ADVANCED COMPUTER NETWORKS

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(5^{th} Week)

Outline

- 2. Data Communications
  - 2.1. Error Detection and Correction
  - 2.2. Data Link Control Protocols
  - 2.3. Multiplexing

2.3. Multiplexing

2.3.Outline

- Frequency-Division Multiplexing
- Synchronous Time-Division Multiplexing
- Cable Modems
- Asymmetric Digital Subscriber Line
- xDSL
- Multiple Channel Access

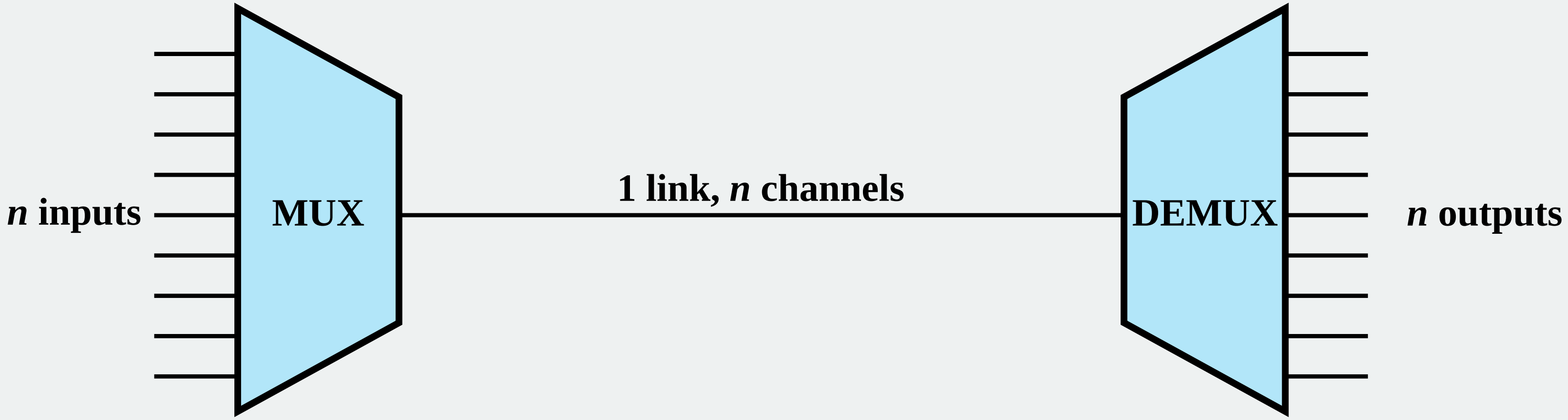
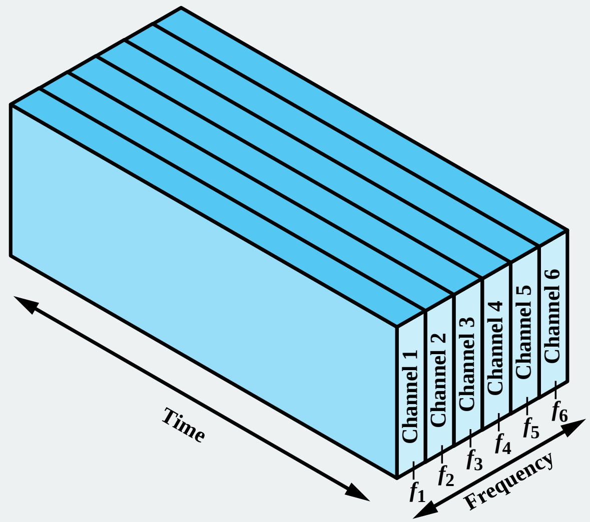
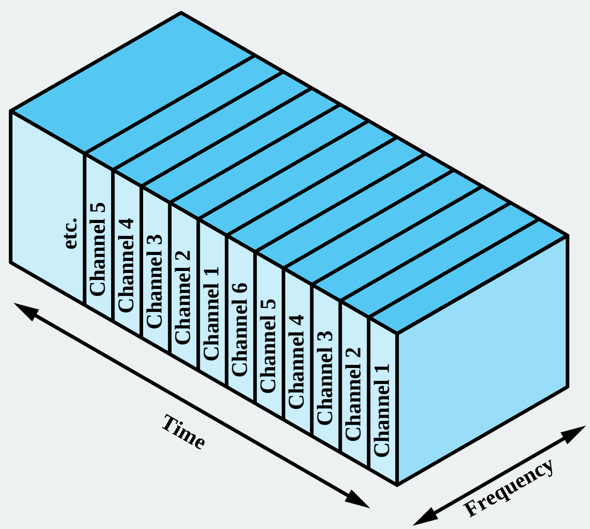


