Ch10: Multiplexing and Multiple Access

Information source and input transducer → Source Coding → Channel Coding → Modulator

↓

Channel

↓

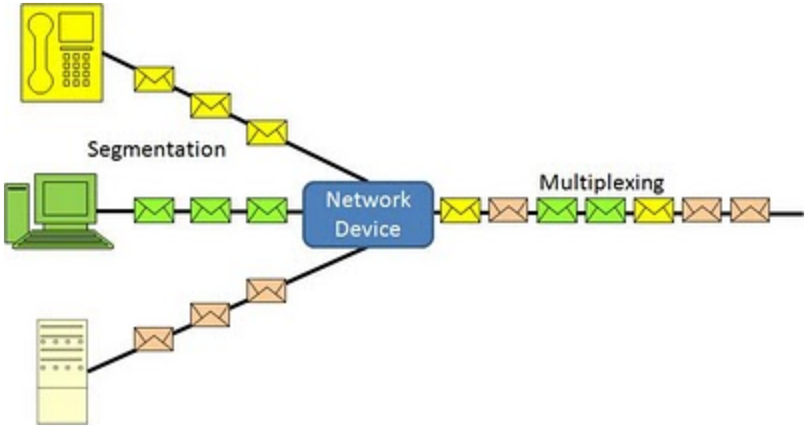
Demodulator (Matched Filter) → Channel Decoding → Source Decoding → Information sink and output transducer

Ch10: Multiplexing & Multiple Access

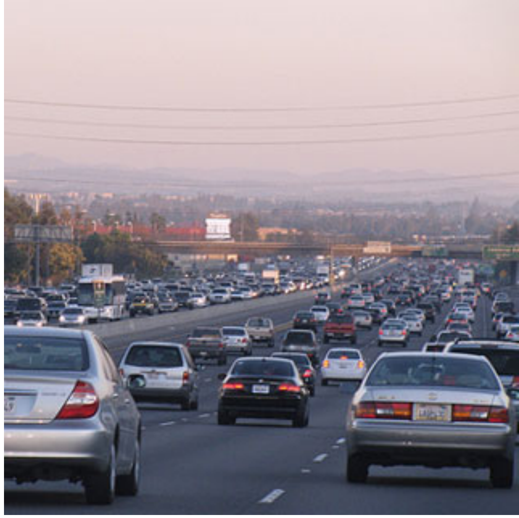
- Questions to be answered:
  - **Multiplexing: How can multiple users communicate simultaneously without interfering each other?**
  - **Multiple Access: How to allocate channels to users? What happens if there are more users than available channels?**

Ch10: Multiplexing and Multiple-Access

- ❑ Multiplexing
- ❑ Multiple-Access techniques
    - TDMA
    - FDMA
    - CDMA
    - SDMA



Multiplexing



- Looking at the right picture, can you figure out how multiple cars are sharing the same road?

- **Multiplexing** allows one channel to be used by multiple users to **send multiple messages.**

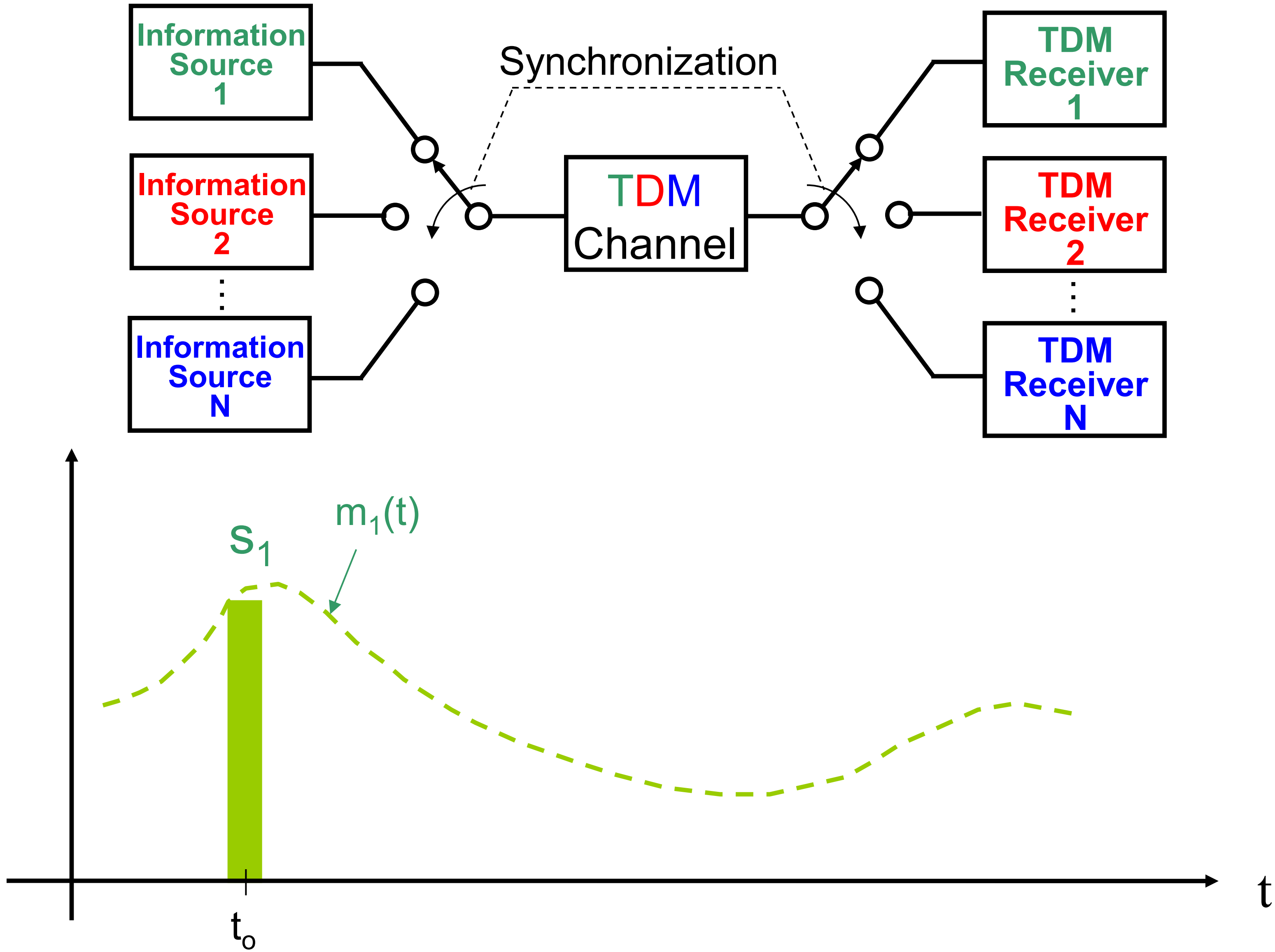
- Multiplexing is an extremely popular technique. It is used in mobilephone technology, telephone exchanges, microwave links, etc.

