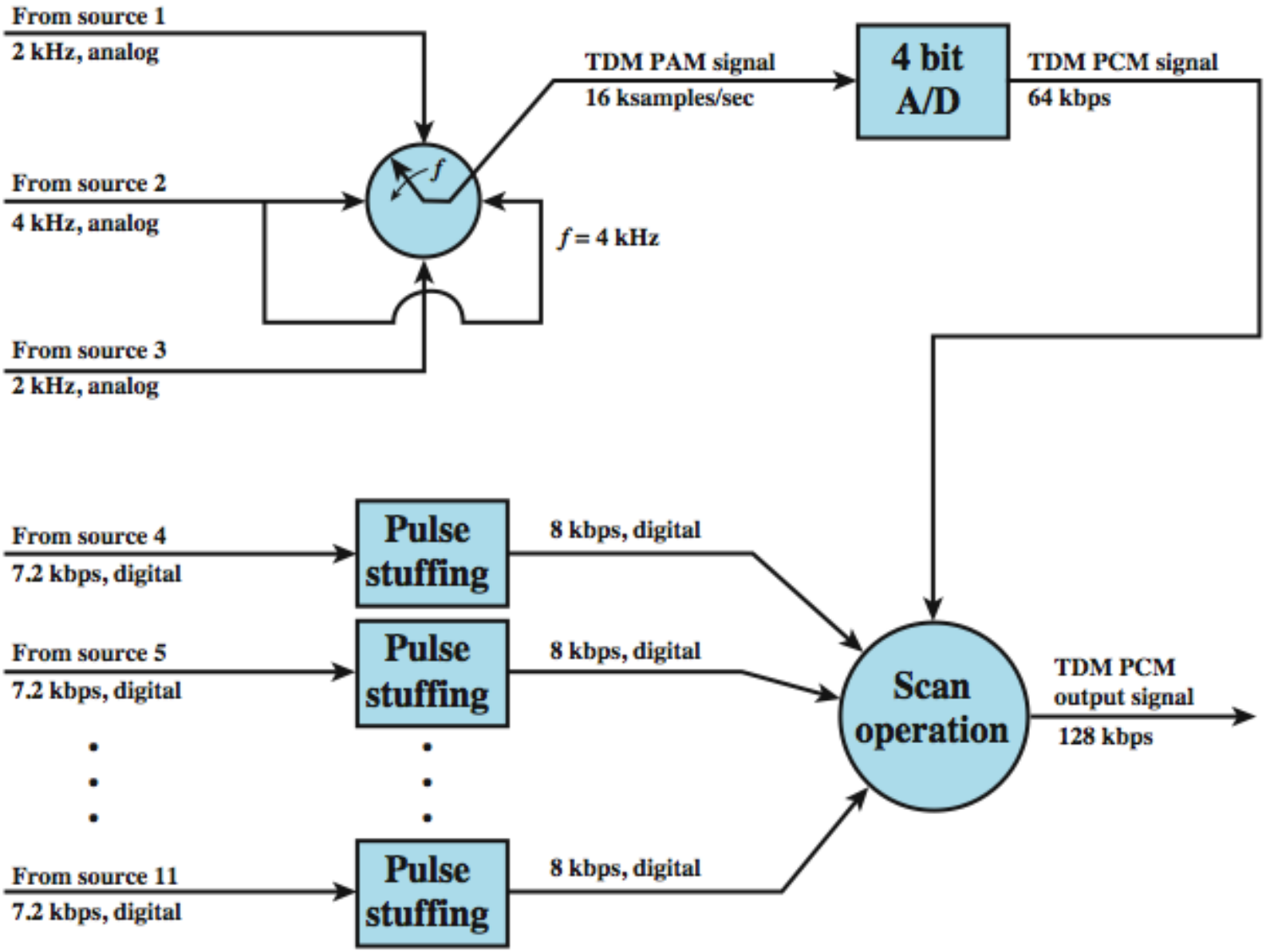
