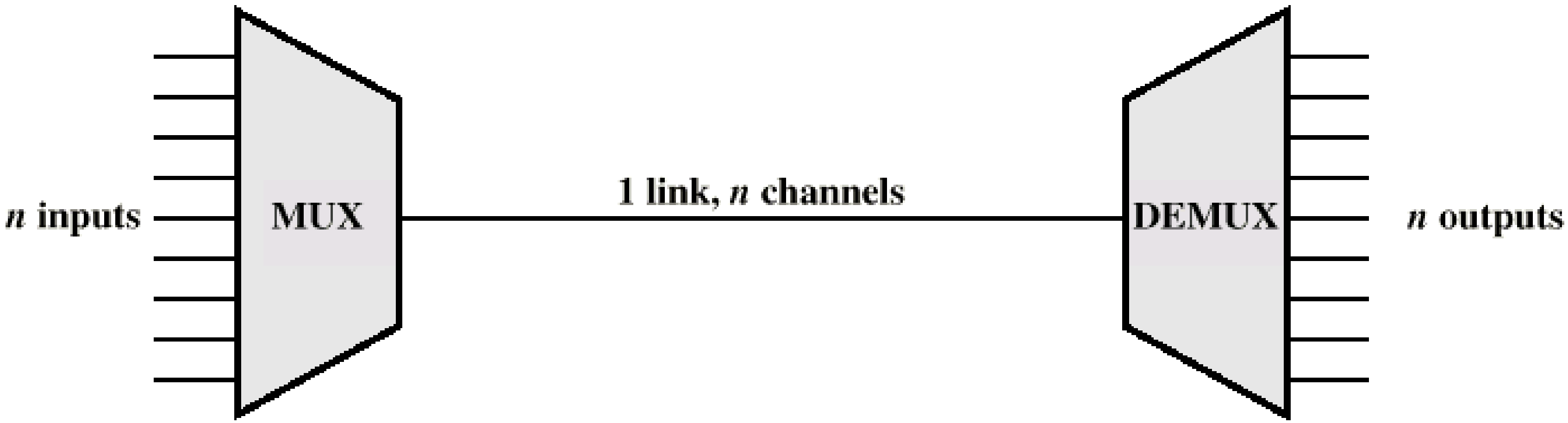
Multiplexing



How to share the capacity of a data link?

- FDM: Frequency Division Multiplexing
- TDM: Time Division Multiplexing (Synch, Stat)
- CDMA

Multiplexing

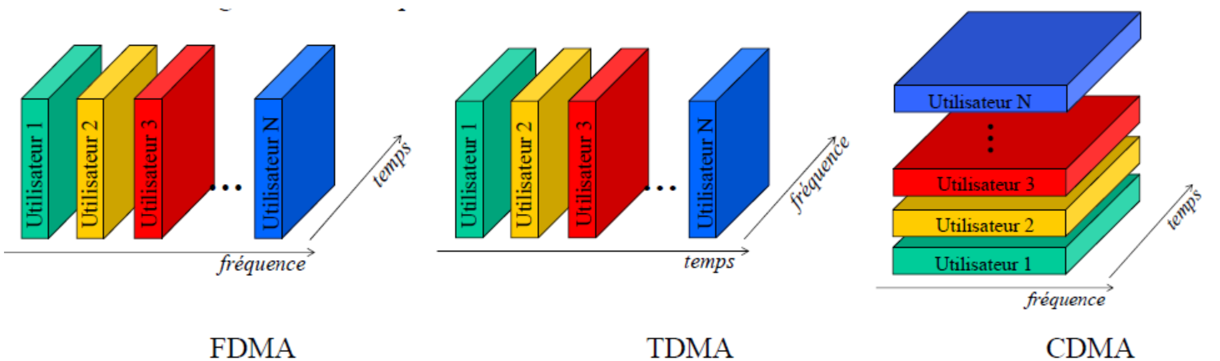


Fig. 83 - Les différentes méthodes d'accès multiples déterministes

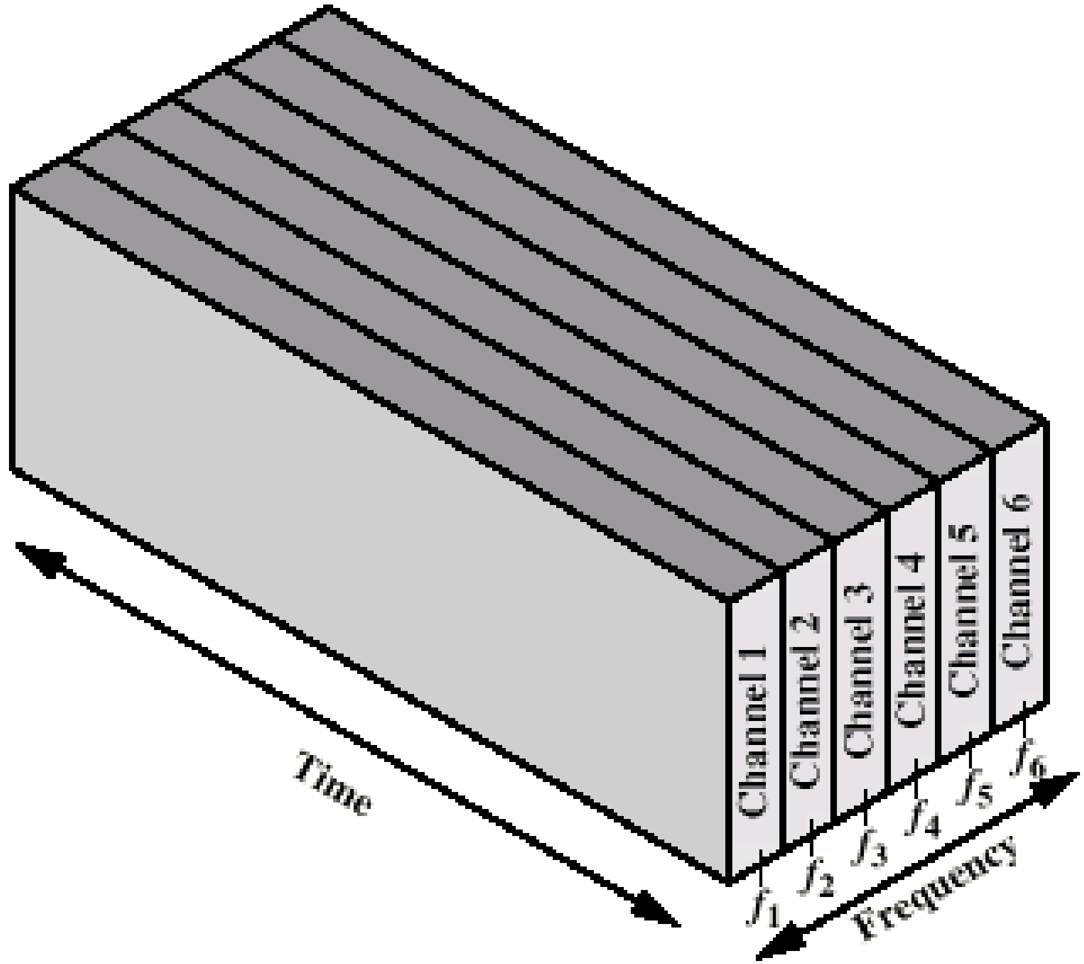
Frequency Division Multiplexing

- FDM: A number of signals can be carried simultaneously.
  - Each signal is modulated to a different carrier frequency
  - Carrier frequencies are sufficiently separated so signals do not overlap (guard bands)
- Available bandwidth of medium exceeds the sum of all channels
- Examples: broadcast radio, cable TV
- Channel allocated even if no data

Terminologies

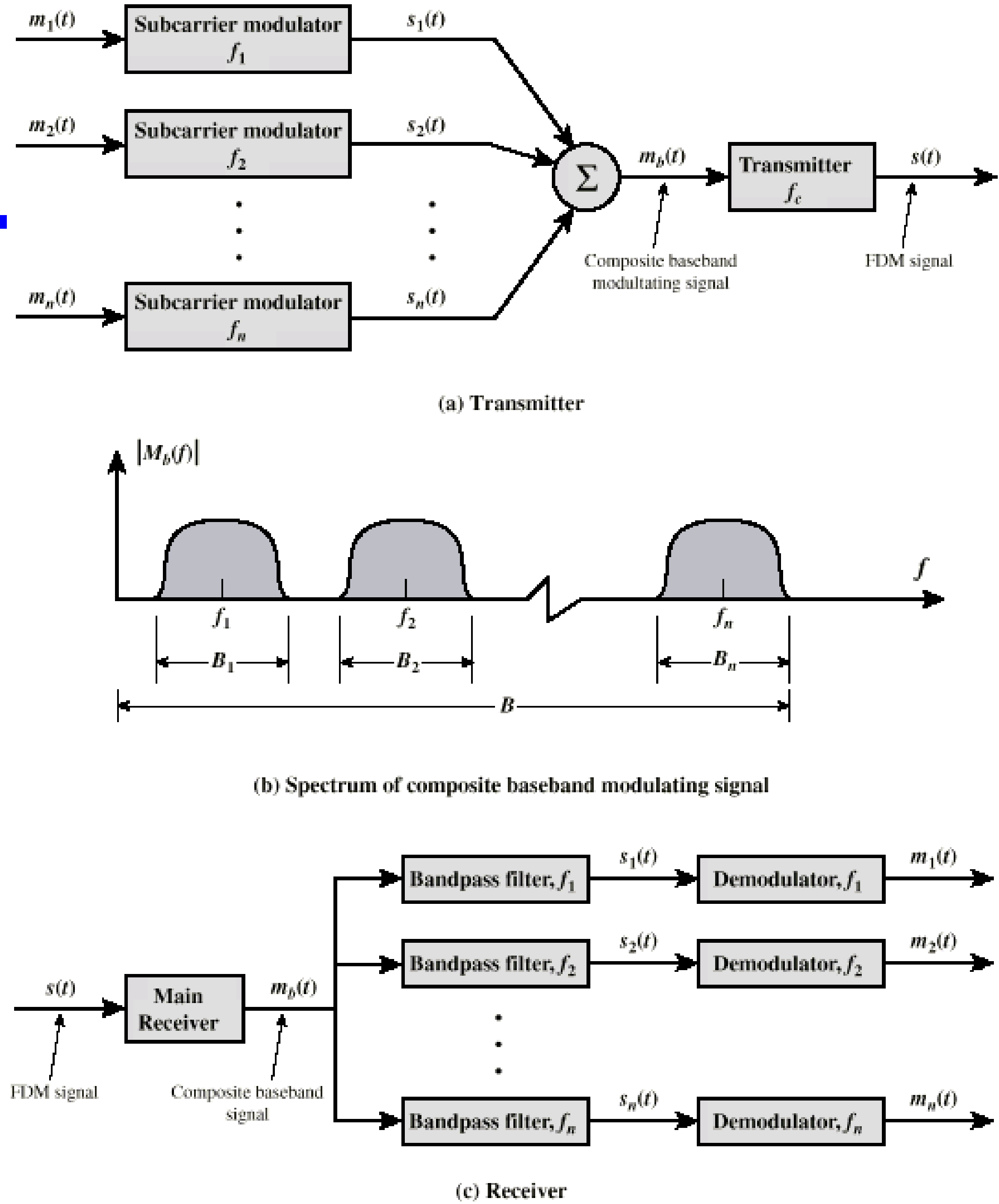
- Channel (FDM): each modulated signal requires a certain bandwidth centered on its carrier frequency, referred to as a **channel**.
- Subcarrier: each of the multiple carriers is referred to as a **subcarrier**. Its frequency is denoted by f_i. f_i must be chosen so that the bandwidths of various signals do not significantly overlap.