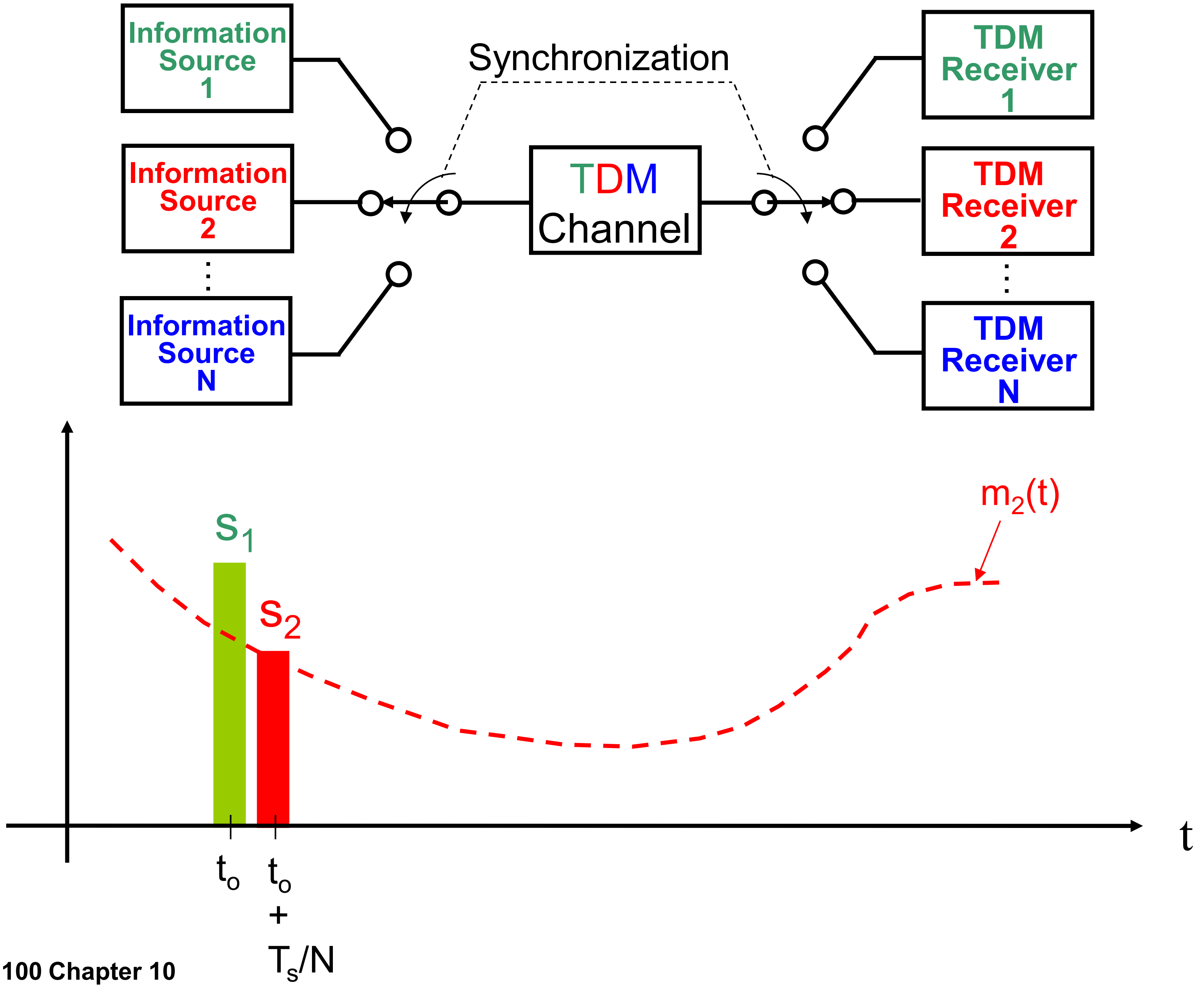
TDM and FDM

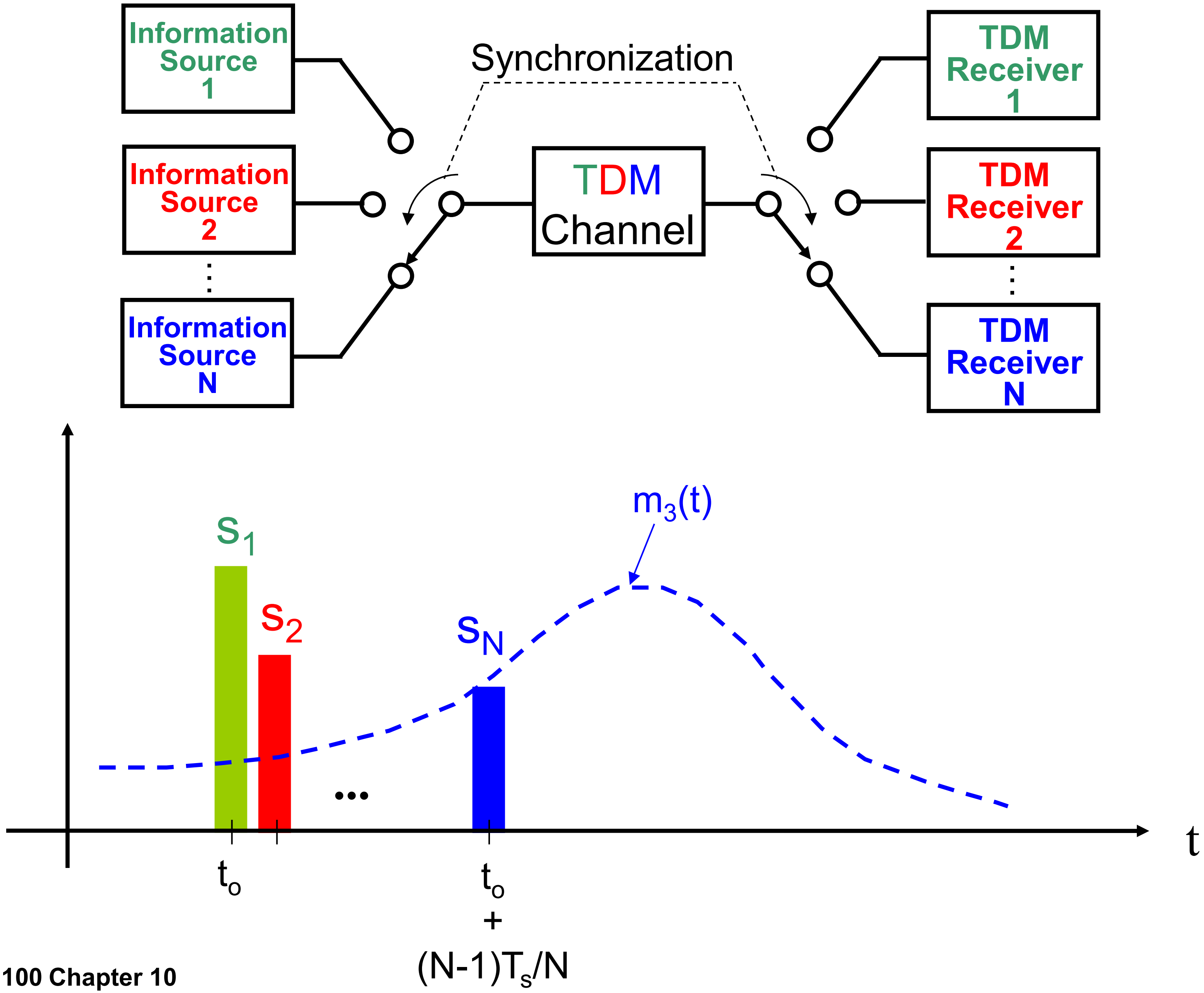
- Two of the most common types of multiplexing are known as **time division multiplexing** (**TDM**) and **frequency division multiplexing** (**FDM**).

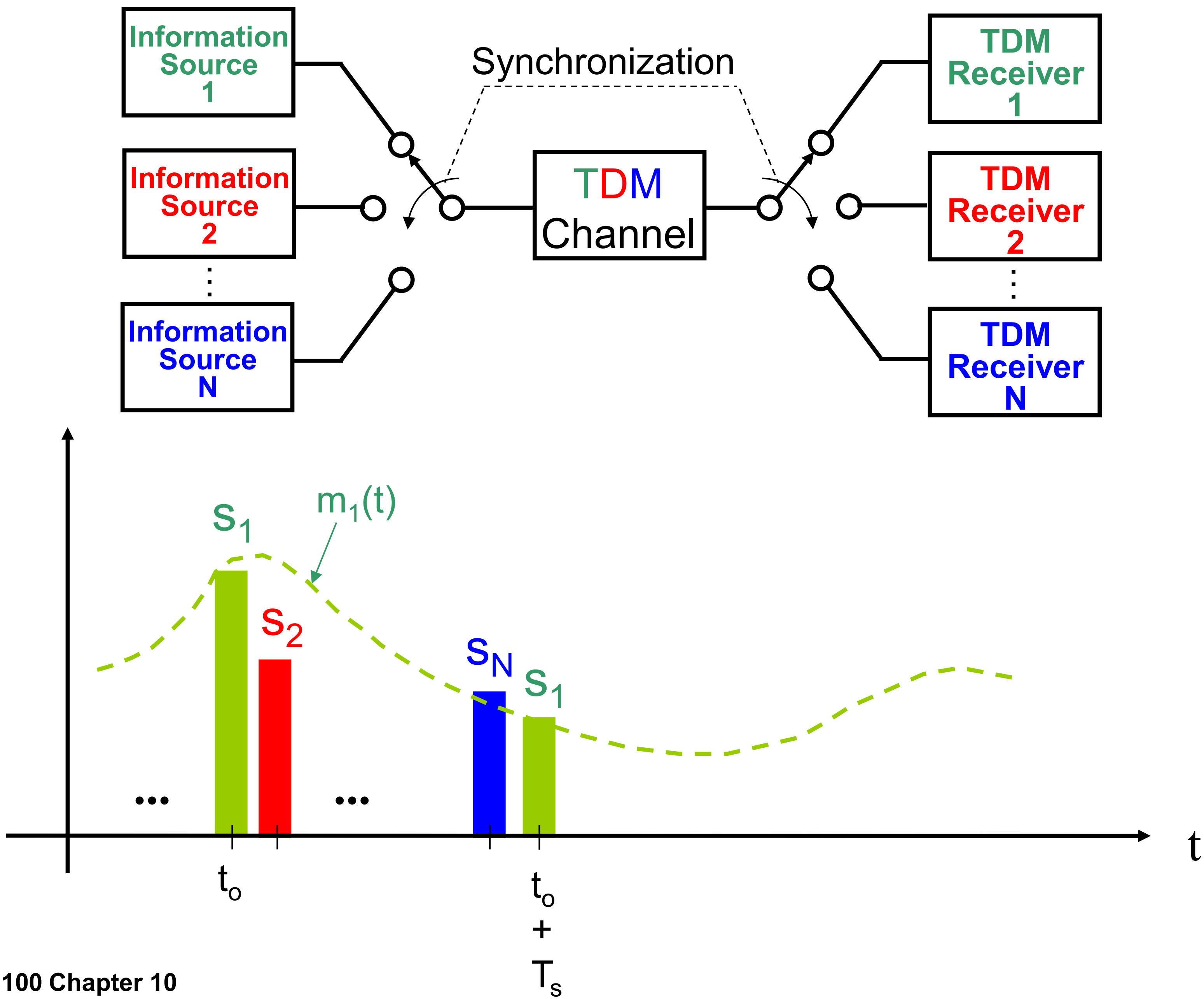
- The key to TDM is to realize that if the widths of pulses utilized to transmit one user's information are made small enough then there is space between the pulses to send additional signals.

