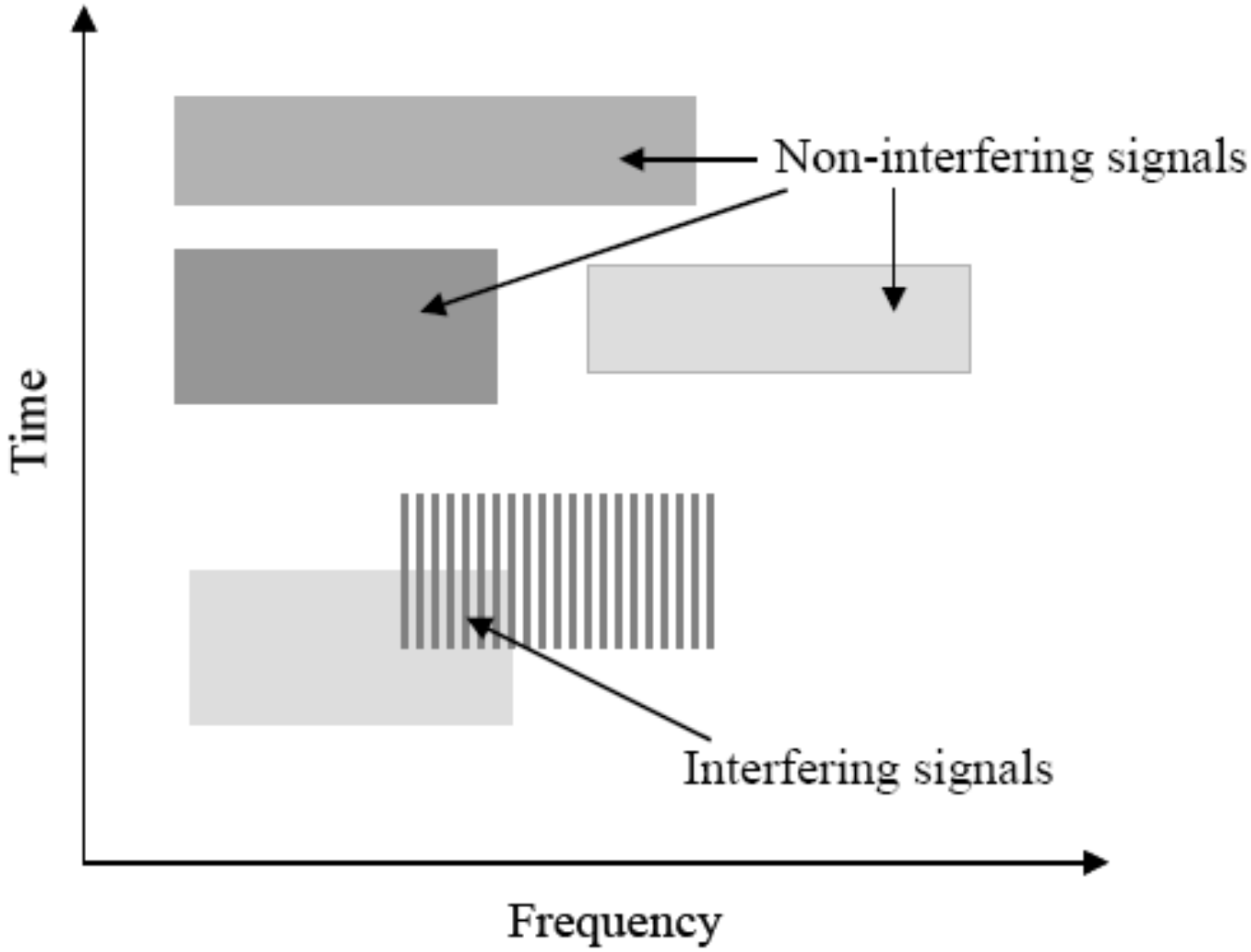
Multiple Access Techniques for Wireless Communications

Contents

1. Frequency Division Multiple Access (FDMA)
2. Time Division Multiple Access (TDMA)
3. Code Division Multiple Access (CDMA)
4. Space Division Multiple Access (SDMA)

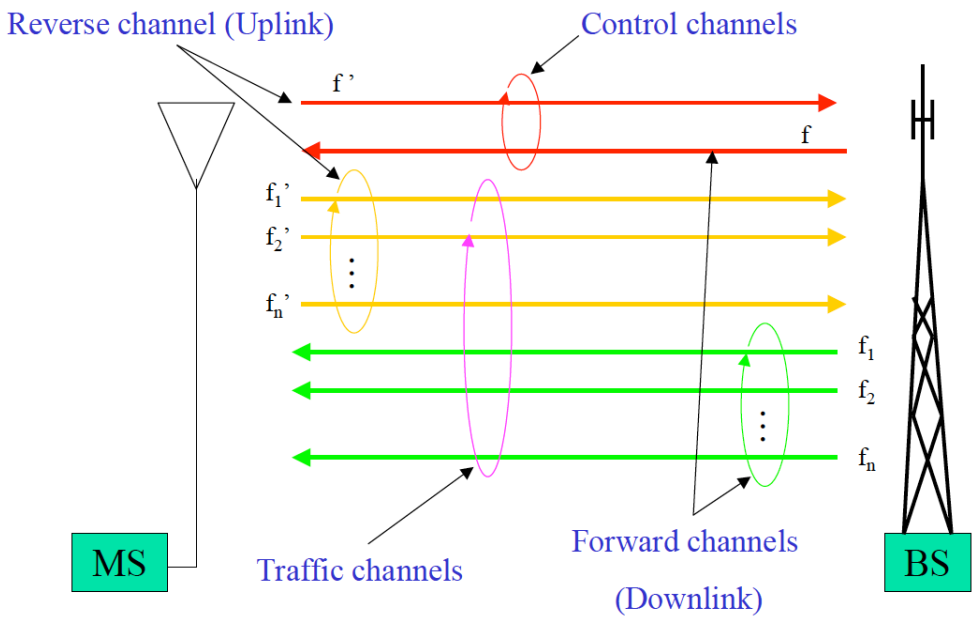
Multiple Access

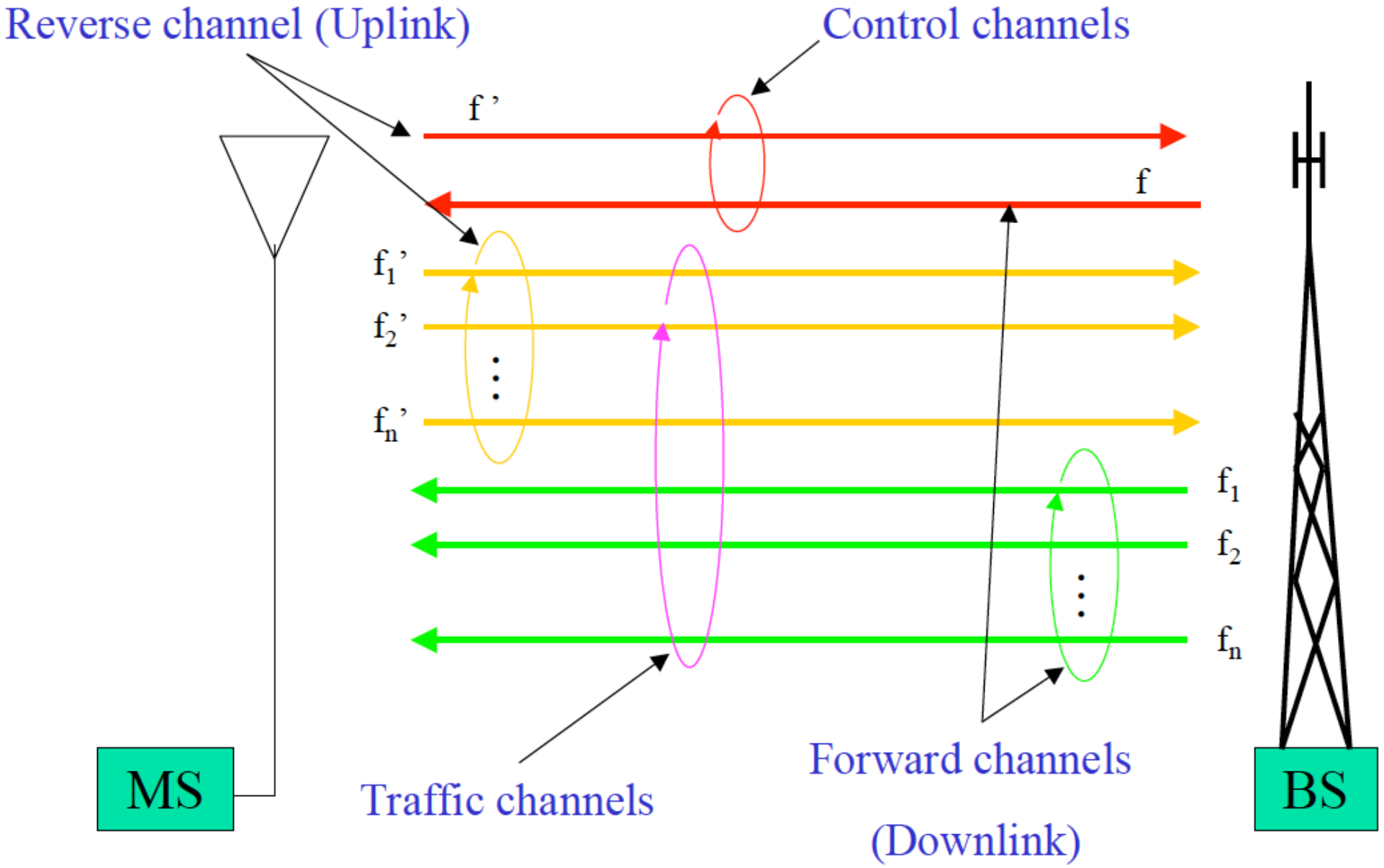
- Enable many mobile users to simultaneously share radio spectrum
- Provide for the sharing of channel capacity between a number of transmitters at different locations
- Aim to share a channel between two or more signals in such way that each signal can be received without interference from another


Non-interfering signals
Time
Interfering signals
Frequency

Types of Channels

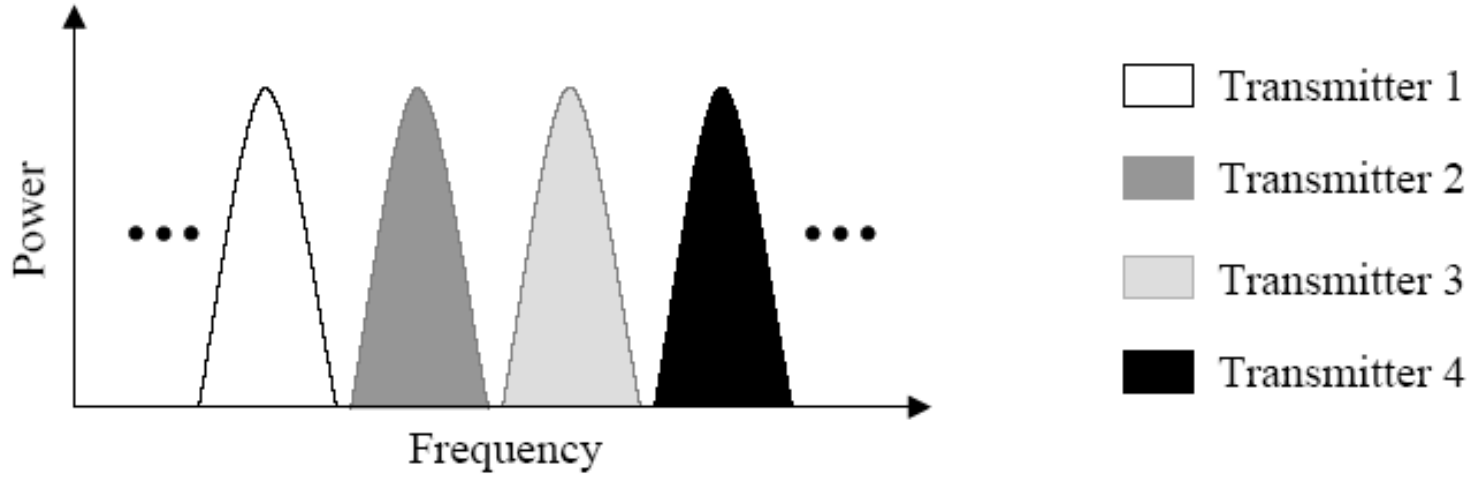
- Control channel
  - ✓ forward (downlink) control channel
  - ✓ reverse (uplink) control channel
- Traffic channel
  - ✓ forward traffic (information) channel
  - ✓ reverse traffic (information) channel



