MAC Protocols for Satellite Systems

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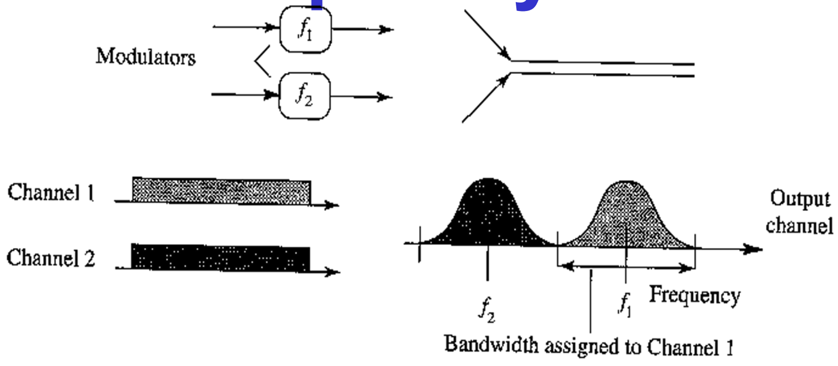
Multiple Access and Multiplexing

- Multiple access concerns a regulated utilization of a shared common resource (frequency, time, code) by different users **distributed over the service area** (e.g. FDMA, TDMA, CDMA)
- Multiplexing concerns a regulated combination of different signals **in one single flow** (e.g. FDM, TDM, CDM) to be utilized by different users
- Both multiple access and multiplexing are used in a satellite system.

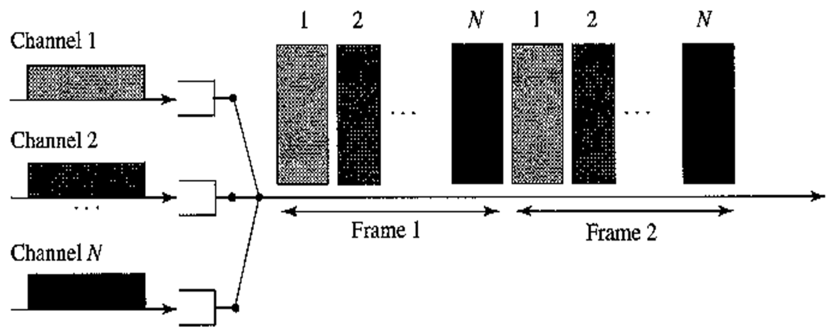
  Two possible approaches:

  - Transparent satellite: at each up-link station signals are first multiplexed, then they access the satellite; e.g. analogue voice signals are multiplexed in frequency at any Earth stations, and then FDM signals access the satellite sharing the common resources in the frequency domain (FDM/FDMA system). Management in charge to ground stations.
  - Regenerative satellite: with a regenerative multibeam satellite up-link signals can be first routed and then multiplexed in the down-links; e.g. TDMA is used in the up-link, and TDM in down link (TDMA/TDM system). Management in charge to ground stations or to on board payload or to both.

Frequency vs. Time Division Multiplexing

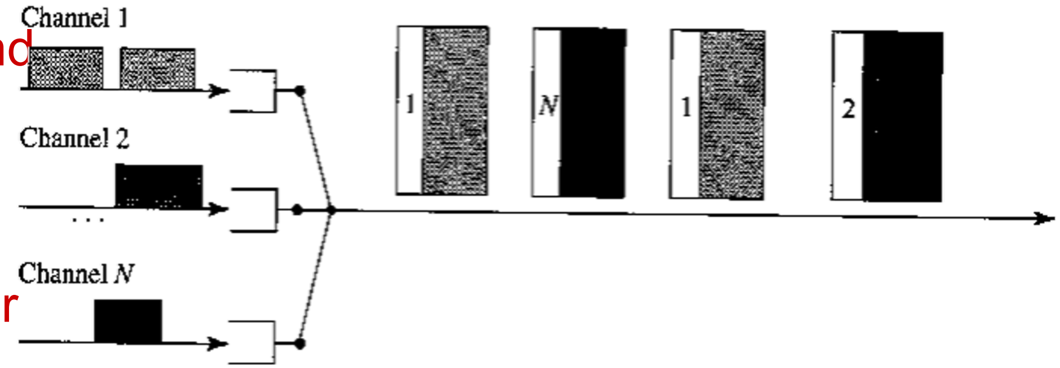


In frequency-division multiplexing, the frequency band is divided into distinct fixed bands, one for each incoming channel. The signal in each incoming channel is modulated to fit into its assigned band.



When a communication link is shared by time-division multiplexing, time is divided into frames. Each frame is divided into time slots that are allocated in a fixed order to the different incoming channels.

- FDM is appropriate for analogue signals
- TDM is appropriate for digital signal and analogue signals (e.g. voice) but A/D conversion before multiplexing is needed
- Both are inefficient with different and/or variable data rate signals
- **Statistical multiplexing** is preferred to FDM and TDM to handle different data rate signals



In statistical multiplexing, the multiplexer visits the incoming channel buffers in some order. The multiplexer empties a buffer before moving to the next one. The buffer contents are tagged to indicate their incoming channel. An idle channel does not waste transmission time.

Multiple access strategies

- Distributed
  - Each station takes the decision independently
  - It decides the start time and duration of transmission
  - Each station disseminates control information to the other stations
  - Lower overhead (especially for long delays)
- Centralized
  - A central entity takes decisions for the system
  - The entity allocates bandwidth according to some criterium
  - Each station sends a request
  - Easy implementation of priority access
  - Less reliable (the entity may fail or congest)

MAC Protocol Classification

Fixed Assignment Multiple Access protocols (FAMA)

Random Access protocols (RAP)

Demand Assignment Multiple Access protocols (DAMA)

Hybrid protocols

Summary of Main Multiple Access Technique

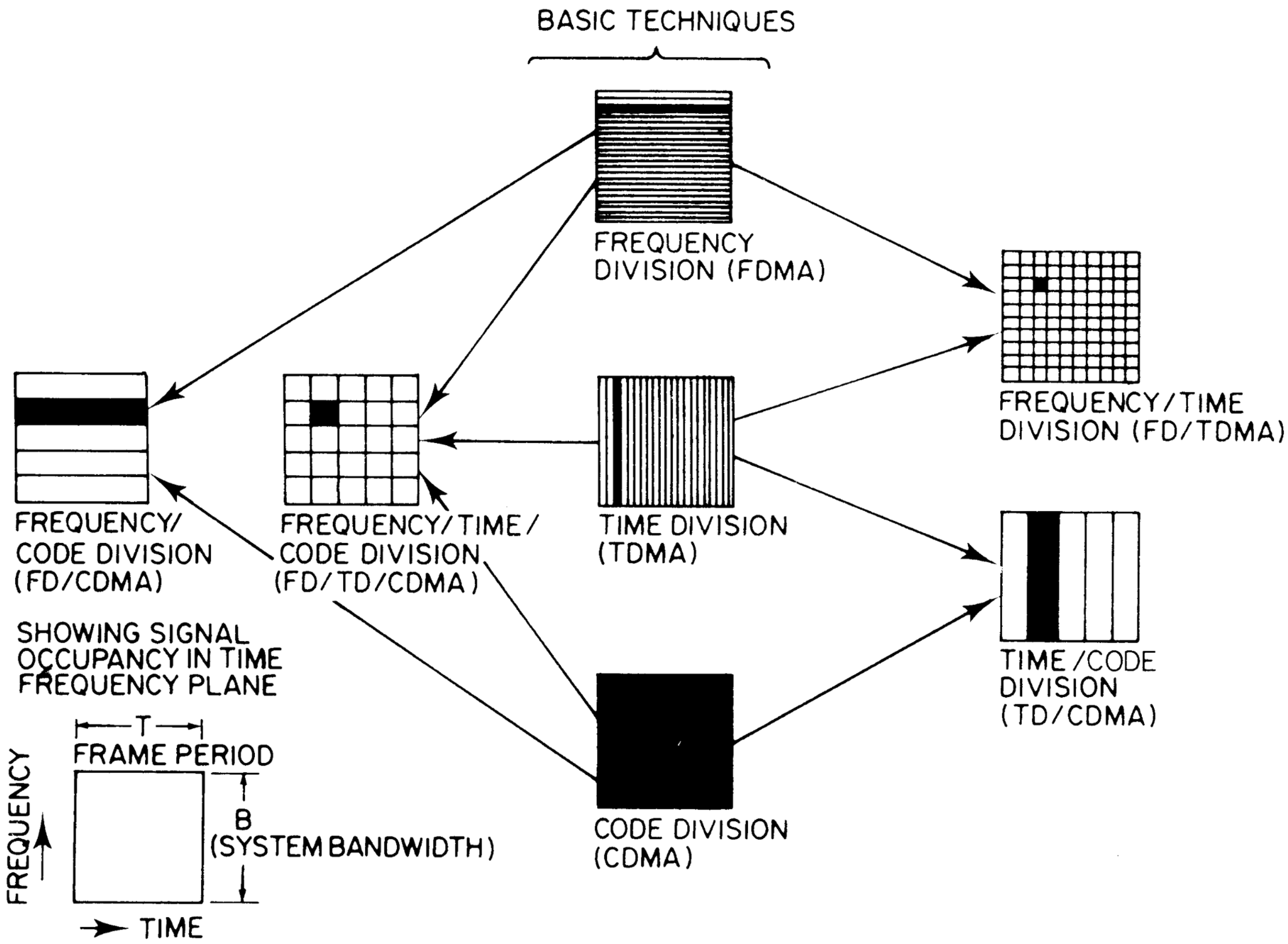
MA Technique

- **Orthogonal**
  - **FDMA**
    - Single carrier per link (SCPL)
    - Single carrier per station (SCPS)
    - Single carrier per channel (SCPC)
  - **OFDMA**
  - **TDMA (MF-TDMA)**
    - Fixed allocation
    - DAMA
  - **CDMA**
    - Direct Sequence (DS-CDMA)
    - Frequency Hopping (FH-CDMA)
- **Non-orthogonal**
  - **CDMA**
  - **PMA**
    - ALOHA
    - Slotted ALOHA
    - Packet reservation

Circuit switched: SCPL, SCPS, SCPC, Fixed allocation, DAMA, DS-CDMA, FH-CDMA

Packet switched: ALOHA, Slotted ALOHA, Packet reservation

Pure and Hybrid Multiple Access Techniques

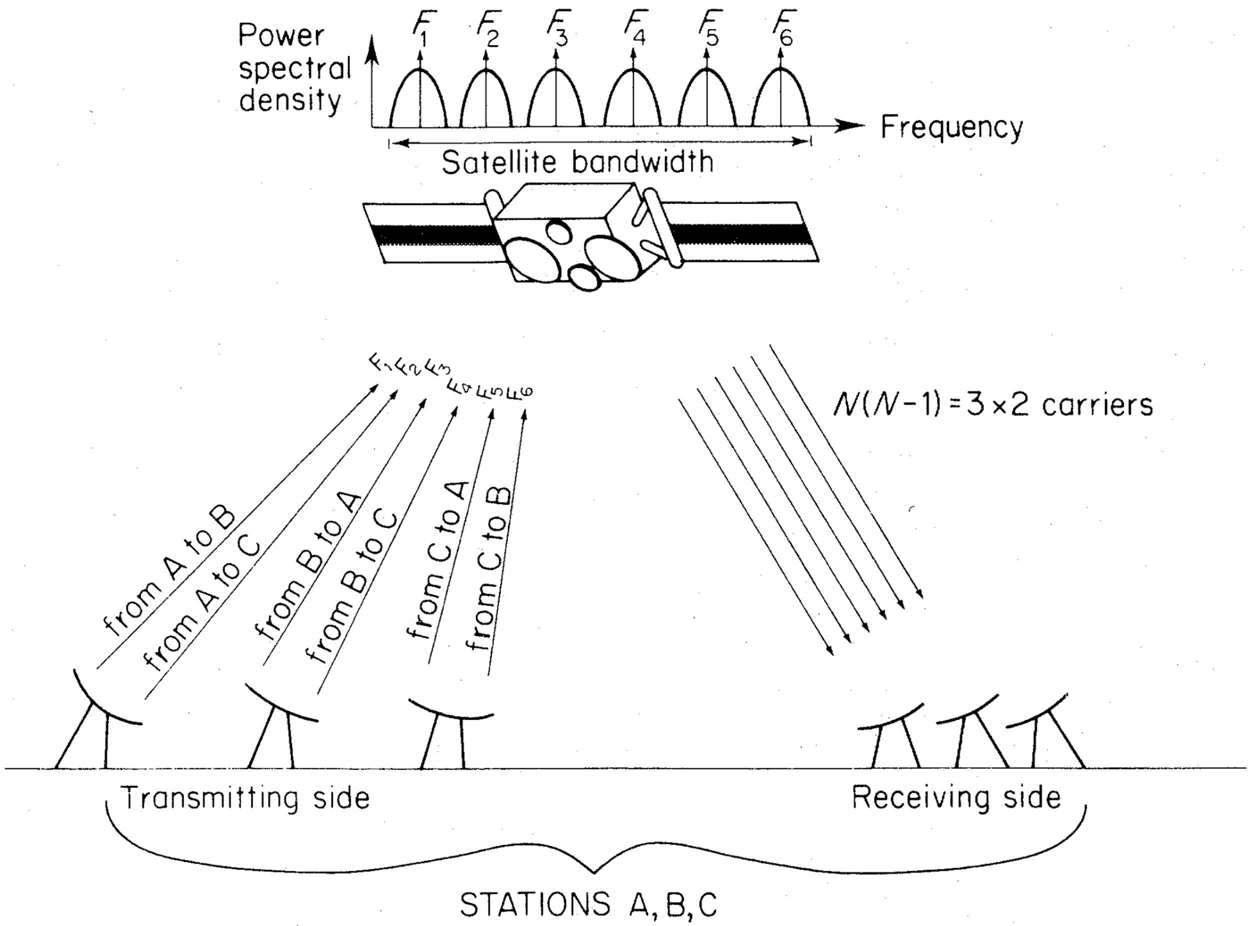


Frequency Division Multiple Access (FDMA)

- Sharing discipline of transparent satellite on-board repeater is in the frequency domain.
  - Various implementations: SCPL, SCPS, SCPC.
  - Problem: intermodulation (IM) among carriers on board.

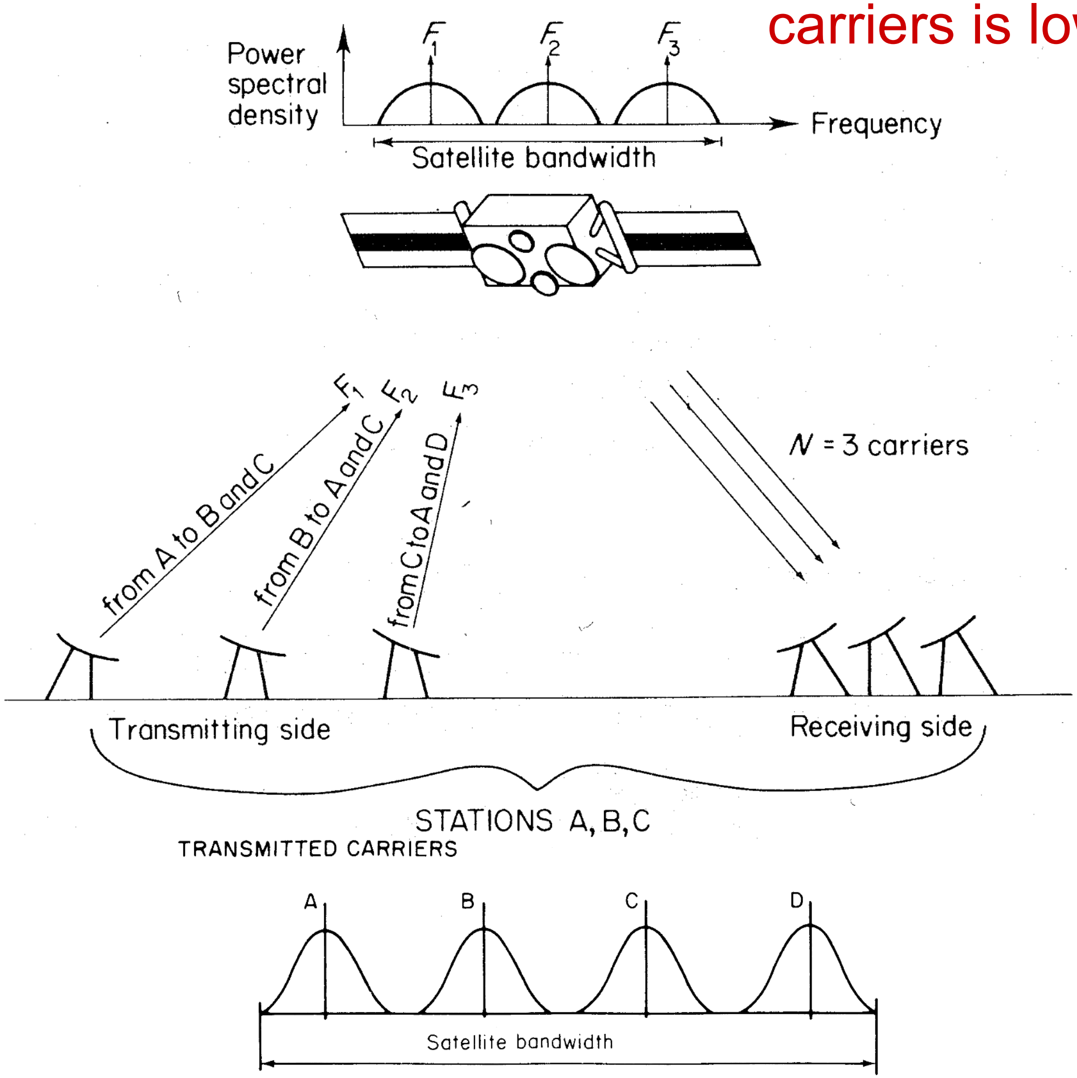
Single Carrier per Link (SCPL)

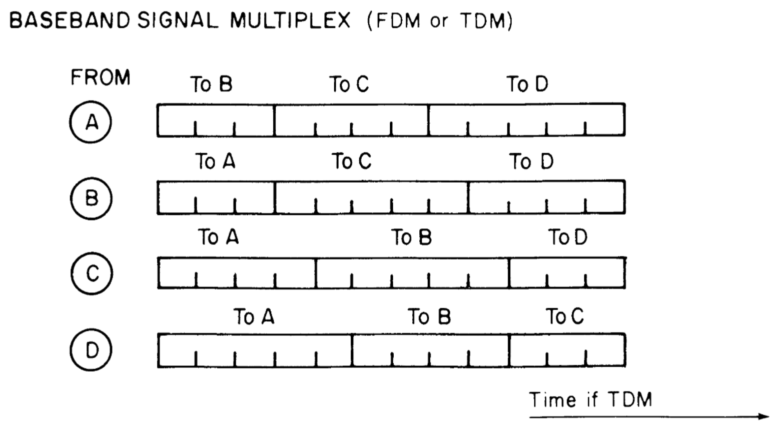
Each station is assigned a carrier for each link. In case of full two-way connectivity between N stations carriers are $N_c = N\,(N - 1) \cong N^2$. High IM.