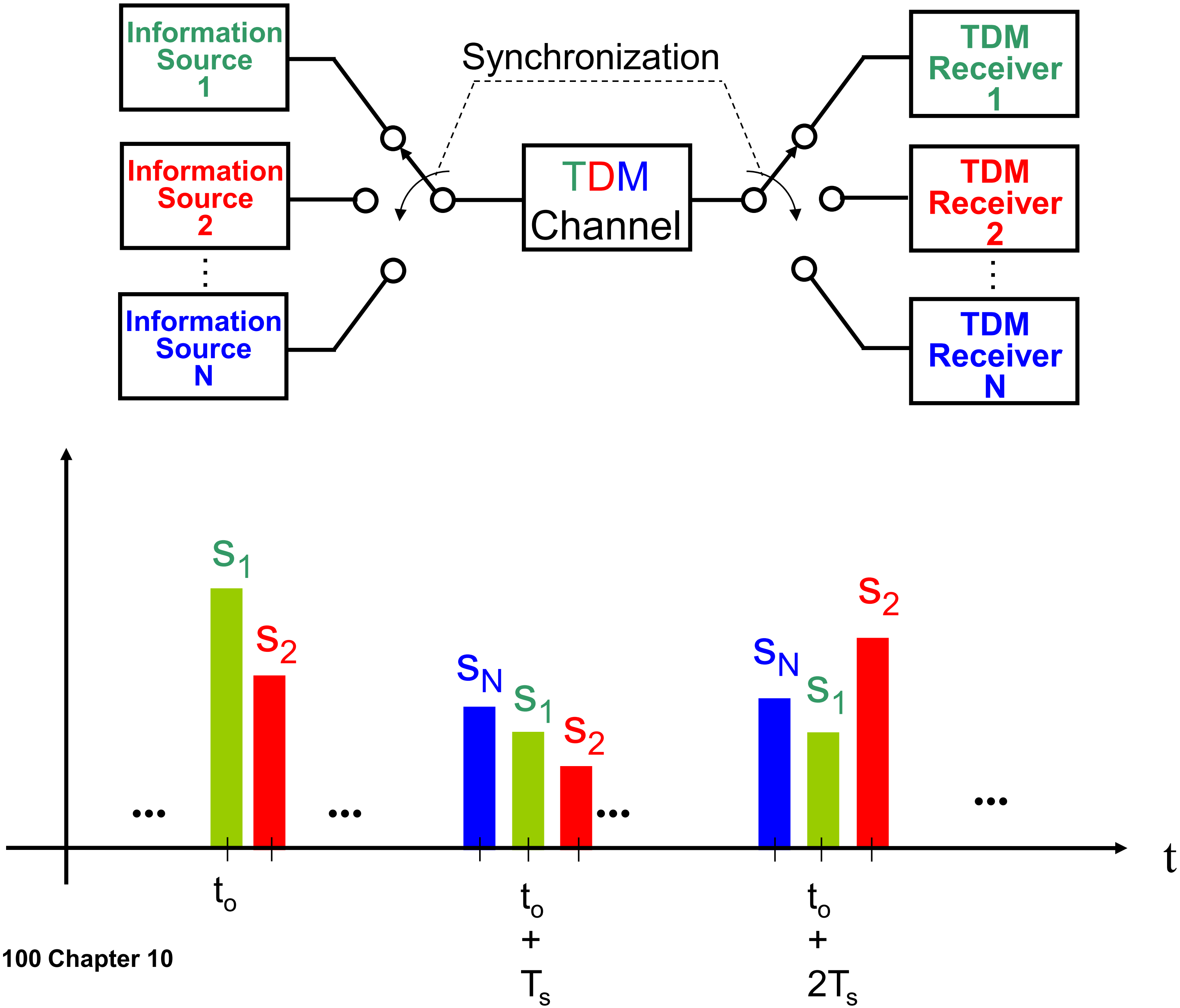
- Suppose we wish to time-multiplex signals. A possible approach is shown in the following diagram.


Information Source 1
Information Source 2
Information Source N
Synchronization
TDM Channel
TDM Receiver 1
TDM Receiver 2
TDM Receiver N
$m_1(t)$
S_1
t_o
t


Information Source 1
Information Source 2
Information Source N
Synchronization
TDM Channel
TDM Receiver 1
TDM Receiver 2
TDM Receiver N
S1
S2
m2(t)
t
to
to + Ts/N