Figure 8.1 Multiplexing



(a) Frequency division multiplexing



(b) Time division multiplexing

Figure 8.2 FDM and TDM

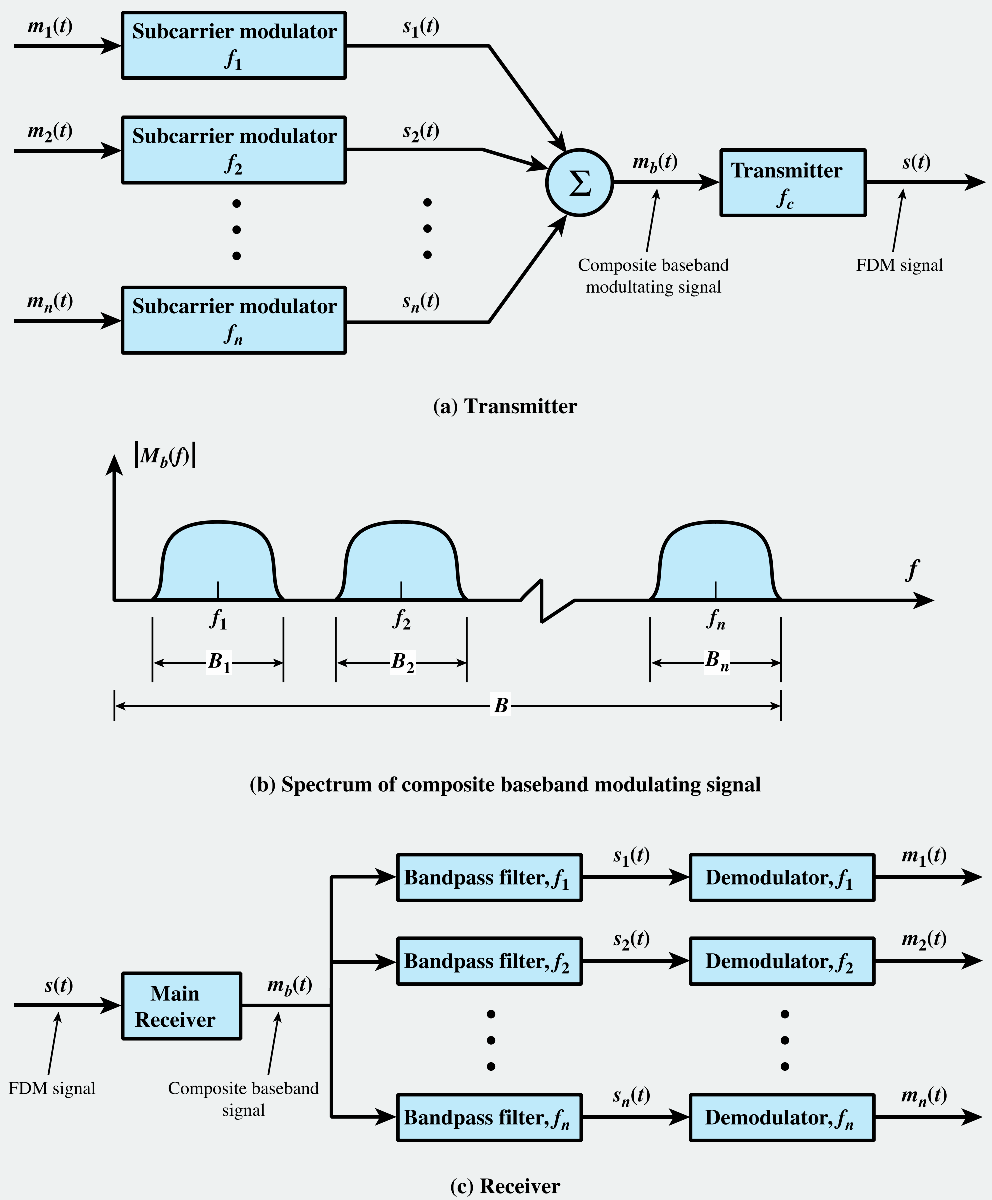


Figure 8.3 FDM System

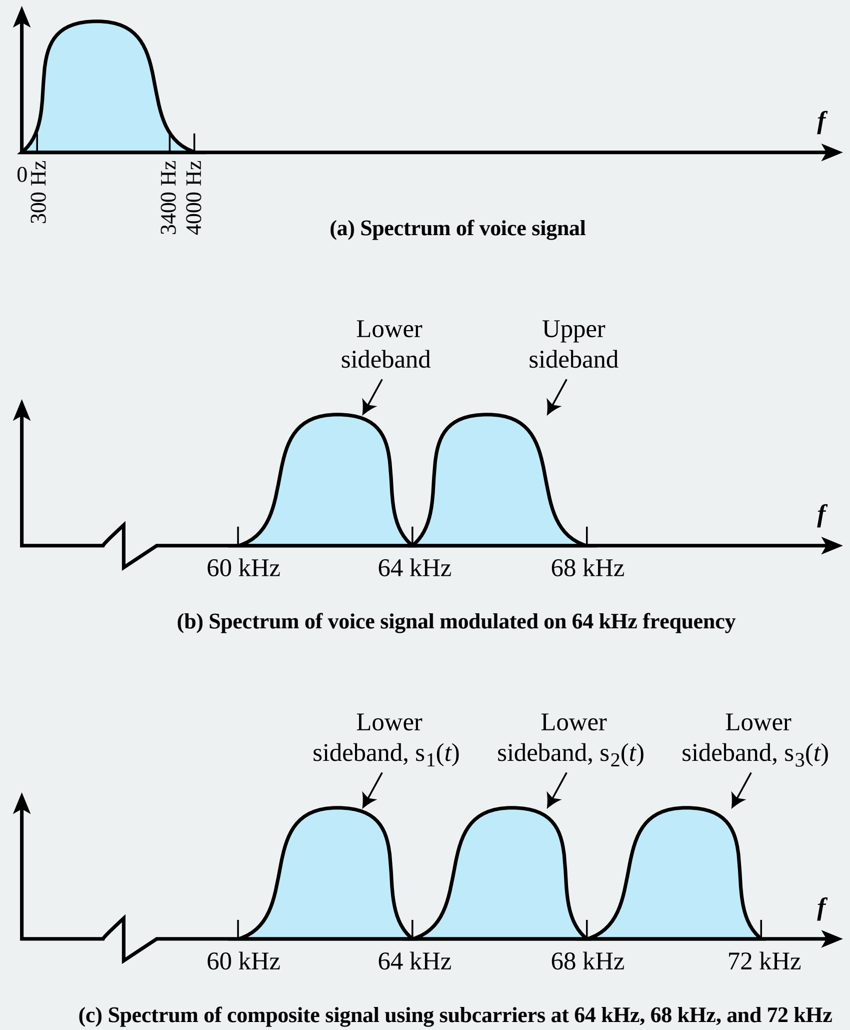


Figure 8.4 FDM of Three Voiceband Signals

Analog Carrier Systems

- Long-distance links use an FDM hierarchy
- AT&T (USA) and ITU-T (International) variants

Group	Supergroup	Mastergroup
• 12 voice channels (4kHz each) = 48kHz • Range 60kHz to 108kHz	• FDM of 5 group signals supports 60 channels • Carriers between 420kHz and 612 kHz	• FDM of 10 supergroups supports 600 channels

- Original signal can be modulated many times

North American and International FDM Carrier Standards

Number of Voice Channels	Bandwidth	Spectrum	AT&T	ITU-T
12	48 kHz	60–108 kHz	Group	Group
60	240 kHz	312–552 kHz	Supergroup	Supergroup
300	1.232 MHz	812–2044 kHz		Mastergroup
600	2.52 MHz	564–3084 kHz	Mastergroup	
900	3.872 MHz	8.516–12.388 MHz		Supermaster group
N ´ 600			Mastergroup multiplex	
3,600	16.984 MHz	0.564–17.548 MHz	Jumbogroup	
10,800	57.442 MHz	3.124–60.566 MHz	Jumbogroup multiplex	

Wavelength Division Multiplexing (WDM)

Multiple beams of light at different frequencies

Carried over optical fiber links

- Commercial systems with 160 channels of 10 Gbps
- Lab demo of 256 channels 39.8 Gbps

Architecture similar to other FDM systems

- Multiplexer consolidates laser sources (1550nm) for transmission over single fiber
- Optical amplifiers amplify all wavelengths
- Demultiplexer separates channels at destination

Dense Wavelength Division Multiplexing (DWDM)

- No official or standard definition
- Use of more channels more closely spaced

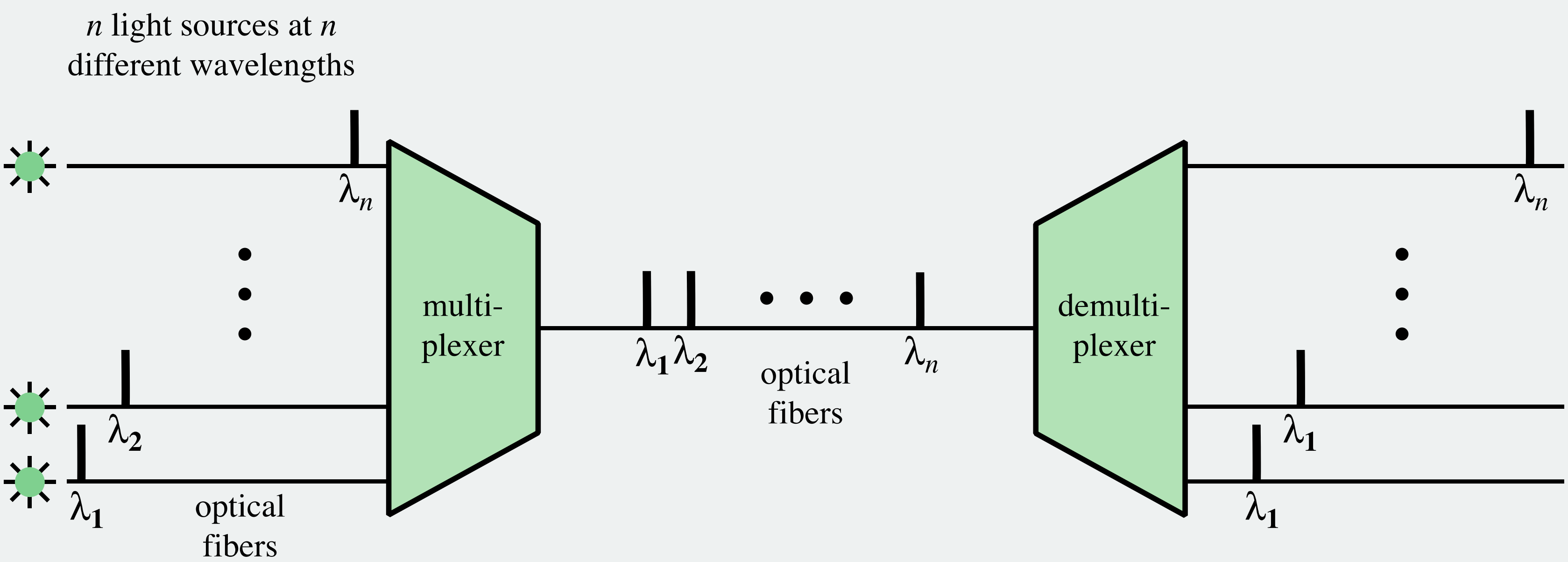


Figure 8.5 Wavelength Division Multiplexing

ITU WDM Channel Spacing (G.692)

