use
    - an encoding that guarantees a balance (e.g., a differential encoding)
    - or a technique known as bit stuffing

12.17 Circuit Termination, DSU/CSU, and NIU

- The DSU portion of a DSU/CSU handles the data
  - It translates data between the digital format used on the carrier's circuit and the digital format required by the customer's computer
- The interface standard used on the computer side depends on the rate that the circuit operates
  - If the data rate is less than 56 Kbps, the computer can use RS-232
  - For rates above 56 Kbps, the computer must use interface hardware that supports higher speeds (e.g., use RS-449 or V.35 standards)

12.17 Circuit Termination, DSU/CSU, and NIU

- One additional piece of equipment may be used
  - Network Interface Unit (NIU), sometimes as Smartjack
- NIU forms a boundary between equipment owned by the telco and equipment provided by the subscriber
  - The tele. company refers to the boundary as the demarc
- A digital circuit needs a DSU/CSU at each end
  - It translates between the digital representation used by phone companies and the digital representation used by the computer industry

12.2 Internet Access Technology: Upstream and Downstream

- Internet access technology refers to a data communications system that connects an Internet subscriber to an ISP
  - such as a telephone company or cable company
- How is access technology designed?
- Most Internet users follow an asymmetric pattern
  - a subscriber receives more data from the Internet than sending
    - a browser sends a URL that comprises a few bytes
    - in response, a web server sends content

12.2 Internet Access Technology: Upstream and Downstream

- **Downstream** to refer to data traveling from an ISP in the Internet to a subscriber
- **Upstream** to refer to data traveling from a subscriber to an ISP

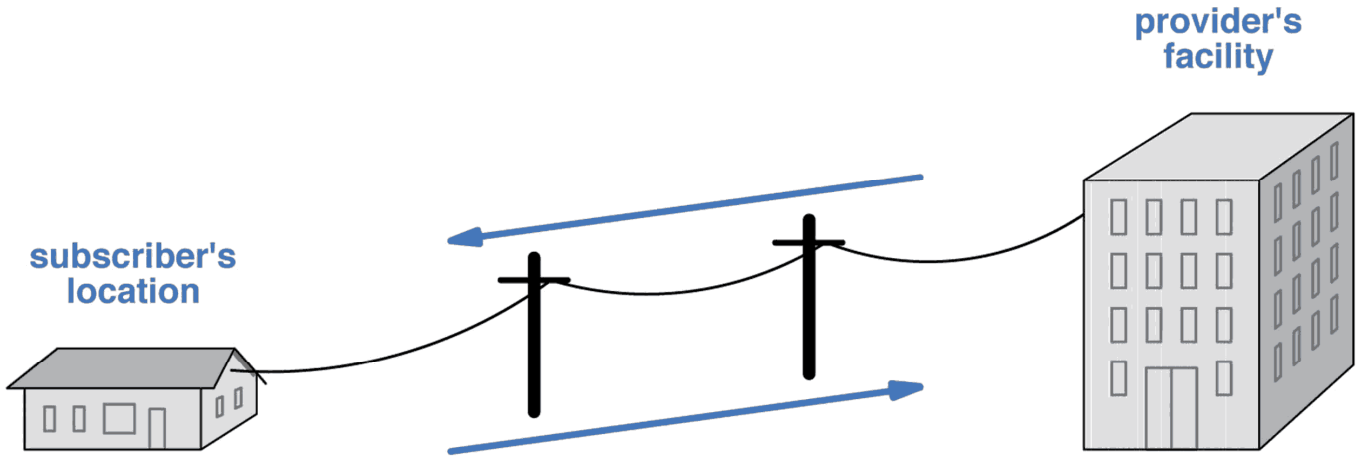


Figure 12.1 Definition of upstream and downstream directions as used in access technologies.

12.3 Narrowband and Broadband Access Technologies

- A variety of technologies are used for Internet access
  - divided into two categories by the data rate they provide
    - In networking terms, network bandwidth refers to data rate
    - The exact boundary between broadband and narrowband is blurry
- Narrowband Technologies: deliver data at <128 Kbps
  - E.g., the maximum data rate for dialup noisy phone lines is 56 Kbps and classified as a narrowband technology
- Broadband Technologies: offer high data rates
  - many suggest that broadband technologies deliver >1 Mbps
  - this isn't always the case, may mean any speed higher than dialup

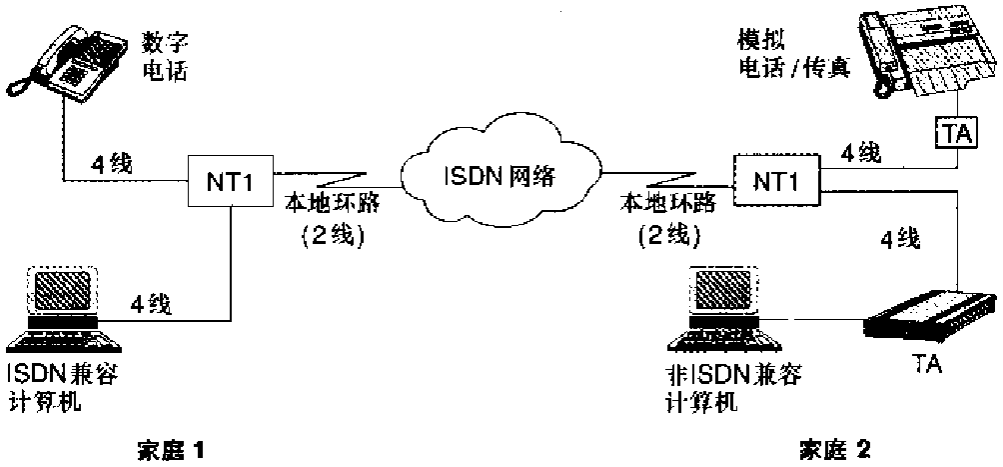
12.3 Narrowband and Broadband Access Technologies

- **The main Narrowband/Broadband access technologies**

Narrowband	Broadband
Dialup telephone connections	DSL technologies
Leased circuit using modems	Cable modem technologies
Fractional T1 data circuits	Wireless access technologies
ISDN and other tel. co. data services	Data circuits at T1 speed or higher

12.4 The Local Loop and ISDN

- **Local loop describes the physical connection between a telephone company Central Office and a subscriber**
  - **consists of twisted pair and dialup call with 4 KHz of bandwidth**
    - **It often has much higher bandwidth; a subscriber close to a CO may be able to handle frequencies above 1 MHz**



12.4 The Local Loop and ISDN

- **Integrated Services Digital Network (ISDN)**
  - ISDN offers three separate digital channels
    - designated B, B, and D (usually written 2B + D)
  - The 2B channels (each 64 Kbps) are intended to carry digitized voice, data, or compressed video
    - Both B channels can be combined or bonded to produce a single channel with an effective data rate of 128 Kbps
  - The D channel (16 Kbps) is used as a control channel
  - Newer local loop technologies provide higher data rates at lower cost, relegating ISDN to a few special cases

12.14 ISDN

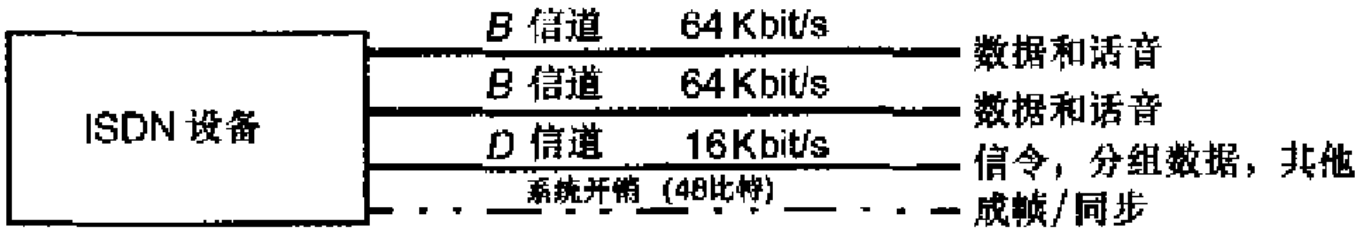


图 12.4 ISDN 的基本速率接口（BRI）是由电话公司提供的 2B+D 的捆绑。BRI 由两个用于传输用户数据或话音（或二者都有）的 64 kbit/s 的 B 信道和一个用于传输信令和控制信息的 16 kbit/s 的 D 信道组成。如果当前没有信令或控制信息，D 信道也可同样用来传输数据。BRI 还包括附加的 48 比特用于成帧和同步