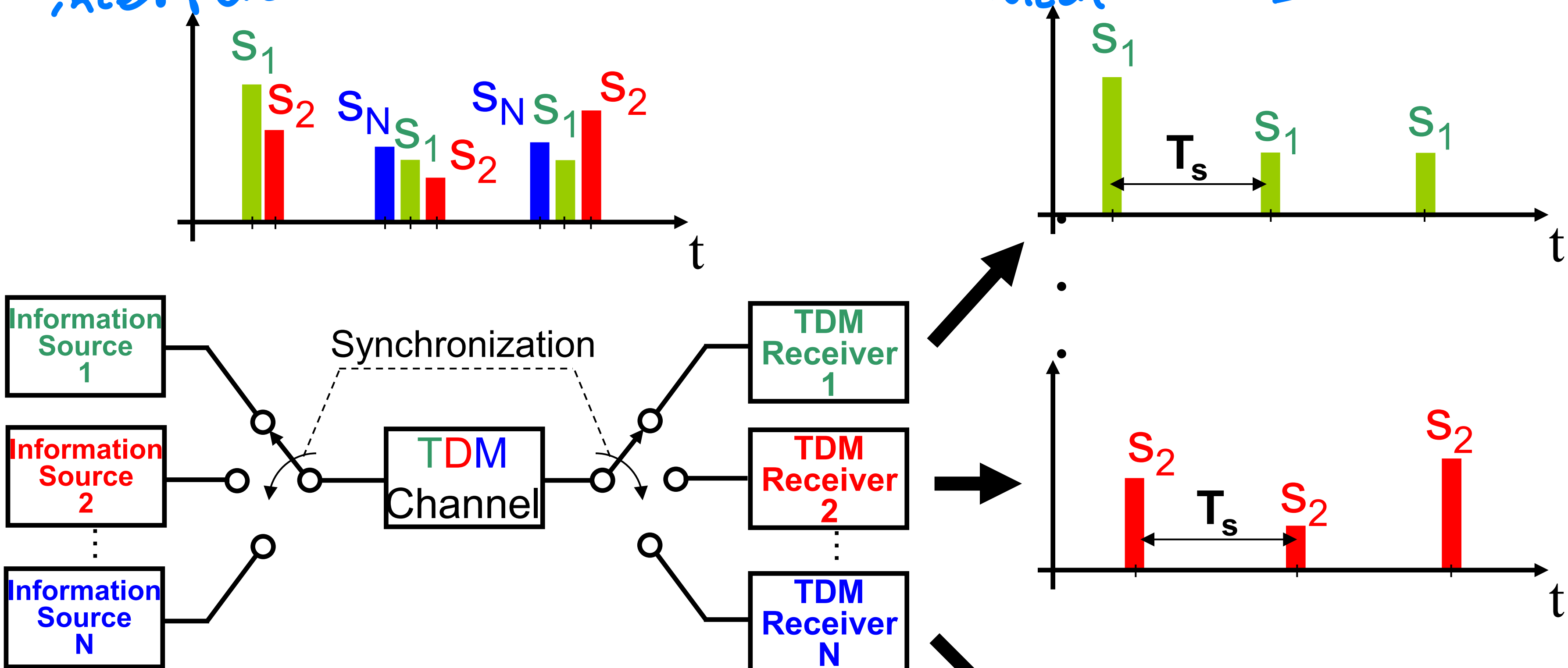

Information Source 1
Information Source 2
Information Source N
Synchronization
TDM Channel
TDM Receiver 1
TDM Receiver 2
TDM Receiver N
$m_3(t)$
S_1
S_2
S_N
...
t
t_o
$t_o + (N-1)T_s/N$


Information Source 1
Information Source 2
Information Source N
Synchronization
TDM Channel
TDM Receiver 1
TDM Receiver 2
TDM Receiver N
m1(t)
S1
S2
SN
S1
t
to
to + Ts


Information Source 1
Information Source 2
Information Source N
Synchronization
TDM Channel
TDM Receiver 1
TDM Receiver 2
TDM Receiver N
S1
S2
SN
S1
S2
SN
S1
S2
t
to
to + Ts
to + 2Ts

Ensure no interference

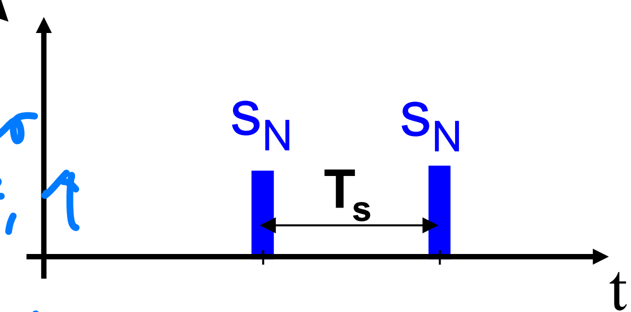
$B: 4kHz$ Pulse width $\geq \frac{1}{2B}$ (sampling rate)



Two ways to increase NumUsers

是為 cover 多的用戶，↑

Ts is determined by?



Pulse width is determined by?

× interference
越窄越好，但不可無窮窄

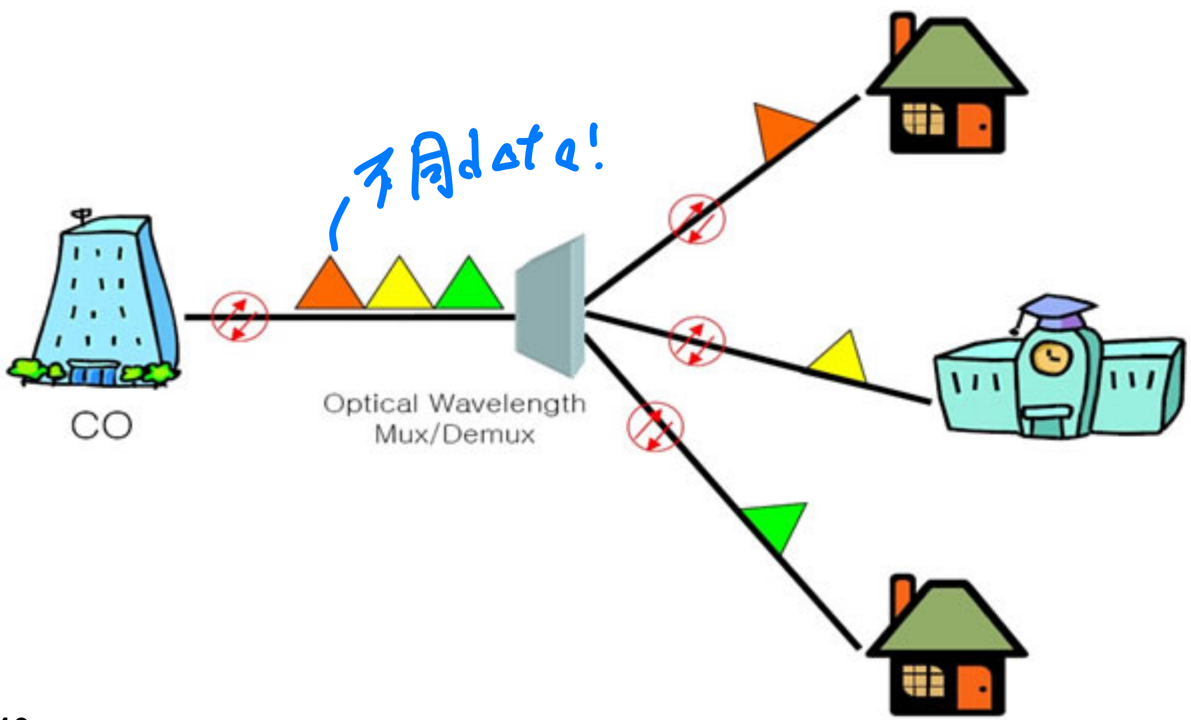
Time Division Multiplexing

- At the receiver, the TDM signal must be **de-multiplexed** to recover the original signals.
- The key to demodulation is **synchronization**. The transmitter and receiver must be perfectly synchronized so that they known which samples come from which message.
- Usually, synchronization is performed by **reserving some time slots** specifically to transmit synchronization signals- Similar to the start and stop bits in computer serial ports.

Ensure enough space!

TDM (Continued)

- TDM is used in mobile telephone systems like GSM and also in optical networks.



FDM

Radio own freq.

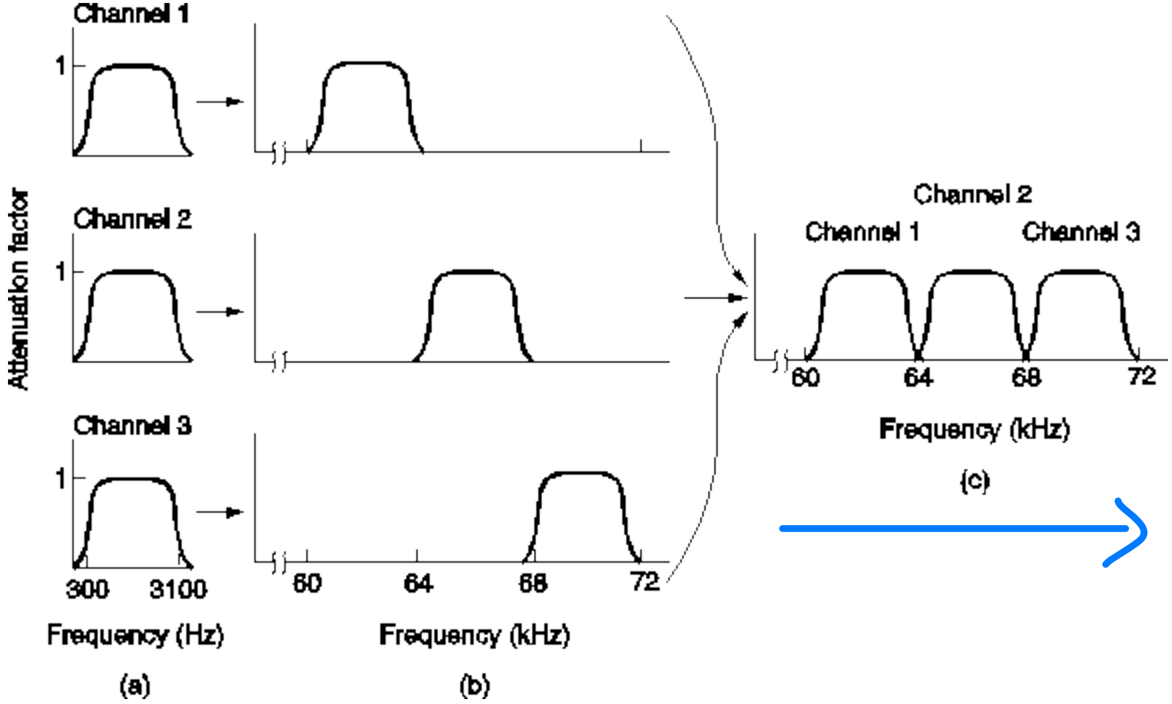
- In **FDM**, several messages are transmitted simultaneously by **choosing a different carrier frequency** for each signal.

