Ad Hoc Nets - MAC layer

Part II – TDMA and Polling

More MAC Layer protocols

- **Bluetooth Piconet: a polling/TDMA scheme**
- **Cluster TDMA: based on TDMA (with random access and reserved slots)**
  - research protocol developed at UCLA for the DARPA-WAMIS project (1994)

Bluetooth:

Where does the name come from?

Bluetooth working group history

- **February 1998: The Bluetooth SIG is formed**
  - promoter company group: Ericsson, IBM, Intel, Nokia, Toshiba
- **May 1998: Public announcement of the Bluetooth SIG**
- **July 1999: 1.0A spec (>1,500 pages) is published**
- **December 1999: ver. 1.0B is released**
- **December 1999: The promoter group increases to 9**
  - 3Com, Lucent, Microsoft, Motorola
- **March 2001: ver. 1.1 is released**
- **Aug 2001: There are 2,491+ adopter companies**

What does Bluetooth do for you?

Synchronization

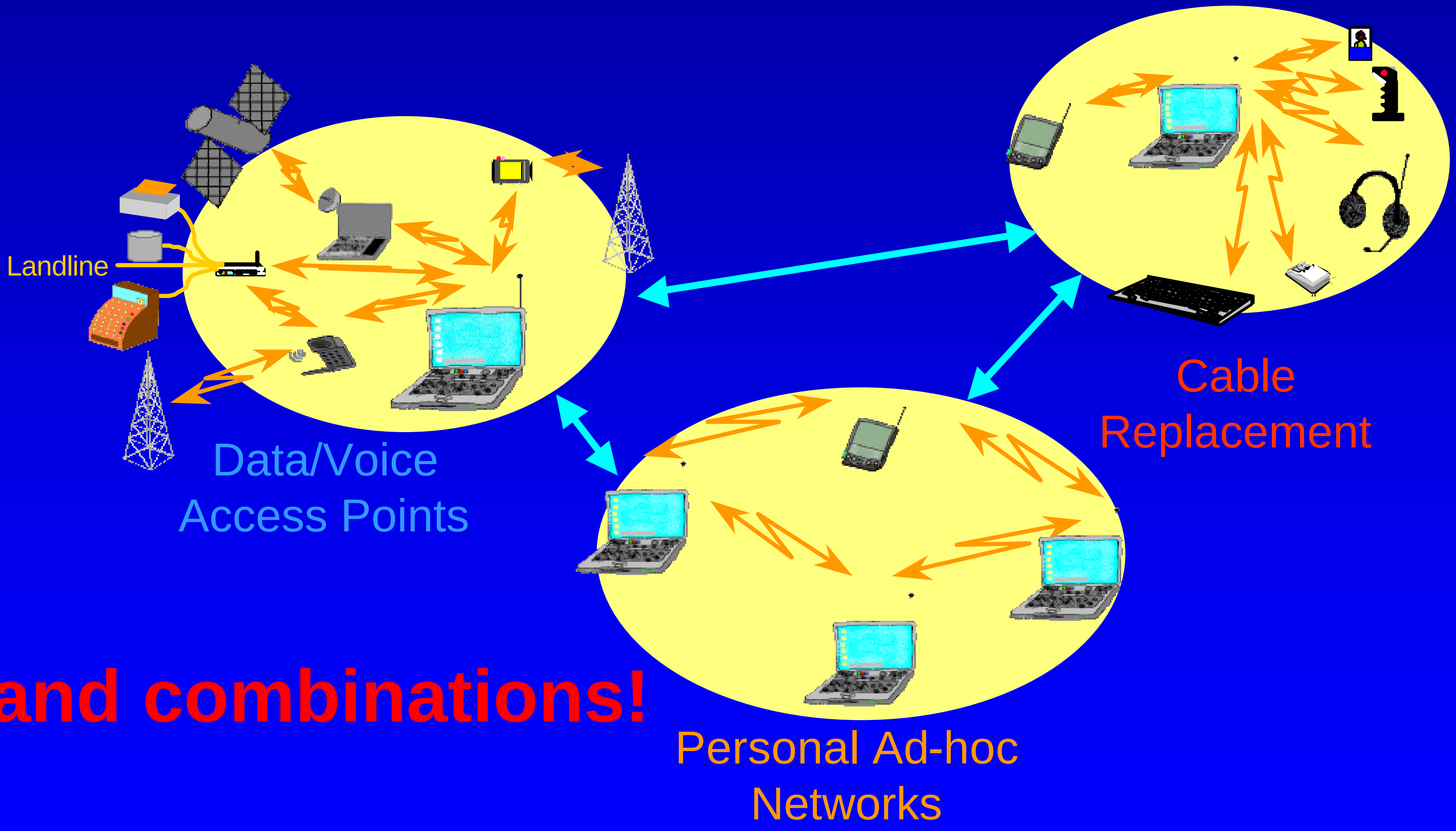
- Automatic synchronization of calendars, address books, business cards
- Push button synchronization
- Proximity operation

Cordless Headset

User benefits

- Multiple device access
- Cordless phone benefits
- Hands free operation

Putting it all together..



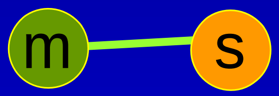
...and combinations!

Example...

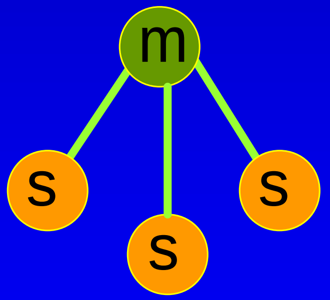
Early morning. Turning on the heat in the car from my bedroom window via Bluetooth.

Bluetooth Physical link

- **Point to point link**
  - master - slave relationship
  - radios can function as masters or slaves

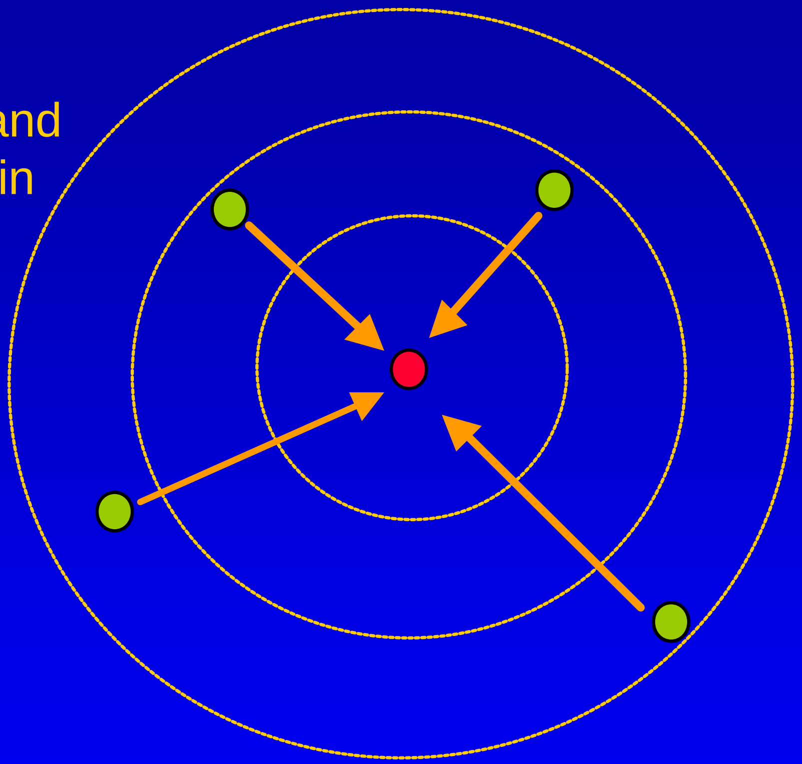


- **Piconet**
  - Master can connect to 7 slaves
  - Each piconet has max capacity =1 Mbps
  - hopping pattern is determined by the master

