Multiple Access

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Overview

- Traffic Routing
- What is Multiple Access
  - Principles
- Multiple access techniques
  - FDMA, TDMA, CDMA, Hybrid Access schemes, Contention Access schemes

Traffic Routing

Given a demand for traffic in a network of *N* stations,

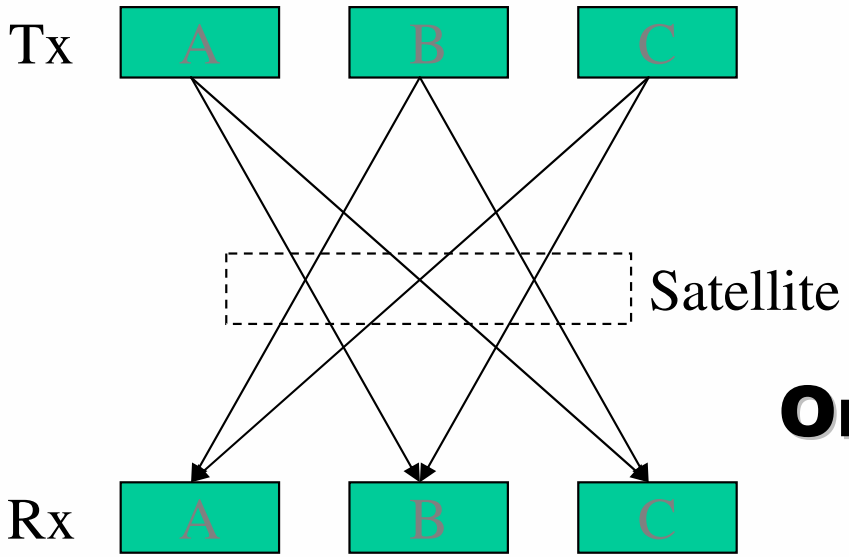
"How is traffic routed between earth stations and satellite?"

Traffic Routing (1)

- Establish an adequate information transfer capacity between each pair of stations ➔ essential !!
- Capacity ➔ function of demand (traffic intensity and acceptable blocking capacity (typical value: 0.5-1%)
- A set of capacities required for exchanges between *N* stations:
  - Matrix of dimension N with 0 in diagonals (Cxx=0)

Traffic Routing (2)

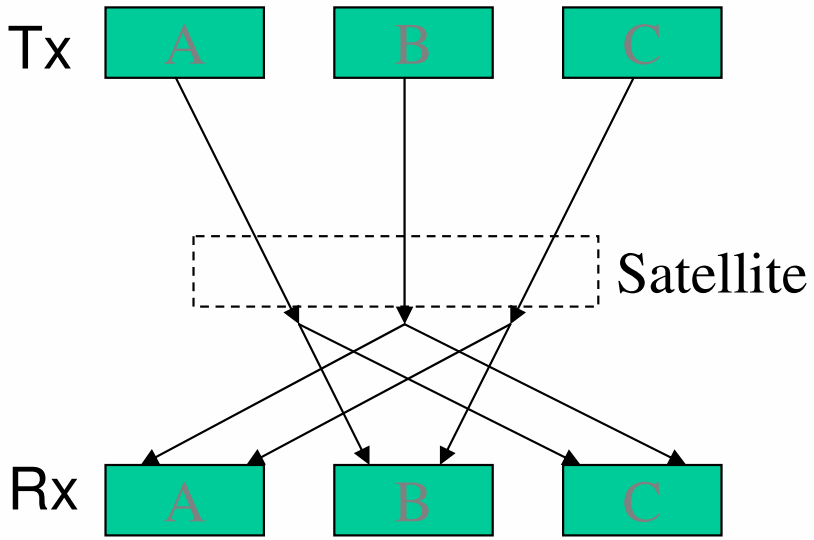
- At network level, two techniques are to be considered for traffic routing:
  - **One carrier per station-to-station link**
    - One carrier carries traffic from station X to station Y



One Carrier Per Link

Traffic Routing (3)

- **One carrier per transmitting station**
  - Use broadcast property of satellite
    - Enables every station to receive all carriers transmitted to satellite
  - All traffic from station X can be carried by single carrier



One Carrier Per Transmitting Station

Traffic Routing (4)

One carrier per station-to-station link	One carrier per transmitting station
Greater number of carriers	Smaller number of carriers
Each carrier has a smaller capacity	Each carrier has greater capacity
Rx station receives only traffic which is intended for it	Rx station must extract X' to Y' traffic from the total traffic conveyed by the carrier received from station X

Multiple Access: The Basics

What is multiple access?

The principles of access to the satellite resources

What is multiple access?

- Allows many users to share satellite's resources (capacity)
- Three types of basic schemes:
  - Frequency Division Multiple Access (FDMA)
  - Time Division Multiple Access (TDMA)
  - Code Division Multiple Access (CDMA)
- Hybrid schemes e.g. FDMA/TDMA also occur

Multiple Access Principles

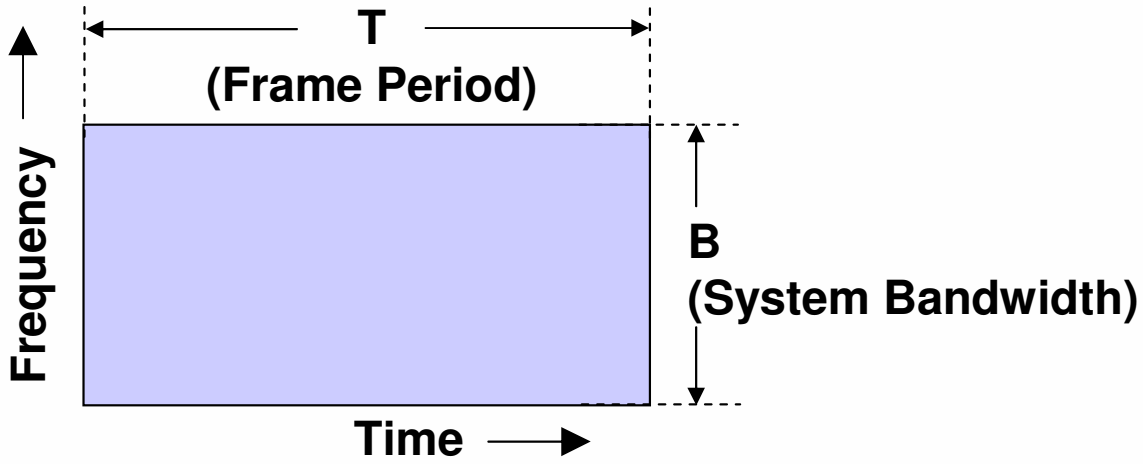
"The principles of access to the satellite resources"

Principles Overview

- Several carriers are handled simultaneously by satellite repeater
- Repeater consists of several adjacent channels (transponders)
- In term of multiple access and satellite repeater channel, two aspects to be considered:
  - Multiple access to a particular repeater channel
  - Multiple access to a satellite repeater

Multiple access to a particular channel (1)

- Each satellite channel (transponder) amplifies all carriers within its pass-band at a time
- Resource offered by each channel can be represented as shown below
  - Rectangle over time and frequency
- In absence of special precautions, carriers would occupy rectangle simultaneously and mutually interfere

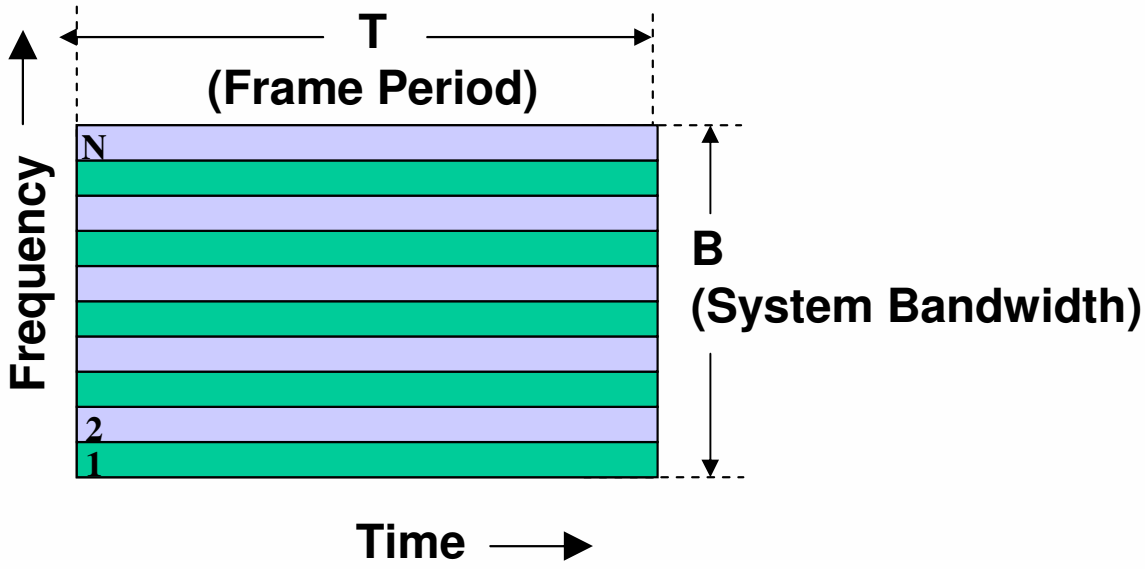


Multiple access to a particular channel (2)

- To avoid this interference, earth station receivers must be able discriminate between the received carriers
- Discrimination techniques/basic multiple access:
  - FDMA
  - TDMA
  - CDMA