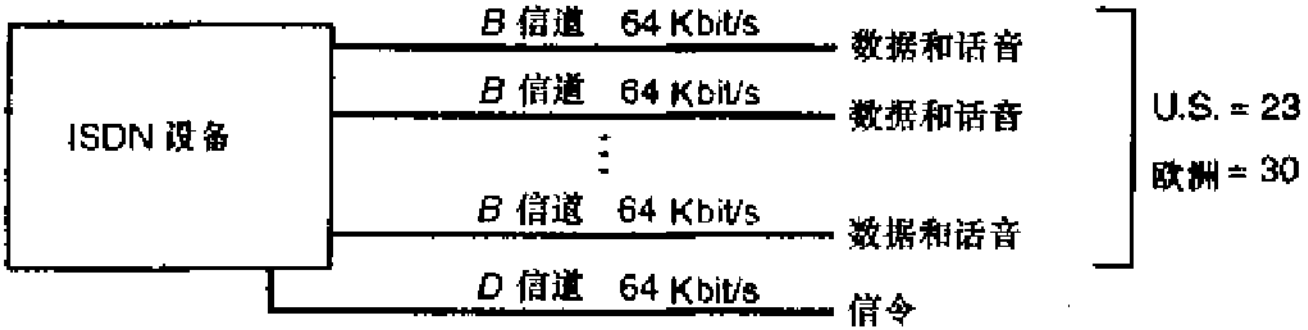


图 12.5 ISDN 的初等速率接口（PRI）以两种方式捆绑，第一种是 23B+D 配置，基于北美的 DS-1 格式，速率是 1.544 Mbit/s。第二种是 30B+2D 配置，基于欧洲的 E-1 格式，速率是 2.048 Mbit/s

ADSL

Asymmetric Digital Subscriber Line

非对称数字用户线路

12.5 Digital Subscriber Line (DSL) Technologies

- **ADSL uses FDM (频分多路复用) to divide the bandwidth of the local loop into three regions**
  - **one of the regions corresponds to traditional analog phone service known as Plain Old Telephone Service (POTS)**
  - **and two regions provide data communication**

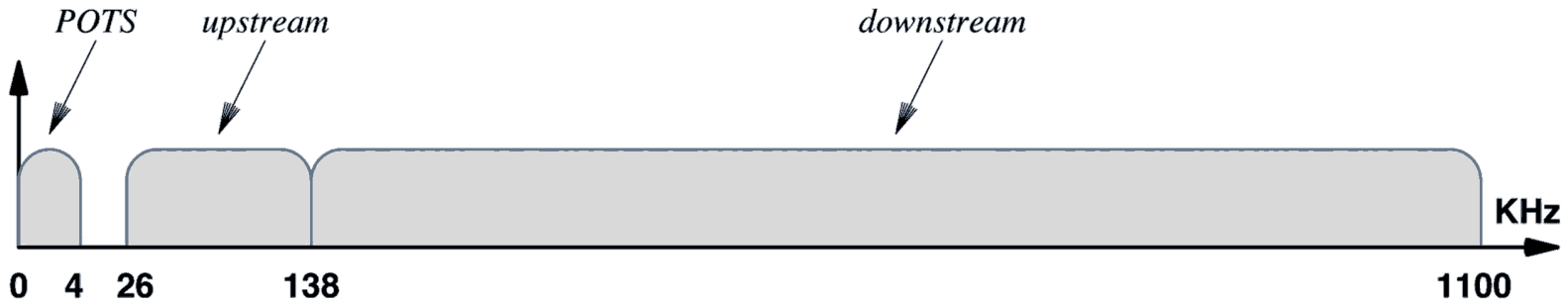


Figure 12.5 An illustration of how ADSL divides the available bandwidth of the local loop.

12.5 Digital Subscriber Line (DSL) Technologies

- **DSL is one of the main tech. used to provide high-speed data communication services over a local loop**
- **Figure 12.4 (below) lists DSL variants**
  - **Because the names differ only in the first word, the set is collectively referred to by the acronym xDSL**

Name	Expansion	General Use
ADSL	Asymmetric DSL	Residential customers
ADSL2	Asymmetric DSL ver 2	Approximately three times faster
SDSL	Symmetric DSL	Businesses that export data
HDSL	High bit rate DSL	Businesses up to 3 miles away
VDSL	Very-high bit rate DSL	Proposed version for 52-Mbps

12.6 Local Loop Characteristics and Adaptation

- ADSL technology is complex
  - because no two local loops have identical electrical characteristics
- ADSL is adaptive
  - That is, when a pair of ADSL modems are powered on, they probe the line between them to find its characteristics
  - agree to communicate using techniques that are optimal for the line

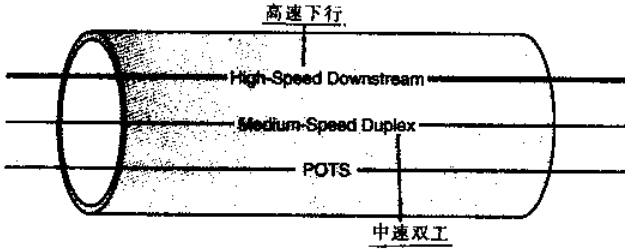


图 14.2 一个 ADSL 三信道管

12.6 Local Loop Characteristics and Adaptation

- ADSL uses Discrete Multi Tone modulation (DMT)
  - that combines frequency division multiplexing and inverse multiplexing techniques
- FDM in DMT is implemented by dividing the bandwidth into 286 separate frequencies(subchannels)
  - 255 sub-channels allocated for downstream data transmission
  - 31 allocated for upstream data transmission
  - 2 upstream channels are reserved for control information

12.6 Local Loop Characteristics and Adaptation

- There is a separate modem running on each sub-channel, which has its own modulated carrier
  - Carriers are spaced at 4.1325 KHz intervals to keep the signals from interfering with one another
- To guarantee that its transmissions do not interfere with analog phone signals
  - ADSL avoids using the bandwidth below 26 KHz
- Two ends assess the signal quality at each frequency