Frequency (THz)	Wavelength in Vacuum (nm)	50 GHz	100 GHz	200 GHz
196.10	1528.77	X	X	X
196.05	1529.16	X		
196.00	1529.55	X	X	
195.95	1529.94	X		
195.90	1530.33	X	X	X
195.85	1530.72	X		
195.80	1531,12	X	X	
195.75	1531.51	X		
195.70	1531.90	X	X	X
195.65	1532.29	X		
195.60	1532.68	X	X	
…	…			
192.10	1560.61	X	X	X

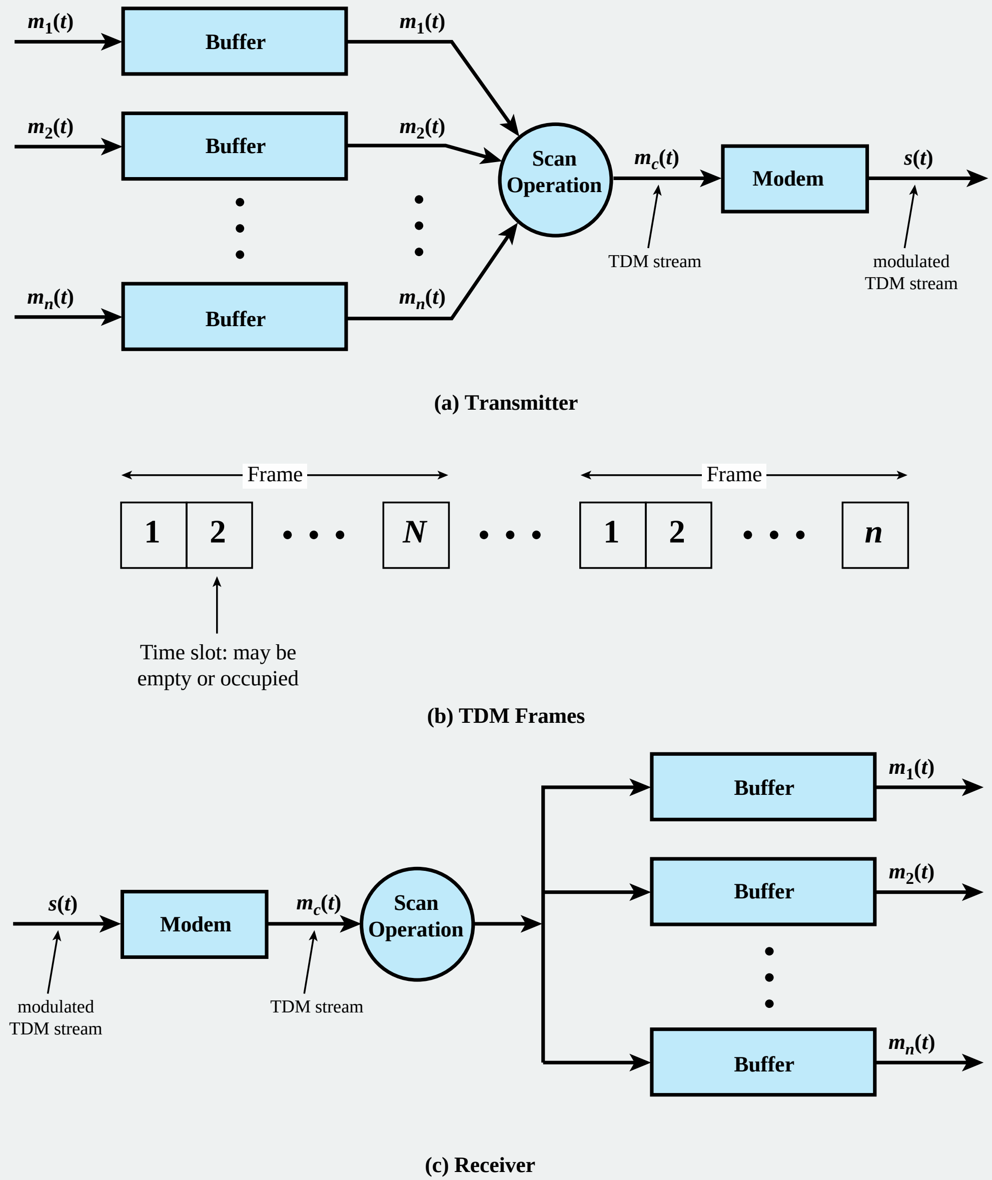


Figure 8.6 Synchronous TDM System

TDM Link Control

- No headers and trailers
- Data link control protocols not needed
- Flow control
  - Data rate of multiplexed line is fixed
  - If one channel receiver can not receive data, the others must carry on
  - Corresponding source must be quenched
  - Leaving empty slots
- Error control
  - Errors detected and handled on individual channel

(a) Configuration

Input$_1$ • • • • • • • • • • • F_1 f_1 f_1 d_1 d_1 d_1 C_1 A_1 F_1 f_1 f_1 d_1 d_1 d_1 C_1 A_1 F_1

Input$_2$ • • • F_2 f_2 f_2 d_2 d_2 d_2 d_2 C_2 A_2 F_2 f_2 f_2 d_2 d_2 d_2 d_2 C_2 A_2 F_2

(b) Input data streams

• • • f_2 F_1 d_2 f_1 d_2 f_1 d_2 d_1 d_2 d_1 C_2 d_1 A_2 C_1 F_2 A_1 f_2 F_1 f_2 f_1 d_2 f_1 d_2 d_1 d_2 d_1 d_2 d_1 C_2 C_1 A_2 A_1 F_2 F_1

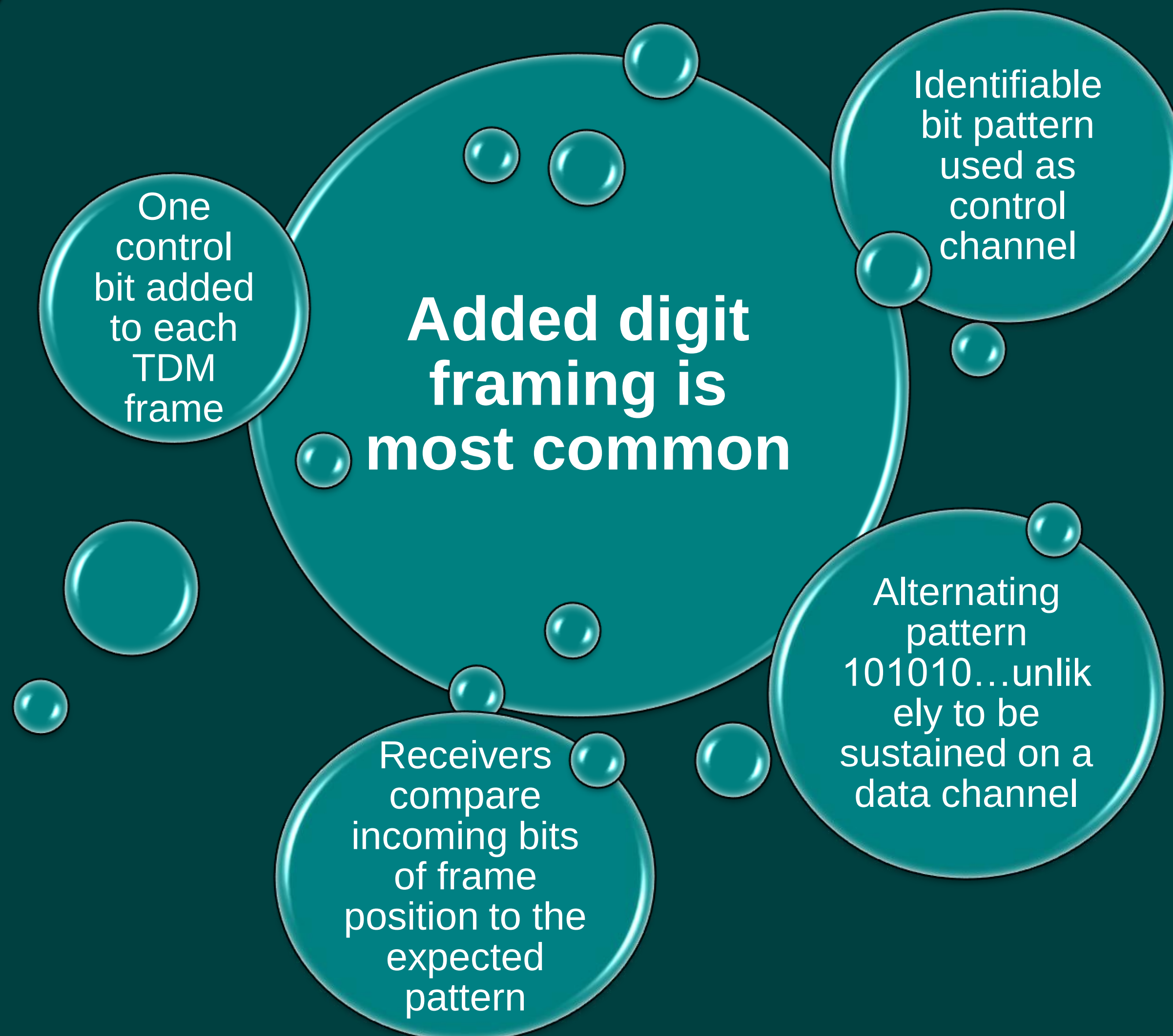
(c) Multiplexed data stream

Legend:
F = flag field
A = address field
C = control field
d = one octet of data field
f = one octet of FCS field