- These **carrier frequencies** are chosen so that the signal spectra are **not overlapping.**

interference

FDM

- An example of such processing is shown below



FDM

- The baseband messages all occupy the **same** frequency spectrum.

- These messages are then translated to different parts of the spectrum by using a **mixer (modulator)** with **different carrier frequencies.**

FDM

partition signals in frequency domain

- **Frequency division multiplexing**, then, is the positioning of signal spectra in frequency domain such that each message signal can be filtered out.

$f_2 - f_1 \geq W_1 + W_2$

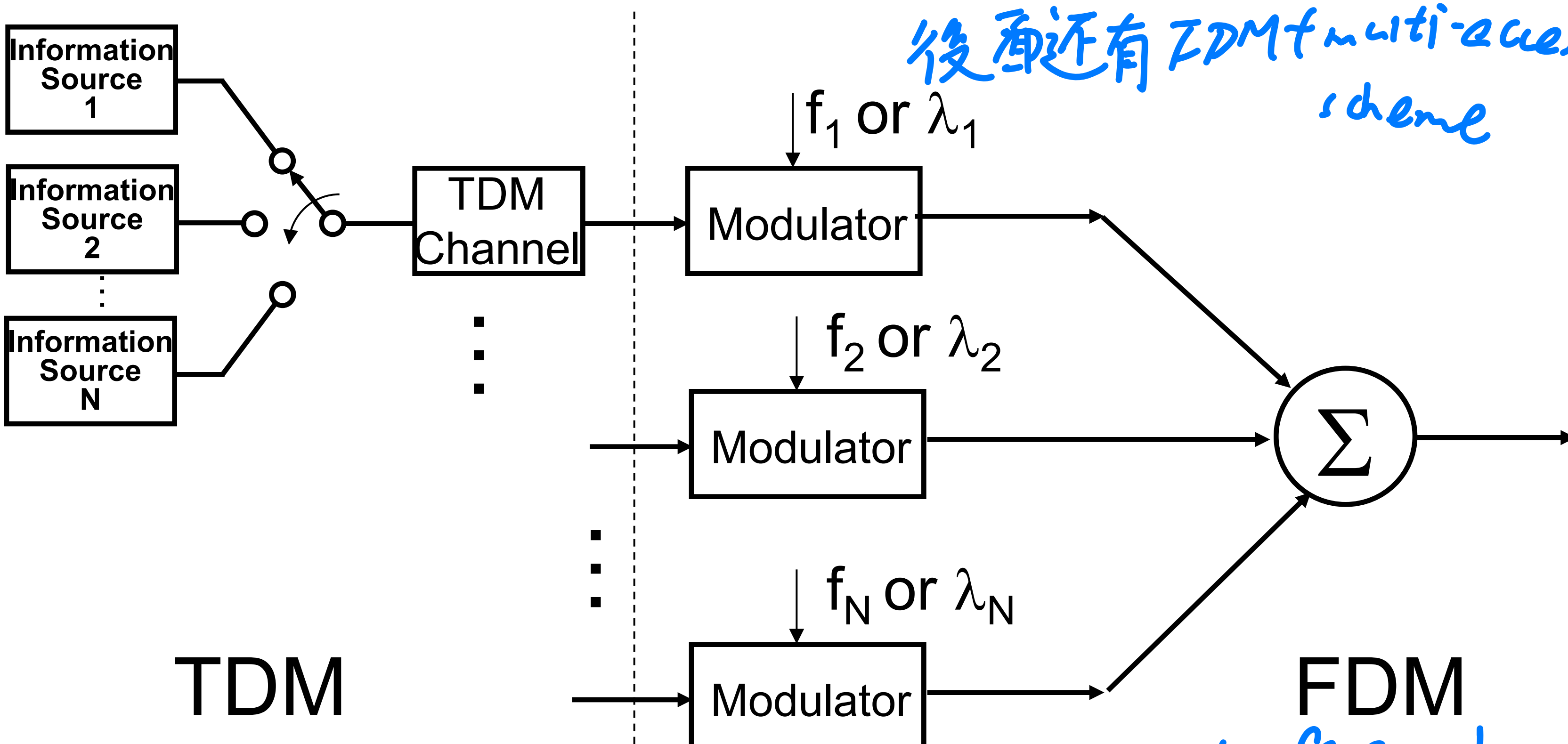
- **The spacing between the two channels (carrier frequencies, e.g. f_1 and f_2) must be at least (W_1+W_2) where W_1 and W_2 are the bandwidth of the two baseband messages carried by f_1 and f_2, respectively.**

Time and Frequency Division Multiplexing

可一起使用!

- For certain applications, such as synchronous optical network (SONET) or synchronous digital hierarchy (SDH), both TDM and FDM can be employed simultaneously

後面还有 TDM + multi-access scheme



combination, make sure no interference!

Ch10: Multiplexing and Muliple-Access

- ❑ **Multiplexing**
- ❑ **Multiple-Access techniques**
  - TDMA
  - FDMA
  - CDMA
  - SDMA

codes

Same idea

Multiple Access Schemes

- **Time Division Multiple Access (TDMA)**
  - **Different users** are **assigned different time slots** (e.g., GSM cellular phones)

→ [illegible] & users in channel
efficient, may waste some time-slot
if no-user

- **Frequency Division Multiple Access (FDMA)**
  - **Different users** are **assigned different frequency bands** (e.g., First-generation mobile phones)

Multiple Access allocates channels to different users and also handles the situation when there are more messages than available channels (usually # Channels < # Users).

Code Division Multiple Access (CDMA)

- It is a spread spectrum multiple access technique which allows multiple signals occupying the same bandwidth to be transmitted simultaneously without interfering with one another.

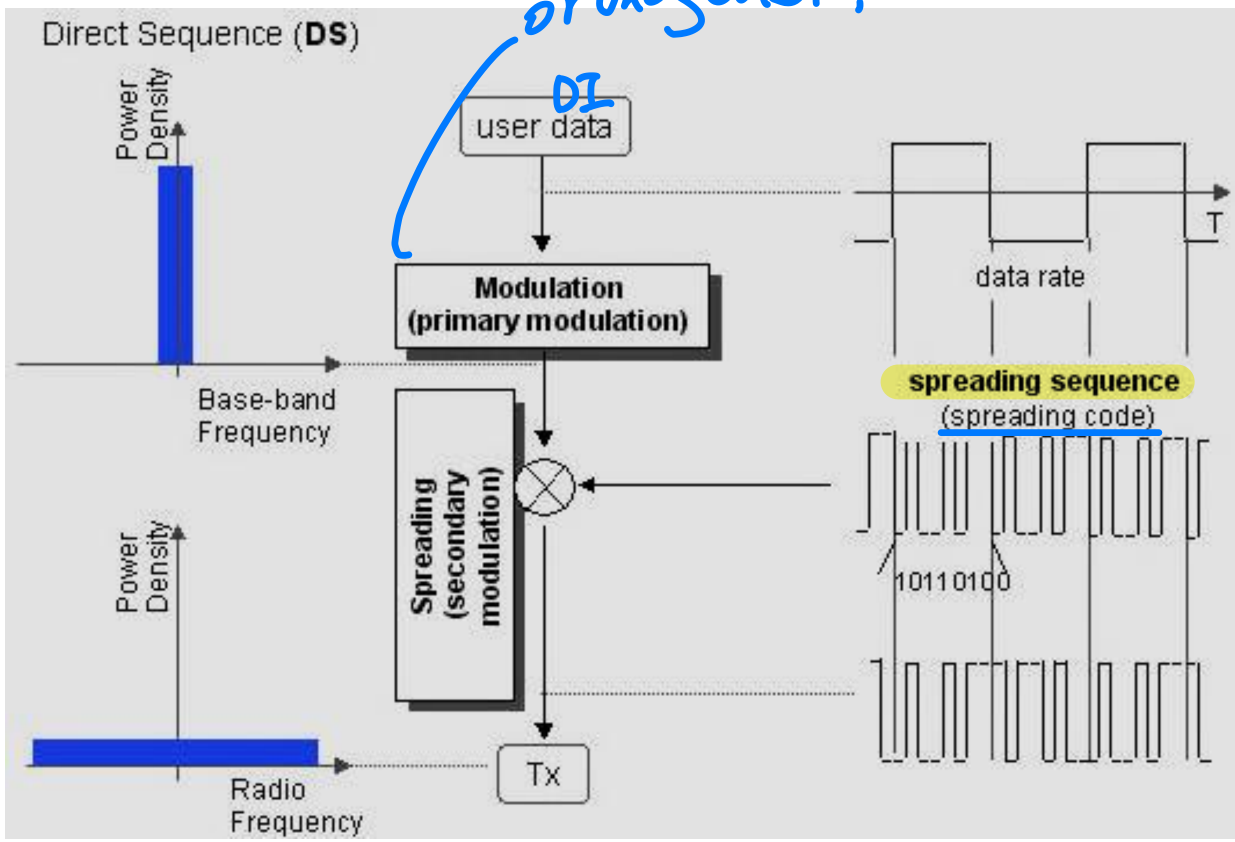
- In a CDMA system, each user is assigned a particular code.