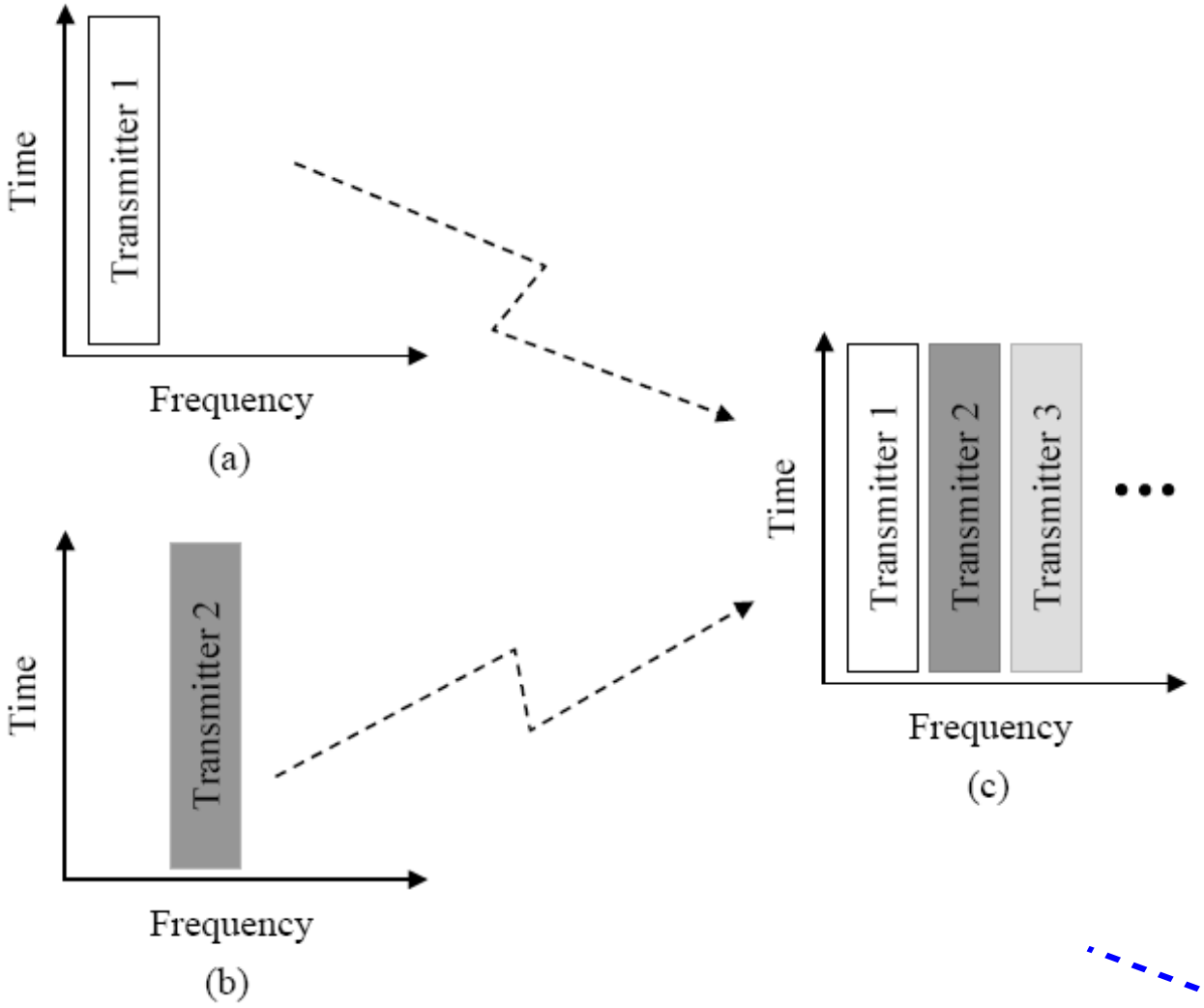

Reverse channel (Uplink)
Control channels
f '
f
f1'
f2'
fn'
f1
f2
fn
MS
Traffic channels
Forward channels
(Downlink)
BS

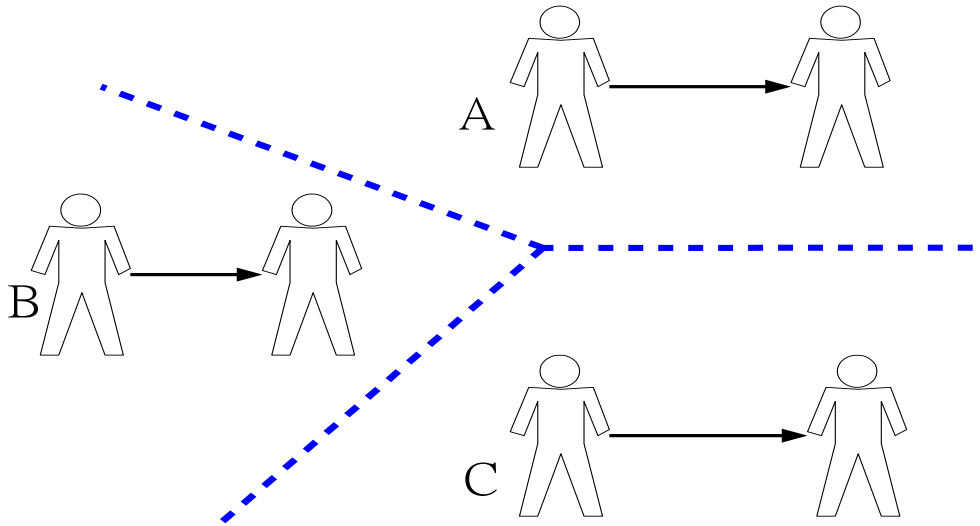
1. Frequency Division Multiple Access (FDMA)

- Allocation of separate channels to FDMA signals
- Single Channel Per Carrier (SCPC)
  - ✓ use a single signal at a given frequency and bandwidth (not multiplexed as subcarriers onto a single carrier)
- All 1G systems use FDMA



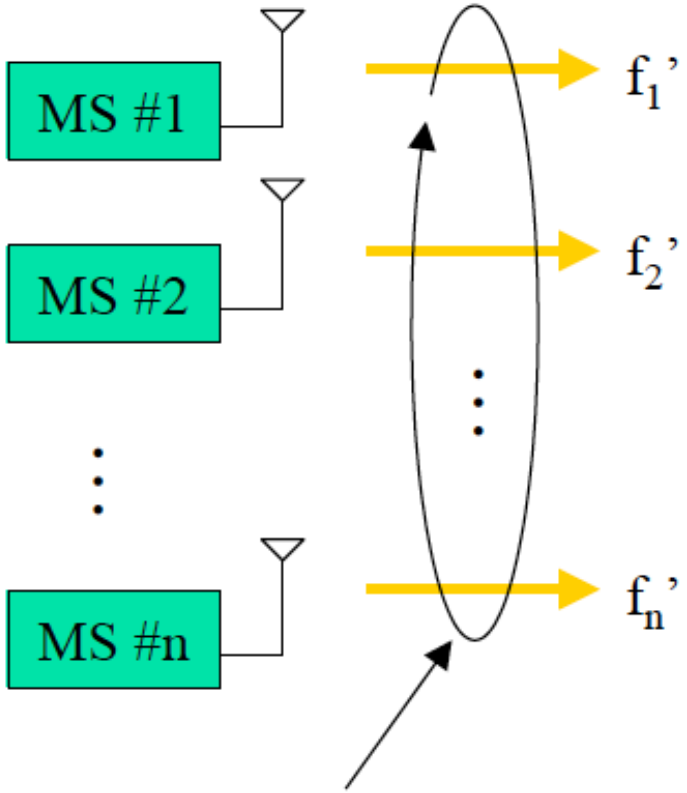
- Note: carrier wave
  - in telecommunications, a carrier signal, carrier wave, or just carrier, is a waveform (usually sinusoidal) that is modulated


Time
Transmitter 1
Frequency
(a)
Time
Transmitter 2
Frequency
(b)
Time
Transmitter 1
Transmitter 2
Transmitter 3
Frequency
(c)


A
B
C

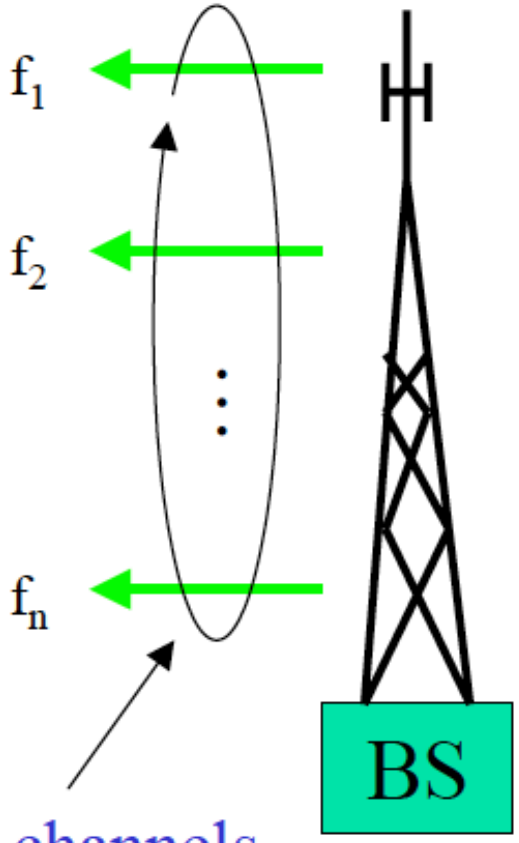
FDMA 示意圖

FDMA



Reverse channels

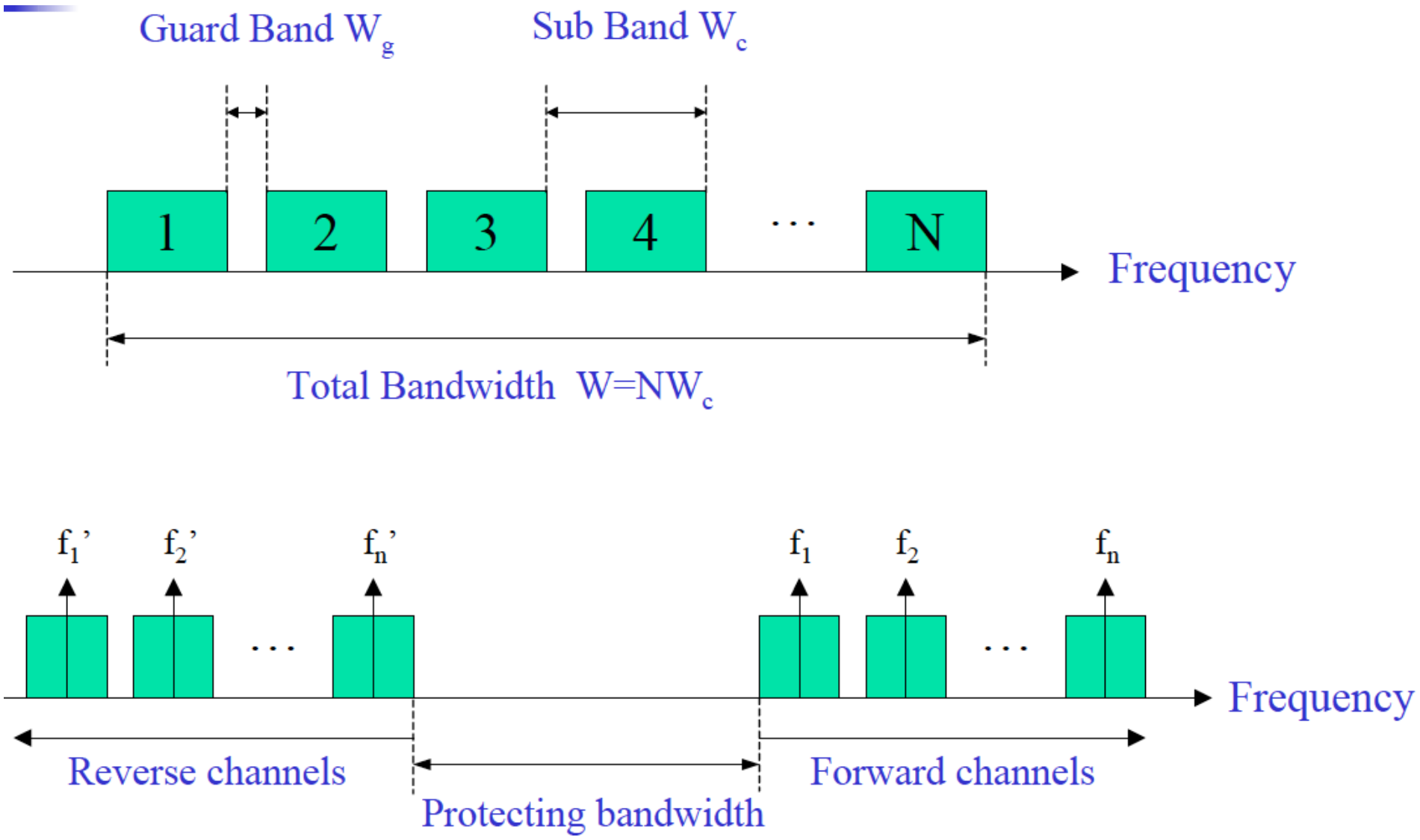
(Uplink)