Figure 8.7 Use of Data Link Control on TDM Channels

Framing

- No flag or SYNC characters bracketing TDM frames
- Must still provide synchronizing mechanism between source and destination clocks



- Problem of synchronizing various data sources
- Variation among clocks could cause loss of synchronization
- Issue of data rates from different sources not related by a simple rational number

Pulse Stuffing is a common solution

Have outgoing data rate (excluding framing bits) higher than sum of incoming rates	Stuff extra dummy bits or pulses into each incoming signal until it matches local clock	Stuffed pulses inserted at fixed locations in frame and removed at demultiplexer

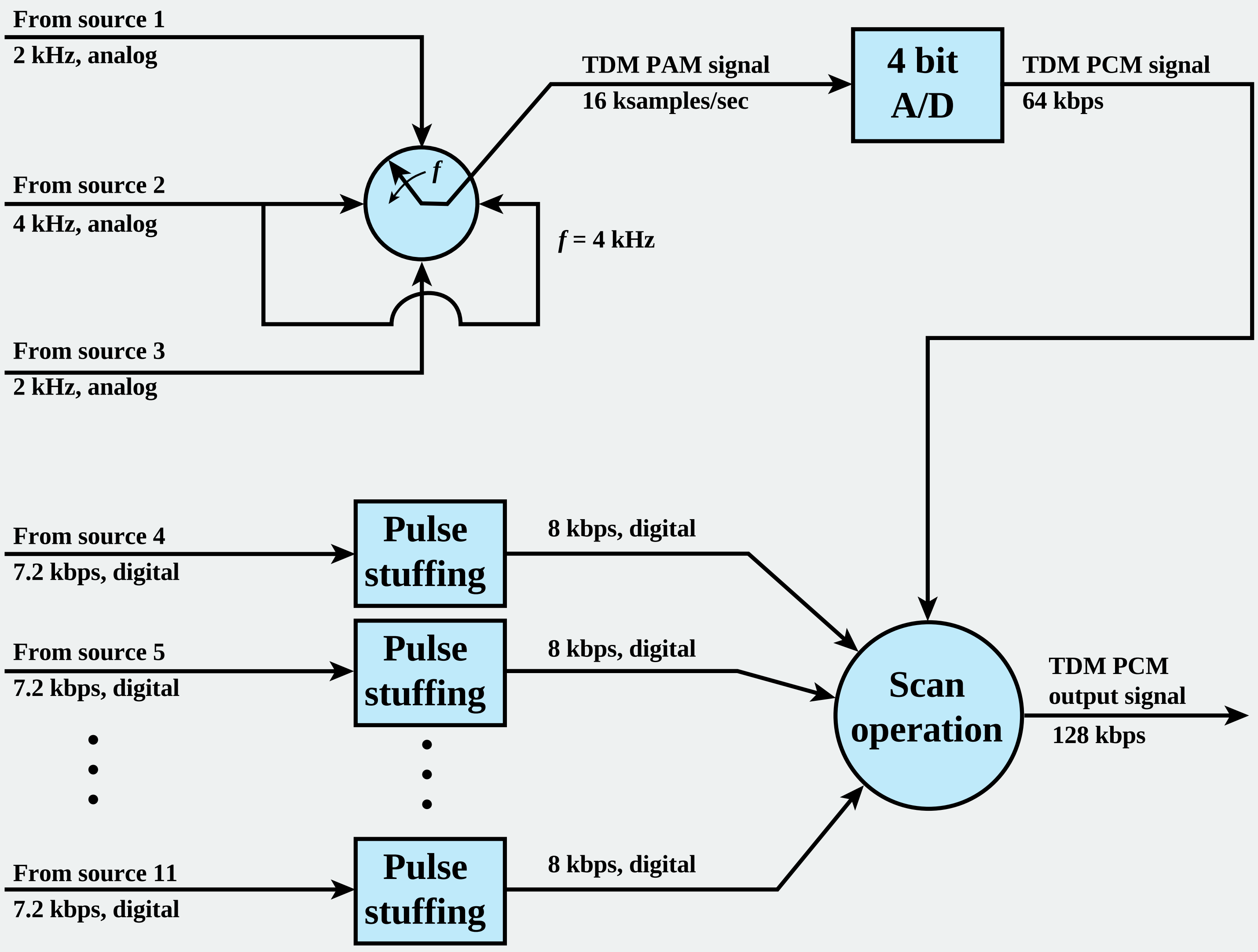
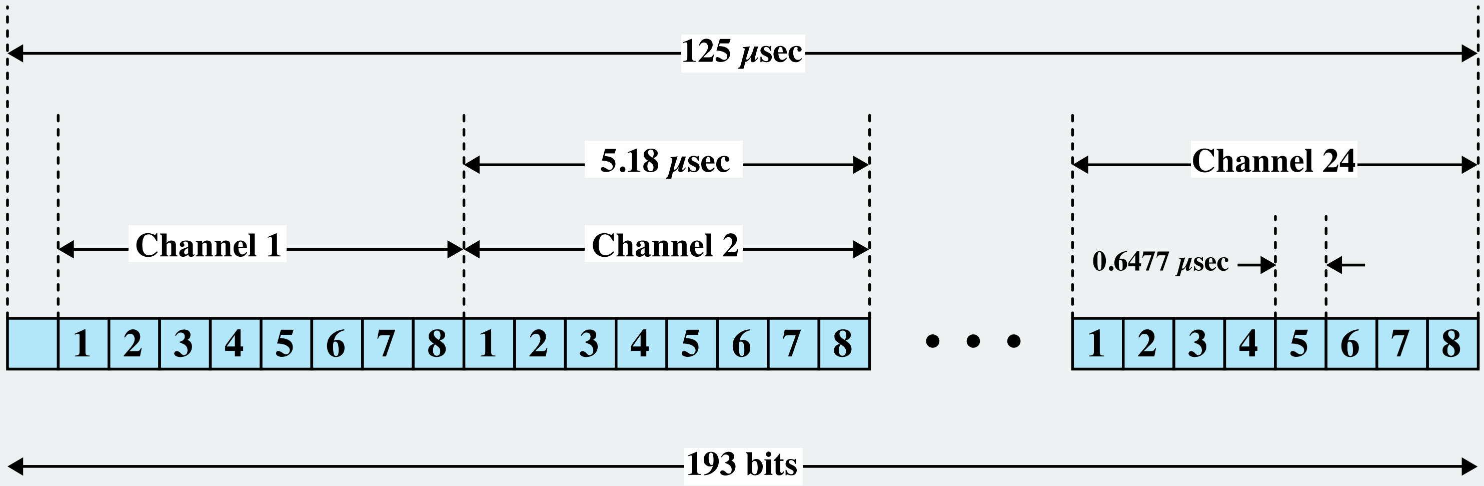


Figure 8.8 TDM of Analog and Digital Sources

North American and International TDM Carrier Standards

North American			International (ITU-T)		
Designation	Number of Voice Channels	Data Rate (Mbps)	Level	Number of Voice Channels	Data Rate (Mbps)
DS-1	24	1.544	1	30	2.048
DS-1C	48	3.152	2	120	8.448
DS-2	96	6.312	3	480	34.368
DS-3	672	44.736	4	1920	139.264
DS-4	4032	274.176	5	7680	565.148



Notes:

1. The first bit is a framing bit, used for synchronization.
2. Voice channels:
   - •8-bit PCM used on five of six frames.
   - •7-bit PCM used on every sixth frame; bit 8 of each channel is a signaling bit.
3. Data channels:
   - •Channel 24 is used for signaling only in some schemes.
   - •Bits 1-7 used for 56 kbps service
   - •Bits 2-7 used for 9.6, 4.8, and 2.4 kbps service.