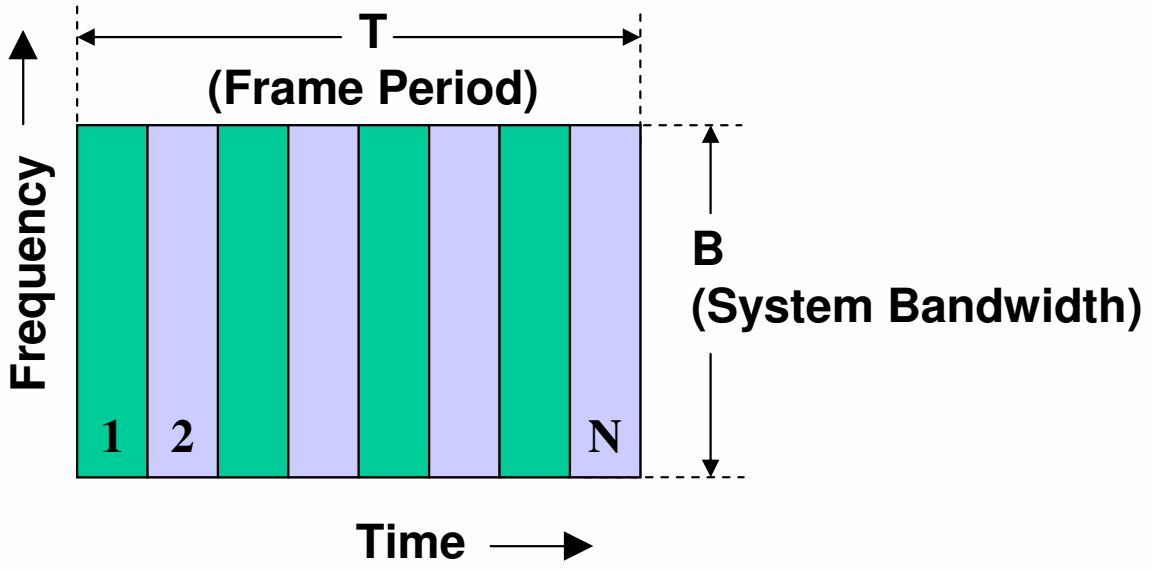
Principles of FDMA

- Carriers discriminated at receiver as a function of location in frequency domain
- Spectra of carriers occupy different sub-bands
  - Filtering will discriminate between carriers



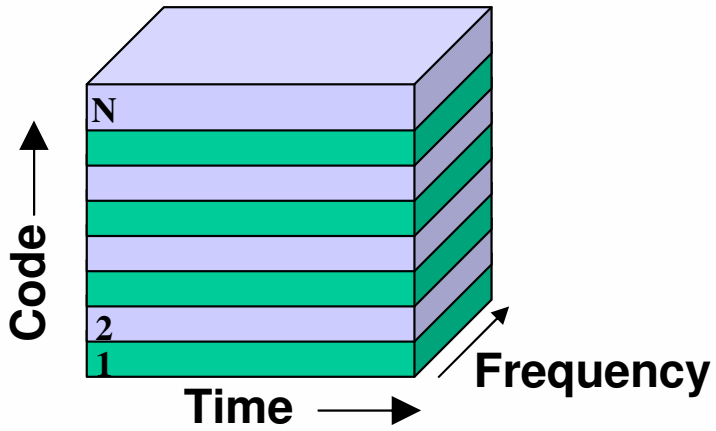
Principles of TDMA

- Carriers discriminated at receiver as a function of temporal location of carriers
- Several carriers received sequentially can be discriminated by temporal gating, even in same frequency band



Principles of CDMA

- Carriers discriminated at receiver by addition of 'signature' which known to receiver and specific to each carrier
  - The signature realised by use of pseudo-random (PN) codes
- SSMA: Codes broaden carrier spectrum in comparison with that obtained if modulated only by useful information



Multiple access to satellite repeater

- Hybrid access schemes can be considered as representative of multiple access to a satellite repeater
  - For every carrier with given frequency, there is an obligatory FDMA access to the repeater together with FDMA, TDMA or CDMA, access to each channel
- In all cases, spectral occupation of carrier must not exceed channel bandwidth

Multiple Access Techniques

"Frequency Division Multiple Access,
Time Division Multiple Access,
Code Division Multiple Access,
Hybrid schemes,
Contention Access schemes"

FDMA - Frequency Division Multiple Access

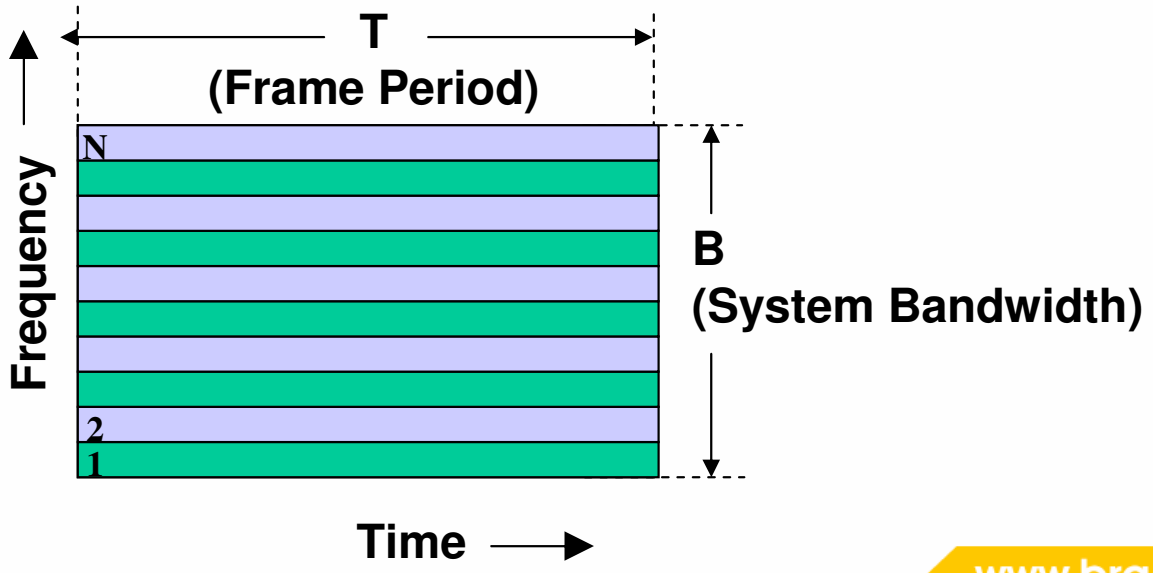
What is it?

How does it work?

Advantages/Disadvantages

FDMA Overview

- Simplest and most established technique
- Divides available bandwidth into channels that are assigned to users
- Transmission scheme depends on multiplexing and modulation techniques used

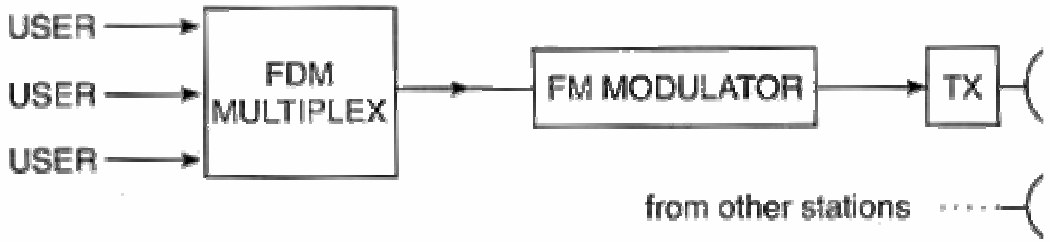


Transmission schemes for FDMA

- Depend on the multiplexing and modulation techniques used
- In each case, channel carries several carriers simultaneously
  - If a non-linear channel transfer characteristic
  - Inter-modulation between carriers
- Transmission schemes
  - FDM/FM/FDMA
  - TDM/PSK/FDMA
  - SCPC/FDMA

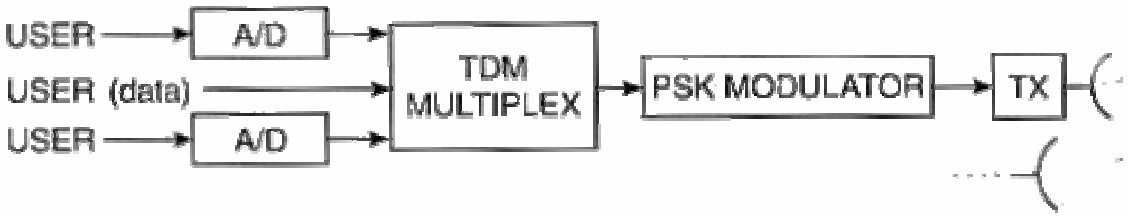
MCPC/FDMA

- Frequency Division Multiplex (FDM) / Frequency Modulation (FM) / FDMA
  - Also known as Multiple Channels Per Carrier (MCPC) FDMA
  - FDM/FM/FDMA



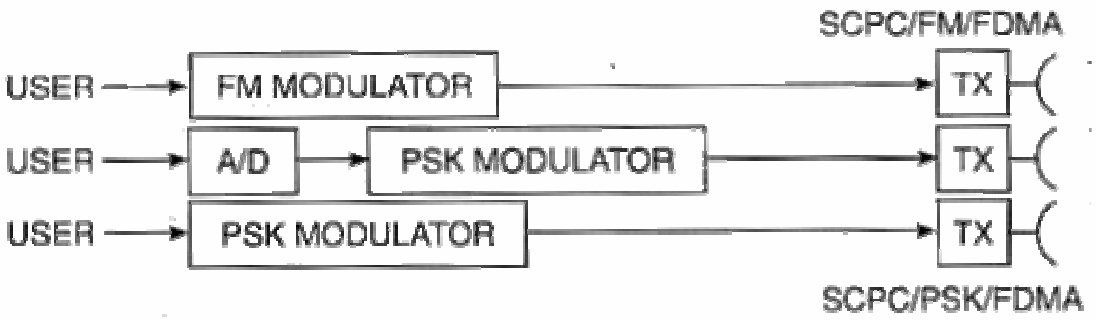
MCPC/FDMA

- Digital version: Time Division Multiplex (TDM) / Phase-Shift Keying (PSK) / FDMA
  - TDM/PSK/FDMA