Forward channels

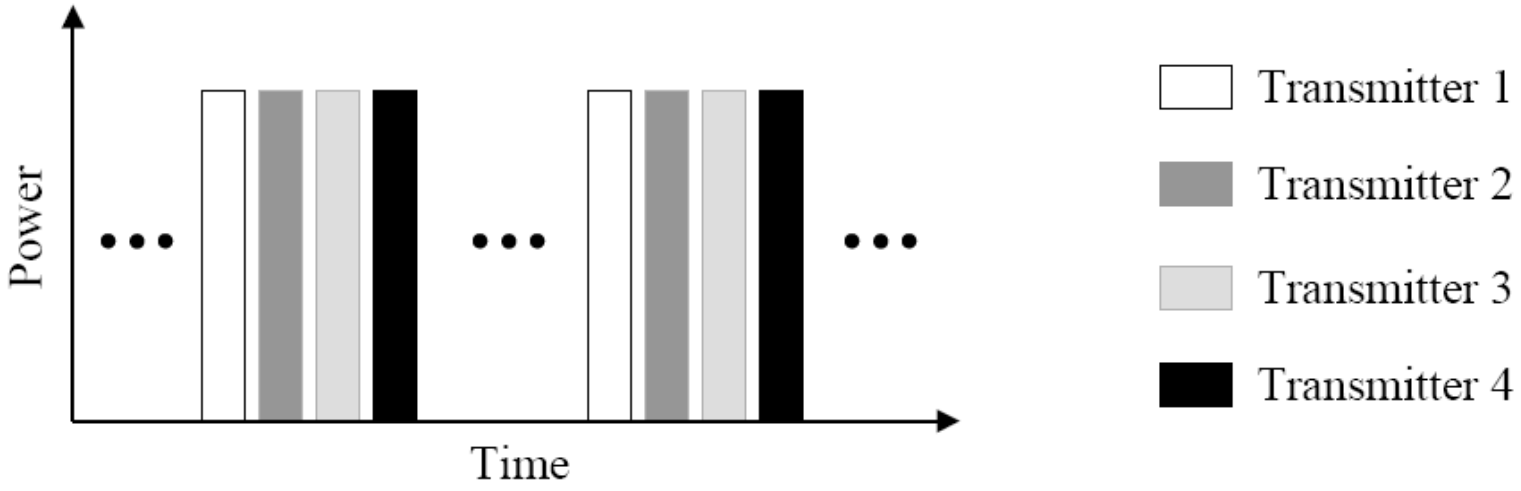
(Downlink)

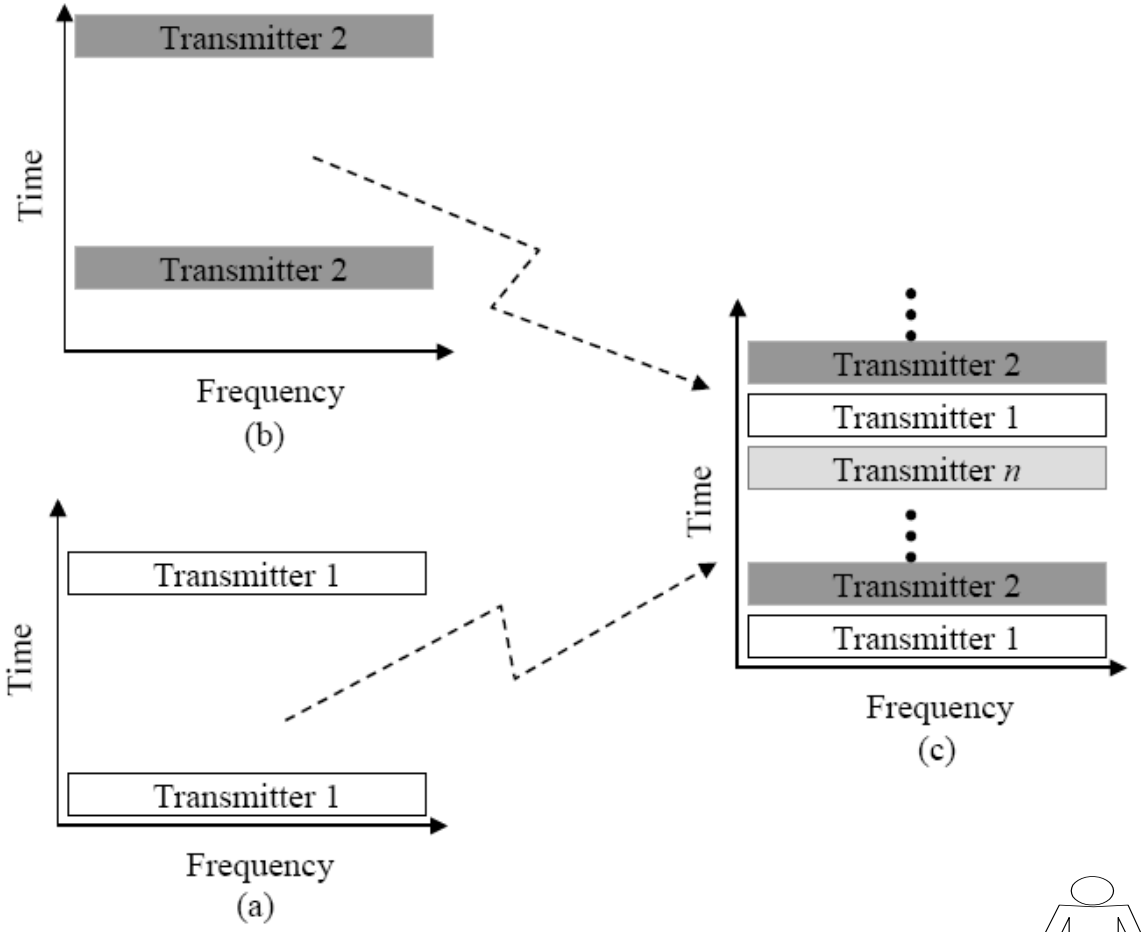
FDMA Channel Structure

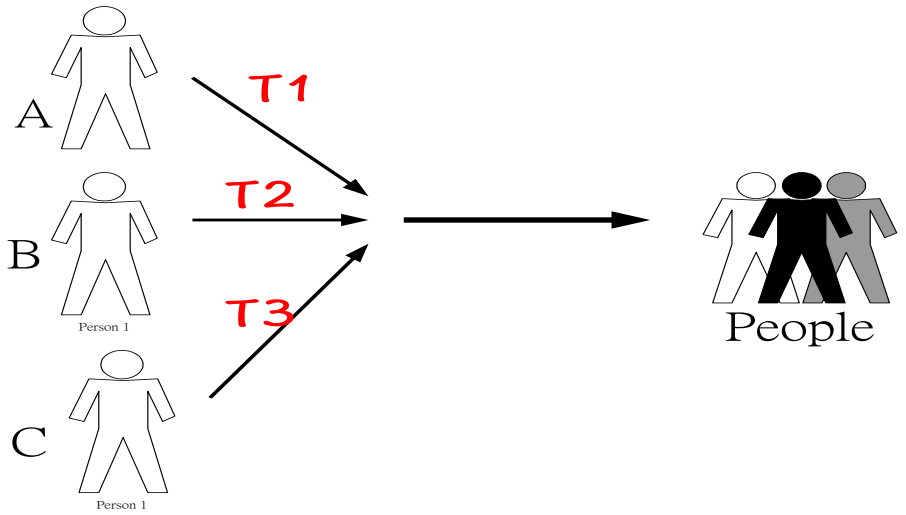


2. Time Division Multiple Access (TDMA)

- Multiple Channels Per Carrier (MCPC)
  - ✓ several subcarriers are combined or multiplexed into a single bitstream before being modulated onto a carrier transmitted from a single location to one or more remote sites
- Most of 2G systems use TDMA

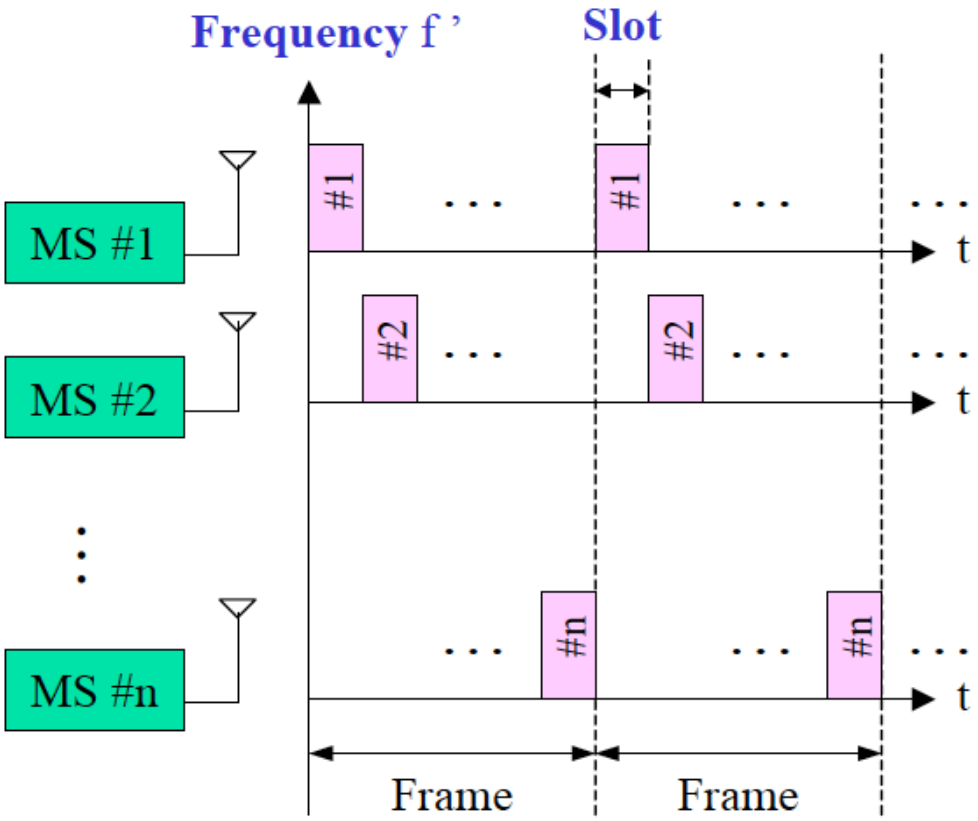



Transmitter 2
Time
Transmitter 2
Frequency
(b)
Transmitter 1
Time
Transmitter 1
Frequency
(a)
Transmitter 2
Transmitter 1
Transmitter n
Transmitter 2
Transmitter 1
Time
Frequency
(c)