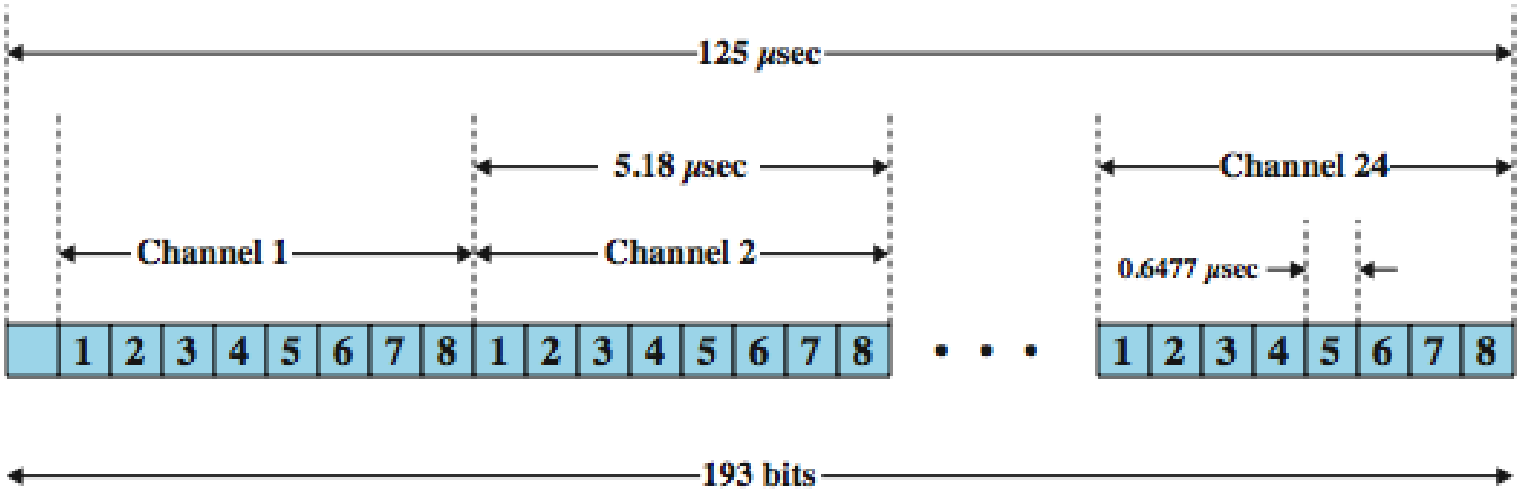
TDM Example