SCPC/FDMA (1)

- Single Carrier Per Channel (SCPC) FDMA
  - Uses analogue (FM) or digital (PSK) modulation
  - SCPC/FM/FDMA
  - SCPC/PSK/FDMA



Advantages

- Known, tried and tested method
  - Oldest access technique
- Requires no synchronisation between earth stations
- Simple to implement and operate

Disadvantages

- Lack of flexibility for re-configuration:
  - To accommodate capacity variations, frequency plan changes are required
    - Modification of transmitting and receiving frequencies and filter bandwidths of earth stations
- Loss of capacity as number of accesses increases due to generation of inter-modulation products
  - Reduced satellite transmitting power
- Carrier powers at satellite input must be same
  - Adaptable control to compensate for rain attenuation on uplinks

TDMA - Time Division Multiple Access

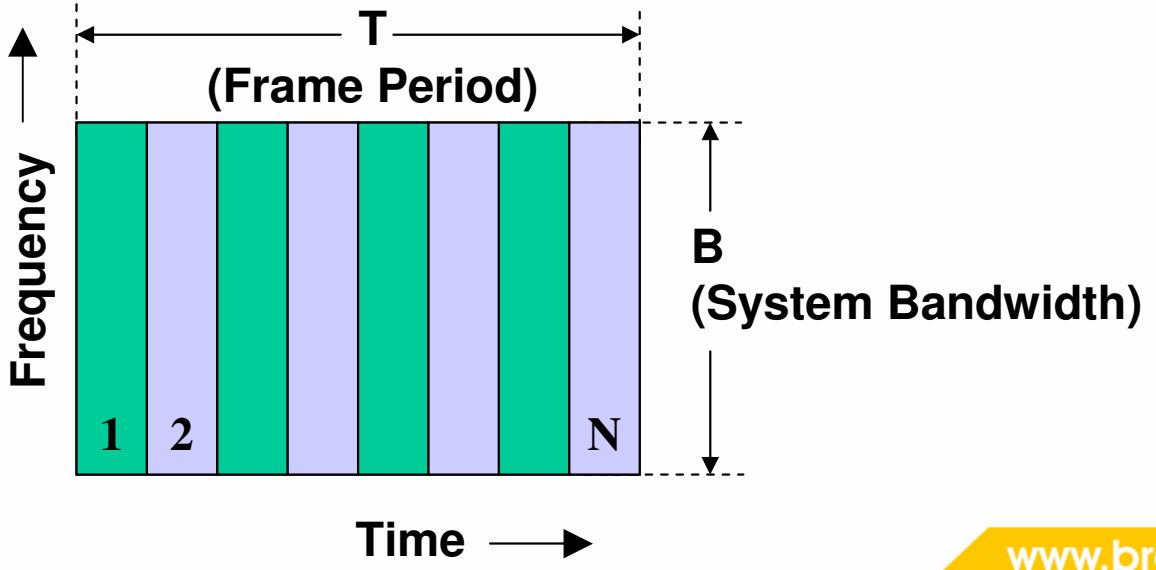
What is it?

How does it work?

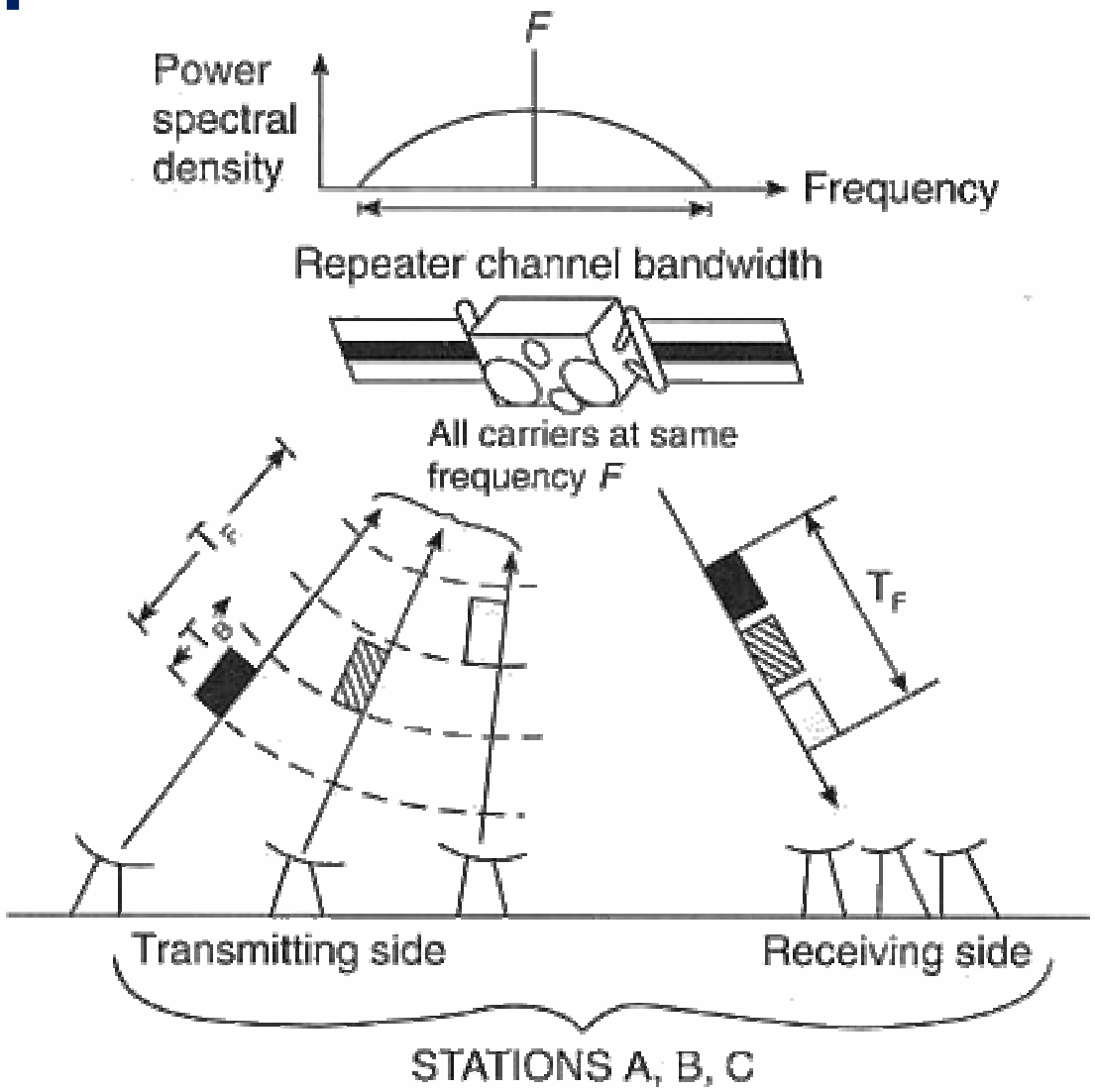
Advantages/Disadvantages

TDMA Overview

- Divides time domain into a series of time slots
- Earth stations, one after each other, transmit 'bursts' of carrier in assigned slots
- Number of slots together form TDMA frame
- All bursts of carrier have same frequency and occupy full repeater channel bandwidth



Operation

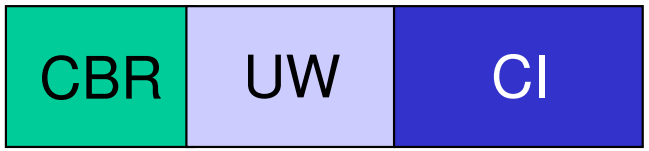

F
Power spectral density
Frequency
Repeater channel bandwidth
All carriers at same frequency F
T_F
T_B
T_F
Transmitting side
Receiving side
STATIONS A, B, C

Data Bursts (1)

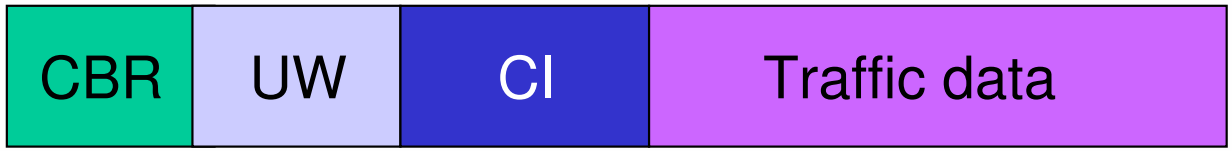
- Reference Burst:
  - To ensure a user transmits within a specific time slot
    - Reference bursts are transmitted at start of each frame
  - Data burst consist of three elements:
    - Carrier and bit timing recovery (CBR)
      - Enables stations to lock to carrier frequency and bit timing clock burst
    - Unique word (UW)
      - Provides burst reference time for precise synchronisation and resolution of phase ambiguity
    - Control information (CI)
      - Provides information for each receiving station to control position of transmission bursts as well as other network management information

Data bursts (2)

- Traffic Burst
  - Initially, contain a preamble like format of reference burst (CBR, UW and CI), followed by a data burst