A
B
C
Person 1
Person 1
T1
T2
T3
People

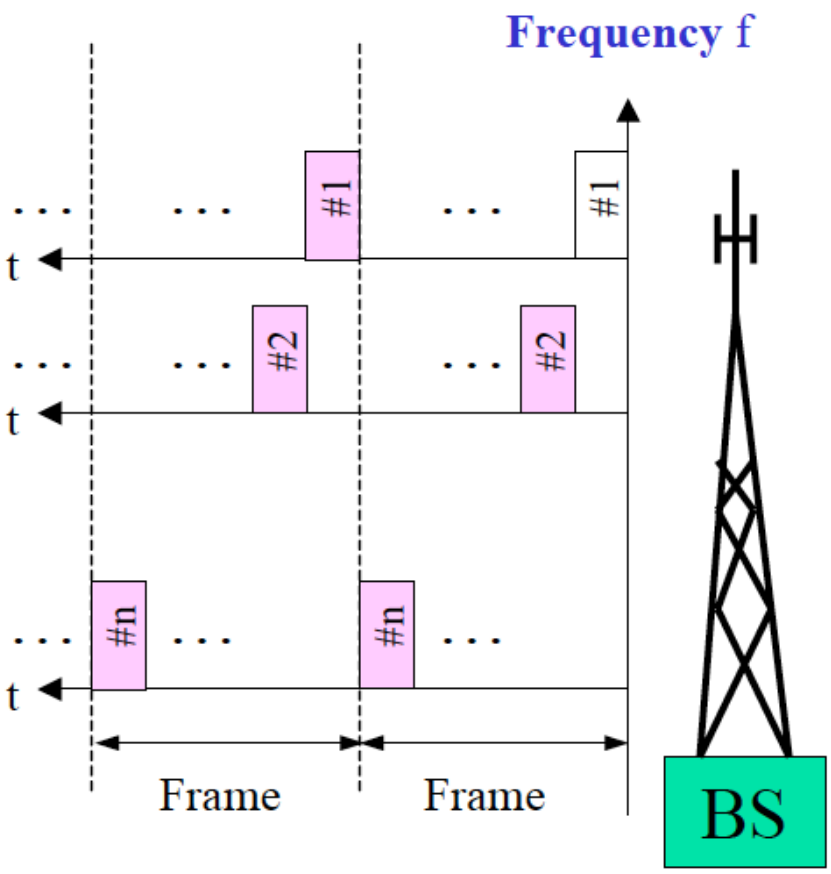
TDMA 示意圖

TDMA



Reverse channels

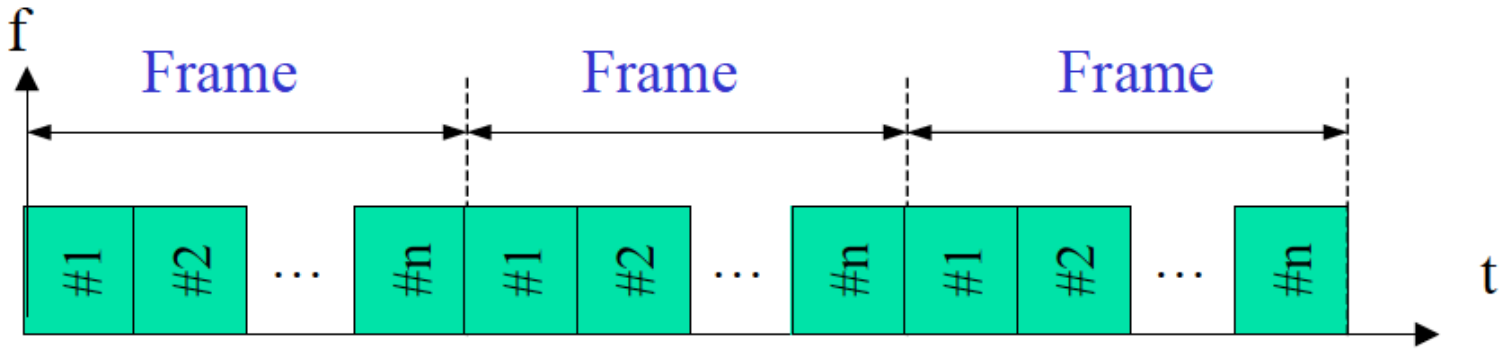
(Uplink)



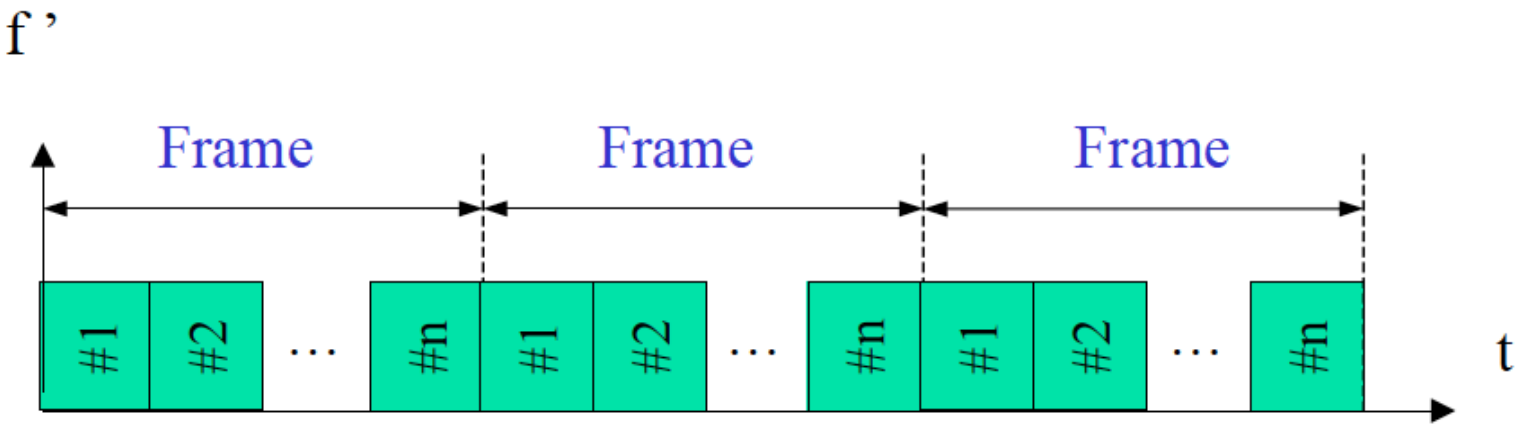
Forward channels

(Downlink)

