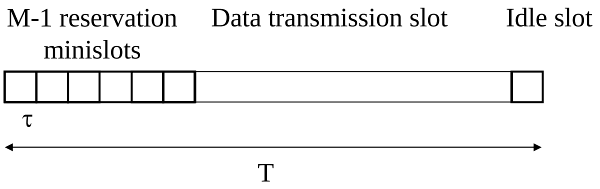
Lecture 4
Dynamic conflict free access

Minislotted alternating priority

- Usable in slotted systems such as TDMA
- M users labeled 0,1,2,…,M-1



M-1 reservation minislots

Data transmission slot

Idle slot

τ

T

- The minislots are utilized to find the user with the highest priority among those wishing to transmit

Minislotted alternating priority

- Given that user *i* transmitted in the last slot, we define
  - **Fixed priorities**
    Transmission order: 0,1,2,…,M-1
    - User i has always higher priority than user i+1
  - **Round robin**
    Transmission order: i+1,i+2,..,i+M (modulo M)
    - Time slots are allocated to the users in a cyclic order to esnure that between two consecutive transmissions of user i all other users have change to transmit once
  - **Alternating priorities:**
    Transmission order: i,i+1,…,i+M-1
    - Round robin in terms of transmission changes. Once the channel is given to an user, it is allowed to transmit all the messages in its transmission buffer

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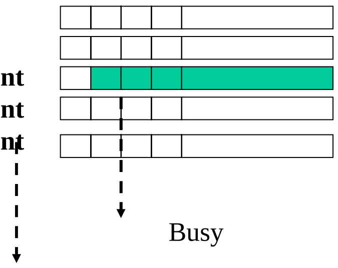
Minislotted alternating priority

- An user having the highest priority 0 will transmit an unmodulated carrier of length M-1 minislots followed by the message of duration T
- An user with priority i=1,2,…,M-1 will first listen i minislots and if they are busy transmit M-1-i minislots followed by the message of duration T



M=5

User 0 No data
User 1 No data
User 2 Packet to be sent
User 3 Packet to be sent
User 4 Packet to be sent

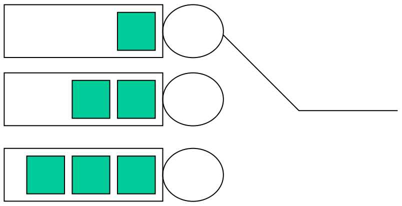
Minislotted alternating priority

- The system is conflict free and does not waste slots if high priority users do not have data
- The protocol overhead is the M-1 minislots
- Maximum throughput

$$S \le \frac{T}{T + M\tau} = \frac{1}{1 + Ma}, \quad a = \frac{\tau}{T}$$

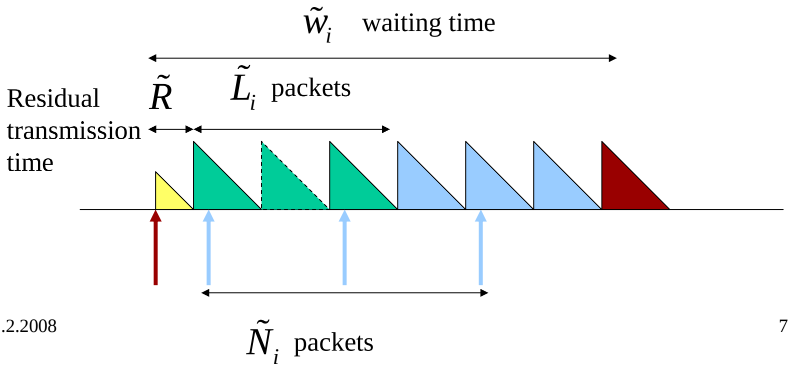
Minislotted fixed priority

- Assume that fixed priorities are utilized
- The queuing system now appears as *priority queuing* system, in which users from priority class 0 are served as long as there are no more data in the transmission buffer. If class 0 queue is empty than class 1 will be served. If both 0 and 1 are empty, then class 2 would be served. Etc.



Minislotted fixed priority

- Consider a random tagged packet that joins user k.
- Upon the arrival of user k>i, user i has L_i packets waiting to be transmitted.
- Let $\tilde{N}_i$ denote the number of packets that arrive at user i during the waiting time of the tagged packet



Minislotted fixed priority

- Expected waiting time

$$w_k = E\{\tilde{w}_k\} = \frac{1}{2}(T+M\tau) + \sum_{i=0}^{k} E\{\tilde{L}_i\}(T+M\tau) + \sum_{i=0}^{k-1} E\{N_i\}(T+M\tau)$$

Time till next slot begins

Transmission time of the packets ahead in the queue

Transmission time of the higher priority packets that arrived while the tagged packet waited to be served