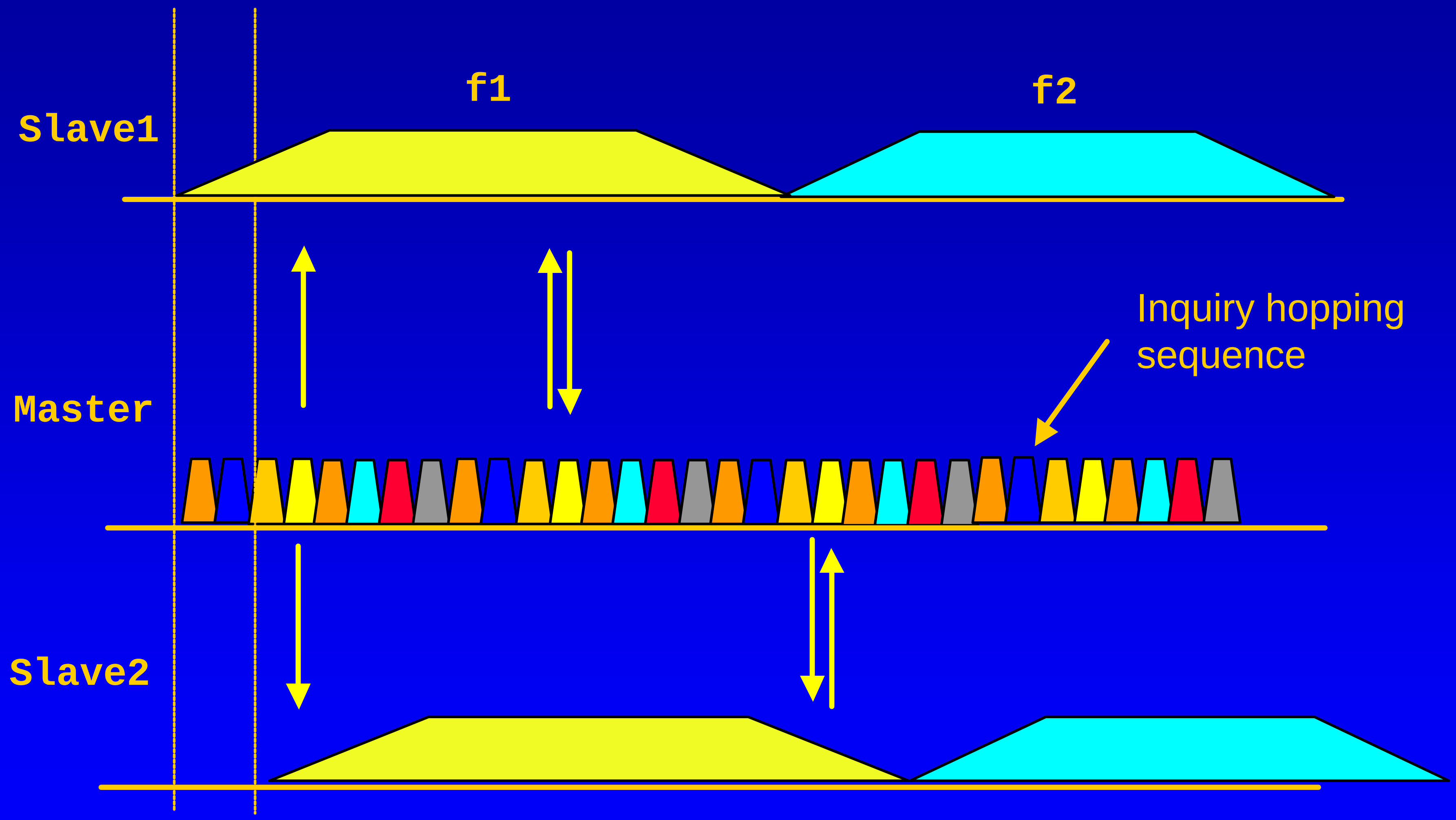


Connection Setup

- **Inquiry - scan protocol**
  - to learn about the clock offset and device address of other nodes in proximity

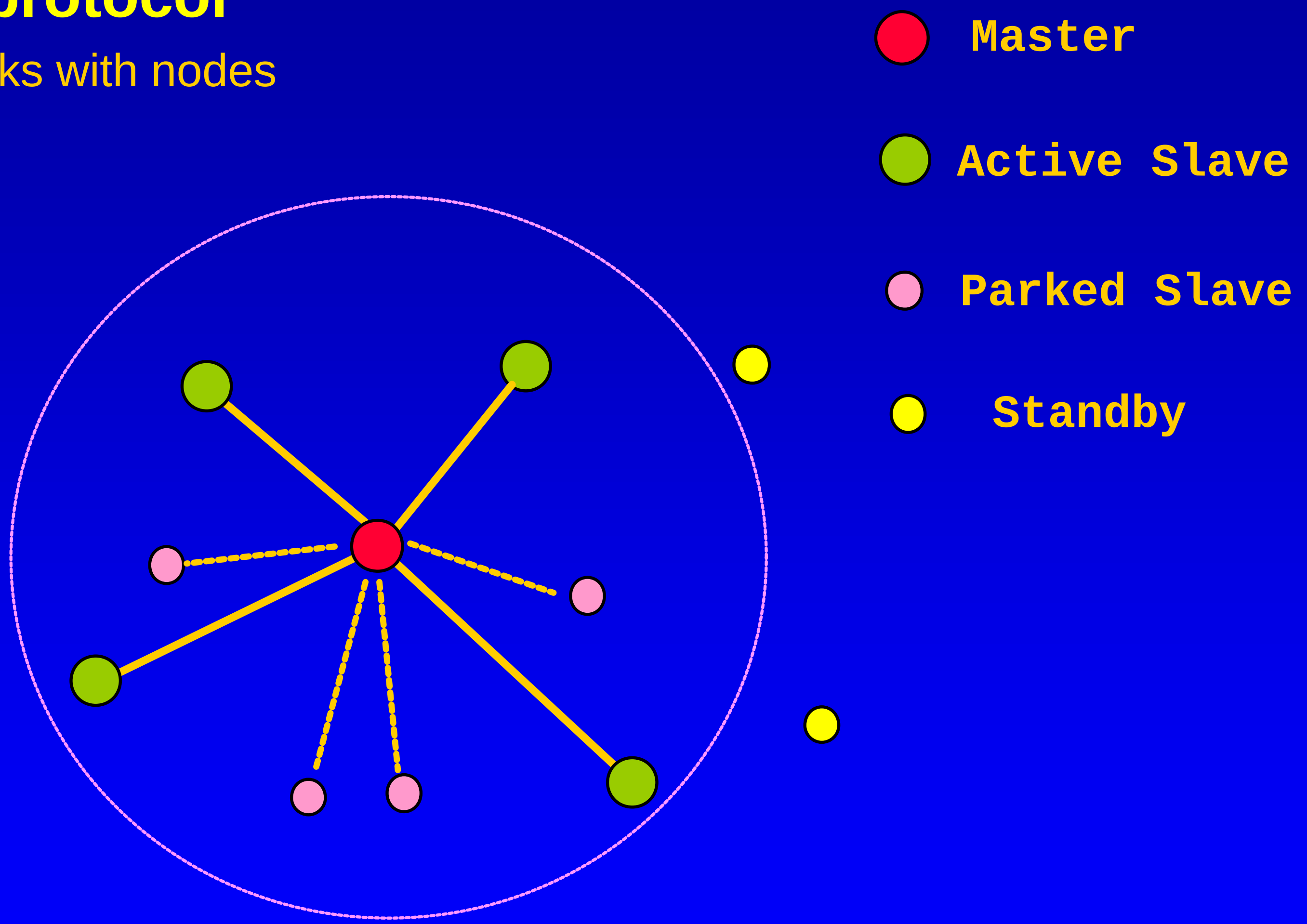


Inquiry on time axis



Piconet formation

- **Page - scan protocol**
  - to establish links with nodes in proximity

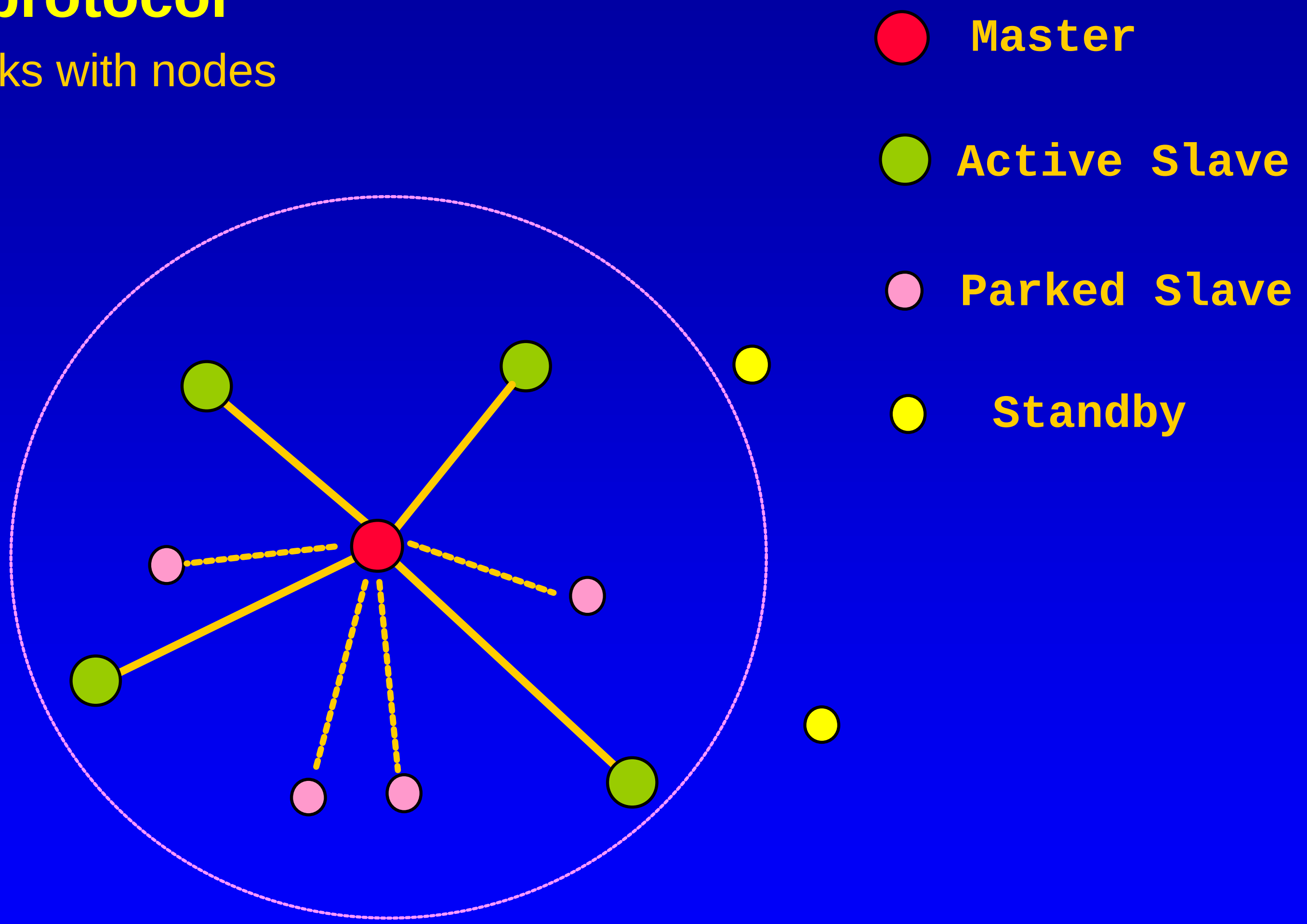


Addressing

- **Bluetooth device address (BD_ADDR)**
  - 48 bit IEEE MAC address
- **Active Member address (AM_ADDR)**
  - 3 bits active slave address
  - all zero broadcast address
- **Parked Member address (PM_ADDR)**
  - 8 bit parked slave address