From source 1
2 kHz, analog
From source 2
4 kHz, analog
From source 3
2 kHz, analog
f
f = 4 kHz
TDM PAM signal
16 ksamples/sec
4 bit
A/D
TDM PCM signal
64 kbps
From source 4
7.2 kbps, digital
From source 5
7.2 kbps, digital
From source 11
7.2 kbps, digital
Pulse
stuffing
Pulse
stuffing
Pulse
stuffing
8 kbps, digital
8 kbps, digital
8 kbps, digital
Scan
operation
TDM PCM
output signal
128 kbps

Digital Carrier Systems/Standards

- Long-distance links use TDM hierarchy
- AT&T (USA) and ITU-T (International) variants
- US system based on DS-1 format
- Can carry mixed voice and data signals
- DS-1 multiplexes 24 channels into one frame
- Each frame contains 8 bits per channel plus a framing bit: 24*8+1=193 bits
- Each voice channel contains one word of digitized data (PCM, 8000 samples per sec)
- A total data rate of 8000*193=1.544Mbps
- Can interleave DS-1 channels for higher rates
  - DS-2 is four DS-1 at 4*1.544Mbps=6.312Mbps

DS-1 Transmission Format



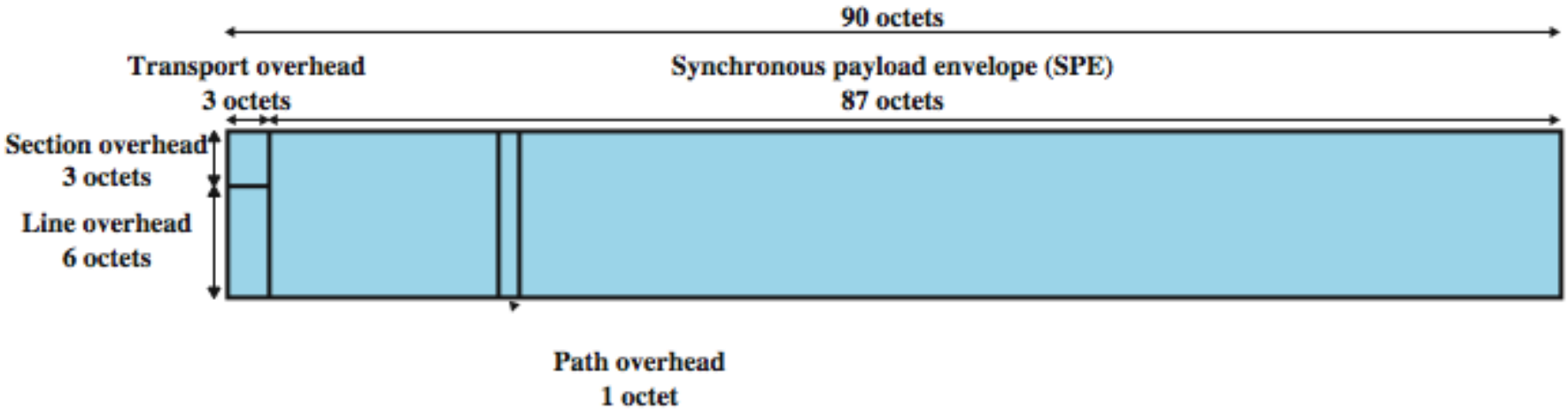
Notes:

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.

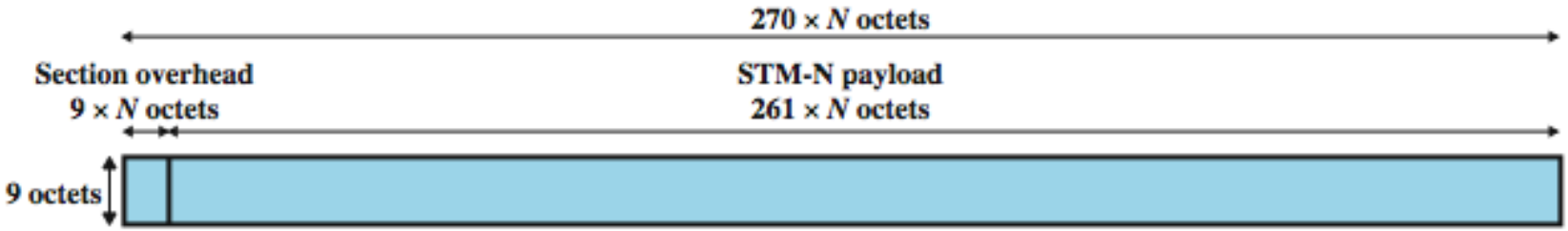
SONET/SDH

- Synchronous Optical Network (SONET) standardized by American National Standards Institute (ANSI)
- Synchronous Digital Hierarchy (SDH) standardized by the ITU-T (international)
- Have hierarchy of signal rates
  - Synchronous Transport Signal level 1 (STS-1) or Optical Carrier level 1 (OC-1) is 51.84Mbps
  - multiple STS-1 combine into STS-N signal
  - STS-3 data rate =3* 51.84Mbps=155.52Mbps
  - ITU-T lowest rate is 155.52Mbps (STM-1)