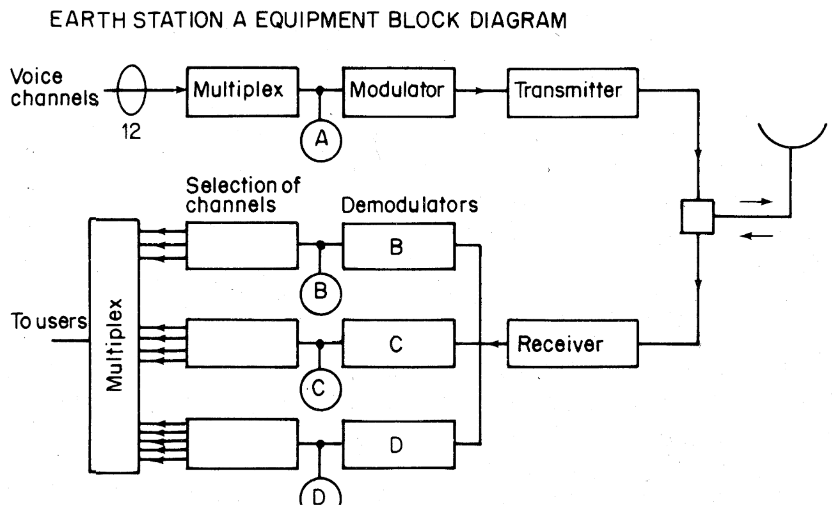


Single Carrier per Station (SCPS)

Each station is assigned a single carrier for all its links. The number of carriers is lower than SCPL, $N_c = N$. Lower IM.

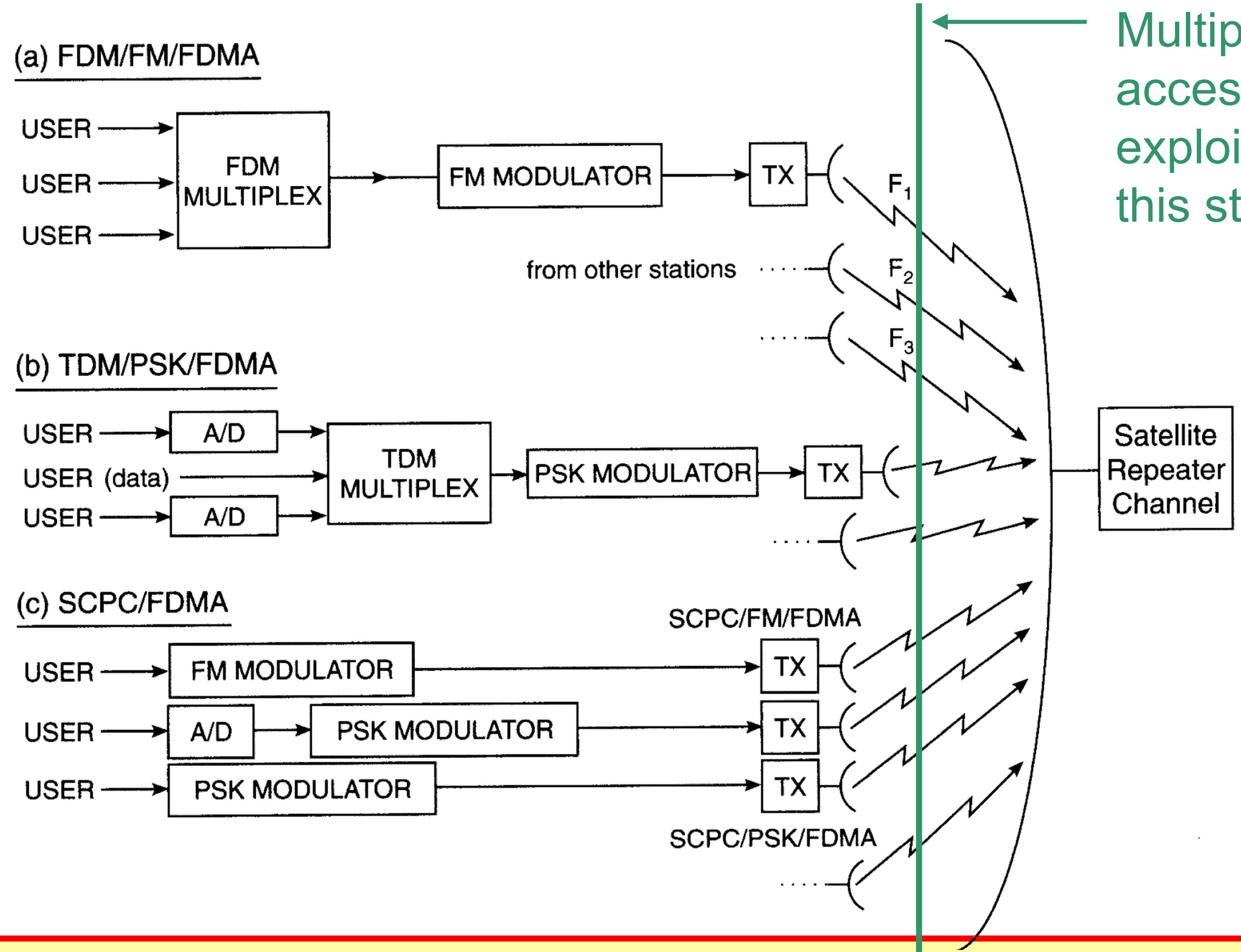






Single Channel per Carrier (SCPC)

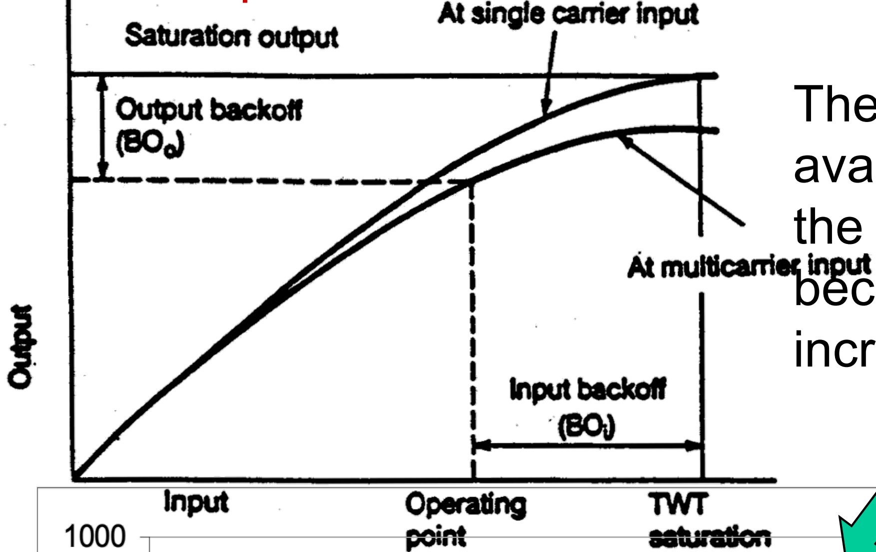
Each station is assigned a single carrier per channel. IM can be reduced through carrier switching techniques in idle periods. Flexible usage of resource.

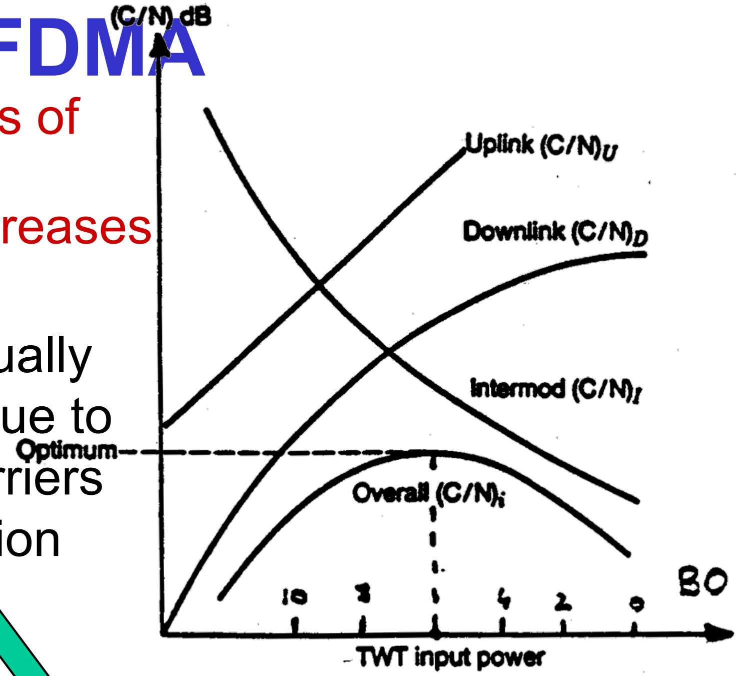


Multiple access exploited at this stage

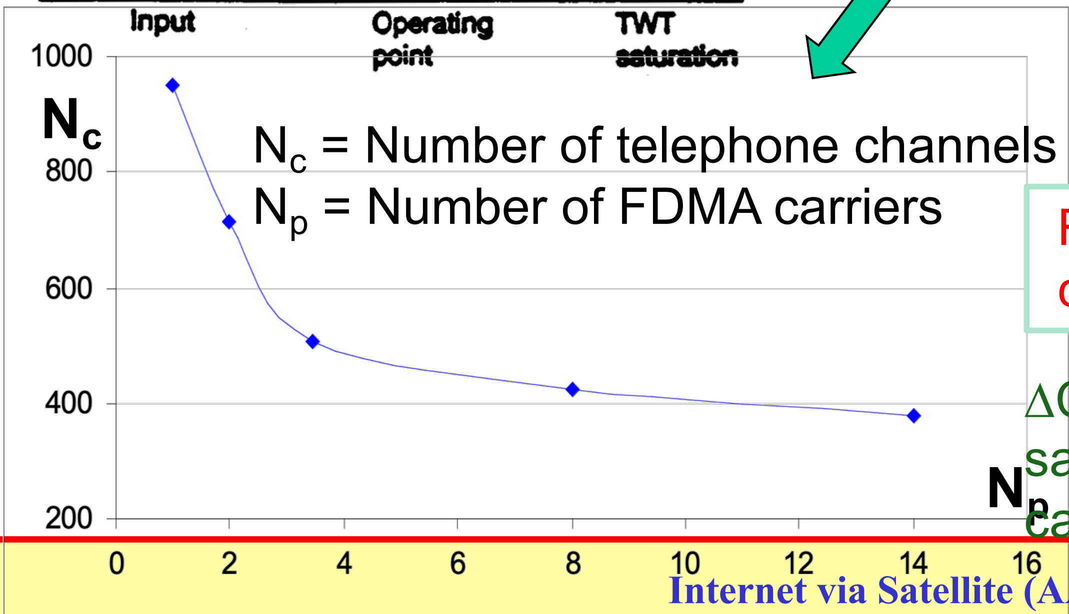
Intermodulation in FDMA

- Problem: intermodulation noise due to nonlinearities of equipment (amplifiers)
- The problem worsens as the number of carriers increases





The total capacity actually available is reduced due to the use of multiple carriers because intermodulation increases.



N_c = Number of telephone channels
N_p = Number of FDMA carriers

Relationship between channels and carriers

N_p	$\Delta C(\%)$
1	100
2	≅ 90
4	≅ 60
8	≅ 50
14	≅ 40

$\Delta C(\%)$ = fraction of satellite transponder capacity

Satellite Switched FDMA

- A beam bandwidth is divided into a number of frequency slots
- The number of FDMA carriers in a spot beam varies according to the Earth station traffic requirements within the beam
- Connectivity among spot beams is provided on board the satellite using either a static **microwave switch** or a **baseband switch**
- Fine channelization obtained using SAW or MSW filters
- Advantages
  - Simple network configuration
  - Low user earth station cost
- Disadvantages:
  - Multiple carrier transmission requires earth station HPA power back-off
  - It cannot operate with hopping beams
  - Flexible carrier bit rate assignment is difficult and complicates payload design
  - Dynamic network reconfiguration without loss of data is difficult (only static assignment is allowed)

OFDM (OFDMA) CONCEPT

- Starting issue: in case of frequency selective channels the aim can be to **not exploiting** or at least **simplifying equalization**.
- Concept: parallel transmission (FDM) that then becomes OFDM because waveforms are orthogonal.
- Characteristic: Modulation e demodulation can be implemented with FFT e IFFT. Thus, possibility to work directly and fully in digital format.

OFDM implementation

- The information to be transmitted is divided in a large number of subchannels at a lower bit rate
- Example broadcasting: the aim is to receive only a part of the total information (radio or TV)
- L transmitted programs (for example 8)
- Each program composed of M carriers (for example 4)
- In this way the carriers associated to a program have the maximum possible spacing ensuring the best independence conditions.
- Definitively the total number of carriers is N = ML
- A classical approach requires M matched filters at the receiver
- Alternative technique: considering a set of partially overlapped spectra but satisfying the first orthogonality criterium of Nyquist

OFDM implementation (2)

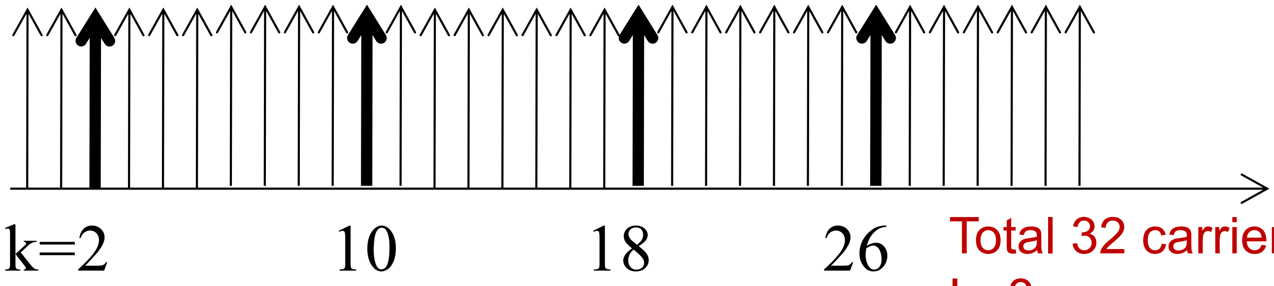
- $\{f_k\}$ set of carriers with $f_k = f_0 + k/T_s$ and $k = 0, \ldots, N-1$
- T_s symbol duration
- $\psi_{j,k}(t)$ base with $k = 0, \ldots, N-1$ and $j \in (-\infty, +\infty)$
- $\psi_{j,k}(t) = g_k(t-jT_s)$
- $g_k(t) = \exp(2\pi j f_k t)$ for $0 \le t \le T_s$ and 0 elsewhere
- for $j \ne j'$ or $k \ne k' \Rightarrow$

$$\int_{-\infty}^{+\infty} \psi_{j,k}(t)\psi^*_{j',k'}(t)\,dt = 0 \qquad \int_{-\infty}^{+\infty} \left\|\psi_{j,k}(t)\right\|^2 dt = \mathrm{T_s}$$

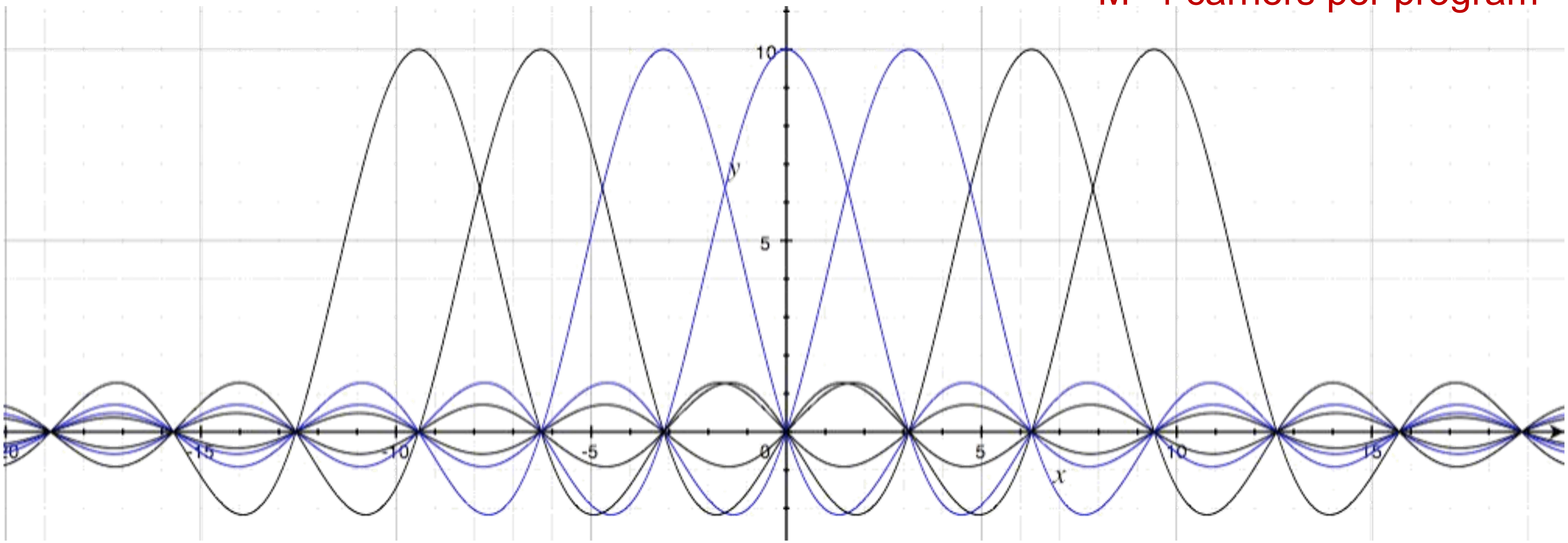
- The emitted signal can be represented by a set of complex coefficients $\{C_{j,k}\}$, thus the OFDM signal becomes

$$x(t) = \sum_{j=-\infty}^{+\infty}\sum_{k=0}^{N-1} C_{j,k}\psi_{j,k}(t) \qquad C_{j,k} = \frac{1}{T_s}\int_{-\infty}^{+\infty} x(t)\psi^*_{j,k}(t)\,dt$$

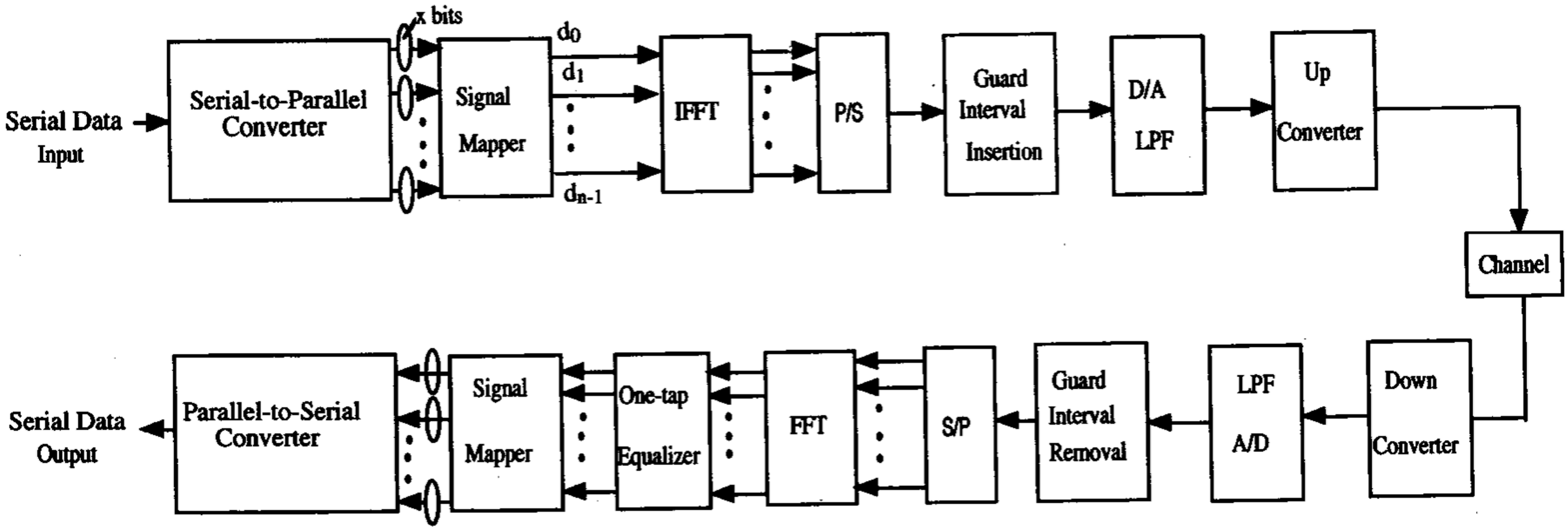
OFDM Carriers



Total 32 carriers
L=8 programs
M=4 carriers per program



FFT BASED OFDM SYSTEM



OFDM signal Demodulation with partial FFT

- It is possible to use FFT algorithm.
- Moreover, since we must get just one of the L programs it is convenient to use a partial algorithm.
- First, the received signal is sampled in $[0, T_s]$.

$$y(t) = \sum_{k=0}^{N-1} H_k C_k e^{j2\pi f_k t} \quad 0 \le t < T_s;\ T = T_s/N$$

- Then, the signal is shifted at the frequency $f_0 + 1/2T$

$$\tilde{y}(t) = e^{-j\pi t/T} \sum_{k=0}^{N-1} H_k C_k e^{j2\pi kt/NT}$$

- At this stage the signal is sampled at the frequency $f_e = 1/T$

$$y_n = \frac{(-1)^n}{N} \tilde{y}(nT) \qquad \tilde{y}(nT) = (-1)^n \sum_{k=0}^{N-1} H_k C_k e^{j2\pi kn/N}$$

- If $y_n = \frac{1}{N} \sum_{k=0}^{N-1} Y_k e^{j2\pi kn/N}$ and $Y_k = H_k C_k$ $\quad Y_k = \sum_{n=0}^{N-1} y_n e^{-j2\pi kn/N}$

$\{y_n\}$ = IDFT di $\{Y_k\}$

Partial FFT calculation

- To calculate Y_k implies to exploit a DFT over N points in an interval ≤ T'_s.
- This operation can be executed using the well known FFT algorithms:
  - Decimation in frequency (DIF)
  - Decimation in time (DIT)
- If the algorithm is executed over all the N points, the two approaches have the same complexity (number of operations)
- If the algorithm is executed over a part of the N points (M for example), DIT is more efficient.