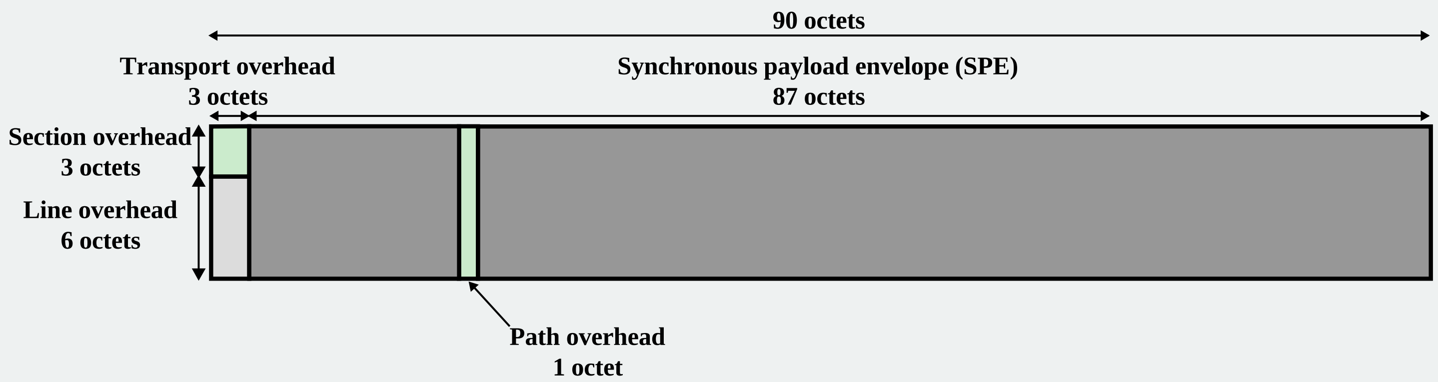
Figure 8.9 DS-1 Transmission Format

SONET/SDH

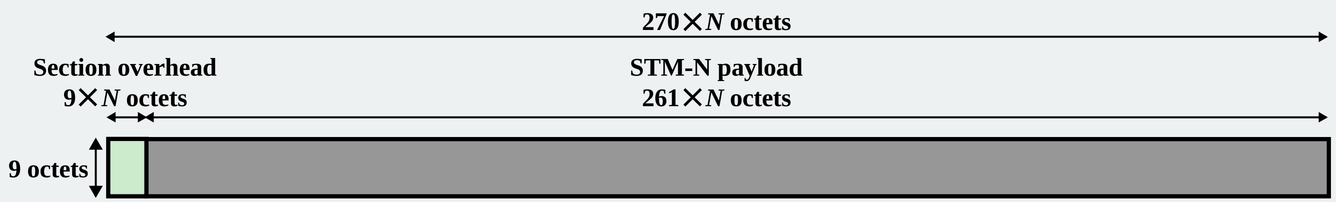
- Synchronous Optical Network (ANSI)
- Synchronous Digital Hierarchy (ITU-T)
- High speed capability of optical fiber
- Defines hierarchy of signal rates
    - Synchronous Transport Signal level 1 (STS-1) or Optical Carrier level 1 (OC-1) is 51.84Mbps
    - Carries one DS-3 or multiple (DS1 DS1C DS2) plus ITU-T rates (e.g., 2.048Mbps)
    - Multiple STS-1 combine into STS-N signal
    - ITU-T lowest rate is 155.52Mbps (STM-1)

SONET/SDH Signal Hierarchy

SONET Designation	ITU-T Designation	Data Rate	Payload Rate (Mbps)
STS-1/OC-1		51.84 Mbps	50.112 Mbps
STS-3/OC-3	STM-1	155.52 Mbps	150.336 Mbps
STS-12/OC-12	STM-4	622.08 Mbps	601.344 Mbps
STS-48/OC-48	STM-16	2.48832 Gbps	2.405376 Gbps
STS-192/OC-192	STM-64	9.95328 Gbps	9.621504 Gbps
STS-768	STM-256	39.81312 Gbps	38.486016 Gbps
STS-3072		159.25248 Gbps	153.944064 Gbps



(a) STS-1 frame format



(b) STM-N frame format

Figure 8.10 SONET/SDH Frame Formats

Cable Modems

is a device that allows a user to access the Internet and other online services through a cable television network.

Downstream

- Cable scheduler delivers data in small packets
- Active subscribers share downstream capacity
- Also allocates upstream time slots to subscribers

Upstream

- User requests timeslots on shared upstream channel
- Headend scheduler notifies subscriber of slots to use

-Dedicate two cable TV channels to data transfer
-Each channel shared by number of subscribers
using statistical TDM