SONET Frame Format



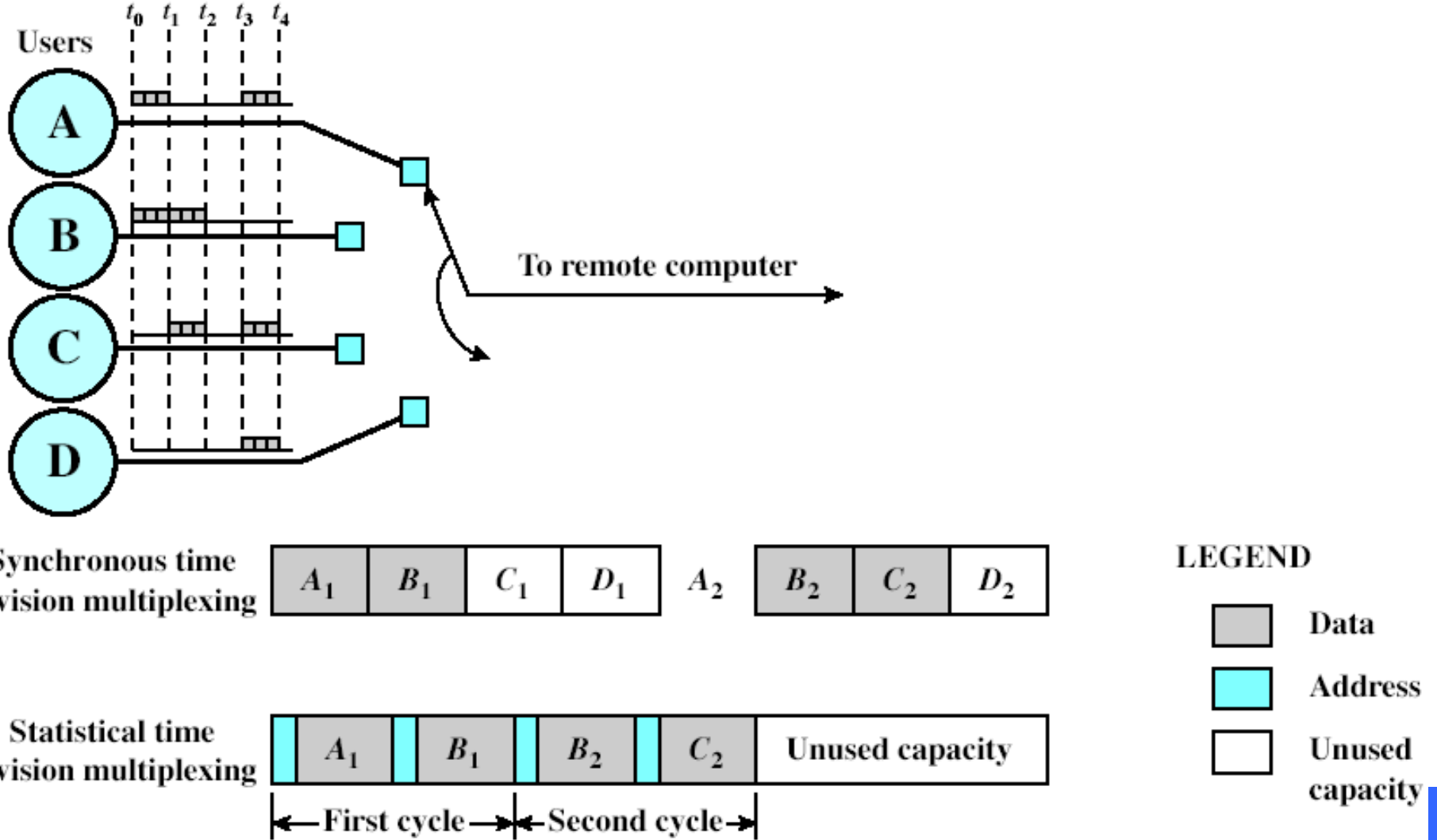
(a) STS-1 frame format



(b) STM-N frame format

Statistical TDM

- In synchronous TDM many slots are wasted
- Statistical TDM allocates time slots dynamically, on demand