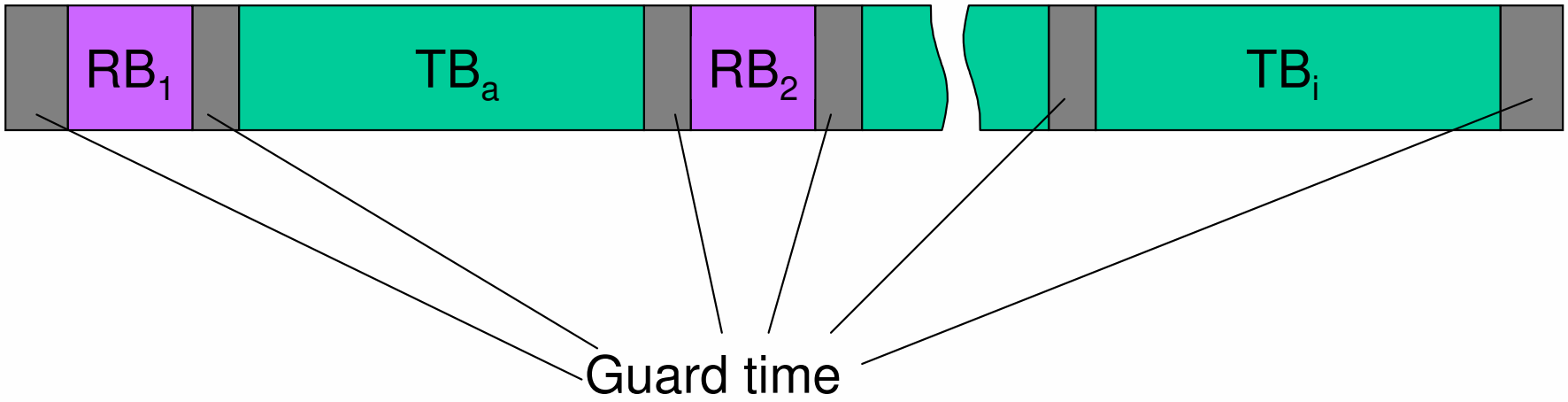
Reference Burst



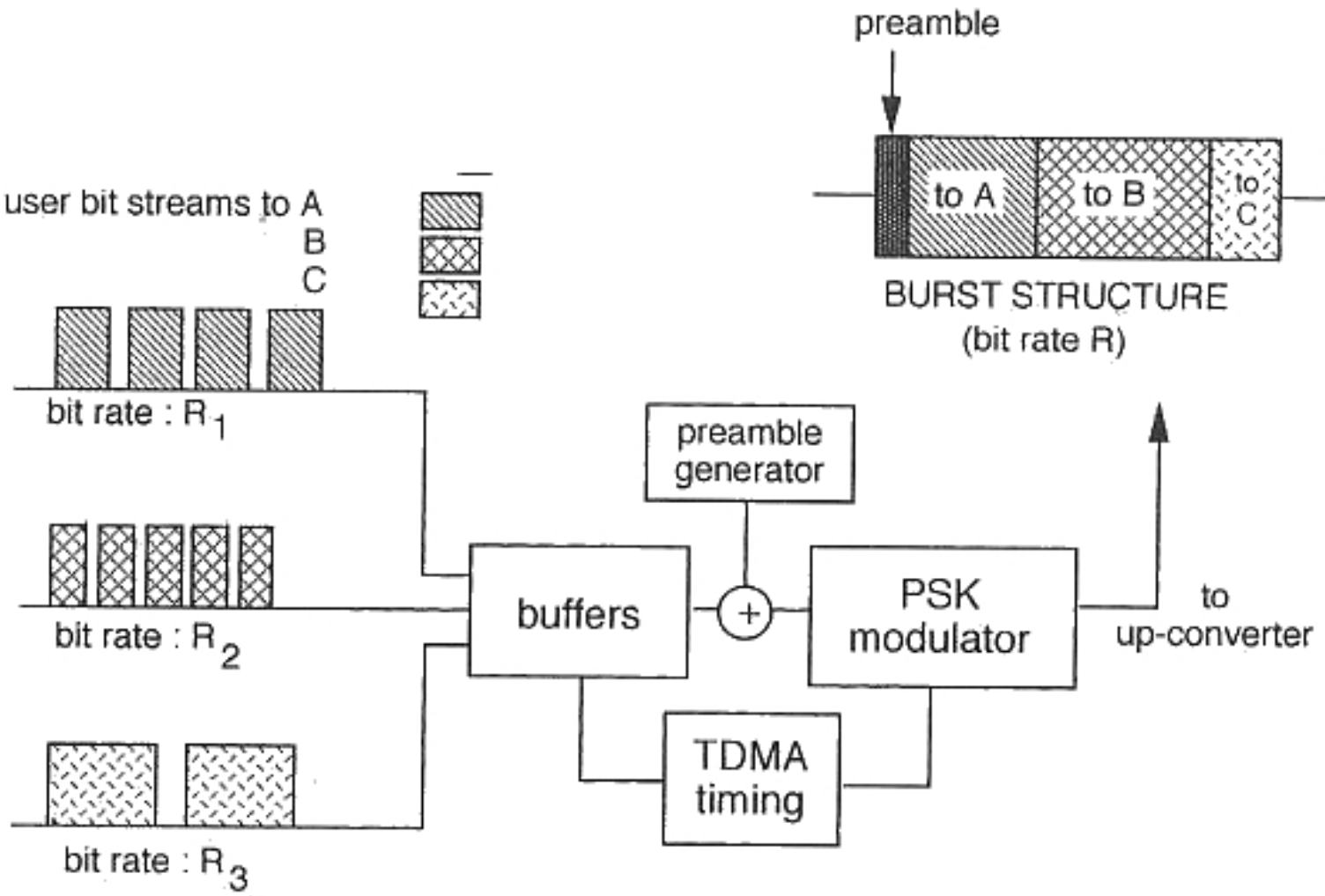
Traffic Burst

Frame Structure

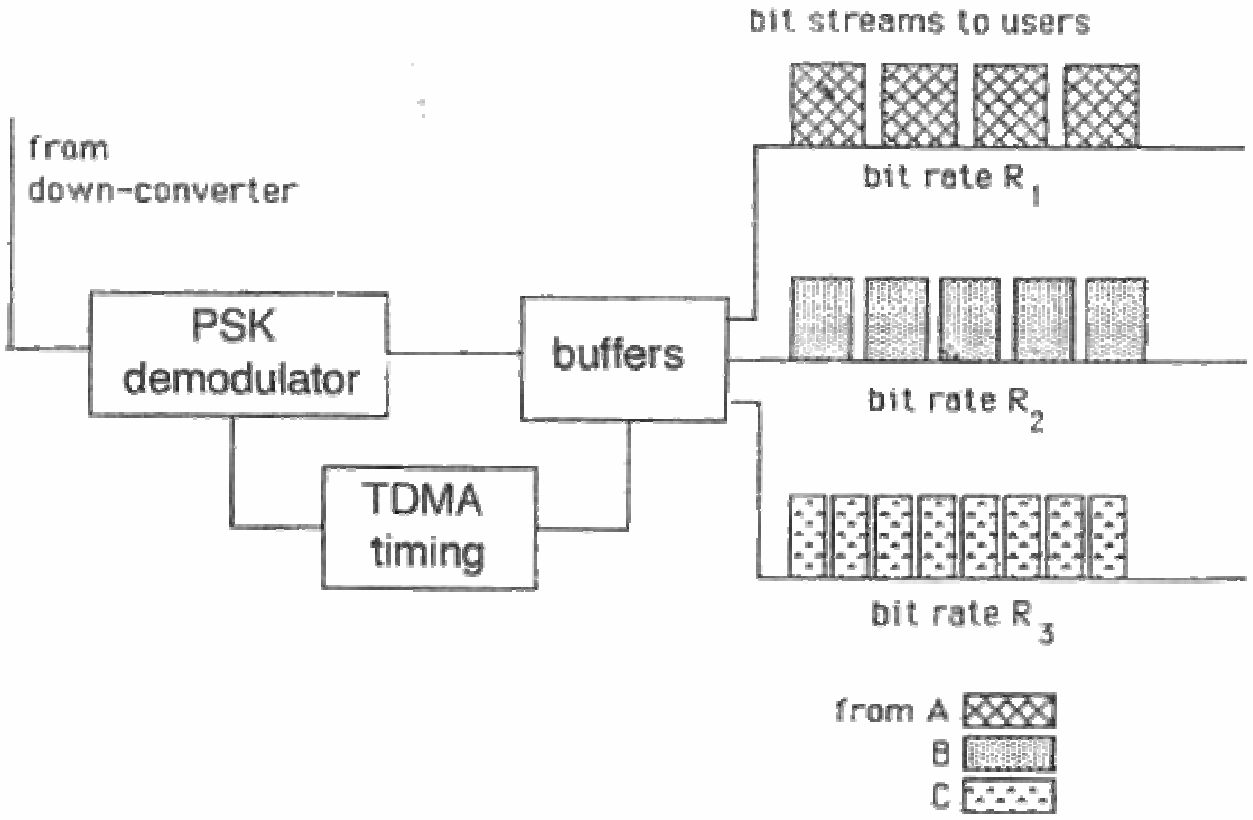
- Frames consist of reference bursts, traffic bursts and guard time-slots (periods of time where nothing is sent)



Burst Generation



Burst Reception



TDMA Throughput

- TDMA throughput is given by:

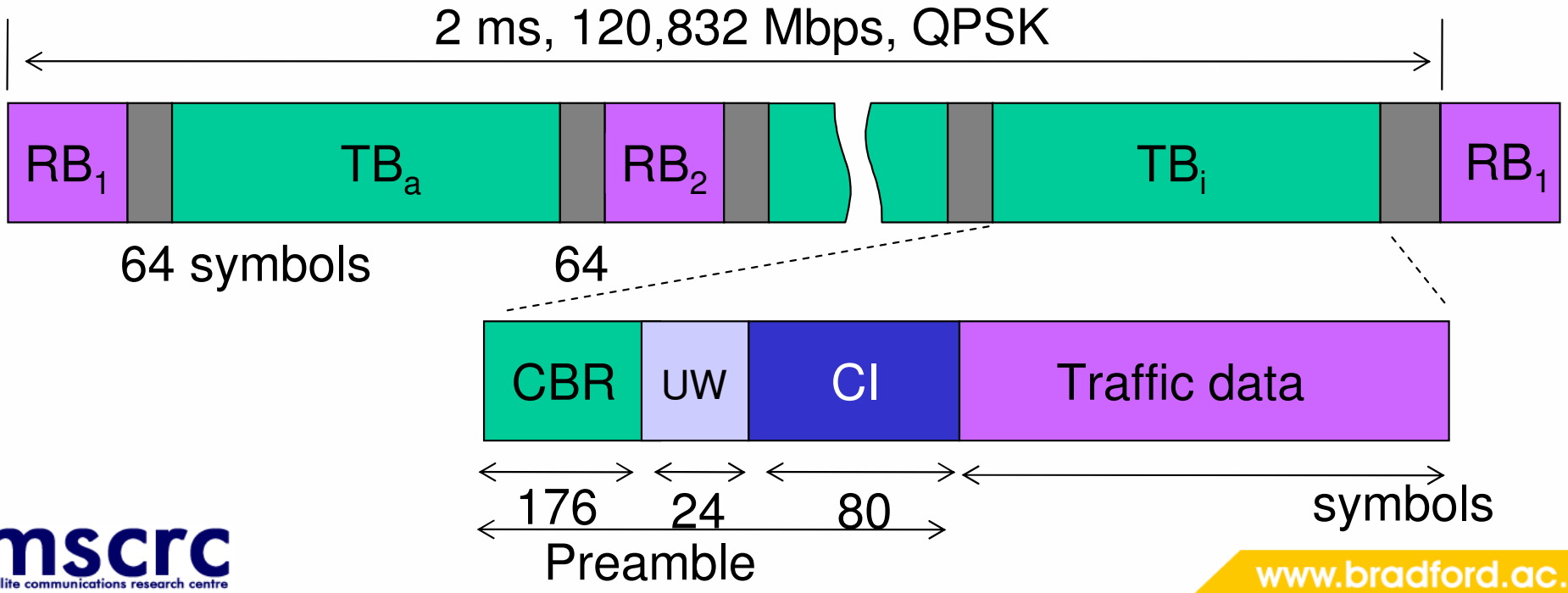
$$\eta = 1 - \frac{(P+2)\cdot(p+g)}{R\cdot T_F}$$

where:

- P is number of bursts in frame, dependent on number of stations in the network (N)
  - $P = N(N-1)$ for 'one carrier per link'
  - $P = N$ for 'one carrier per transmitting station'
- p is number of bits in frame header
- g is duration of guard time in bits
- R is bit rate of frame
- T_F is frame duration in seconds

TDMA Throughput - Example

- The TDMA frame used in the INTELSAT/EUTELSAT networks and provides insight in the bursts structure. Draw a graph from the TDMA throughput expression, as a function of number of accesses.



TDMA Synchronisation

- Purpose of synchronisation
  - To avoid burst overlap from others in the frame
- Initial timing access relies on reference bursts and information transmitted broadcast
- Following initial timing synchronisation during a call
  - The synchronisation is maintained to ensure bursts arrive at satellite in the correct relative position

TDMA Advantages

- Satellite repeater channel amplifies a single carrier that occupies all repeater channel bandwidth:
  - No inter-modulation interference
  - Full use of saturation power
- Transmission throughput remains high for large number of accesses
- No need to control transmitting power of stations
- All stations transmit and receive at same frequency
  - Simplifies tuning

TDMA Disadvantages

- Need for synchronisation:
  - Complex procedures and provision of two reference stations
  - Increases cost and complexity of earth stations
- Power and bandwidth need to be increased, compared to continuous access (i.e. FDMA access), due to high burst rate

CDMA - Code Division Multiple Access

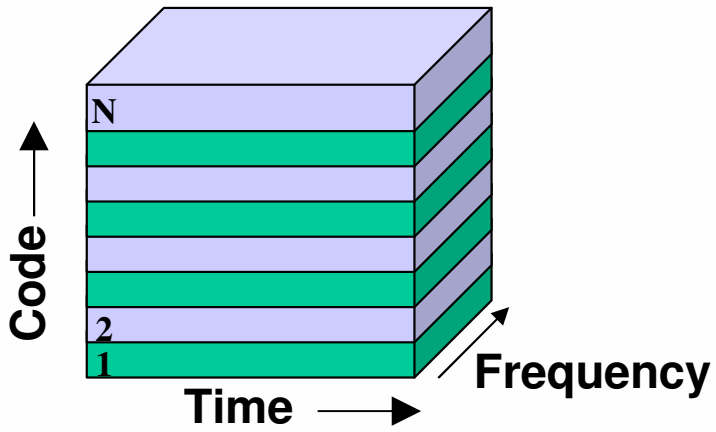
What is it?

How does it work?

Advantages/Disadvantages

CDMA Overview (1)

- Total available bandwidth is accessible to all users at the same time
- Unique code applied to each user's transmission to distinguish between users
  - Use Pseudo random codes (PN-sequence)
- Code only known at transmitter and receiver



CDMA Overview (2)

- Codes must have properties:
  - Each code must be easily distinguishable from a replica of itself shifted in time
  - Each code must be easily distinguishable regardless of other codes used on network
- Transmission of code combined with useful information requires greater RF bandwidth than that required to transmit information alone
  - Hence CDMA often known as spread spectrum technique

CDMA Overview (3)

- Two CDMA techniques:
  - Direct-sequence (DS)
    - Code used to spread user signal before transmission.
  - Frequency-hopping (FH)
    - Code used to determine frequency of transmission of data frame within allowed frequency bandwidth

DS-CDMA
Direct Sequence-Code Division Multiple Access

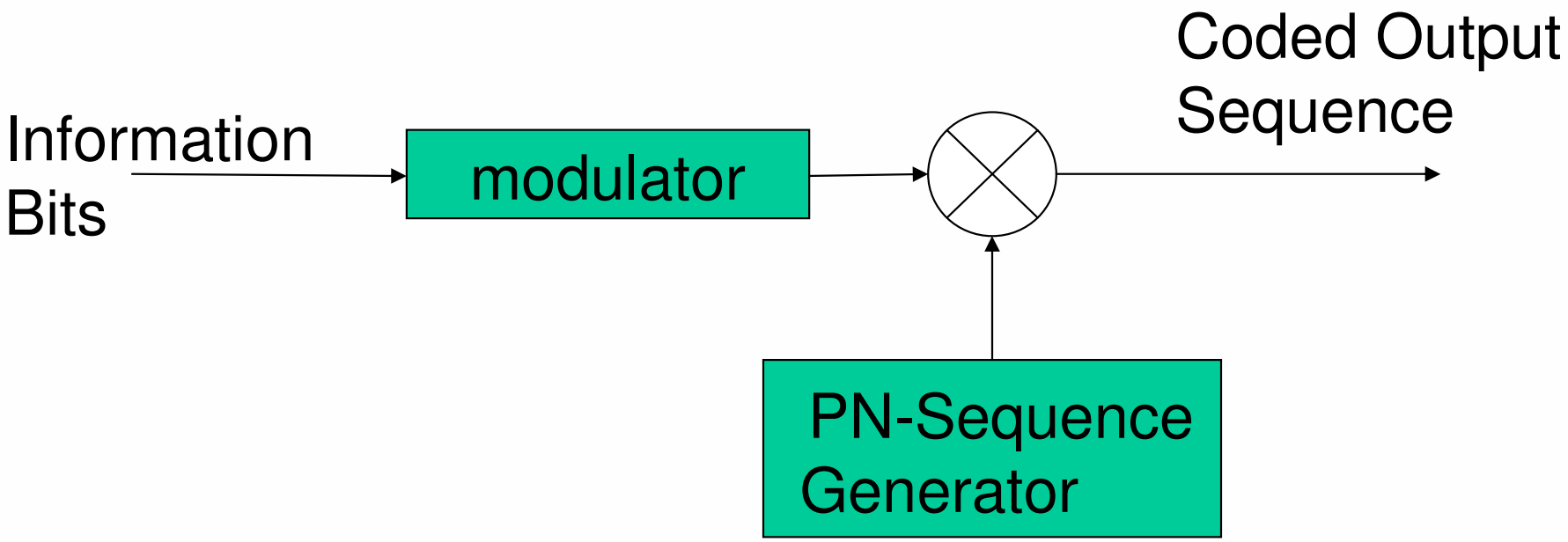
What is it?

How does it work?