- Littles law states that

$$E\{\tilde{L}_i\} = \lambda_i w_i$$

$$E\{N_i\} = \lambda_i w_k$$

Minislotted fixed priority

- Waiting time for the tagged packet

$$w_k = \frac{1}{2}(T + M\tau) + \sum_{i=0}^{k} \lambda_i w_i (T + M\tau) + \sum_{i=0}^{k-1} \lambda_i w_k (T + M\tau)$$

$$\Leftrightarrow w_k = \frac{1}{2}(T + M\tau) + \sum_{i=0}^{k} \rho_i w_i + \sum_{i=0}^{k-1} \rho_i w_k$$

$$\Leftrightarrow w_k = \frac{\frac{1}{2}(T + M\tau) + \sum_{i=0}^{k-1} \rho_i w_i}{1 - \sum_{i=0}^{k} \rho_i}$$

Minislotted fixed priority

- Expected waiting time

$$w_0 = \frac{\frac{1}{2}(T + M\tau)}{1 - \rho_0}$$

$$w_1 = \frac{\frac{1}{2}(T + M\tau) + \rho_0 \frac{\frac{1}{2}(T + M\tau)}{1 - \rho_0}}{1 - \rho_0 - \rho_1} = \frac{\frac{1}{2}(T + M\tau)}{(1 - \rho_0 - \rho_1)(1 - \rho_0)}$$

$$\vdots$$

$$w_k = \frac{\frac{1}{2}(T + M\tau)}{\left(1 - \sum_{i=0}^{k} \rho_i\right)\left(1 - \sum_{i=0}^{k-1} \rho_i\right)}$$

Minislotted fixed priority

- Expected waiting time

$$w = \sum_{k=0}^{M-1} \frac{\lambda_k}{\lambda} w_k = \frac{\frac{1}{2}(T + M\tau)}{1-\rho}, \quad \lambda = \sum_{k=0}^{M-1} \lambda_k, \quad \rho = \lambda(T + M\tau)$$

- Expected delay

$$\boxed{D = w + (T + M\tau) = (1 + Ma)T\left[1 + \frac{1}{2(1-\rho)}\right]}$$

- Normalized delay

$$\boxed{\hat{D} = \frac{D}{T} = (1 + Ma)\left[1 + \frac{1}{2(1-\rho)}\right]}$$

Minislotted alternating priority

- Although the mean delay was derived for fixed prioriy, the *priority conservation law* states that for any M/G/1 queue and any nonpreemptive work-conserving queueing discipline

$$\sum_{k=0}^{M-1} \rho_k w_k = \text{Constant}$$

  Hence, the mean delay is the same for all the three queuing disciplines considered here. However, the higher moments of the delay are different.

- Normalized delay

$$\boxed{\hat{D} = \frac{D}{T} = (1 + Ma)\left[1 + \frac{1}{2(1-\rho)}\right]}$$

- Throughput

$$\boxed{S = \frac{\rho}{1 + Ma} \Rightarrow \rho = (1 + Ma)S}$$

TDMA

- Delay of user k in regular TDMA

$$\hat{D}_{TDMA,k} = 1 + \frac{1}{2(1-\rho_k)} \qquad \rho_k = \lambda_k T$$

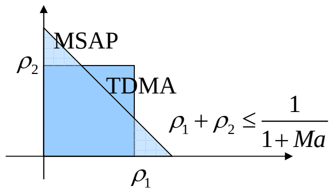
- Average delay

$$\hat{D}_{TDMA,k} = \sum_k \frac{\lambda_k}{\lambda} \hat{D}_{TDMA,k} = 1 + \sum_{k=0}^{M-1} \frac{\rho_k}{\rho} \frac{1}{2(1-\rho_k)} \qquad \rho = \sum_{k=0}^{M-1} \rho_k$$

- Corresponding delay for MSAP

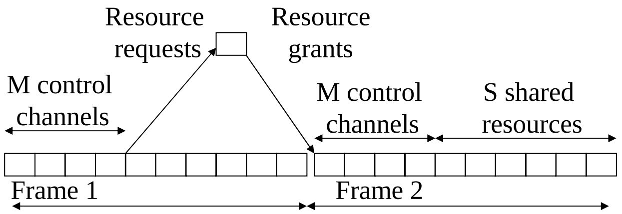
$$\hat{D}_{MSAP} = (1+Ma)\left[1 + \frac{1}{2\left(1-(1+Ma)\rho\right)}\right]$$

- Capacity region
  - For high load TDMA is better, but for low load MSAP is superior
  - MSAP performance is sensitive to the characteristic parameter a



Reservations

- In cellular systems, slot allocations are typically controlled by the packet scheduling entity situated at the base station (or radio network controller)
- Base station controlled system



- Performance is similar to MSAP as the control channels take some of the available capacity
- This kind of resource allocation scheme is used e.g. in UMTS, LTE and Mobile WiMAX

Reservations

- Reservations are also used in some short range radio systems where either
  - Single station is elected as master and it polls the others (e.g. Bluetooth)
  - Time is divided into super frames, and in the beginning of each frame certain resource reservation slots are used (e.g. IEEE802.15.3 and IEEE802.15.4)