Frequency Division Multiplexing Diagram



FDM System

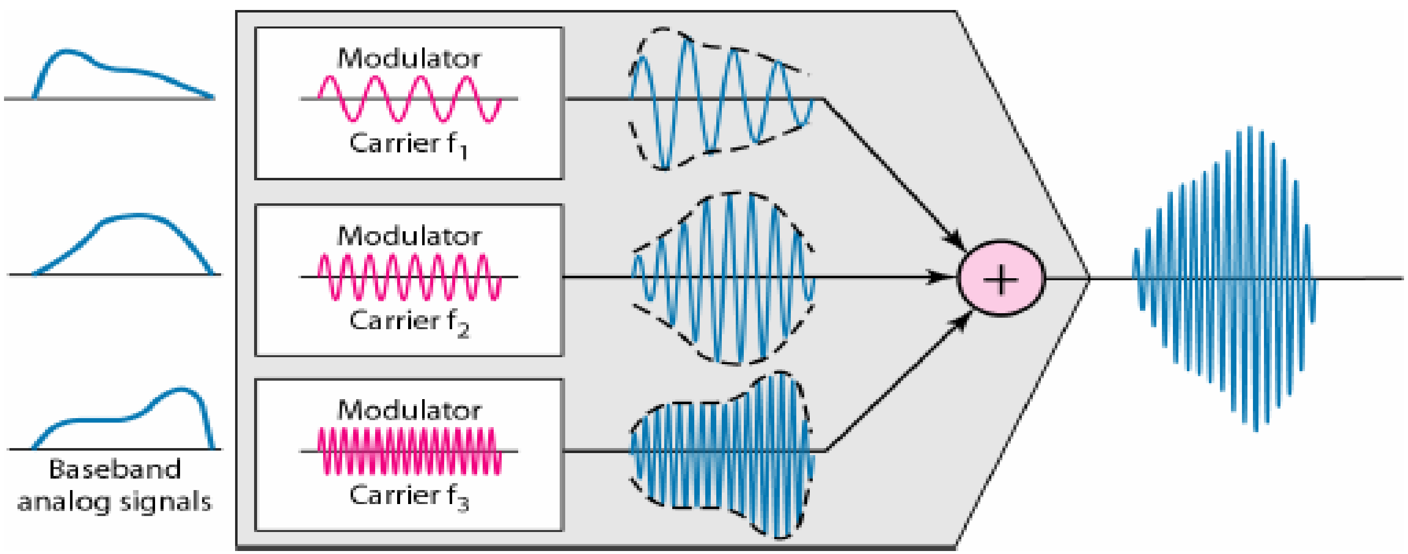
$$B > \sum_{i=1}^{n} B_i$$



Frequency Division Multiplexing Diagram

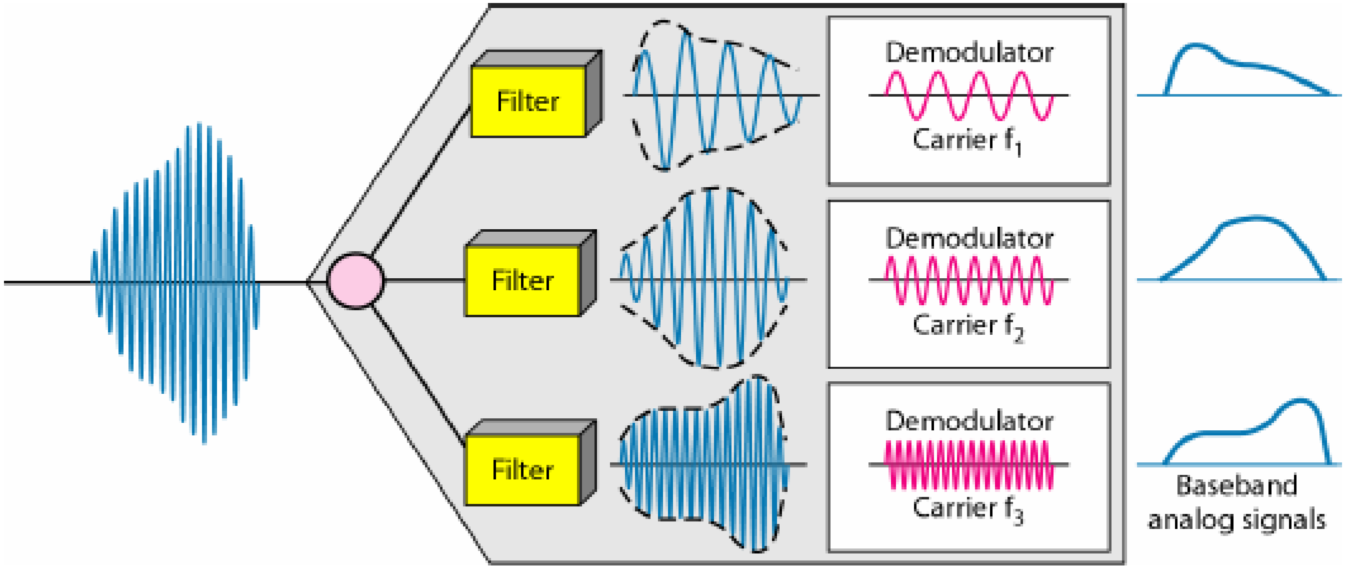
Frequency Division Multiplexing

FDM multiplexing example



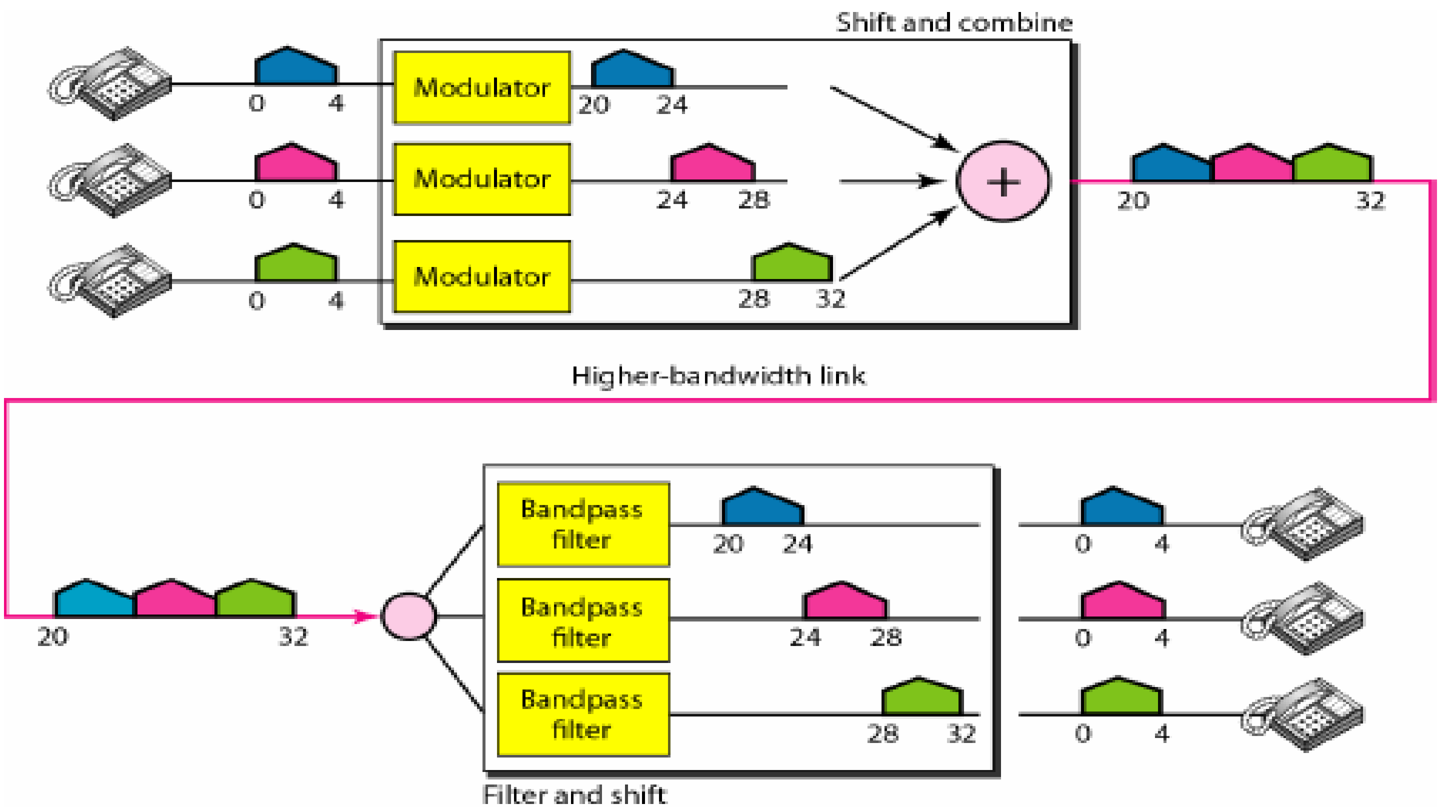
Frequency Division Multiplexing

FDM demultiplexing example



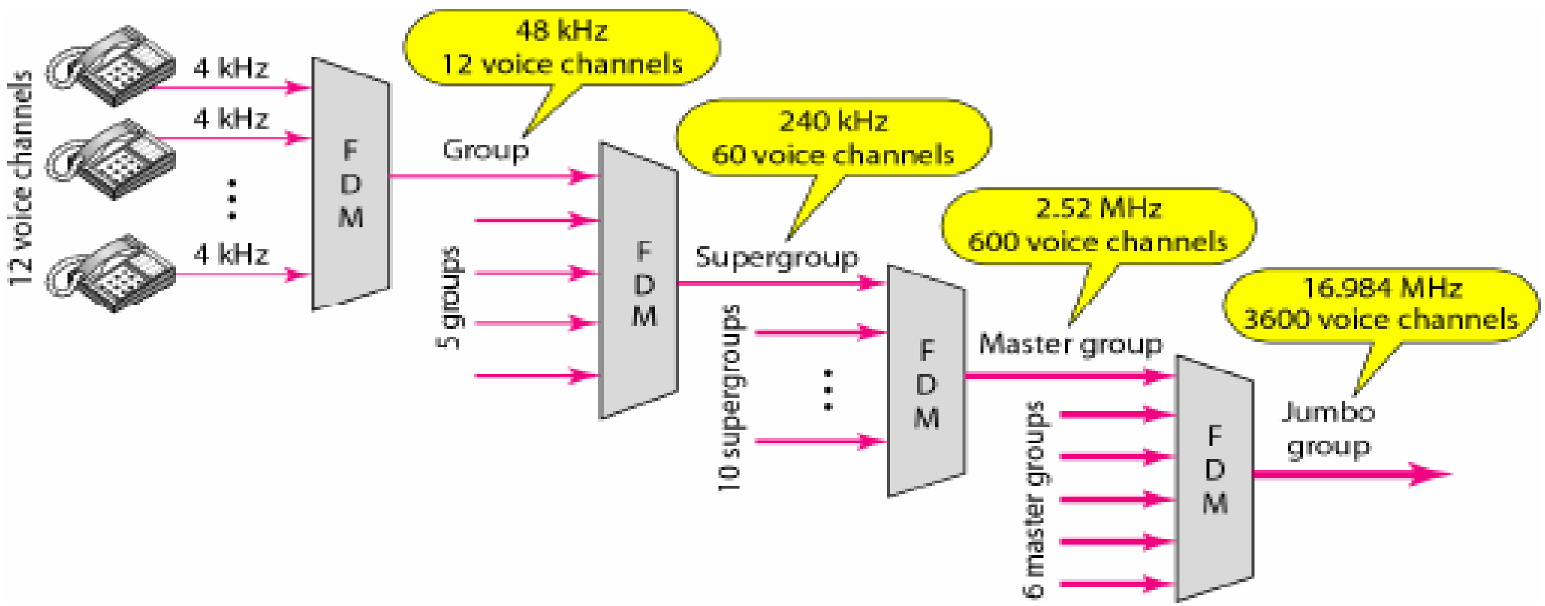
Frequency Division Multiplexing

Example

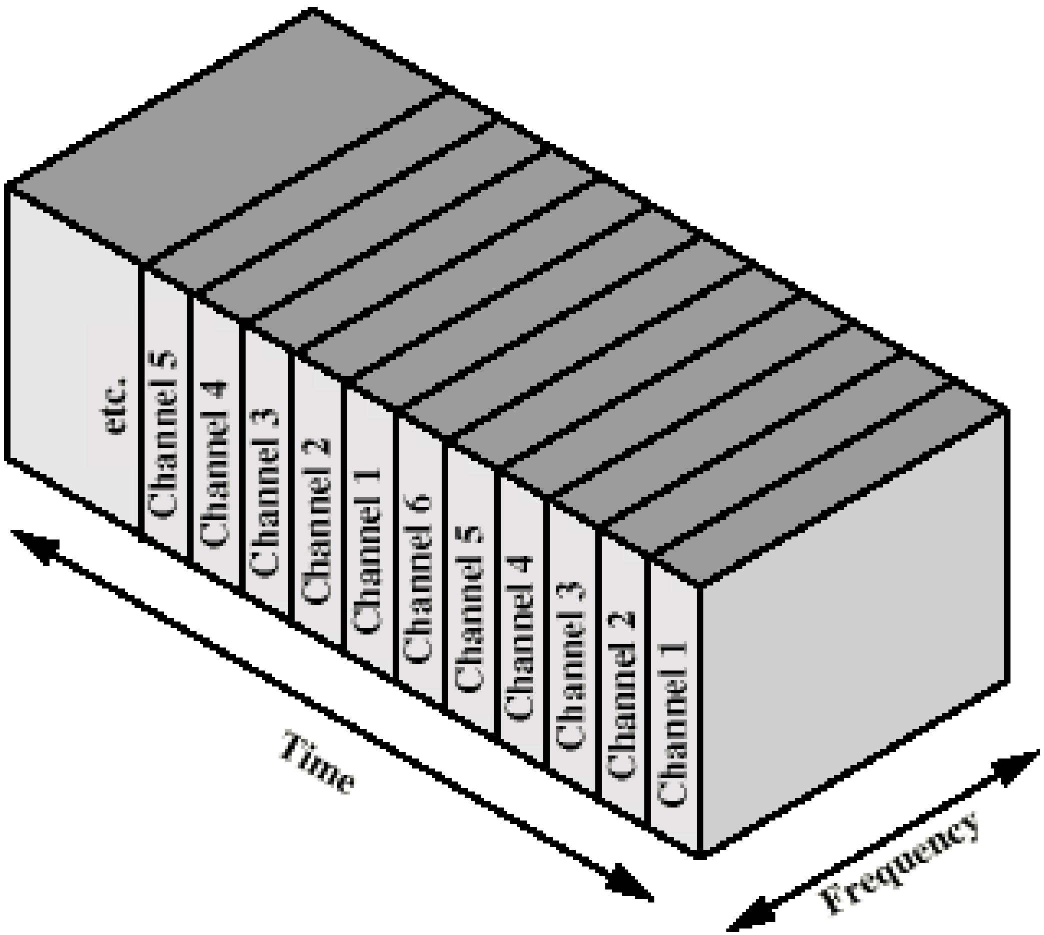


Frequency Division Multiplexing

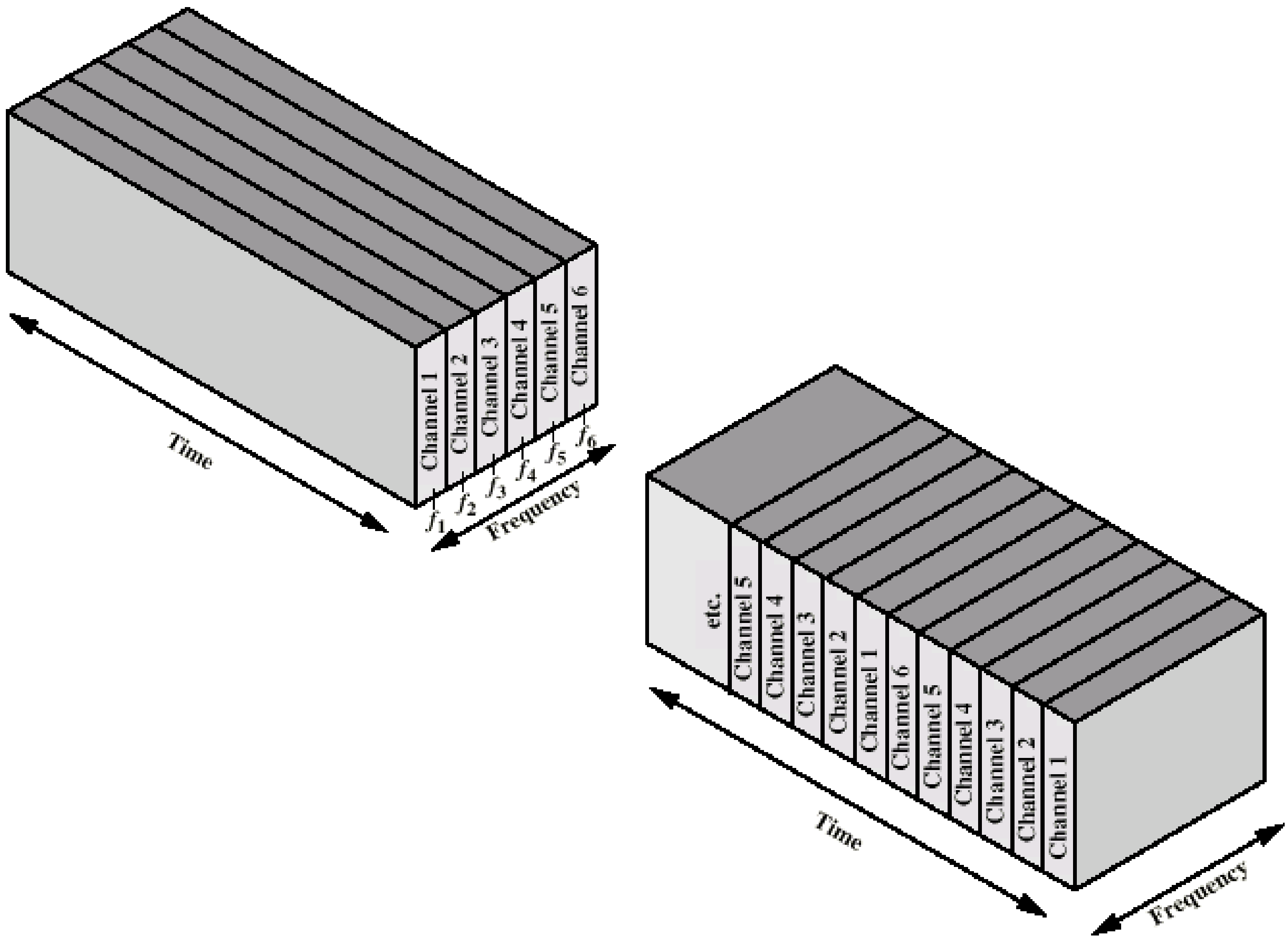
Analog hierarchy



Time Division Multiplexing

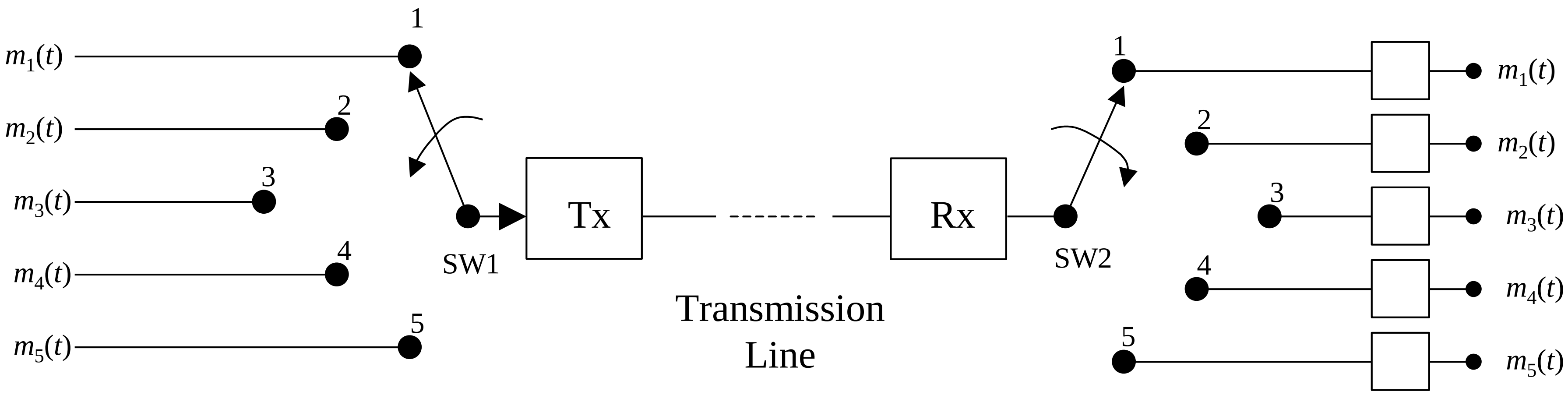


FDM vs TDM



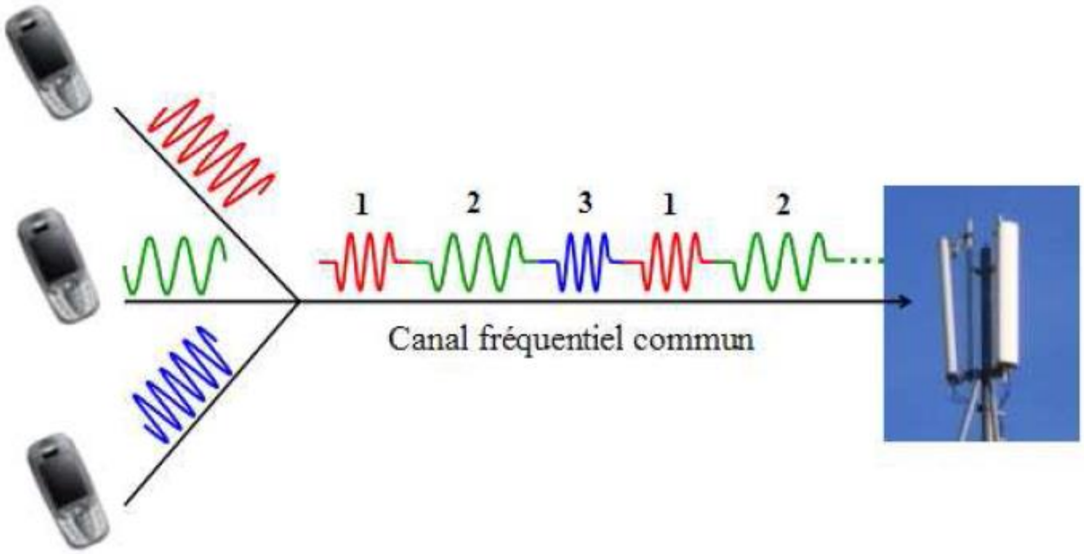
Channel 1
Channel 2
Channel 3
Channel 4
Channel 5
Channel 6
f_1
f_2
f_3
f_4
f_5
f_6
Time
Frequency
etc.
Channel 5
Channel 4
Channel 3
Channel 2
Channel 1
Channel 6
Channel 5
Channel 4
Channel 3
Channel 2
Channel 1
Time
Frequency

FDM vs TDM



$m_1(t)$
$m_2(t)$
$m_3(t)$
$m_4(t)$
$m_5(t)$
1
2
3
4
5
SW1
Tx
Transmission
Line
Rx
SW2
1
2
3
4
5
$m_1(t)$
$m_2(t)$
$m_3(t)$
$m_4(t)$
$m_5(t)$

TDM



Terminologies

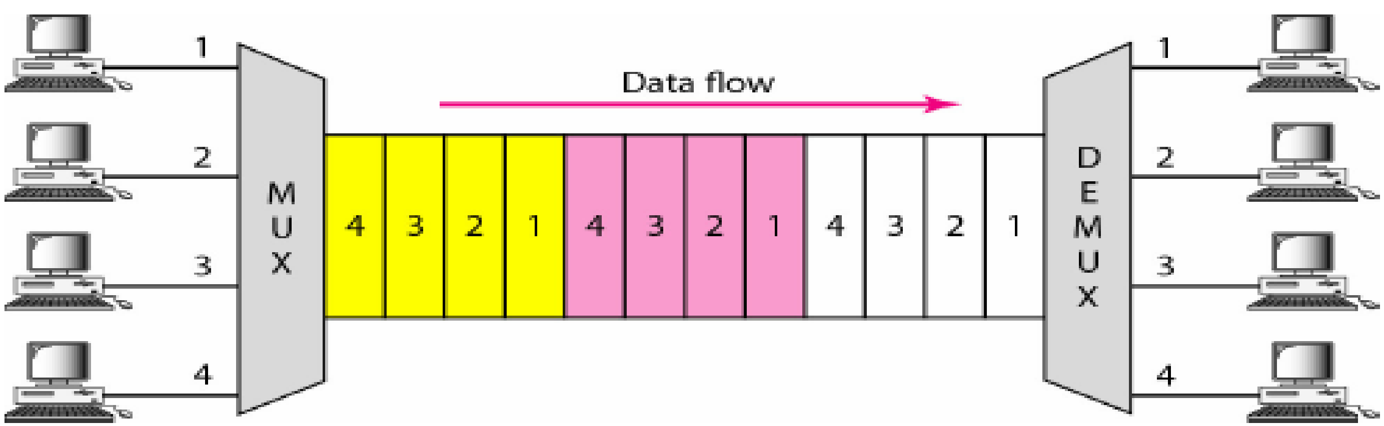
- Frames: a cycle of time slots, each of which is dedicated to a data source.
- Channel (TDM): the sequence of slots dedicated to one source, from frame to frame, is called a **channel**.

TDM

Time Division Multiplexing (TDM)

Note

TDM is a digital multiplexing technique for combining several low-rate channels into one high-rate one.



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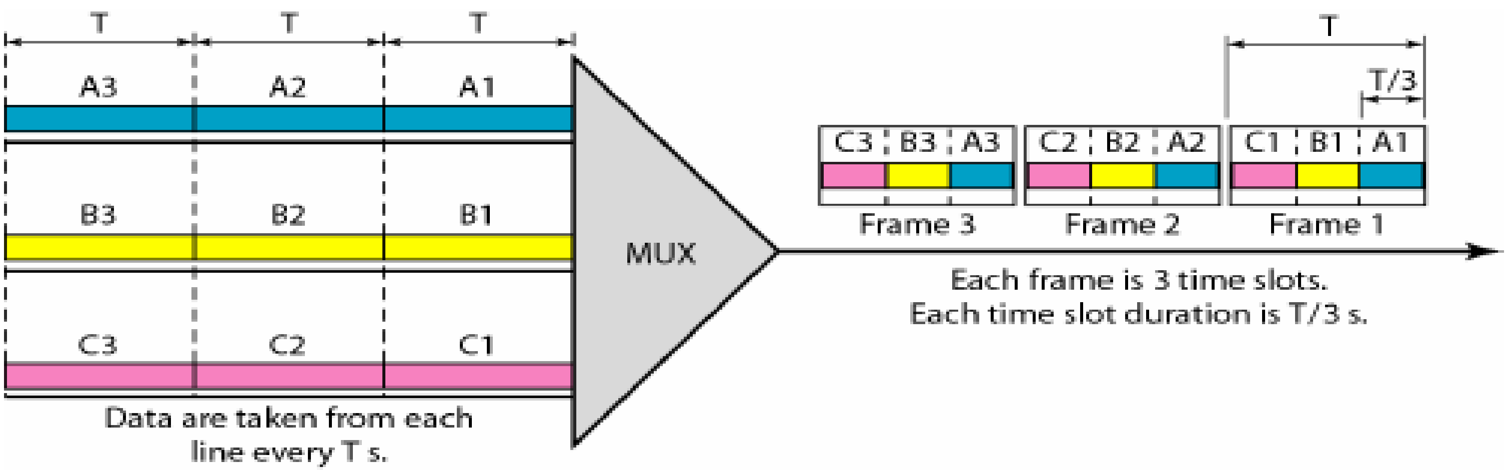
TDM

Synchronous Time Division Multiplexing

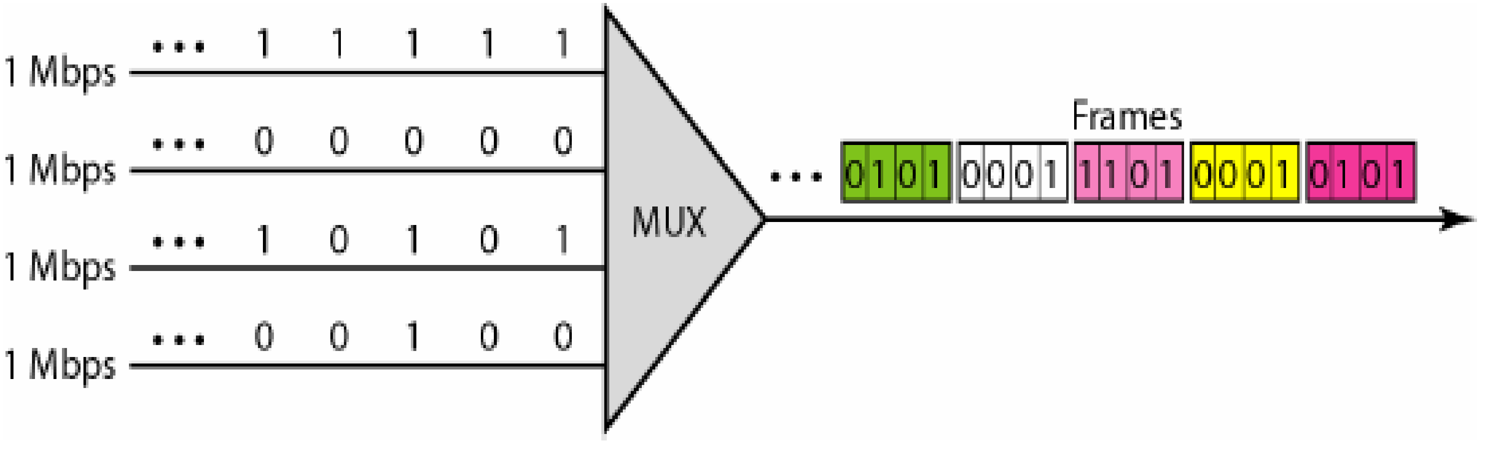


Note

In synchronous TDM, the data rate of the link is *n* times faster, and the unit duration is *n* times shorter.

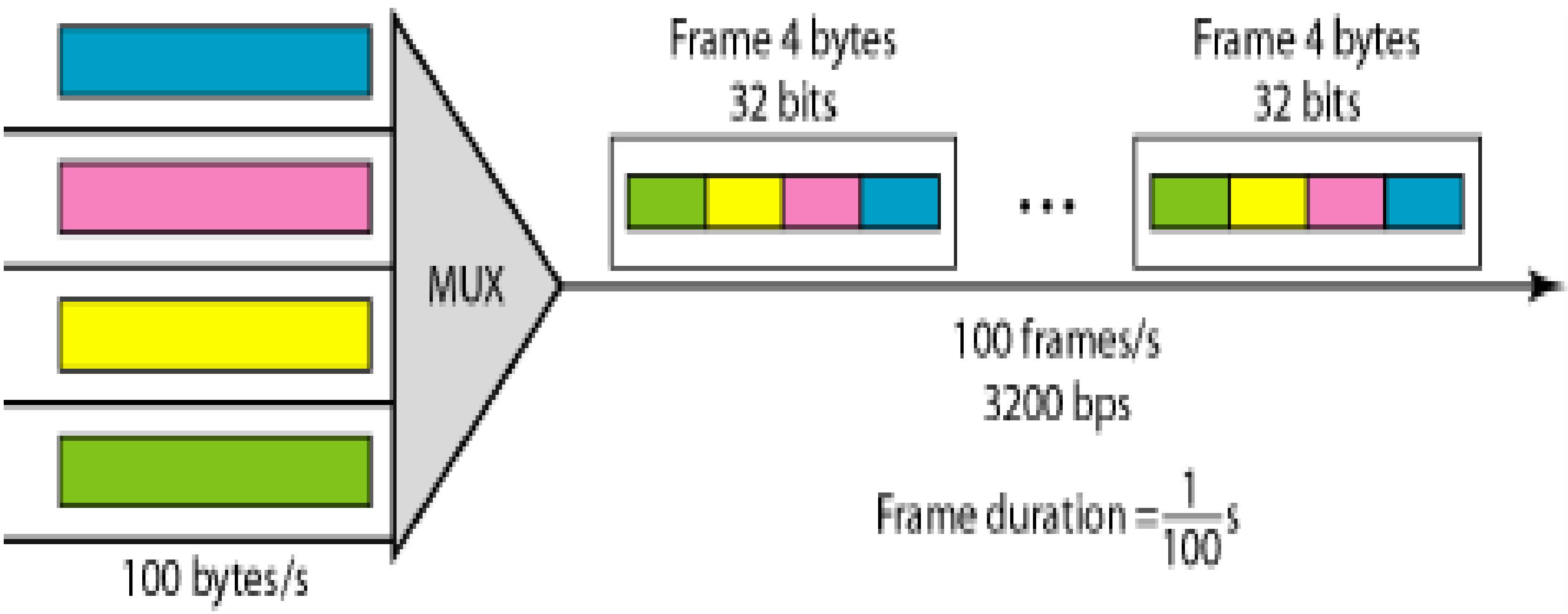
TDM

Example



1 Mbps
• • • 1 1 1 1 1
1 Mbps
• • • 0 0 0 0 0
1 Mbps
• • • 1 0 1 0 1
1 Mbps
• • • 0 0 1 0 0
MUX
Frames
• • • 0101 0001 1101 0001 0101

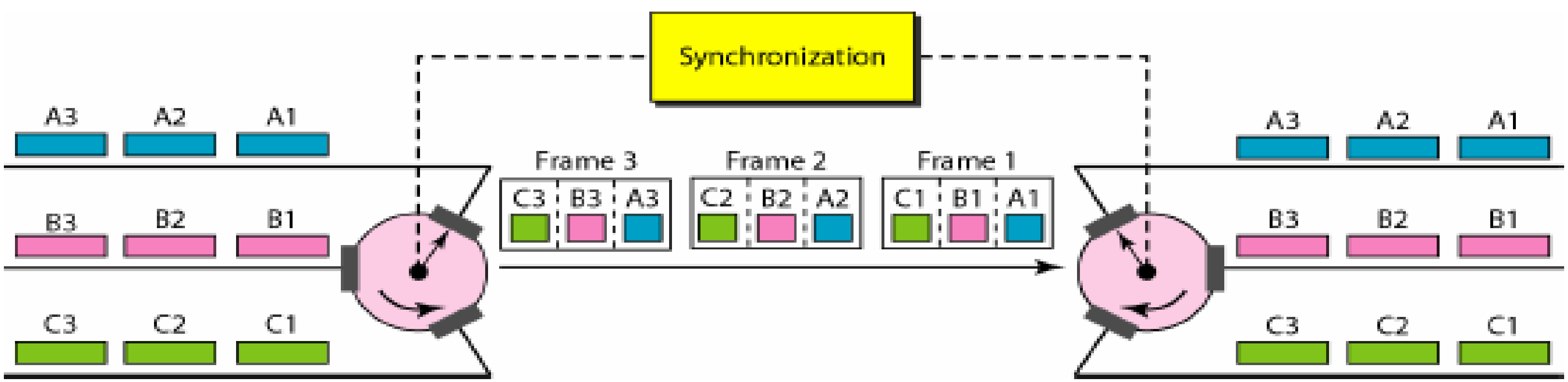
TDM


Frame 4 bytes
32 bits
Frame 4 bytes
32 bits
MUX
100 frames/s
3200 bps
Frame duration = 1/100 s
100 bytes/s

TDM

Interleaving

• TDM can be visualized as two fast rotating switches, one on the MUX side and the other on the DEMUX side. The switches are synchronized and rotate at the same speed but in opposite directions. On the MUX side, as the switch opens in front of a connection, that connection has the opportunity to send a unit onto the path. This process is called **inteleaving**.



TDM Synchronization

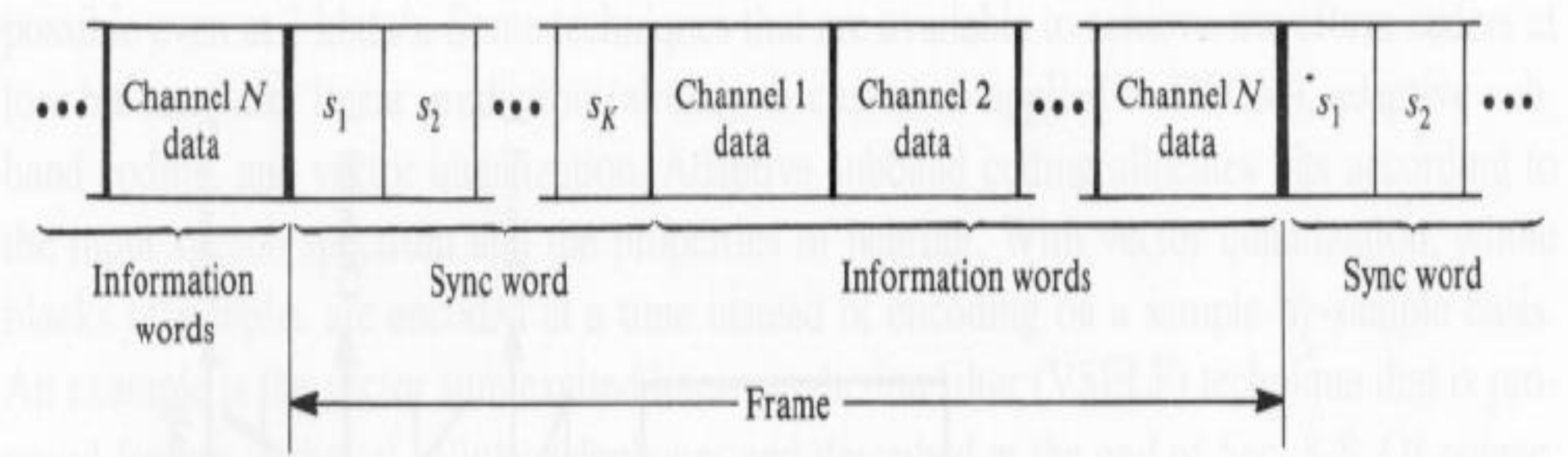
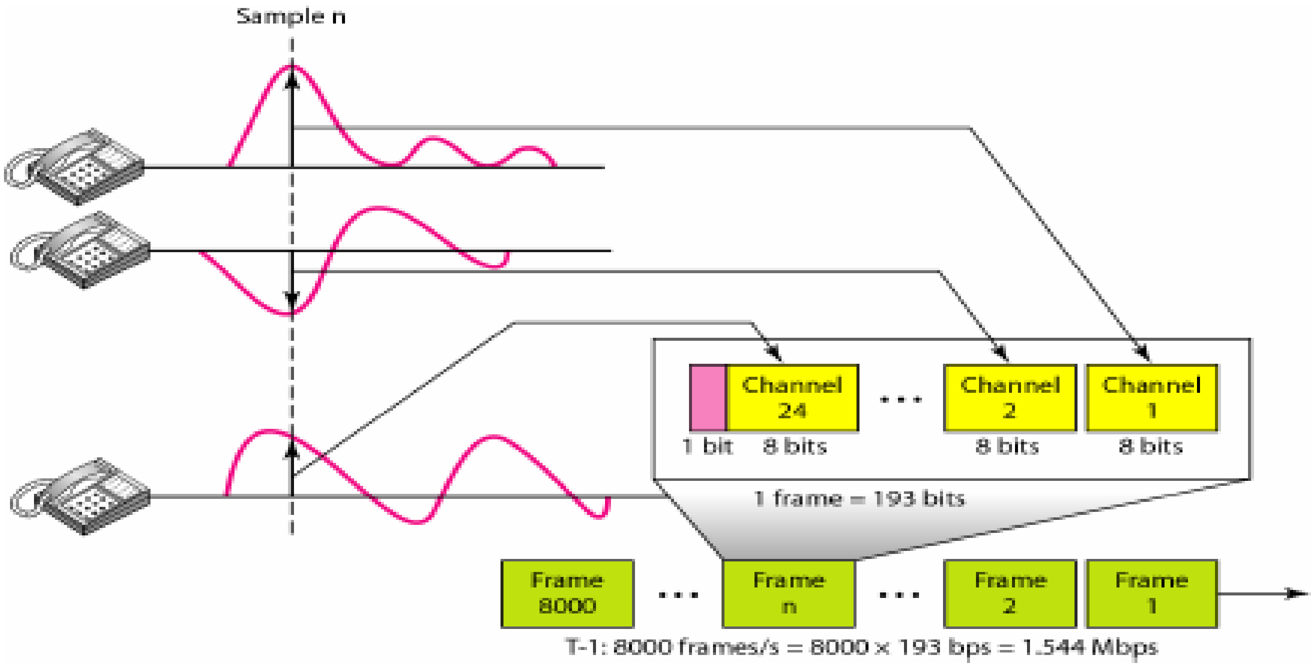


Figure 3-36 TDM frame sync format.

TDM

DS-1 requires 8 kbps overhead due to the synchronization bit:

T1 line = 24 slots x 8 bits + 1 bit for synchronization = 193 bits x 8kbps = 1.544Mbps

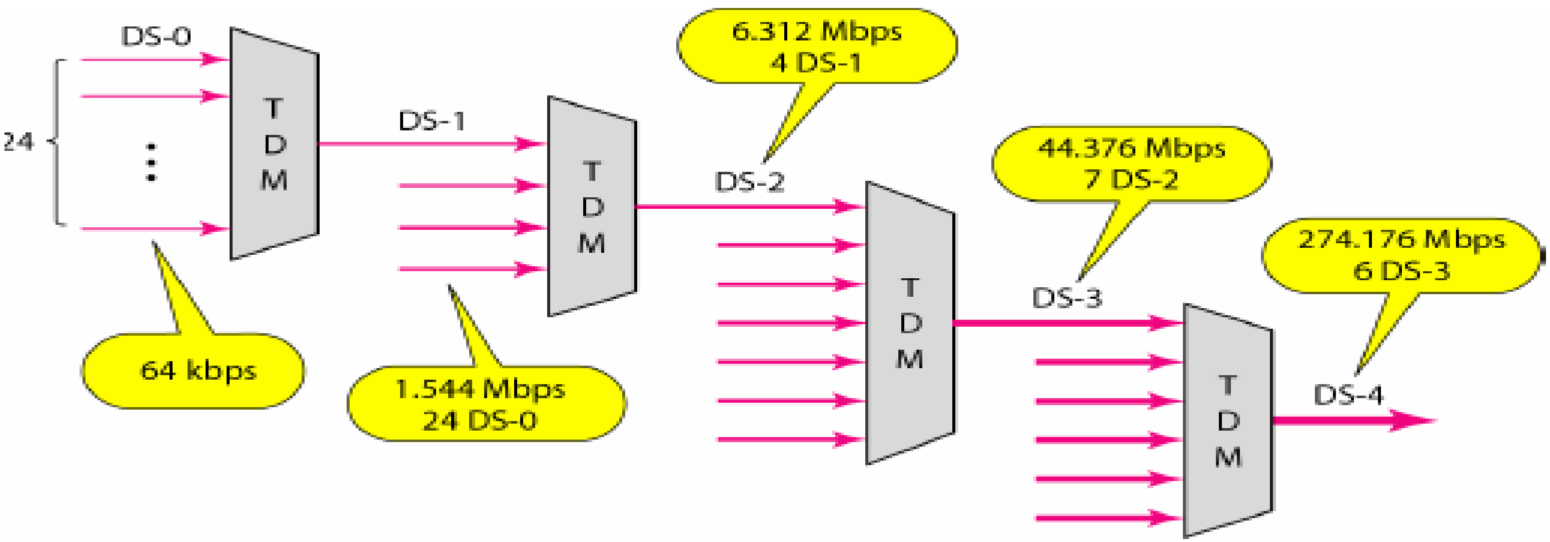


TDM

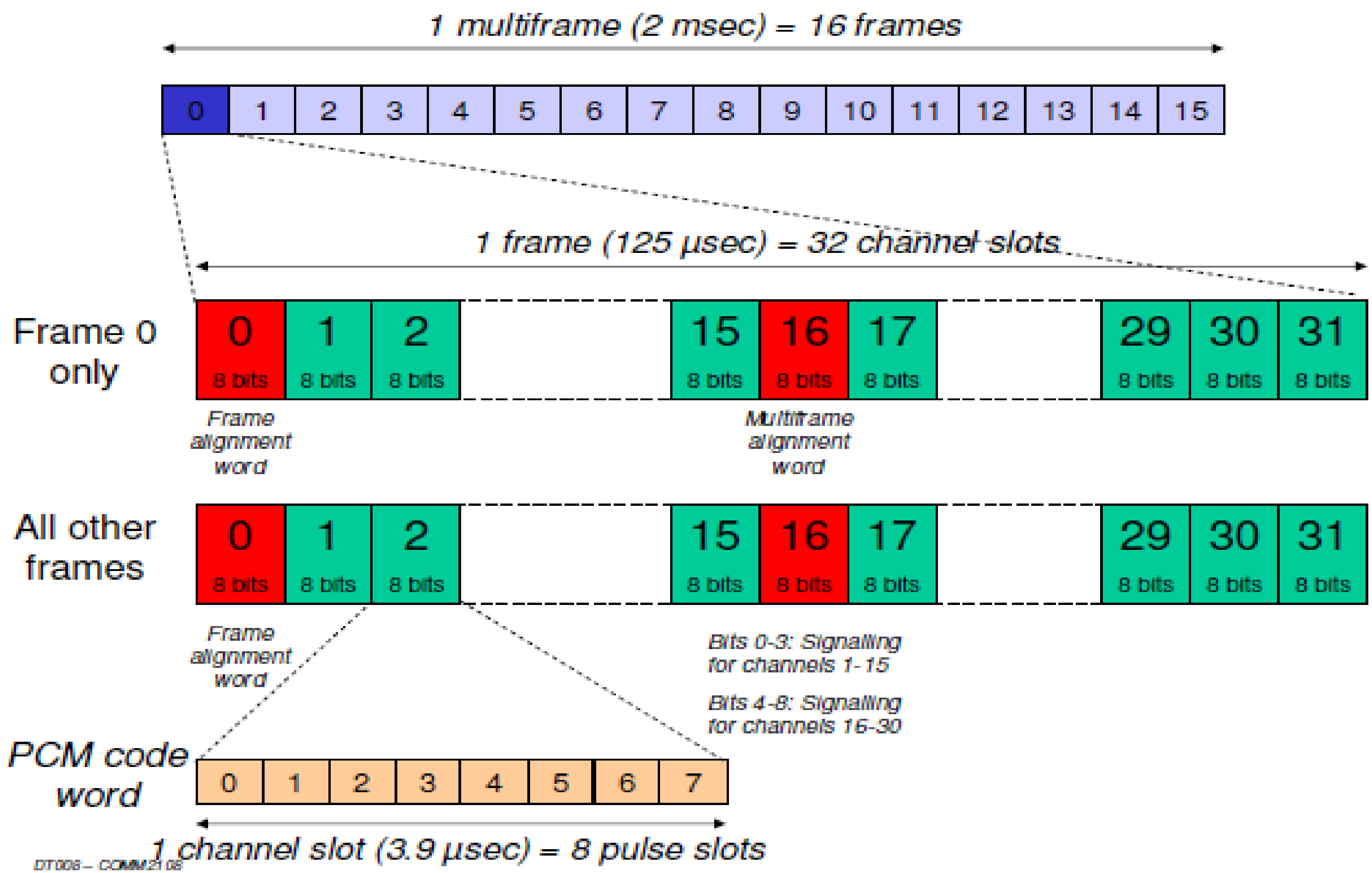
Digital hierarchy

Telephone companies implement TDM through a hierarchy of digital signals, called **Digital Signal** (DS) Service.