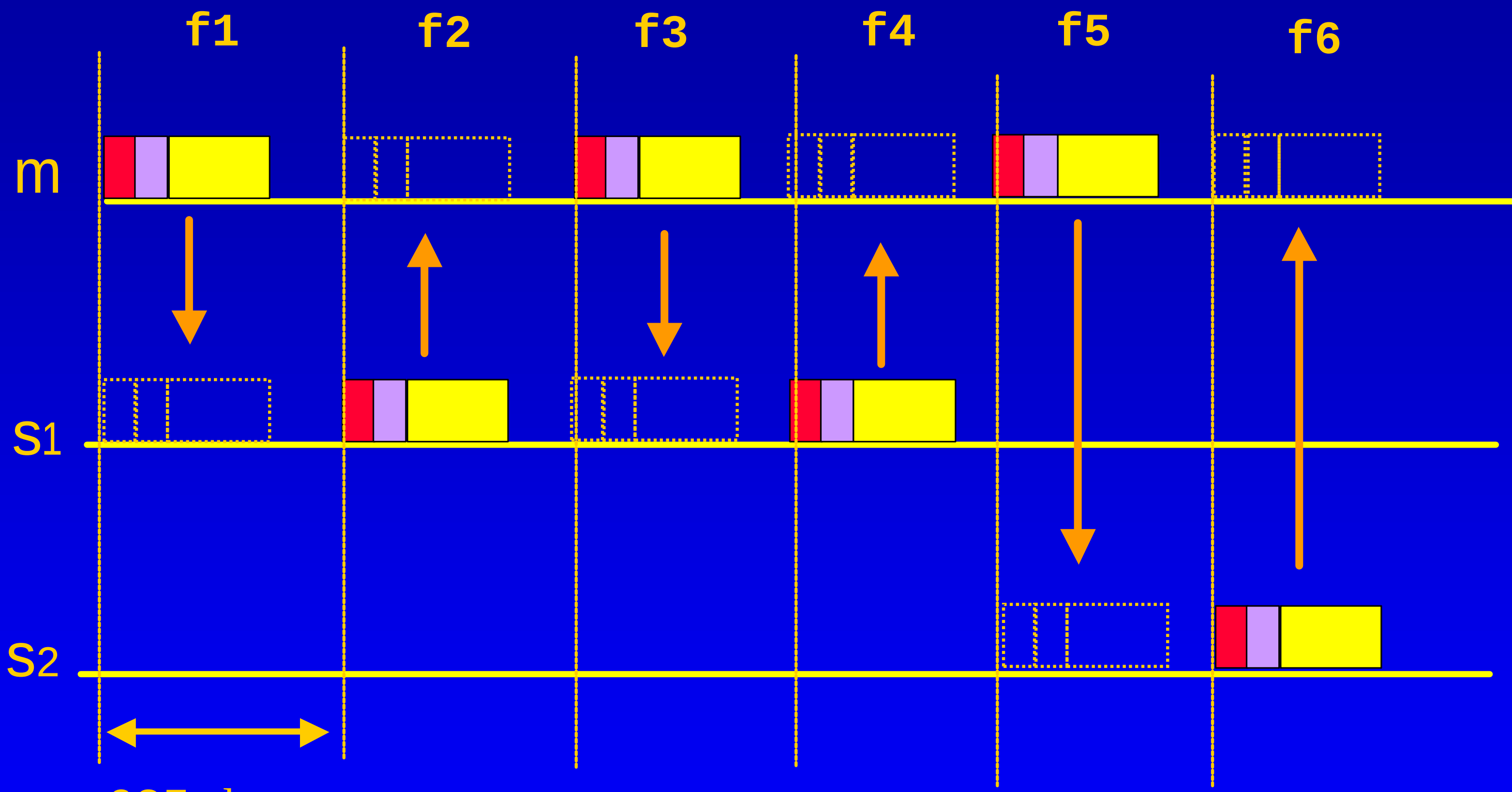
Bluetooth Piconet

- **Page - scan protocol**
  - to establish links with nodes in proximity



Piconet MAC protocol : Polling

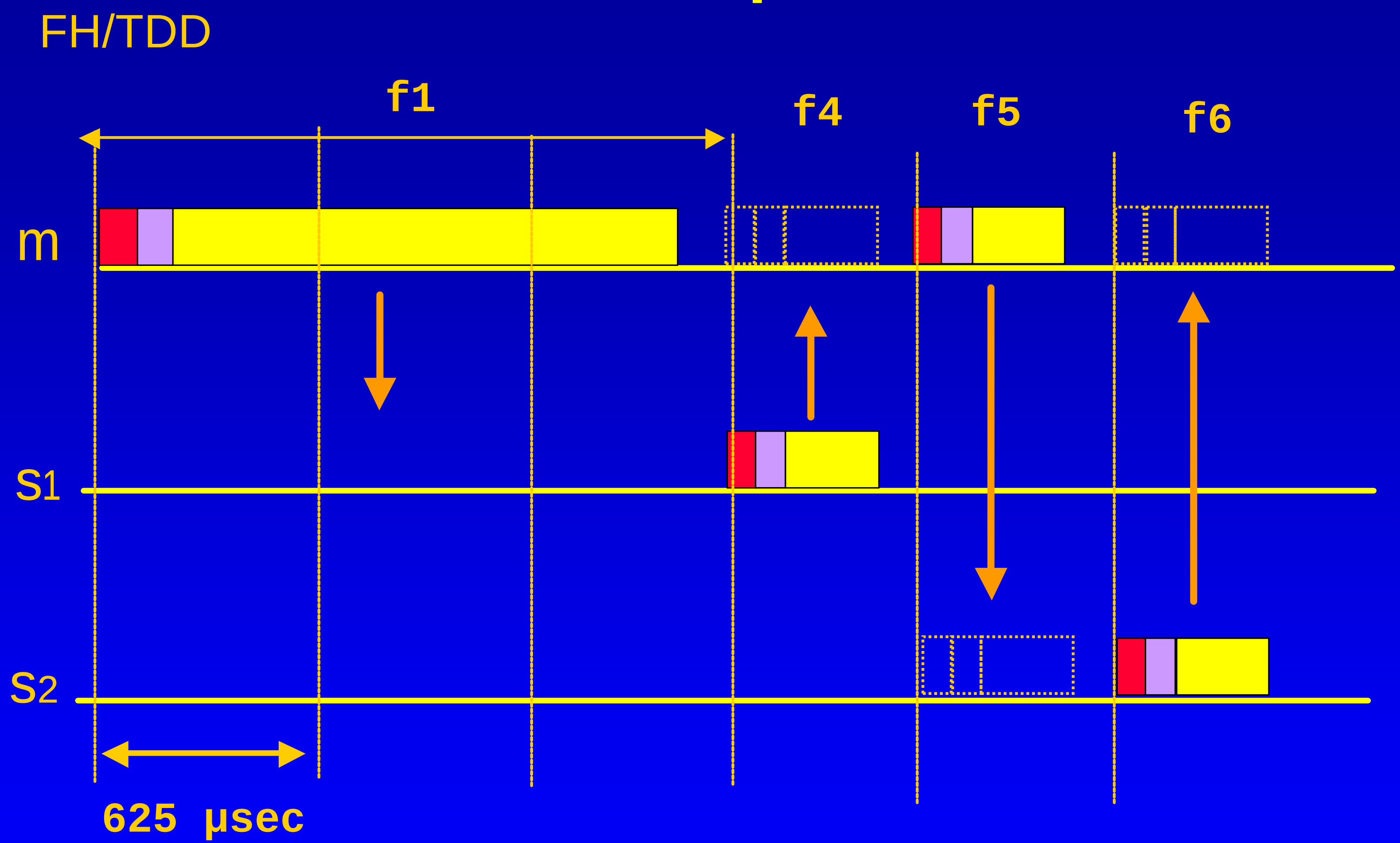
FH/TDD



625 lsec

1600 hops/sec

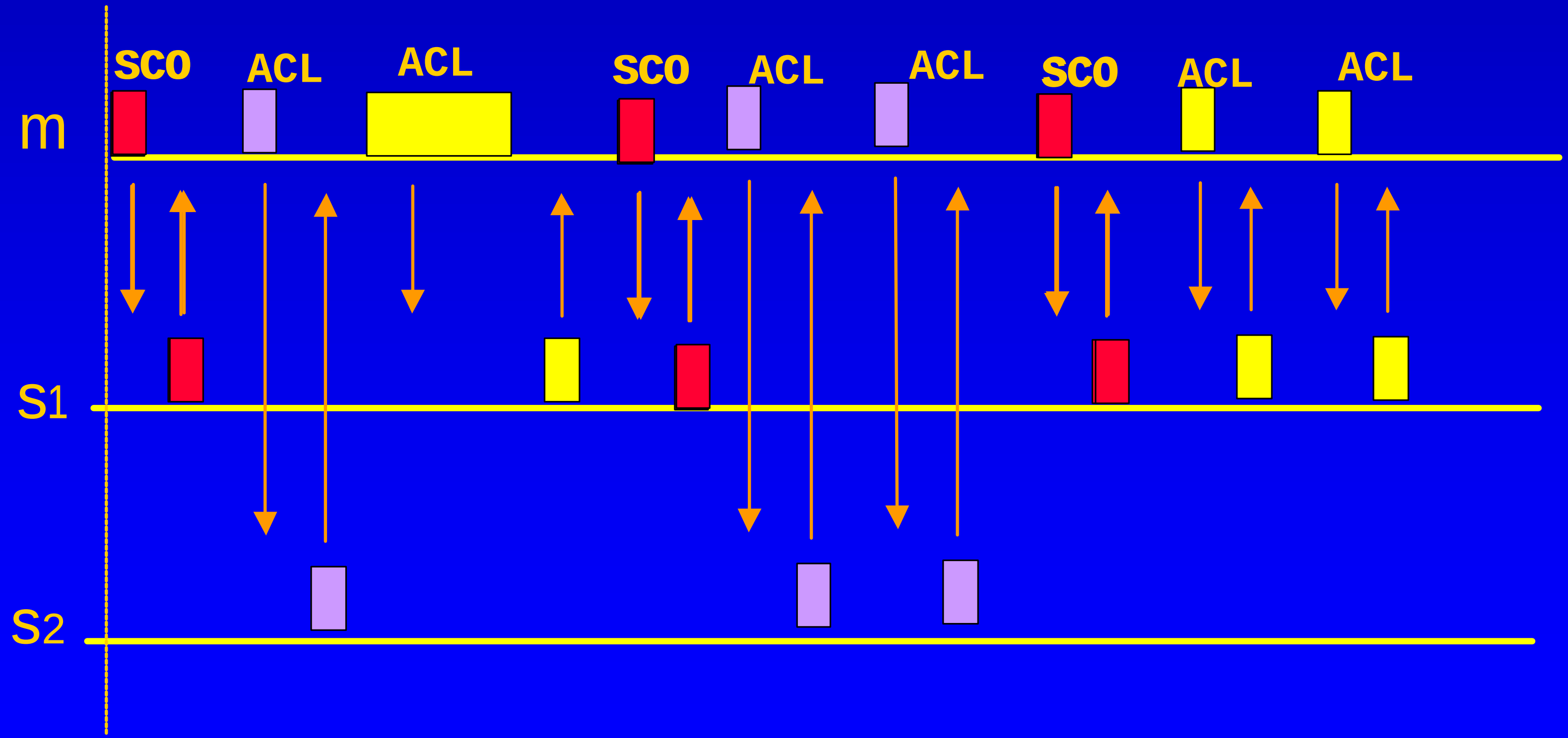
Multi slot packets