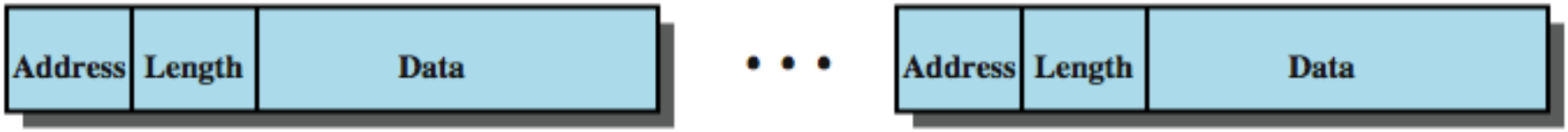
Statistical TDM

- Multiplexer scans input lines and collects data until frame full
- Line data rate lower than input lines rates
- Overhead per slot for statistical TDM because each slot carries an address as well as data
- May have problems during peak periods
  - must buffer inputs

Statistical TDM Frame Format

(a) Overall frame

(b) Subframe with one source per frame

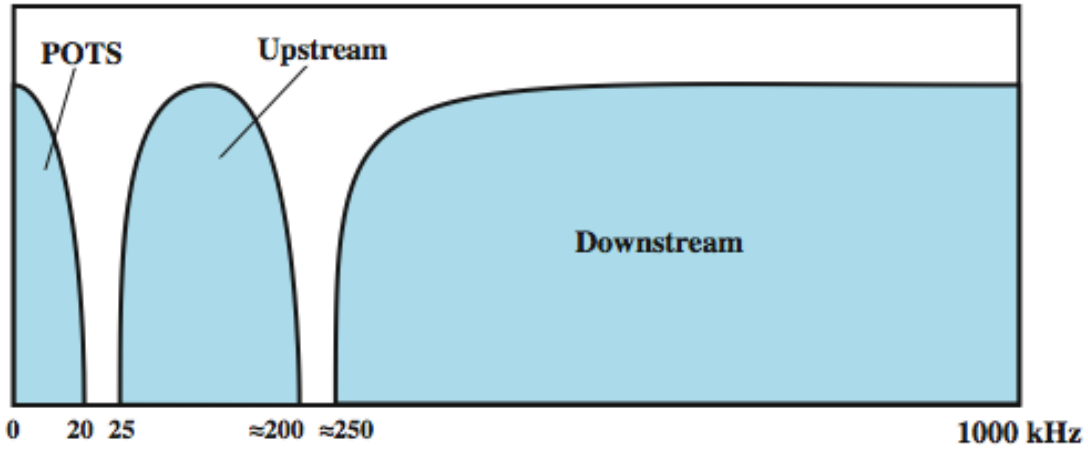


(c) Subframe with multiple sources per frame

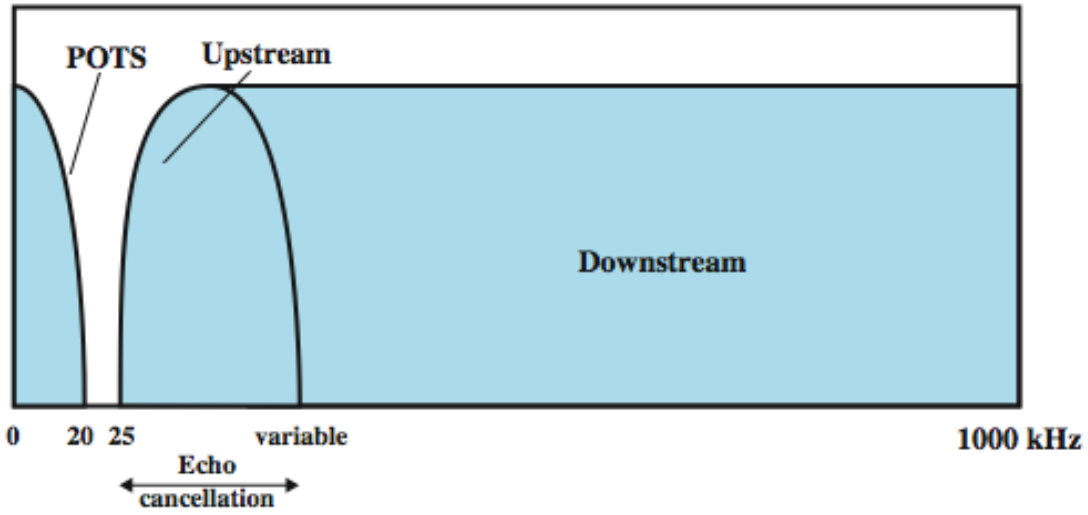
Asymmetric Digital Subscriber Lines (ADSL)