- This unique code enables the desired message to be extracted at receiver.

Code Division Multiple Access (Transmitter Side)

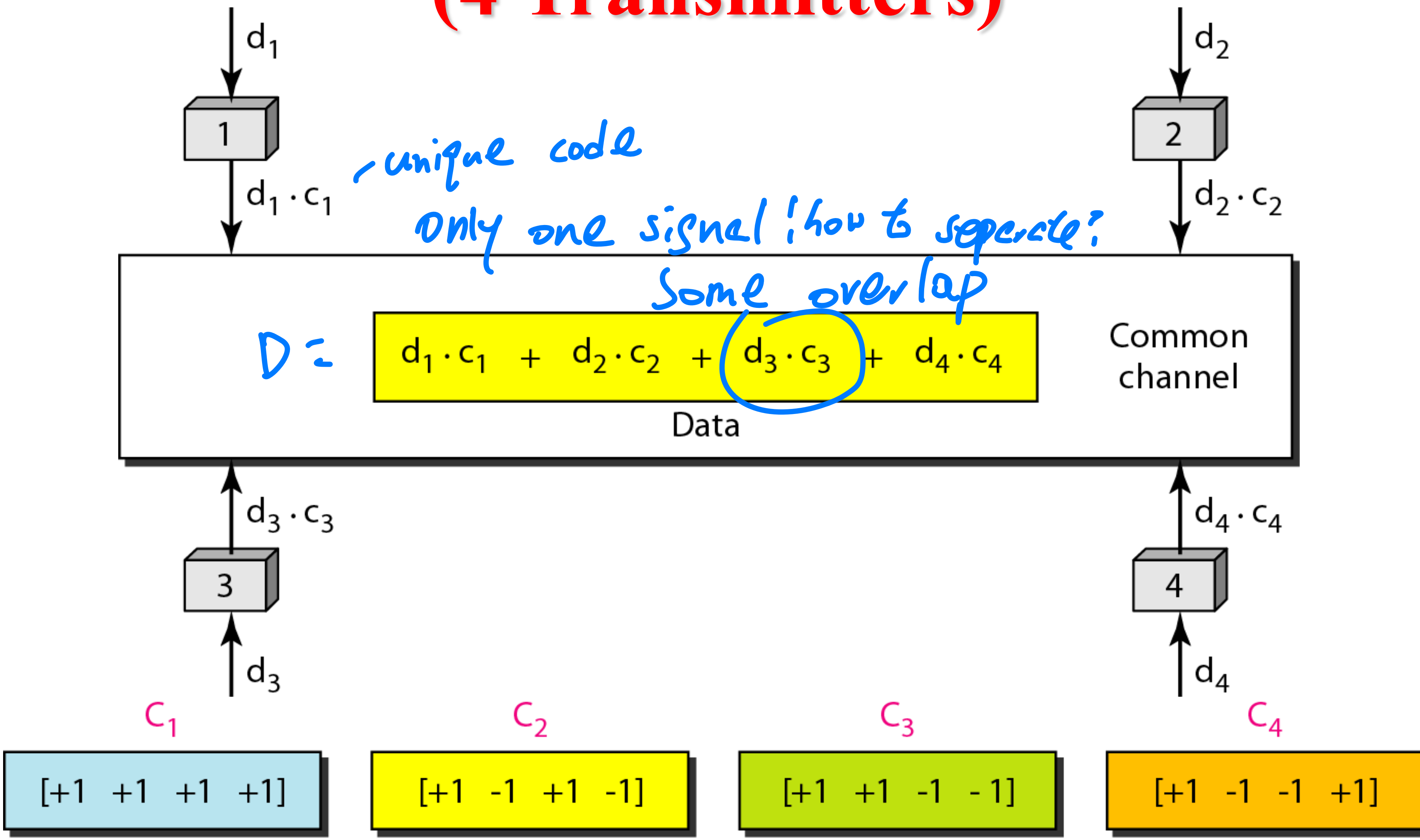
orthogonal!

1010
bit 1
bit rate ×4
1010

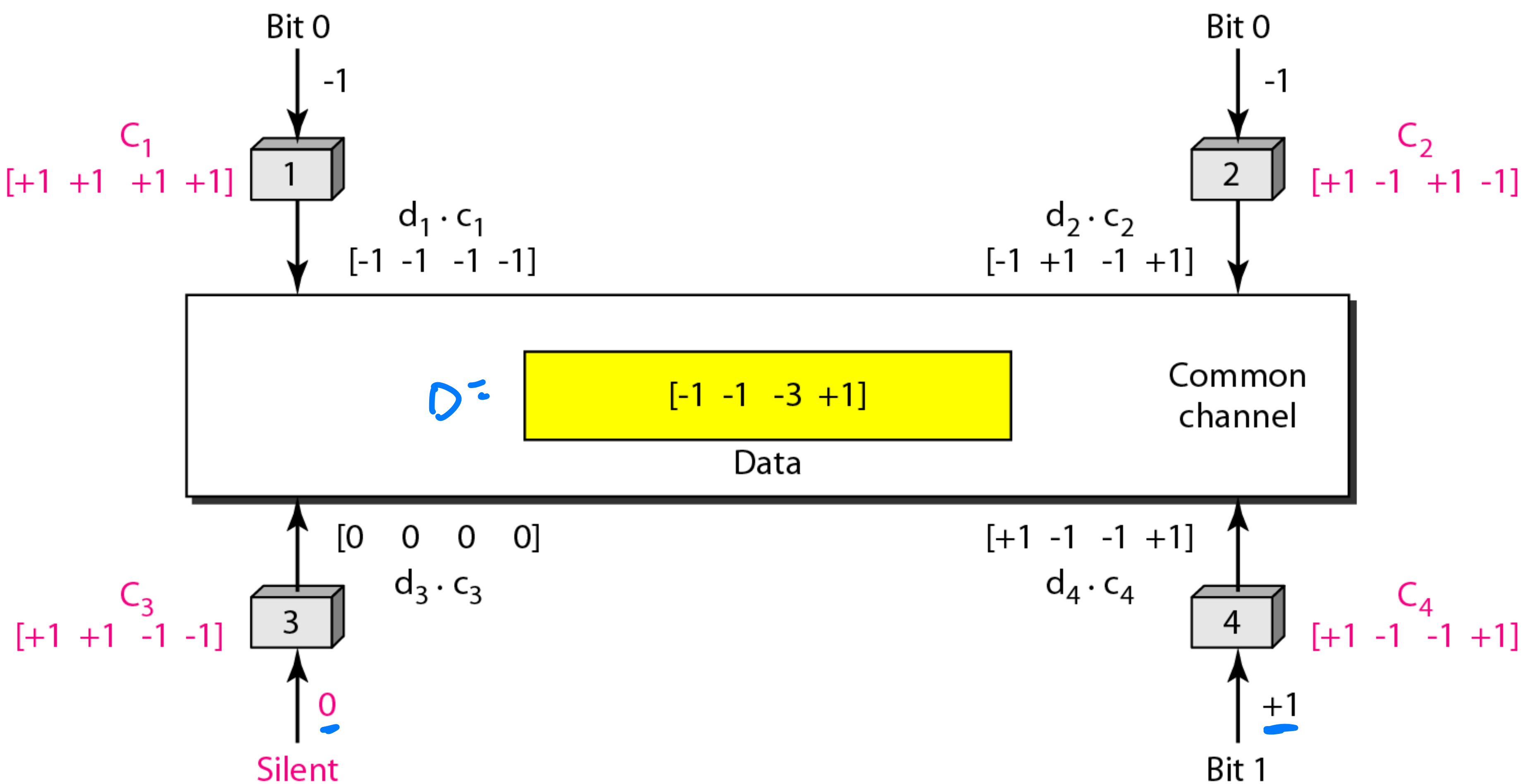


hybrid of FDM, TDM

Code Division Multiple Access (4 Transmitters)