The following figure shows the data rates supported by each level:



TDM



1 multiframe (2 msec) = 16 frames
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
1 frame (125 µsec) = 32 channel slots
Frame 0 only
0 8 bits
1 8 bits
2 8 bits
15 8 bits
16 8 bits
17 8 bits
29 8 bits
30 8 bits
31 8 bits
Frame alignment word
Multiframe alignment word
All other frames
0 8 bits
1 8 bits
2 8 bits
15 8 bits
16 8 bits
17 8 bits
29 8 bits
30 8 bits
31 8 bits
Frame alignment word
Bits 0-3: Signalling for channels 1-15
Bits 4-8: Signalling for channels 16-30
PCM code word
0 1 2 3 4 5 6 7
1 channel slot (3.9 µsec) = 8 pulse slots

TDM

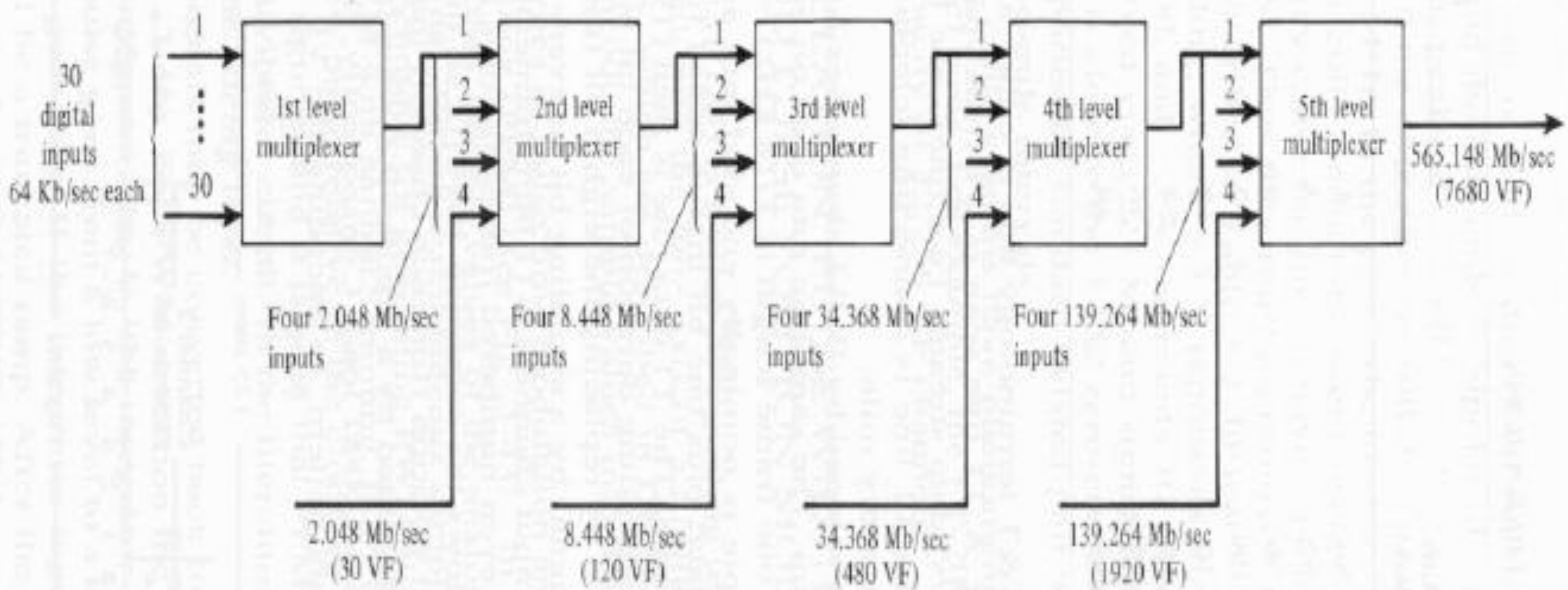
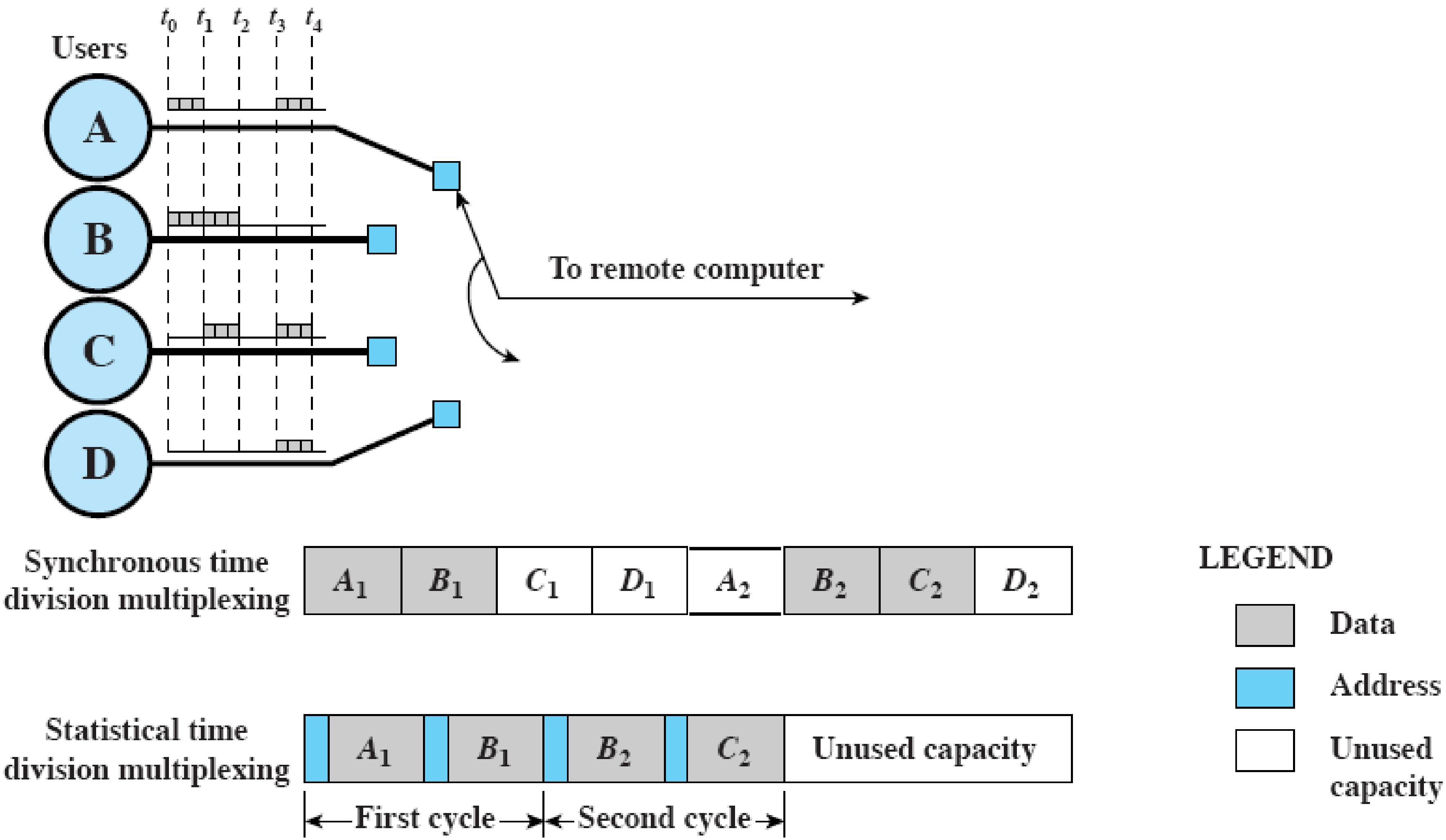


Figure 3-41 CCITT digital TDM hierarchy

Statistical TDM

- In Synchronous TDM many slots are wasted
- Statistical TDM allocates time slots **dynamically** based on demand
- Multiplexer scans input lines and collects data until frame full
- Data rate on line lower than aggregate rates of input lines

Synchronous TDM vs. Statistical TDM



CDMA

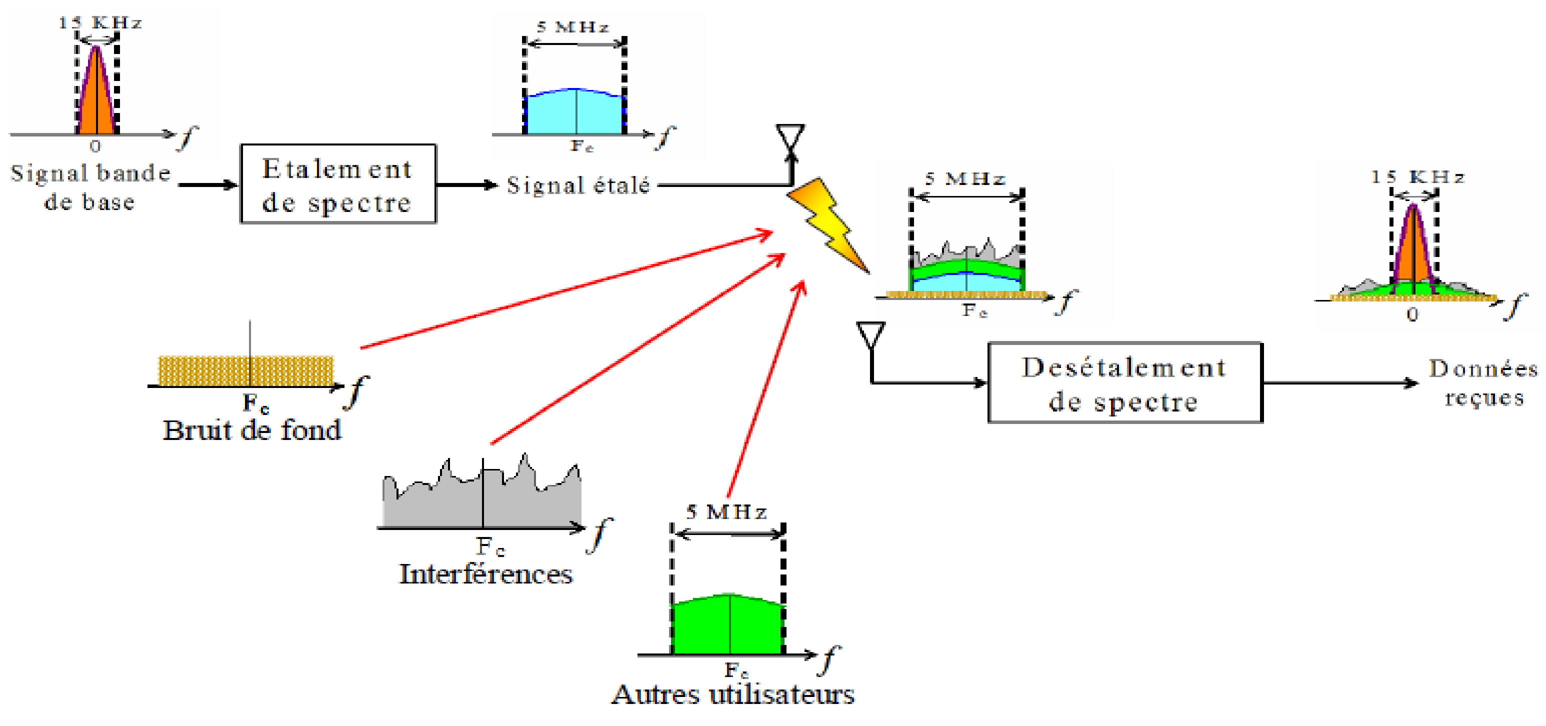
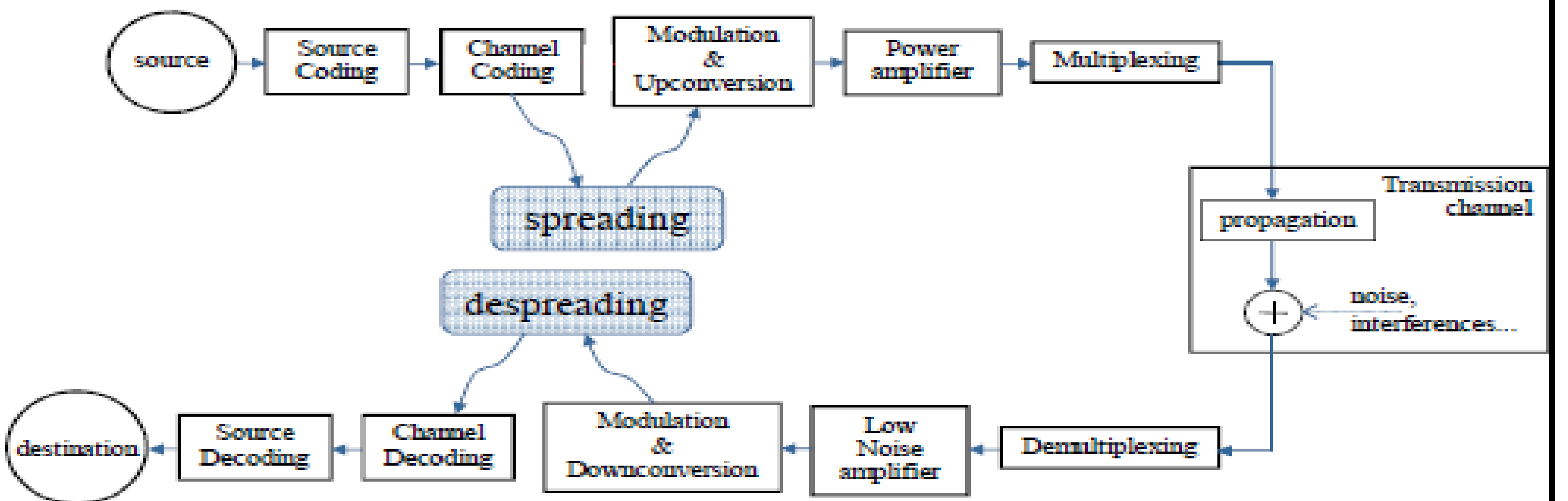


Fig. 85 – Principe du processus étalement/desétalement de spectre employé en CDMA

CDMA

Transmission chain



- The spreading sequence consists of +1 and -1.
  ⇒ the power of the transmitted signal remains unchanged.

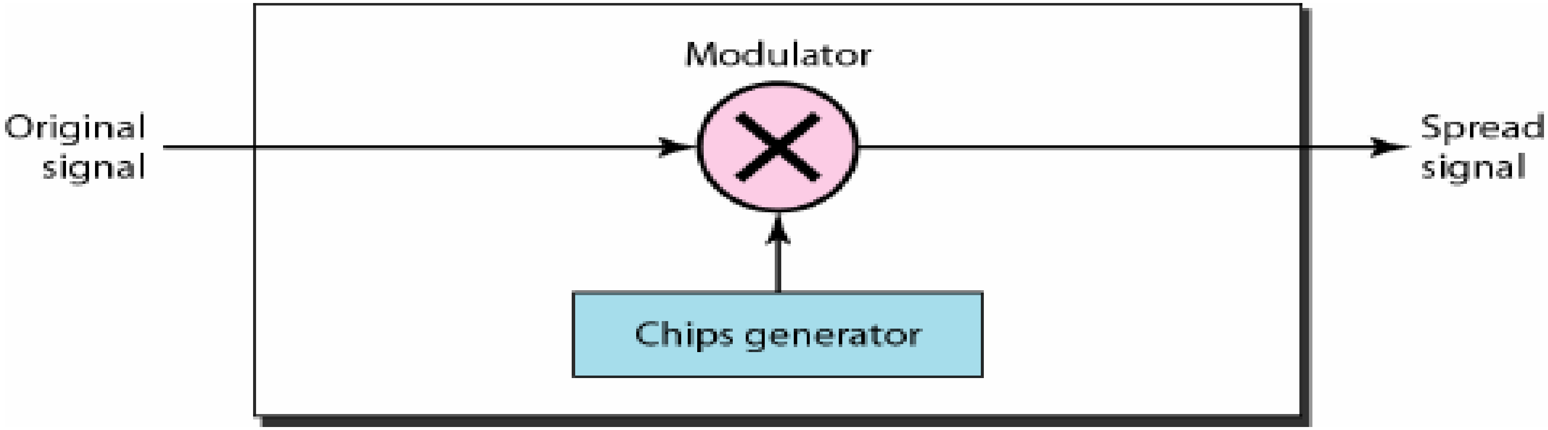
CDMA

Direct Sequence Spread Spectrum (DSSS)

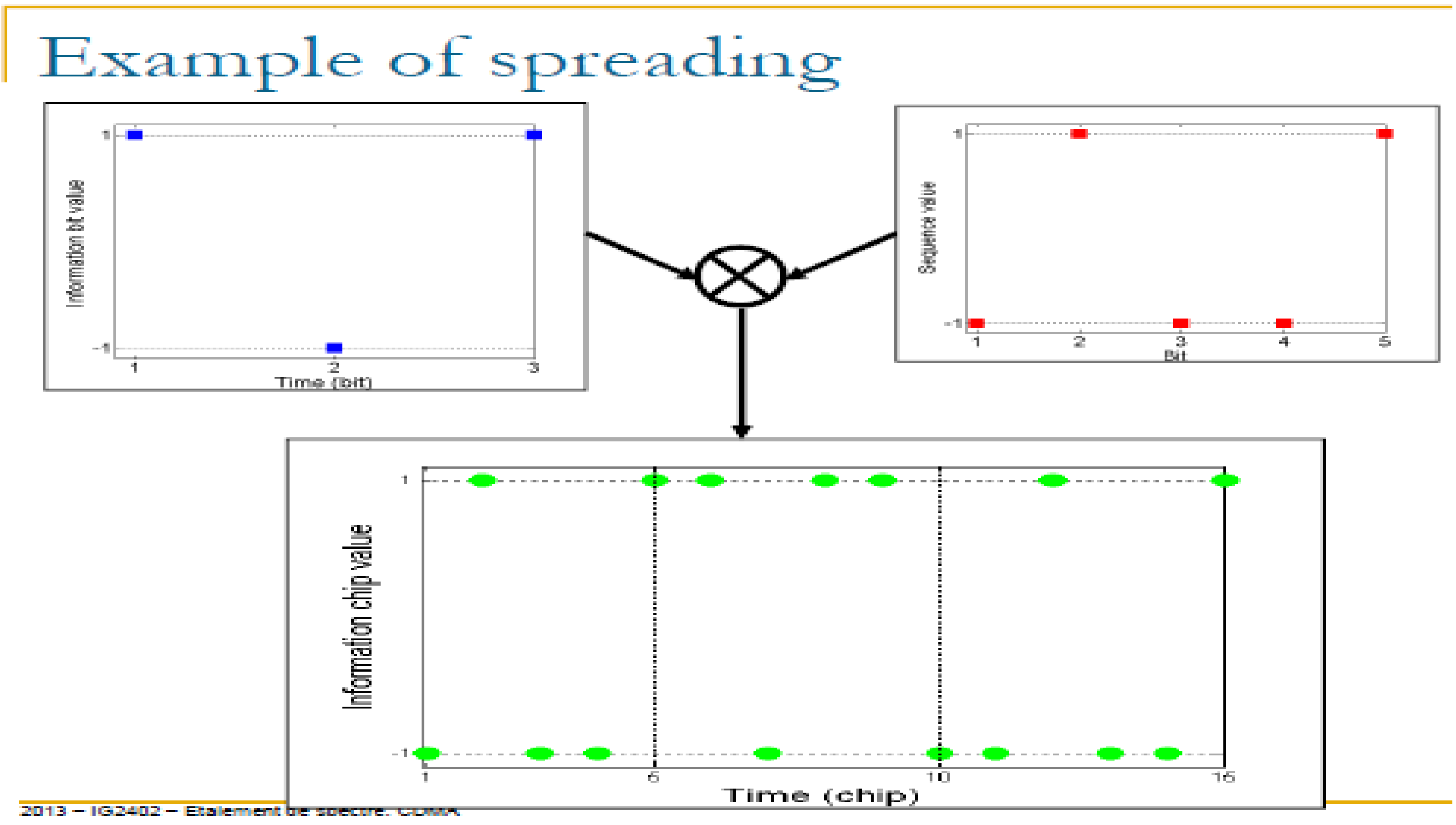
With DSSS each bit in the original signal is represented by multiple bits in the transmitted signal using a spreading code.

The spreading code spreads the signal across a wider frequency band in direct proportion to the number of bits used.

> eg. a 10-bit spreading spreading code spreads the signal across a frequency band that is 10 times greater than a 1-bit spreading code.

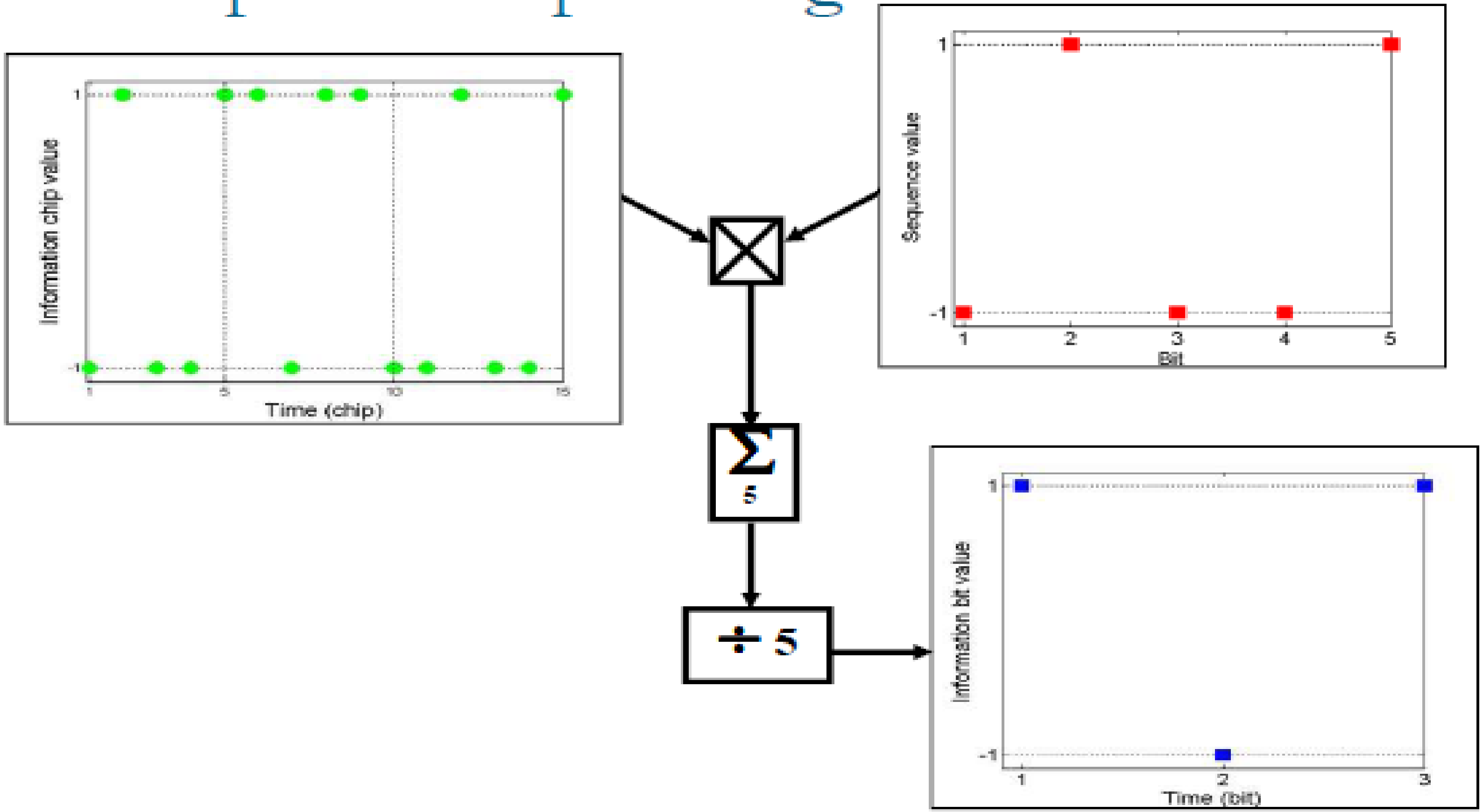


CDMA


Example of spreading
Information bit value
Time (bit)
Sequence value
Bit
Information chip value
Time (chip)

CDMA

Example of despreading



CDMA

Spread spectrum: benefits (1/)

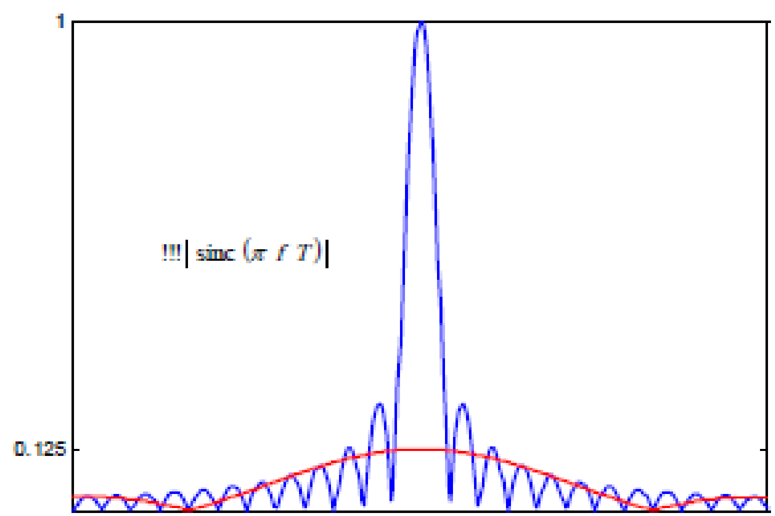
- Spectral occupancy ⇒ Resistance to (un)intended jamming
  - Recall: for a pseudo-random transmission, the PSD is (using a BPSK):

$$E_{bit} \times \left| \mathrm{sinc}\left(\pi\ f\ T_b\right)\right|^2$$

  - ⇒ with SS, the PSD is:

$$\frac{E_{bit}}{\ell} \times \left| \mathrm{sinc}\left(\pi\ f\ \frac{T_b}{\ell}\right)\right|^2$$