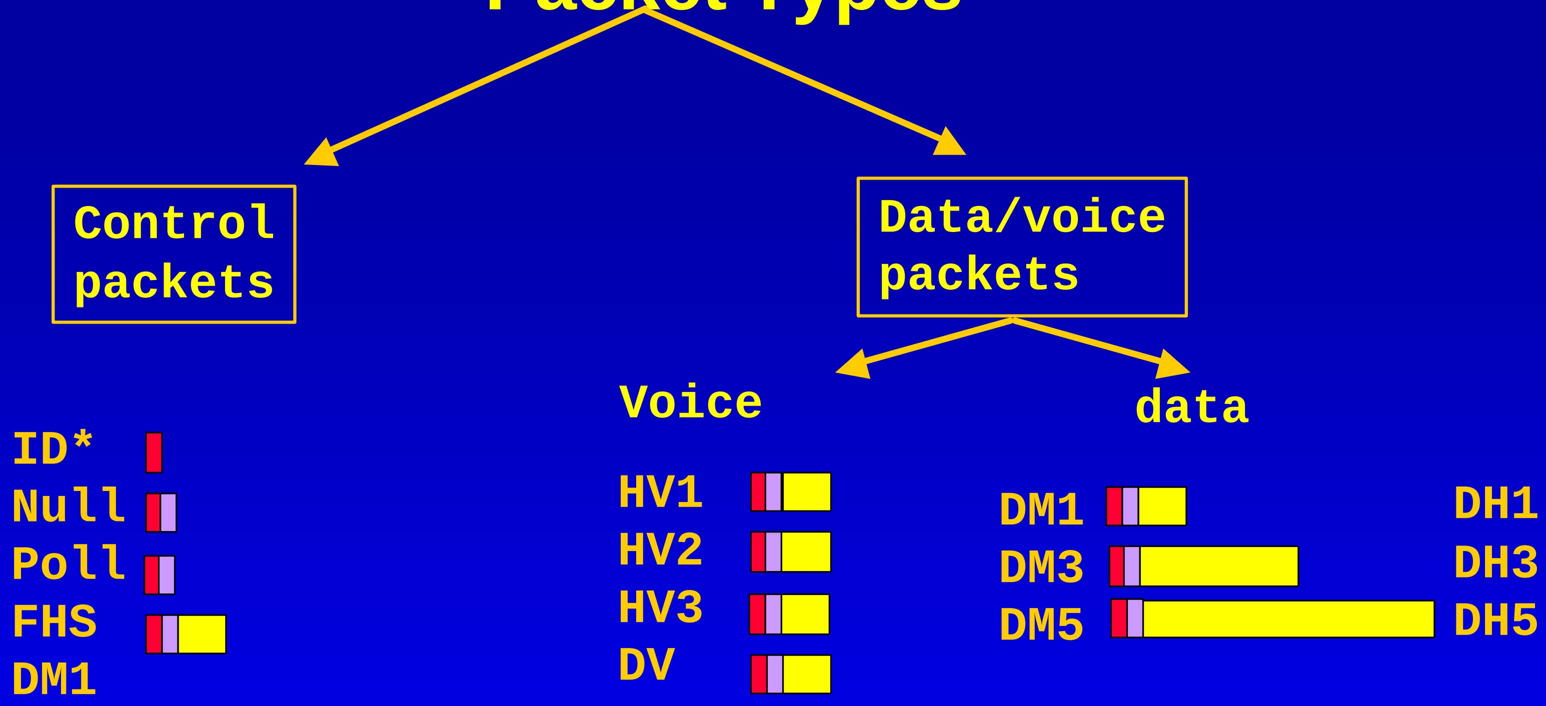
Data rate depends on type of packet

Physical Link Types

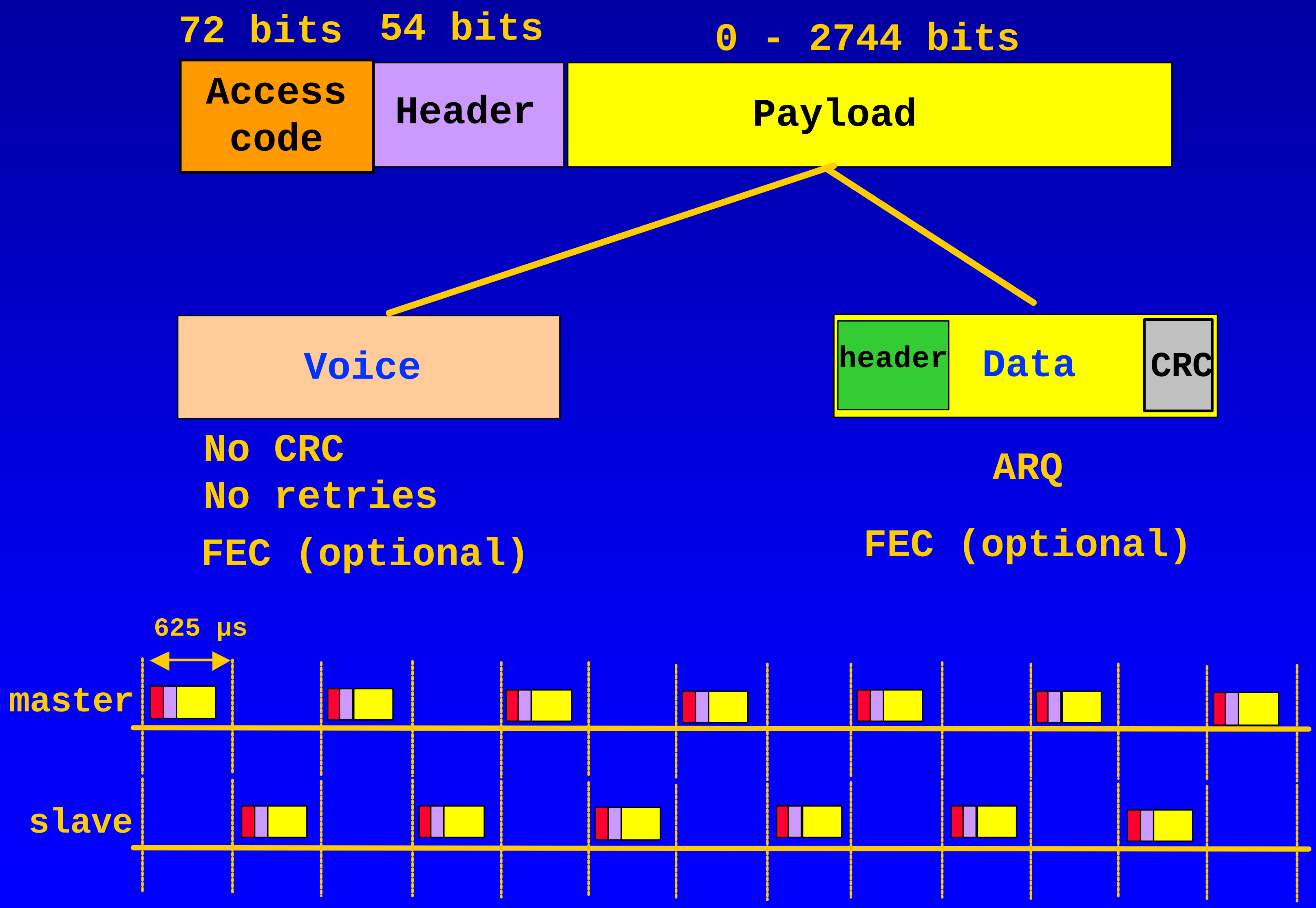
- Synchronous Connection Oriented (SCO) Link
  - slot reservation at fixed intervals
- **Asynchronous Connection-less (ACL) Link**
  - Polling access method