TDMA Channel Structure

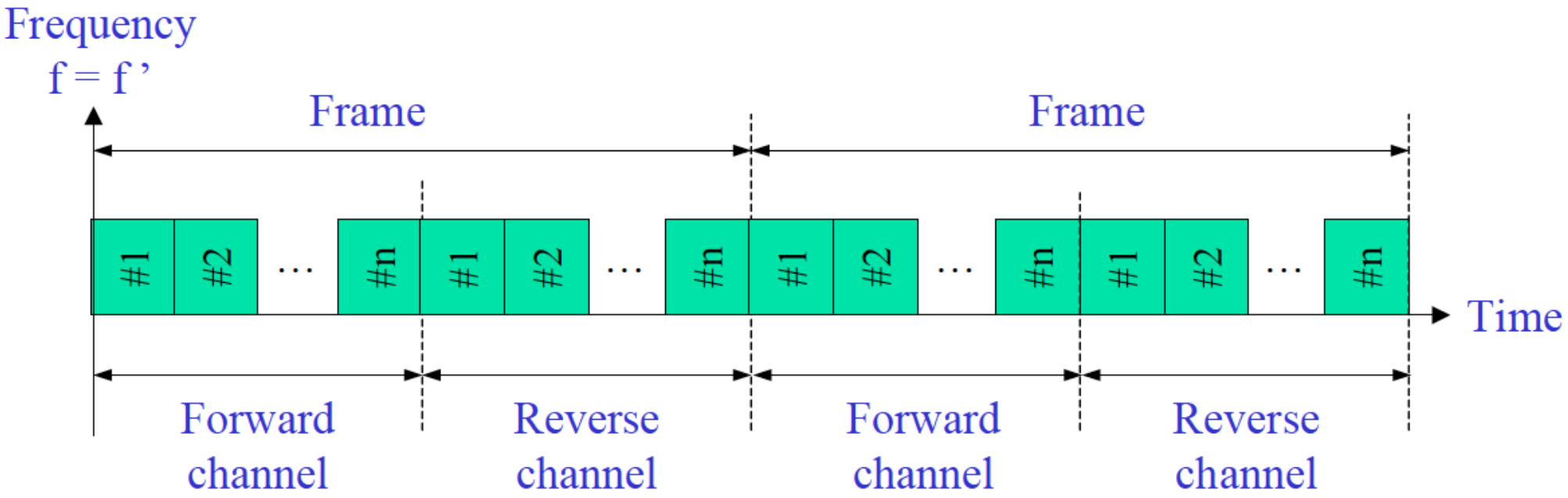


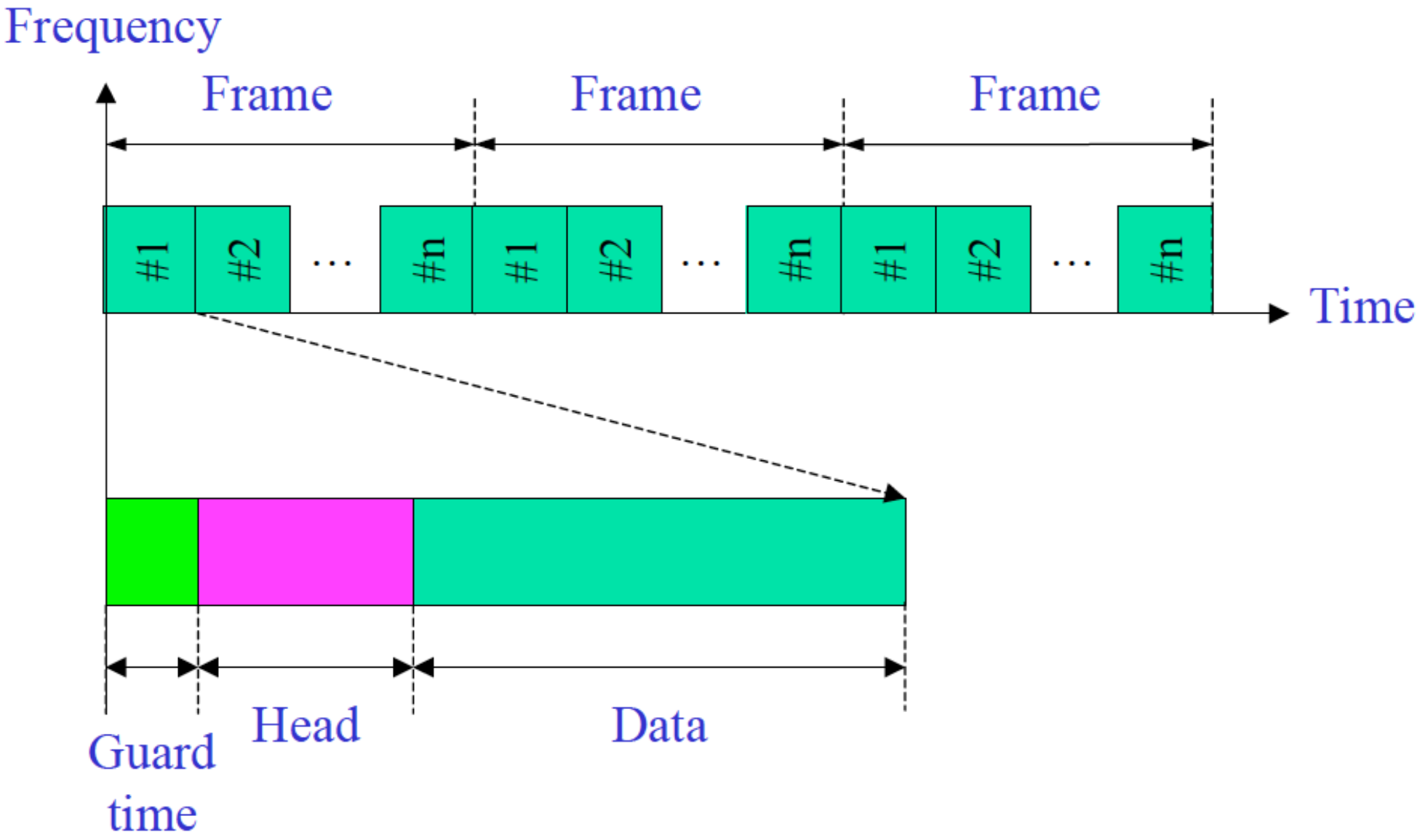
(a). Forward channel



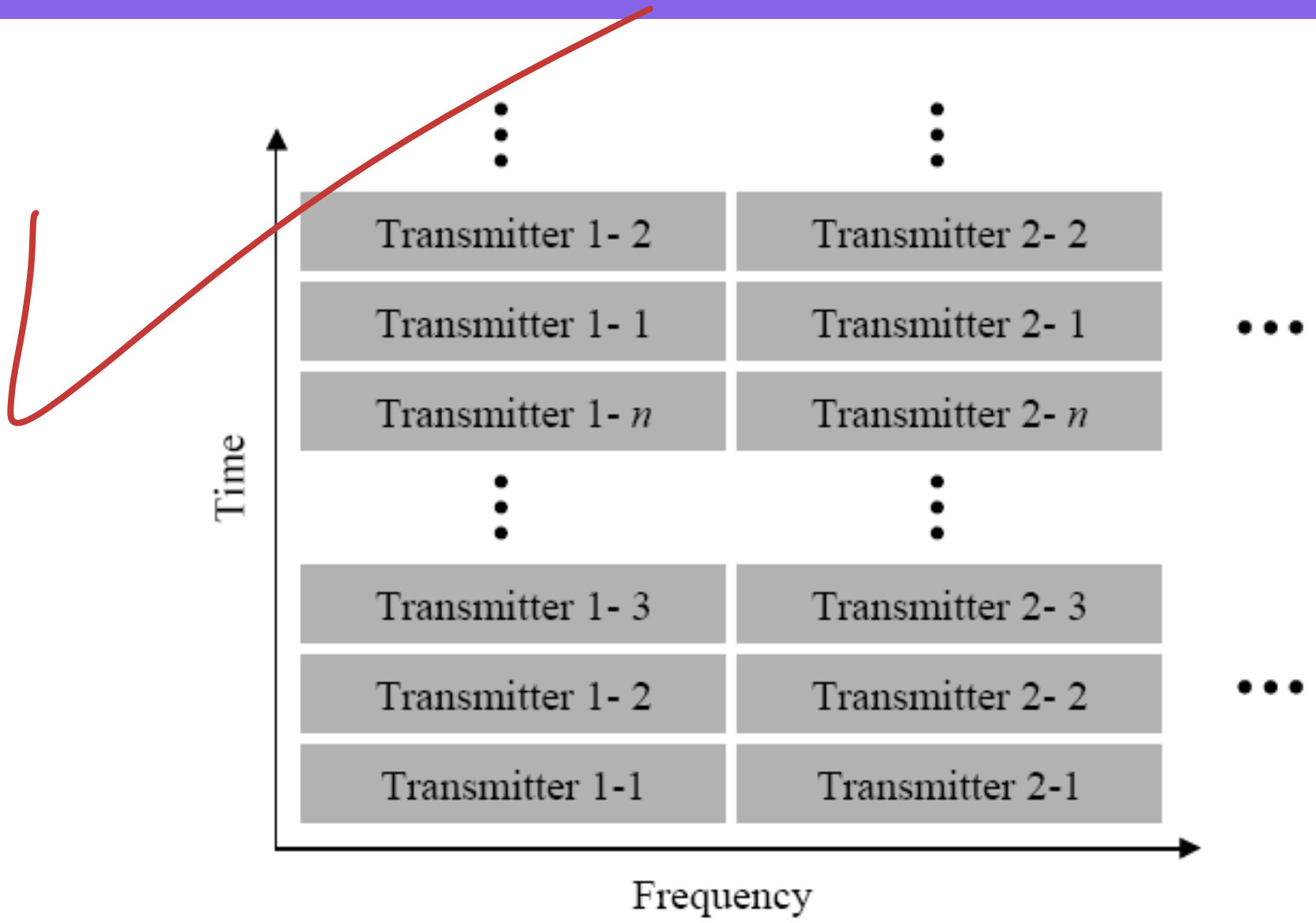
(b). Reverse channel

TDMA Frame Structure



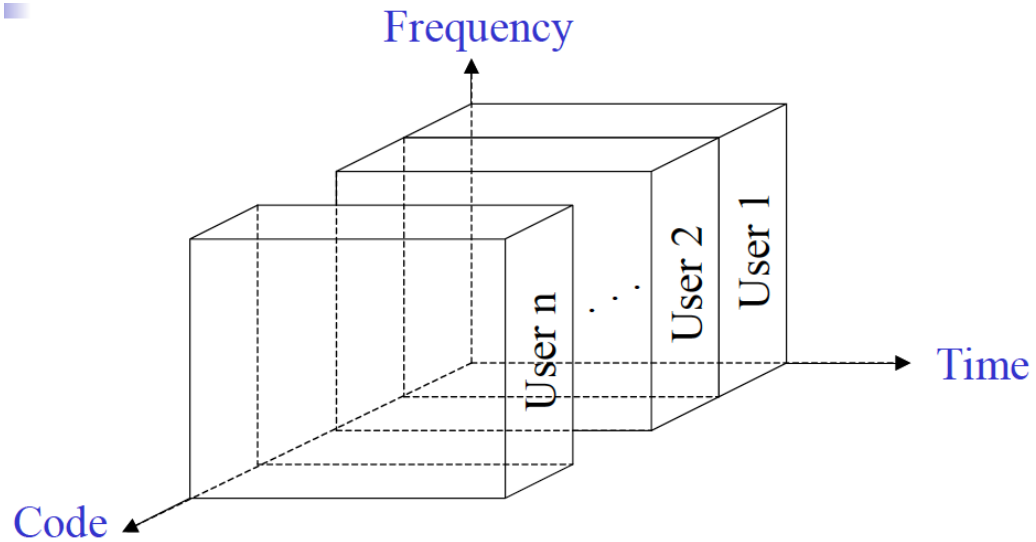

Frequency
Frame
Frame
Frame
#1
#2
…
#n
#1
#2
…
#n
#1
#2
…
#n
Time
Guard time
Head
Data

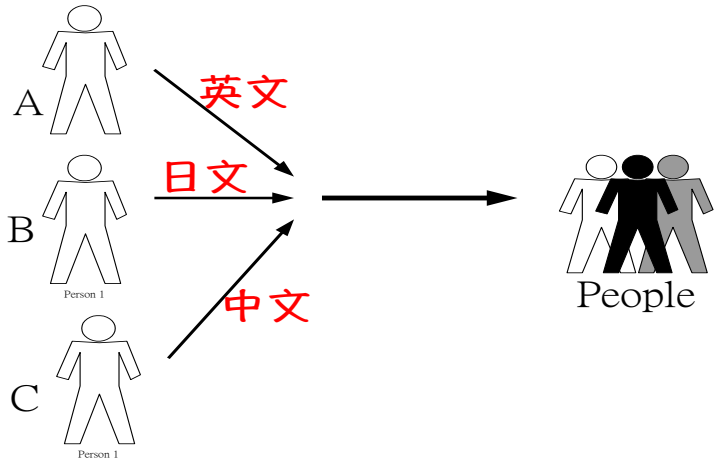
Combined used of Synchronous TDMA and FDMA



3. Code Division Multiple Access (CDMA)

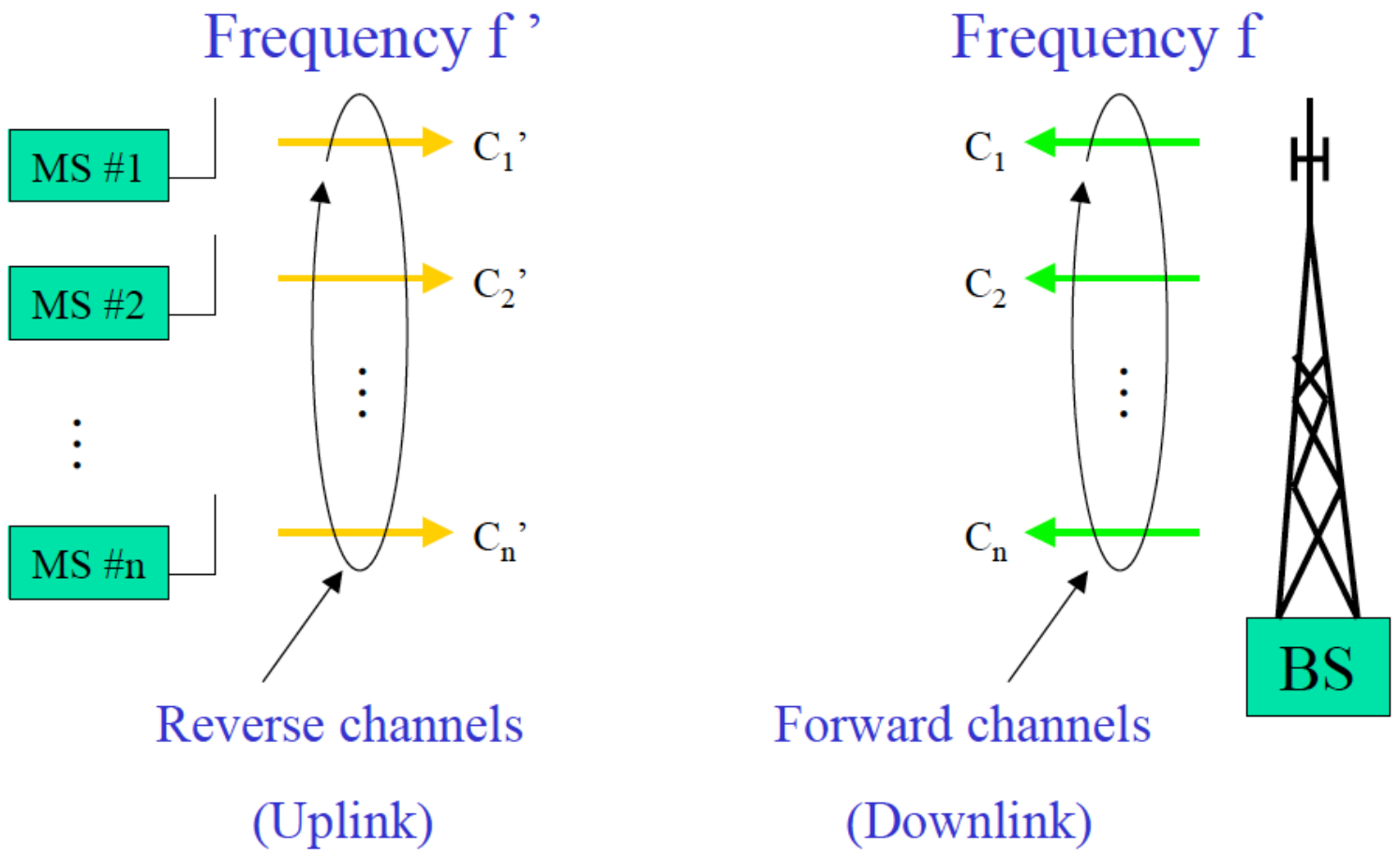
- Users share bandwidth by using code sequences that are orthogonal to each other
- Some 2G systems use CDMA
- Most of 3G systems use CDMA





CDMA 示意圖

Code Division Multiple Access (CDMA)

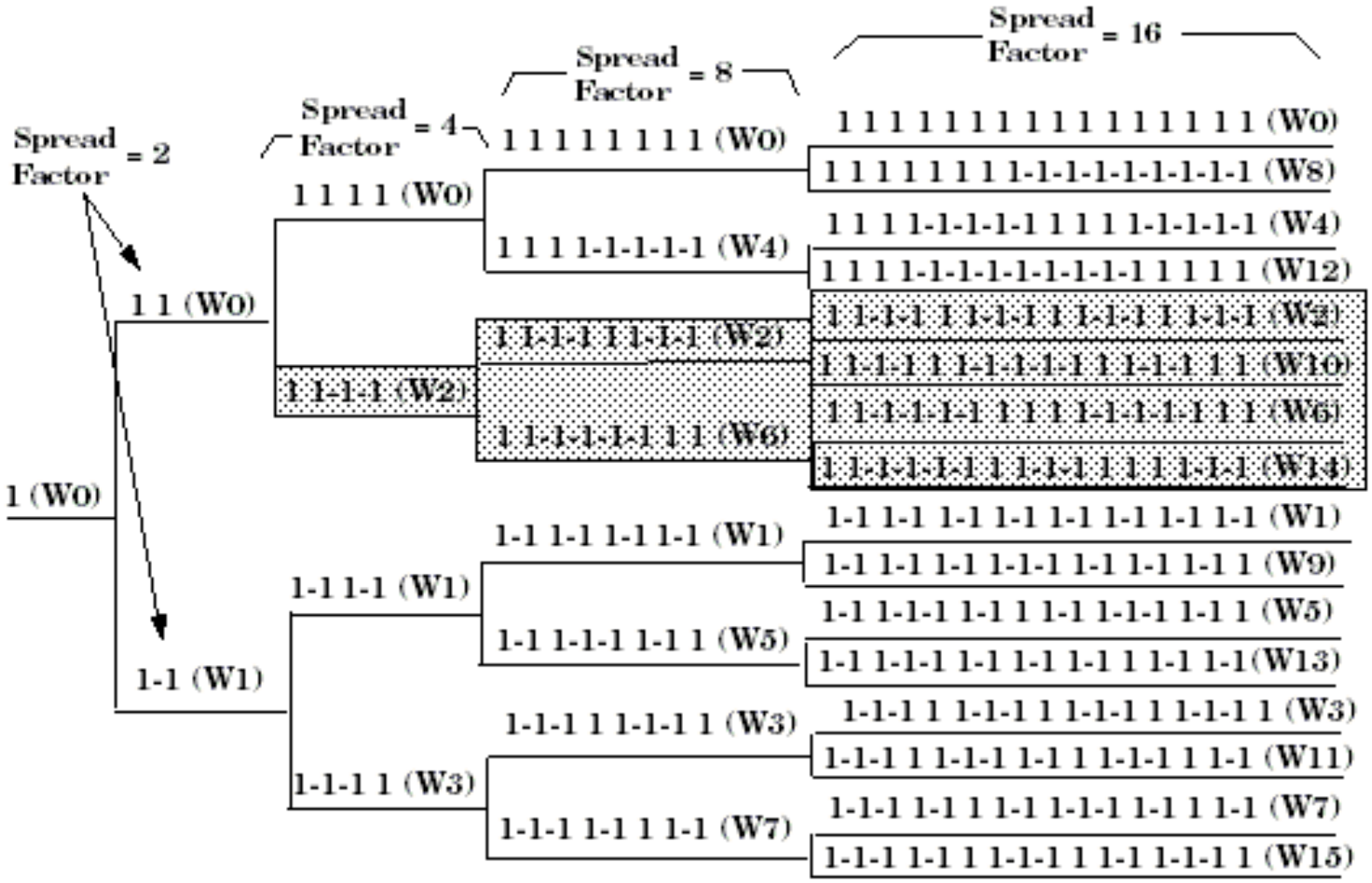


$C_i' \times C_j' = 0$, i.e., C_i' and C_j' are orthogonal codes

$C_i \times C_j = 0$, i.e., C_i and C_j are orthogonal codes

- Multiplexing technique (CDMA) used with spread spectrum
- Start with data signal rate (D), called bit data rate
- Break each bit into *k* chips according to fixed pattern specific to each user, called user's code [Walsh–Hadamard code]
- New channel has chip data rate *kD* chips per second
- E.g. *k*=6, three users (*A*,*B*,*C*) communicating with base receiver *R*
  - ✓ Code for A = <1,-1,-1,1,-1,1>
  - ✓ Code for B = <1,1,-1,-1,1,1>
  - ✓ Code for C = <1,1,-1,1,1,-1>