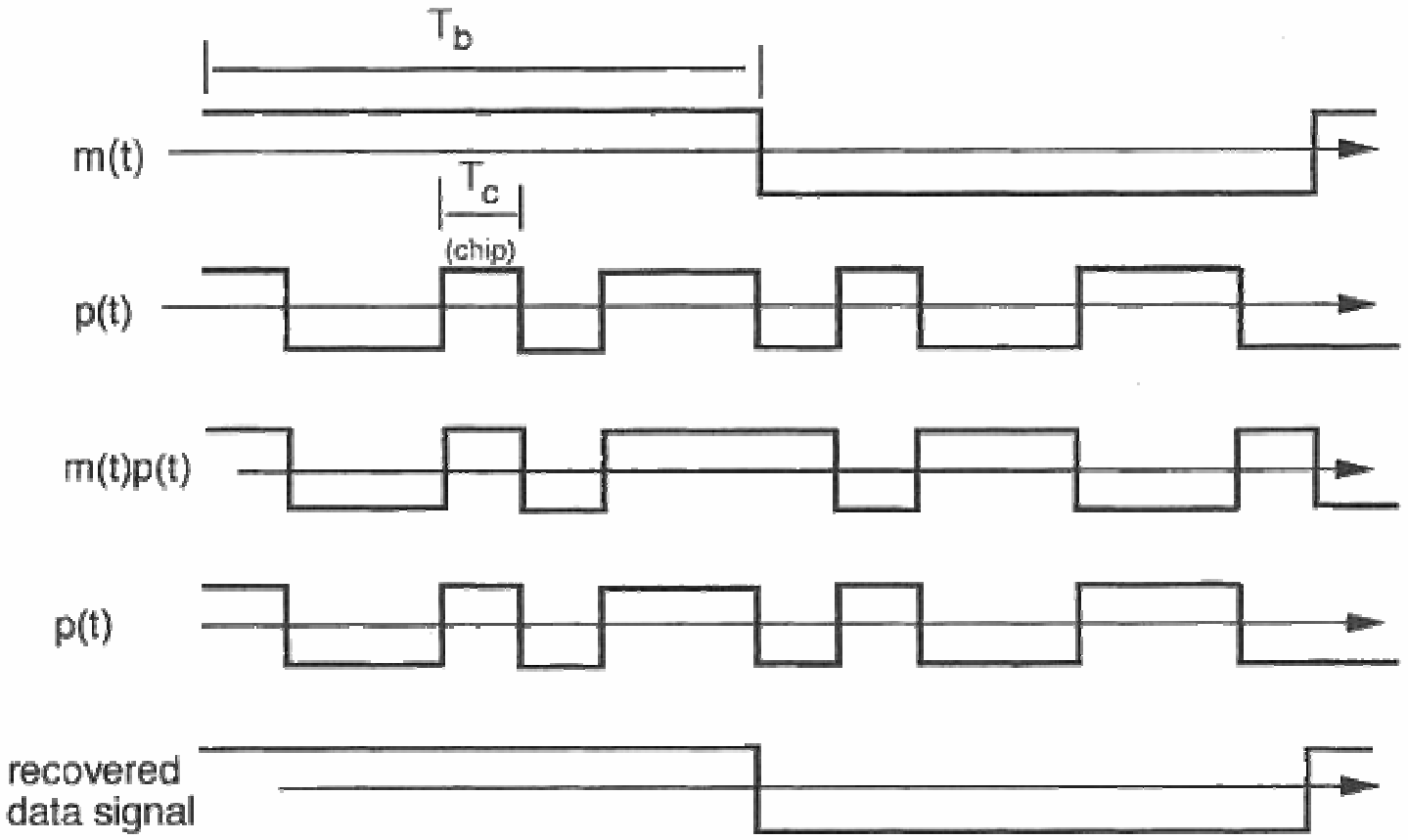
Direct Sequence CDMA – DS-CDMA

- Spreading sequence multiplied with modulated signal prior to transmission
- Code rate (chip rate) is pseudo random nature with noise-like spectrum
- Chip rate much greater than information bit rate
  - Subsequent convolution of information and code sequences results in spreading of information bandwidth

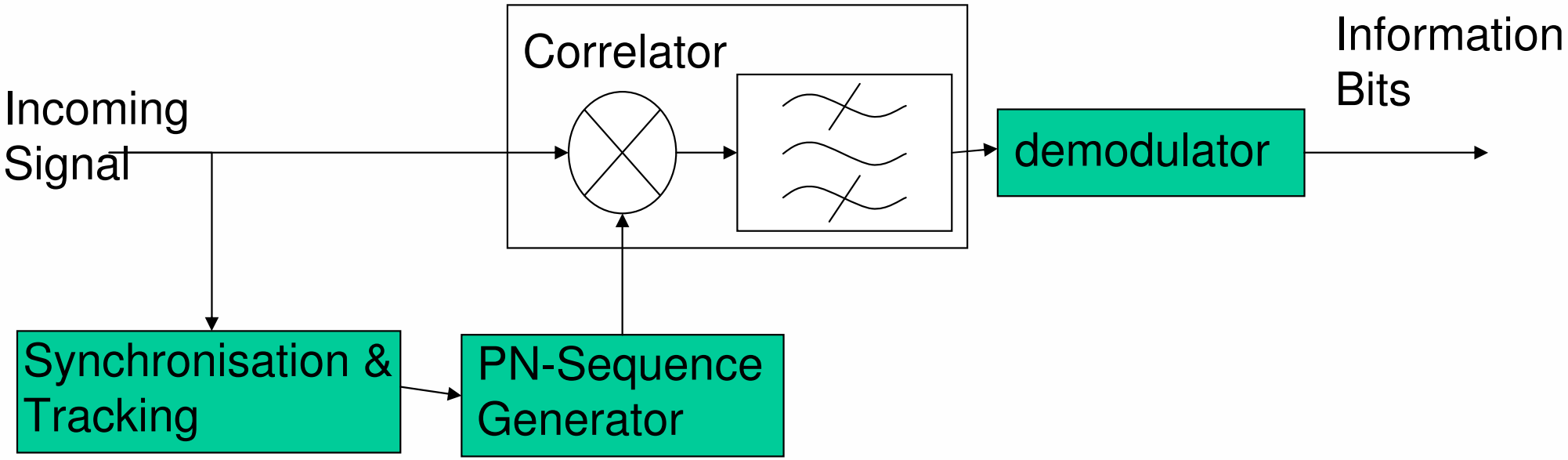
DS-CDMA Transmitter



DS-CDMA Spreading



DS-CDMA Receiver



FH-CDMA

Frequency Hopping-Code Division Multiple Access

What is it?

How does it work?

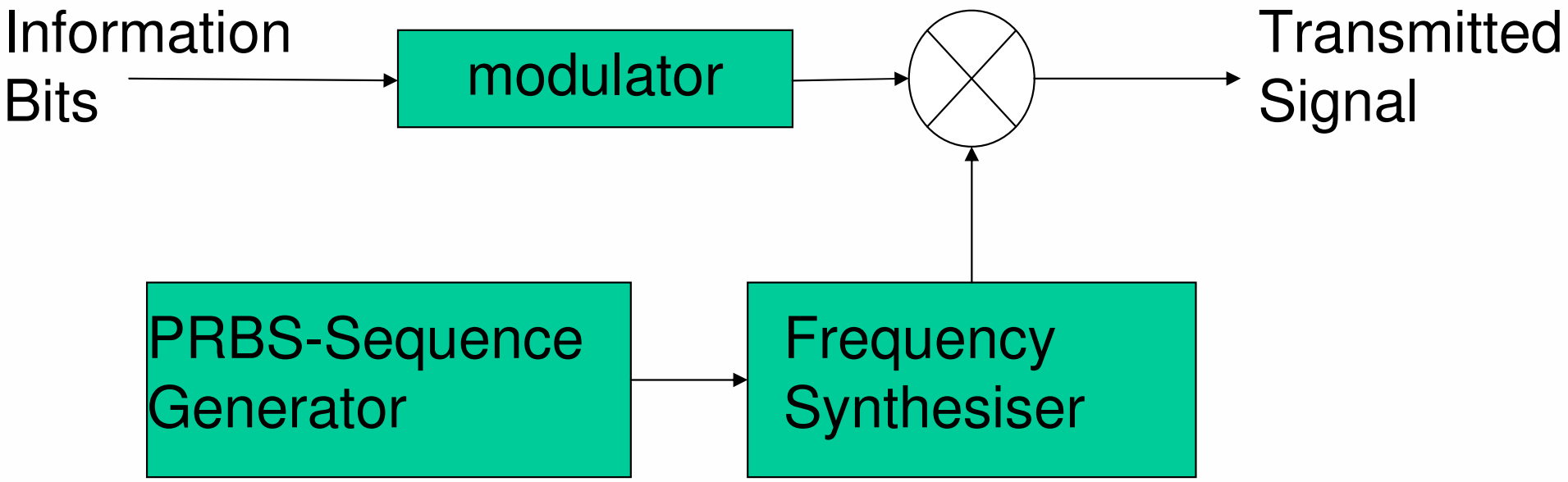
Frequency Hopping CDMA – FH-CDMA (1)

- Pseudo-random sequence is used to change transmission frequency with each change in pseudo-code
- Achieved by driving a frequency synthesiser (output which is controlled by generated PRBS generator)
- Frequency synthesiser output is then applied to the modulated user data sequence

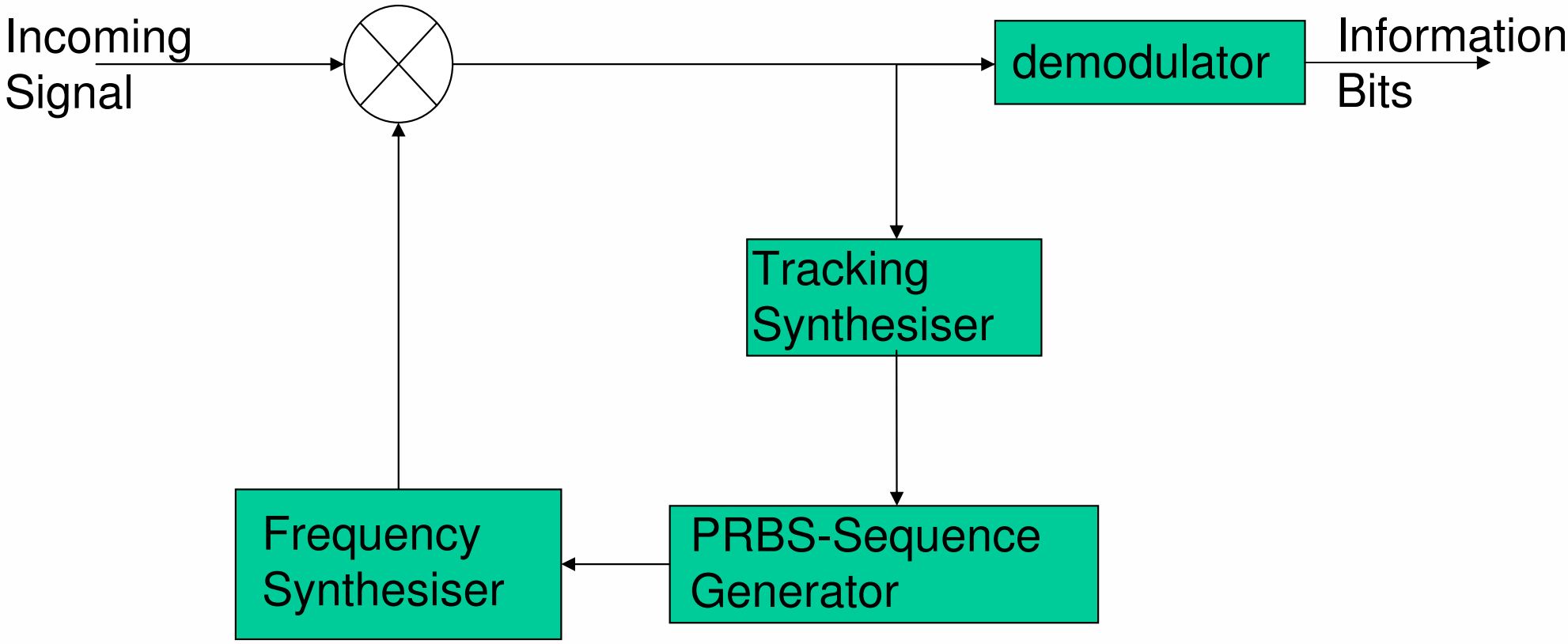
Frequency Hopping CDMA – FH-CDMA (2)