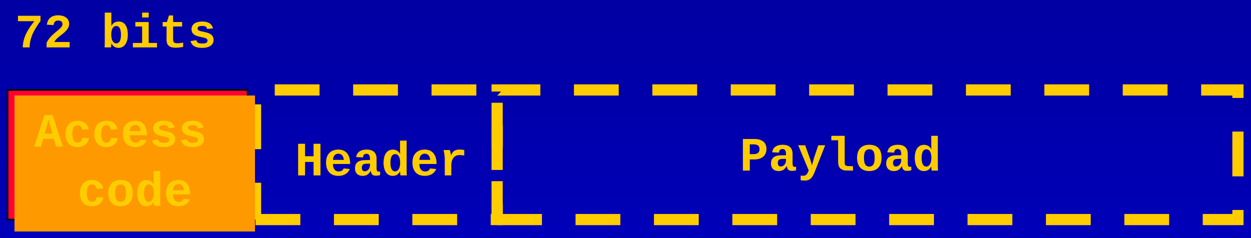
Packet Types



Packet Format



Access Code

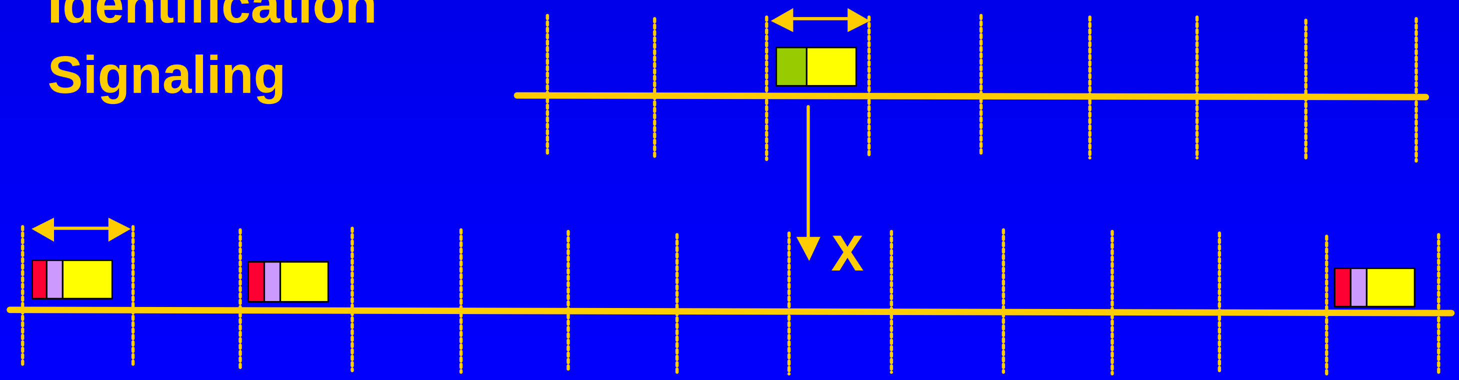


Purpose

- **Synchronization**
- **DC offset compensation**
- **Identification**
- **Signaling**

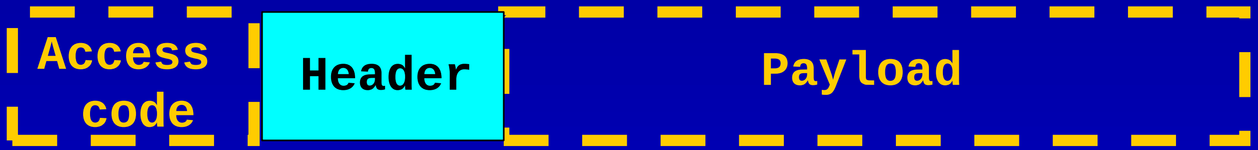
Types

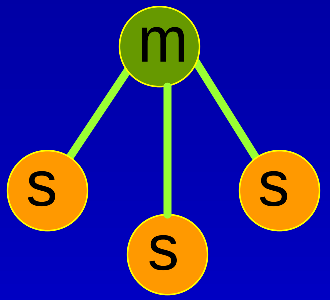
- Channel Access Code (CAC)
- Device Access Code (DAC)
- Inquiry Access Code (IAC)



Packet Header

54 bits





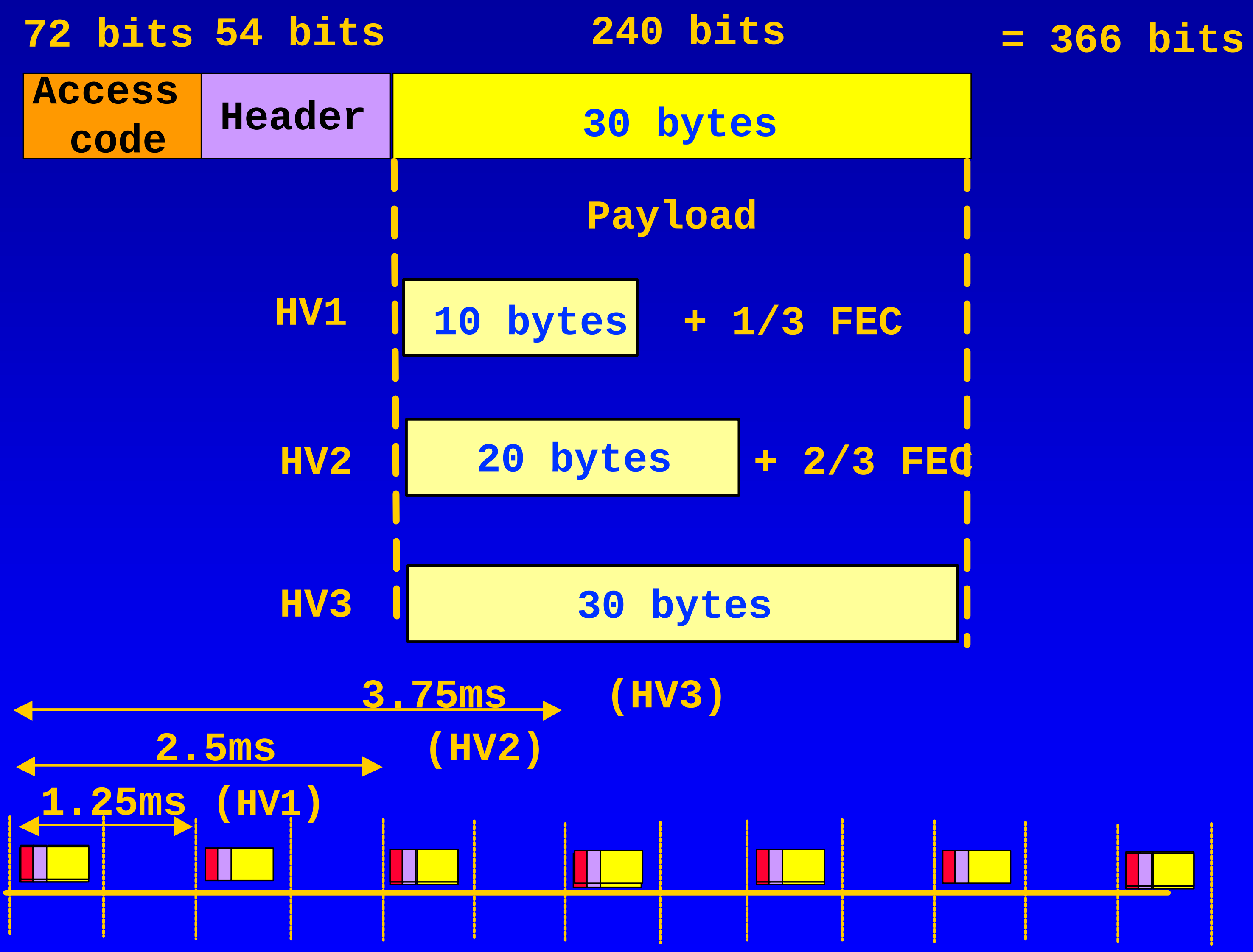
Purpose

- **Addressing (3)** → Max 7 active slaves
- **Packet type (4)** → 16 packet types (some unused)
- **Flow control (1)** → Broadcast packets are not ACKed
- **1-bit ARQ (1)** → For filtering retransmitted packets
- **Sequencing (1)** → Verify header integrity
- **HEC (8)**