  - with ℓ=8:



ISEP – Domaine Réseaux & Télécommunications – Emmanuelle Vivier

CDMA

Spread spectrum: benefits (2/)

- Spreading gain ⇒ lower trans. power for same perfs.
  - Recalls:
    - for a M-ary linear modulation on a Gaussian channel: $BER \sim Q\left(f(M) \times \sqrt{\frac{E_{bit}}{N_0}} \right)$
    - for a linear transmission, the signal-to-noise ratio is: $C/N = \frac{E_{bit}}{N_0}$
  - for a spread-spectrum transmission, the signal-to-noise ratio is:

$$C/N = \boxed{\frac{1}{\ell}} \times \frac{E_{bit}}{N_0}$$

  - *exemple:*

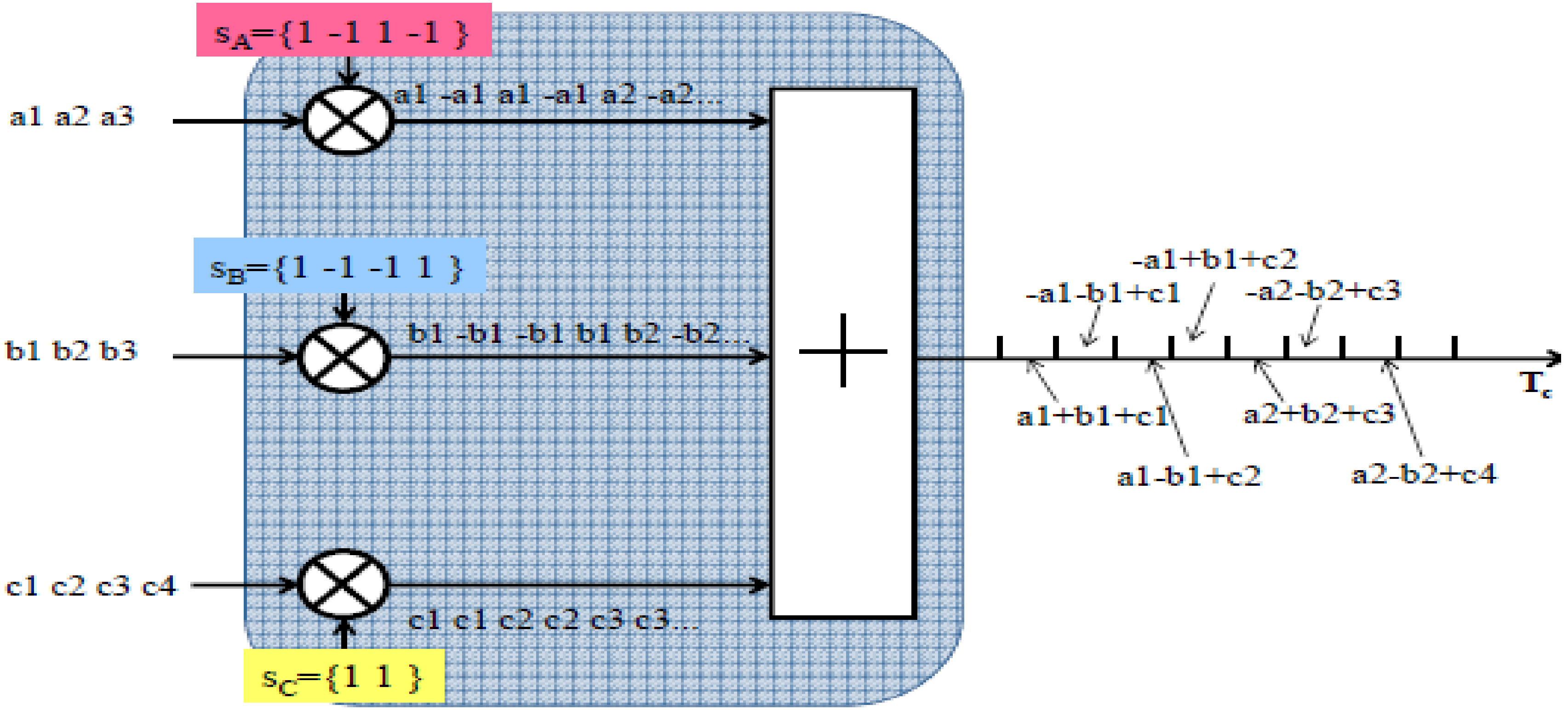
ℓ=128; QPSK, TEB=10^{-3} ⇒ E_{bit}/N_0 = 7dB

⇒ without SS : C/N = 7dB = 5

⇒ with SS : C/N = -14 dB = 1/25

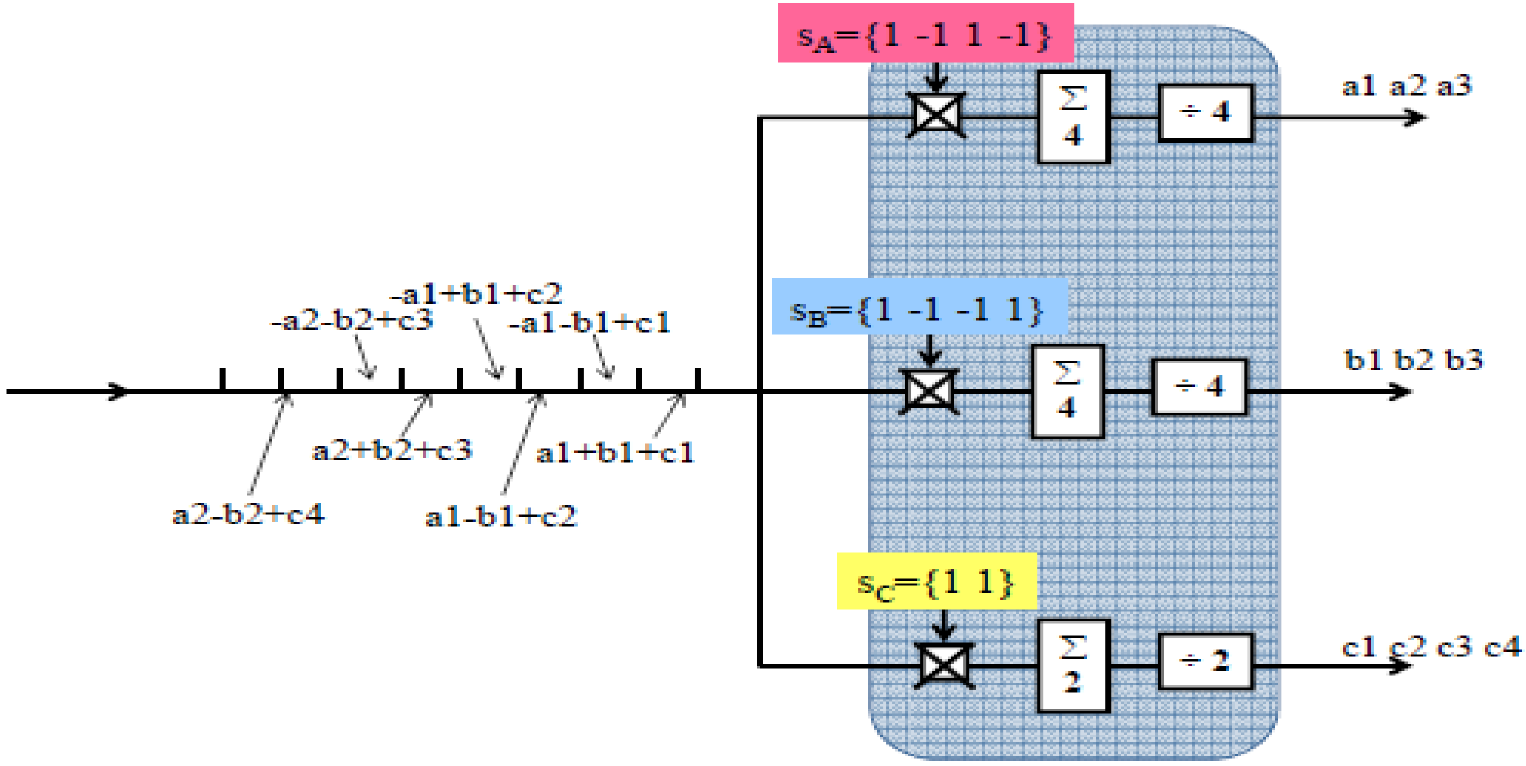
CDMA

CDMA Multiplexing



CDMA

CDMA Demultiplexing



CDMA

Codes Utilisés

- m-sequences (Pseudo Noise Seq.)
- Gold Codes
- Kasami Codes
- Barker Codes
- Walsh-Hadamard Codes

CDMA

Codes Orthogonaux (Walsh-Hadamard Codes)

Pour avoir des interférences nulles,
1 contrainte : codes orthogonaux

$$\int_0^T c_n(t) \cdot c_m(t) dt = \delta_{nm}$$

T : durée bit du signal d'entrée

Les signaux $c_n(t)$ sont à la cadence chip : T_c.

Le nombre de codes orthogonaux de cette forme sont au maximum de N=T/Tc.

CDMA

Codes Orthogonaux (Walsh-Hadamard Codes)

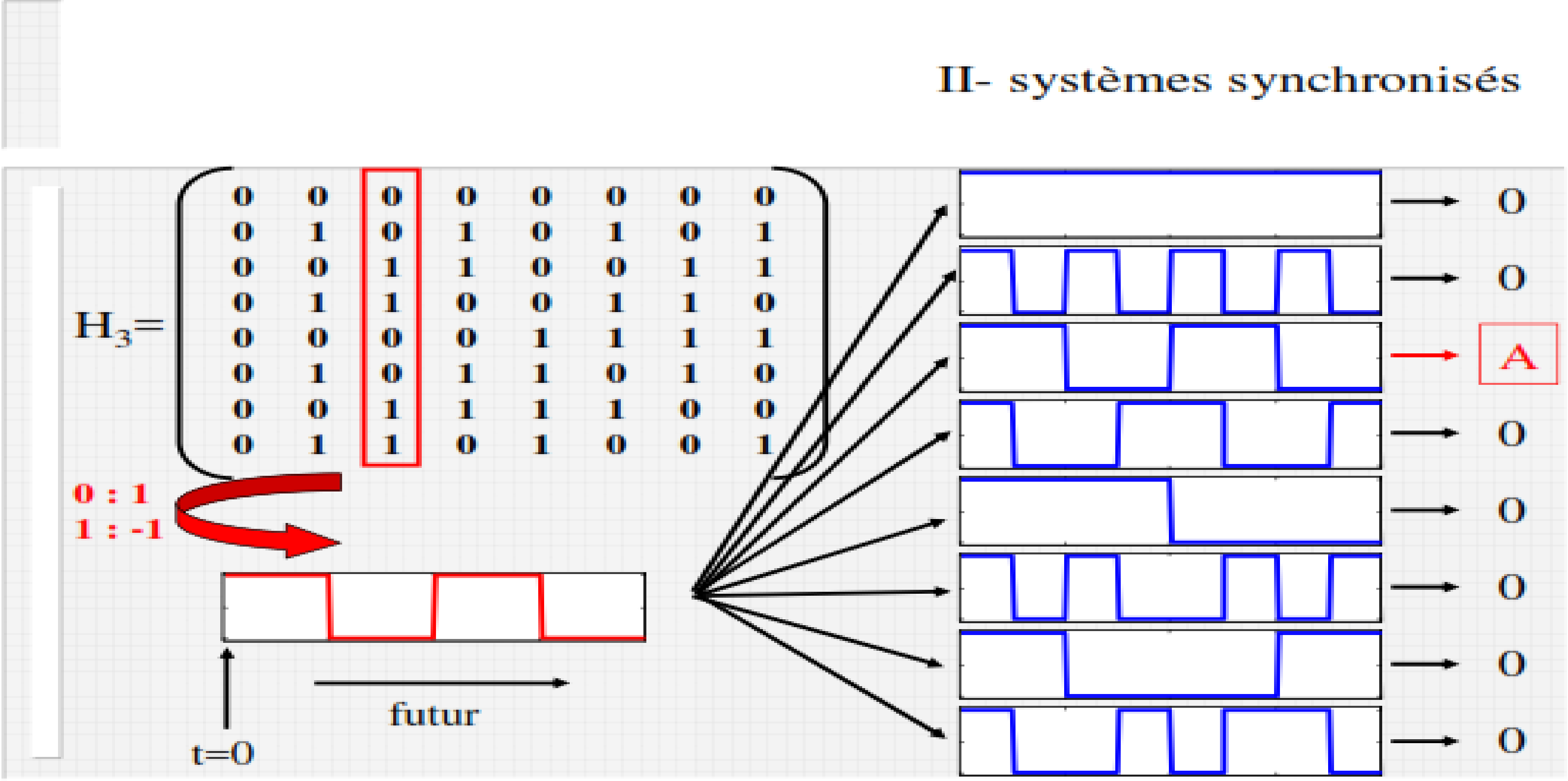
Construction des codes :
codes de Walsh / matrices de Hadamard

$$H_0 = [0] \quad ; \quad H_1 = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix} \quad ; \cdots \quad H_{N+1} = \begin{bmatrix} H_N & H_N \\ H_N & \overline{H}_N \end{bmatrix}$$

N=puissance de 2
les codes sont donnés par les colonnes

CDMA

Codes Orthogonaux: (Walsh-Hadamard Codes)



CDMA

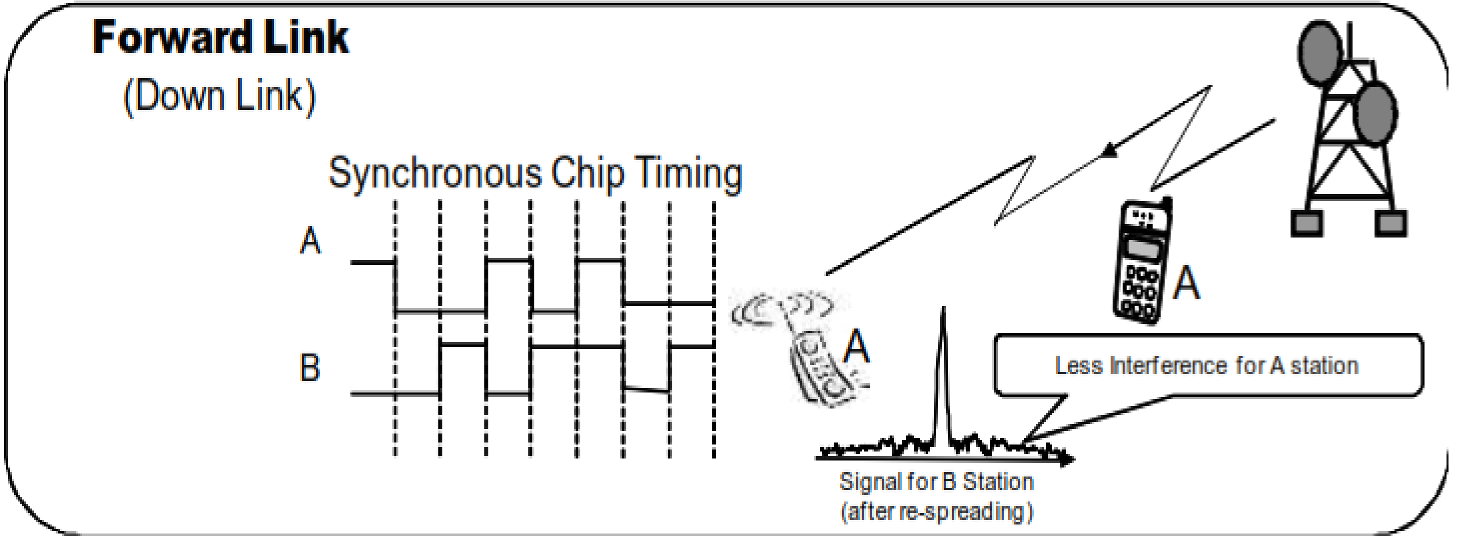
Exemple utilisation des codes Walsh-Hadamard Codes:

IS-95 CDMA Standard (2G, USA, Korea, …), CDMA2000 (3G: evolution de IS-95)

In IS-95 CDMA, 64 Walsh codes are used per base station. This enables to create 64 separate channels per base stations (i.e. a base station can handle maximum 64 unique users at a given time).In CDMA-2000 standard, 256 Walsh codes are used to handle maximum 256 unique users under a base.

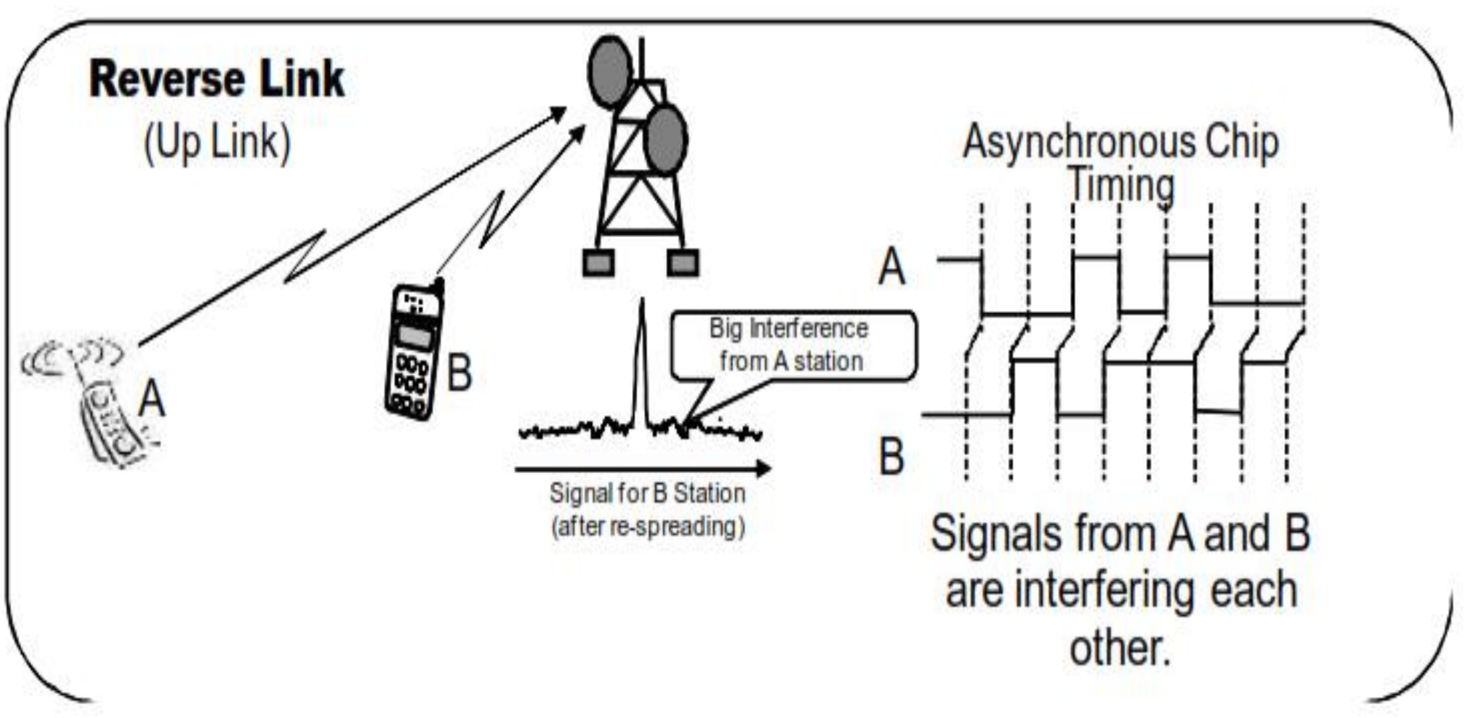
CDMA

Codes Orthogonaux: Appropriés pour les systèmes synchrones



CDMA

Codes Orthogonaux: non appropriés pour les systems asynchrones à cause de leur mauvaise intercorrélation



CDMA

Codes non orthogonaux: appropriés pour des systems asynchrones

La contrainte sur les codes non-orthogonaux est différente :

$$\Gamma_c = \int_0^T c_n(t) \cdot \left[c_m(t - T + \tau) + c_m(t + \tau) \right] dt << 1$$

On ne veut plus une corrélation nulle mais une corrélation faible, par contre elle doit rester faible avec un décalage τ entre les 2 codes.

CDMA

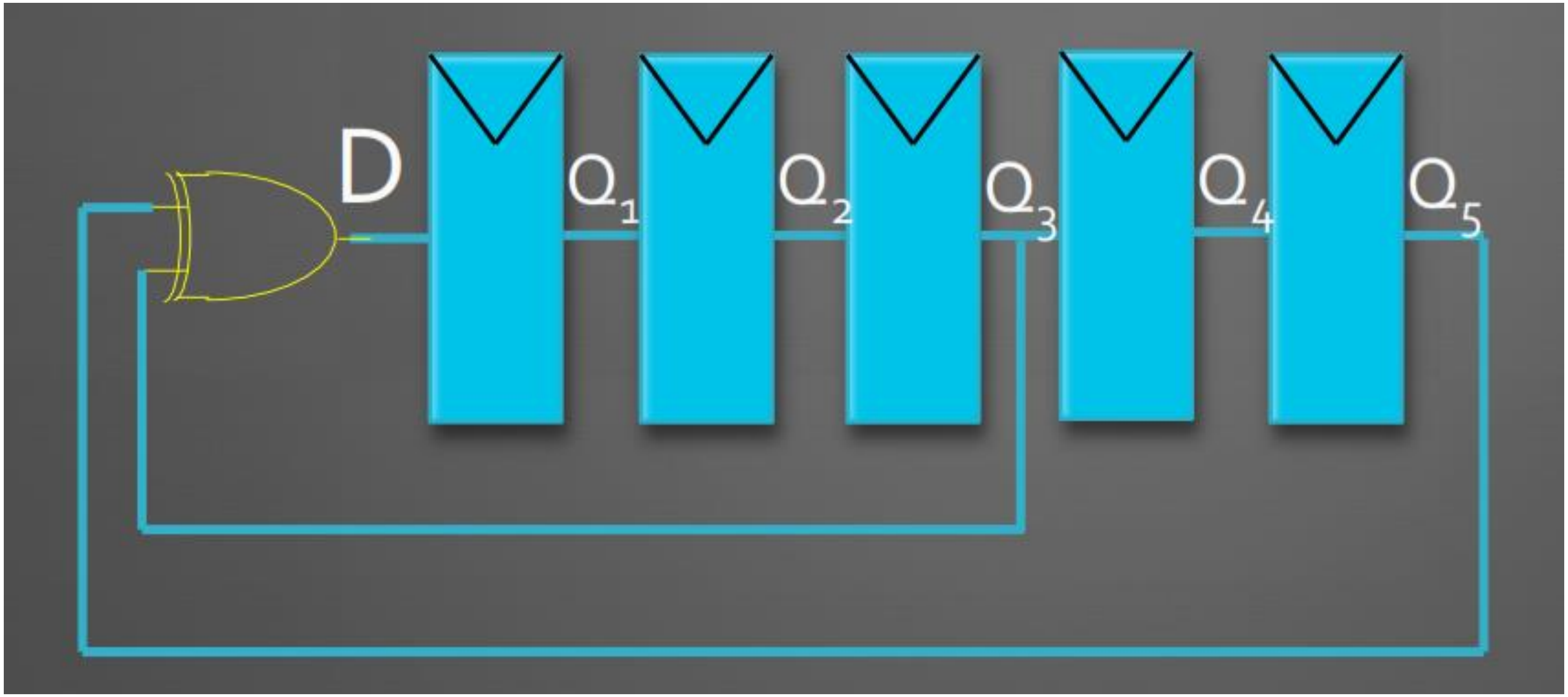
m-sequences (Pseudo Noise Seq.)

Ce sont les codes les plus longs qui peuvent être générés à l'aide de registres à décalage linéaires bouclés

Linear Feedback Shift Register (LFSR)

CDMA

m-sequences (Pseudo Noise Seq.)



Polynôme caractéristique: Ex. $1 + x^3 + x^5$

Contenu Initial du registre (Seed), Ex. 00001

CDMA

Séquence complète (Exemple précédent)

Step	Q1	Q2	Q3	Q4	Q5
0	0	0	0	0	1
1	1	0	0	0	0
2	0	1	0	0	0
3	0	0	1	0	0
4	1	0	0	1	0
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					

Step	Q1	Q2	Q3	Q4	Q5
16	0	0	1	1	1
17	0	0	0	1	1
18	1	0	0	0	1
19	1	1	0	0	0
20	0	1	1	0	0
21	1	0	1	1	0
22	1	1	0	1	1
23	1	1	1	0	1
24	0	1	1	1	0
25	1	0	1	1	1
26	0	1	0	1	1
27	1	0	1	0	1
28	0	1	0	1	0
29	0	0	1	0	1
30	0	0	0	1	0
repeat	0	0	0	0	1

CDMA

- A *shift register sequence* is the pattern in the msb

Step	Q1	Q2	Q3	Q4	Q5	Step	Q1	Q2	Q3	Q4	Q5
0	0	0	0	0	1	16	0	0	1	1	1
1	1	0	0	0	0	17	0	0	0	1	1
2	0	1	0	0	0	18	1	0	0	0	1
3	0	0	1	0	0	19	1	1	0	0	0
4	1	0	0	1	0	20	0	1	1	0	0
5	0	1	0	0	1	21	1	0	1	1	0
6	1	0	1	0	0	22	1	1	0	1	1
7	1	1	0	1	0	23	1	1	1	0	1
8	0	1	1	0	1	24	0	1	1	1	0
9	0	0	1	1	0	25	1	0	1	1	1
10	1	0	0	1	1	26	0	1	0	1	1
11	1	1	0	0	1	27	1	0	1	0	1
12	1	1	1	0	0	28	0	1	0	1	0
13	1	1	1	1	0	29	0	0	1	0	1
14	1	1	1	1	1	30	0	0	0	1	0
15	0	1	1	1	1						

Sequence: 1000010010110011111000110111010

CDMA

m-sequence

- This is an example of a maximal length shift register seq.
  - Repeats after $31 = 2^5-1$ steps
- In general, an *N*-bit MLSRS repeats after steps
- Not all characteristics polynomials produce MLSRSs

CDMA

m-sequence

It is interesting to note that, multiple m-sequences exist for a particular value of L > 2. The number of available m- sequences is denoted by $\frac{\phi(2^L - 1)}{L}$. The numerator $\phi(2^L - 1)$ is known as the Euler number, i.e. the number of positive integers, including 1, that are relatively prime to L and less than $(2^L - 1)$. When $(2^L - 1)$ itself is a prime number, all positive integers less than this number are relatively prime to it. For example, if L = 5, it is easy to find that the number of possible sequences = $\frac{30}{5} = 6$.