- At receiver, the same pseudo-random sequence is used to drive a similar frequency synthesiser in synchronisation with the transmitter

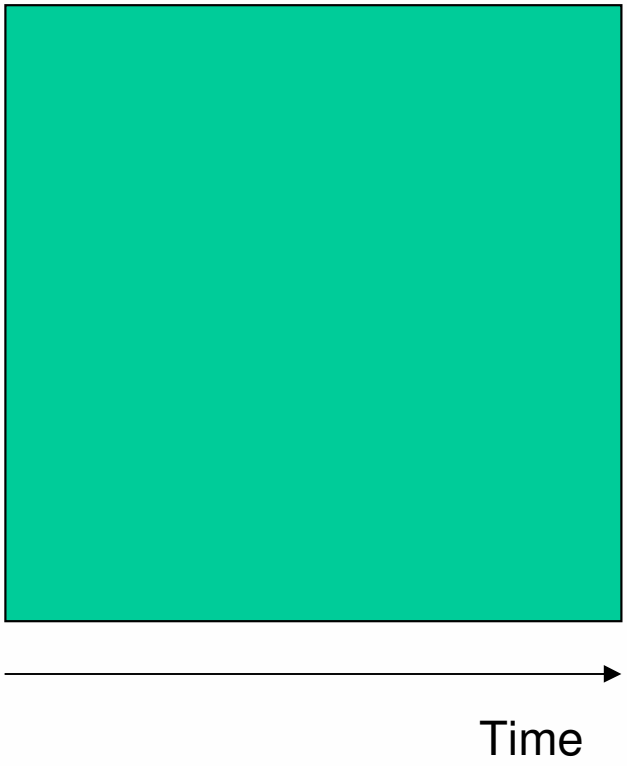
FH-CDMA Transmitter



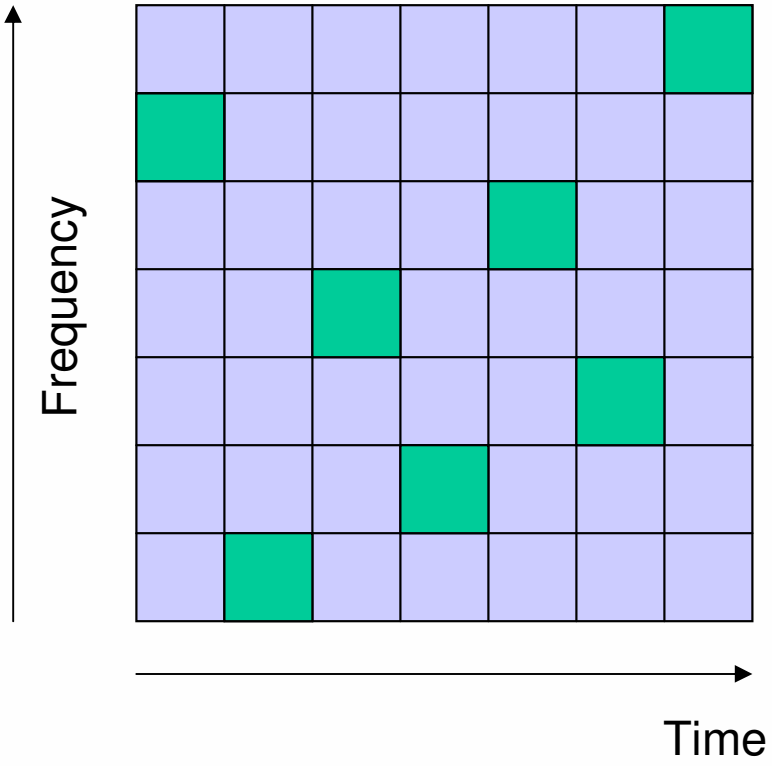
FH-CDMA Receiver



Comparison of DS-CDMA and FH-CDMA



DS-CDMA



FH-CDMA

CDMA Throughput

- CDMA throughput given by:

$$\eta = N_{\max} \cdot \frac{R_b}{R_c} \; ; N_{\max} = 1 + \left(R_c / R_b \right) / \Gamma \left(E_b / N_o \right)$$

where:

  - N_{max} is maximum number of accesses
  - R_b is information bit rate
  - R_c is chip rate

CDMA Throughput – Example

- Consider a CDMA network occupying the whole of a 36 MHz satellite repeater channel. The receiving bandwidth, B_N=36 MHz. Assumed: each carrier has the capacity of one telephone channel that is 64 kbit/s. With BPSK, spectral efficiency, Γ, 1 bit/sHz. Calculate (For Eb/No, 8.4 dB, 9.6 dB and 10.5 dB)
  - Chip rate and spreading ratio
  - Maximum number of accesses
  - Maximum capacity of network
  - CDMA throughput

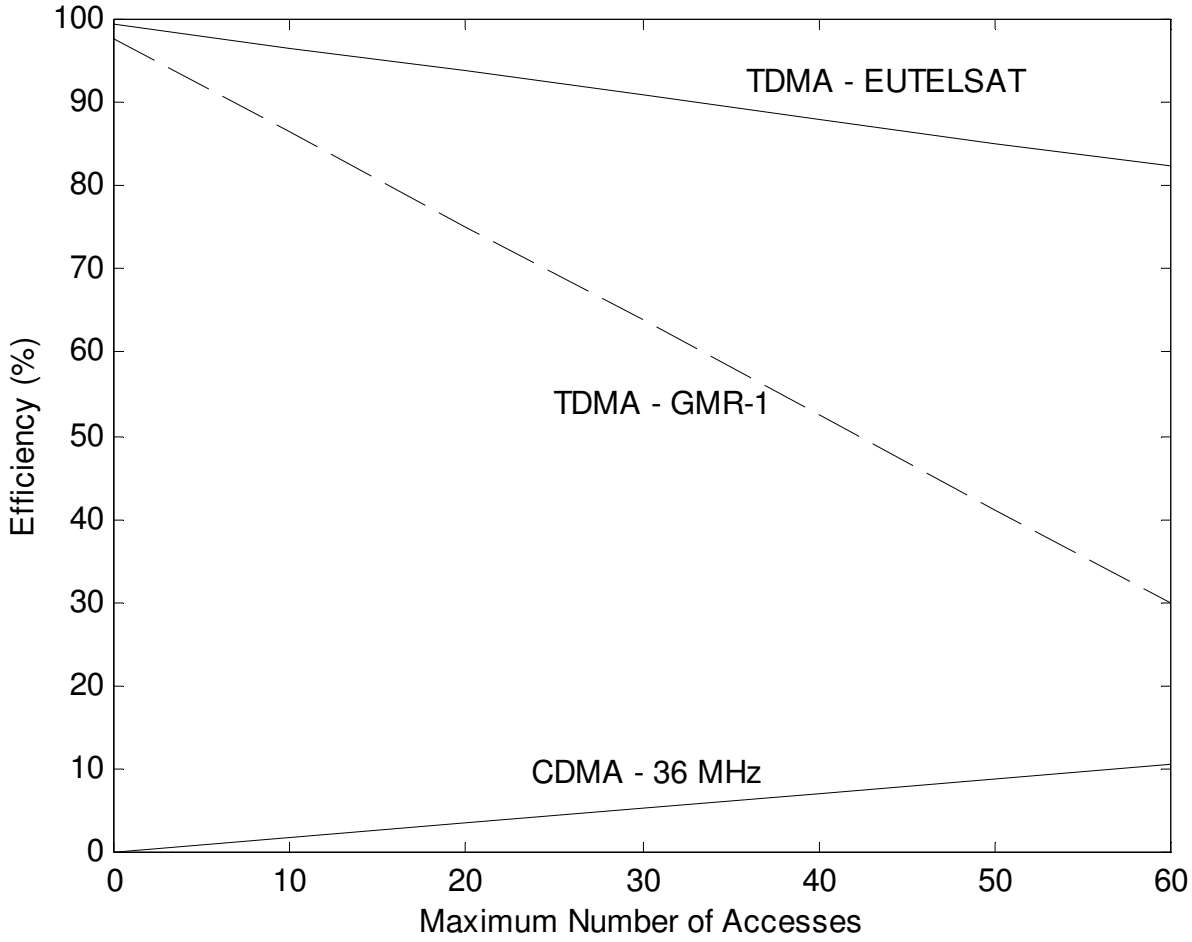
Advantages

- Simple to operate:
  - Does not require synchronisation between earth stations
  - Only required synchronisation is receiver to received carrier
- Protection from interference due to other systems and multi-path
- With multi-beam satellites offers potential of 100% frequency re-use

Disadvantages

- Low throughput compared to TDMA and FDMA
  - High bandwidth for low network capacity, with respect to a single un-spread carrier