Example: Walsh Code Spread Factors



$$W_2 = \begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix}$$

(a) 2×2

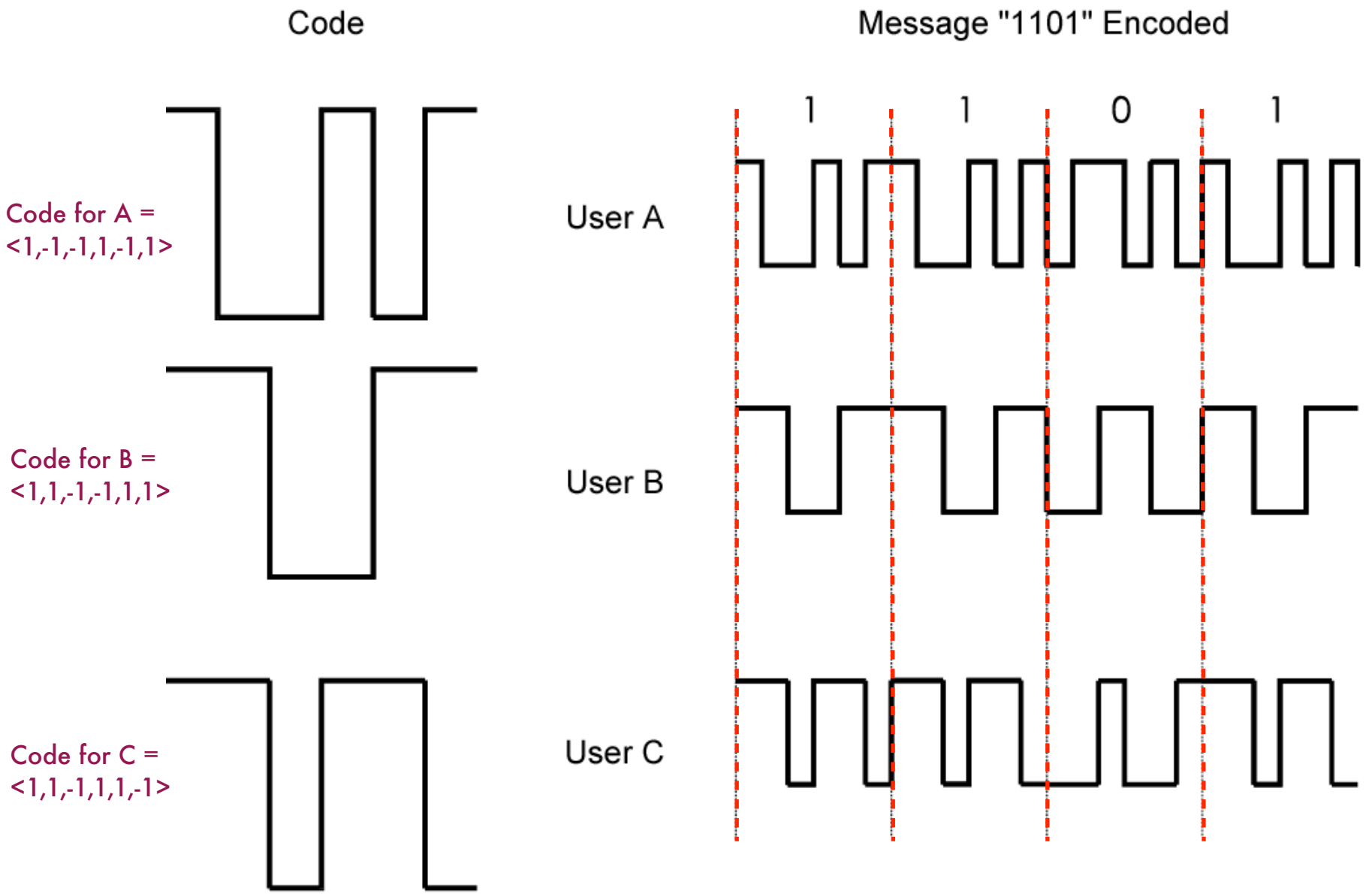
$$W_4 = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 \end{pmatrix}$$

(b) 4×4

$$W_8 = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 1 & 0 & 1 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 & 1 & 0 & 0 & 1 \end{pmatrix}$$

(c) 8×8

CDMA Example



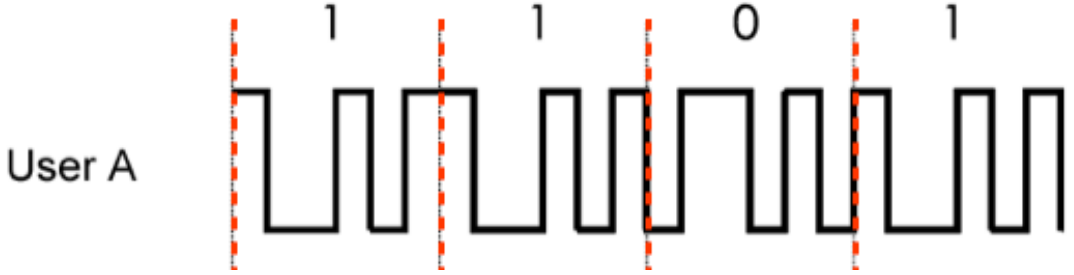
CDMA Explanation

- Consider A communicating with BS
- BS knows A's code
- Assume communication already synchronized
- A wants to send a 1
  - ✓ send chip pattern <1,-1,-1,1,-1,1>
    - A's code
- A wants to send 0
  - ✓ send chip pattern <-1,1,1,-1,1,-1>
    - complement of A's code