12.15 Asymmetric Digital Subscriber Line Technology

- **ADSL is a local loop technology.**

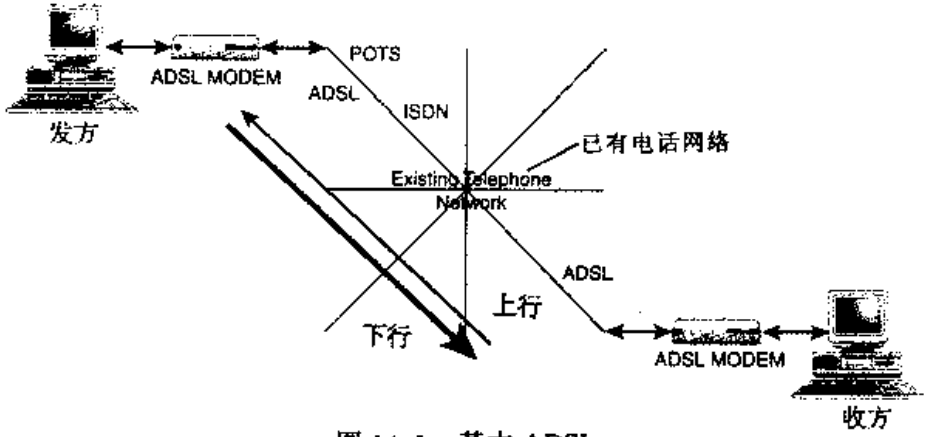


图 14.1 基本 ADSL

- **Other DSL Technologies**

ADSL Modems

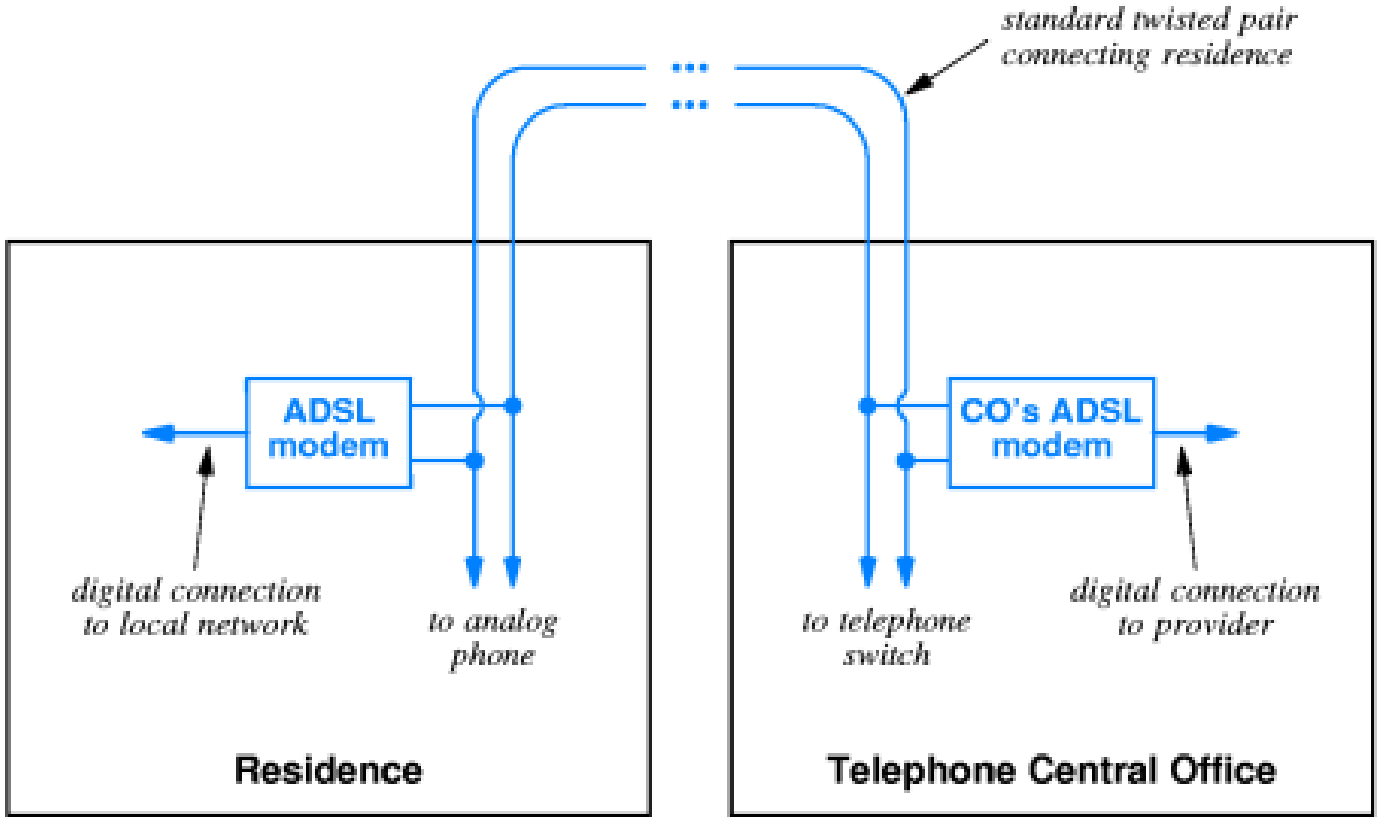


Figure 12.7 ADSL modems connected to existing local loop wiring. The modems can use a pair of wires simultaneously with analog telephone service.

12.7 The Data Rate of ADSL

- How fast can ADSL operate? ADSL can achieve
  - a downstream rate of 8.448 Mbps on short local loops
  - and an upstream rate of 640 Kbps
    - Network control channel requires 64 Kbps
    - The effective upstream rate for user data is 576 Kbps
- ADSL2 can download at close to 20 Mbps

表 14.4 DSL 交叉参考

名称	描述	速率	模式
DSL	数字用户线	192Kbps	双工
HDSL	高数据/位速率 DSL	1.544Mbps 2.048Mbps	双工
SDSL	单数据线 DSL	1.544Mbps 2.048Mbps	双工
ADSL	非对称 DSL	1.5 到 9Mbps 16 到 640Kbps	顺流 逆流
VDSL	超高速 DSL	1.3 到 52Mbps 1.5 到 23Mbps	顺流 逆流

12.7 The Data Rate of ADSL

- ADSL does not guarantee a data rate
  - only guarantee to do as well as line conditions allow
  - Those farther from a CO (or local loop passes near sources of interference) has lower data rates
  - subscribers who live near the CO (or a local loop does not pass near sources of interference) has higher data rates
  - the downstream rate varies from 32 Kbps to 8.448 Mbps
  - the upstream rate varies from 32 to 640 Kbps

12.8 ADSL Installation and Splitters

- Analog phones operate at frequencies below 4 KHz
  - lifting a receiver can generate noise that interferes with DSL signals
- ADSL uses an FDM device known as a splitter
  - It divides the bandwidth by passing low frequencies to one output and high frequencies to another
  - A splitter is passive; it does not require power
  - A splitter is usually installed at the location where the local loop enters a residence or business

12.8 ADSL Installation and Splitters

- A variation of ADSL wiring (DSL-lite)
  - not require a splitter to be installed on the incoming line
  - a subscriber can install DSL by plugging a splitter into a wall jack and plugging a telephone into the splitter

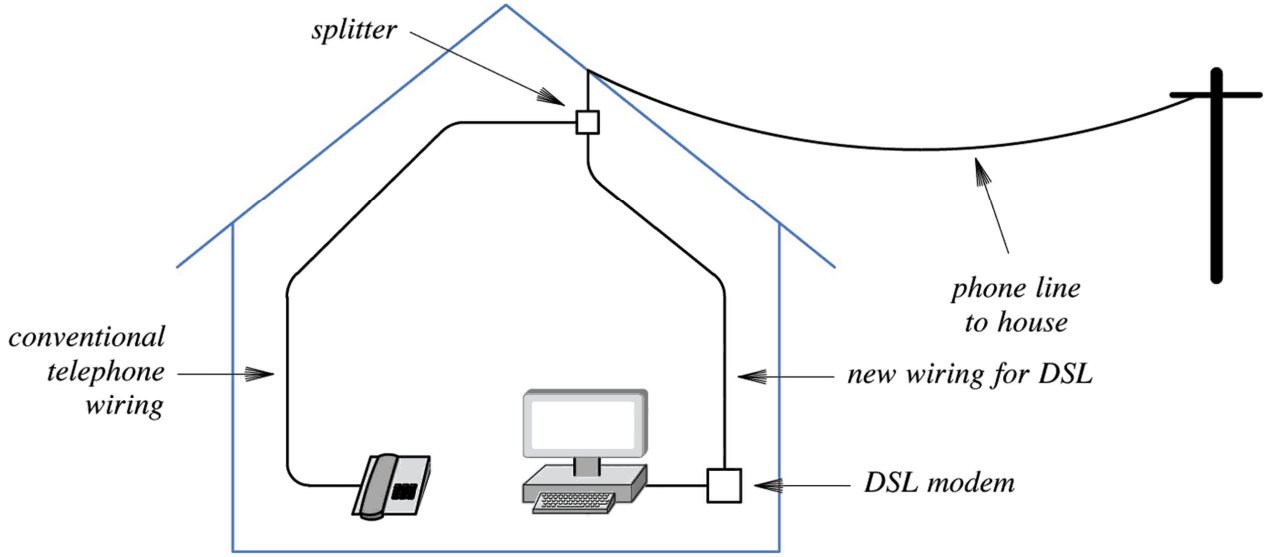


Figure 12.6 Illustration of a splitter and the wiring used with ADSL.

12.9 Cable Modem Technologies

- **Community Antenna TeleVision (CATV)**
  - A variety of wireless and wired technologies have been developed for use in the local loop
  - An alternative access technology that uses the wiring already in place for cable television
- It uses FDM to deliver TV signals over coaxial cable
  - CATV is not available in all countries

12.9 Cable Modem Technologies

- Coaxial cable has high bandwidth and is less susceptible to electromagnetic interference than twisted pair
- CATV systems use FDM to deliver many channels
  - In CATV the bandwidth is insufficient to handle a FDM scheme that extends a channel to each user
  - Using a separate channel per subscriber does not scale

12.10 The Data Rate of Cable Modems

- How fast can a cable modem operate?
  - In theory, a cable system can support data rates of 52 Mbps downstream and 512 Kbps upstream.
- In practice, the rate can be much less
- The data rate of a cable modem only pertains to communication between the local cable office and the subscriber's site

12.10 The Data Rate of Cable Modems

- The bandwidth is shared among a set of *N* subscribers (the size of the set is controlled by the cable provider)
  - sharing the bandwidth with other subscribers can be a disadvantage
    - because the effective data rate available to each individual subscriber varies over time
  - if *N* subscribers share a single frequency, the amount of capacity available to an individual subscriber will be 1/*N*

12.11 Cable Modem Installation

- Cable modem installation is straightforward
- Cable modems attach to the cable wiring directly
- The FDM hardware in existing cable boxes and cable modems guarantees that data and entertainment channels will not interfere with one another

12.12 Hybrid Fiber Coax (HFC)

- HFC can provide high-speed data communications
  - a HFC system uses a combination of optical fibers and coaxial cables
  - fiber used for the central facilities and coax used for connections to individual subscribers
- An HFC system is hierarchical
  - It uses fiber optics for the portions that require the highest bandwidth
  - and it uses coax for parts that can tolerate lower data rates

12.12 Hybrid Fiber Coax (HFC)

- **Trunk** to refer to the high-capacity connections between the cable office and each neighborhood area
- **Feeder circuit** to refer to the connection to an individual subscriber
  - Trunk connections can be up to 15 miles long
  - Feeder circuits are usually less than a mile

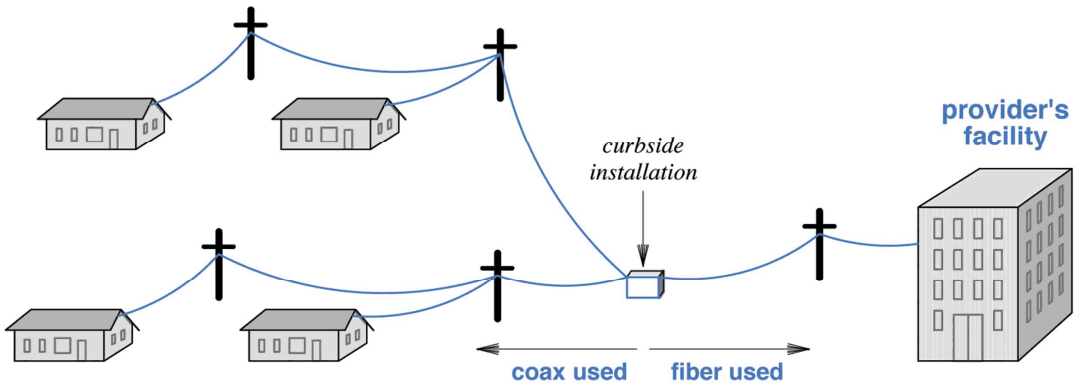


Figure 12.7 Illustration of a Hybrid Fiber Coax access system.