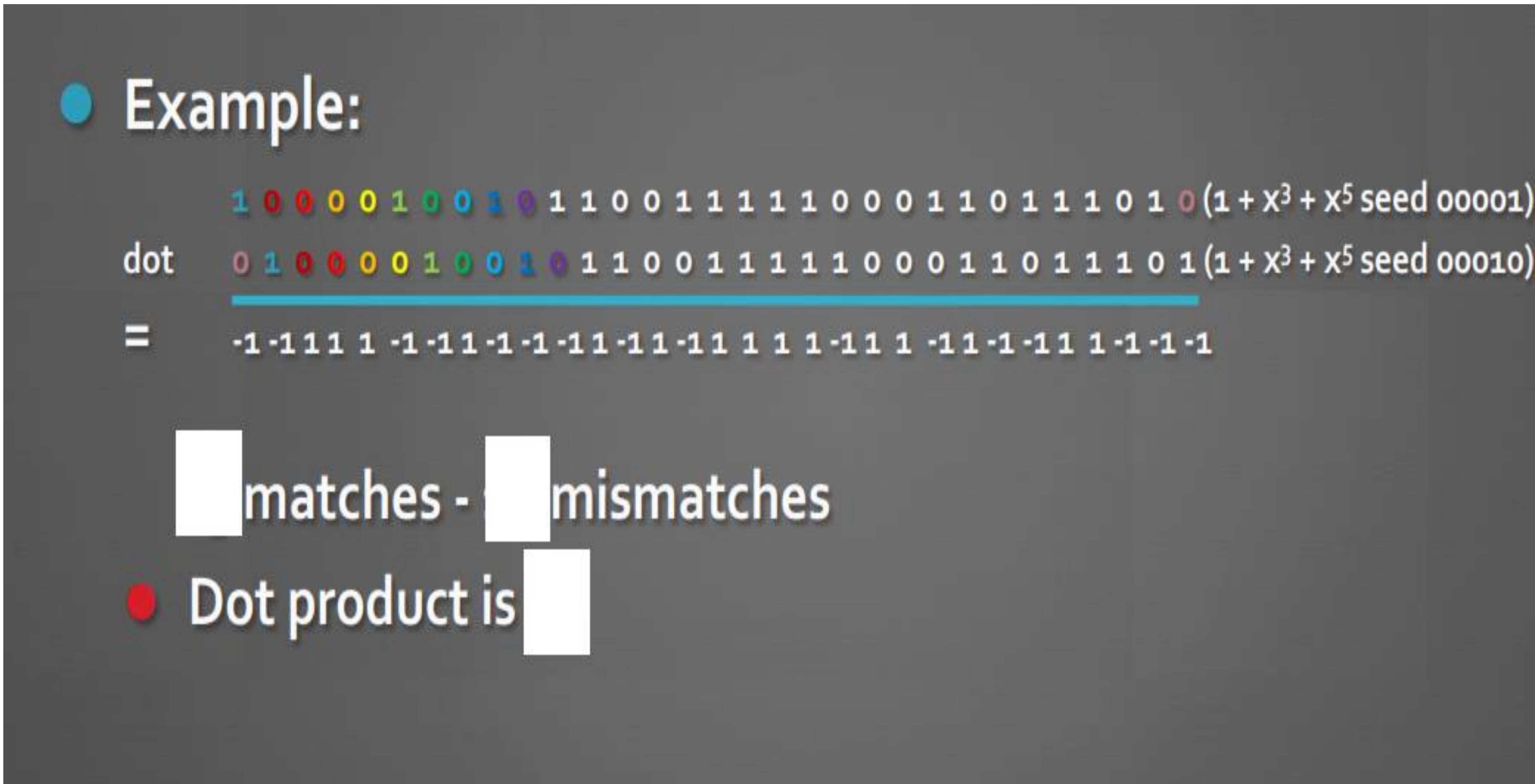
CDMA

Corrélation

- *Cross-correlation* of two sequences
  - Measure of the similarity of the sequences when one is shifted by varying amounts.
  - Take the dot product of one sequence with each shifted version of the other
- *Autocorrelation*
  - Cross-correlation of a sequence with itself.

CDMA

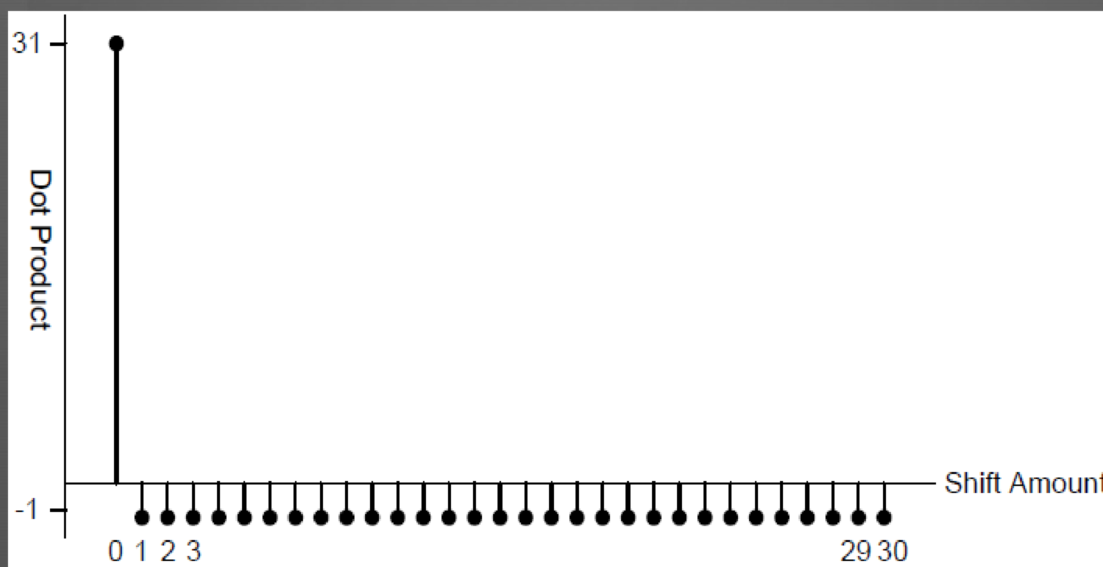
Corrélation



CDMA

m-sequence autocorrelation

- A MLSRS has an autocorrelation of 2^N-1 at an offset of 0
  - Autocorrelation of -1 at all other offsets



- Hence the MLSRS has characteristics of random noise

CDMA

GOLD Codes

The cross correlation properties are as important in communication systems as autocorrelation properties. Cross correlation is a measure of agreement between the two different codes. The periodic cross correlation between any pair of m-sequences is very high. Such high values of cross correlation are undesirable in CDMA communications. Gold developed new sequences with better cross correlation properties called Gold sequences

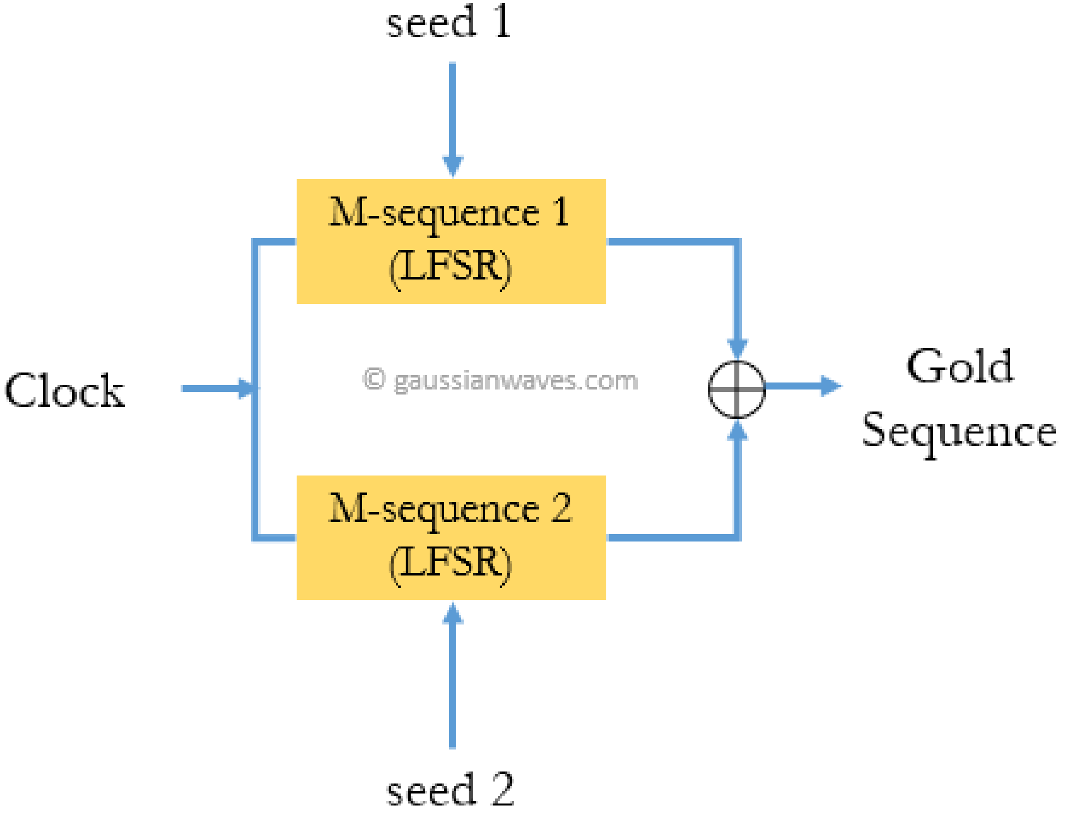
CDMA

GOLD Codes

- Communication systems need a set of bit sequences that:
  - Are easy to generate with hardware or software
  - Have a low cross-correlation with other sequences in the set
    - Easy to tell the sequences apart even when corrupted by noise
- Gold Codes are such a class of 2^N-1 sequences of length 2^N-1
  - Formed by XORing MLSRSs generated by different taps
  - Each seed gives a different Gold code
  - Each code is quite different than the others

CDMA

Gold Code Generation



CDMA

Preferred type m-sequences

Note that there exists numerous choice of Gold sequences based on the m-sequence configuration of the LFSRs and what is initially loaded into the two LFSRs. Not all the Gold sequences possess good correlation properties. In order to have a Gold code sequence with three valuedpeak cross−correlation magnitudes, that is both bounded and uniform, the m-sequences generated by the two LFSRs need to be of preferred type.

CDMA

Three valued cross-correlation values occur when n is odd or when mod(n,4)=2.

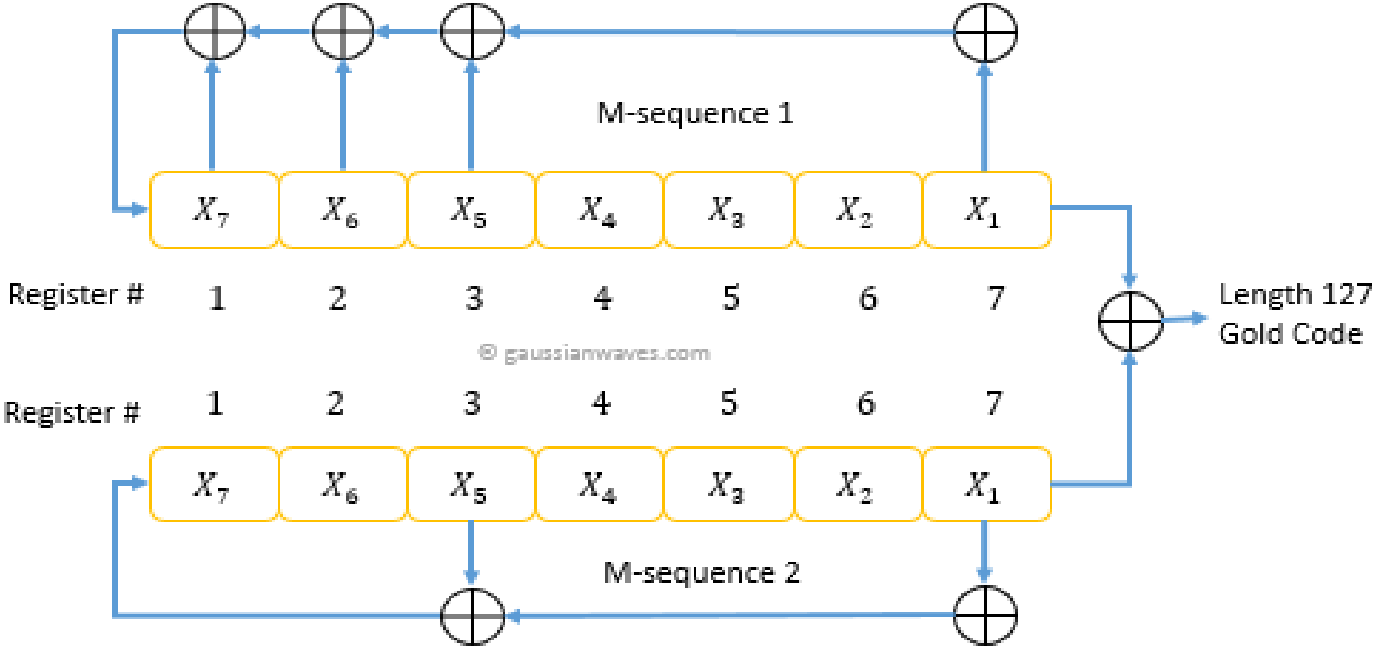
The peak cross-correlation magnitude achieves the minimum possible value only when n is odd (n=[5,7,9,11,…]). Therefore, this is the best choice here.

When mod(n,4)=2, the m-sequences listed in table are still of preferred type (three valued cross-correlation), but the lower bound is weaker when compared to the lower bound when n is odd.

CDMA / GOLD Codes

Length of LFSR	Length of Gold code	Preferred pairs of m-sequences		Three valued Cross-correlation (unnormalized)		
n	$N = 2^n - 1$	m-sequence 1	m-sequence 2			
5	31	[5,4,3,2]	[5,2]	-9	-1	7
6	63	[6,5,2,1]	[6,1]	-17	-1	15
7	127	[7,3,2,1]	[7,3]	-17	-1	15
		[7,3,1]	[7,1]	-17	-1	15
		[7,5,4,3,2,1]	[7,3,2,1]	-17	-1	15
9	511	[9,6,4,3]	[9,4]	-33	-1	31
		[9,8,4,1]	[9,6,4,3]	-33	-1	31
10	1023	[10,9,7,6,4,1]	[10,9,8,7,6,5,4,3]	-65	-1	63
		[10,7,6,4,2,1]	[10,8,5,1]	-65	-1	63
		[10,9,7,6,4,1]	[10,8,7,6,5,4,3,1]	-65	-1	63
11	2047	[11,8,5,2]	[11,2]	-65	-1	63

CDMA / GOLD Codes



CDMA / GOLD Codes

- To uniquely define a Gold code:
  - State characteristic polynomial for the two LFSRs
  - State seed for the second LFSR
  - Always use a seed of 00…001 for the first LFSR
- Example: $GC(1+x^2+x^3+x^4+x^5,\ 1+x^3+x^5,\ 00011)$
- There are 2^N-1 Gold codes in a family
  - Defined by the different possible seeds (except 00…000)

CDMA / GOLD Codes

- GC($1+x^2+x^3+x^4+x^5$, $1+x^3+x^5$, 00001)

	1000010110101000111011111001001	($1+x^2+x^3+x^4+x^5$ seed 00001)
xor	1000010010110011111000110111010	($1+x^3+x^5$ seed 00001)
	0000000100011011000011001110011	

- GC($1+x^2+x^3+x^4+x^5$, $1+x^3+x^5$, 00010)

	1000010110101000111011111001001	($1+x^2+x^3+x^4+x^5$ seed 00001)
xor	0100001001011001111100011011101	($1+x^3+x^5$ seed 00010)
	1100011111100010001111100010100	

CDMA / GOLD Codes

Generating Preferred Pairs of m-sequences:

1) Take a m-sequence (d) for given length N ($N=2^n-1$) ,where n is the number of registers in the LFSR).

2) Decimate the m-sequence by a decimation factor of q. This is our second sequence. d'=d[q]

3) If the value of q is chosen according to the following three conditions, then the two m-sequences d and d'will be preferred pairs.

CDMA / GOLD Codes

A) n is odd or mod(n,4)=2

B) q is odd and either $q=2^k+1$ or $q=2^{2k}-2k+1$ for an integer k.

C) The greatest common divisor of n and k satisfies the following conditions:

- gcd(n,k)=1, when n is odd
- gcd(n,k)=2, when mod(n,4)=2

CDMA / GOLD Codes

- Example:

Lets consider generation a preferred pairs of m-sequence of length N=63 (n=6). Since mod(n=6,4)=2, the first condition is satisfied. Taking q=5 and k=2 satisfies condition 2 and 3. So we will use a decimation factor of q=5 in our simulation for preferred pairs generation.

CDMA / GOLD Codes

- Cross-Correlation :

The cross-correlation property of the preferred pairs for Gold code generation are three valued and the values are:

$[-1/Nt(n), -1/N, 1/N(t(n)-2)]$, where t(n) is given by:

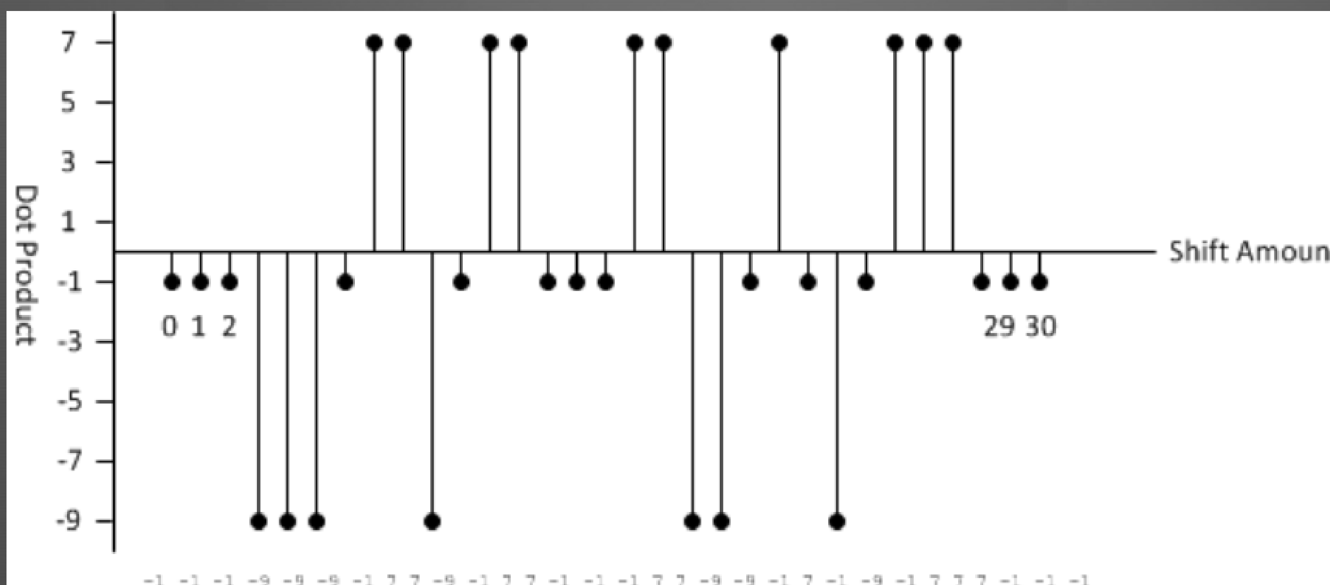
$t(n)=2^{(n+1)/2}+1$, if n is odd

$t(n)= 2^{(n+2)/2}+1$ if n is even

For our example, the theoretical cross-correlation values for the previous preferred pairs of m-sequences are [−0.2698,−0.0159,0.2381].

CDMA / GOLD Codes

- Cross-correlation of
  - GC($1+x^2+x^3+x^4+x^5$, $1+x^3+x^5$, 00001)
  - GC($1+x^2+x^3+x^4+x^5$, $1+x^3+x^5$, 00010)

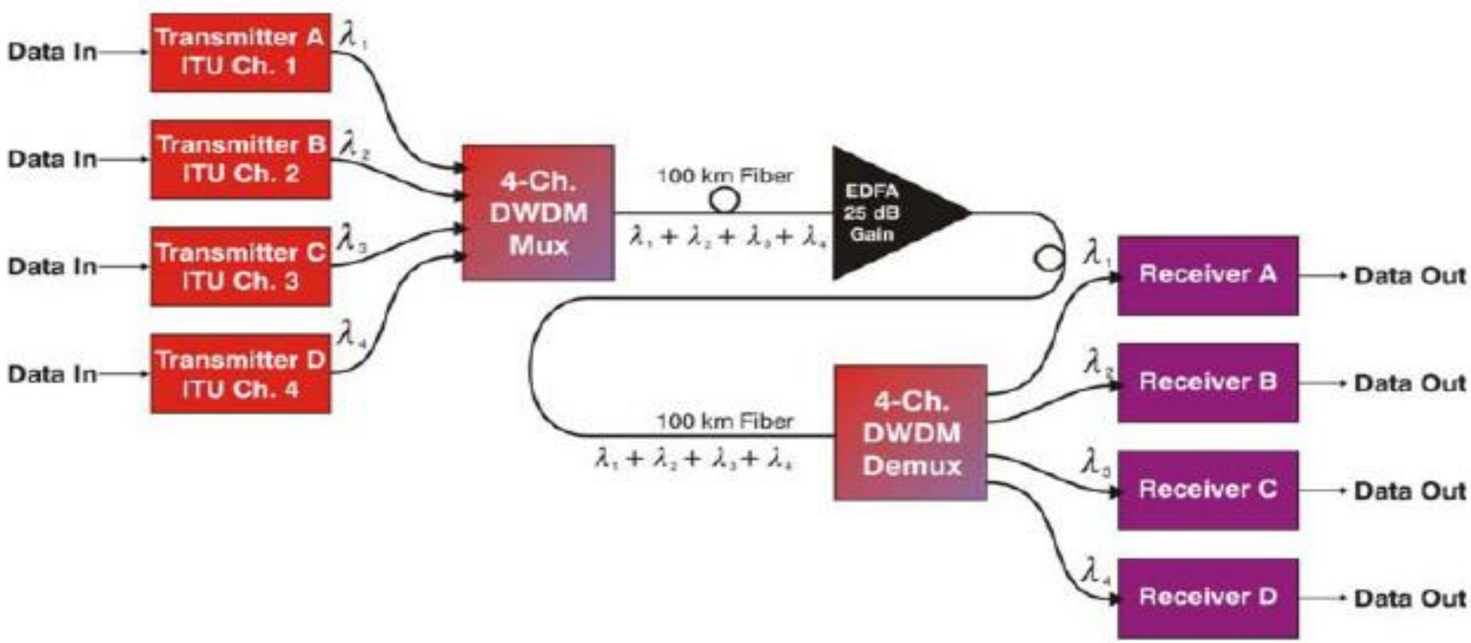


CDMA / GOLD Codes

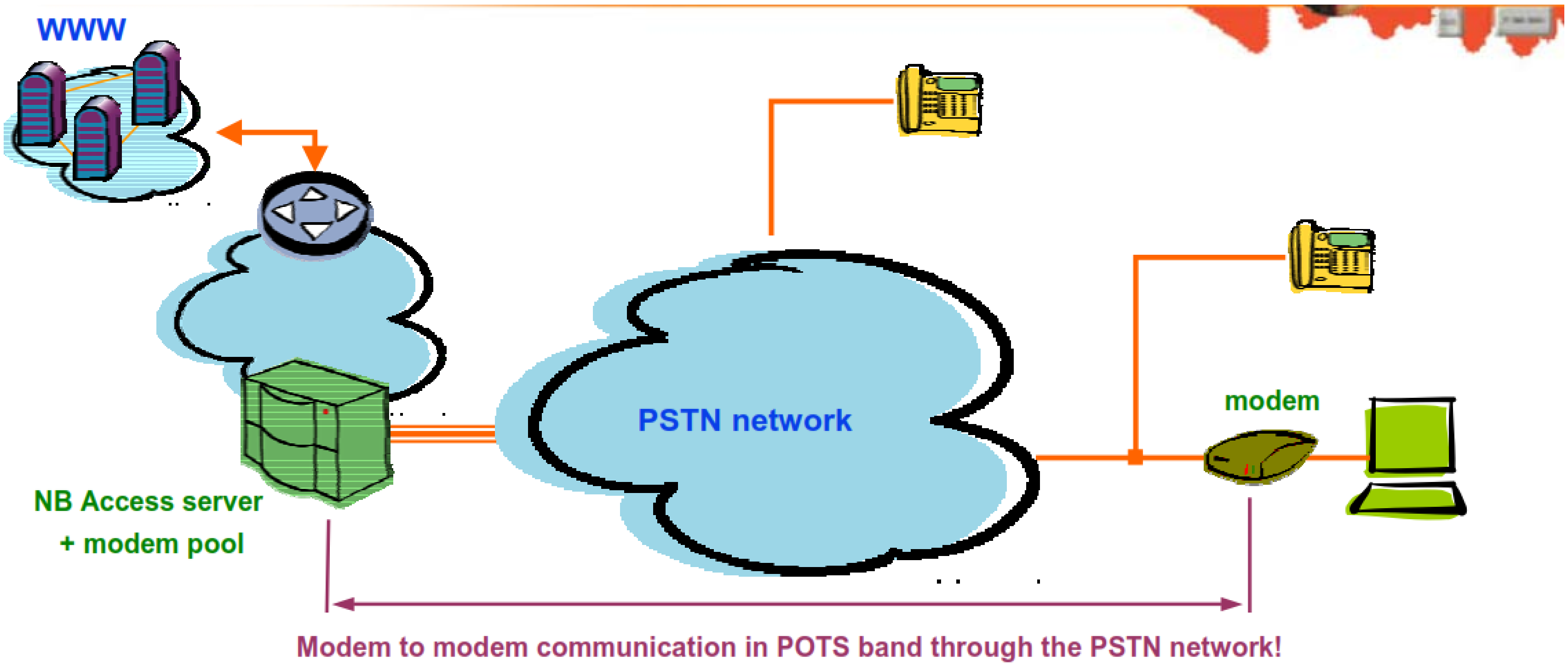
- Exemple Utilisation Gold codes: 3G/UMTS (*Universal Mobile Telecommunications System*)/2000

Multiplexage par longueur d'onde

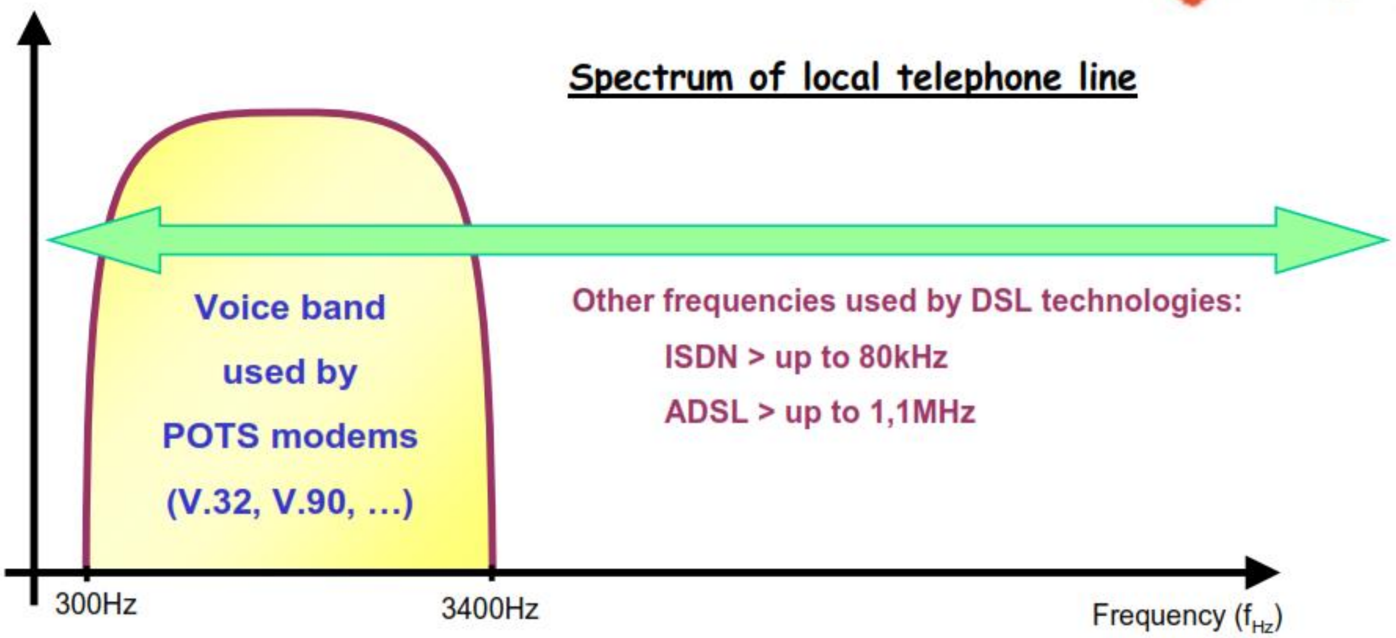
- Optical FDM is usually called *wavelength division multiplexing* (WDM) and utilizes separate wavelengths (λ) of light.