- Link between subscriber and network
- Uses currently installed twisted pair cable
- Is Asymmetric - bigger downstream than upstream
- Uses Frequency division multiplexing
  - reserve lowest 25kHz for voice POTS (Plain Old Telephone Service
  - uses FDM or echo cancellation to support downstream and upstream data transmission
- Has a range of up to 5.5km

ADSL Channel Configuration



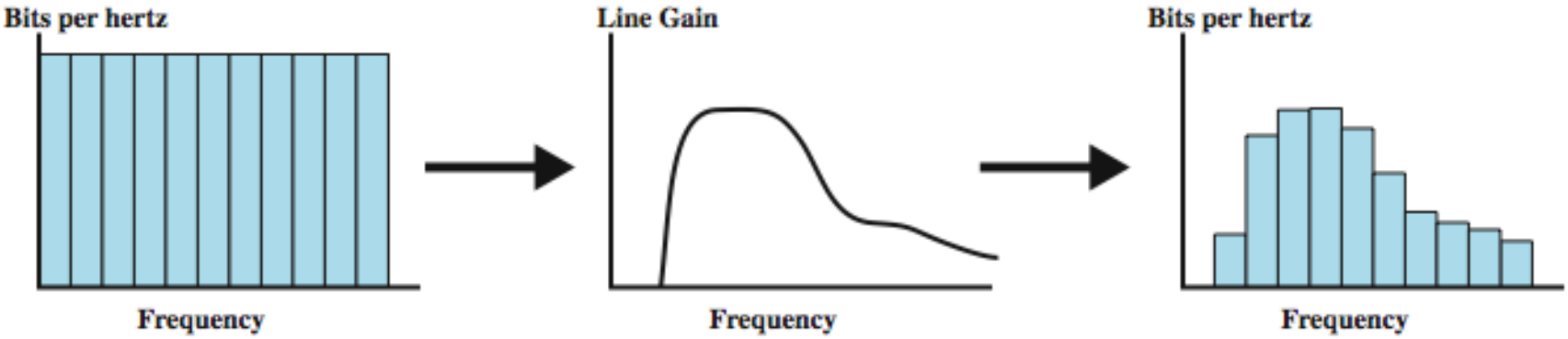
(a) Frequency-division multiplexing



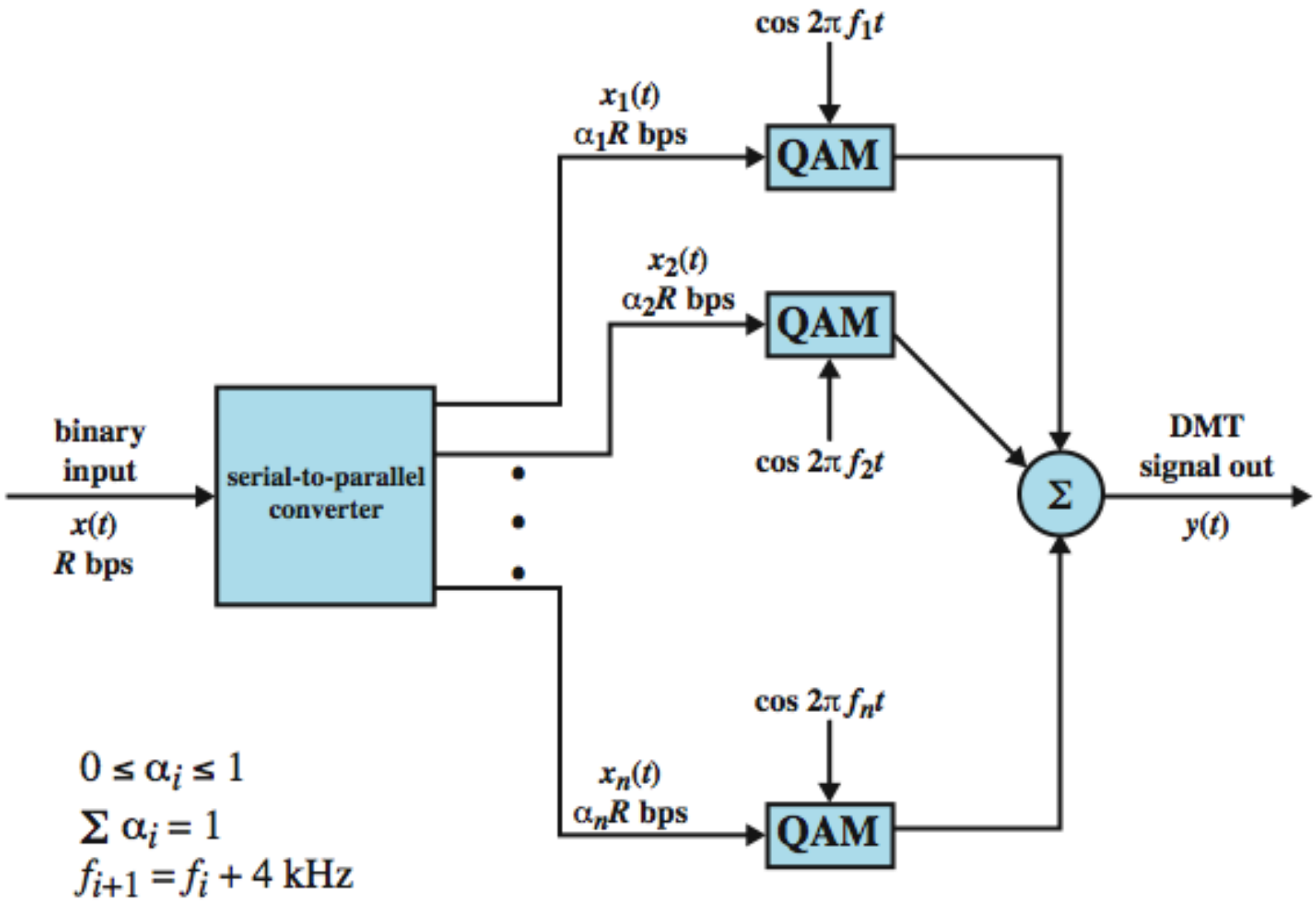
(b) Echo cancellation

Discrete Multi-Tone (DMT)

- DMT Modulation used in ADSL
- Multiple carrier signals at different frequencies
- Divide into 4kHz sub-channels
- Test and use subchannels with better SNR
- Present ADSL/DMT designs employ 256 downstream subchannels at 4kHz (60kbps)
  - in theory 15.36Mbps, in practice 1.5-9Mbps



Discrete Multi-Tone (DMT) Transmitter



$0 \le \alpha_i \le 1$

$\sum \alpha_i = 1$

$f_{i+1} = f_i + 4$ kHz

xDSL

- High data rate DSL (HDSL)
  - 2B1Q coding on dual twisted pairs(upstream & downstream)
  - up to 2Mbps over 3.7km
- Single line DSL (SDSL)
  - 2B1Q coding on single twisted pair (residential)
  - echo cancelling to separate upstream and downstream
  - up to 2Mbps over 3.7km
- Very high data rate DSL (VDSL)
  - DMT/QAM for very high data rates
  - separate bands for separate services
    - POTS: 0-4KHz
    - ISND: 4-80KHz
    - Upstream: 300-700KHz
    - Downstream: >1MHz

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	≥ 10 MHz
Bits/cycle	Varies	4	4	Varies