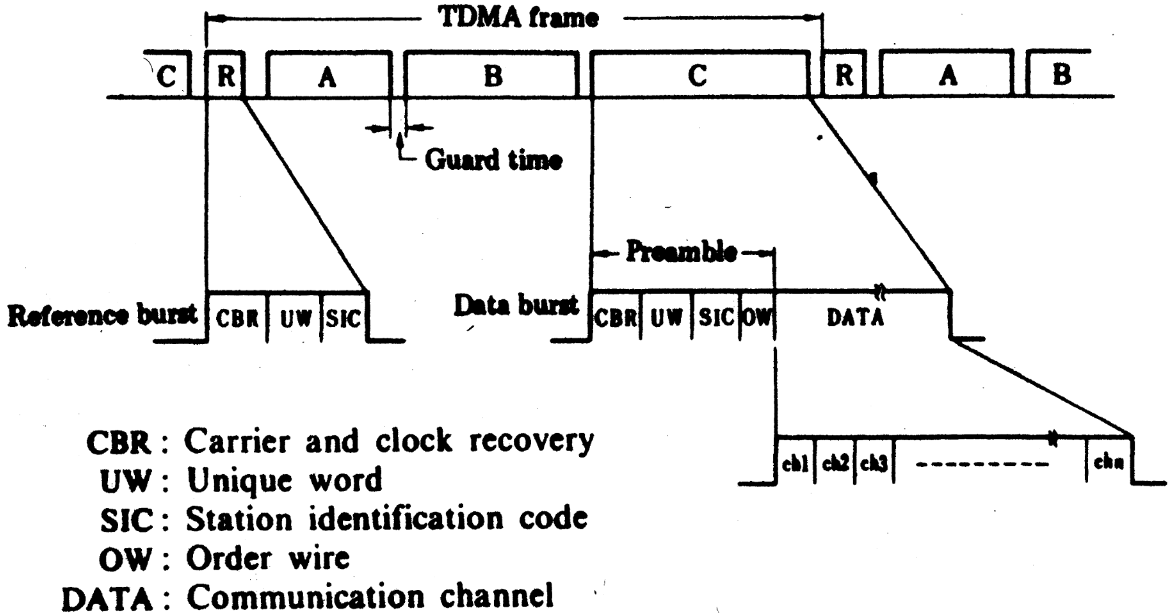
Partial FFT examples

N	256	512	1024	2048	4096
M	16	32	64	128	256
DIT	80	176	384	832	1792
DIF	256	528	1088	2240	4608
$(N/2)\cdot Log_2N$	1024	2304	5120	11264	24576

Time Division Multiple Access (TDMA)

- The sharing discipline of the satellite repeater is in the time domain.
  - Time is cyclically assigned to stations for their transmissions according to a "**frame**" structure.
  - Problem: **synchronization** of transmissions so that packets do not collide on board (each user experiences different propagation delay and, in some case, it is also variable during time).
  - Appropriate for digital. For analogue signals A/D conversion and time compression (processing delay) are needed.
  - Flexible in accommodating different needs in terms of:
    - ❑ Source data rates,
    - ❑ Different Quality of Service (QoS) requirements,
    - ❑ Bandwidth on Demand (BoD)

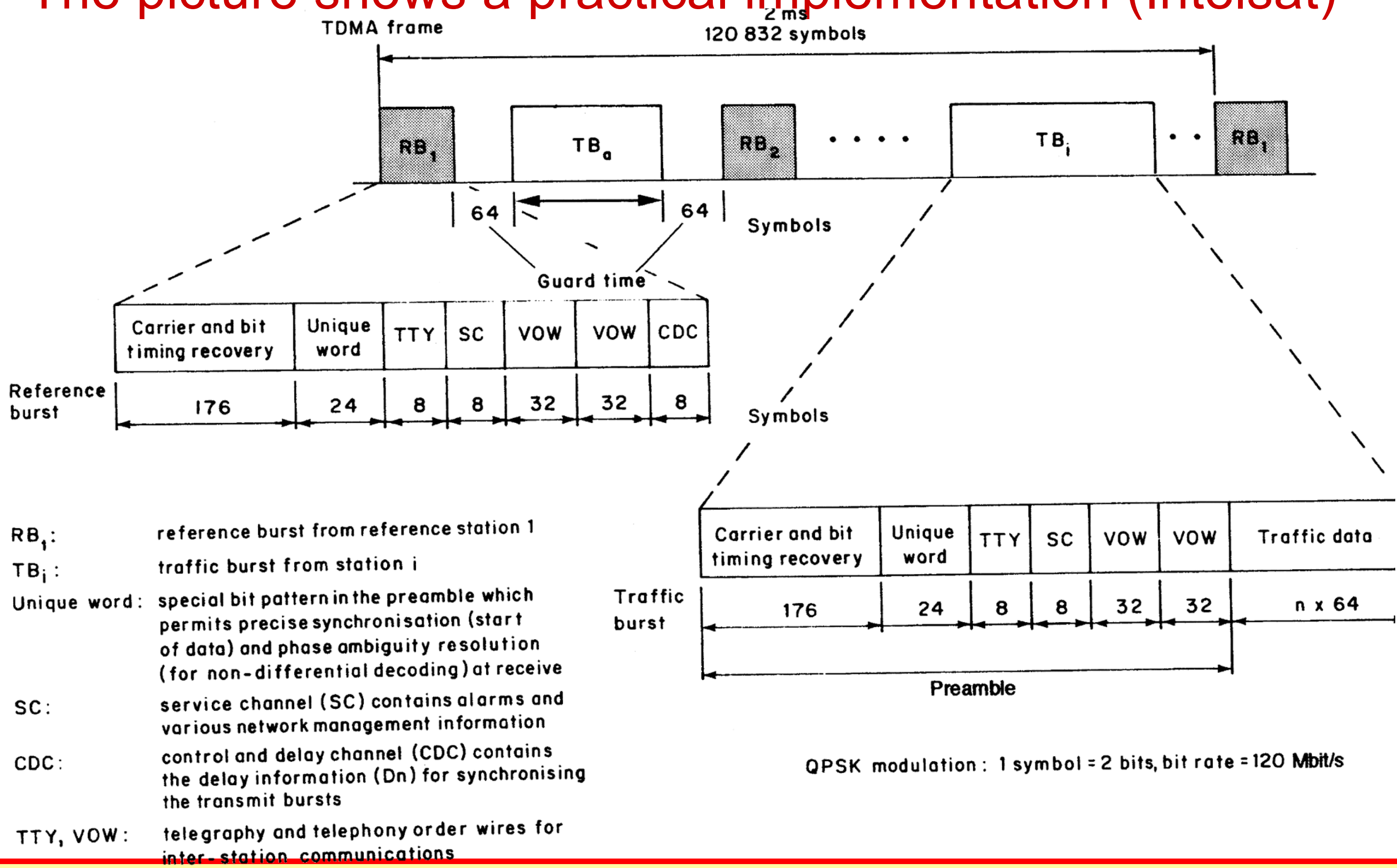
TDMA Frame Structure



- A reference burst is located to identify the beginning of the TDMA frame (generally **two** such bursts are provided by two different stations for redundancy)
- Signal packets contain a Carrier and clock (Bit timing) Recovery (CBR) field, for carrier phase/frequency synchronization and bit-timing, a Unique Word (UW) field for packet phase synchronization, as well as "payload data"
- A guard time is provided between the packets to avoid garbling on board the satellite (due to imprecise knowledge of distances)

TDMA frame structure (2)

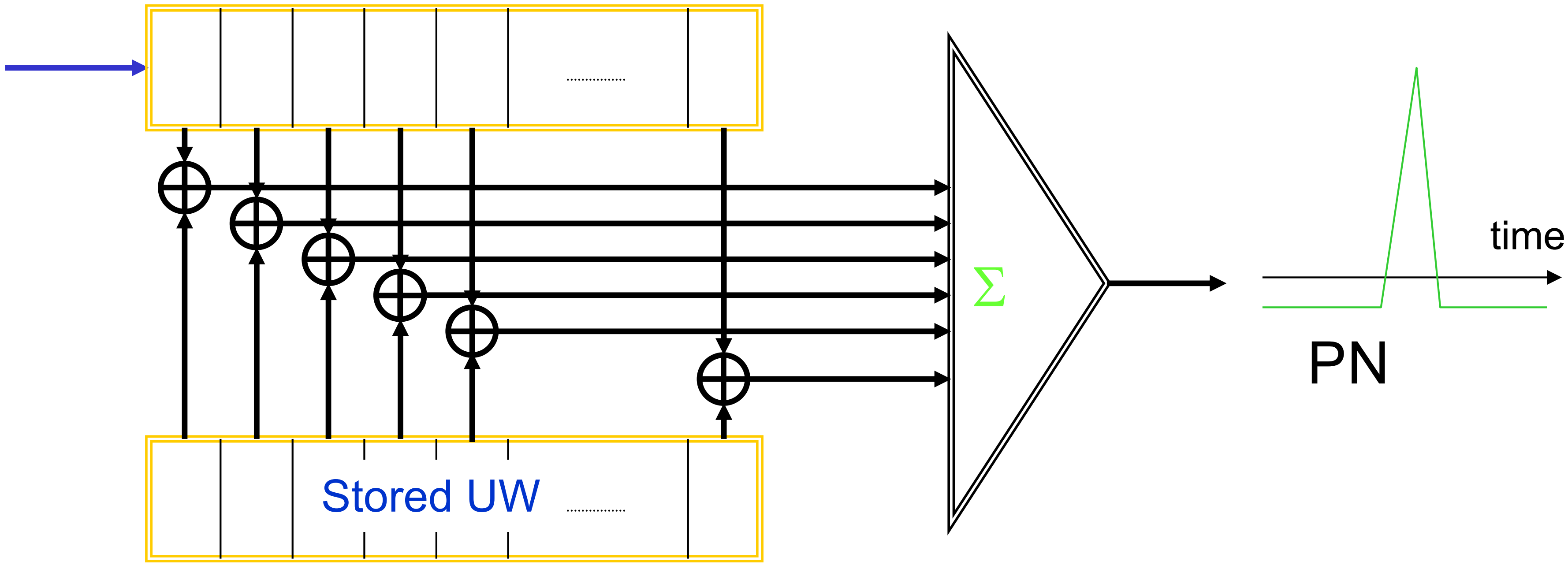
- TDMA is a concept not a standard
- The picture shows a practical implementation (Intelsat)



Header functions

- To synchronize demodulator local oscillator to the received carrier
  - Bit sequence which provides a constant carrier phase for rapid **carrier recovery**
- To synchronize the receiving station bit detector clock to symbol rate (**bit timing**)
  - After carrier recovery a sequence of bits with alternating opposite phases
- To identify the start of a burst
  - Unique word
- Transfer of service messages

Unique Word in TDMA transmissions



- The **Unique Word** is a predefined pseudo-noise pattern with good auto-correlation and cross-correlation properties
  - High detection probability
  - Low false alarm probability
  - Provides frame time reference
- Permits precise synchronization and phase ambiguity resolution (for non differential decoding)

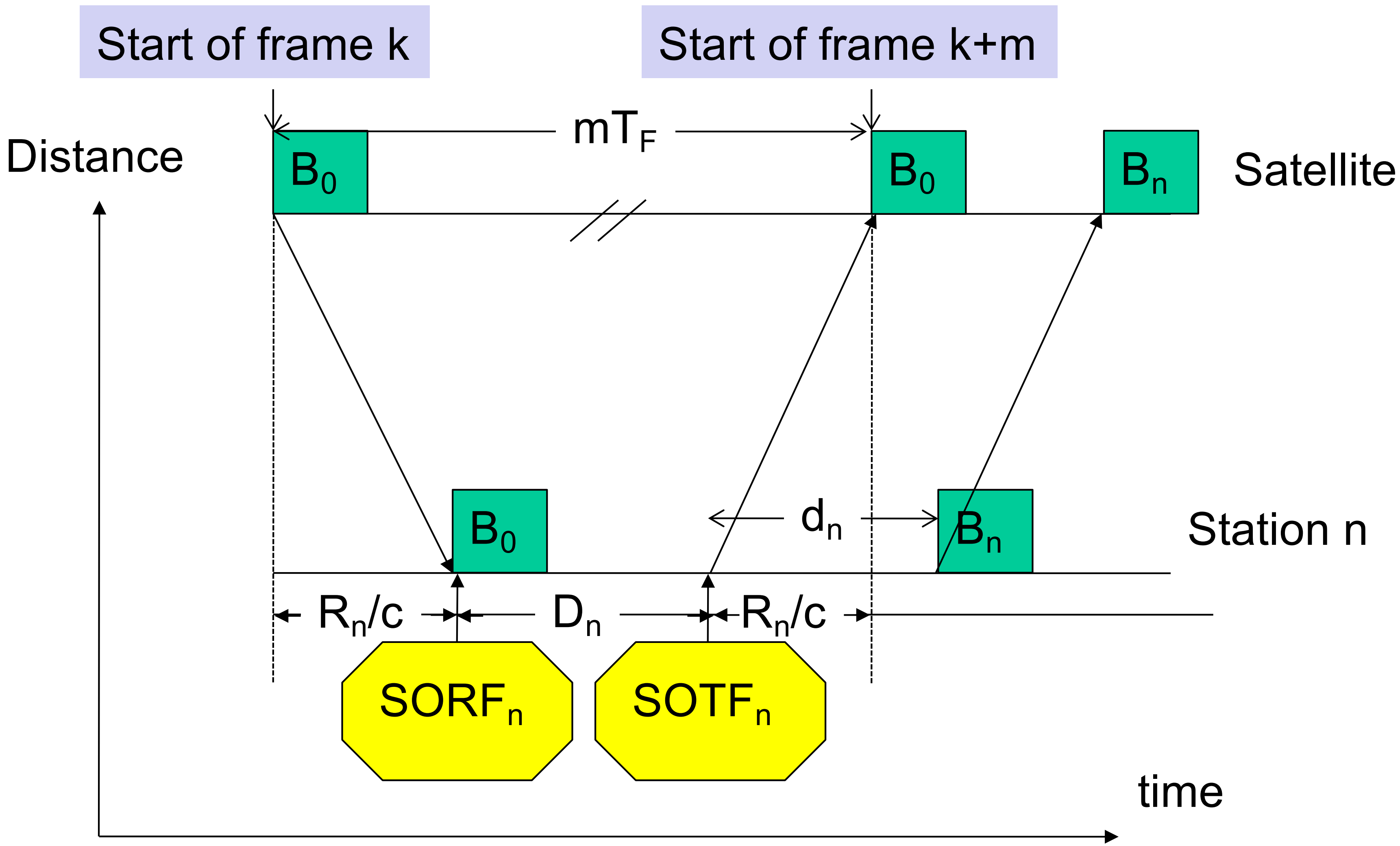
Synchronization

- Accurate synchronization needed to avoid burst overlap in the frame caused by
  - different propagation time among stations (max 19.6 ms for GEO satellite)
  - residual movement of a geostationary satellite (250 μs)
  - Doppler effect (20 ns/s)
- Each station *n* must transmit its burst so that it arrives at the satellite with a delay d_n after the reference burst
- Burst Time Plan (BTP) ➔ set of d_n

Synchronization (2)

- **$SOTF_n$**
  - start of transmit frame
  - instant at which the station n should transmit to position its burst in the time slot occupied by the reference burst
  - Positioning is correct when station *n* transmits with a delay d_n after $SOTF_n$
- **$SORF_n$**
  - Start time of the receiving frame
  - start time frame k at satellite + propagation time in the downlink R_n/c
- Start time of frame (k+m) = $SOTF_n$ + propagation time in the uplink R_n/c
- $SOTF_n(k+m) - SORF_n(k) = D_n = mT_F - 2R_n/c$
  - $D_n>0 \Rightarrow m$ I $mT_F > 2R_n/c$ for station n the furthest from the satellite
- Station n determines $SORF_n$ by detecting the unique word and then transmit D_n+d_n later

Synchronization exploitation



Closed loop synchronization

- Station n determines the position of its burst in the frame by measuring the time between detection of the unique word of the reference burst and the detection of the unique word of its own burst
- $d_{0n}(j)$ value observed on reception of the frame having used $D_n(j)$ to determine the transmission time
- $e_n(j) = d_{0n}(j) - d_n$ = burst position error
- $D_n(j+1) = D_n(j) - e_n(j)$
- Correction every round trip propagation time

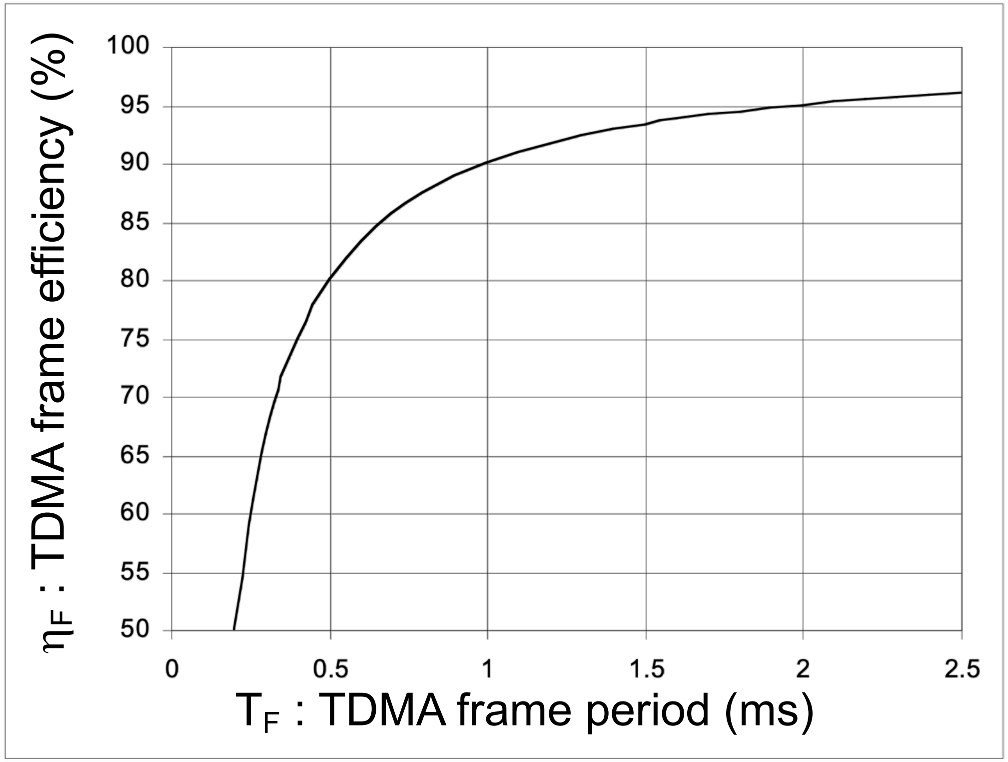
Open loop synchronization

- Used in case of assignment on demand
- Knowledge of satellite position and calculation of R_n
- The reference station transmits sequentially to all stations the relative D_n
- Correction every 2 round trip times (1 to measure RTT + 1 to transmit to reference station) + calculation time + distribution time = several seconds