Comparison of TDMA and CDMA

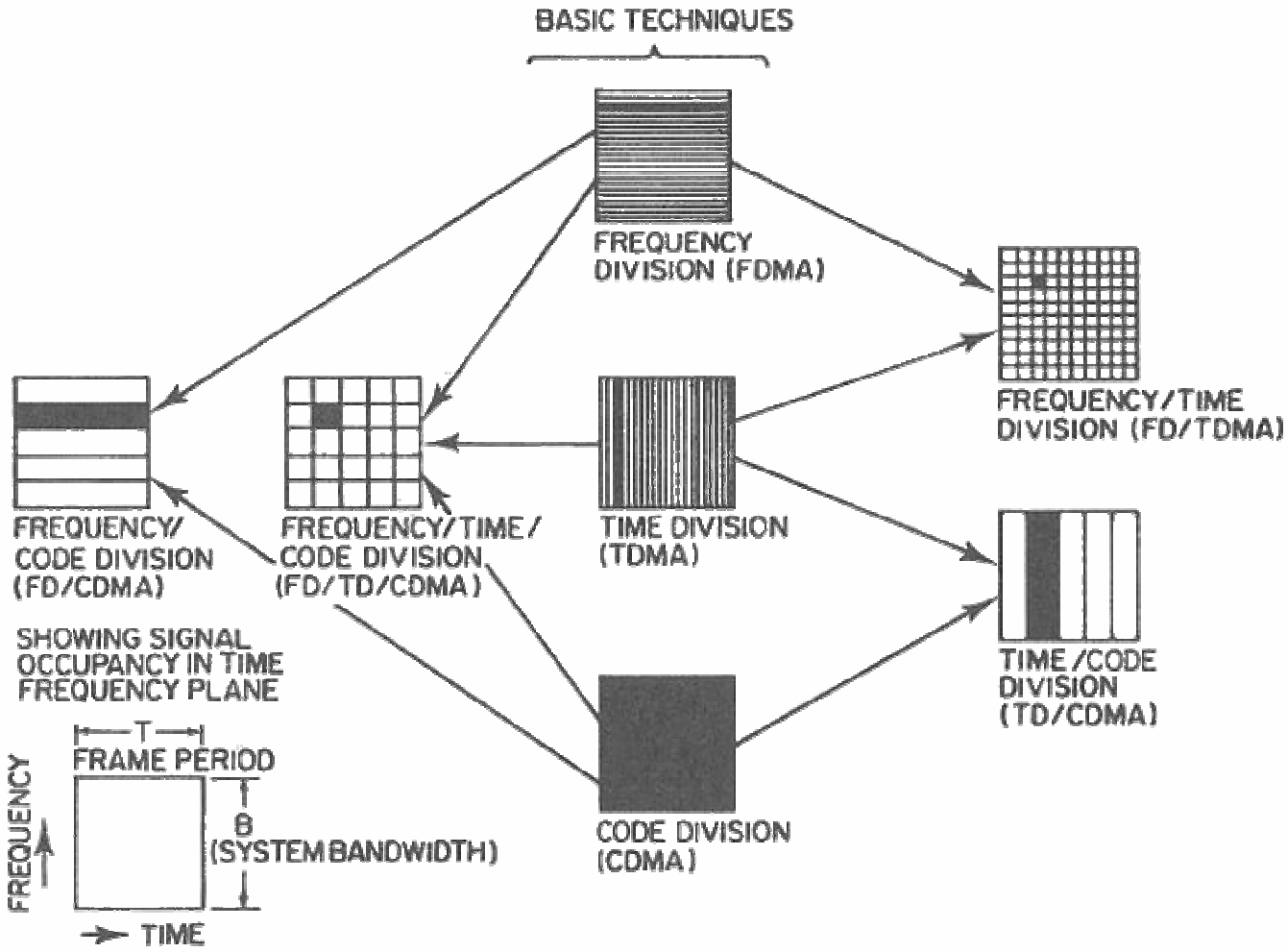


Hybrid Access Schemes

What are they?

How do they work?

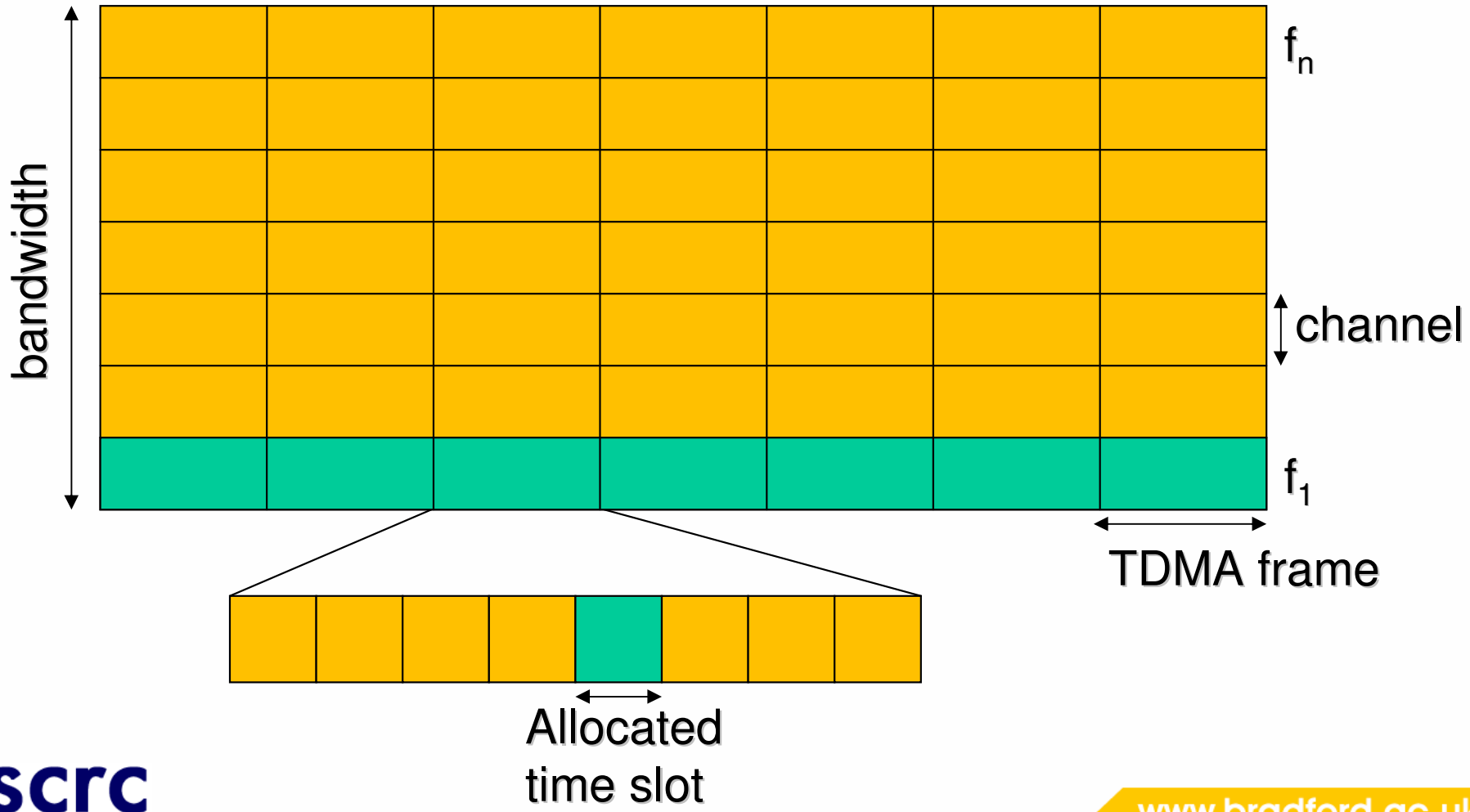
Hybrid Access Schemes (1)



Hybrid Access Schemes (2)

- Schemes that combine two of more techniques
  - Commonly FDMA with either CDMA or TDMA
- Example
  - FDMA/TDMA in GSM
    - Spectrum is divided into RF channels
    - Each frame within a channel contains 8 timeslots

FDMA/TDMA Access Scheme



Contention Access Schemes

What are they?

How do they work?

Why is it important?

- Transmission of packet data is bursty
- Often not practical to have a channel resource permanently assigned to signal link
- Use contention access rather than multiple access:
  - Transmitter vies for satellite resource on a per-demand basis
  - Probability of packet collision
    - Therefore need for re-transmission protocols

Contention Access Overview

- Can be referred to as random access
- Permits transmission of messages almost without restriction in format of short bursts
- Possibility of collisions of bursts at satellites is accepted
- Performance measured in terms of throughput

Schemes

- There are several possible schemes including:
  - ALOHA
    - Totally asynchronous protocol
  - Slotted-ALOHA
    - Similar to ALOHA, but uses time slots
  - Slot-reservation ALOHA

ALOHA

- Packets are transmitted with no restriction on time of transmission
- Earth stations can detect correct reception by monitoring re-transmission from satellite or by reception of ACK packets
- If collision detected earth station waits a random time and re-transmits packet
- Relatively inefficient
  - Maximum throughput of only 18.4%

Slotted ALOHA

- Divide time domain into slots:
  - Duration equal to duration of a single packet burst time
- Transmission only allowed at start of slot
- Packets either fully overlap, or do not overlap at all
  - In ALOHA partial overlapping can occur
- Throughput increases to 36%
- Complexity of earth stations increased
  - Due to need of synchronisation as in TDMA

Slot Reservation ALOHA

- Extension of slotted ALOHA that allows slots to be reserved for transmission by earth station
- Can be achieved:
  - Implicitly
    - Transmitting station contends initially for slot, which it retains until transmission is complete
    - Network informs other stations that slot is not available
  - Explicitly
    - Transmitting station requests network to reserve a particular slot prior to transmission
- Mode of operation is termed packet reserved multiple access (PRMA) scheme

Further Reading

- Sheriff & Hu – "Mobile Satellite Communications" Chapter 5, Section 5.5 (pg 183 ff).
- Maral and Bousquet – 'Satellite Communication Systems' – Chapter 4 (pg. 141 ff)