12.13 Access Technologies That Employ Optical Fiber

- There are available a variety of technologies that either employ optical fiber in a hybrid system or deploy optical fiber all the way to each subscriber
- Figure 12.8 summarizes names of key technologies

Name	Expansion	
FTTC	Fiber To The Curb	到小区边界外
FTTB	Fiber To The Building	允许高上行
FTTH	Fiber To The Home	更高上行，视频信道
FTTP	Fiber To The Premises	FTTB和FTTH的通称

12.14 Head-End and Tail-End Modem Terminology

- An access technology requires a pair of modems
  - with one at the subscriber's site, one at the provider's site
- Head-end modem to refer to a modem used at the CO
  - not individual devices
  - A set of head-end modems used by a cable provider is known as a Cable Modem Termination System (CMTS)
- Tail-end modem: a modem used at the subscriber
- Data Over Cable System Interface Spec. (DOCSIS)
  - specifies both the format of data that can be sent as well as the messages that are used to request services (e.g., pay-per-view)

12.15 Wireless Access Technologies

- How to provide access in rural areas?
  - Imagine a farm or remote village many miles from the nearest city
  - The twisted pair wiring used to deliver telephone service to such locations exceeds the maximum distance for technologies like ADSL
  - Rural areas are least likely to have cable television service

12.15 Wireless Access Technologies

- Even in suburban areas, tech. like ADSL may have technical restrictions on the type of line they can use
  - it may be impossible to use high frequencies on telephone lines that contain loading coils, bridge taps, or repeaters
- Local loop technology may not work on all lines
  - To handle special cases, a variety of wireless access technologies have been explored

Technology	Description
3G services	Third generation cellular telephone services for data (e.g., EVDO)
WIMAX	Wireless access technology up to 155 Mbps using radio frequencies
Satellite	Various commercial vendors offer data services over satellite

12.16 High-Capacity Connections at the Internet Core

- Access technologies handle the last mile problem
  - where the last mile is defined as the connection to a typical residential subscriber or a small business
- Small Office Home Office (SOHO)
  - An access technology provides sufficient capacity for a residential subscriber or a small business
- Connections to large businesses or connections among providers require substantially more bandwidth
- Core refers to connections at the backbone of Internet
- Core technologies refers to high-speed technologies

12.16 High-Capacity Connections at the Internet Core

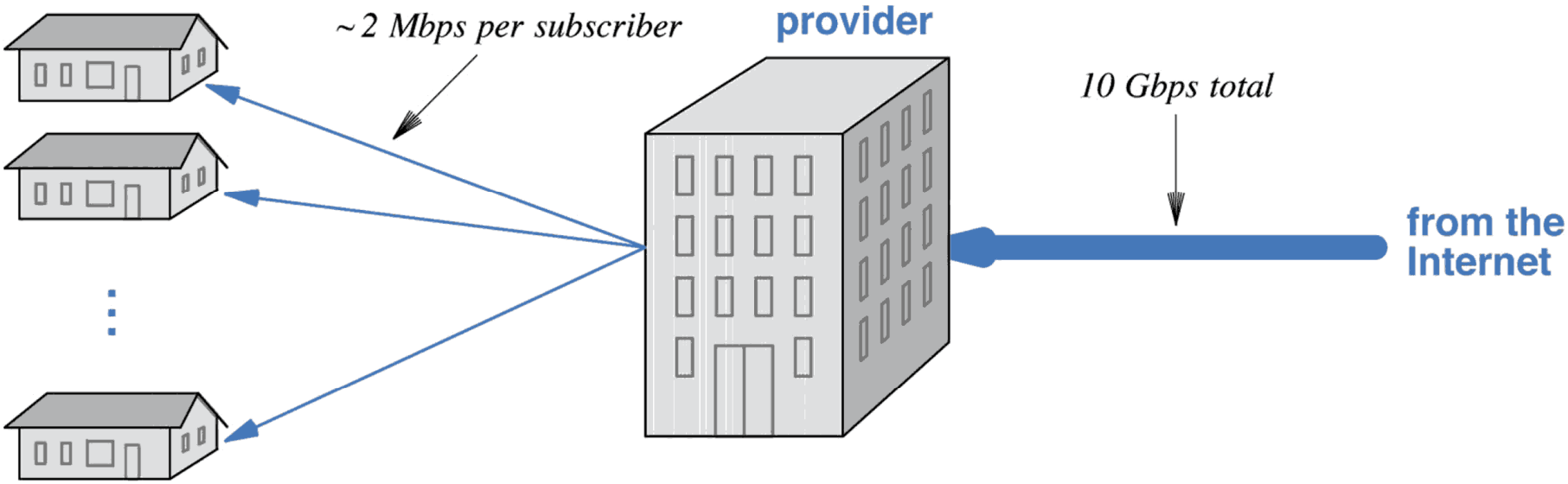


Figure 12.10 Aggregate traffic from the Internet to a provider assuming the provider has 5,000 customers each downloading 2 Mbps.

12.16 High-Capacity Connections at the Internet Core

- What technology can a provider use to move data a long distance at a rate of 10 Gbps?
  - The answer lies in a point-to-point digital circuit leased from a telephone company
  - High-capacity digital circuits are available for a monthly fee, and can be used to transfer data
- Telephone companies have the authority to install wiring that crosses municipal streets
- A circuit can extend between two buildings, across a city, or from a location in one city to a loc. in another
  - The fee charged depends on the data rate of the circuit and the distance spanned

12.18 Telephone Standards for Digital Circuits

- A digital circuit leased from a telco follows the same digital transmission standards that the telco uses to transport digital phone calls
- In the USA, standards for digital telephone circuits were given names that consist of the letter T followed by a number
  - One of the most popular is known as T1
  - Many small businesses use a T1 circuit to carry data

12.18 Telephone Standards for Digital Circuits

- T-standards are not universal
  - Japan adopted a modified version of the T-series standards
  - Europe chose a slightly different scheme; it uses the letter E

Name	Bit Rate	Voice Circuits	Location
basic rate	0.064 Mbps	1	
T1	1.544 Mbps	24	North America
T2	6.312 Mbps	96	North America
T3	44.736 Mbps	672	North America
E1	2.048 Mbps	30	Europe
E2	8.448 Mbps	120	Europe
E3	34.368 Mbps	480	Europe

12.19 DS Terminology and Data Rates

- **The data rates of T standards have been chosen so they can each handle multiple voice calls**
  - **Capacity of circuits doesn't increase linearly with numbers**
    - **E.g., the T3 standard defines a circuit with much more than three times the capacity of T1**

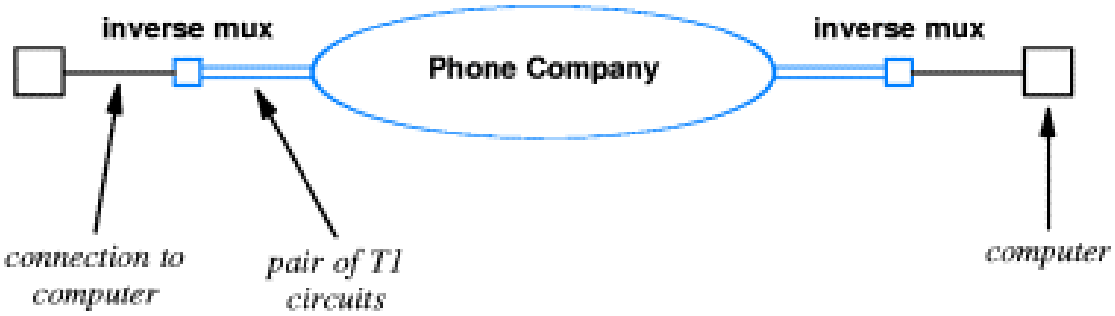


Figure 12.4 An inverse mux using two T1 circuits to provide a connection with twice the capacity. Inverse multiplexing is attractive economically for intermediate capacities because two T1 circuits are much less expensive than a T3 circuit.