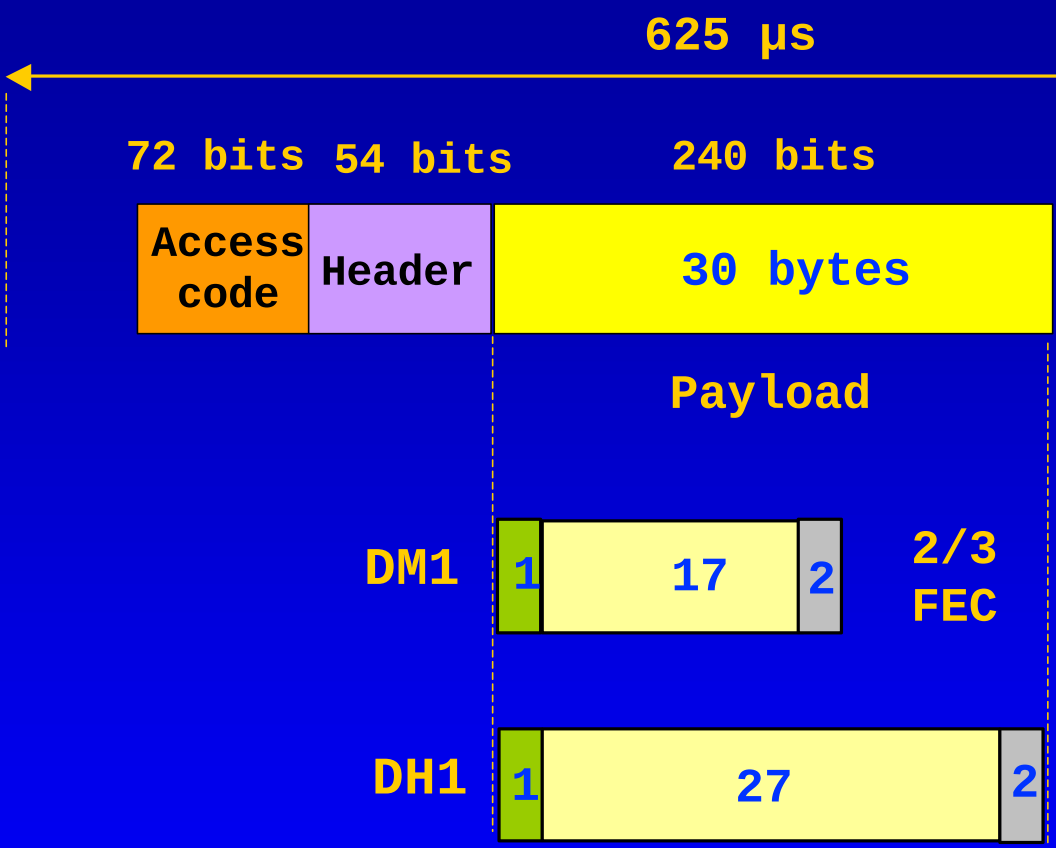
total 18 bits

Encode with 1/3 FEC to get 54 bits

Voice Packets (HV1, HV2, HV3)

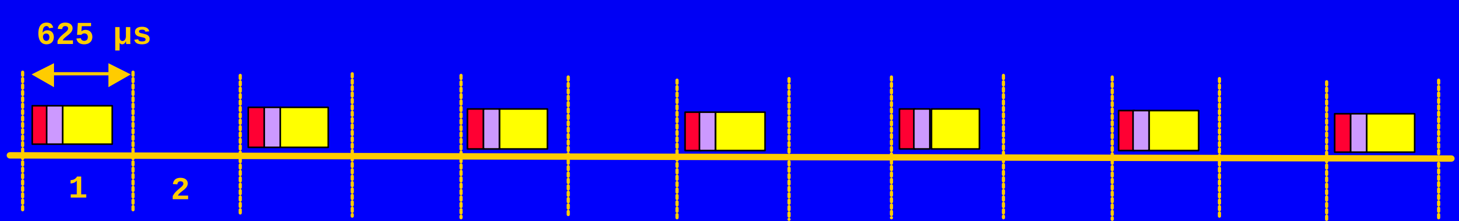


Data rate calculation: DM1 and DH1

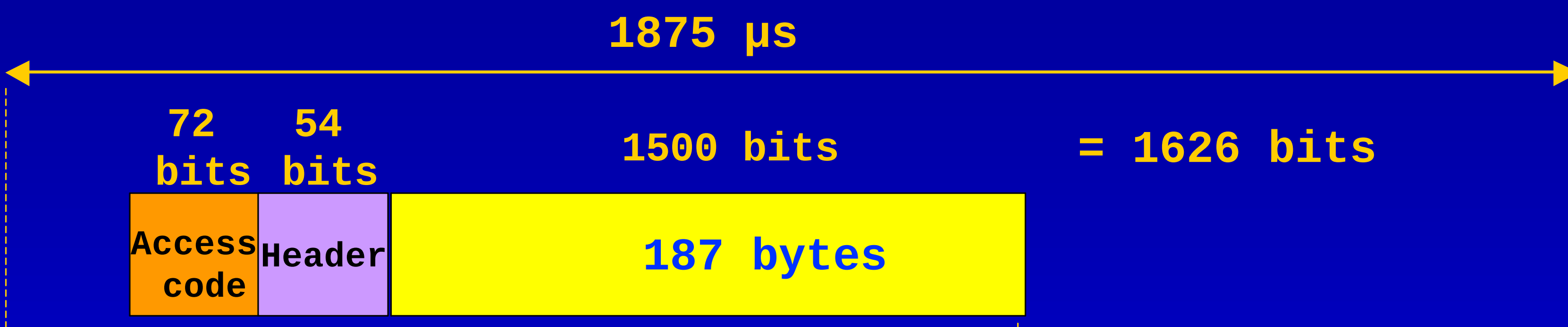


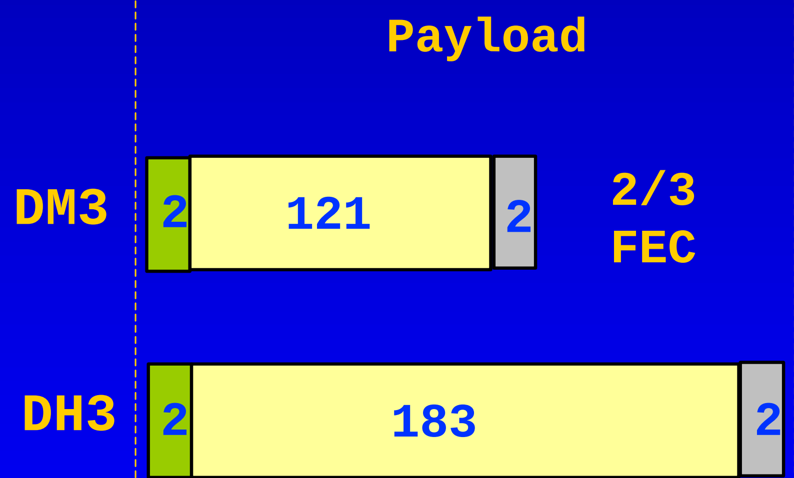
Di	Size	Freq	Rate
r ↑	17	1600/2	108.8
↓	17		108.8