Acquisition of synchronization

- Performed each time a station asks to enter
- Closed loop
  - Transmit low power burst
  - Observes its position
  - Corrects it
- Open loop
  - Receives D_n from reference station
  - Transmits at $D_n + d_n$ after receiving the reference burst

TDMA Frame Efficiency



- High η_F asks for high T_F
- Disadvantage:
  - a) delay due to buffering
  - b) need for large memories
- Compromise:

  $T_F \cong$ few milliseconds $\Rightarrow \eta_F$=95%

Frame duration

$$T_F = 2T_R + \sum_{i=1}^{M} T_{Pi} + (M+2)T_G$$

Frame efficiency

$$\eta_F = 1 - \frac{T_X}{T_F}$$

where:

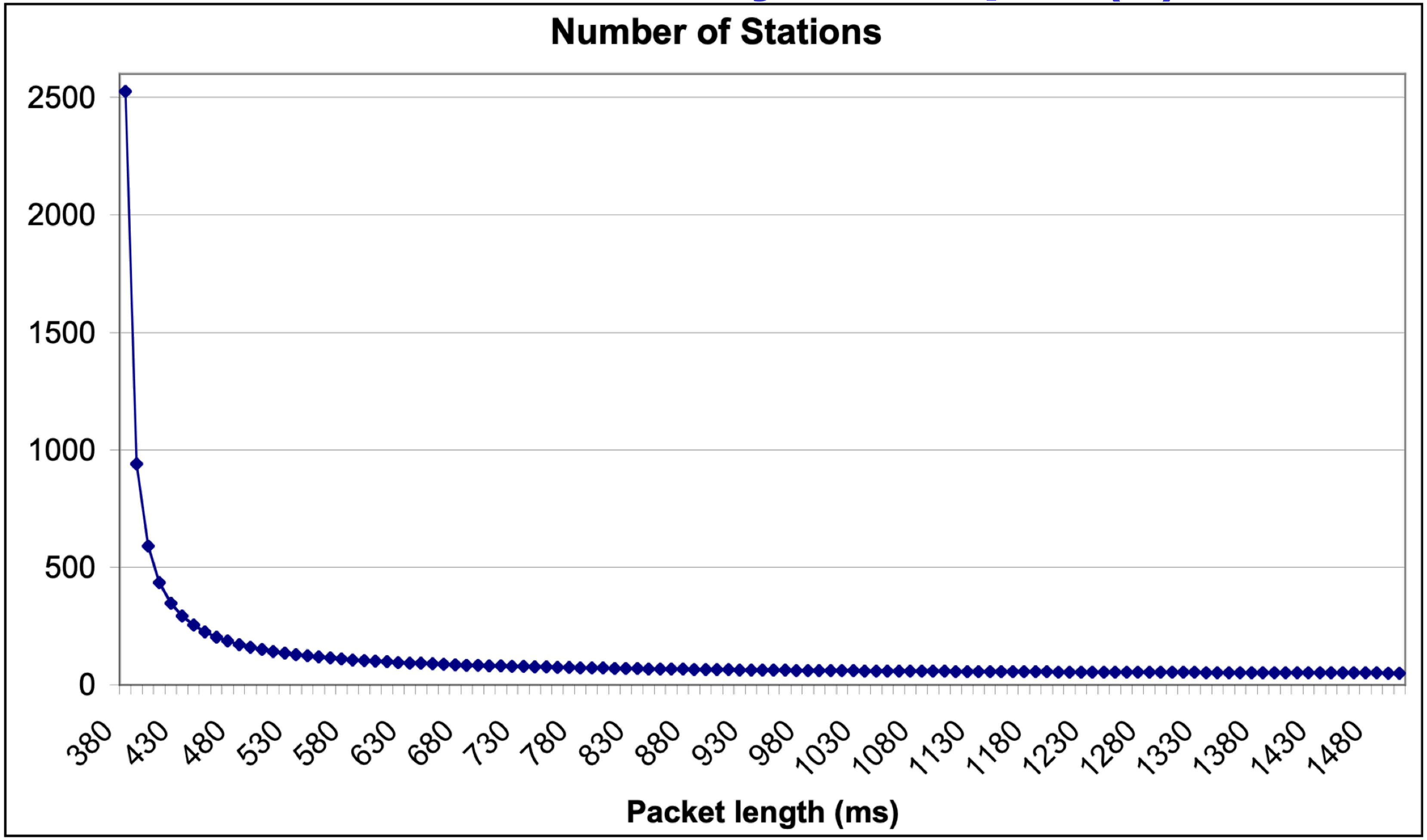
- T_F = frame period
- η_F = frame efficiency
- T_R = reference burst duration
- T_{pi} = i^{th} user transmission period
- T_G = guard time
- M = Number of users
- T_X = Overall time not used for "payload data"

Efficiency improvement

To improve efficiency of the TDMA frame it is possible to act on some (not all) parameters:

Parameter	Action	Remark
T_F= frame period	Increase	a) delay due to buffering b) need for large memories
T_R= reference burst duration	Decrease	Usually already minimum required
T_{pi}= i^{th} user transmission period	Increase	With the same T_F less users ⇒ less guard times
T_G= guard time	Decrease	More sophisticated synchronization required
M=Number of users	Increase	Also number of guard times increases but the contribution of the reference bursts duration is divided over more users

Frame efficiency example (1)



$\eta_F = 0.95 \quad T_p = T_R \quad T_G = 19.7$ ms

Satellite-Switched TDMA

- The space switch allows dynamic interconnection among up-link and down-link spot beams according to the switch state configuration stored in the on board control memory
- Capable of providing multicast connectivity
- It provides interconnection by the use of a
  - **microwave switch matrix (MSM)** or
  - **baseband switch matrix (BSM)**
- Simple on board hardware
- Use of hopping beams allowed
- Dynamic network reconfiguration easily achievable without loss or traffic

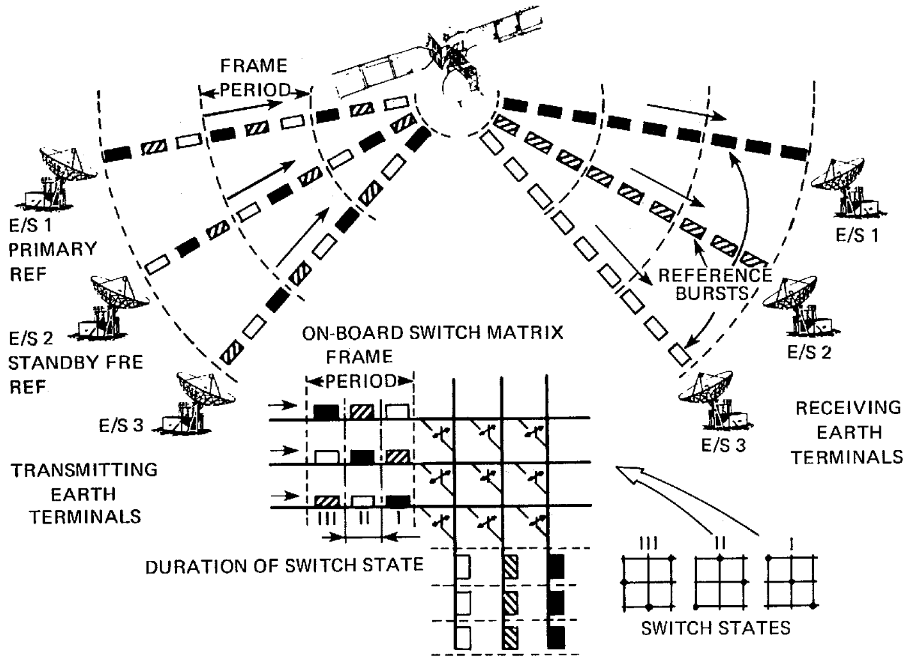
MSM states

- MSM dynamically switches up-beams with down-beams within each TDMA frame according to a preprogrammed sequence of switch states
- The possible states:
  - No connect
  - Multiple single up beam to single down beam
  - Partial broadcast
  - Full broadcast
- The number of different single point switch states is N!

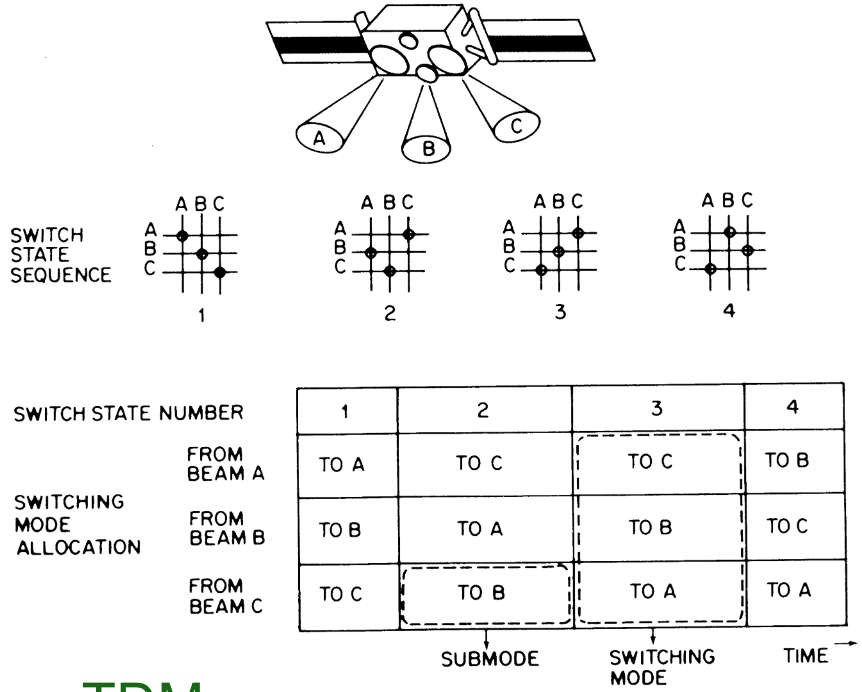
SS-TDMA

Access: TDMA

On board switching strategy



Microwave switch matrix in a SS-TDMA operation



Distribution: TDM

SS-TDMA advantage

- Terminals share a common carrier in the time domain
- The number of up and down conversion chains needed to implement is significantly reduced (vs FDMA)
- Enhance beam to beam interconnectivity
- Allow adjustment of beam to beam traffic capacity in very small increments
- Static interconnection
  - the number of transponders increases as the square of the number of beams
- Dynamic switching
  - the number of transponders increases linearly
  - eliminates the need for stations to perform transponder hopping to gain access to the various down-beams of a multibeam system
- Traffic accommodation
  - In TDM the earth station forms a TDMA burst or a TDM frame by multiplexing terrestrial channels having the same destination beam
  - If the earth station has traffic to multiple destinations, it may need to form multiple TDMA bursts or TDM carriers
  - In case of on board cross connect it may not be necessary

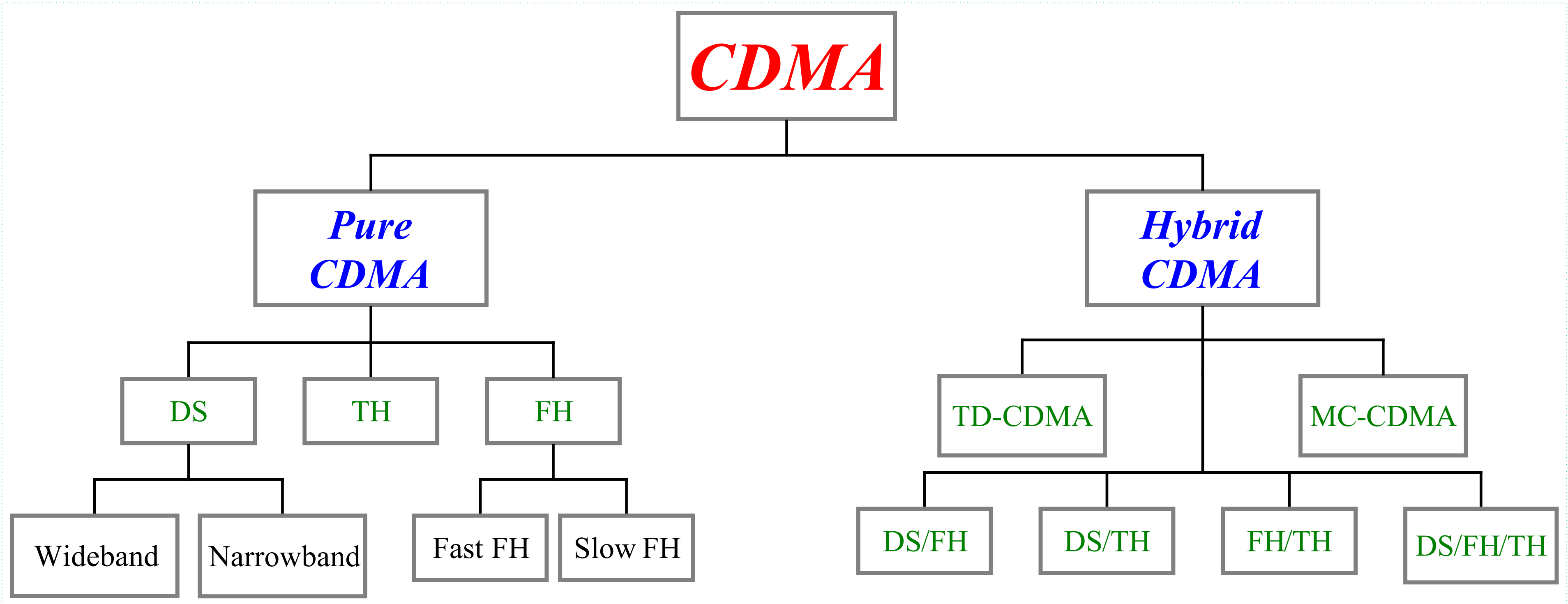
Code Division Multiple Access (CDMA)

- Satellite repeater sharing discipline is neither in frequency nor in time but in the "code domain".
  - Orthogonal or quasi-orthogonal. When "quasi-orthogonal" an interference noise raises proportional to the number of other users.
  - Interference noise is avoided only if codes are orthogonal and signals are perfectly synchronous on board.
- Different implementations:
  - ❑ Direct sequence (DS-CDMA)
  - ❑ Frequency hopped (FH-CDMA)
- Orthogonal vs. Non-orthogonal
  - – Definition: $$\int c_i(t)\cdot c_j(t)dt \begin{cases} = 0 & i \neq j \\ \neq 0 & i=j \end{cases}$$
    Where $c_i(t)$ is the spreading code of i-th user and $c_j(t)$ is the spreading code of the j-th user
  - – Orthogonality depends on proprieties of selected spreading codes and synchronization between different user signals
  - – Orthogonal CDMA provides higher capacity

Why?

CDMA Alternatives (2)