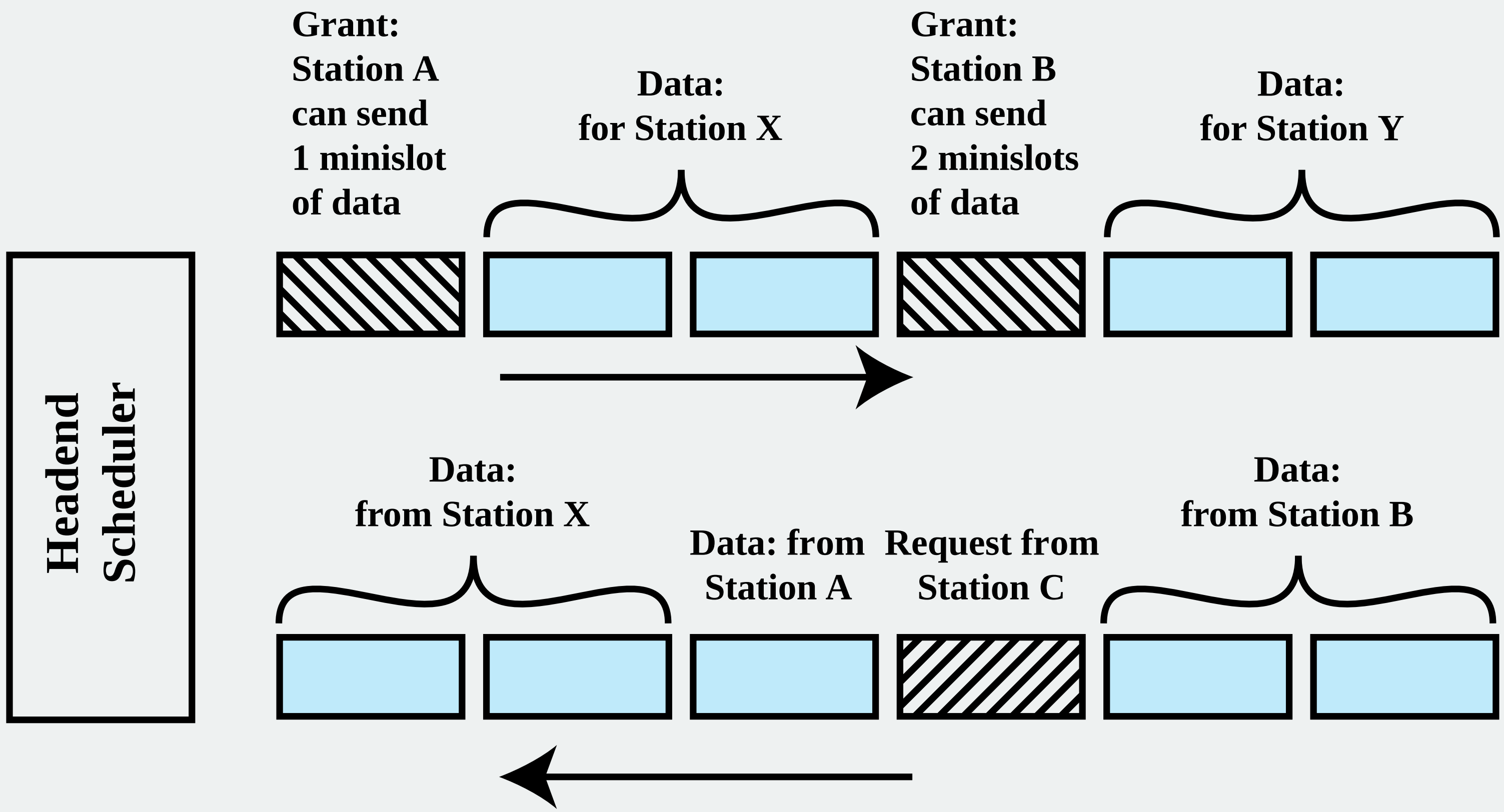


Figure 8.12 Cable Modem Scheme

Cable Spectrum Division

- To support both cable television programming and data channels, the cable spectrum is divided in to three ranges (each of which is further divided into 6-MHz channels):
  - User-to-network data (upstream): 5 - 40 MHz
  - Television delivery (downstream): 50 - 550 MHz
  - Network to user data (downstream): 550 - 750 MHz

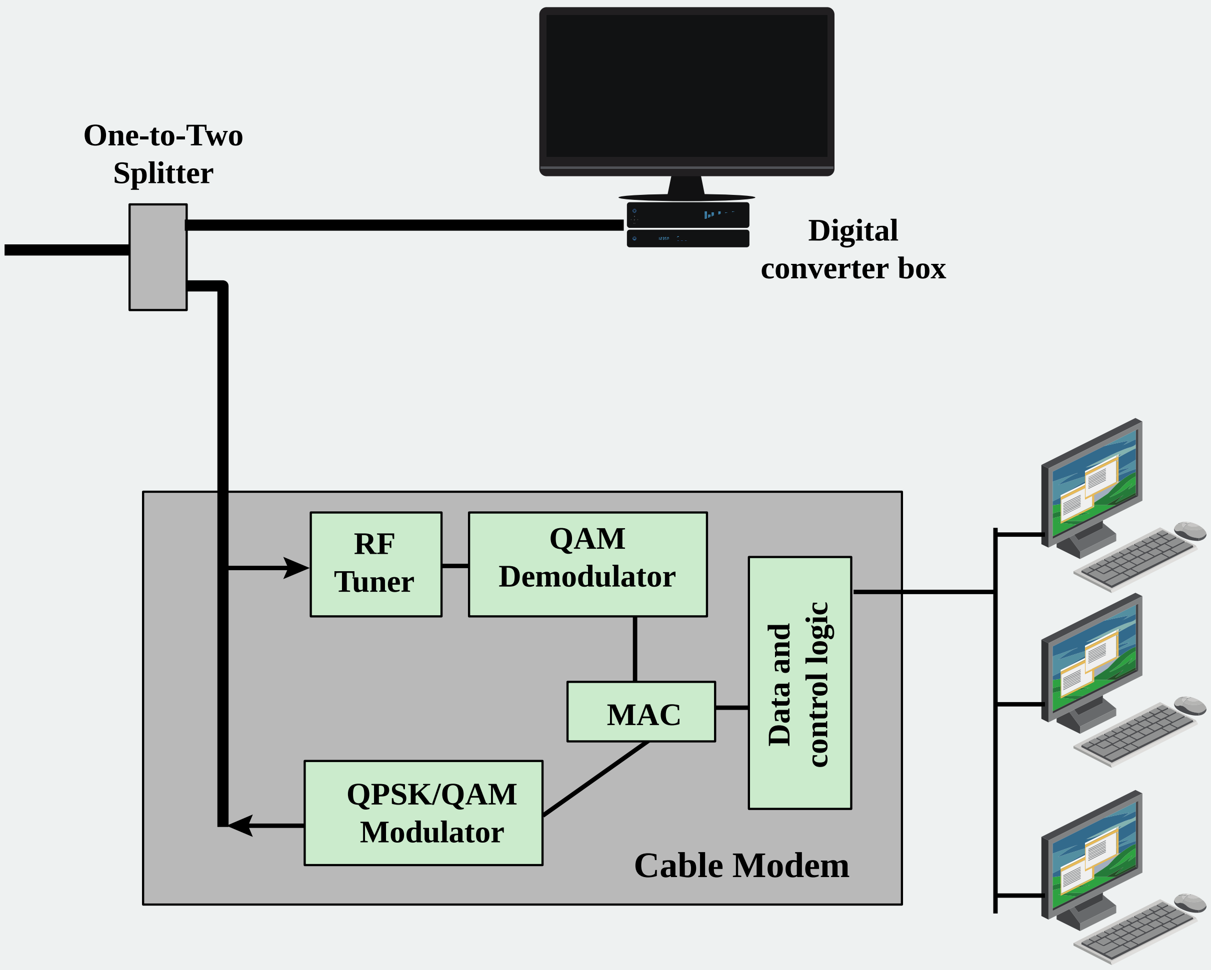
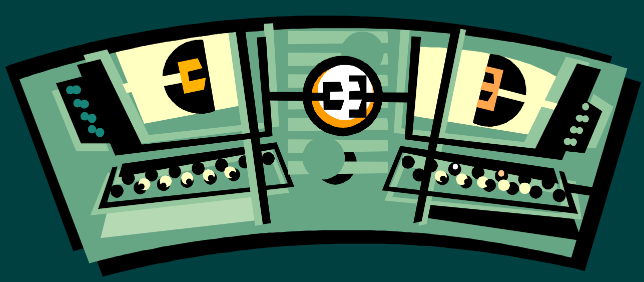
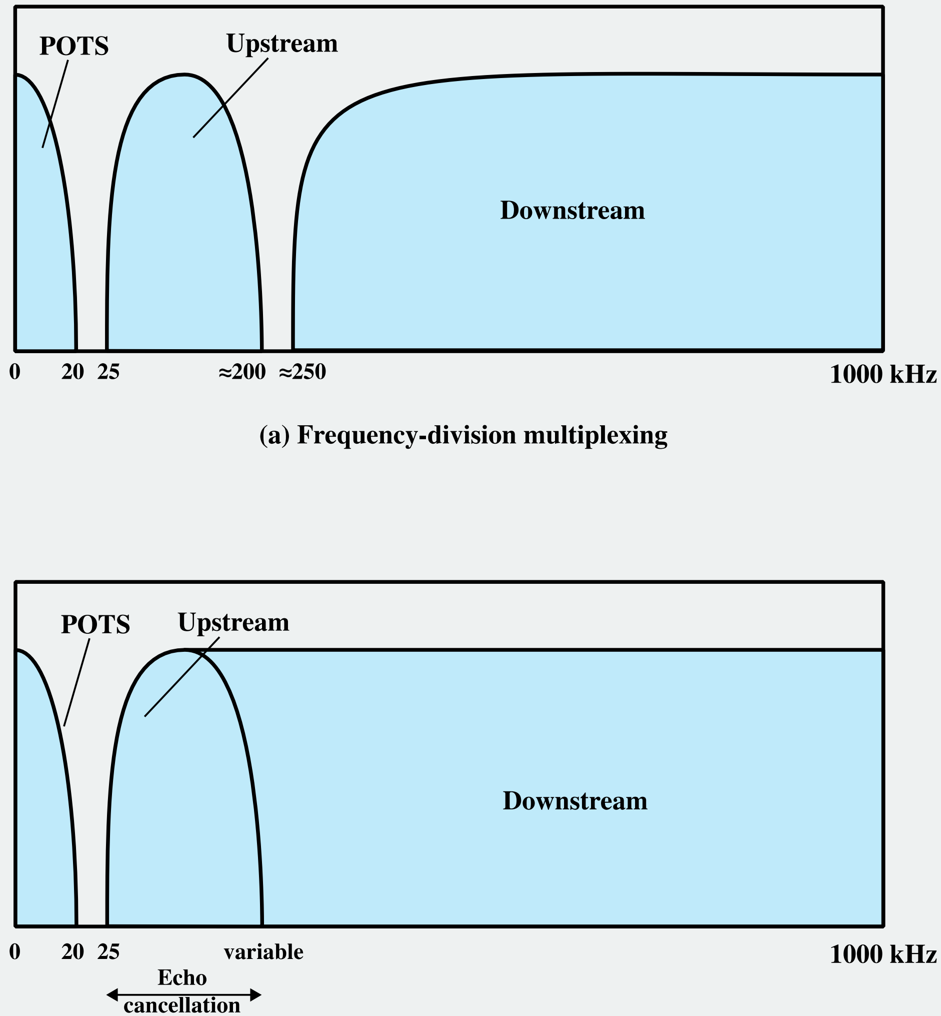