↑	27		172.8
↓	27		172.8



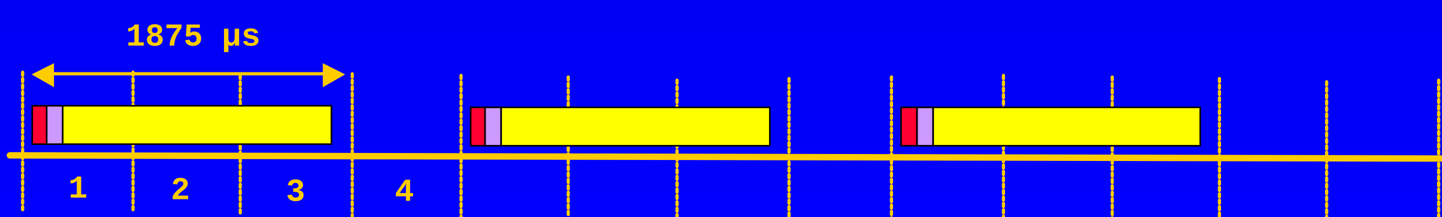
Data rate calculation: DM3 and DH3



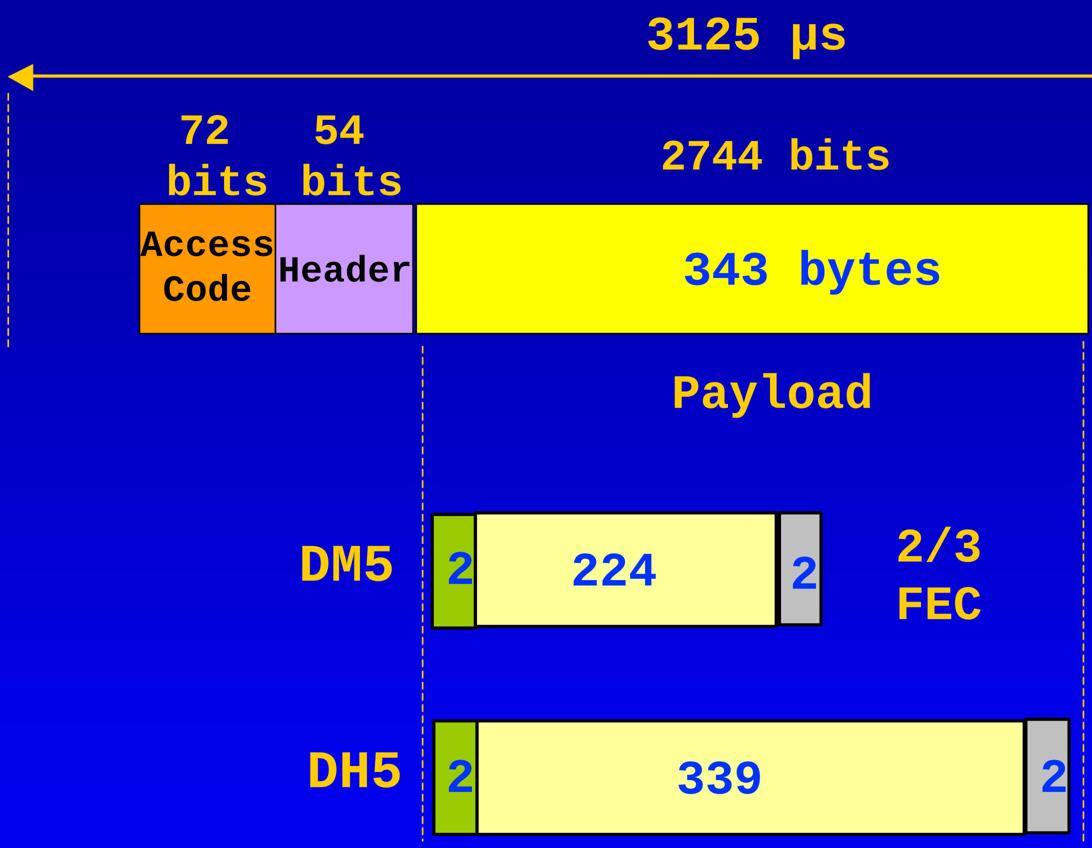


Dir	Size	Freq	Rate
↑	121	1600/4	387.2
↓	17		54.4

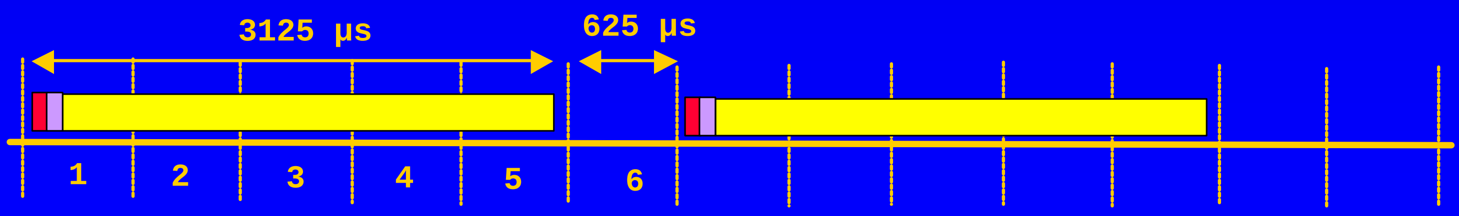
↑	183		585.6
↓	27		86.4



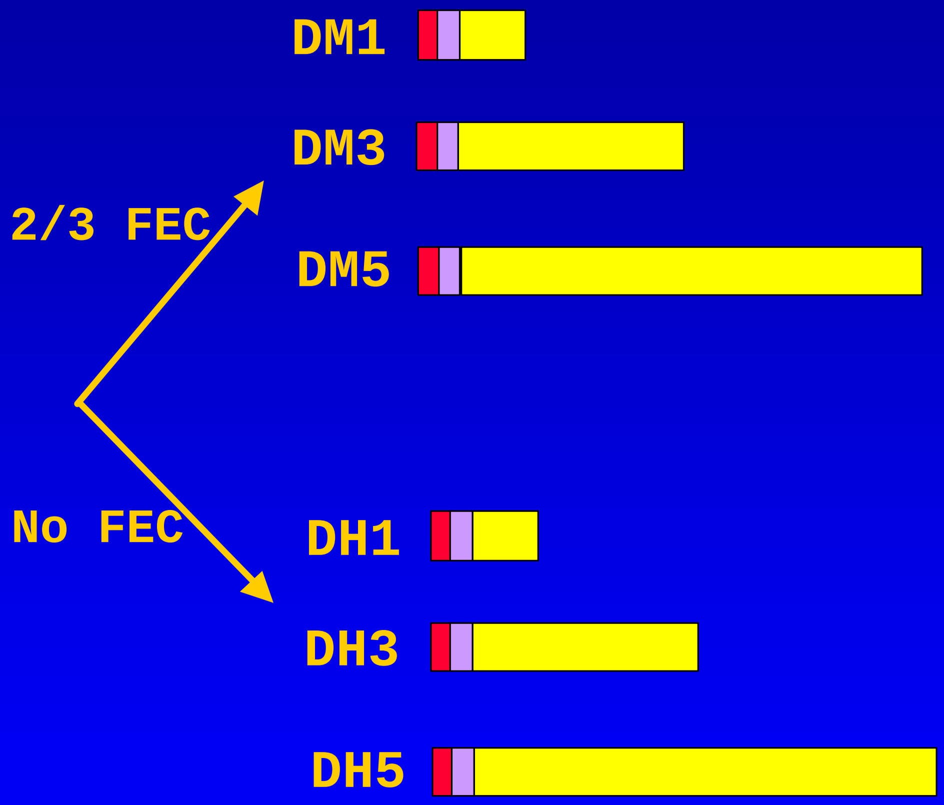
Data rate calculation: DM5 and DH5



Di	Size	Freq	Rate
r↑	224	1600/6	477.8
↓	17		36.3
↑	339		723.2
↓	27		57.6



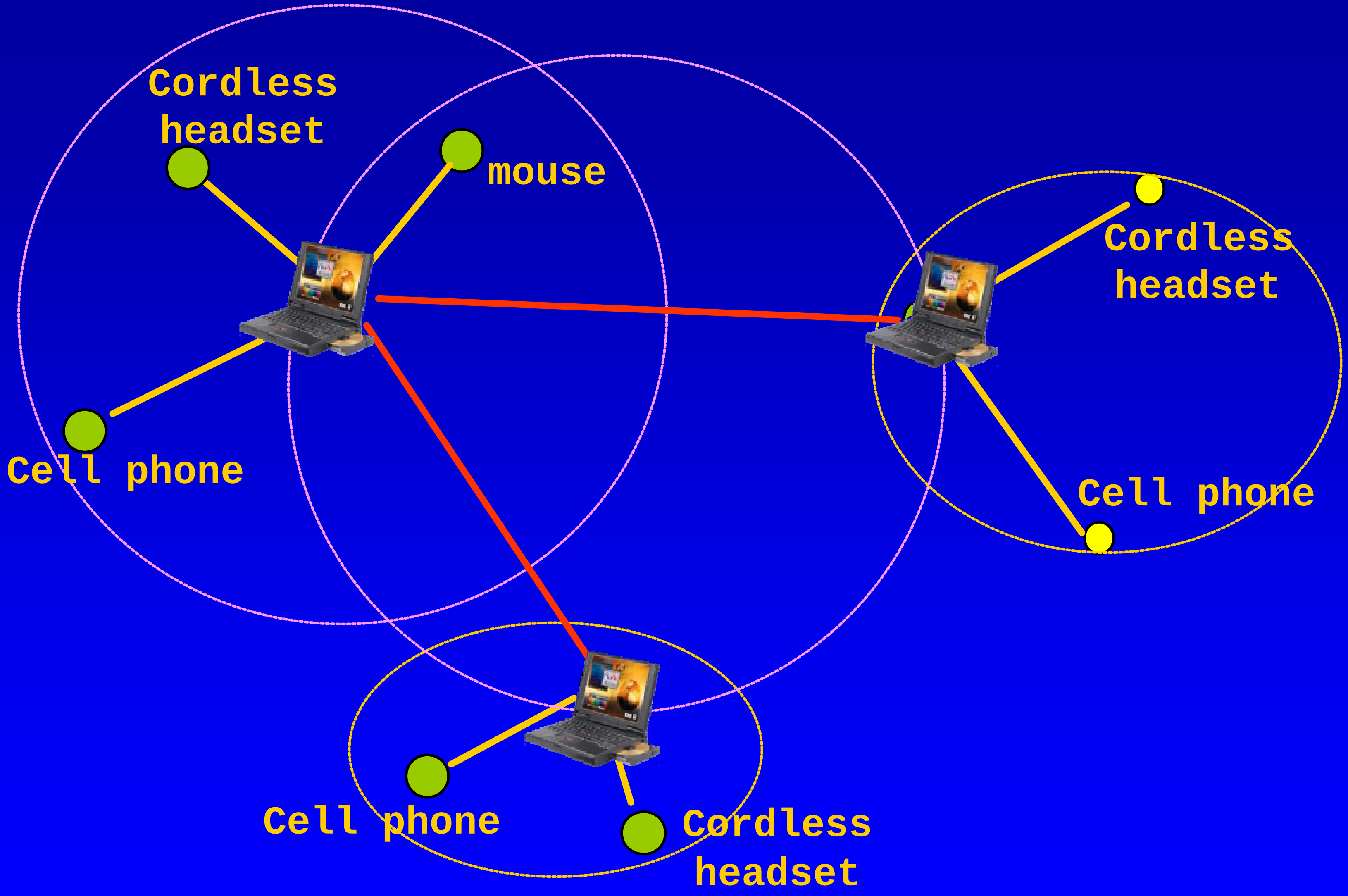
Data Packet Types