POTS modem communication



- Frequencies within the voice band are transmitted through the switched connection of a PSTN network.
- This voice band is used for voice communication or modem communication (i.e. fax, V.32, V.90, …)



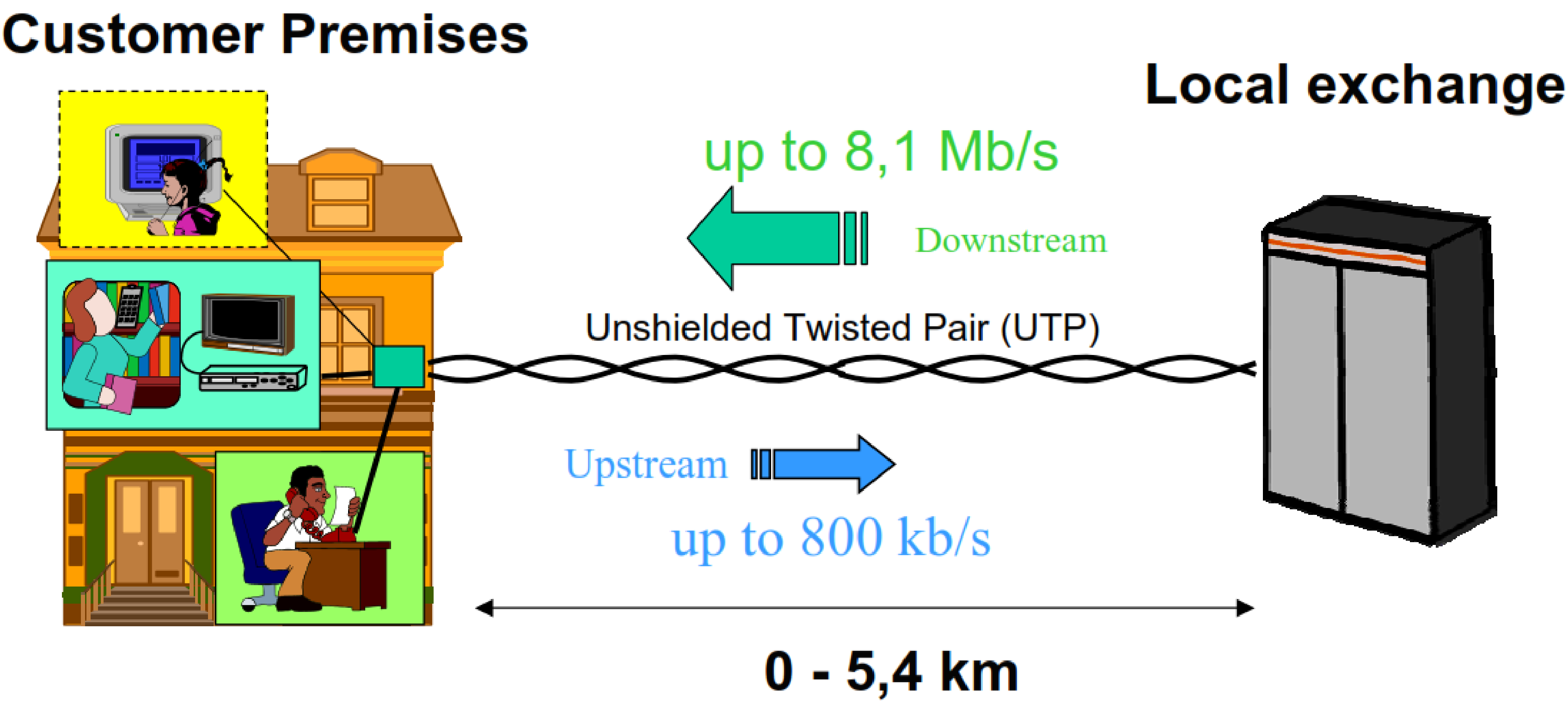
- DSL technologies use also other frequencies outside the voice band to modulate information on your local telephone line.
- ISDN provides you with a 160 kbps connection on your local line.
- ADSL provides you a high speed connection on your local line.

Solutions offered by ADSL

PROBLEM	SOLUTION
Bitrate of analogue modem limited to 56 kb/s	ADSL - modem
PSTN not suited for high speed data traffic	Redirection of data traffic to specific network (B-ISDN)

ADSL

ADSL : Asymmetric Digital Subscriber Line



Historique de l'ADSL

- Besoins : Haut Débit à bas prix
  - Fibre optique trop onéreuse
  - Fin du monopole de téléphonie locale
- Chronologie
  - 1987 : Développé par les laboratoires BellCore
  - 1996 : Expérimentation télévision numérique
  - 1999 : Première commercialisation de l'ADSL
- Utilisation dans le monde :

- 2001 : environ 10 millions

- 2003 : plus de 72 millions

- Cas de la Corée: Près de 21,3 lignes pour 100 habitants, alors que l'Allemagne, pourtant numéro 1 européen n'en a que 2,23 lignes pour 100 habitants.

Principe de l’ADSL

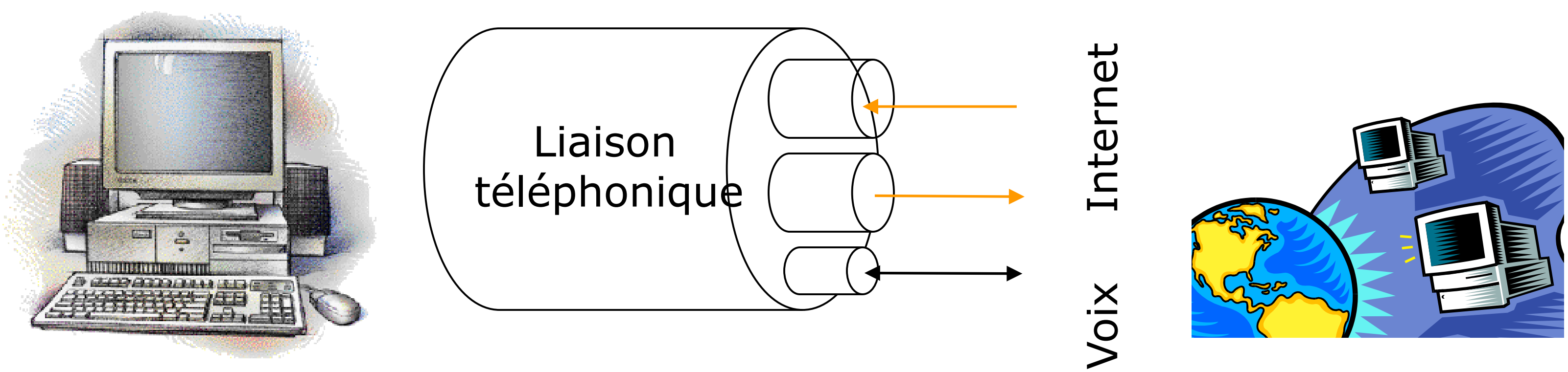
- Notion de paire de cuivre
  - Utilisation de la paire téléphonique de cuivre
    - La liaison ADSL s'installe par dessus la ligne téléphonique d'abonné.
    - Coté abonné, il faut installer:
      - un filtre ADSL
      - un modem ADSL

Principe de l'ADSL

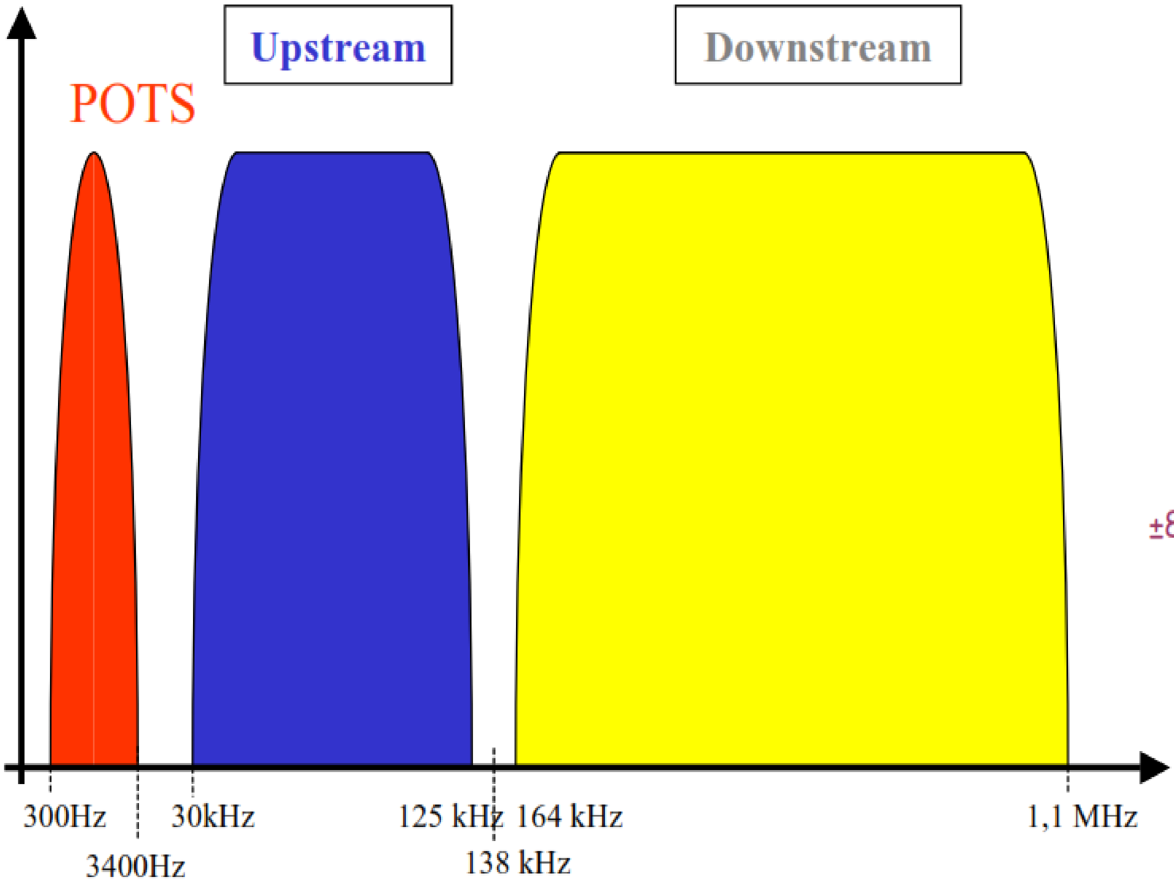
Notion asymétrie de la ligne

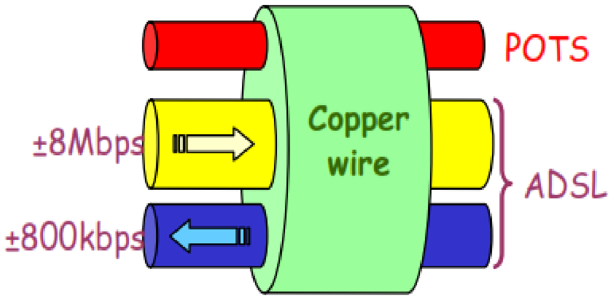
- 3 canaux de transmission (multiplexage)
  - Flux montant : Emission des données
  - Flux descendant : Réception des données
  - Canal analogique : RTC

Canaux numériques (Flux montant et Flux descendant)



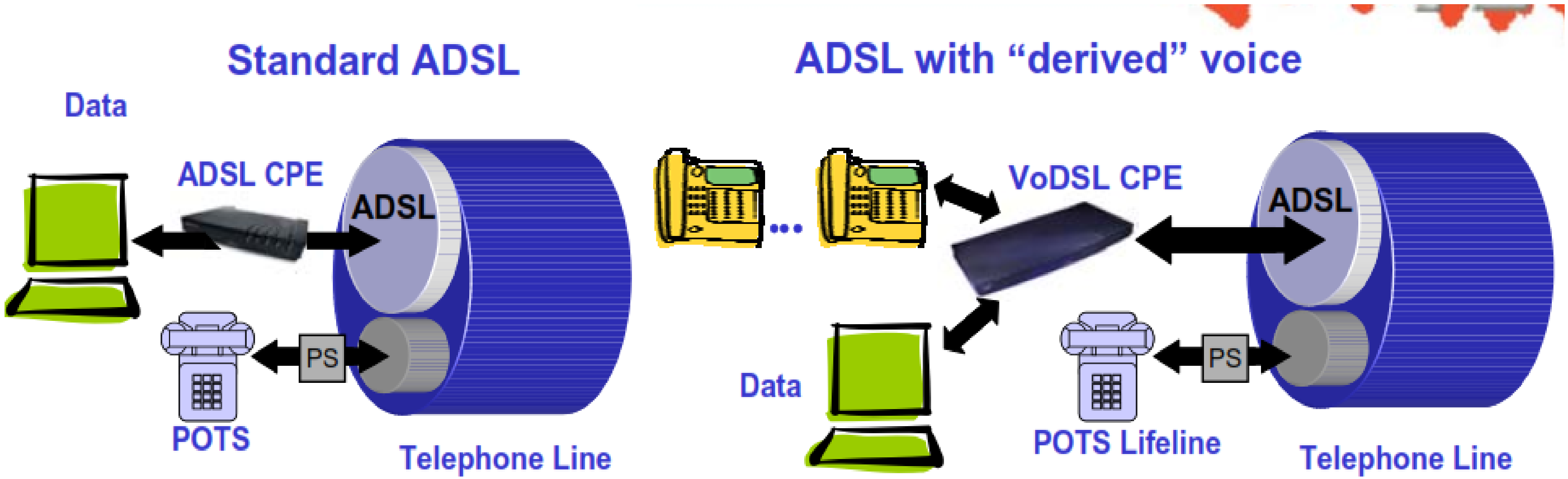
Principe de l'ADSL





- ADSL uses frequencies on the local line up to 1,1MHz.
- These frequencies do NOT overlap with the POTS band and is so allowing simultaneous voice communication.

Principe de l'ADSL



- ADSL suitable for all types of communication (voice and data)
- Evolution towards Full Digital Loop (FDL)
  - Elimination of POTS lifeline (AND splitter)

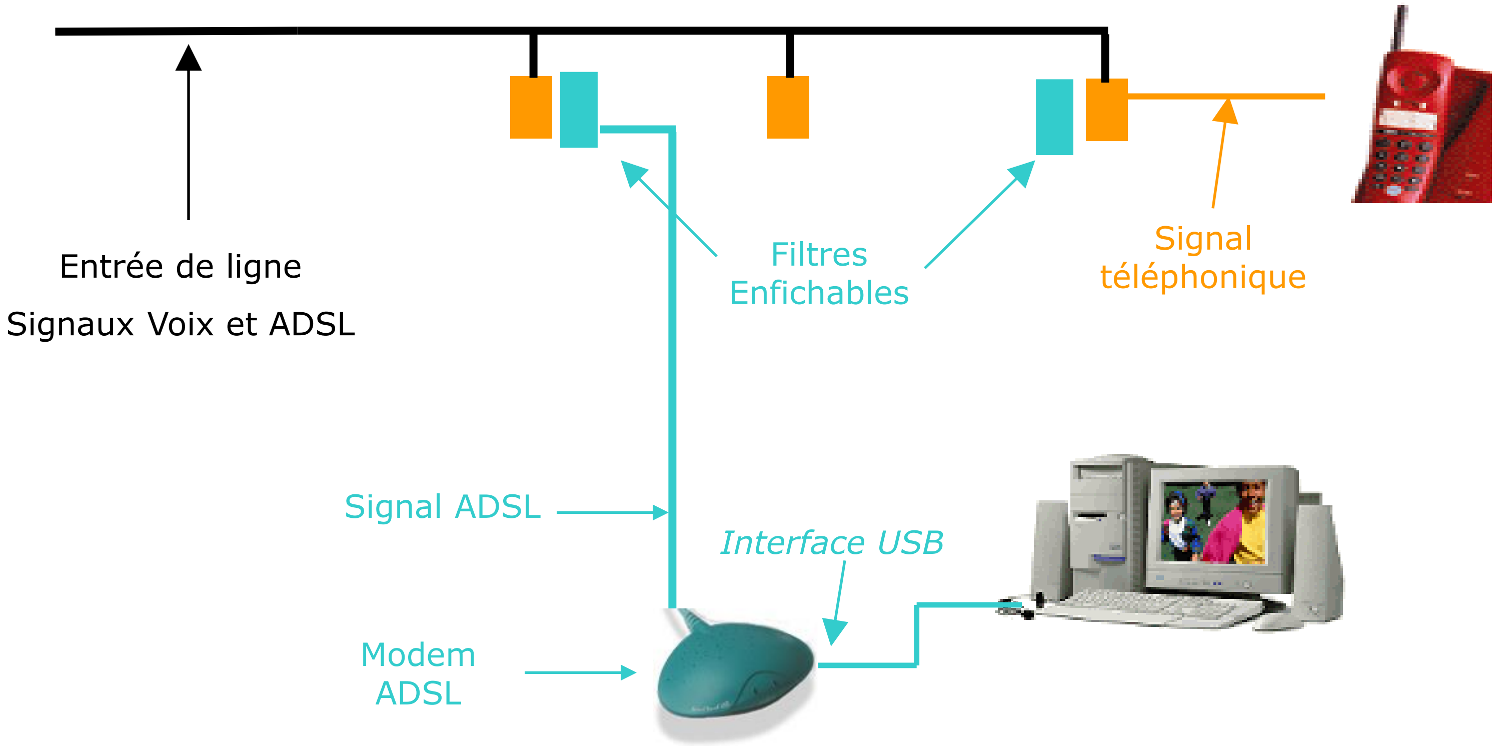
Principe de l'ADSL

Notion de débit

- Débit ascendant
  - Débit offert de l'abonné vers le serveur (jusqu'à 640 Kbit/s)
- Débit descendant
  - Débit offert du serveur vers l'abonné (jusqu'à 8 Mbit/s)
- Débit minimum garanti
  - Débit garanti au client 100% du temps
- Débit crête
  - Débit instantané pouvant être atteint sur une durée limitée

Principe de l'ADSL

- Notion de filtre (splitter)



Les technologies xDSL

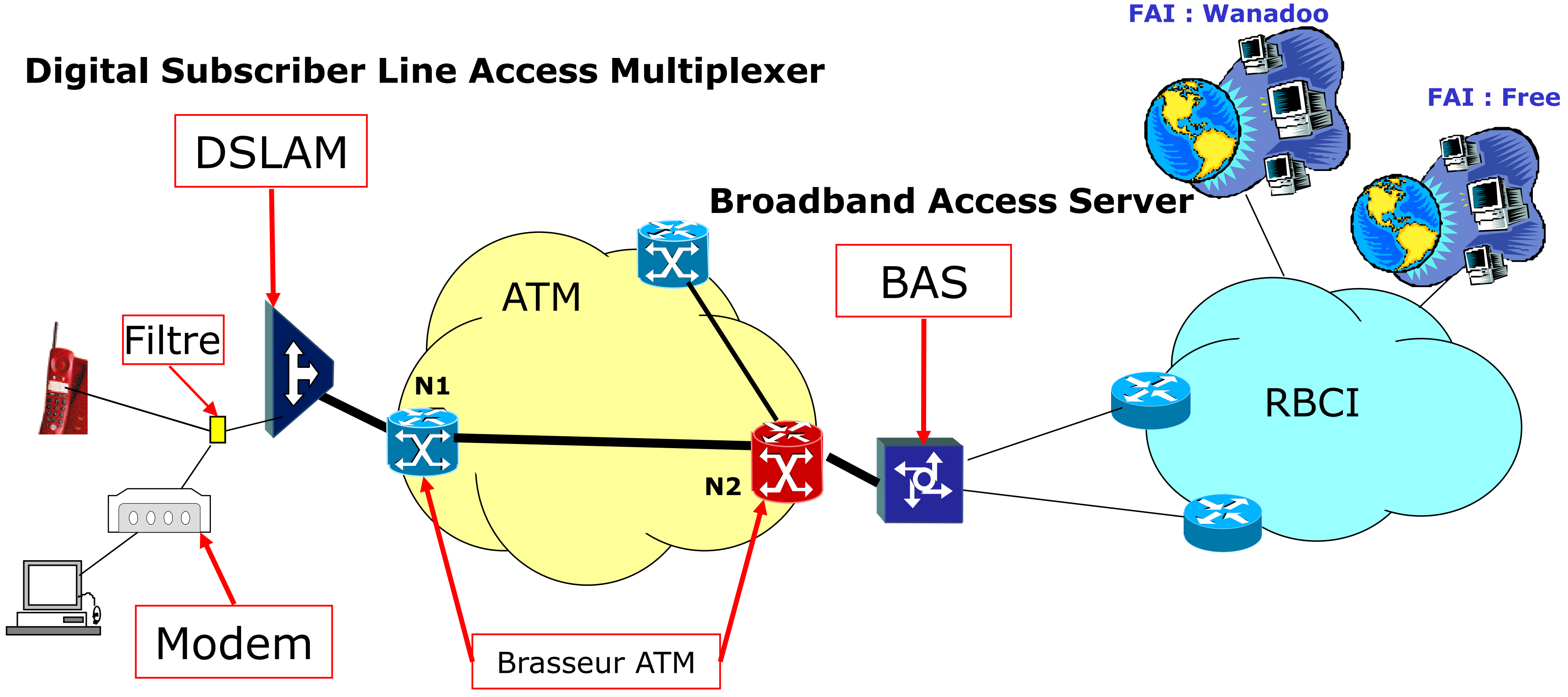
- Les différences
  - La vitesse
  - La distance
  - Le débit entre le flux montant et le descendant

Les technologies xDSL

- La comparaison

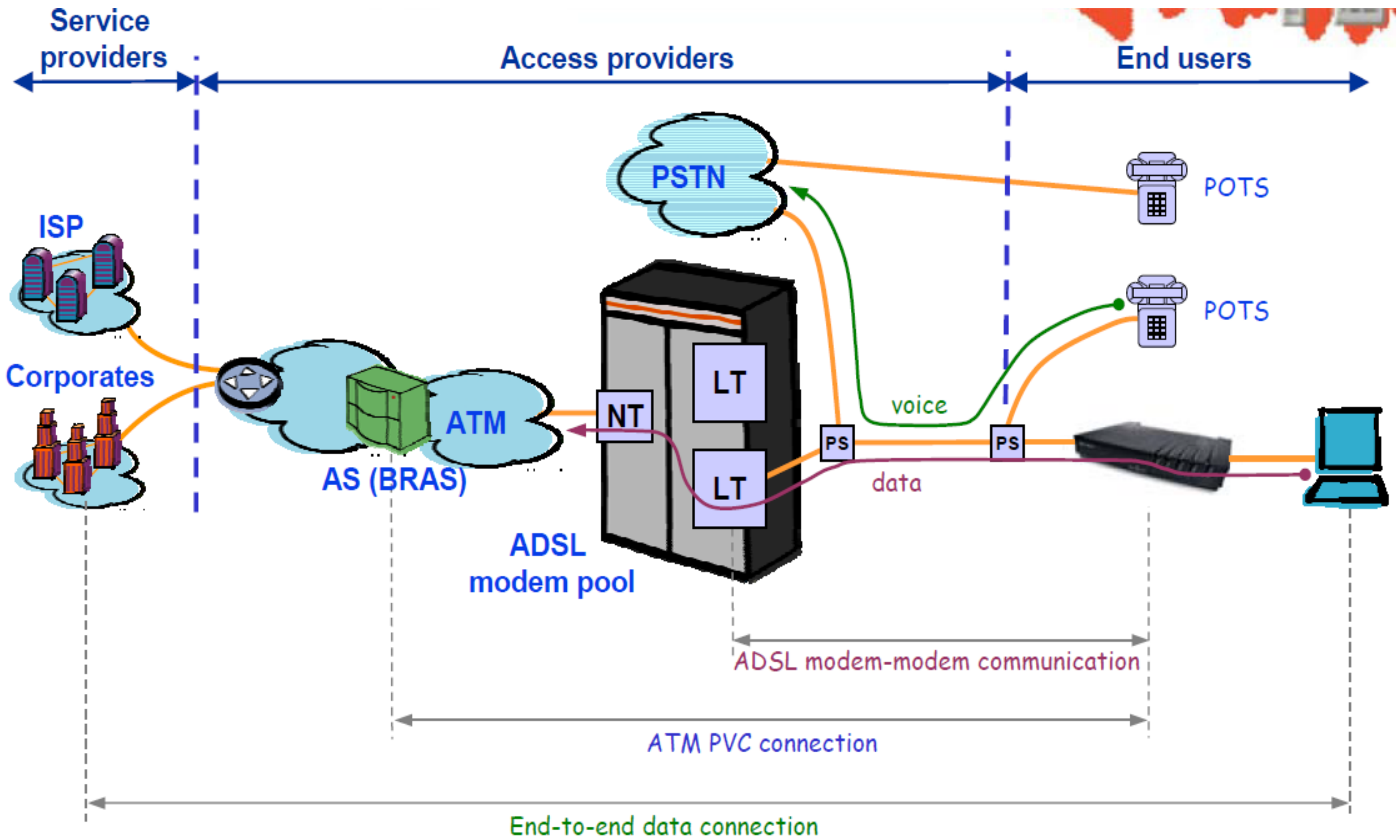
Technologie	Définition	Mode de transmission	Débit Download	Débit Upload	Distance maximale
HDSL	High data rate DSL	Symétrique	1.544 Mbps 2.048 Mbps	1.544 Mbps 2.048 Mbps	3.6 km
HDSL 2	High data rate DSL 2	Symétrique	1.544 Mbps	1.544 Mbps	3.6 km
SDSL	Single line DSL	Symétrique	768 Kbps	768 Kbps	3.6 km
ADSL	Asymmetric DSL	Asymétrique	1.544-9 Mbps	16-640 Kbps	5.4 km
RADSL	Rate Adaptive DSL	Asymétrique	0.6-7 Mbps	0.128-1 Mbps	5.4 km
VDSL	Very high data DSL	Asymétrique	15-53 Mbps	1.544-2.3 Mbps	1.3 km

Les équipements



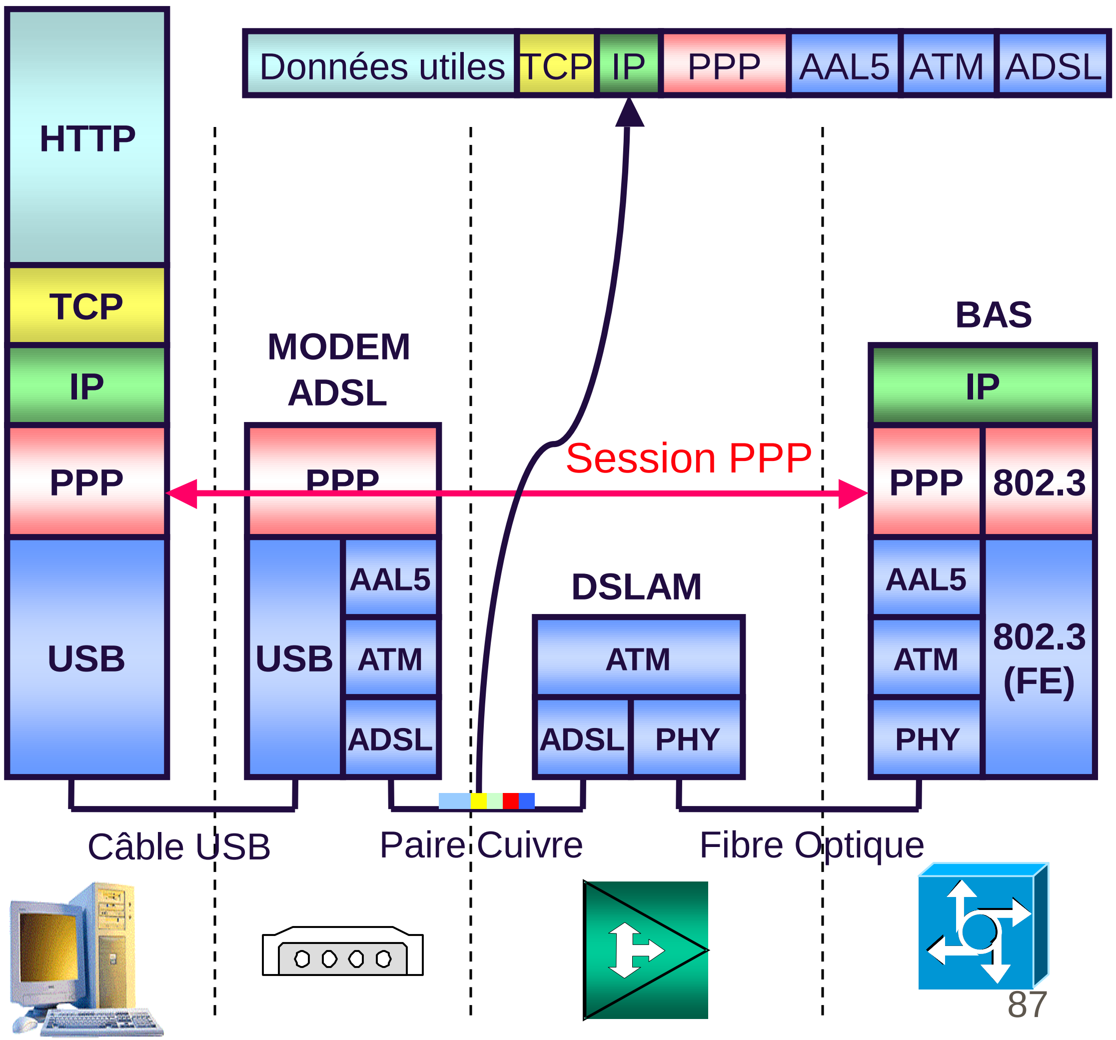
Les équipements 2/2

- DSLAM (Digital Subscriber Line Access Multiplexer)
  - Assure le rôle de multiplexeur vers l'interface haut débit
- Brasseur ATM (Asynchronus Transfert Mode)
  - Assure la diffusion des paquets contenant les données
- BAS (Broadband Access Server)
  - Point de concentration assurant l'aiguillage du flux vers les FAI
  - Assure le lien avec le PAS pour l'identification
- PAS (Plate-forme d'Accès aux Services)
  - Assure l'identification et la facturation