Figure 8.13 Cable Modem Configuration

Asymmetrical Digital Subscriber Line (ADSL)

- Link between subscriber and network
- Uses currently installed twisted pair cable
- Is Asymmetric - bigger downstream than up
- Uses Frequency Division Multiplexing
  - Reserve lowest 25kHz for voice (POTS)
  - Uses echo cancellation or FDM to give two bands
- Has a range of up to 5.5km





(a) Frequency-division multiplexing

(b) Echo cancellation

Figure 8.14 ADSL Channel Configuration

Discrete Multitone (DMT)

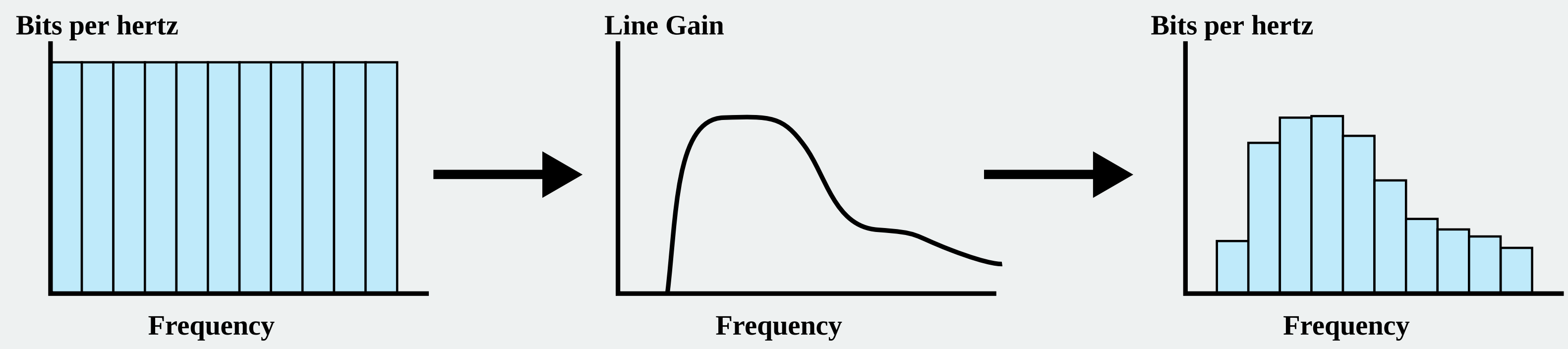
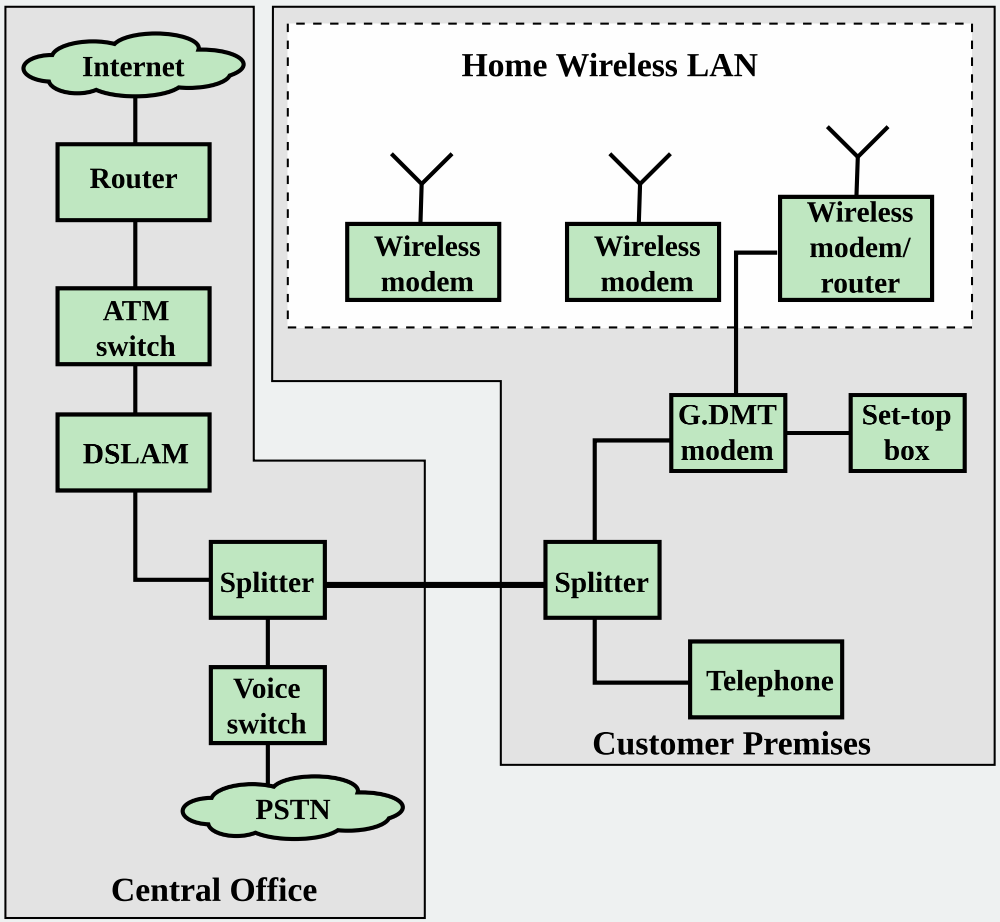


Figure 8.15 DMT Bits per Channel Allocation

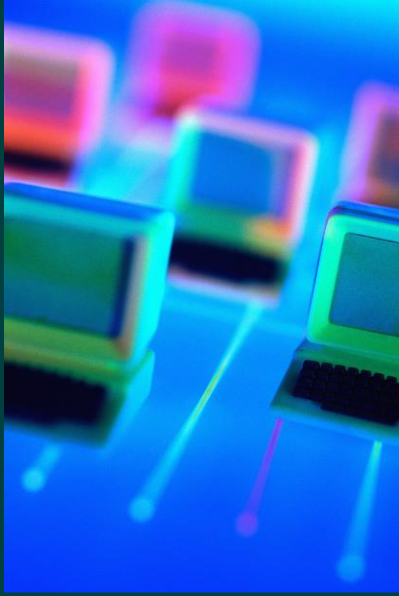
- Multiple carrier signals at different frequencies
- Divide into 4kHz subchannels
- Test and use subchannels with better SNR
- 256 downstream subchannels at 4kHz (60kbps)
  - In theory 15.36Mbps, in practice 1.5-9Mbps



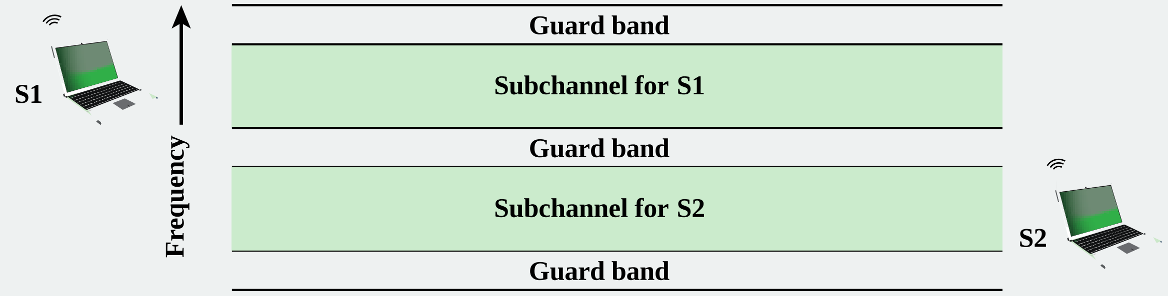
ATM = Asynchronous Transfer Mode
DSLAM = Digital Subscriber Line Access Multiplexer
PSTN = Public Switched Telephone Network
G.DMT = G.992.1 Discrete Multitone