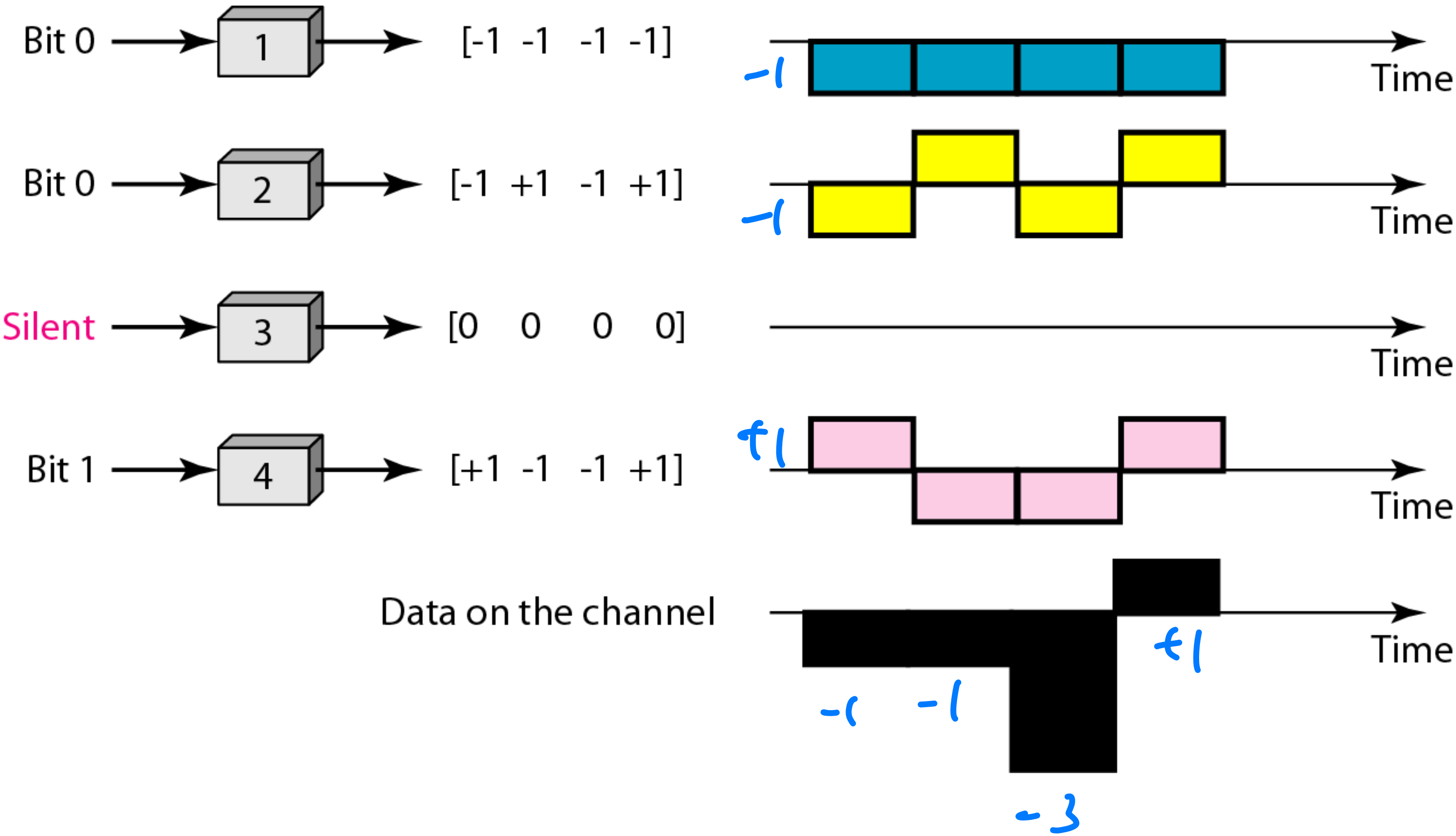


Code Division Multiple Access (Sum of transmit data)

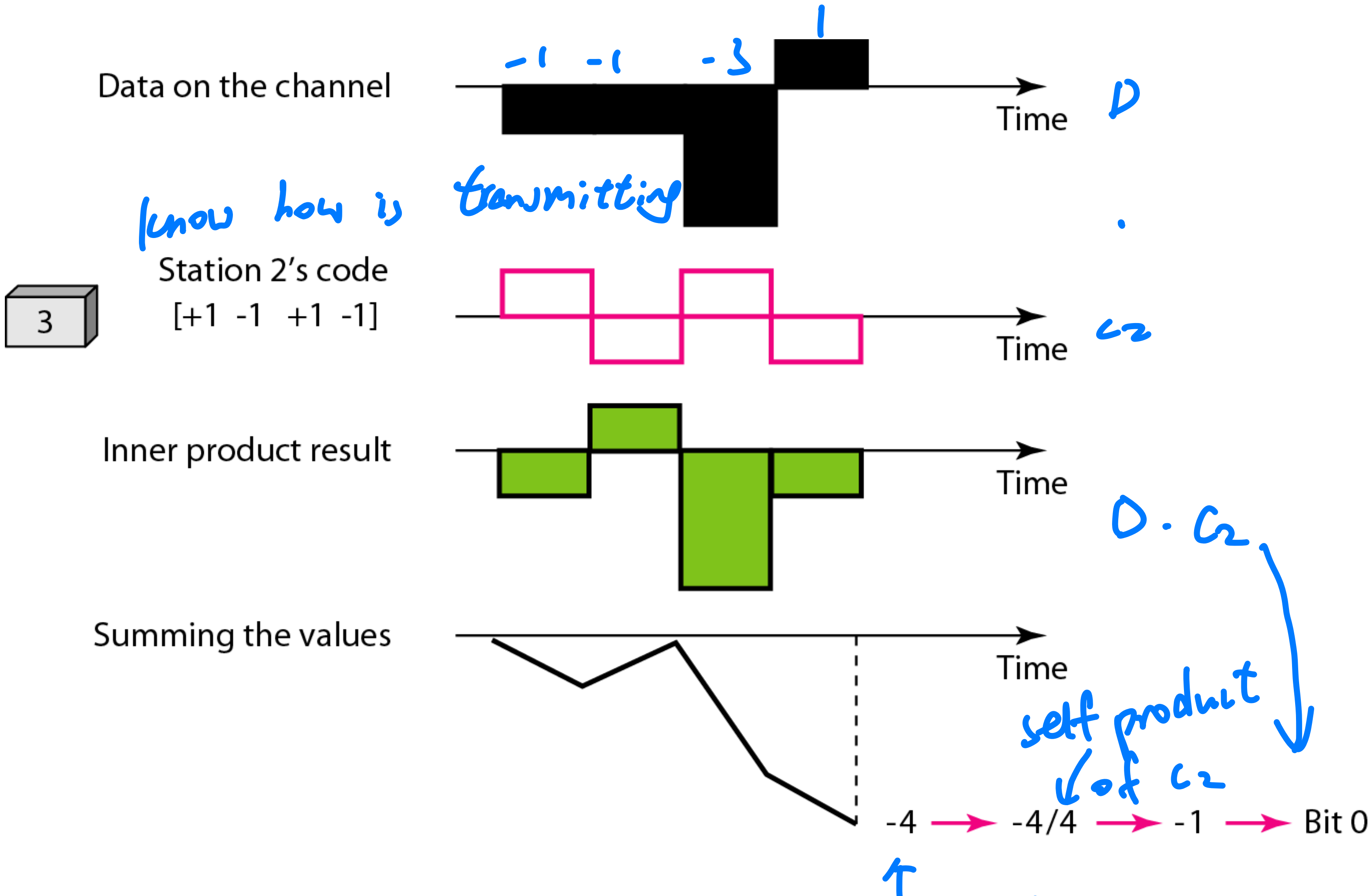


Code Division Multiple Access

This is orthogonal!