12.19 DS Terminology and Data Rates

- Telcos may lease circuits with lower capacity than those listed in the figure
  - they are known as fractional T1 circuits
- Digital Signal Level (DS) standards
  - To multiplex multiple phone calls onto a single connection
    - For example, DS1 denotes a service that can multiplex 24 phone calls onto a single circuit
  - DS-n表示一个标准，而T-n表示符合一定标准的电路

12.20 Highest Capacity Circuits (STS Standards)

- Telephone companies use trunk to denote a high-capacity circuit, and have created a series of standards for digital trunk circuits
- Synchronous Transport Signal (STS) standards specify the details of high-speed connections

Copper Name	Optical Name	Bit Rate	Voice Circuits
STS-1	OC-1	51.840 Mbps	810
STS-3	OC-3	155.520 Mbps	2430
STS-12	OC-12	622.080 Mbps	9720
STS-24	OC-24	1,244.160 Mbps	19440
STS-48	OC-48	2,488.320 Mbps	38880
STS-192	OC-192	9,953.280 Mbps	155520

12.21 Optical Carrier Standards

- Telcos define an equivalent set of Optical Carrier (OC) standards
  - Fig. 12.12 gives the names for optical standards as well as for copper standards
- One should observe a distinction between the STS and OC terminology:
  - the STS standards refer to the electrical signals used in the digital circuit interface (i.e., over copper)
  - the OC standards refer to the optical signals that propagate across the fiber

12.22 The C Suffix

- The STC and OC terminology described above has one additional feature not shown in Figure 12.12
  - an optional suffix of the letter C, which stands for concatenated
- The suffix denotes a circuit with no inverse multiplexing
  - an OC-3 circuit can consist of three OC-1 circuits operating at 51.840 Mbps each
  - or it can consist of a single OC-3C (STS-3C) circuit that operates at 155.520 Mbps

12.22 The C Suffix

- **Is a single circuit operating at full speed better than multiple circuits operating at lower rates?**
  - **The answer depends on how the circuit is being used**
- **In general, having a single circuit operating at full capacity provides more flexibility**
  - **and eliminates the need for inverse multiplexing equipment**

12.23 Synchronous Optical NETwork (SONET)

- The phone companies have defined a broad set of standards for digital transmission.
- Telcos defined a broad set of standards for digital transmission
  - In North America: SONET
  - In Europe: Synchronous Digital Hierarchy (SDH)
- SONET specifies some details, such as
  - how data is framed
  - how lower-capacity circuits are multiplexed into a high-capacity circuit
  - how synchronous clock information is sent along with data

12.23 Synchronous Optical NETwork (SONET)

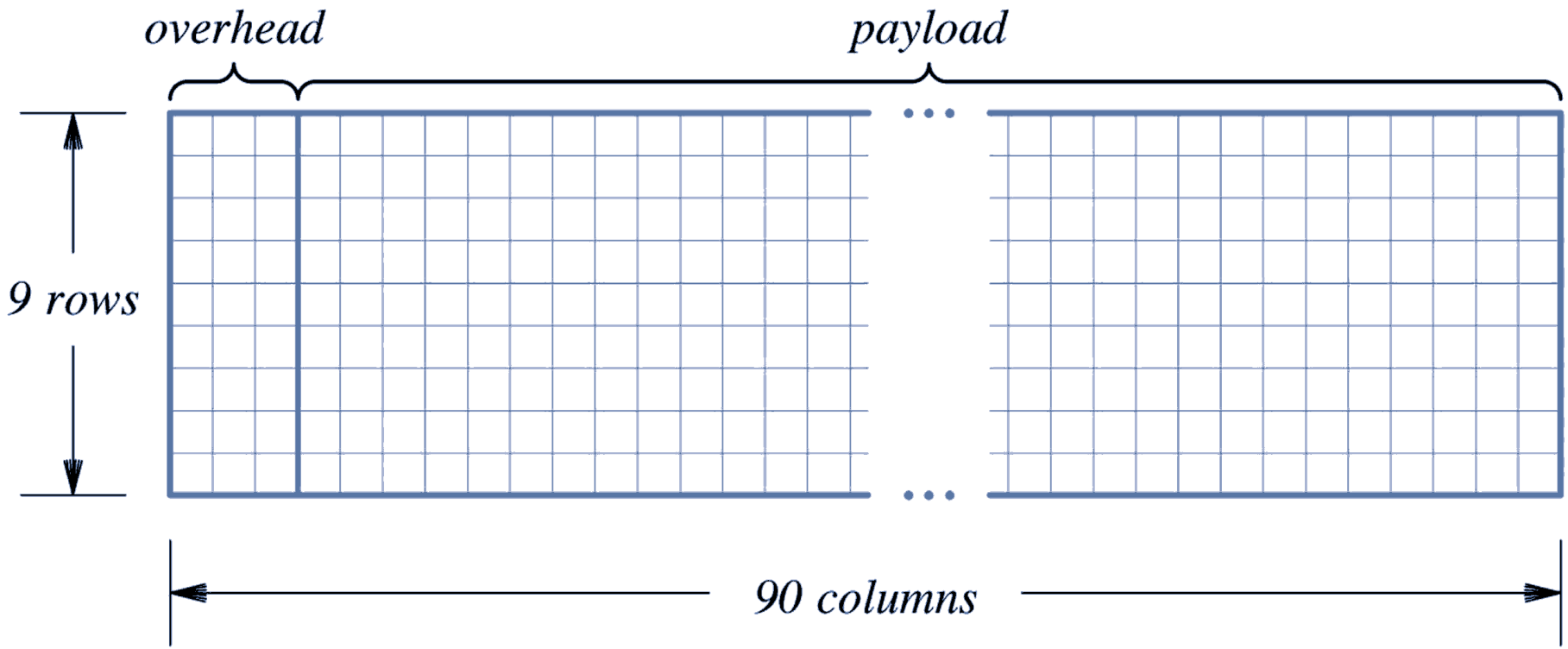


Figure 12.13 Illustration of a SONET frame when used over an STS-1 circuit.

PART II Packet Transmission

Ch 19 Networking Technologies Past And Present

网络技术过去与现在

13.17 Example WAN Technologies

- ARPANET
- 公用电话交换网PSTN
- 公用分组交换网X.25
- Frame Relay (帧中继)
- SMDS (交换多兆位数据服务 Switched Multi-megabit Data Service)
- ATM异步传输模式 (Asynchronous Transfer Mode)

广域网结构

- 4.1 广域网结构
  - 虚电路和数据报
    - 虚电路：面向连接，类似电话系统
    - 数据报：无连接，类似电报系统
  - 两者比较
- 4.2 广域网实例

虚电路方式

- 原理
  - 建立虚电路 —填表
  - 数据转发—查表
  - 释放虚电路—删表
- 特点
  - 存在虚电路建立过程
  - 数据转发沿着同一条路径
  - 报文的投递可靠
  - 报文中不需要目的地址，只需要虚电路号
  - 虚电路必需进行释放

数据报方式

- 原理
  - 路由器为每个入站的报文单独选择一条输出线路
- 特点
  - 不需要虚电路建立过程
  - 路由器必须为每个输入报文单独进行路由选择
  - 报文投递是不可靠的
  - 每个报文必须包含目的地址

两者比较（1）

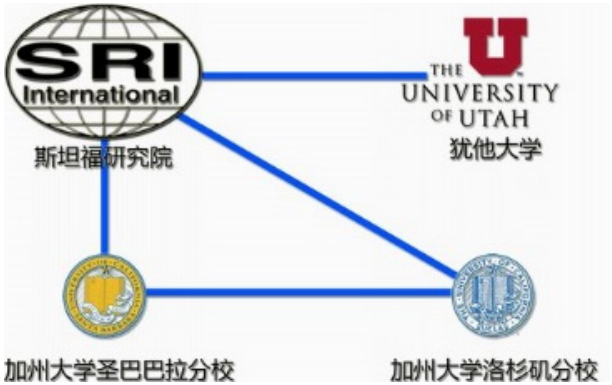
- 从广域网内部来看
  - 交换机的内存空间与线路带宽的权衡
  - 虚电路建立时间和路由选择时间的比较
  - 拥塞控制的难易程度
- 从提供用户服务的角度来看
  - “虚电路派” — “跳到跳”(hop-by-hop) 控制
  - “数据报派” — “端到端”(end-to-end) 控制

两者比较（2）

项目	数据包	虚电路
电路建立	不需要	需要
地址	每个报文都必须有完整的源和目的地址	每个报文只需要一个虚电路号
状态信息	子网不存储状态信息	每条虚电路都要占用子网的表空间
路由选择	每个报文单独进行	在建立虚电路时进行路由选择
路由器失效的影响	除在崩溃时丢失路由器中的报文，对其它的报文没有影响	所有经过失效路由器的虚电路都要被中止
拥塞控制	难	容易

13.17.1 ARPANET

- ARPANET (1969-1990)
  - the network was one of the first packet switched WANs
  - ARPA (Advanced Research Projects Agency美国国防部高级研究计划署)
  - Initially 4 sites
  - leased serial data lines; only 56Kbps
  - Born: 1969; Obsolete: 1990



4.2.1 PSTN

- **PSTN (1876-Now)**
  - **Public Switched Telephone Network，公共交换电话网**
  - **目前世界上最大的网络，拥有用户数量大约是8亿**
  - **以电路交换技术为基础；传输模拟话音的通信网络。**
  - **组成**
    - **本地回路：模拟线路；干线：数字化；电话交换机：数字化程控**
  - **两台计算机想通过PSTN进行通信时，必须引入Modem**

13.17.2 X.25

- X.25 (1976-Now)
  - The standard is still known as the CCITT X.25 standard.
    - CCITT国际电话电报咨询委员会(Consultative Committee for International Telephone and Telegraph)
  - X.25是关于数据终端设备DTE和数据电路设备DCE之间的接口
    - X.25建议：一个DTE如何连接到有关分组交换网上