Figure 8.17 DSL Broadband Access

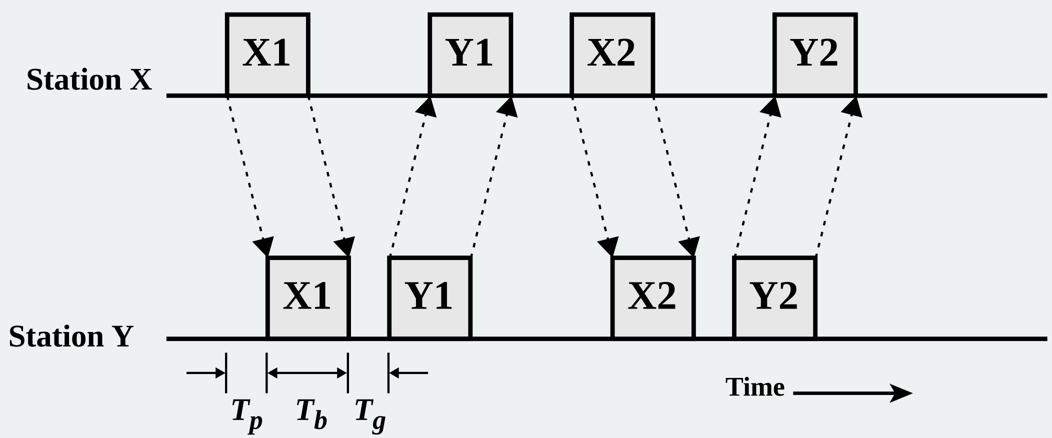
xDSL



- High data rate DSL (HDSL)
  - 2B1Q coding on dual twisted pairs
  - Up to 2Mbps over 3.7km
- Single line DSL
  - 2B1Q coding on single twisted pair (residential) with echo cancelling
  - Up to 2Mbps over 3.7km
- Very high data rate DSL
  - DMT/QAM for very high data rates
  - Separate bands for separate services



(a) Frequency-division duplex (TDD)



T_p = Propagation delay

T_b = Burst transmission time

T_g = Guard time

(b) Time-division duplex (TDD)

Figure 8.18 Duplex Access Techniques

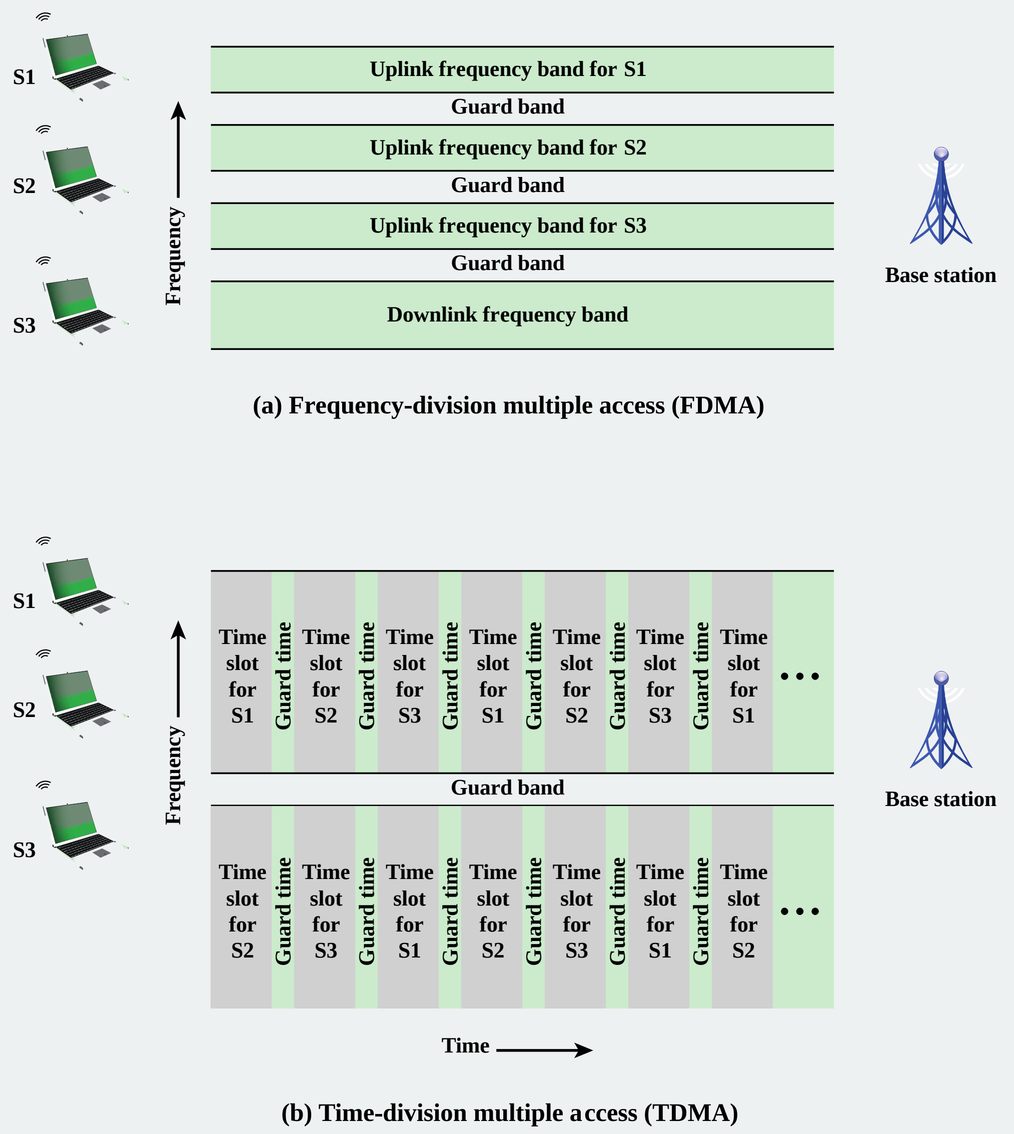


Figure 8.19 Multiple Channel Access Techniques

Comparison of xDSL Alternatives

	ADSL	HDSL	SDSL	VDSL
Data rate	1.5 to 9 Mbps downstream 16 to 640 kbps upstream	1.544 or 2.048 Mbps	1.544 or 2.048 Mbps	13 to 52 Mbps downstream 1.5 to 2.3 Mbps upstream
Mode	Asymmetric	Symmetric	Symmetric	Asymmetric
Copper pairs	1	2	1	1
Range (24-gauge UTP)	3.7 to 5.5 km	3.7 km	3.0 km	1.4 km
Signaling	Analog	Digital	Digital	Analog
Line code	CAP/DMT	2B1Q	2B1Q	DMT
Frequency	1 to 5 MHz	196 kHz	196 kHz	$\geq$ 10 MHz
Bits/cycle	Varies	4	4	Varies

UTP = unshielded twisted pair

FDMA

- Frequency-Division Multiple Access
  - Technique used to share the spectrum among multiple stations
  - Base station assigns bandwidths to stations within the overall bandwidth available
  - Key features:

Each subchannel is dedicated to a single station

If a subchannel is not in use, it is idle; the capacity is wasted

Requires fewer overhead bits because each subchannel is dedicated

Individual subchannels must be separated by guard bands to minimize interference

TDMA

- Time-Division Multiple Access
  - There is a single, relatively large, uplink frequency band that is used to transmit a sequence of time slots
  - Repetitive time slots are assigned to an individual subscriber station to form a logical subchannel
  - Key features:

Each subchannel is dedicated to a single station

For an individual station data transmission occurs in bursts rather than continuously

Guard times are needed between time slots, to account for lack of perfect synchronization among the subscriber station

Downlink channel may be on a separate frequency band

The uplink and downlink transmission may be on the same frequency band