Code Division Multiple Access (Receiver Side)



inner product

CDMA: Example

Prove that a receiving station can get the data sent by a specific sender if it multiplies the entire data on the channel by the sender's chip code.

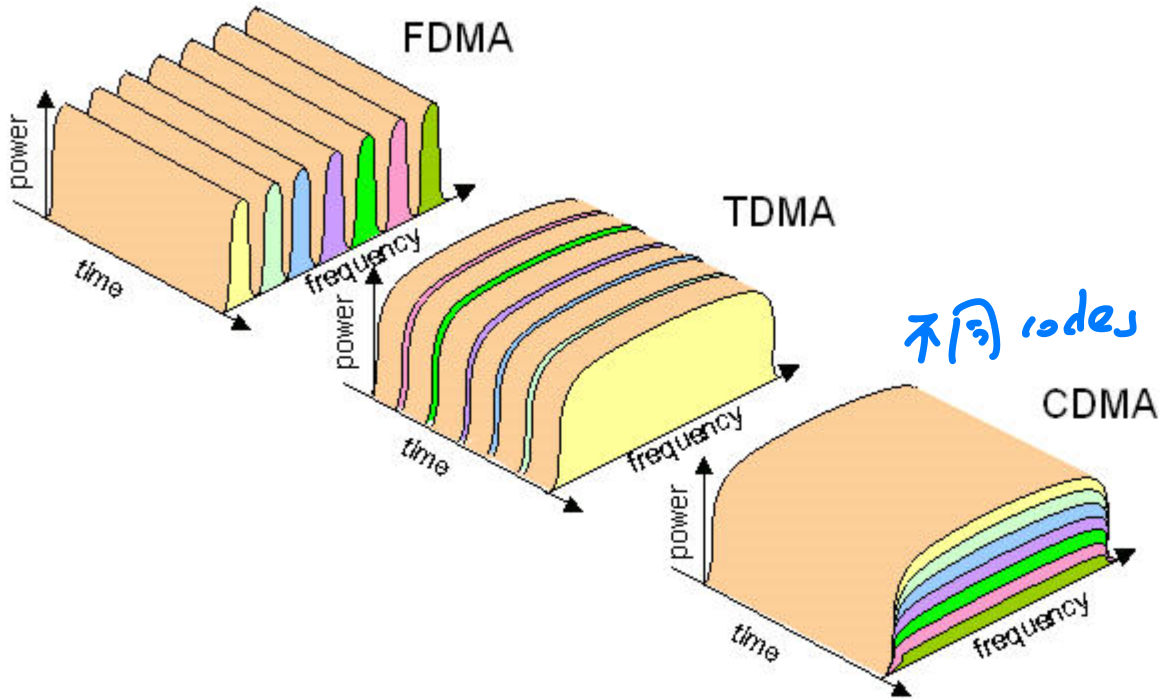
Solution

Let us prove this for the first station, using our previous four-station example. We can get that the data on the channel as D = (d1 · c1 + d2 · c2 + d3 · c3 + d4 · c4). The receiver which wants to get the data sent by station 1 multiplies these data by c1.

Make sure to be orthogonal!

$$
\begin{aligned}
D \cdot c_1 &= (d_1 \cdot c_1 + d_2 \cdot c_2 + d_3 \cdot c_3 + d_4 \cdot c_4) \cdot c_1 \\
&= d_1 \cdot c_1 \cdot c_1 + d_2 \cdot c_2 \cdot c_1 + d_3 \cdot c_3 \cdot c_1 + d_4 \cdot c_4 \cdot c_1 \\
&= d_1 \times N + d_2 \times 0 + d_3 \times 0 + d_4 \times 0 \\
&= d_1 \times N
\end{aligned}
$$

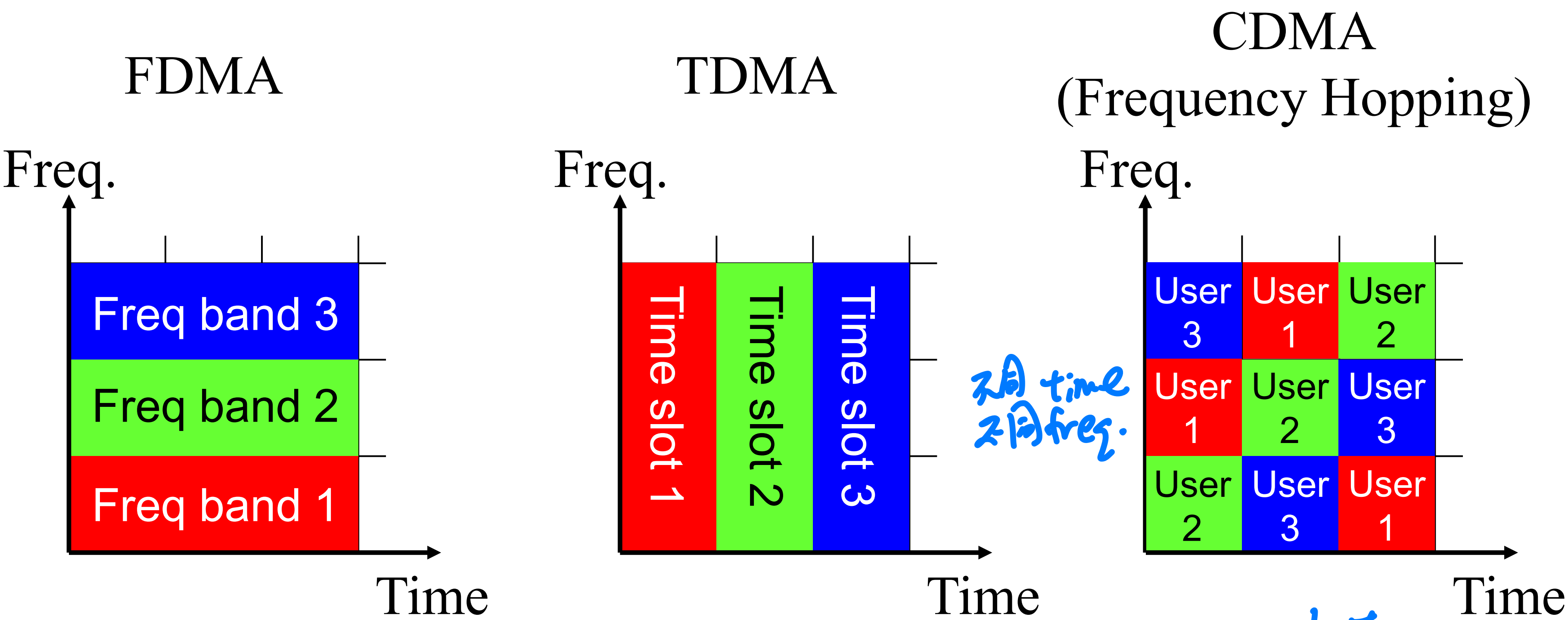
Multiple Access: Comparison



不同 codes!

use freq + time domain simuteneously

Multiple Access: Frequency Hopping



user need to know this random!

Multiple Access Schemes

increase flexibility of allocation

Allow more subcarriers to you specific users!

OFDMA

$N=64 \rightarrow$

$N=128 \rightarrow$

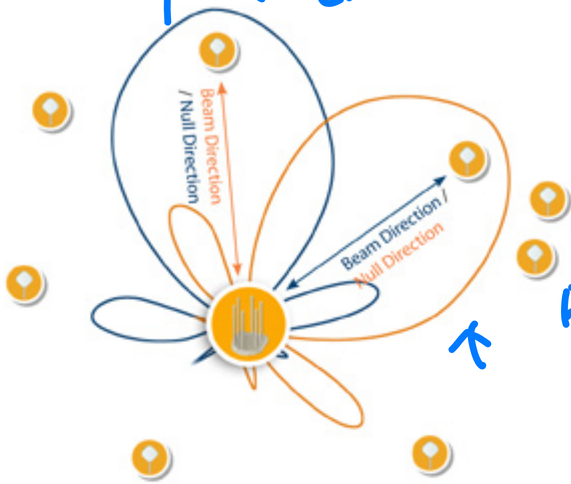
orthogonal

Assign subsets of carriers to users

1. TDMA
2. FDMA
3. CDMA
4. SDMA

(space division multiple access scheme

digital space to send!



Assign different space:

use different attenuder to focus

- Reuse freq. + time domains for users

- need much attenudes, smart