- **Each X.25 network consists of two or more X.25 packet switches interconnected by leased lines.**
- **Computer connected to the packet switches can send and receive packets.**
- **X.25 was invented before personal computers became popular.**
- **many early X.25 networks were engineered to connect ASCII terminals to remote timesharing computers.**

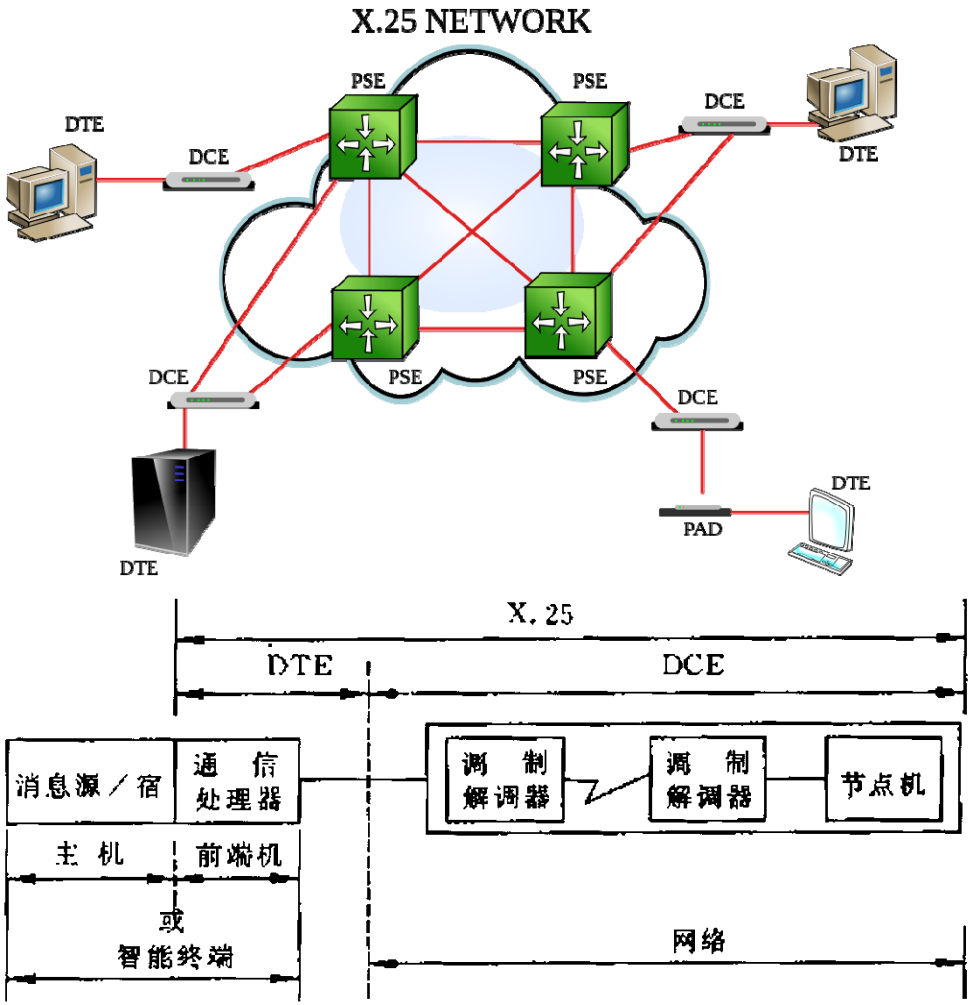


图 15.12 X.25 环境下的 DTE 与 DCE

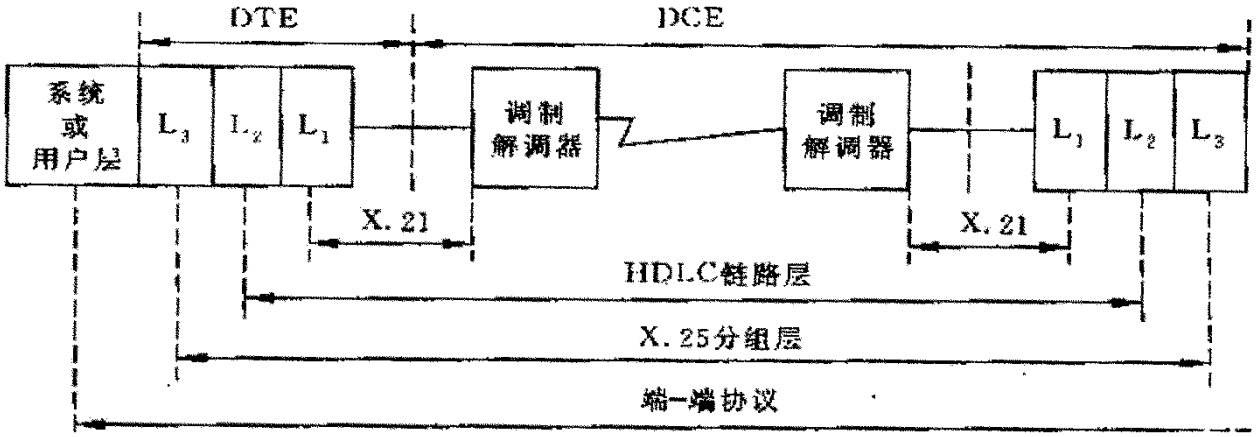
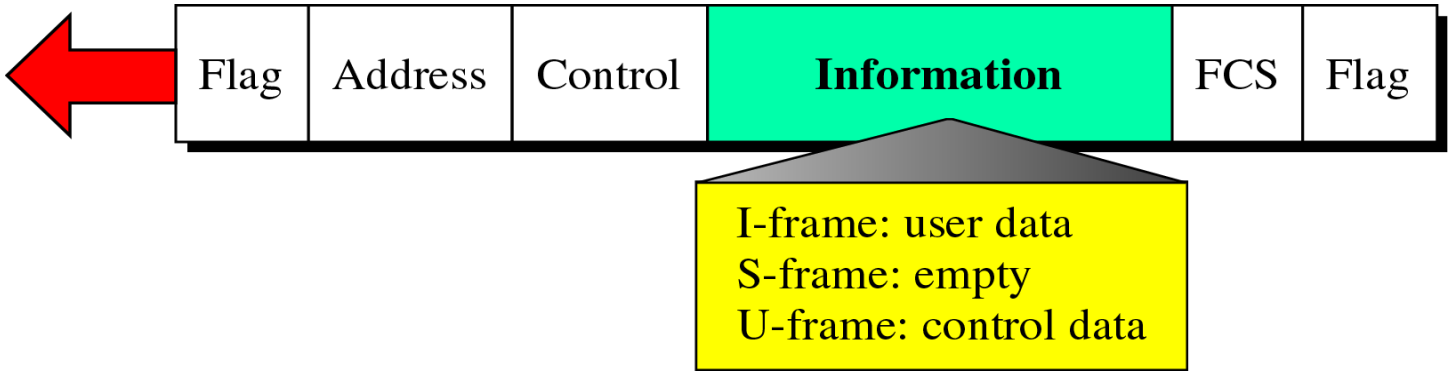
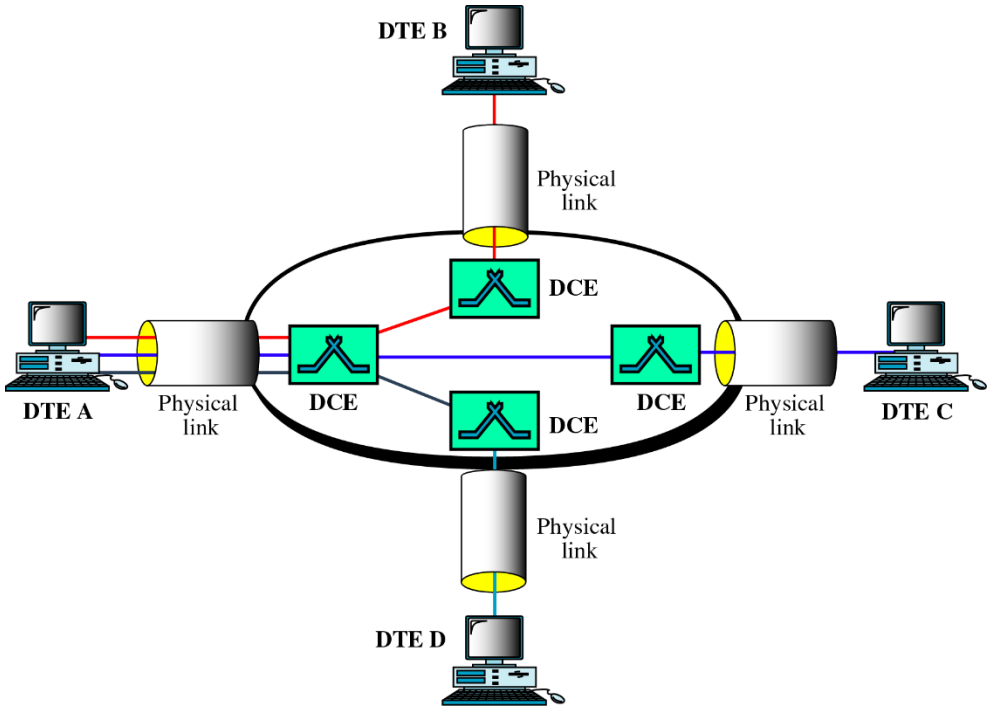