- Pure CDMA vs. Hybrid CDMA

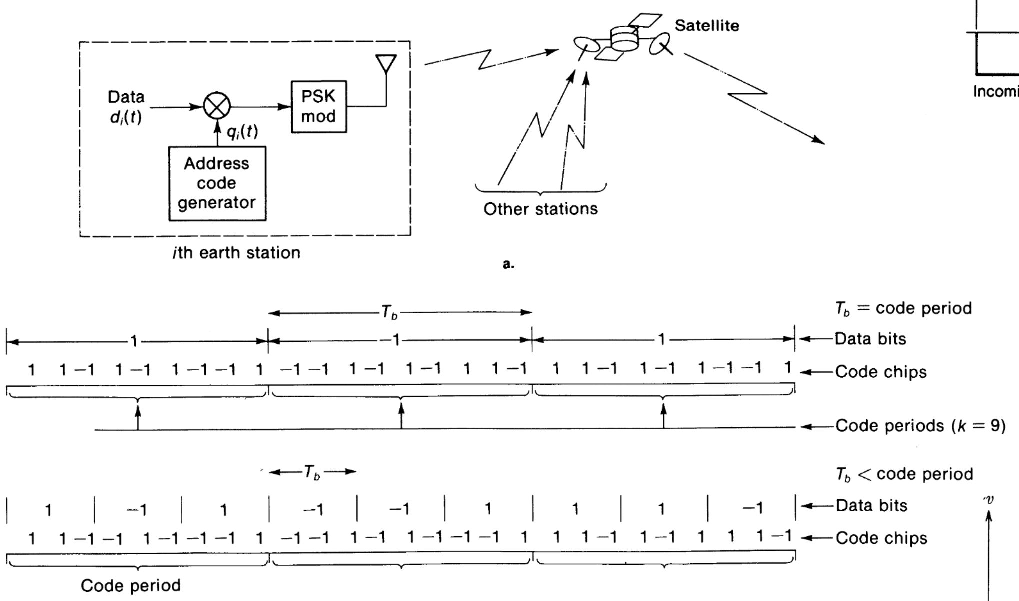


Legend:
DS = Direct Sequence
TH = Time Hopping
FH = Frequency Hopping

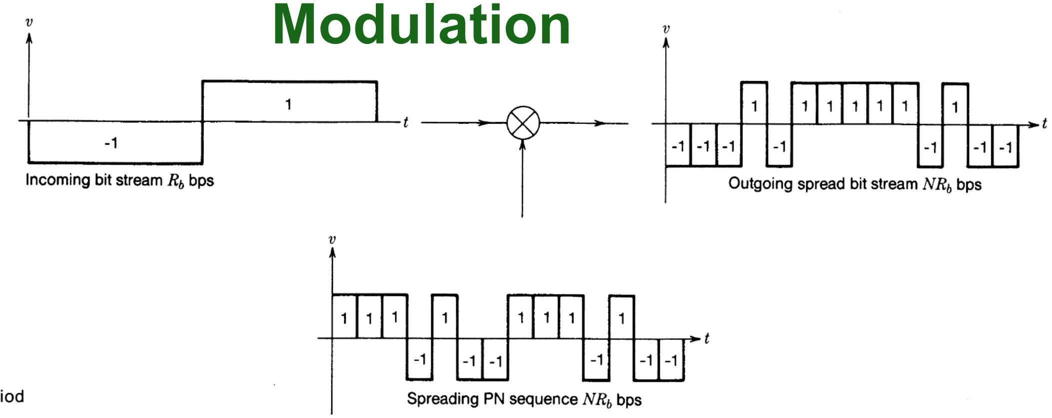
TD = Time Division
MC = Multi Carrier

DS-CDMA Modulation and Demodulation

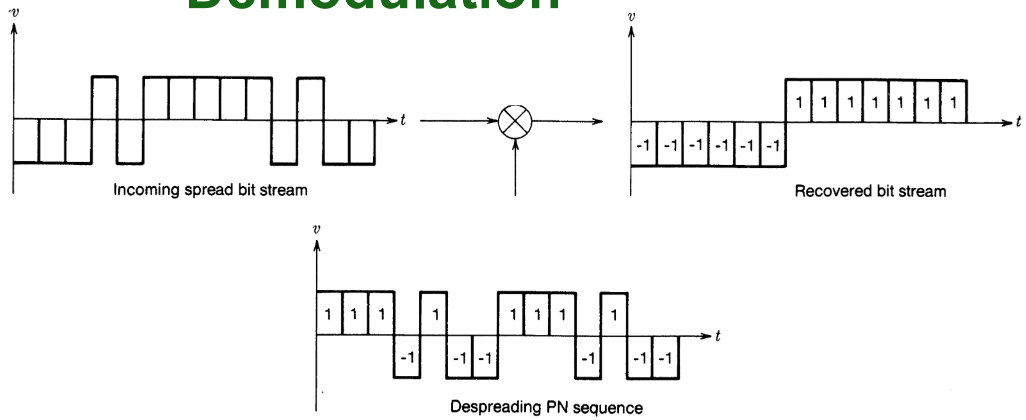
Concept



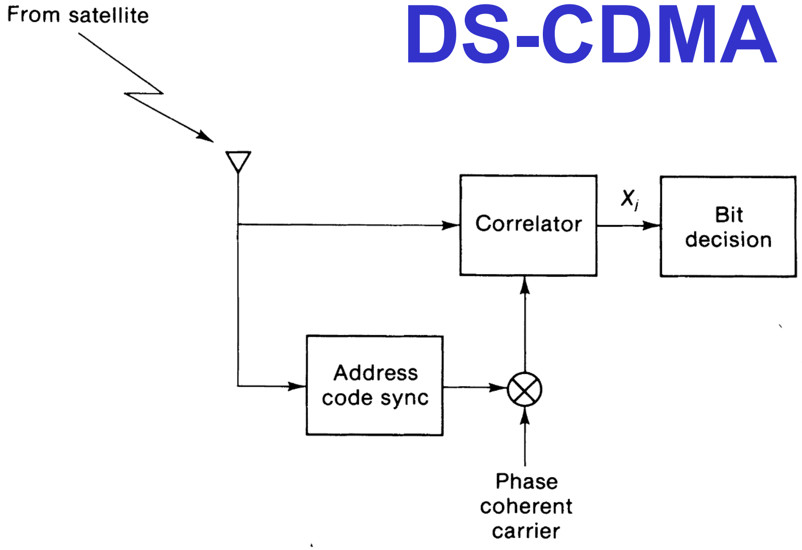
Modulation



Demodulation



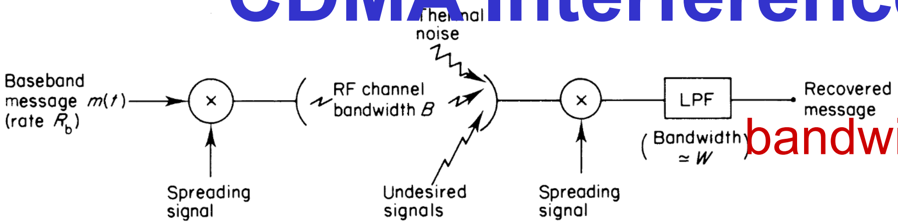
DS-CDMA Receiver Architecture



Correlator aims at comparing the local signal replica with the incoming signal. The output of the correlator is provided to a decision circuit: decision is affected by noise only if the CDMA signal is orthogonal and perfect sync is achieved, or by noise and interference otherwise.

If the signal is also coded, after the bit decision there is the decoder.

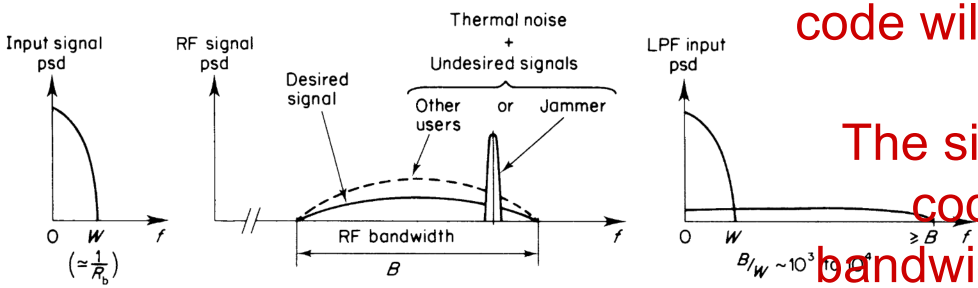
CDMA Interference Rejection Capability



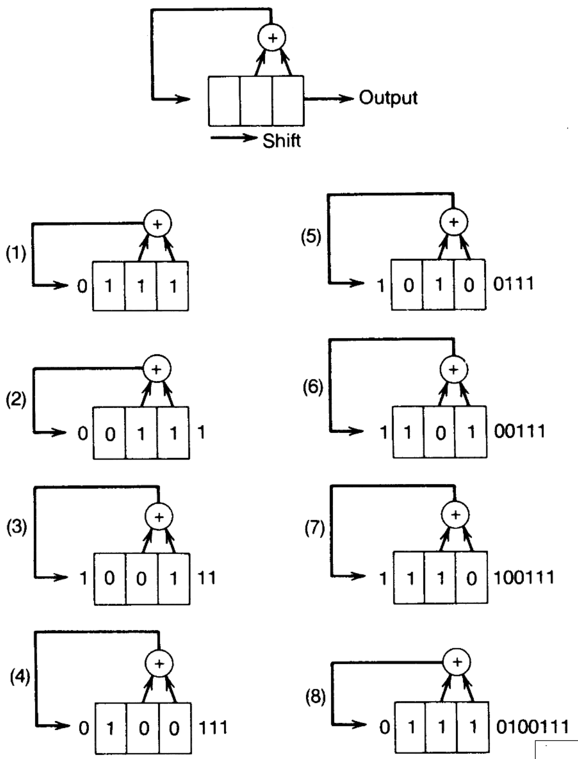
Each signal is spread over a radio frequency bandwidth much larger than the information bandwidth (spread spectrum).

The signal recovered with the proper spread spectrum code will be demodulated and its bandwidth will return to be the information bandwidth.

The signal recovered with different spread spectrum code (other user) will not be demodulated and its bandwidth will remain the radio frequency bandwidth.



MLR Sequences for Quasi-synchronous CDMA



Maximum Length Register (MLR) sequences are widely used due to their ease of implementation and for some nice statistical properties:

- number or 0 and 1 differing for only one
- equal probability of runs of equal sequences
- good autocorrelation properties

Figure shows the mechanism to generate a MLR code
In addition, there is a well established theory to identify sequences of any acceptable length

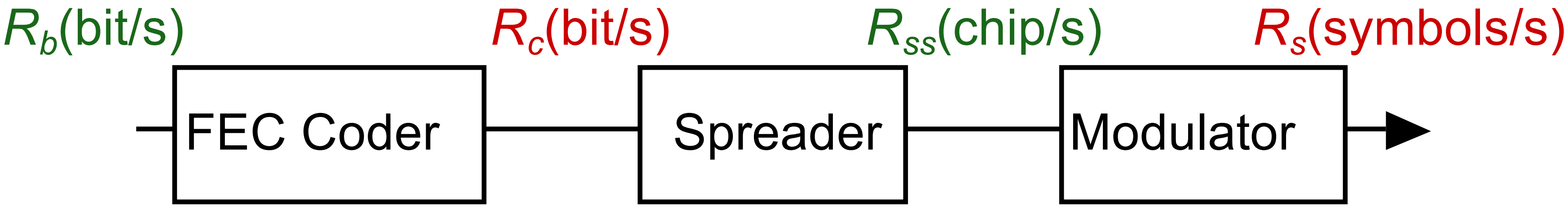
Orthogonal CDMA Codes

An example of a set of orthogonal codes: Walsh-Hadamard (WH) codes

$$C(0) = 0 \qquad C(1) = \begin{bmatrix} C(0) & C(0) \\ C(0) & \overline{C(0)} \end{bmatrix} \qquad C(n) = \begin{bmatrix} C(n-1) & C(n-1) \\ C(n-1) & \overline{C(n-1)} \end{bmatrix}$$

where $\overline{C(n-1)}$ is 0 if C(n) is 1 and vice versa.

CDMA: definitions



$r = R_b/R_c$ = FEC code rate < 1

$g = R_{ss}/R_b$ = spread-spectrum code rate >> 1

$R_s = R_{ss}/ \log_2 M$ = symbol rate (baud)

M = number of transmitted symbols

- U = number of users (i.e. earth stations)
- N_0 = thermal noise power density
- E_s = received energy per symbol
- E_b = received energy per bit
- g = R_{ss}/R_b (spreading factor)

Calculation of E_b/N_0

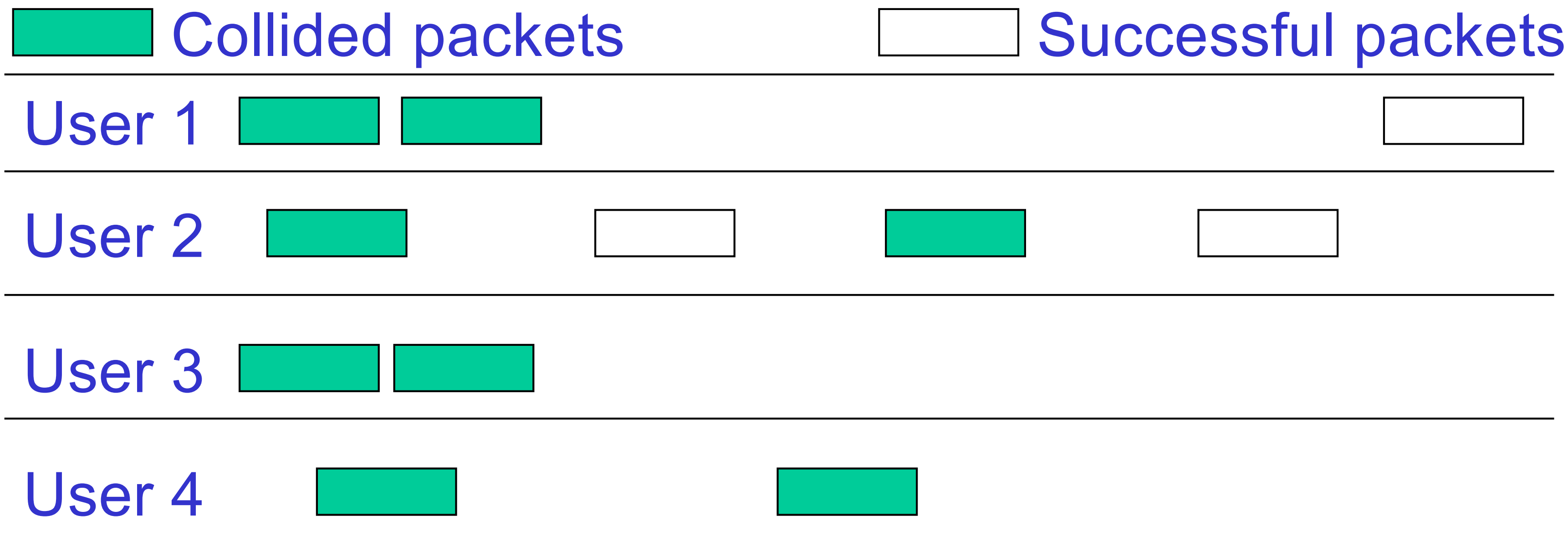
- Overall noise + interference power density: $N_0' = N_0 + I_0 = N_0 + (U-1)E_s$
- Ratio of symbol energy to overall noise density: $\dfrac{E_s}{N_0'} = \dfrac{E_s/N_0}{1+(U-1)E_s/N_0}$
- Relationship between E_b and E_s: $E_s R_s = E_b R_b = C$ (C = average power)
- Ratio of bit energy to noise density: $\dfrac{E_b}{N_0} = \dfrac{E_b/N_0'}{1-(U-1)(\log_2 M/g)E_b/N_0'}$
- Assumes non orthogonal spread spectrum codes
- $P_{error} = f\,(E_b/N_0\,,\,r)$

CDMA suitability for satellite communications

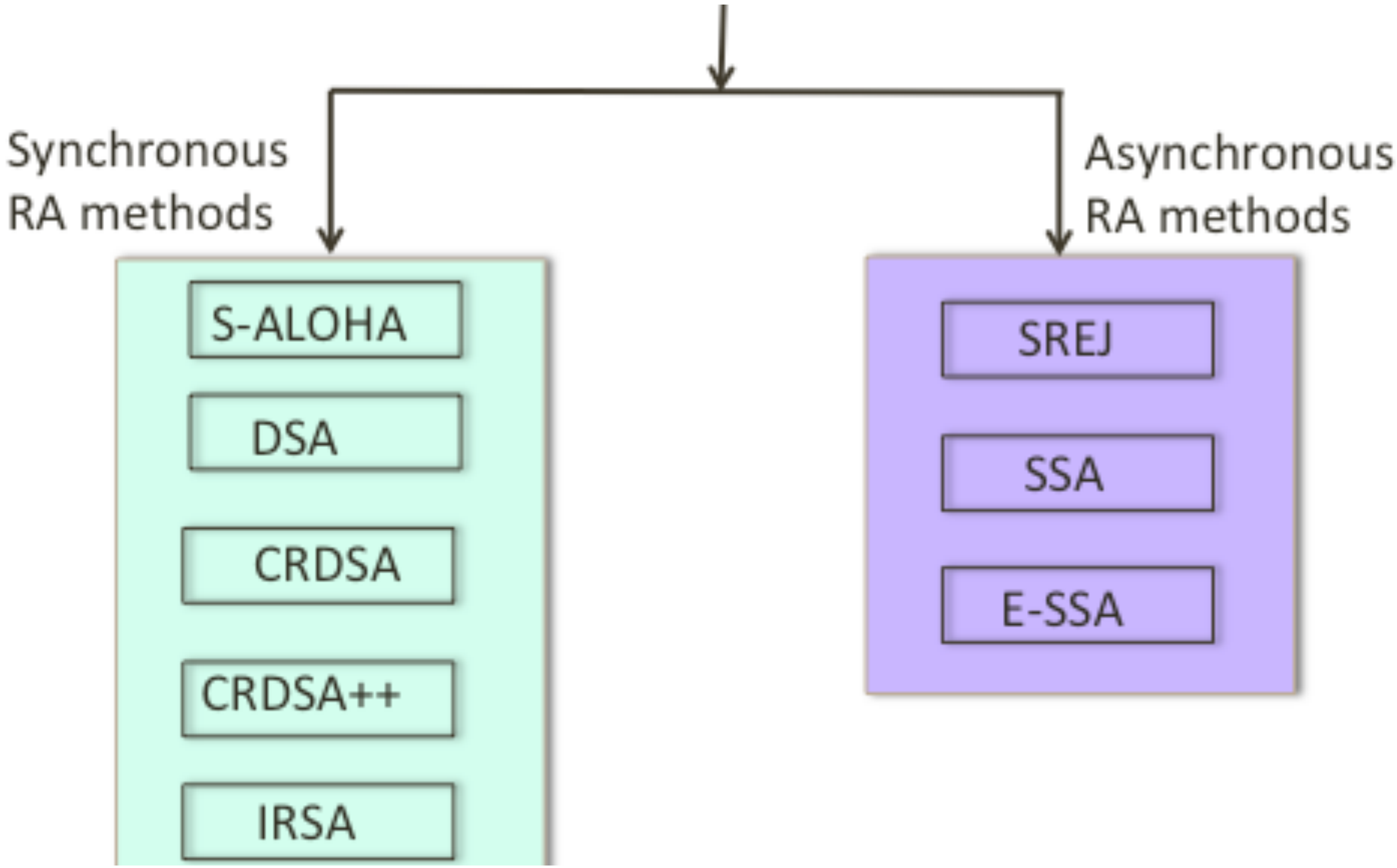
- Higher capacity than TDMA
- Full frequency reuse
- Satellite soft handover
- Satellite path diversity exploitation
- Fading effect mitigation
- Applicability of interference mitigation techniques (MUD)
- Flexible support of a wide range of services
- Provision of accurate user positioning
- Simplified satellite antenna design compatible with adaptive antennas

Random Access Protocols (RAP)

- Each station transmits a packet as soon as available
  - No coordination among stations: packets may collide
  - Every station "sees" its transmission: collision are detected after RTT that for satellites can be high,
    - up to 270 ms in case the management is on board
    - up to 540 ms in case the management is on ground
  - Collided packets are retransmitted after a random delay
- Performance: throughput, delay



Random Access classification



Asynchronous RAP: Aloha

- Efficiency
  - Assumptions:
    - Poisson distributions (parameter λ packets/s)
    - Packets of equal length (τ s)
  - Throughput: fraction of transmitted packets that on average can pass the channel successfully
  - Normalized channel packet rate $\xi = \lambda\tau$
  - Normalized channel traffic rate G (in general $G \geq \xi$)
  - ξ=1 perfect synchronization (end of a packet $\equiv$ start of the next $\Rightarrow$ G= ξ) $\Rightarrow$ normalized channel packet rate
  - The start times of the packets plus packet retransmission: Poisson process
  - Low traffic load $\xi \approx 0$ few collisions $\Rightarrow$ $G \approx \xi$
  - High traffic load $\Rightarrow$ many collisions $\Rightarrow$ $G > \xi$
  - All traffic-load conditions, **throughput** = G times the probability of a transmission being successful = $\mathbf{GP_0}$
  - Fraction of packets successfully transmitted is:

$$\xi = G \cdot e^{-2G}$$

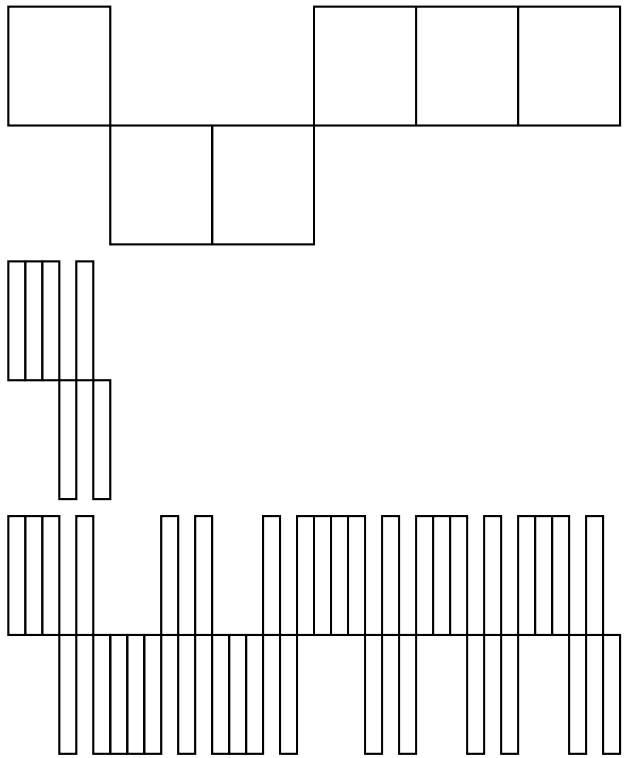
    where G is the offered traffic load (normalized channel capacity)
  - Maximum throughput is 18%

Asynchronous RAP: Selective-Reject Aloha

- Collision (overlapping) may be partial
- To avoid the loss of both entire packets they can be segmented
- In case of collision only the overlapped sub-packets are lost
- Overhead increases
- Total efficiency increases

CDMA Aloha

- Use of spread spectrum and CDMA in Aloha
- Each packet is spread according to a different PN (Pseudo Noise) code
- The effect of collision is weakened