Service providers
Access providers
End users
PSTN
POTS
POTS
ISP
Corporates
ATM
AS (BRAS)
NT
LT
LT
PS
PS
voice
data
ADSL modem pool
ADSL modem-modem communication
ATM PVC connection
End-to-end data connection

Les protocoles

- Modem USB



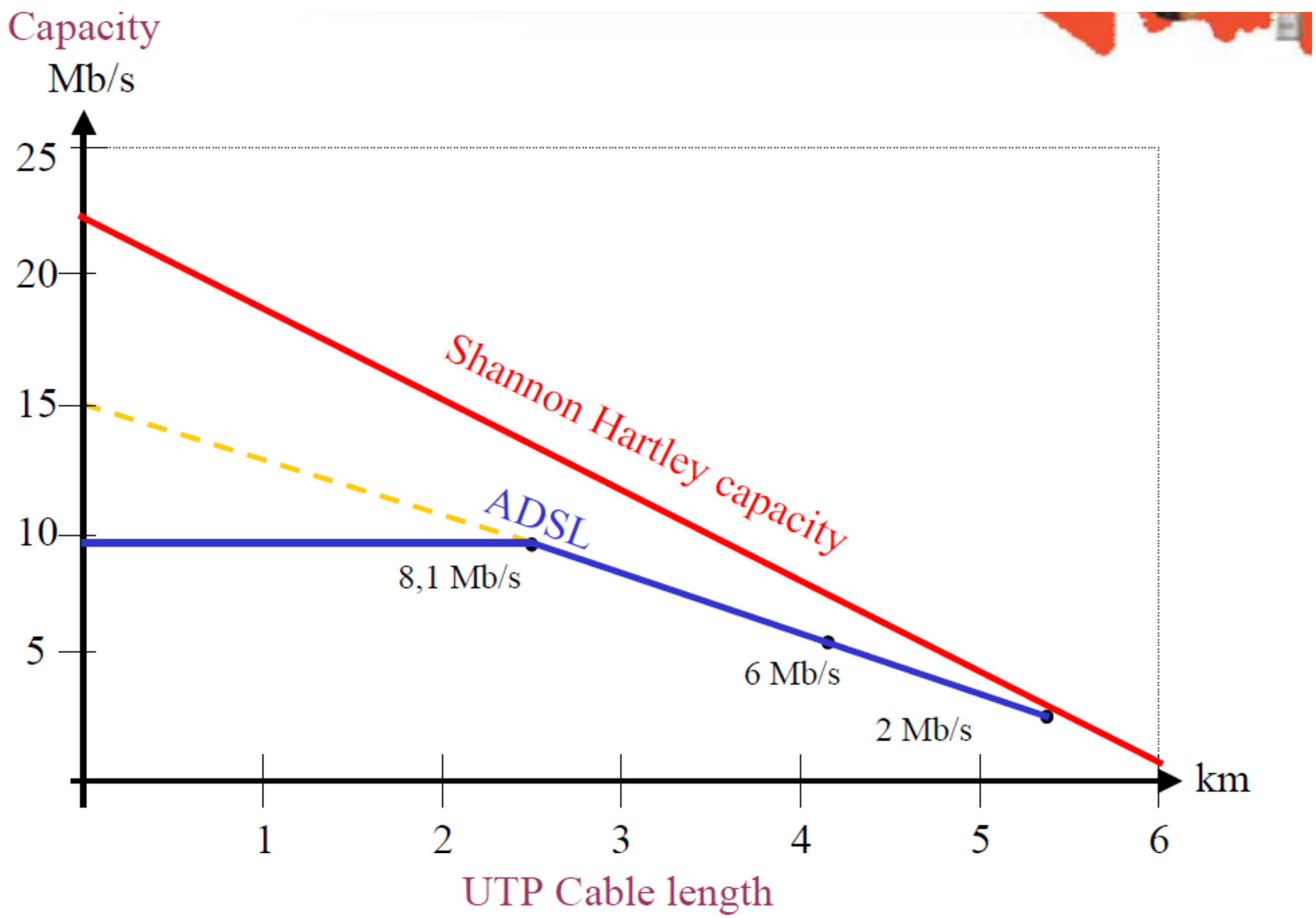
Shannon-Hartley capacity theorem

- M

Capacity [bps] ≈ 1/3 x W x SNR x G

W = bandwidth in Hz
SNR = Signal to Noise ratio in dB
G = Gainfactor achieved by error correction

Shannon-Hartley: Capacity vs. Distance



Theoretically ADSL can reach a downstream capacity of apc. 15Mbps at 0km. Although in practice this is limited to 8,1Mbps

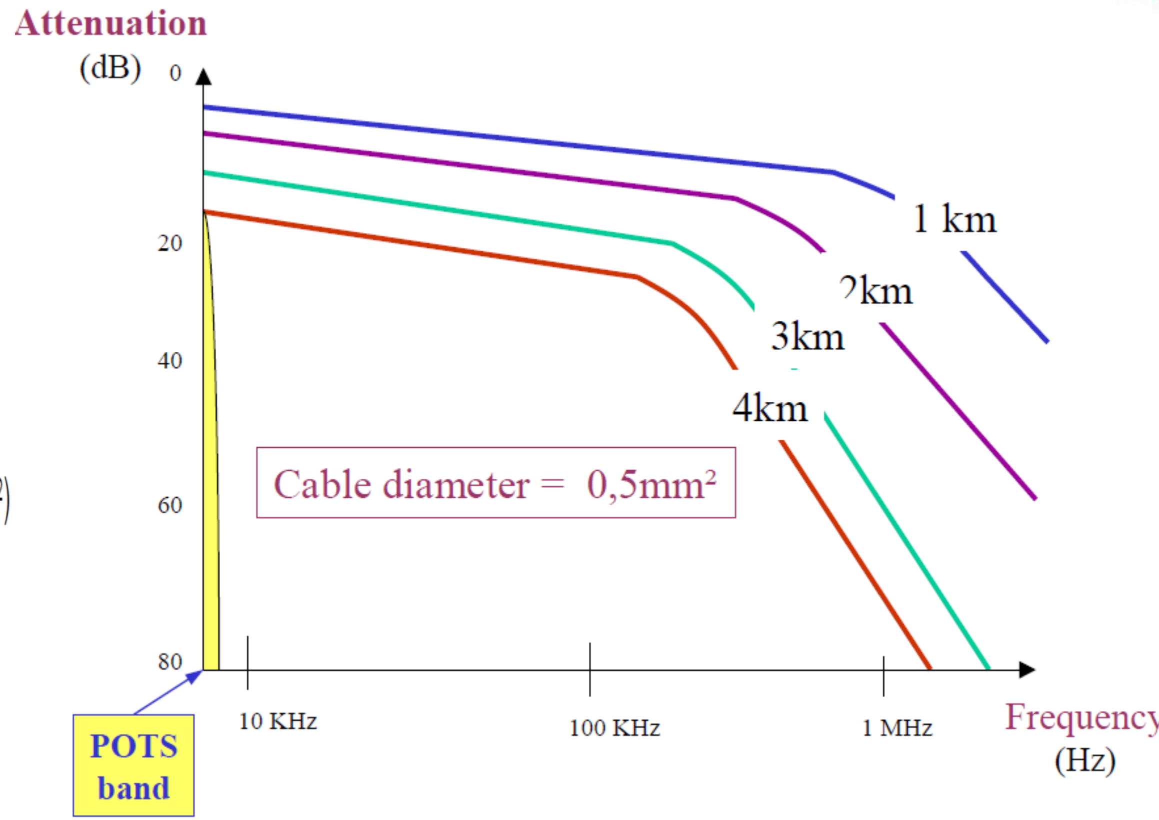
Attenuation vs. frequency

R = resistance (Ω)

φ = resistivity (Ωm)

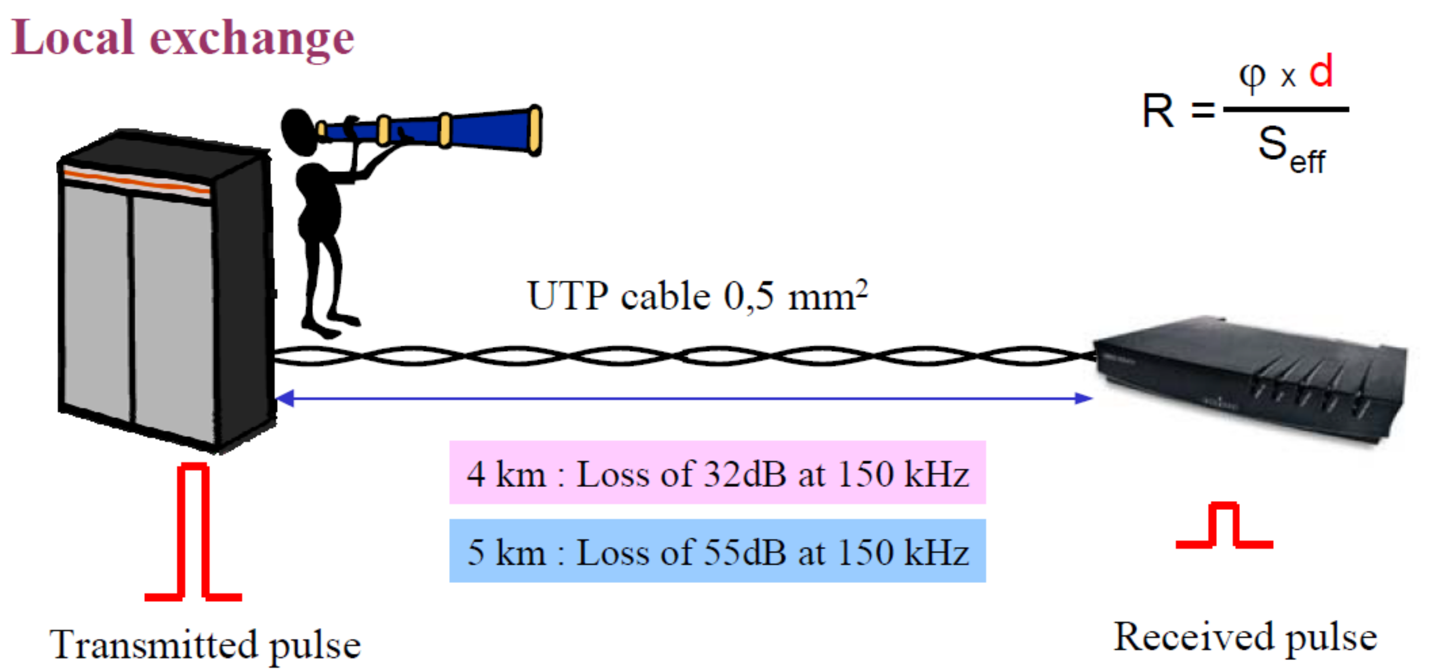
d = distance, length of conductor (m)

Seff = effective cross sectional area of conductor (m²)

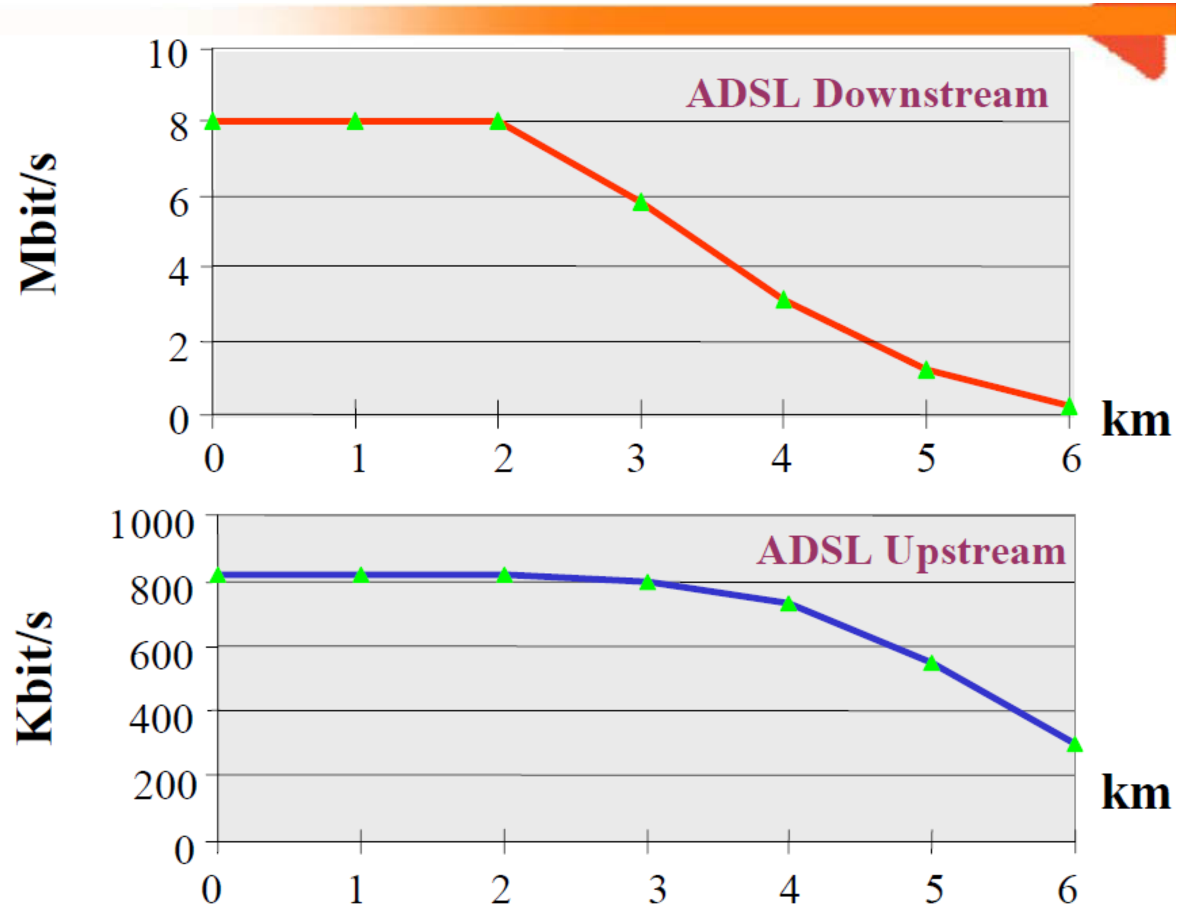


$$R = \frac{\varphi \times d}{S_{eff}}$$

Attenuation due to distance



Speed characteristics vs. distance

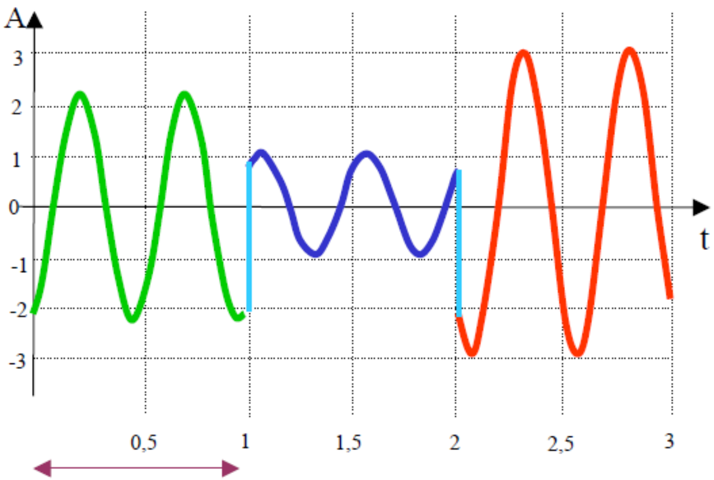


Quadrature Amplitude Modulation (QAM)

Symbol is represented by a variation of amplitude & phase for a particular frequency

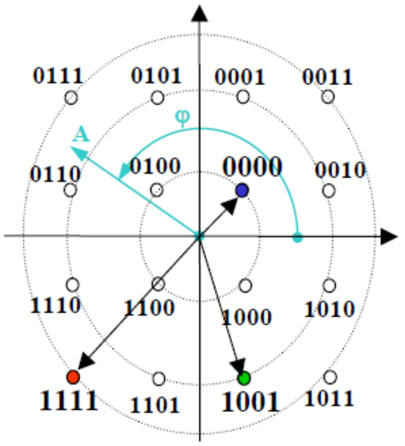
$$y = A \cdot \sin(2\pi\, f.t + \varphi)$$

Transmitted data = 1001 0000 1111



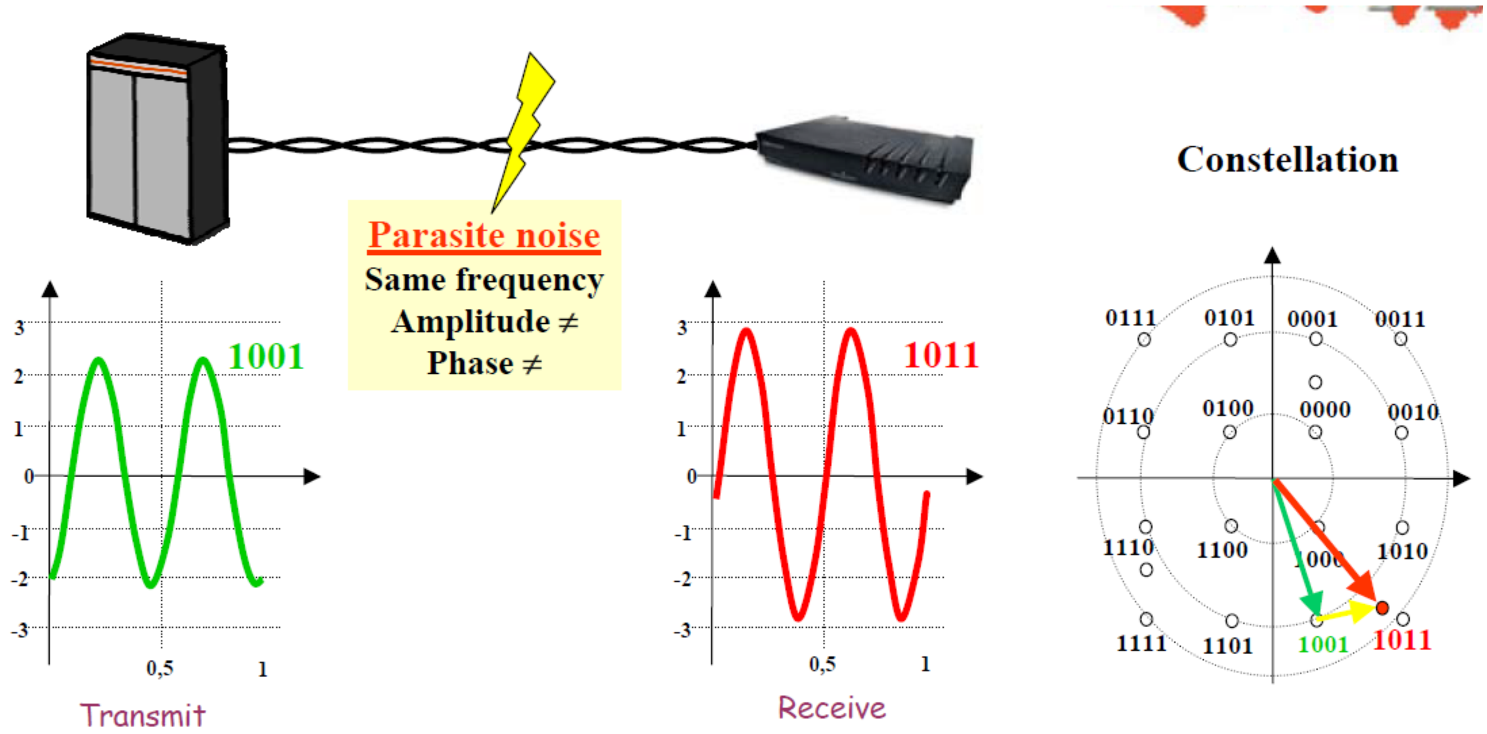
Symbol length (Ts)

Constellation



4 bits/symbol
>> QAM-16

QAM and noise



QAM vs. SNR

Bits/symbol	QAM	Signal/Noise ratio (dB) for BER<10^{-7}
4	QAM-16	21,8
6	QAM-64	27,8
8	QAM-256	33,8
9	QAM-512	36,8
10	QAM-1.024	39,9
12	QAM-4.096	45,9
14	QAM-16.384	51,9

table can be used in 2 ways :

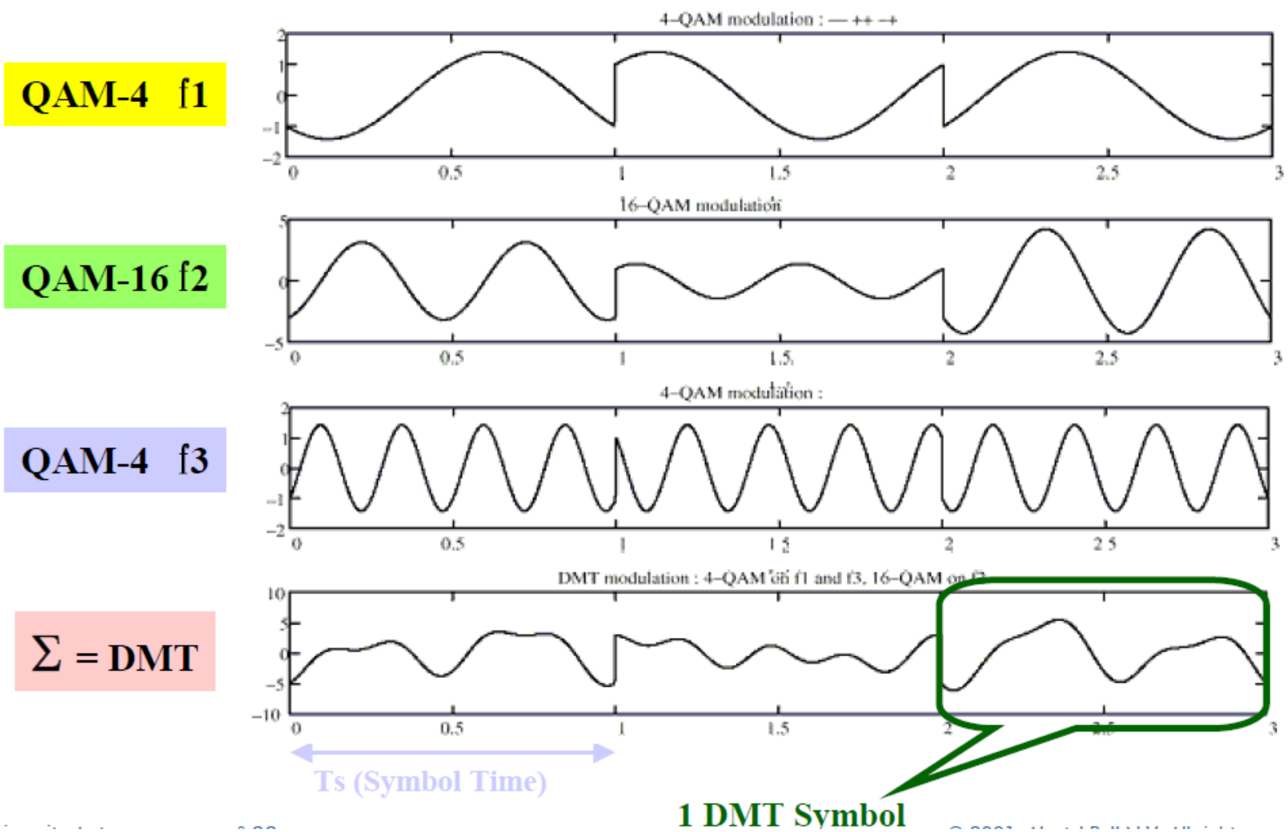
(a) what is minimum required SNR to modulate N bits on a carrier

(b) how many bits can be modulated given a SNR of Y dB

Discrete Multi Tone (DMT)

- For ADSL multiple carrier frequencies are modulated on the 1 ADSL line using Quadrature Amplitude Modulation.
- These frequencies are equally spaced and for each carrier the SNR is measured to determine the maximum achievable QAM.
- The sum of all frequencies is put on the line
- This principle is called Discrete Multi Tone (DMT)