图 15.13 DTE/DCE 接口的协议层次



X.25的特点

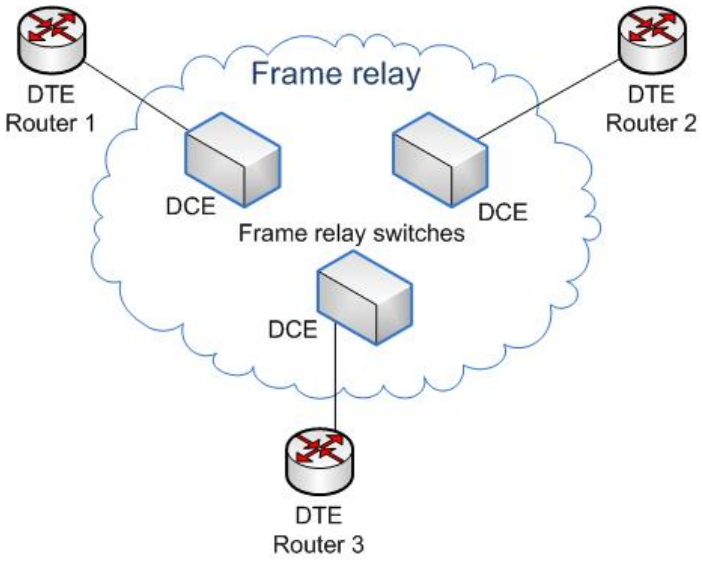
- X.25是面向连接的，它支持交换虚电路服务
  - 交换虚电路SVC
  - 永久虚电路PVC
- X.25提供差错控制
- X.25提供流量控制

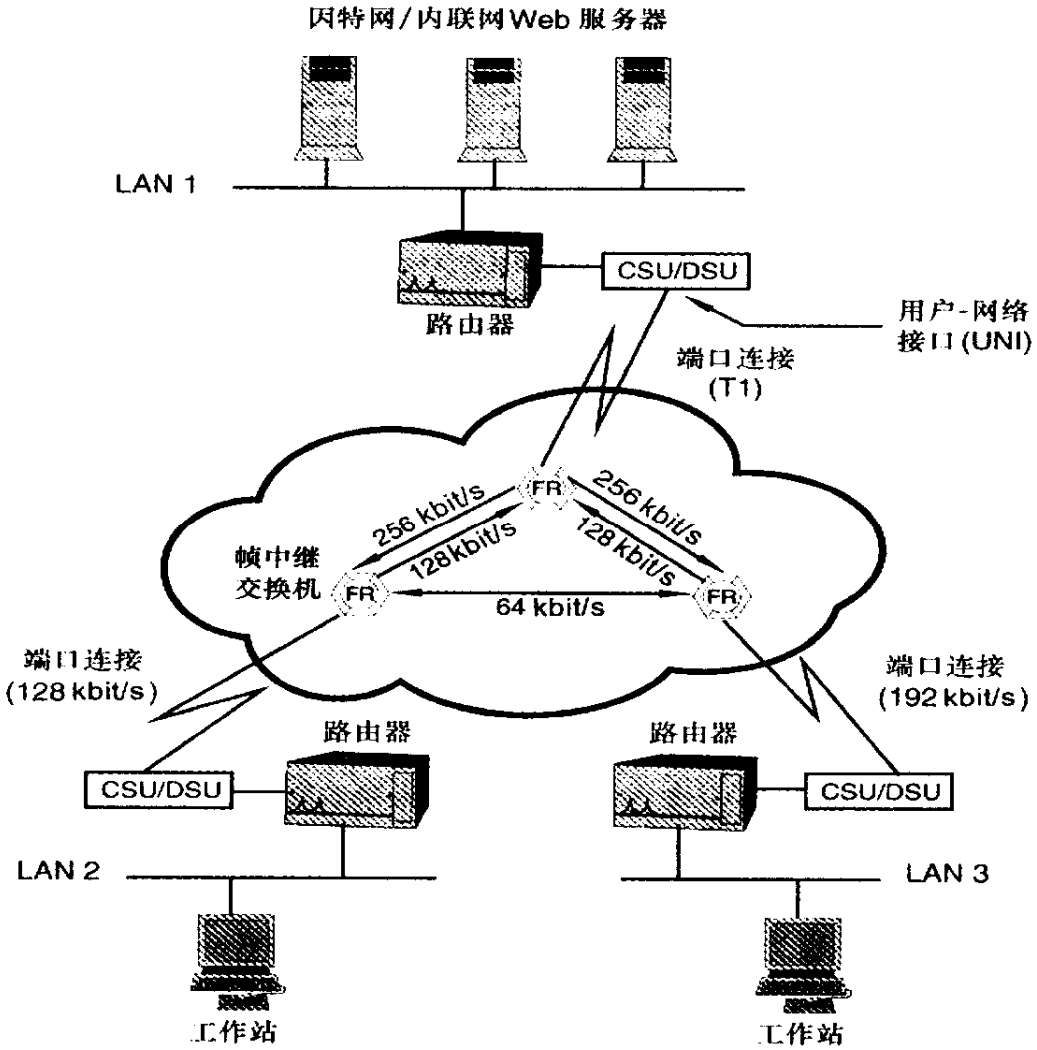


13.17.3 Frame Relay

- **Frame Relay (1972-Now) 帧中继**
  - **The inventors designed Frame Relay service for use in bridging LAN segments**
  - **Frame Relay is designed to accept and deliver blocks of data**
  - **Each block can contain up to 8KB of data.**
  - **To handle data from a LAN segment, a Frame Relay connection must operate at high data rates (in practice, 1.5Mbps or 56Kbps).**

FR


Frame relay
DTE
Router 1
DTE
Router 2
DCE
DCE
Frame relay switches
DCE
DTE
Router 3


因特网/内联网Web 服务器
LAN 1
CSU/DSU
路由器
用户-网络
接口(UNI)
端口连接
(T1)
帧中继
交换机
FR
256 kbit/s
128kbit/s
256 kbit/s
128 kbit/s
64 kbit/s
端口连接
(128 kbit/s)
端口连接
(192 kbit/s)
路由器
路由器
CSU/DSU
CSU/DSU
LAN 2
LAN 3
工作站
工作站

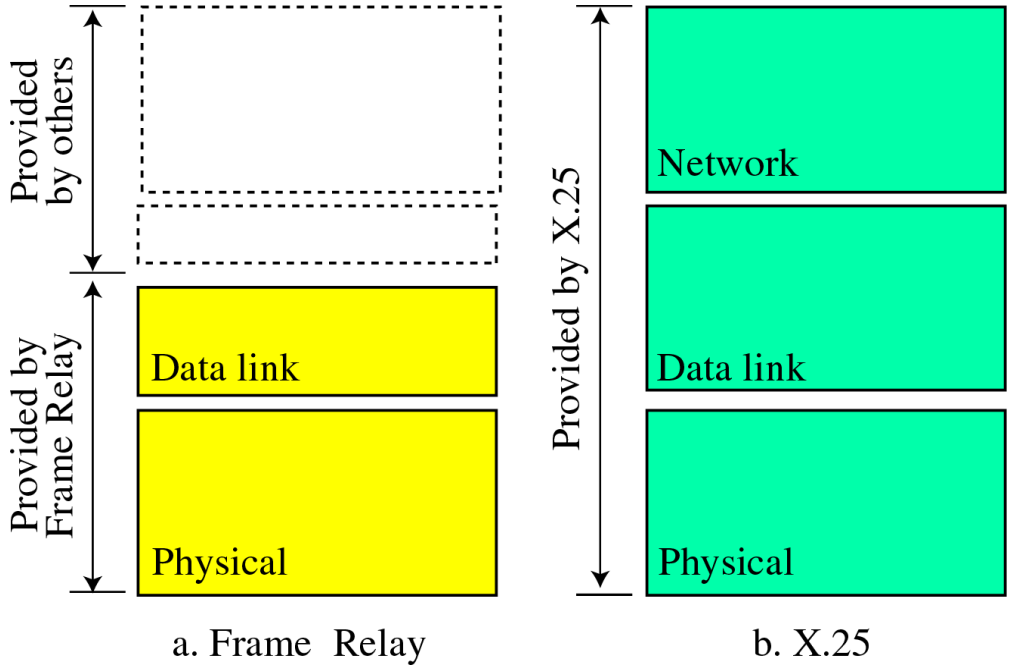
X.25与FR的比较

	X.25	FR
传输线路	slow, analog, unreliable	fast, digital, reliable
计算机	slow, expensive	fast, inexpensive
简易	X.25协议复杂，网络保证数据传输的可靠性，而端用户对传输数据的处理相对简单	FR协议比较简单，但网络不保证数据传输的可靠性，端用户对传输数据的处理相对复杂
智能程度	Intelligent Network / Stupid Terminal	Stupid Network / Intelligent Terminal