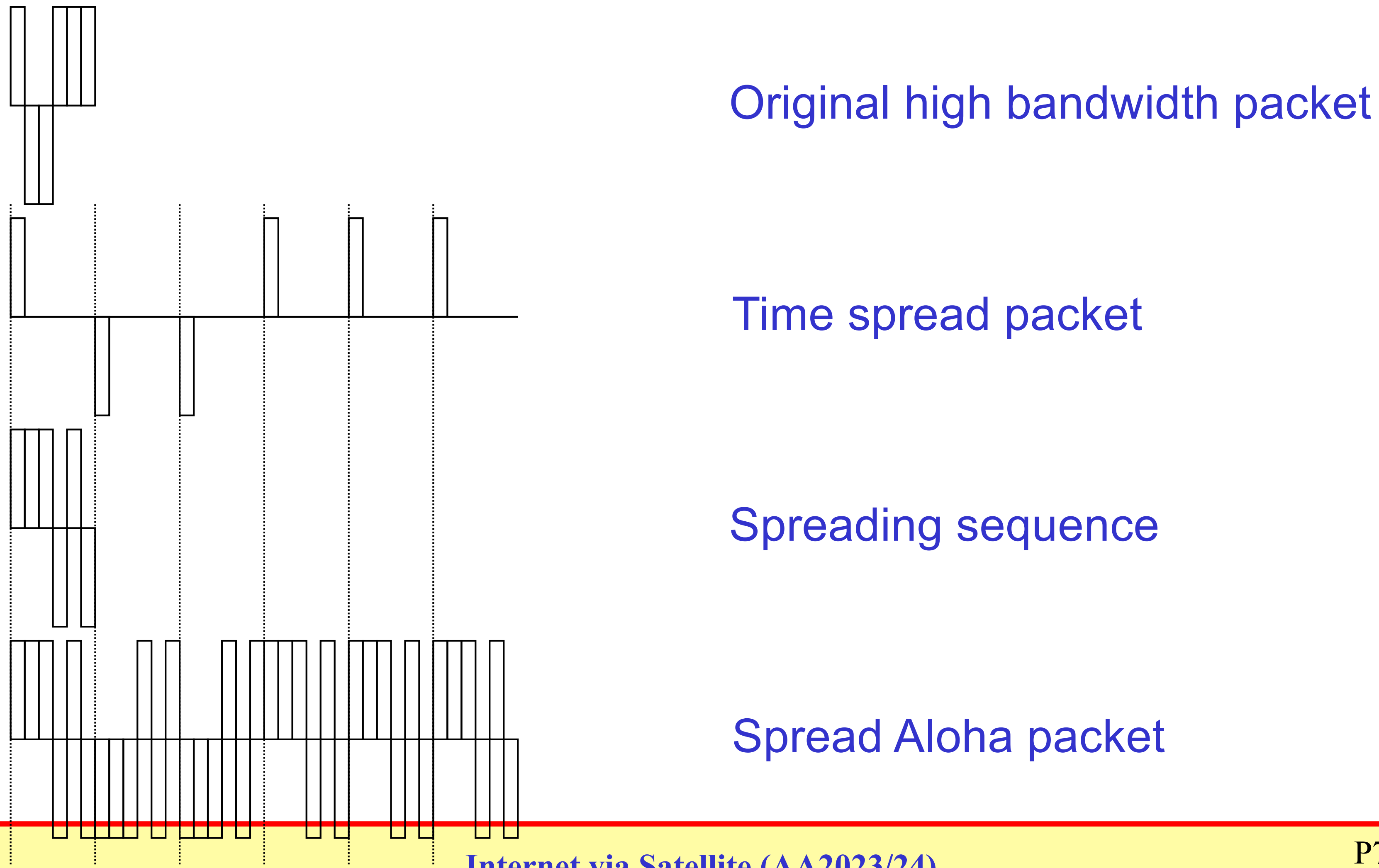
Original low bandwidth packet

Spreading sequence

CDMA packet

Spread Aloha Scheme

- Packets generated at high bandwidth
- Spread in time to make stretched packets
- Stretched packets multiplied by a spreading sequence



Comparison Spread vs CDMA Aloha

- Identical final packets
- CDMA: low bandwidth packet spread in frequency
  - Use of non linear processing
- Spread: high bandwidth packet spread in time
  - The energy per information symbol in the original and in the spread packets is identical
  - The same energy spread over an interval longer than in the original packet
  - Terminal at much lower transmitter power level allowed

Enhanced SSA (E-SSA)

- Return Link Multiple Access Messaging Scheme characterized by:
  a) Spread Aloha Random Access with powerful FEC to minimize the packet detection energy;
  b) Open loop Signal-to-Noise plus Interference Ratio (SNIR) Driven Uplink Packet Transmission Control (SDUPTC) to transmit only when the channel is good enough and to optimize gateway received power packet unbalance for optimum SIC (Successive Interference Cancellation) performance;
  c) Packet Oriented SIC at the gateway, named Enhanced Spread Spectrum Aloha (E-SSA), to further boost the MAC performance also in the presence of power unbalance with affordable complexity;
  d) optimized link margin for optimum MAC throughput.

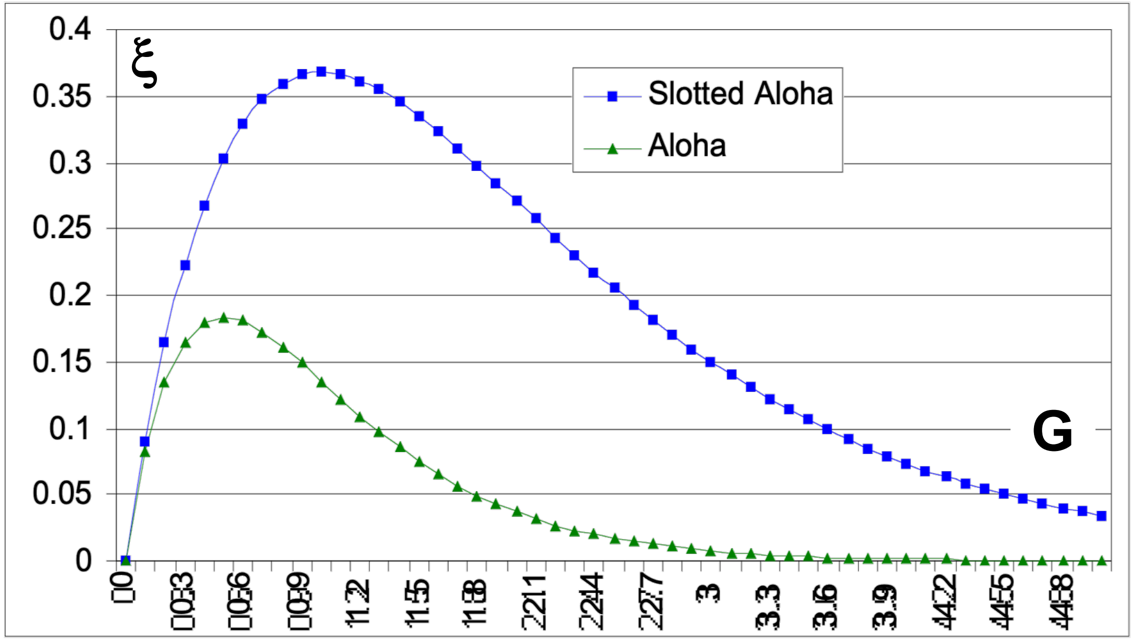
Synchronous RAP: Slotted Aloha

- Slotted Aloha: like Aloha, but packets transmitted in time slots
  - Same assumptions as Aloha in terms of channel control
  - No other new traffic generated during a slot
  - Throughput is higher:

$$\xi = G \cdot e^{-G}$$

  - Maximum throughput is 36%

Performance Comparison of two Aloha Systems



$\xi = G \cdot e^{-2G}$ **Aloha**

$\xi = G \cdot e^{-G}$ **slotted Aloha**

Assumptions

- Packets length is τ seconds
- Packets make up a Poisson point process with parameter λ packets/s
- Normalized channel packet rate is $\xi=\lambda\tau$ (an ideal case with full channel occupancy without overlap has $\xi=1$)
- Start times of packets plus retransmissions is still Poisson distributed
- Normalized channel traffic rate (capacity), G, refers to packets plus retransmissions input to the channel (in general $G\geq\xi$)

Diversity Slotted Aloha (DSA)

- Each packet (also called burst) is transmitted twice over the MAC frame
- It provides a slight throughput gain over S-ALOHA;
- Drawback: for the same peak transmission power of the S-ALOHA scheme, the average transmitted power of DSA is doubled.
- The multiple copies can be either transmitted simultaneously on different frequency channels (frequency diversity) or they may be transmitted on a single high-speed channel, but spaced apart by random time intervals (time diversity).

Contention Resolution Diversity Slotted ALOHA (CRDSA)

- Provides a more efficient use of burst repetition.
- The improvement with respect to both SA and DSA is due to the adoption of Interference Cancellation (IC) for resolving collisions.
- CRDSA generates two replicas of the same burst at random time instants within a frame (as in DSA) instead of only once (as in SA).
- While the driver for DSA is to slightly enhance the SA performance by increasing the probability of successful packet transmission at the expense of increased RA load, CRDSA is designed to resolve most of the DSA packet contentions.
- Burst collisions are cleared up through an iterative Interference Cancellation (IC) approach that uses frame composition information from the replica bursts.
- The incoming baseband frame samples are stored in the gateway demodulator memory to enable iterative signal processing. By scanning the memory, decodable packets are identified and canceled jointly with their replicas. The memory scan is repeated few times to solve the maximum number of packet collisions.
- The main CRDSA advantages lie in the improved packet loss ratio and reduced packet delivery delay versus channel load jointly with a much higher operational throughput compared to SA and DSA.

CRDSA++

- Two main enhancements
  a. an optimized number of packet repetitions (2 in CRDSA, 3-5 in CRDSA++);
  b. the exploitation of the received packets' power unbalance to further boost the RA performance.
- Throughput can be as high as T=0.5 packets/slot for a packet loss ratio of 10^{-5}. This performance, is obtained by repeating four times the same packet in each frame at each transmission instance instead of just 2, under equal power conditions.

CRDSA-IRSA Irregular Repetition Slotted ALOHA (IRSA)

- Each burst is transmitted ℓ times within the MAC frame, where the repetition rate ℓ varies from burst to burst according to a given probability distribution.
- CRDSA can be seen as a special case of IRSA, where the repetition rate is fixed to $\ell = 2$.
- The IRSA approach works as follows:
  - for each transmission, the user adopts a variable repetition rate, which is picked according to a given distribution $\{\Lambda\ell\}$, i.e. for a generic packet ℓ replicas are transmitted within the MAC frame with a probability $\Lambda\ell$.

Coded Slotted ALOHA (CSA)

- The burst a generic user wishes to transmit in the MAC frame is first split into segments and these segments are then encoded through a local packet-oriented code prior to transmission.
- At the receiver side, iterative interference cancellation combined with decoding of the local code is performed to recover from collisions.
- It generalizes the Irregular Repetition Slotted ALOHA (IRSA) technique.

Demand Assignment Systems

DAMA MAC target

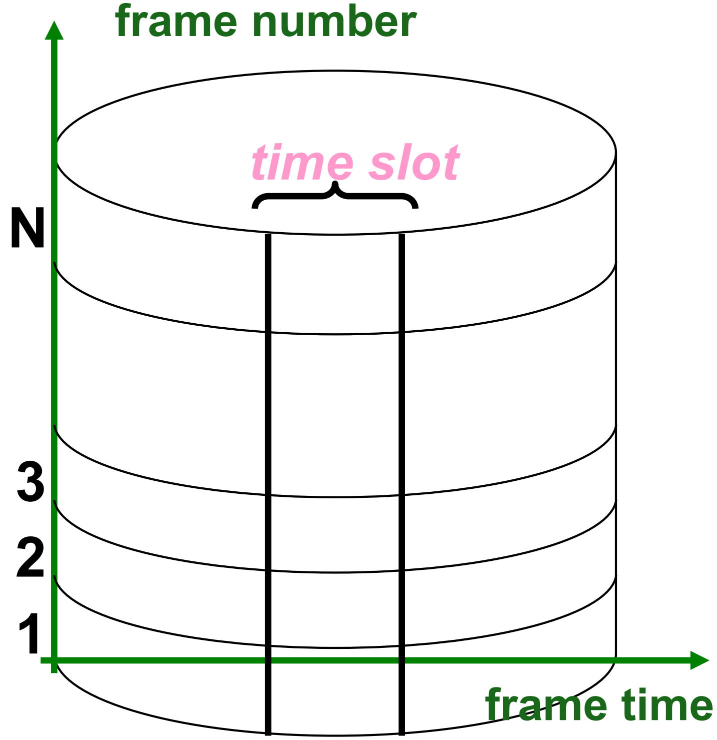
- To maximize the utilization of satellite resources
- To fulfill QoS requirements of the supported applications
- To improve efficiency and performance in case of **random, unpredictable, variable** traffic (FAMA inefficient, RA low performance)

Implicit reservation

- A source occupies a certain slot until its transmission is over

Explicit reservation

- A source occupies a certain slot for a given amount of time



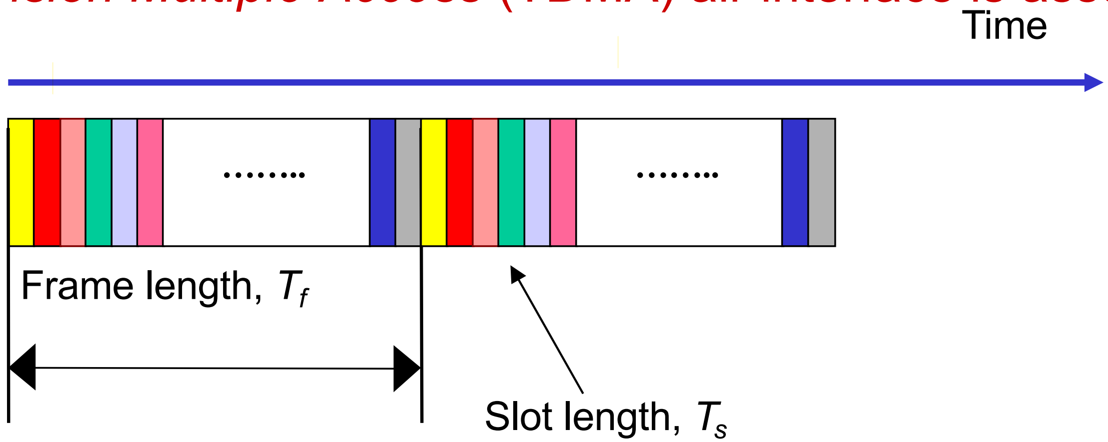
- Request messages allocated in separate subframes or combined with data packets (piggybacked)
- Contention is limited to access times
- At steady-states it virtually works as a TDMA or FDMA system

Demand Assignment based on FDMA

- **SPADE** (**S**CPC **P**ulse-code-modulated multiple-**A**ccess **D**emand-assignment **E**quipment) used on Intelsat IV
- Part of the capacity (transponder of 36 MHz) segmented in the frequency domain
- 160 kHz is reserved to *Common Signaling Channel* (CSC) which is accessed in *TDMA* to manage channel allocation
- CSC divided in 20 units of 50 ms each, in turn slotted in 50 slots 1 ms each allocated to a specific ground station (max 1000).
- When a ground station has to send data, it picks at random a channel. If the channel is unused it is allocated to the station (and the others are precluded) until the station sends the deallocation signal in the CSC.
- If a collision occurs the stations will try again later.
- Additional required processing for the demand assignment.

Demand-Assignment based on TDMA

- A *Time Division Multiple Access* (TDMA) air interface is assumed.



- In demand-assignment MAC schemes, an entity (on ground or on board) manages slot allocation requests made by terminals (*implicit* or *explicit* requests).
- A centralized scheduler (on ground or on board) is required to manage the different priorities of the requests.
- Resource allocations are periodically updated.
- Additional control overhead wrt static assignment

TDMA DAMA in DVB RCS

Glossary: MSL = Minimum Scheduler Latency (delay introduced by the scheduler to generate the BTP)

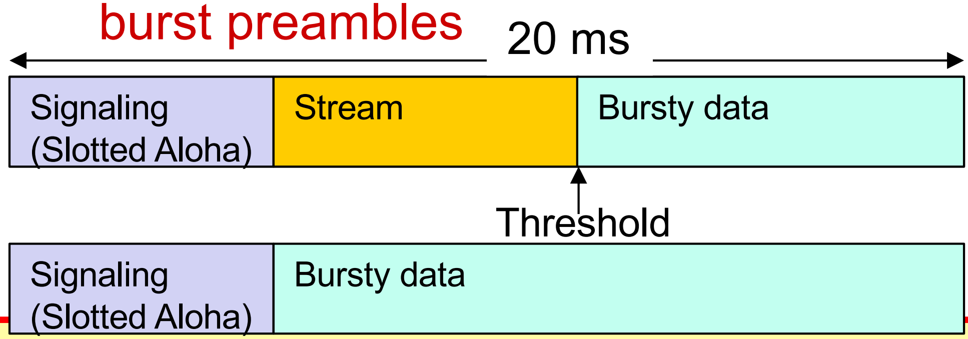
- Continuous Rate Assignment (CRA)
  - Negotiated between RCST and NCC for all the superframes in the period
  - Static capacity assigned at the beginning of the communication
  - No BoD delay, low efficiency
- Rate Based Dynamic Capacity (RBDC)
  - RCST dynamically requires capacity to NCC
  - Capacity assigned after explicit request
  - The request expires every 2 superframes (default)
  - Absolute capacity requests aiming to equaling input and output transmitter buffer rate
  - Suitable for VBR traffic tolerating MSL
  - Trade-off solution
  - RBDC and CRA can be jointly used (CRA ensures a fixed allocation and RBDC ensures a variable assignement for no real time applications)

TDMA DAMA in DVB RCS (2)

- Volume Based Dynamic Capacity (VBDC)
  - RCST dynamically requires a volume of traffic
  - Requests are cumulative
  - NCC satisfies the requests
  - Best-effort service: capacity requests aiming to empty the buffer
  - High BoD delay (RTT~1.6sec.), high efficiency
- Absolute Volume Based Dynamic Capacity (AVBDC)
  - The requests are absolute not cumulative
- Free Capacity Assignment (FCA)
  - No signaling between NCC and RCST
  - Automatic assignment of free capacity otherwise wasted
  - No traffic profile associated (random assignment)

FIFO Ordered Demand Assignment/Information Bit Energy Adaptive (FODA/IBEA)

- Hybrid RBDC/VBDC method, which incorporates also fade countermeasure techniques, based on adaptive coding and symbol rates to the individual channel condition.
- The FODA/IBEA TDMA superframe, which is 20 ms long, can accommodate stream transmissions up to a threshold.
- The remaining space in the superframe is reserved for bursty data. If no stream traffic is present, bursty data can occupy the whole superframe, decremented by the space needed for signaling, which is accessed in SA mode.
- The assignment for stream data is in the same quantity as the request. Once assigned, the allocation is maintained until the application returns the bandwidth to the master control station or the RCST ceases to transmit.
- A sending RCST transmits the stream data in the same time slot together with its bursty data, when present, in order to save the channel overheads due to burst preambles



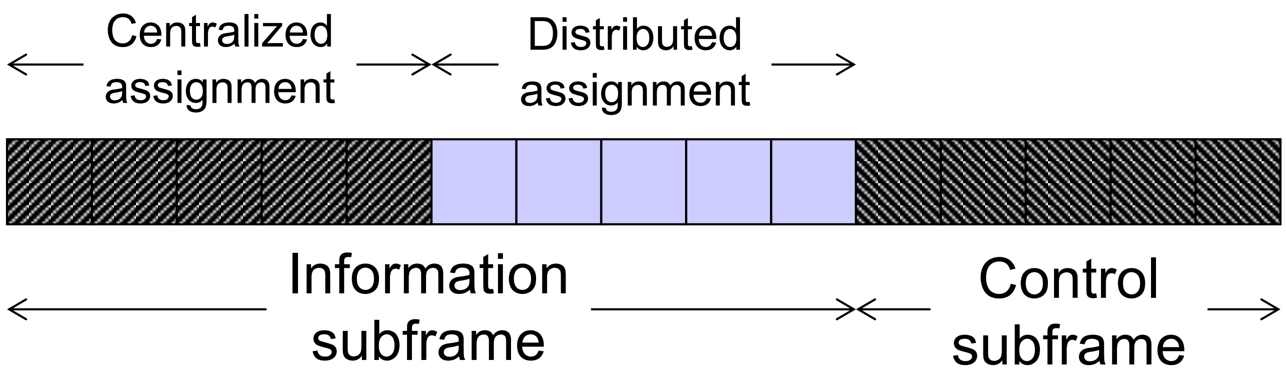
Reservation Aloha

- Combined random access and demand assignment
- Time organized in equal duration frames (= RTT)
- Each slot duration = packet transmission time (constant)
- Implicit reservation
- Satellite in charge to indicate slot current utilization
- Initial access using S-Aloha and then on reservation basis
- Good performance for both CBR (Constant Bit Rate) and bursty traffic
- Unsuitable for short messages fitting one slot (1 RTT to determine the status of the slot), in the event S-Aloha is used.
- Advantage
  - Efficient with bursty traffic
- Disadvantages
  - Inefficient with single slot messages
  - Tracking of slot utilization status
  - Frame size RTT dependent (too large for GEO)