Code for A = <1,-1,-1,1,-1,1>

Code for B = <1,1,-1,-1,1,1>

Code for C = <1,1,-1,1,1,-1>

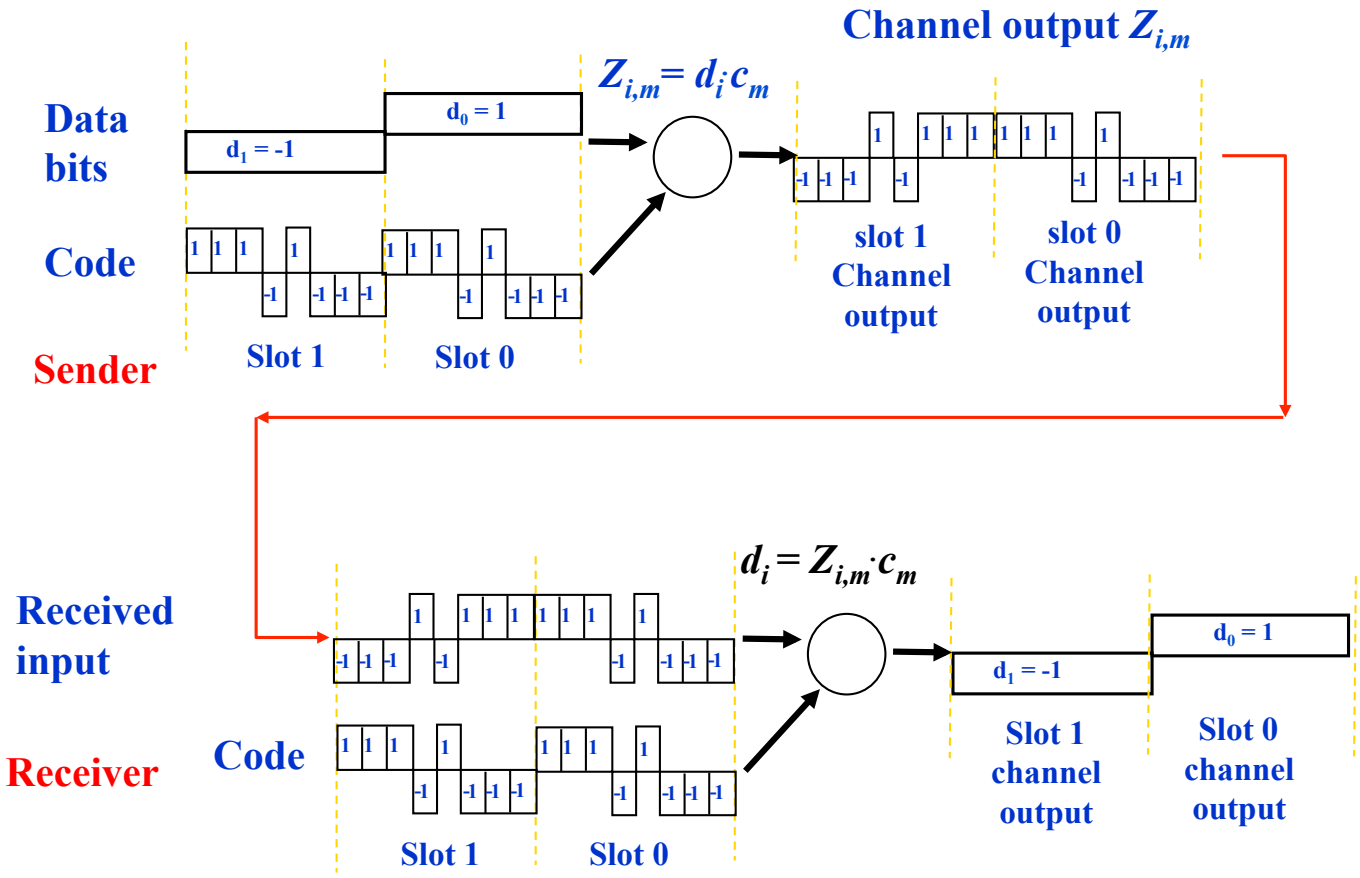


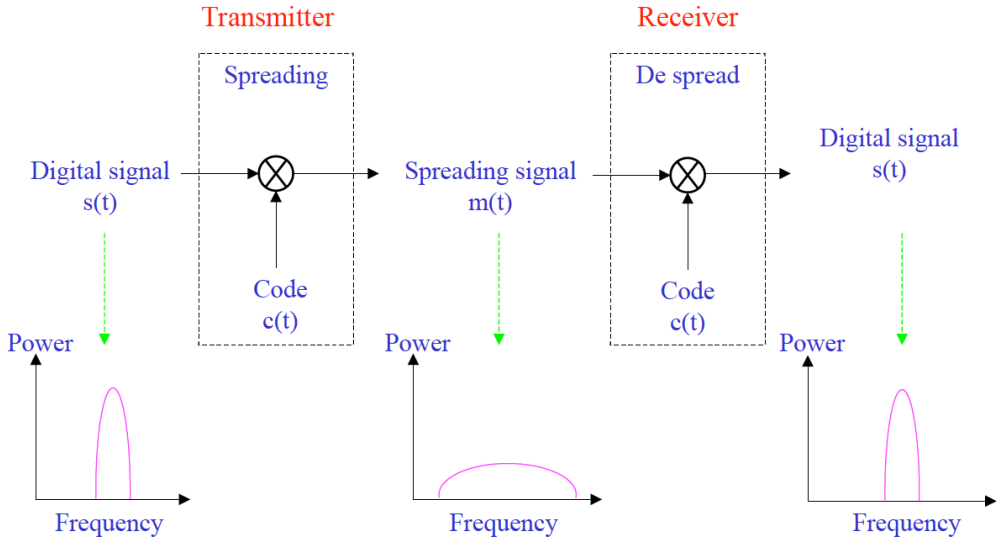
Spread Spectrum (SS) Multiple Access

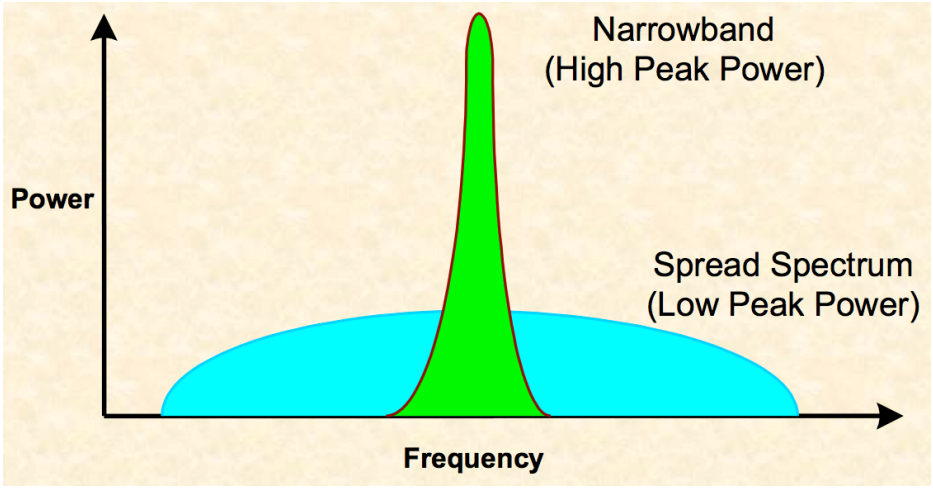
- A transmission technique in which a *PN* code, independent of information data, is employed as a modulation waveform to "spread" the signal energy over a bandwidth much greater than the signal information bandwidth
- At the receiver the signal is "despread" using a synchronized replica of the *PN* code
- Two SS techniques
  - ✓ Direct Sequence Spread Spectrum (DSSS)
  - ✓ Frequency Hopping Spread Spectrum (FHSS)

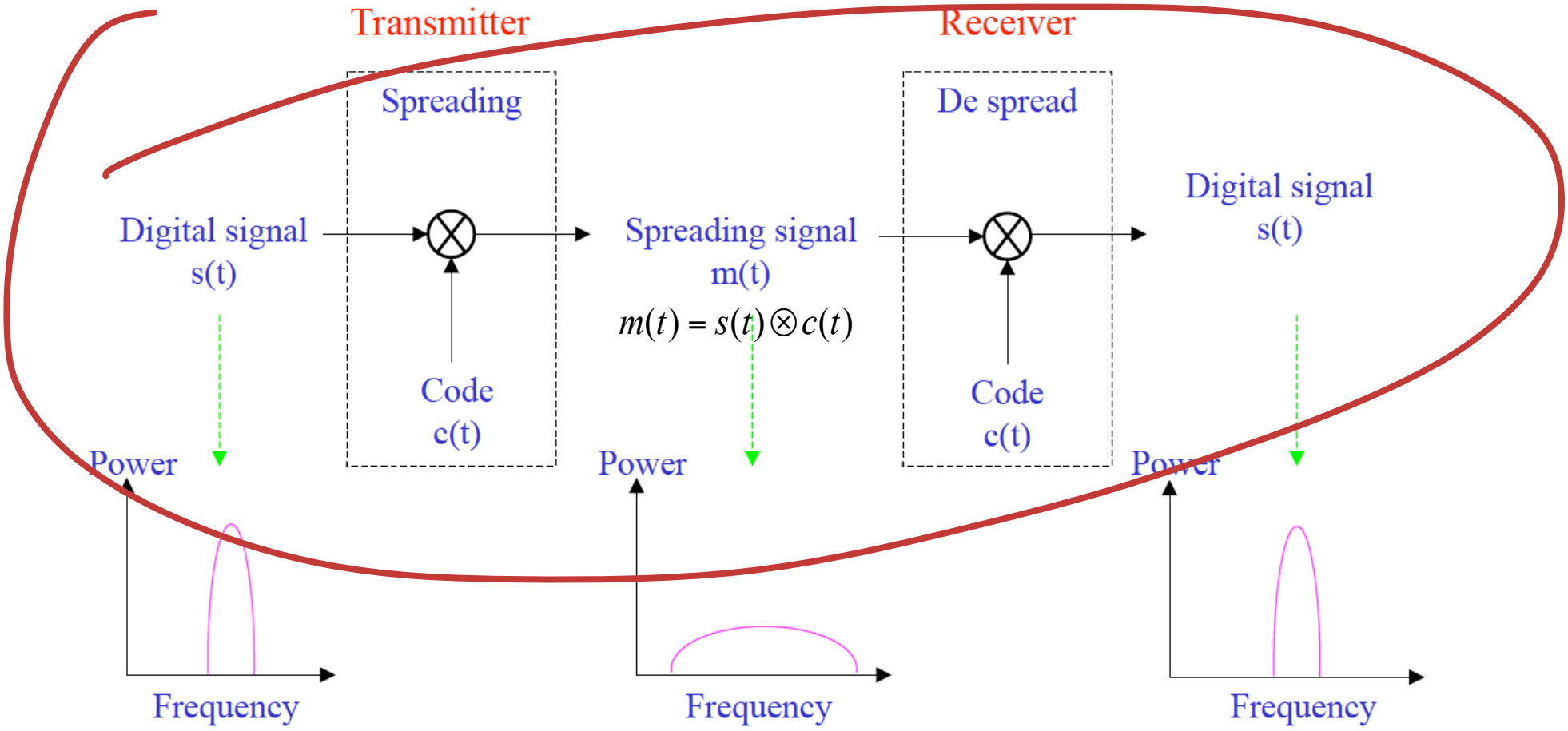
Direct Sequence Spread Spectrum (DSSS)

- A carrier is modulated by a digital code in which the code bit rate is much larger than the information signal bit rate
- These systems are also called pseudo-noise systems


Channel output $Z_{i,m}$
$Z_{i,m} = d_i \cdot c_m$
Data bits
Code
Sender
$d_0 = 1$
$d_1 = -1$
Slot 1
Slot 0
slot 1 Channel output
slot 0 Channel output
Received input
Receiver
Code
$d_i = Z_{i,m} \cdot c_m$
Slot 1
Slot 0
Slot 1 channel output
Slot 0 channel output

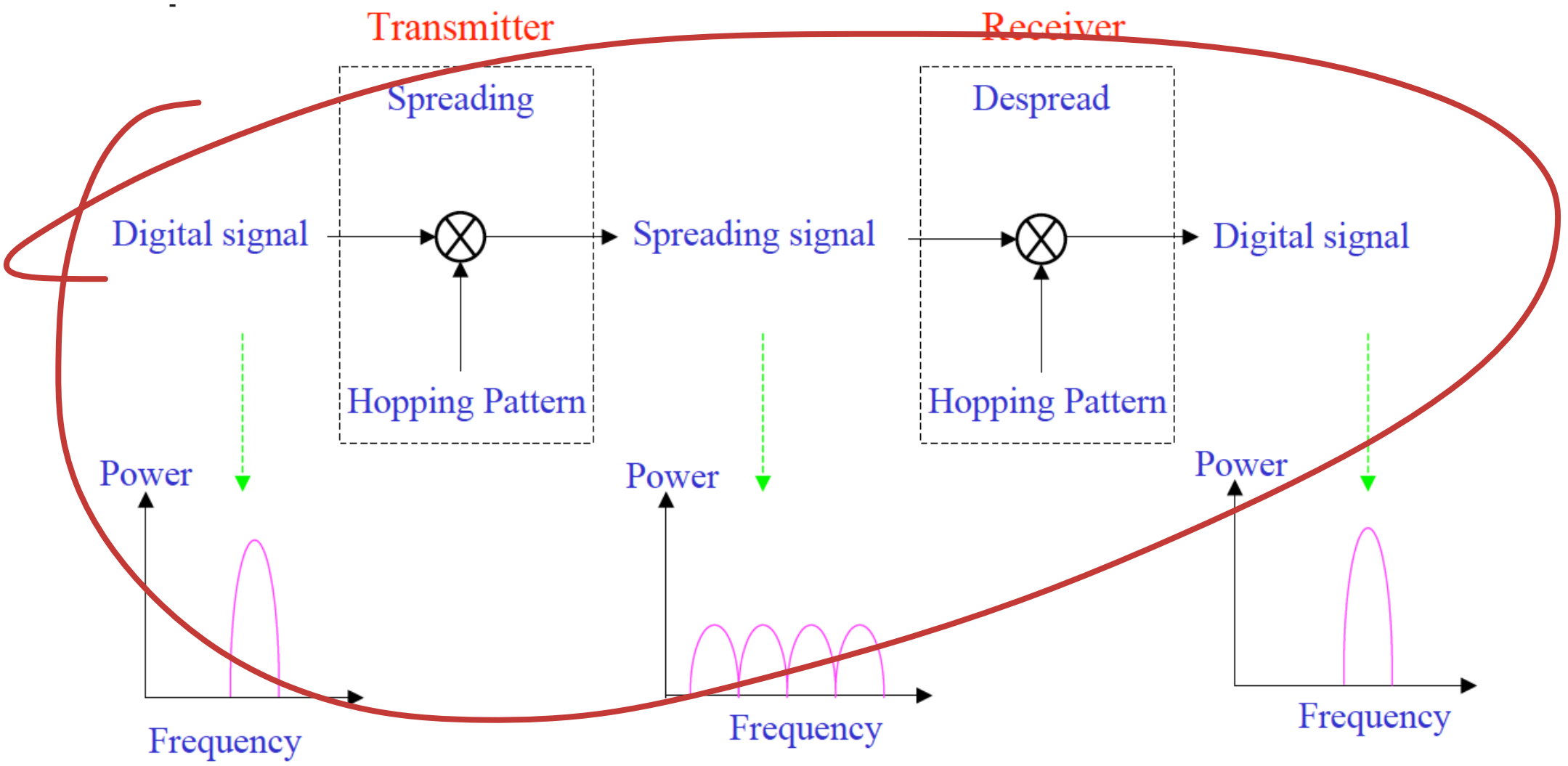

Transmitter
Receiver
Spreading
De spread
Digital signal s(t)
Spreading signal m(t)
Digital signal s(t)
Code c(t)
Code c(t)
Power
Power
Power
Frequency
Frequency
Frequency