性质	X.25	FR
连接建立	在网络层	无
逐跳的流量和差错控制	在数据链路层	无
端到端的流量和差错控制	在网络层	无
数据传输率	固定	可变
多路复用	在网络层	在数据链路层
拥塞控制	不需要	需要

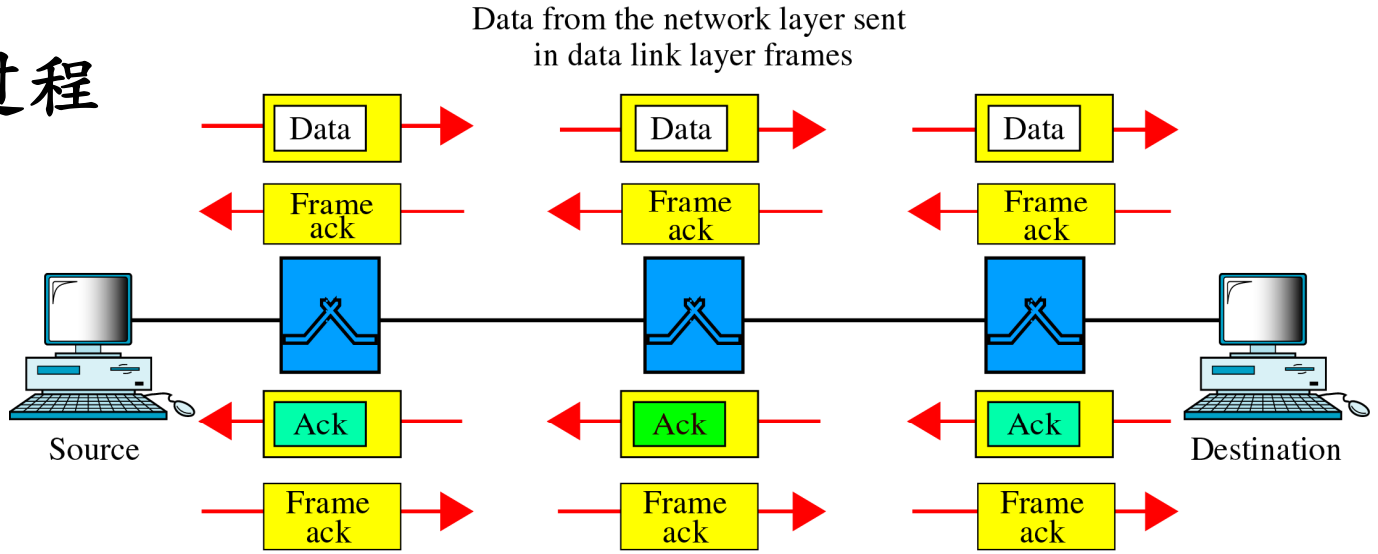
X.25与FR的比较

- FR是轻型化的X.25，与X.25相比
  - 保留了X.25的物理层功能
  - 保留了X.25部分数据链路层功能，并将多路复用功能放在第二层实现
  - 丢弃了X.25第三层

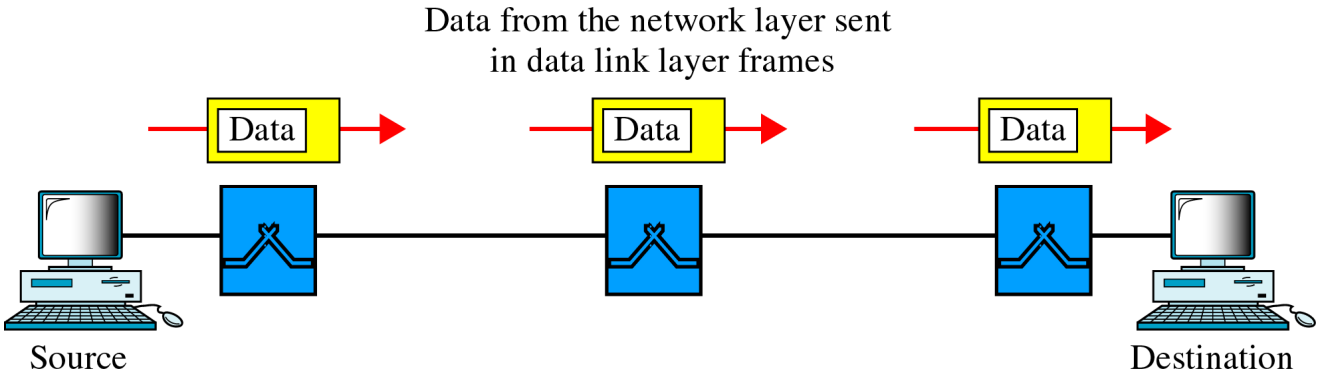


X.25和FR的通信过程

- X.25的通信过程



- FR的通信过程



FR的特点

- 优点
  - FR支持较高速率（T1或T3）
  - FR只包含物理层和数据链路层，比X.25开销小
  - FR允许支持突发数据，且帧长度可达9000字节
- 缺点
  - 不提供差错控制功能
  - 对多媒体数据传输的支持不够

4.2.5 SMDS

- 交换式多兆位数据服务SMDS是用来连接多个局域网
- SMDS的设计是针对突发数据通信的。
- SMDS标准速率是45Mbps，也支持低于45Mbps的速率
- SMDS提供无连接的数据传输服务
- 已被SONET取代

PART II Packet Transmission

Ch 15 Network Characteristics: Ownership, Service Paradigm, and Performance

网络所有权、服务模式和性能

技术问题，往往不仅是技术问题，

还是社会层面的问题

15.2 Network Ownership

- **Network hardware and software can be owned by a single company or individual, or it can be owned by a communication company.**
  - **15.2.1 Private Networks 私有网络**
    - **A network is said to be private if use of the network is restricted to the corporate or individual owner.**
  - **15.2.2 Public Networks 公有网络**
    - **A public network is owned and operated by a service provider.**
    - **Any subscriber can use a public network to communication with other subscriber.**

15.3 Privacy and Public Networks

- When applied to a network, the term public refers to availability of the service, not the data transferred.
- Most public networks provide private communication.

15.4 Advantages and Disadvantages

- The chief advantage of a private network is that the owner has complete control over both the technical decision and policies.
- An owner can guarantee that the network is isolated from computers outside the organization.

- **A large private network can be expensive to install and maintain**
- **The chief advantage of a public network are flexibility and the ability to use state-of-the–art network without maintaining technical expertise.**

15.5 Virtual Private Networks

- Known as a Virtual Private Network (VPN), the technology allows a company with multiple sites to have a private network, but use a public network as a carrier.
- VPN technology restricts traffic so that packets can travel only between the company's sites.
- To build a VPN, a company buys a special hardware and software system for each of its sites.

15.6 Guaranteeing Absolute Privacy

- **VPN system use encryption (加密) to guarantee absolute privacy.**
- **Even if an outsider does manage to obtain a copy of a packet, the outsider will be unable to interpret the contents.**

15.12 Examples of Service Paradigms

Technology	Connection-Oriented	Connectionless	used for LAN	used for WAN
Ethernet		•	•	
Token Ring		•	•	
FDDI		•	•	
Frame Relay	•			•
SMDS		•		•
ATM	•		•	•
LocalTalk		•	•	

性能度量

- 速度
  - 网速怎么这么慢
- 定性描述，定量描述
- 关键量度
  - 延迟（时延）
  - 吞吐率（容量）
  - 抖动（变化量）

网络性能的关键量度

Measure	Description
Latency (delay)	The time required to transfer data across a network
Throughput (capacity)	The amount of data that can be transferred per unit time
Jitter (variability)	The changes in delay that occur and the duration of the changes

延迟

- **Propagation Delay**
  - **The time required for a signal to travel across a transmission medium**
- **Access Delay**
  - **The time needed to obtain access to a transmission medium (e.g., a cable)**
- **Switching Delay**
  - **The time required to forward a packet**

延迟

- **Queuing Delay**
  - **The time a packet spends in the memory of a switch or router waiting to be selected for transmission**
- **Server Delay**
  - **The time required for a server to respond to a request and send a response**

吞吐率

- 吞吐率
  - 网络可以支持的最大传输速率
  - 单位：bps, kbps, Mbps, Gbps
  - 注意：bit per second
- 与时延的关系
  - **Propagation delay specifies the time a single bit remains in transit in a network.**
  - **Throughput, which specifies how many bits can enter the network per unit time, measures network capacity.**

抖动

- 评估时延的变化量
- 处理抖动的方法
  - 设计一个无抖动的等时网络
  - 采用补偿抖动的协议
    - **RTP**：实时传输协议

服务质量（QoS）

- 网络服务的等级
- 服务提供商与用户的契约
  - 层级服务：按服务等级计算金额
    - 例如：电信宽带分4Mbps，6Mbps等
  - 服务保证
    - 证券交易：时延不超过10ms
    - 公司需要备份数据中心：吞吐率不少于1Gbps
- 测量服务质量的工具
  - 简单工具：Ping
    - 原理：Echo协议

8. THANK YOU.

厦门大学软件学院

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