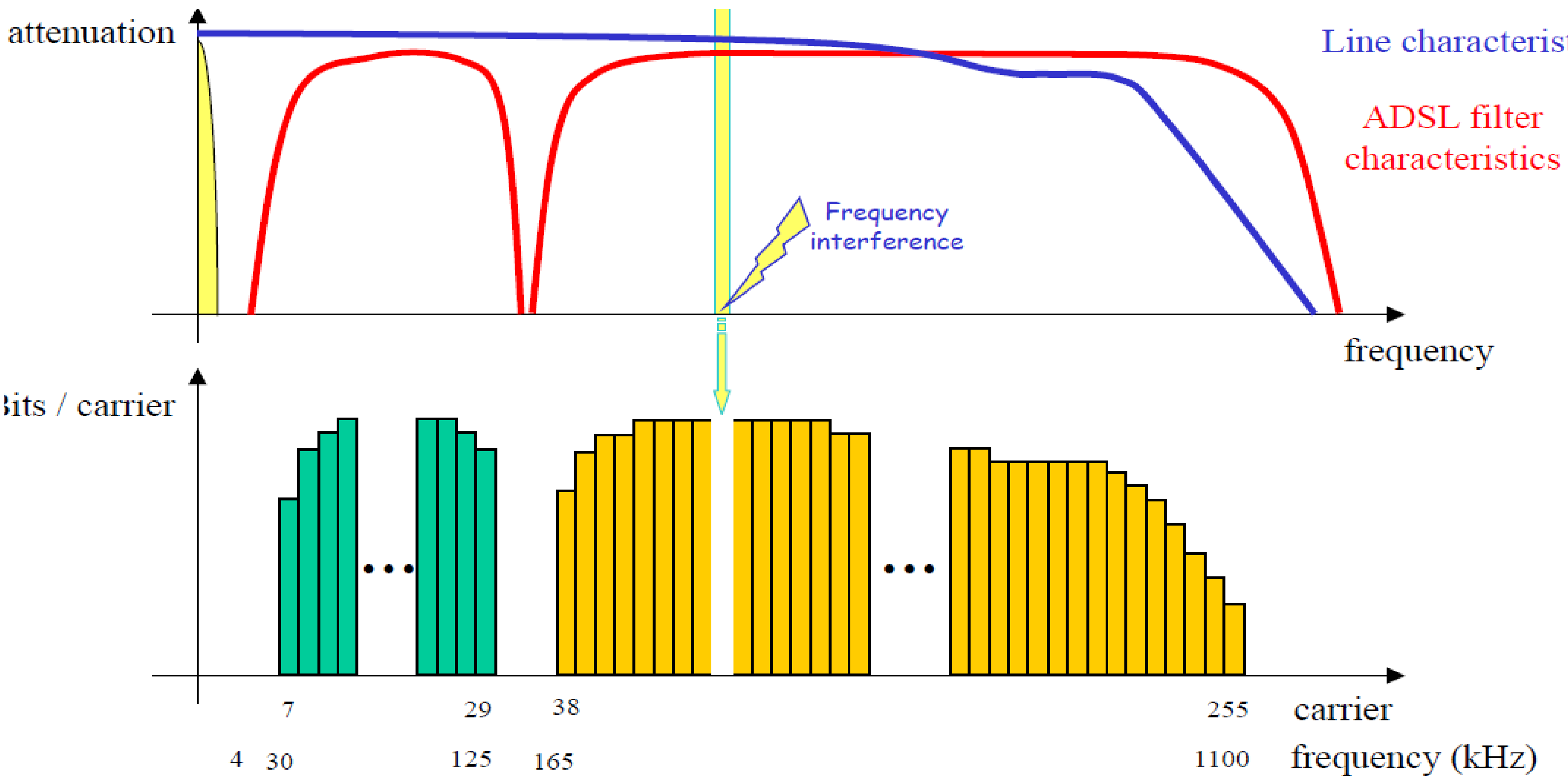
Discrete Multi Tone example



DMT and ADSL

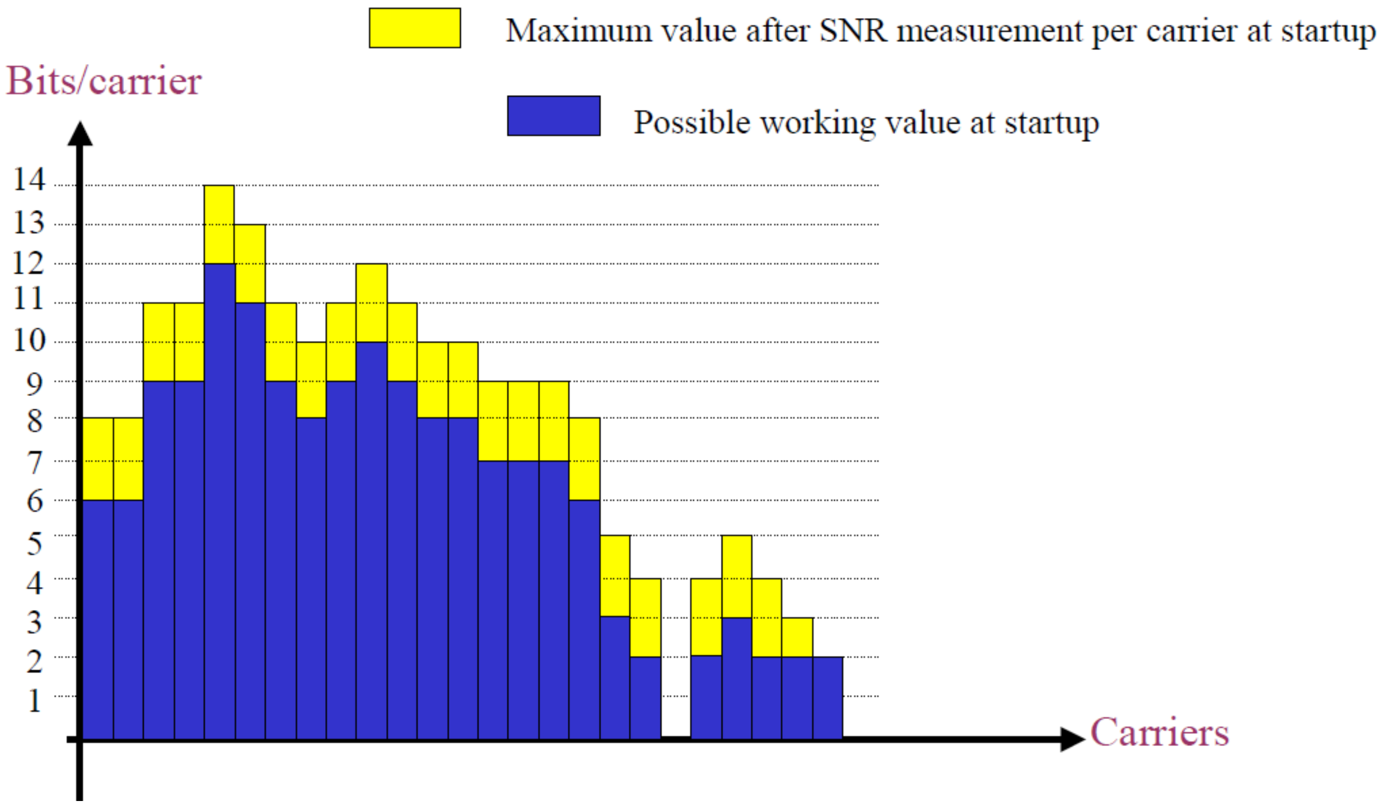
- The spectrum used for ADSL is divided into 255 carriers.
  - Each carrier is situated at n x 4,3125 kHz
- For the upstream direction carriers 7 to 29 are used
- For the downstream direction carriers 38 to 255 are used
- On each carrier the SNR is measured and the QAM determined.
  - Minimum ⇨ QAM-4 ⇨ 2bits/symbol
  - Maximum ⇨ QAM- 16384 ⇨ 14 bits/symbol
- Symbol period for each carrier : $\pm 250\ \mu s$

DMT vs. line characteristics



Dividing the used frequency spectrum in subchannels results in the possibility to assign a different QAM scheme on every subchannel. So depending on the SNR of a specific carrier, more or less data bits can be transported.

bits / carrier

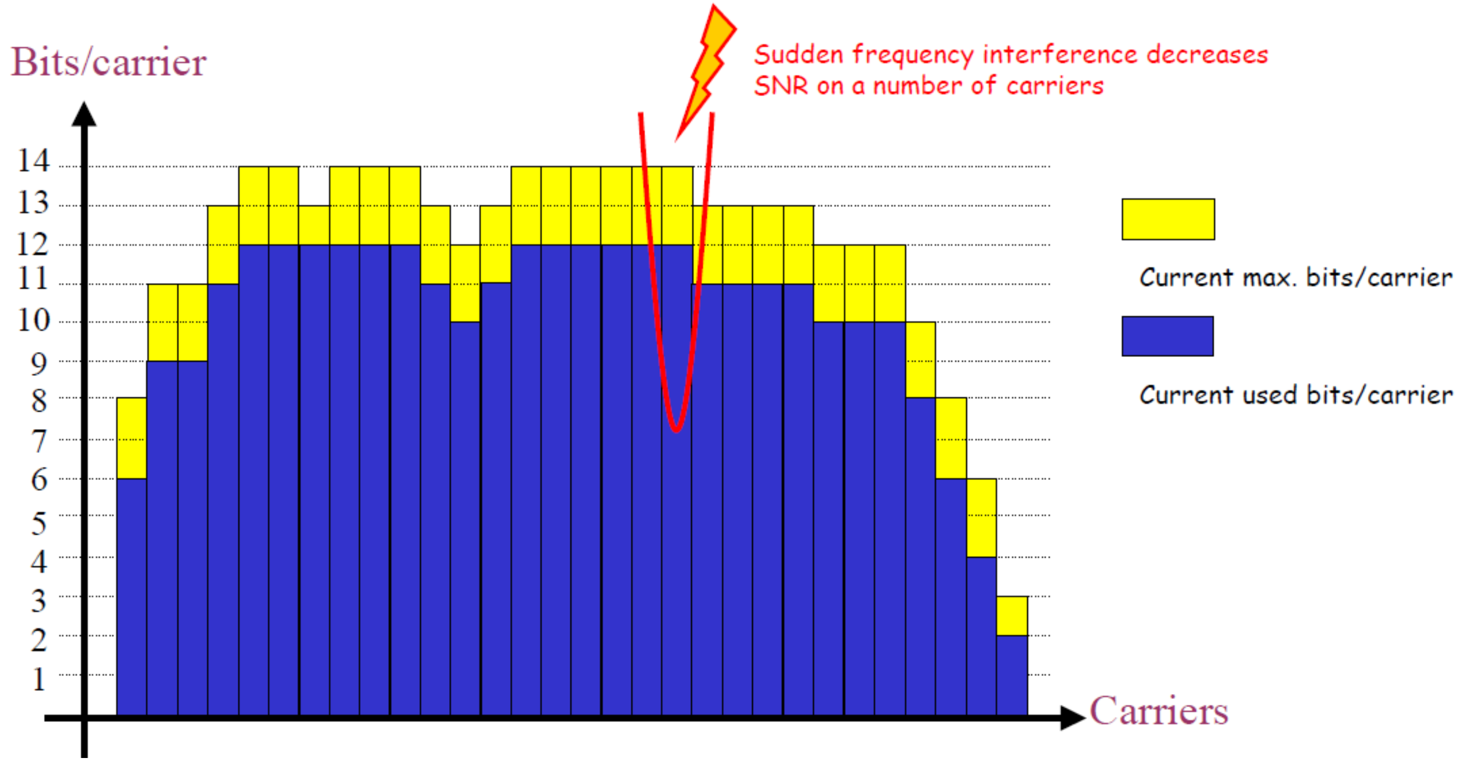


We will always assign less bits to the carriers then allowed by the measured SNR. Typically we assign anaverage of 2 bits less.
Modem does not calculate with bits. It measures the available SNR, then subtracts the Target Noise Margin, and then checks to what constellation it would fit (table slide 31).

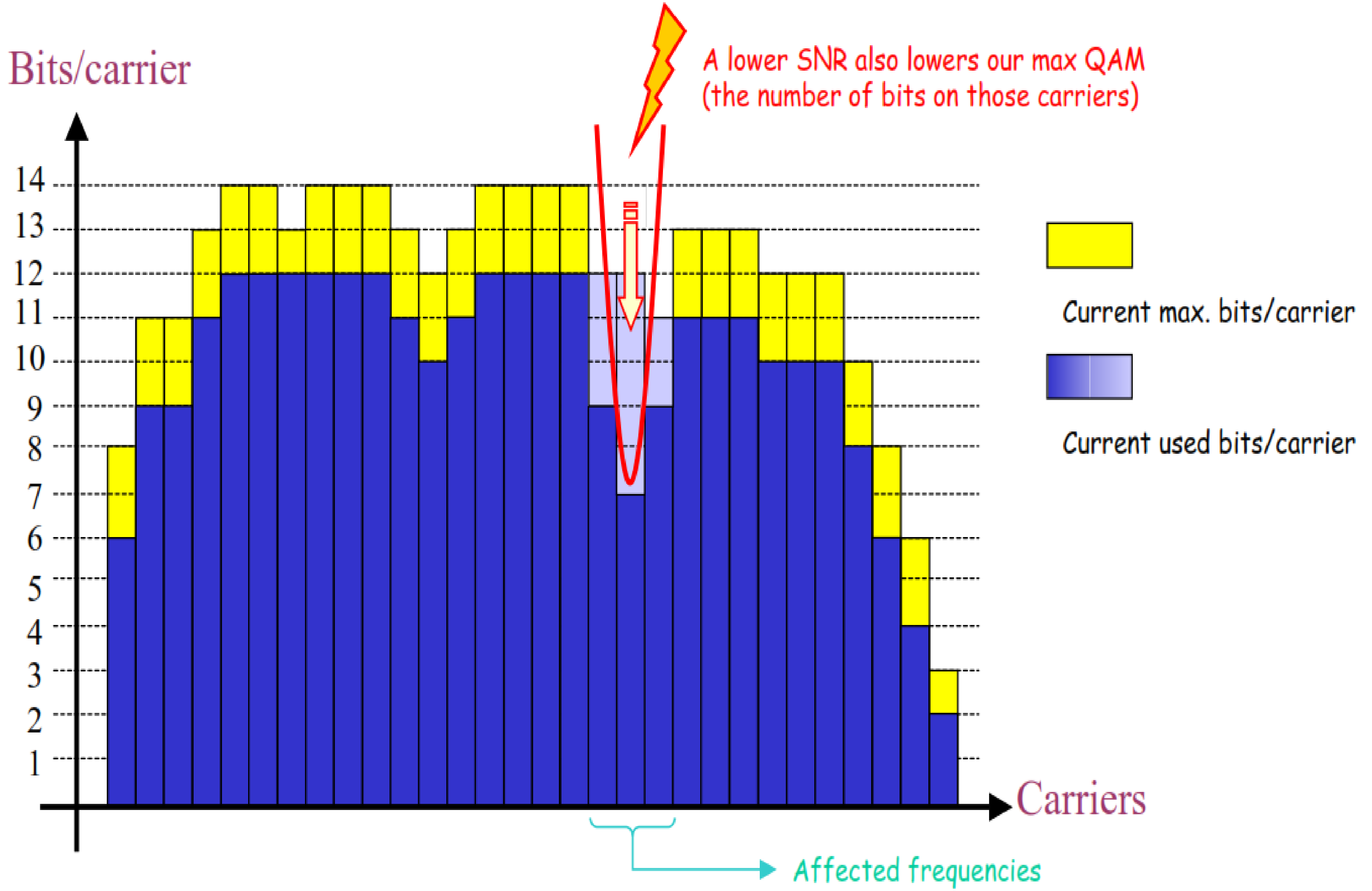
Bitswapping

- After startup we will use a lower QAM then possible on most of the carriers.
  - The measured SNR at startup determines the maximum possible QAM at startup, e.g.: QAM-4096 corresponding to 12bits/symbol >>> used QAM on that carrier: QAM-1024 (10bits/symbol)
  - This results in extra bits that could be allocated on that carrier.
- During showtime (modem operation) the SNR is measured on all carriers at regular intervals (default 1sec).
  - If the SNR on a certain carrier degrades resulting at a lower QAM that can be used on that carrier, the bits of that carrier will be re-allocated to other carriers where the max QAM is higher then the actual used QAM.
  - The modems will try to spread out the re-allocated bits over numerous carriers.

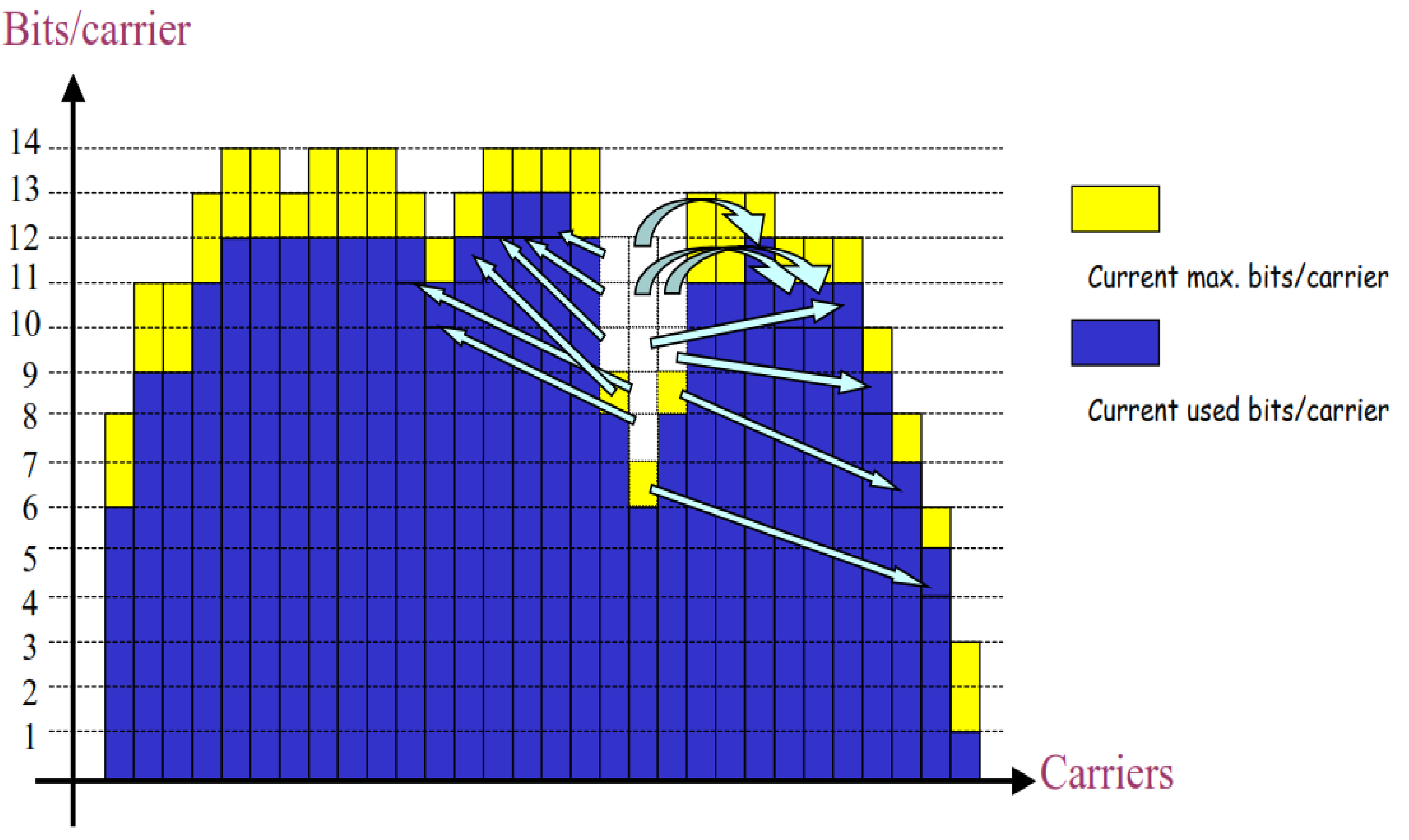
Bitswapping explained



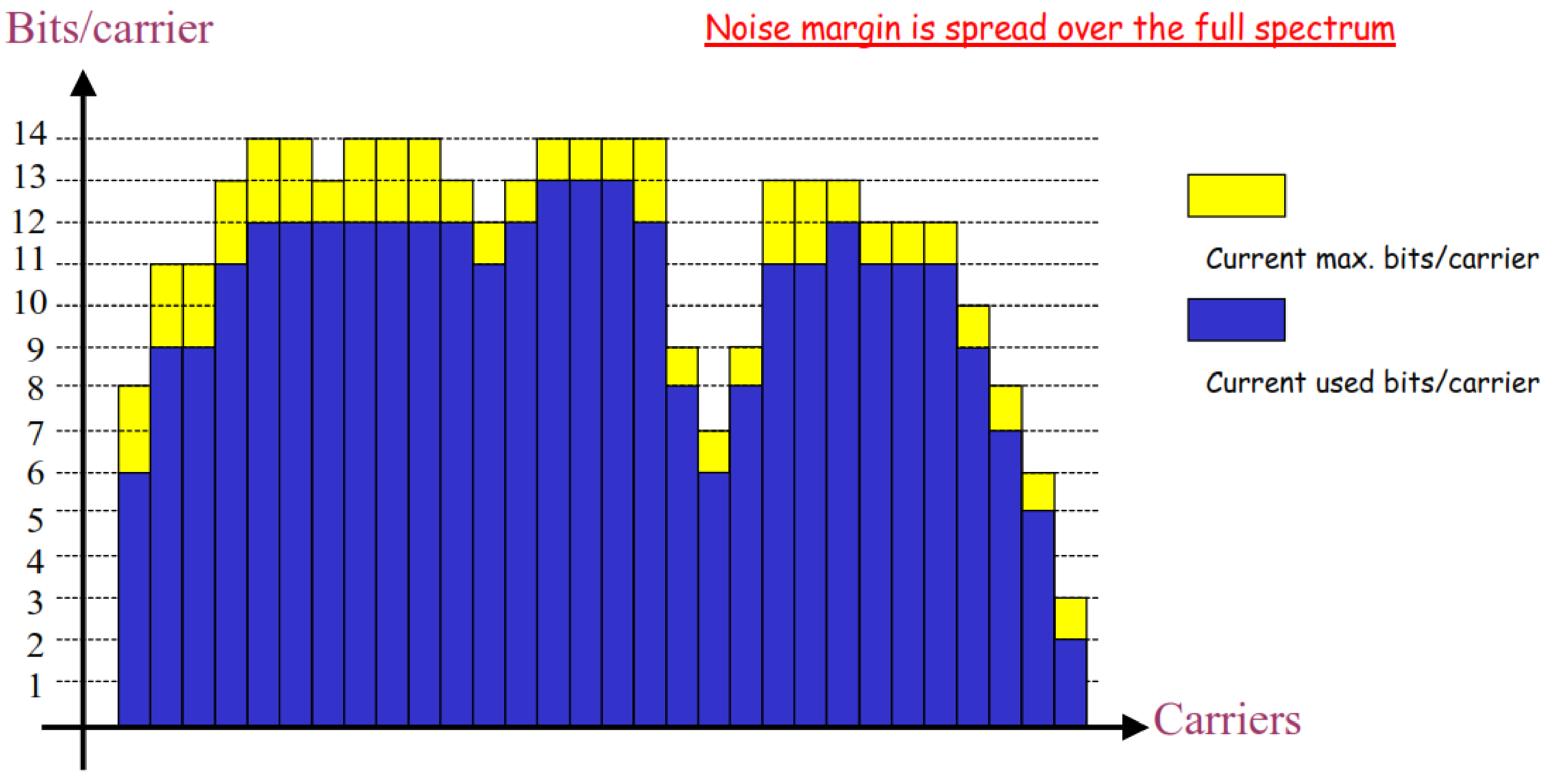
Bitswapping explained



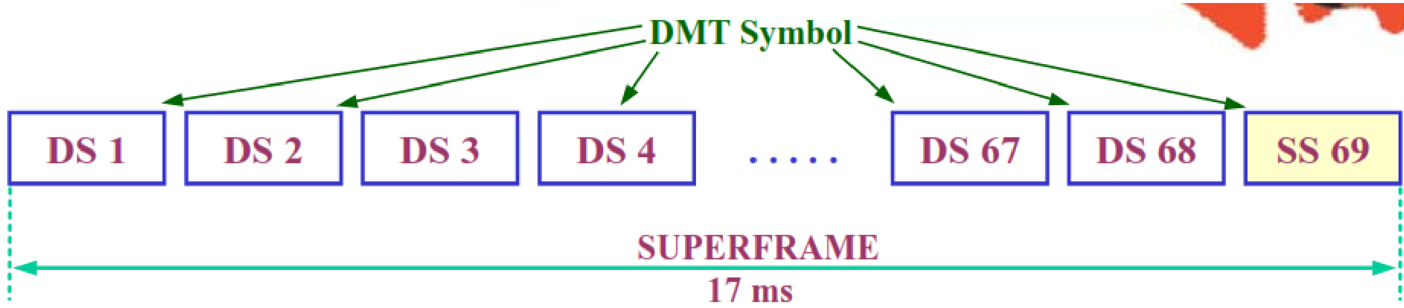
Bitswapping explained



Bitswapping explained



ADSL Superframe

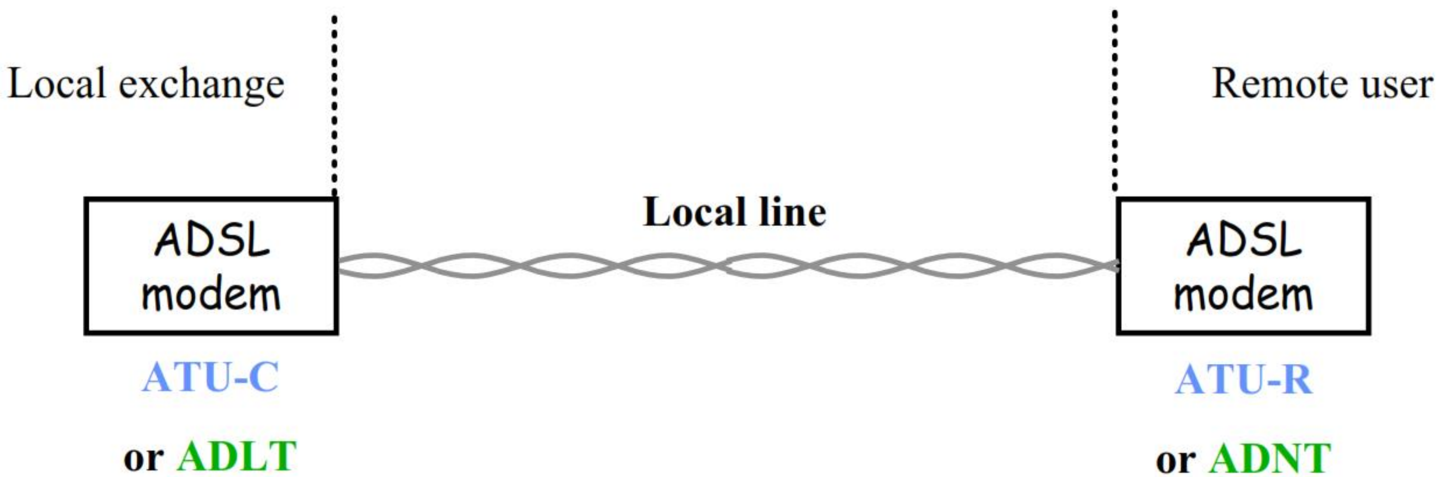


- DMT Symbol:
  - a DMT symbol is the sum of all symbols on each individual carrier.
- Data Symbol (DS):
  - a data symbol is used to transmit information (data).
- Synchronisation Symbol (SS):
  - a sync symbol is transmit after 68 data symbols to assure synchronisation and to detect a possible loss of frame.
- ADSL symbol period:
  - Ts = 17 ms / 69 = 246,377 µs
  - Ts = 17 ms / 68 = 250 µs (symbol period for the data plane!)

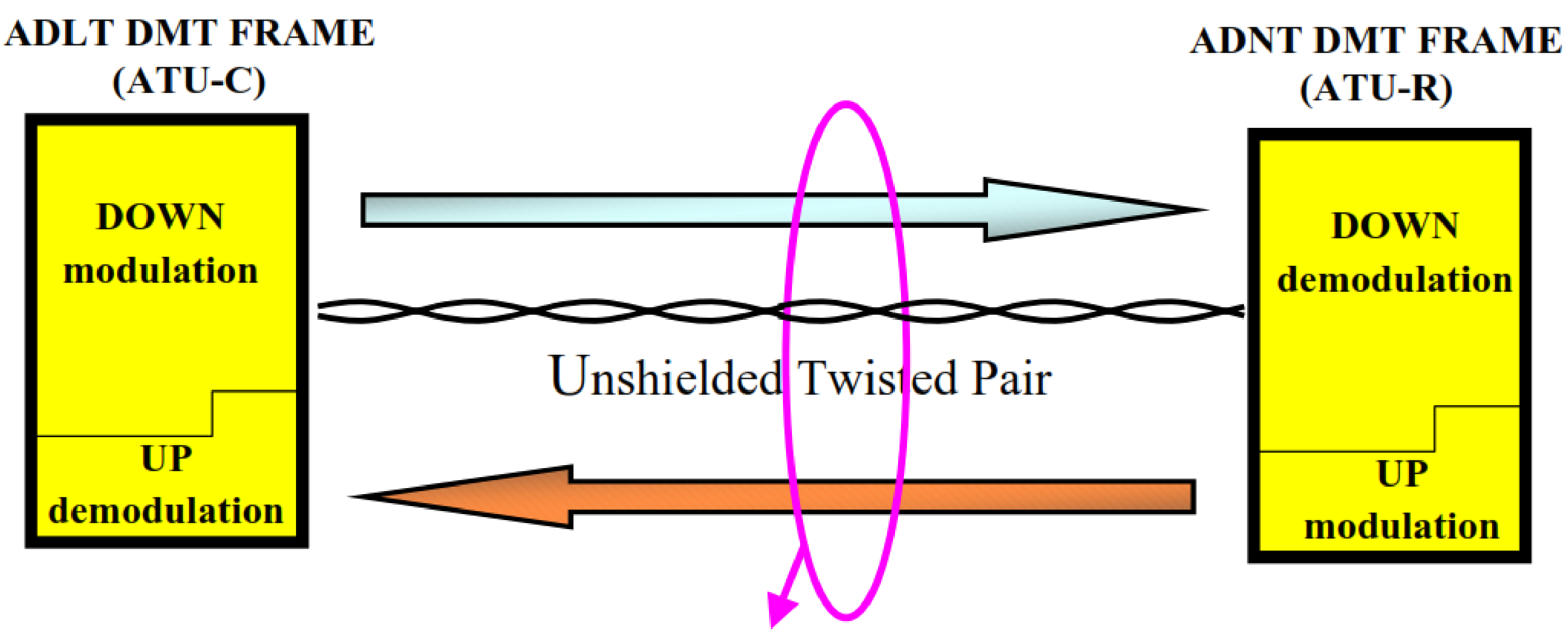
For ADSL modem-to-modem communication we have following concepts:

- ATU-C & ATU-R: ADSL Terminal Unit Central and ADSL Terminal Unit Remote
- ADLT & ADNT: ADSL Line Termination & ADSL Network Termination

Both concepts apply to the ADSL modem.



Communicating modems



2 analogue signals (UP,DOWN) travelling in opposite directions over the UTP

- ATU-R locks to the pilot carrier in the downstream direction (PLL)
  - The better the lock the better the overall SNR!

Communicating modems

- Modems using the ANSI ADSL standard locks to a carrier in the up - and downstream direction, i.e. the ATU-R locks to the pilot (carrier 64:276 KHz) in the downstream part and the ATU-C locks to the pilot in the upstream part (carrier 16:69 KHz). ANSI has 2 pilot carriers, 1 in the downstream and 1 in the upstream.
- Modems using the ITU-T ADSL standards only require the ATU-R to lock to the ATU-C and also use this lock for his upstream transmission.