Narrowband
(High Peak Power)
Power
Spread Spectrum
(Low Peak Power)
Frequency

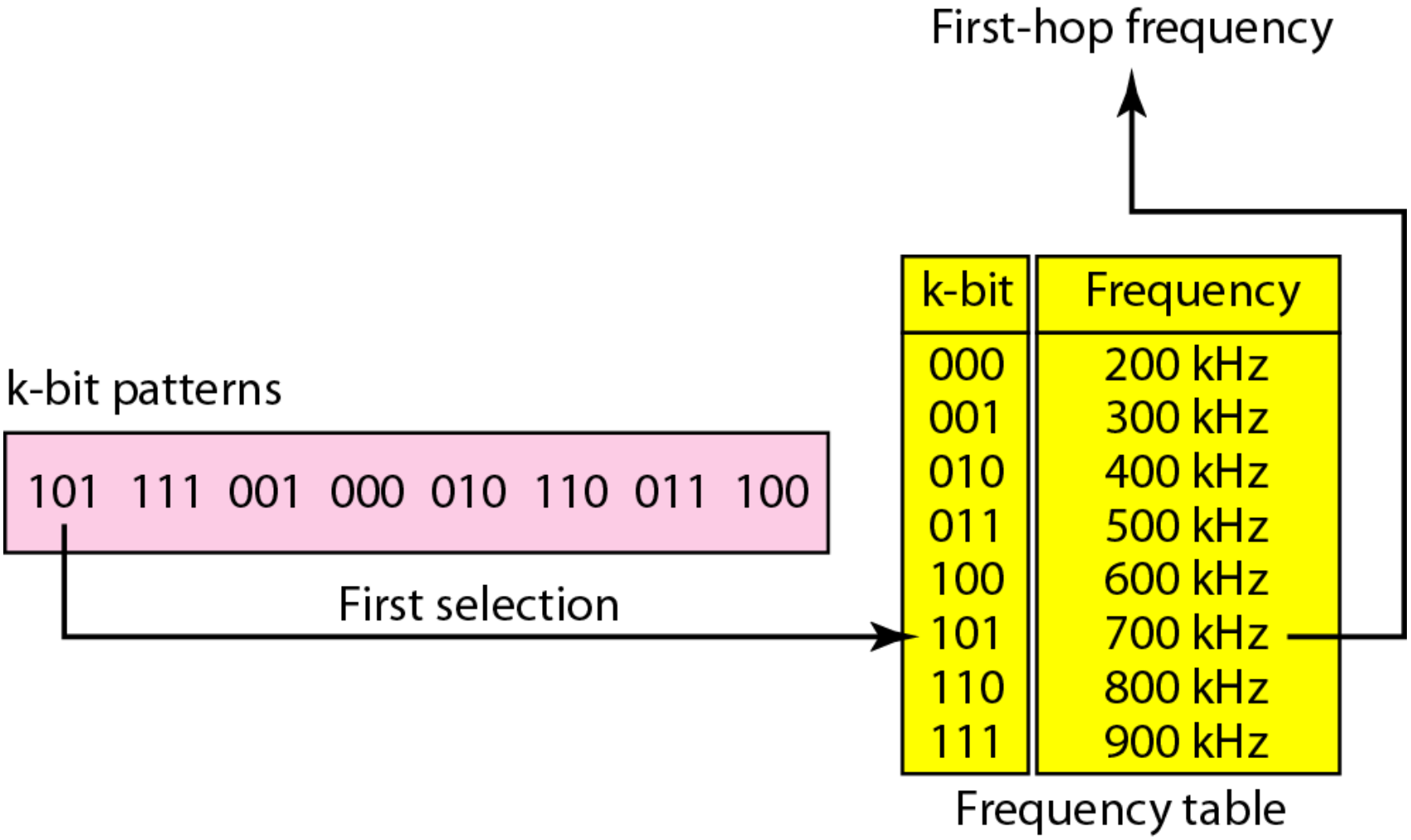

Transmitter
Receiver
Spreading
De spread
Digital signal
s(t)
Spreading signal
m(t)
$m(t) = s(t) \otimes c(t)$
Digital signal
s(t)
Code
c(t)
Code
c(t)
Power
Power
Power
Frequency
Frequency
Frequency

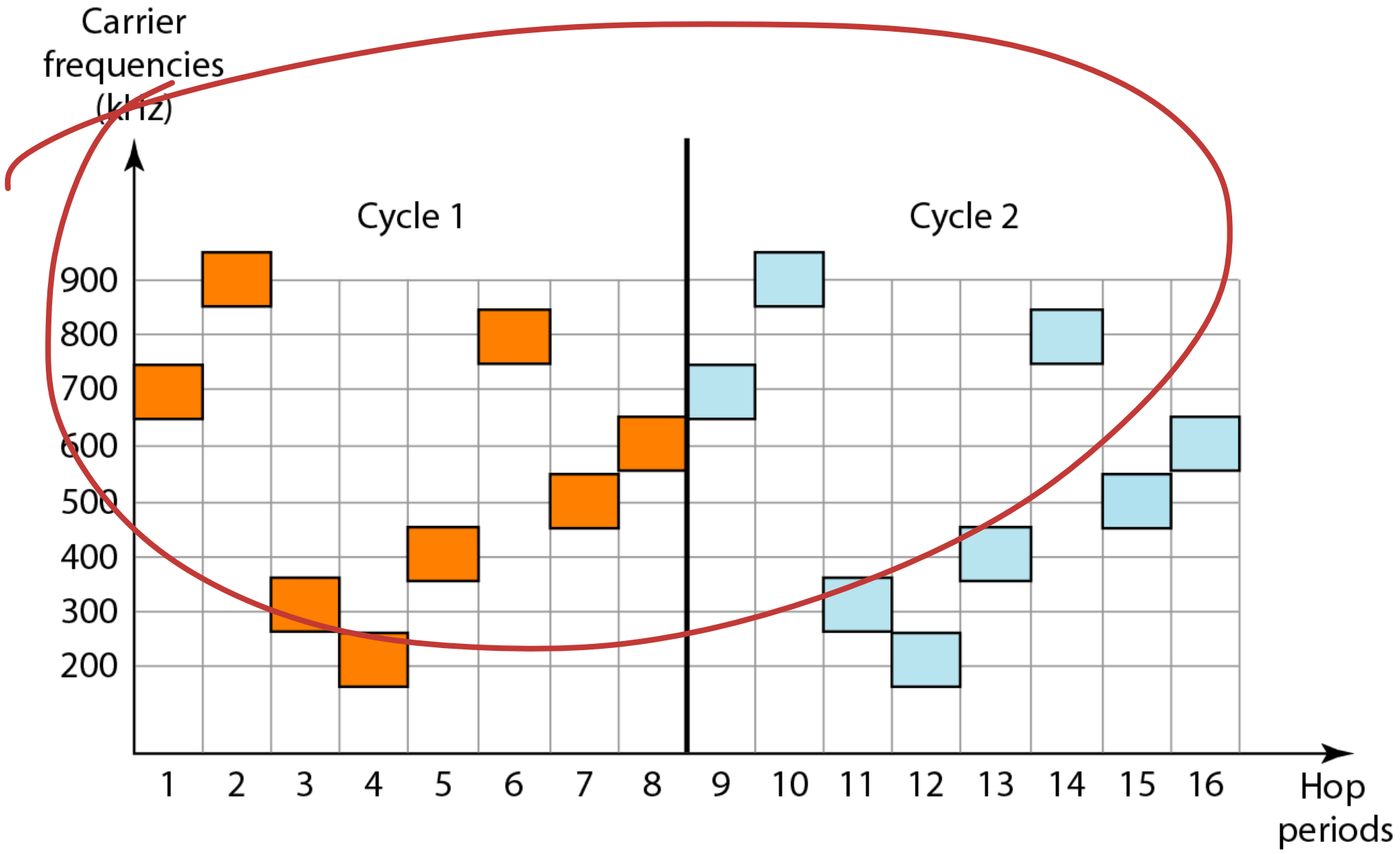
Frequency Hopping Spread Spectrum (FHSS)

- It divides available bandwidth into *N* channels and hops between these channels according to the *PN* sequence (Pseudo-Noise sequence)
- *PN* sequences
  - ✓ periodic but appear random within one period
  - ✓ very easy to generate
  - ✓ generated using LFSR (Linear Feedback Shift Registers)
  - ✓ easy to re-generate and synchronize at the receiver


Transmitter
Receiver
Spreading
Despread
Digital signal
Spreading signal
Digital signal
Hopping Pattern
Hopping Pattern
Power
Power
Power
Frequency
Frequency
Frequency

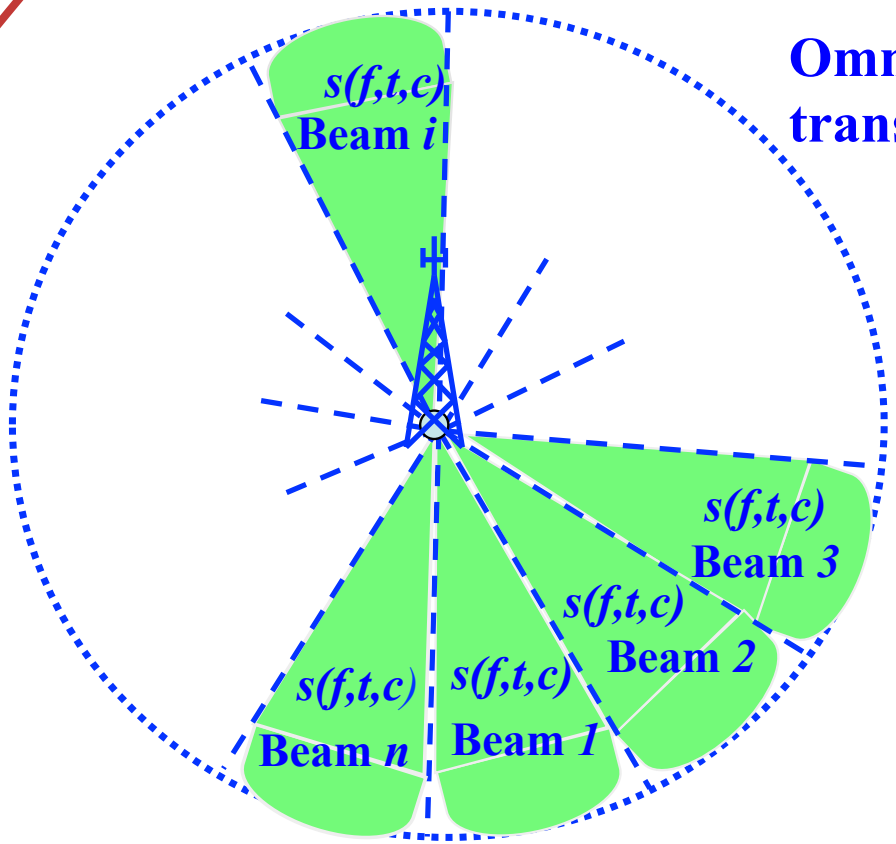
Example of Frequency Hopping Pattern




Carrier
frequencies
(kHz)
Cycle 1
Cycle 2
900
800
700
600
500
400
300
200
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Hop
periods

4. Space Division Multiple Access (SDMA)

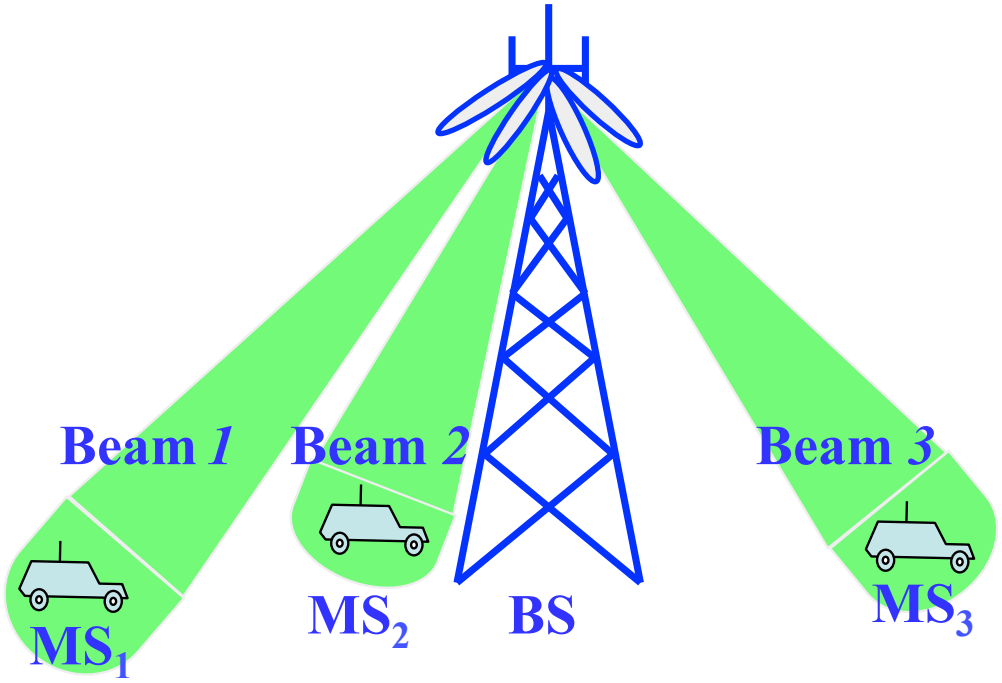
Space divided into spatially separate sectors



Omni-directional transmission

The concept of SDMA

- Noise and interference for each MS and BS is minimized
- Enhance the quality of communication link and increase overall system capacity
- Intra-cell channel reuse can be easily exploited



Technique	FDMA	TDMA	CDMA	SDMA
Concept	Divide the frequency band into disjoint sub-bands	Divide the time into non-overlapping time slots	Spread the signal with orthogonal codes	Divide the space in to sectors
Active terminals	All terminals active on their specified frequencies	Terminals are active in their specified slot on same frequency	All terminals active on same frequency	Number of terminals per beam depends on FDMA/ TDMA/ CDMA
Signal separation	Filtering in frequency	Synchronization in time	Code separation	Spatial separation using smart antennas
Handoff	Hard handoff	Hard handoff	Soft handoff	Hard and soft handoffs
Advantages	Simple and robust	Flexible	Flexible	Very simple, increases system capacity
Disadvantages	Inflexible, available frequencies are fixed, requires guard bands	Requires guard space, synchronization problem	Complex receivers, requires power control to avoid near-far problem	Inflexible, requires network monitoring to avoid intra cell handoffs
Current applications	Radio, TV and analog cellular	GSM and PDC	2.5G and 3G	Satellite systems, LTE