Priority-Oriented Demand Assignment (PODA)

- Both for datagram and Constant Bit Rate (CBR) traffic
- Integration of multiple demand assignment and control techniques
  - Explicit reservation for datagram messages (delay at least 2 RTT)
  - A single explicit reservation to set up CBR stream
  - Reliability upon request using scheduled ack and packet retransmission
- Channel divided in two subframes:
  - **Information** (scheduled datagrams and CBR streams)
  - **Control** (explicit reservation if implicit cannot be sent timely in info, initial reservation access for stations with no scheduled transmission, reservation for delay sensitive traffic if the station cannot wait for the next opportunity to use the header of a scheduled message)

PODA (2)



- Access to control subframe
  - Small number of stations ⇒ fixed assignment of one slot per station in the frame (Fixed PODA, FPODA)
  - Many low duty cycle stations ⇒ S-Aloha random access (Contention based PODA, CPODA)
  - Combination of fixed and random

Split-Channel Reservation Multiple Access (SRMA)

Version 1

- Centralized, explicit reservation
- Request, Answer-to-request message (RAM) version
  - Control information bandwidth divided in two channels
    - Request channel (random access mode, Aloha or S-Aloha)
    - Answer to request channel
  - The station sends a request packet on the request channel (address of destination and length)
  - The arbiter answers (on the basis of prior requests) on the *answer-to-request* channel

Version 2

- Request Message (RM) version
  - Total bandwidth in two channels
    - Request channel (random access mode, Aloha or S-Aloha)
    - Message channel
  - The received request is inserted in a queue (FIFO or any)
  - The response packet is sent on the downlink with the address of the station at the head of the queue

Time-of-Arrival Collision Resolution Algorithm (CRA)

- The frame divided in two subframes
  - Reservation (divided in minislots equal to *reservation request* packet transmission, grouped in pairs)
  - Information (divided in slots equal to *data* packet transmission)
- S-Aloha to contend minislots to make reservation on the uplink
- In case of collision binary tree contention resolution algorithm is used
- The pair of contended minislots are precluded for other requests

Packet-Demand Assignment Multiple Access (PDAMA)

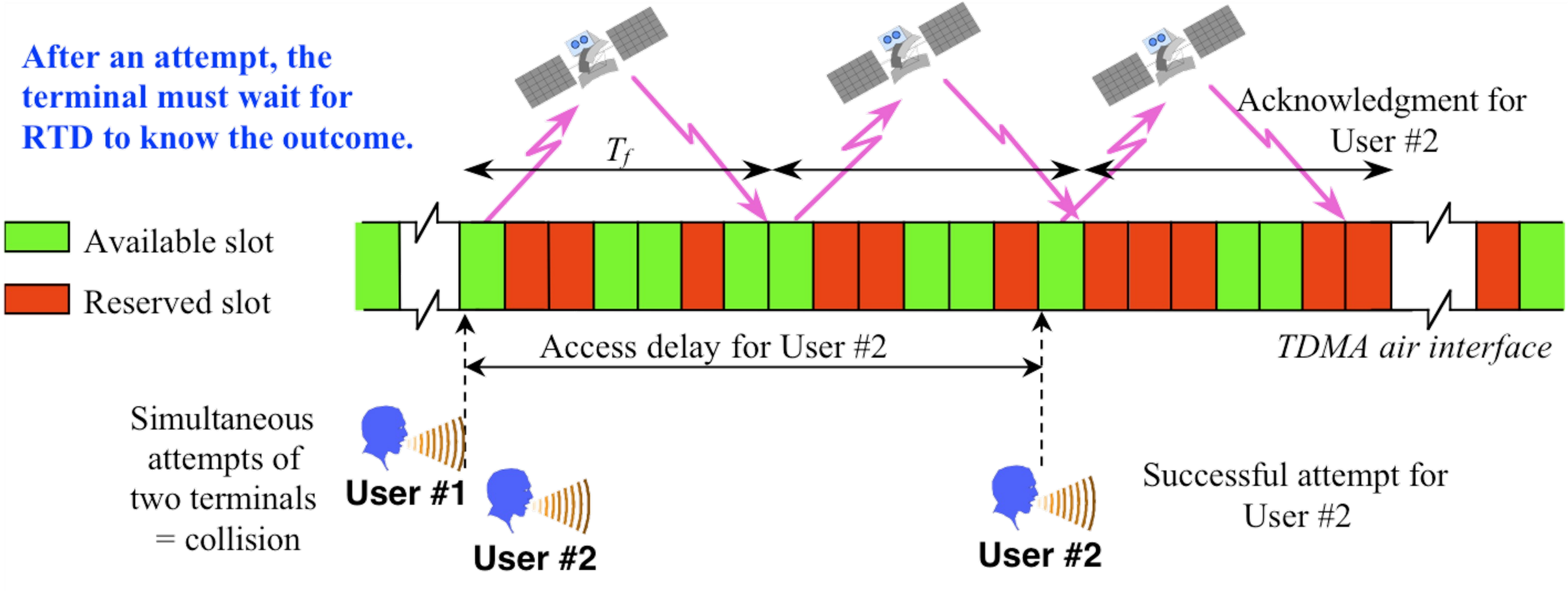
- Reservation based access
- Frame divided in two parts
  - Control
    - Leader (downlink transmission from the satellite to indicate the success of the reservation request)
    - Guard (to take into account different delay among stations)
    - Request (several request slots)
  - Information
- If the request is accepted within a time out (RTT) the station transmits, otherwise it sends again the request

The Classical PRMA Protocol

- *Packet Reservation Multiple Access* (PRMA) initially proposed for terrestrial microcellular systems
  - Voice terminals with *Speech Activity Detection* (SAD)
  - The efficiency of PRMA relies on managing voice sources with speech activity detection: only during a talkspurt, a voice source has reserved one slot per frame to transmit its packets; when there is a silent pause, this slot can be destined to another active source.
  - Reservation of one slot per frame needed for each talkspurt:
    - Transmission of the first packet on an available slot according to a permission probability.
    - Terminals attempting simultaneously collide (no reservation).
    - The terminal waits for knowing the outcome of an attempt sent in downlink by the cell controller.
    - In terrestrial micro-cellular systems the acknowledgement is practically instantaneous.
- A feedback channel broadcast by the cell controller informs the terminals about the state of each slot (i.e., idle or reserved) in a frame.
- As soon as the first packet of a talkspurt is ready, the terminal attempts to transmit it in the first idle slot (contending state), according to a permission probability scheme.
- As soon as the DT transmission attempt is successful on a slot, the UT obtains the reservation of this slot in subsequent frames.

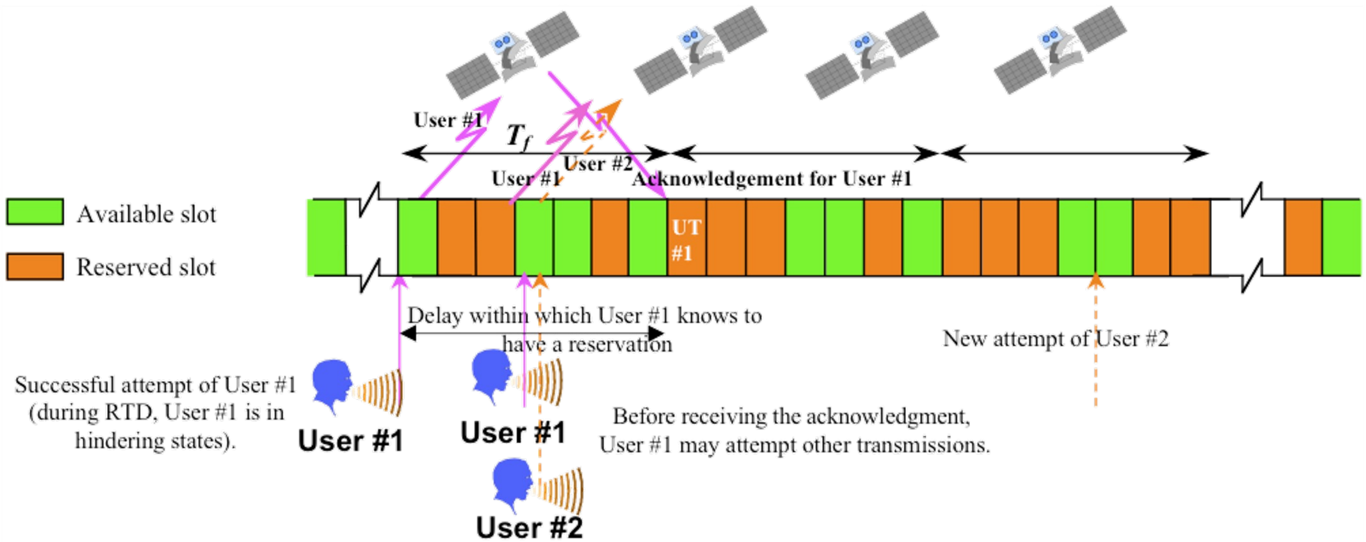
PRMA in LEO-MSSs

- The frame duration $T_f \geq$ RTD, so that a terminal making an attempt on a slot knows in time if it has obtained a reservation.
  - In case of collision, the terminal knows that it must reschedule an attempt after a high delay (5 ms < RTD < 40 ms) that worsens the QoS of the voice real-time service (*front-end clipping*)



PRMA with Hindering States

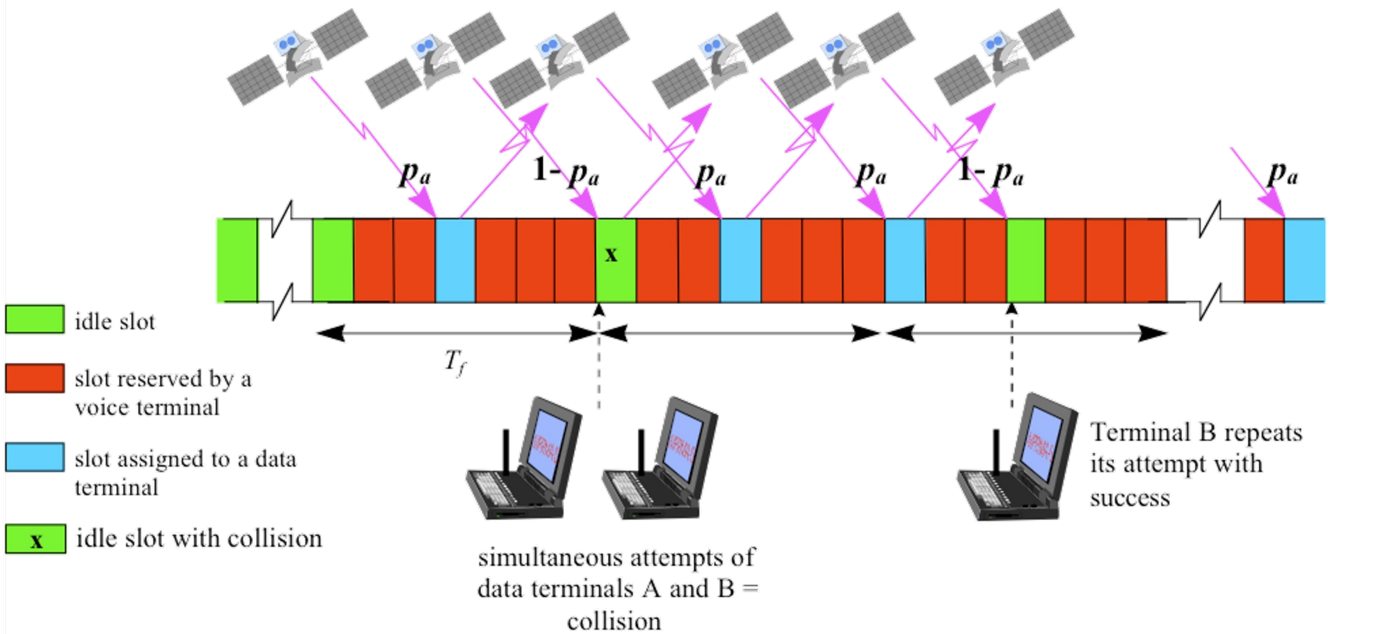
- A modification to the classical PRMA scheme named, *PRMA with Hindering States* (PRMA-HS):
  - After a transmission attempt, the terminal does not stop contending, but it may attempt again on available slots
    - *Advantage*: faster access if the attempt is unsuccessful.
    - *Disadvantage*: terminals that have successfully accessed the system may attempt again so hindering other terminals.



  - Voice and data terminals use a reservation scheme with different permission probabilities: $p_v > p_d$

The Modified PRMA Protocol

- The voice service is as in PRMA (permission probability p_v).
- Data terminals use random access to send the first packet to the satellite (permission probability p_d). This packet acts as a request put in a *First-Input First-Output* queue at the satellite.
- The satellite assigns slots unused by voice to data transmissions with probability p_a.

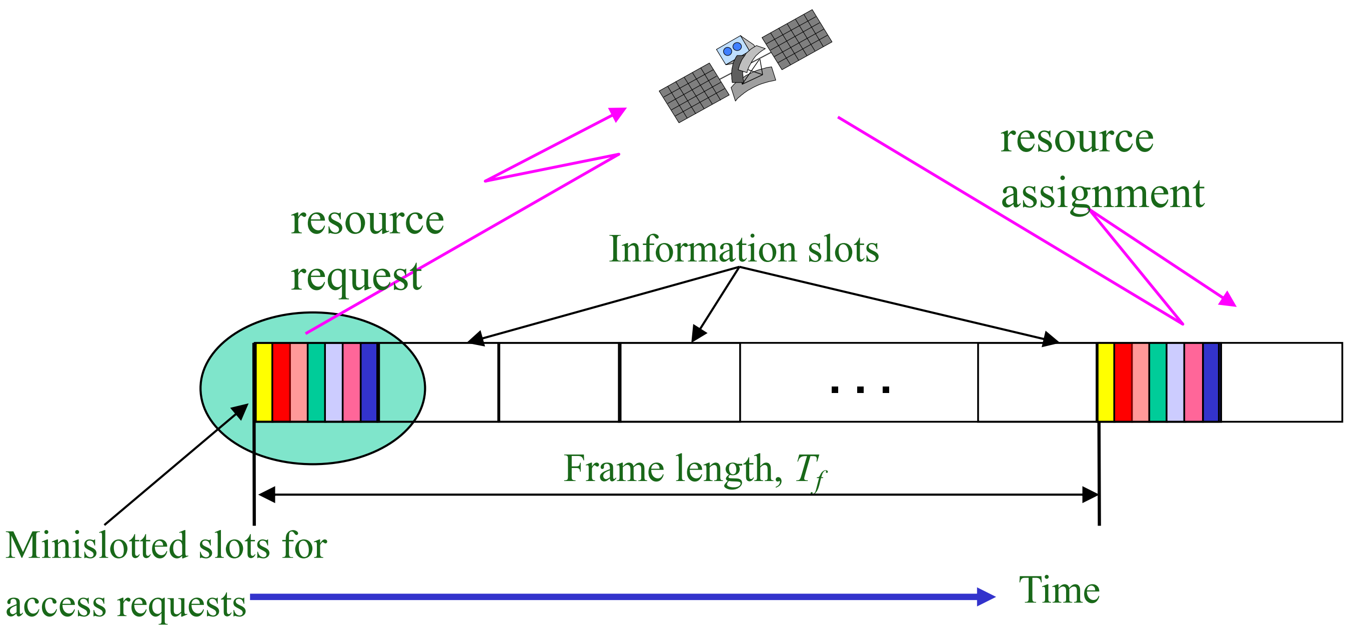


The DRAMA Protocol

- *Dynamic Resource Assignment Multiple Access* (DRAMA)
  - An adaptive number of slots is minislotted to send access requests (access slots are at the beginning of the frame and distinct from information slots).
    - A feedback channel at the beginning of each frame notifies the terminals about the duration of the contention phase.
  - A terminal needing to transmit, waits for the next contention phase and selects a minislot at random to send a request.
  - If the transmission is successful, the terminal will receive slot allocations (if room) in the next frame due to RTD.
  - A voice source sends a transmission request as soon as a talkspurt starts, without waiting for the first packet.

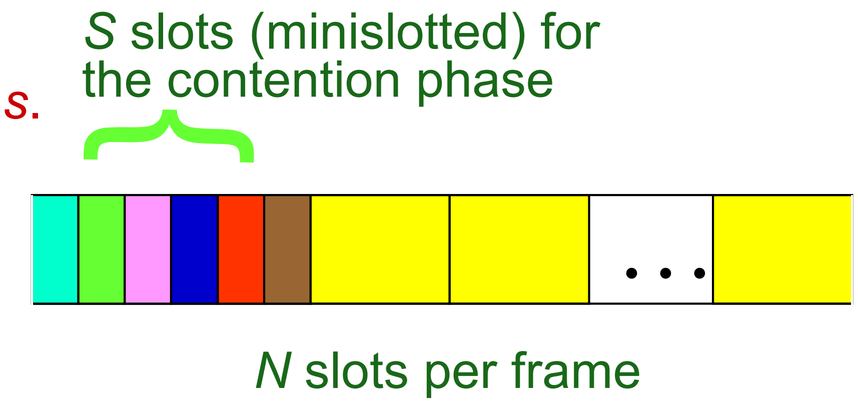
The DRAMA Protocol (cont'd)

- In this scheme the satellite becomes a scheduler that serves the data traffic with slots unused by the voice real-time traffic.
- If there is room, also more than one slot per frame can be assigned to a data source.



DRAMA+ Protocol: Access Phase and Piggybacking

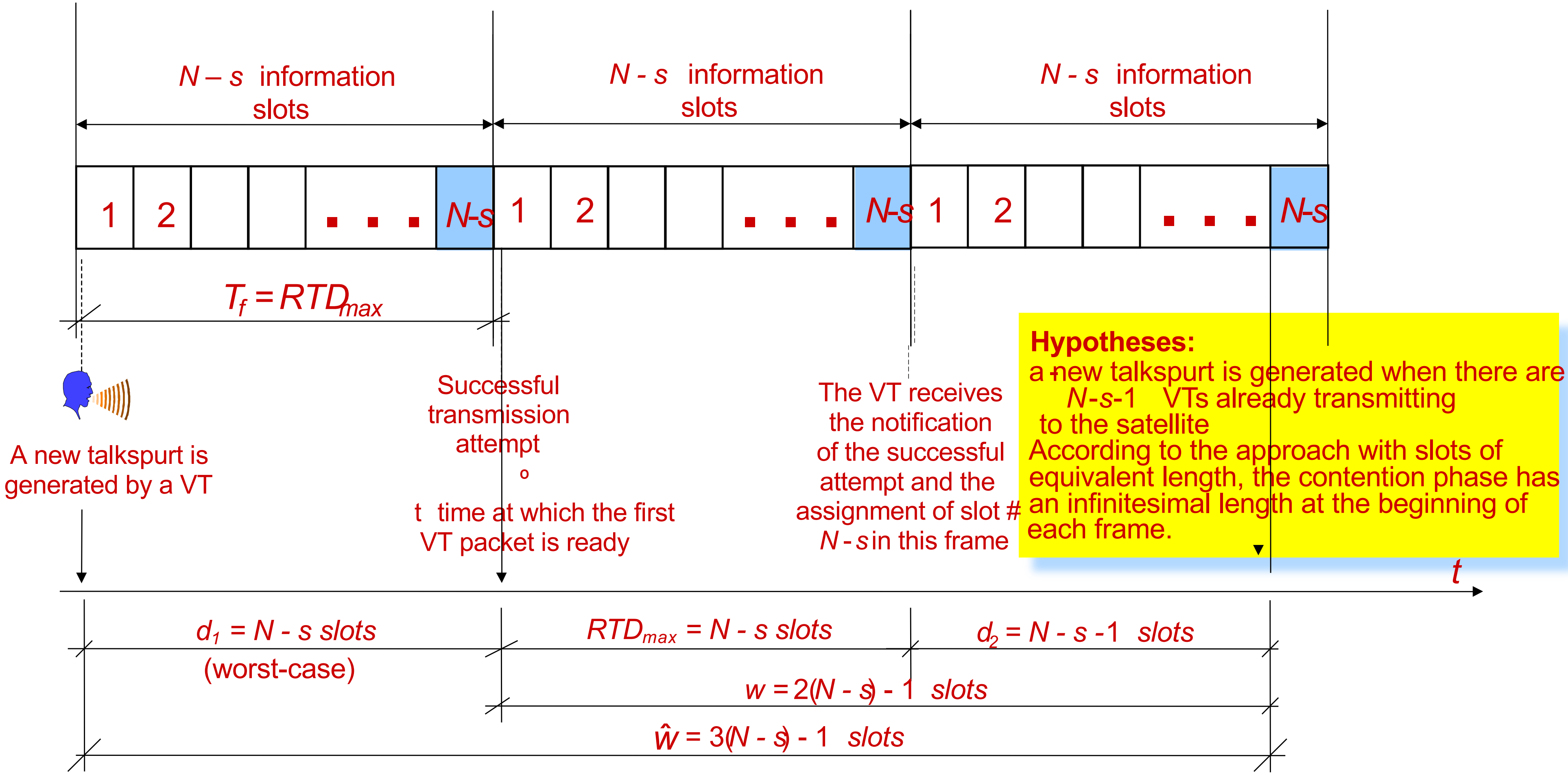
- The frame is rigidly partitioned between contention slots, *s*, and information slots, *N* - *s*.
- Contention slots are minislotted to convey request minipackets by terminals.



Voice Terminals (VTs) and ***Web traffic Terminals*** (WTs) use distinct minislots (the number of minislots for VTs and WTs needs to be optimized). VTs send a request as soon as a new talkspurt is revealed.
The type of terminal is specified in the request minipacket. For a WT request, another field contains the message length for the scheduler.
The satellite acknowledges the correctly received requests (feedback channel).
WTs already transmitting to the satellite adopt the ***piggybacking scheme*** to update their transmission requests.

DRAMA+ Protocol: Access Phase Details

For the sake of simplicity we assume the contention phase concentrated at the beginning of the first slot of the frame.



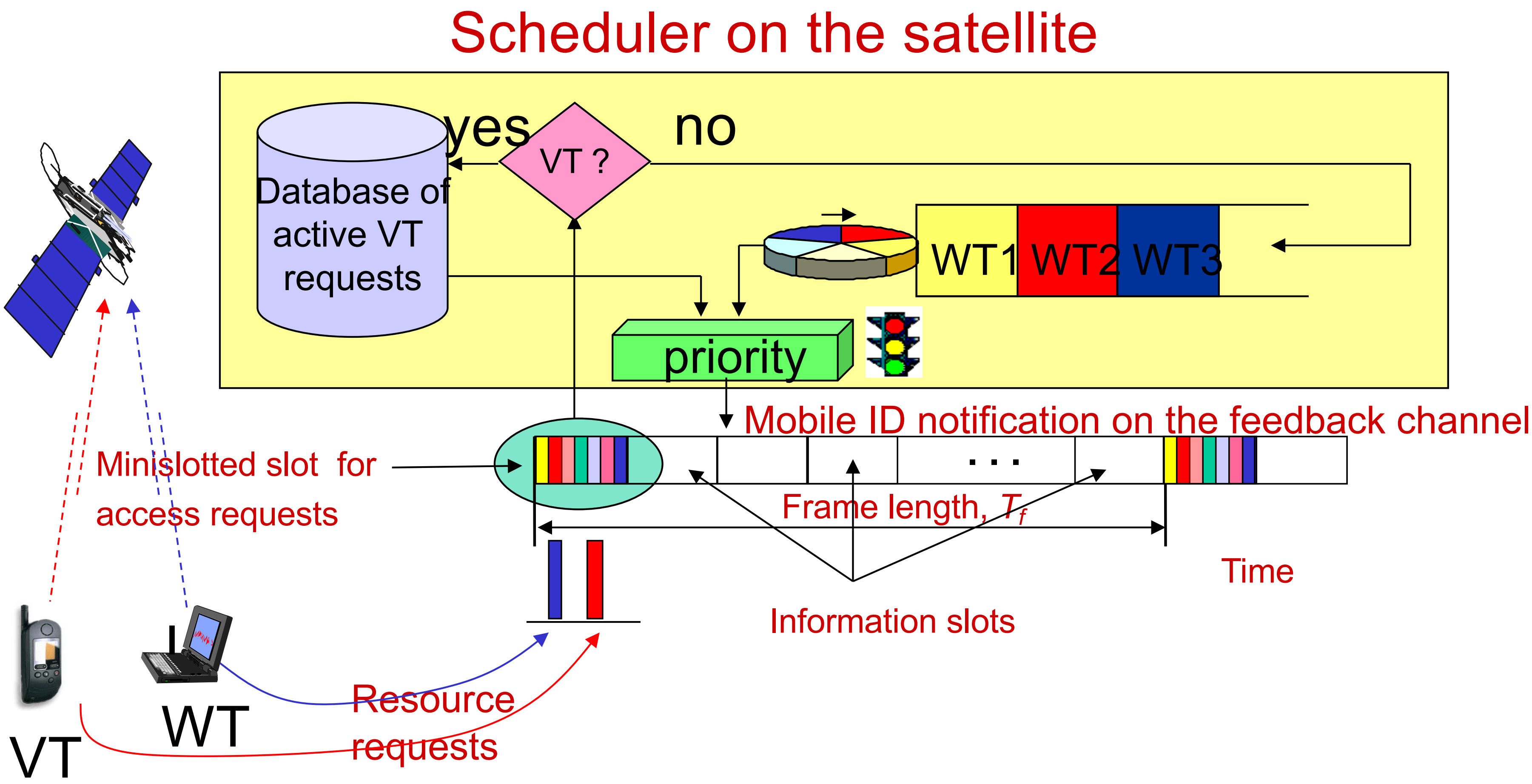
DRAMA+ Protocol: Scheduling Technique

- VT and WT requests are put into two different queues.
  - VT requests are prioritized with respect to WT ones.
  - VT requests are served in FIFO ranking by allocating a slot/frame for all the talk spurt duration.
  - The remaining slots of the frame are assigned to WT requests by a ***Round Robin (RR)*** policy: in a first cycle, one slot is assigned per WT; the following cycles prioritize the most congested WTs.
    - RR outperforms the FIFO policy when the message transmission time, *X*, verifies the following condition:

$$\frac{E[X^2]}{2E[X]^2} > 1$$

    - This condition is fulfilled by the heavily-tailed distribution of the IP datagrams.

Resource Management Scheme for Integrated Traffics



Hybrid RA DA techniques

- For bulk data transmission applications Demand Assignment (DA) techniques are widely used in satellite networks, but they typically require a RA channel for initial capacity allocation.
- In TDMA networks, Slotted Aloha (SA) is used, while CDMA networks adopt Spread Spectrum Aloha (SSA); these are the RA techniques typically used to perform capacity requests.
- Using DA in conjunction with RA will result to be very inefficient when the size of packets is very small and the transmission duty cycle is low.

Combined Free/Demand Assignment Multiple Access (CF-DAMA)

- TDMA based access scheme designed to provide significant improvements in the delay/utilization performance of geo-stationary satellite channels supporting a finite number of users with bursty data traffic.
- It combines *free assignment* of time slots with *demand assignment* allocations, providing a minimum end-to-end delay of one satellite hop at low loads and the high channel utilization of demand assignment at high loads as a result of statistical multiplexing gains and bandwidth allocation tracking user demand.
- The scheduler maintains a reservation request table and a free assignment table.
- The reservation request table queues ground terminal requests for demand assigned slots. Each time a request is received, the scheduler will place an entry at the bottom of the reservation request table indicating the identity (ID) of the requesting terminal and the corresponding number of slots requested.

CF-DAMA (2)

- The free assignment table consists of the ID numbers of all active terminals in the system. The scheduler allocates time slots on a frame-by-frame basis, transmitting the information on a Time Division Multiplex (TDM) downlink. In the first instance, the scheduler will serve entries from the top of the reservation request table by demand assigning contiguous slots to the corresponding terminal, based on the number of slots requested. In the absence of any queued requests, the scheduler will freely assign slots to terminals in a round robin fashion.
- This is achieved by assigning successive slots, one by one, to the terminal currently at the head of the free assignment table, moving each terminal to the bottom of the table after each slot allocation. In this way terminals that have not received a slot for a long time achieve a better chance of obtaining a free assigned slot (*each time a terminal receives demand assigned slots it is removed from the reservation request table and moved to the bottom of the table*).

CF-DAMA with different access strategies

- Random Access Request (RAR) Strategy (CFDAMA-RAR)
  - the uplink frame format incorporates a region of random access request slots at the start of each frame. Each ground terminal will make a request, if required, on a frame-by-frame basis in one of the request slots chosen at random;
- Packet Accompanied Request (PAR) Strategy (CFDAMA-PAR)
  - request slots are interleaved with the uplink data transmission slots. Terminals make requests accompanying their data packet transmissions with access to a particular request slot limited to the terminal transmitting in the adjacent data slot;
- CFDAMA with Combined Requests (CFDAMA-CR)
  - it incorporates both of the request strategies described above, with a region of random access request slots and interleaved packet accompanied request slots;
- CFDAMA with Round Robin requests (CFDAMA-RR)
  - it combines the best features of both strategies and, with suitable control, can provide significantly improved delay/throughput performance of a GEO satellite channel.

CF DAMA comparisons

- The primary disadvantage with the RAR scheme is loss of request packets as a result of channel contention, and the main limitation in the performance of the PAR strategy is channel domination by transmitting terminals, inhibiting other terminals from receiving free assigned slots and making requests.
- The CFDAMA-CR scheme was designed to combine the best features of both strategies and, with suitable control, can provide significantly improved delay/throughput performance of a GEO satellite channel.
- The CFDAMA-RR scheme, on the other hand, has been designed to avoid the limitations of the RAR and PAR strategies and provide equitable access rights for all terminals.
- CF-DAMA is usually the adopted multiple access scheme for larger volumes or periodic transmissions of data.
- Example systems, where RA is used for terminals login and short data transmissions, are the DVB-RCS standard, the IPoS standard, and CDMA type of VSAT systems.

Round Robin Reservation (RRR)

- It combines Random access with Reservation
- Assumption: more slots than stations
- Each station is assigned a home slot
  - The extra slots not assigned to anyone
- If the owner doesn't use the slot, it goes idle and becomes available on a contention (Aloha) basis
- If the owner wants to retrieve its home slot, it transmits a packet in that slot in the next frame, forcing a collision (if other traffic present)
- After the collision a message is broadcasted to inform that only the owner can use the slot.
- Performance worse than Aloha
- Variation: each station keeps track of a "virtual global queue" including the length of its won queue in the header of every packet

Interleaved Frame Flush Out (IFFO)

- Both contention and reservation based access
- Suited for packet switched satellite networks
- The first slot is called the status slot
  - M mini slots assigned to M stations in TDMA (no contention)
  - mini slots used to reserve bandwidth
  - M max number of stations admitted in the network
  - position associated to station (small header – no user id, no synch)
- Then a set of reserved slots (R_k) and a set of unreserved slots (N_k, used on a contention basis)
- The status slot followed by R_k reserved slots
- Frame length L_k = (at least) R slots = RTD (reservation info received by all before next frame)
- The reservations in a frame are honored in the next frame
- If R_k<R the N_k (≥0) slots are used on a contention basis S-Aloha
- R_k and N_k variable as a function of reservations in the previous frame

Interleaved Frame Flush Out (IFFO) 2

- A_k packets arrivals in frame k
- S_k successful in the N_k slots
- A_k reservations in frame k+1 but S_k are cancelled (already served in frame k+1)
- $R_{k+2} = A_k - S_k$ (unsuccessful packets are served in frame k+2 with reservation exploited in frame k+1)
- Info on reservation in status slot of frame k+2
- No attempt in frame k+1 (every other or even numbered)
- Variants:
  - Pure Reservation IFFO
  - Fixed Contention IFFO
  - Controlled Contention IFFO

Split-Channel Reservation Upon Collision (SRUC)

- Primary access through contention
- Reservation invoked in the event of collision
- Mainly for large propagation delays
- M stations divided in F groups of N (M=FN)
- Frame of F slots
- Each group is assigned one slot
- Each slot divided in 2 sub slots
  - SS0 for data and header
  - SS1 for signaling
    - SS1 divided in N (signaling transmitted without contention), small dimension because it serves a subset of stations N<<M
- Each station maintains a Request Queue (RQ)
- To transmit a packet the station sends a reservation request for it in the part of SS1 belonging to its group and assigned to it
- The request is broadcasted to all the stations which insert it in the RQ
- Simultaneous requests are ordered on a predefined priority basis

Split-Channel Reservation Upon Collision (SRUC) 2

- Data Channel Access Protocol (DCAP)
- The RQ is emptied in order
- When the RQ is empty SS0 is available for contention
- A station that wants to transmit tries with SS0 on a contention basis and also through an explicit reservation using SS1
- In case of collision on SS0 it may be served later
- The status of SS0 is made known on the downlink so that if a packet is successful on contention it is not inserted in the RQ
- The Channel Control Procedure implemented in centralized or distributed fashion
- The SRUC protocol is stable because all colliding packets are retransmitted via reservation
- Sub slots for signaling can be separated in frequency other than in time

Announced Retransmission Random Access (ARRA)

- Primary access through contention
- Downlink disseminates control information
- Each station transmits on a separate uplink channel explicit control information which are broadcasted to the downlink
- Each slot can accommodate a complete MAC message and may be divided in two parts
  - K mini slots K bit long (1 minislot = 1 bit)
  - Message slot
- A station may choose to try to transmit in one of the message slots on a contention basis but announces the intention to retransmit the packet if collided sending a message (a bit) in one (i^{th}) of the minislots trying to reserve the i^{th} slot in the next frame
- Stations receiving from satellite examine the minislots. If there are no bits, no contention for that slot, if there are multiple bits, collision occurs.
- The occupied minislots indicate which slots of the following frame have been chosen for retransmission attempts of collided packets (reserved slots)
- If there is collision on the minislot, the corresponding slot won't be used by any of the competitor stations.

Scheduled-Retransmission Multiple Access (SRMA)

- SRMA/FF (Fixed Frame)
  - K slots per frame each with reserved and contention subframe
  - Contention subframe composed of **header** and **body** fields
    - **Header** M minislots, **Body** one information packet
    - Packets arriving during contention uses S-Aloha
    - Packets arriving during reserved slots are scheduled at random for one of the contention slots (configurable number)
    - In both cases one of the M minislots is marked at random to schedule a retransmission in case of collision
  - RTD = R slots time needed to know if a collision occurred
  - In case of collision a reserved slot is assigned if the reservation in the minislot is successful
  - In case of unsuccess in both contention and reserved subframe the station will try in one of the contention slots (configurable number)

Scheduled-Retransmission Multiple Access (SRMA) 2

- Each packet is assigned a status vector (x,y)
  - $x \in \{1, 2, \ldots, K\}$ slot position in which the packet attempts to transmit
  - $y \in \{1, 2, \ldots, M\}$ position of minislot the station indicates the intent to retransmit the collided packet
- The scheduler processes the received vectors of collided packets as follows:
  - Two packets with the same status vector are not rescheduled
  - The rescheduled packets are ordered wrt increasing x
  - Each subset with the same x is ordered wrt y
  - The subset of packets in order exceeding K is discarded and will try again in the next frame
- SRMA/DF (Dynamic Frame)
  - Contention frame of fixed length F slots
  - Reserved frame of length equal to the number of successfully reserved packets in its previous corresponding contention frame (R frames earlier)
  - No limit on the number of reserved slots

Response Initiated Multiple Access (RIMA)

- Satellite link last hop of the Internet access
- TCP/IP used ➔ Capacity requirements predicted
  - Packet size at MAC layer ≈ MTU of the MAC protocol in use or quite small (ACK)
  - Data packet ➔ ACK, ACK ➔ Data packet (with high probability)
- At the beginning of the downlink TDM frame the RIMA **A**llocating **A**gent (AA) located at the satellite issues a **F**rame **D**escriptor **P**acket (FDP) which specifies the slot assignment in the uplink
- Unassigned slots are available for Random Access
- FDP generated using two inputs:
  - RIMA Allocation Algorithm (on packets from the gateway)
  - Additional bandwidth request received from the earth stations
- RIMA Allocation Algorithm estimates the needed bandwidth on the basis of the port number (identifying the application) and the packet size
  - Example: port 21 (➔FTP) and dimension 40 bytes (➔ it is an ACK) ➔➔ will generate MTU size packet (requirements)

Fixed Boundary Integrated Access Scheme (FBIA)

- S-Aloha and reservation on demand
- Reservation in the uplink, control packet in the downlink (OBP required)
- Two types of stations:
  - Short spurts of bursty traffic
  - Heavy load traffic
- Two subframes: contention and reserved parts
- Slot duration = transmission of one data packet
- All the stations synchronized ➔ each station can transmit a packet only at the beginning of a slot
- The contention subframe (K slots) used for bursty stations
- The reservation subframe used for heavy load traffic stations
  - Reservation mini frame (V slots divided in L minislots = transmission time of a reservation request packet)
  - Message mini frame (S slots)
- Bursty traffic station tries on one slot of the contention subframe
- After a RTD it knows if the packet collided and in the event retransmits in the following contention subframe

Fixed Boundary Integrated Access Scheme (FBIA) 2

- Contention based reservation scheme used by stations with large messages or heavy traffic
- The station divides each message into fixed length packets
- The station creates a reservation request packet with its identification that is transmitted in a randomly selected mini-slot in the reservation mini-frame to acquire slots in the message mini-frame
- If the reservation request packet is received without collision at the satellite, it attempts to assign a slot in the message mini-frame
- If all the slots are reserved, the request is rejected
- The **fixed** boundary concerns the possibility to use the message mini frame and the contention subframe: the former for heavy loaded stations and the latter for bursty stations. There is no possibility to exchange even in case the proper space is full and the other is still available.

Combined Random/Reservation Multiple Access (CRRMA)

- N mini slots in each slot for sending transmission requests with contention access and M mini slots for sending data
- On board processing switch
- The first part of a slot is divided in N mini-slots for transmission request packets
- The second part is for one data packet (duration M minislots, M >>N)
- The request in one of the N minislots
- N<<number of stations ➔ probability to collide
- Round Trip Delay = Q slots
- If collision of request packets in the i^{th} slots ➔ mini slots of $(i+Q)^{th}$ slot is "retransmission" state
- If no collision the slot is "free"
- If the state of the $(i+Q)^{th}$ slot is "retransmission-contention" (the mini slots are in "retransmission" and the data portion is in a "contention" state) ➔ multiple (at least two) request packets have collided in the i^{th} slot