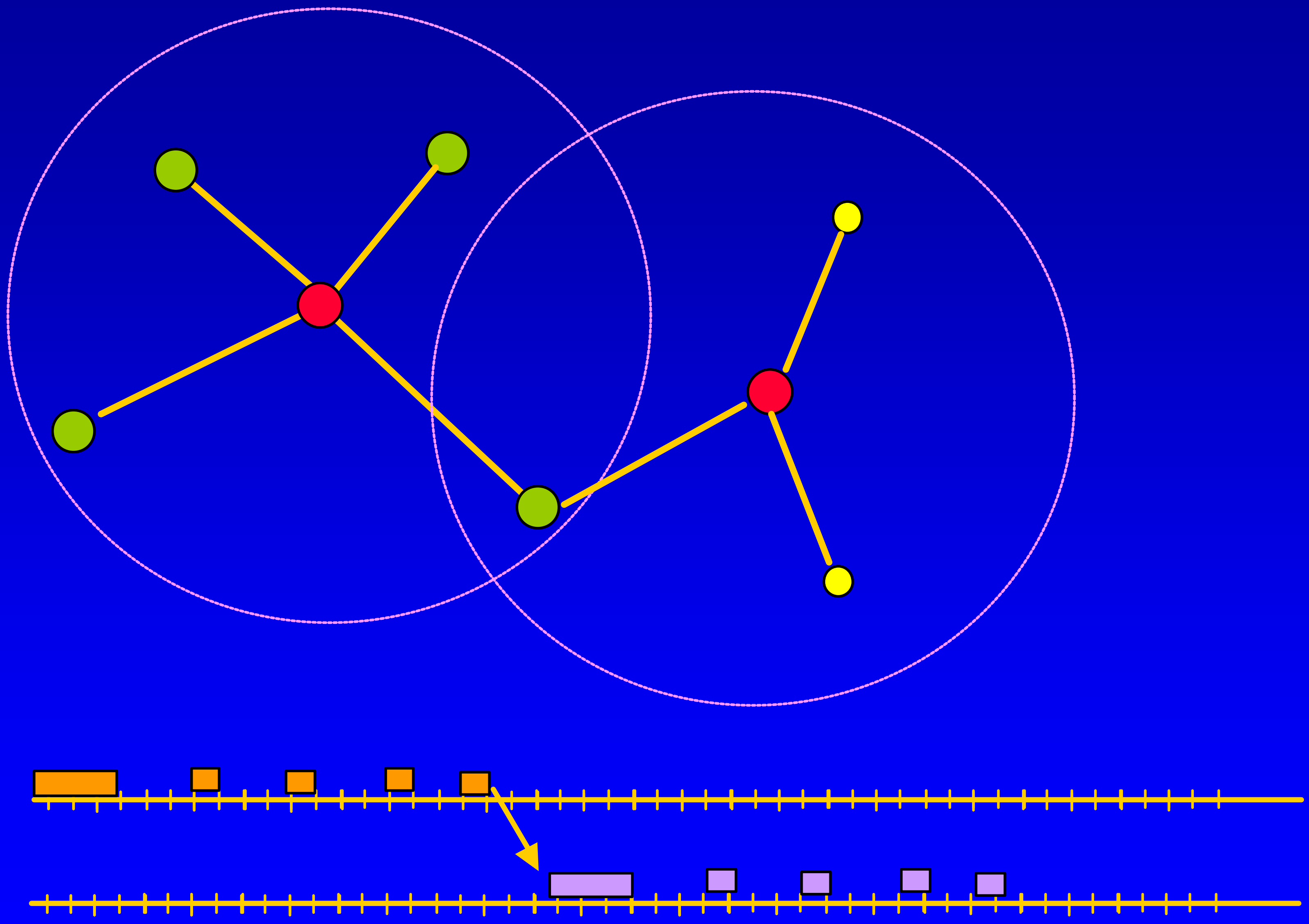
Symmetric	Asymmetric	
108.8	108.8	108.8
258.1	387.2	54.4
286.7	477.8	36.3

Symmetric	Asymmetric	
172.8	172.8	172.8
390.4	585.6	86.4
433.9	723.2	57.6

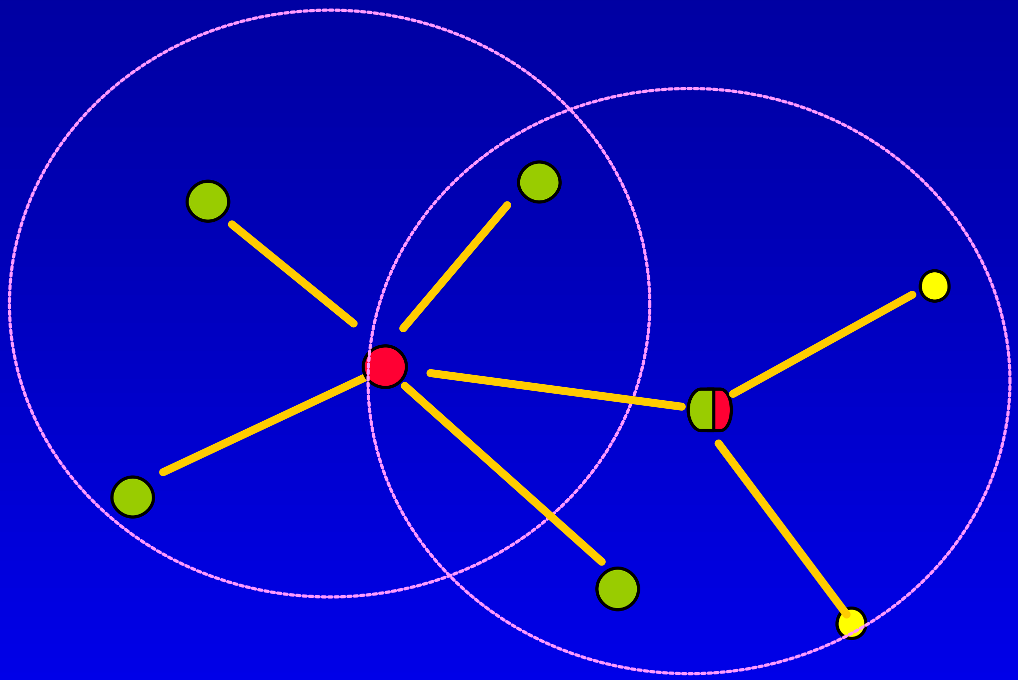
Inter piconet communication



Scatternet



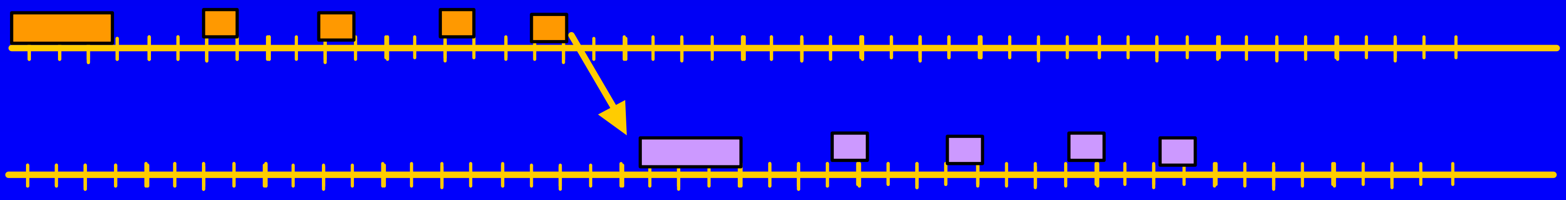
Scatternet, scenario 2



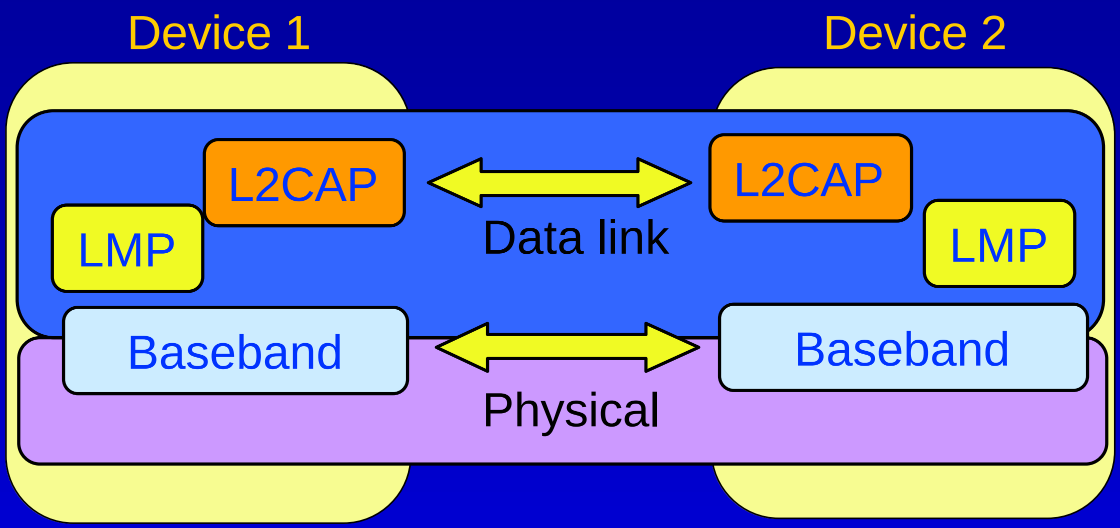
How to schedule presence in two piconets?

Forwarding delay ?

Missed traffic?

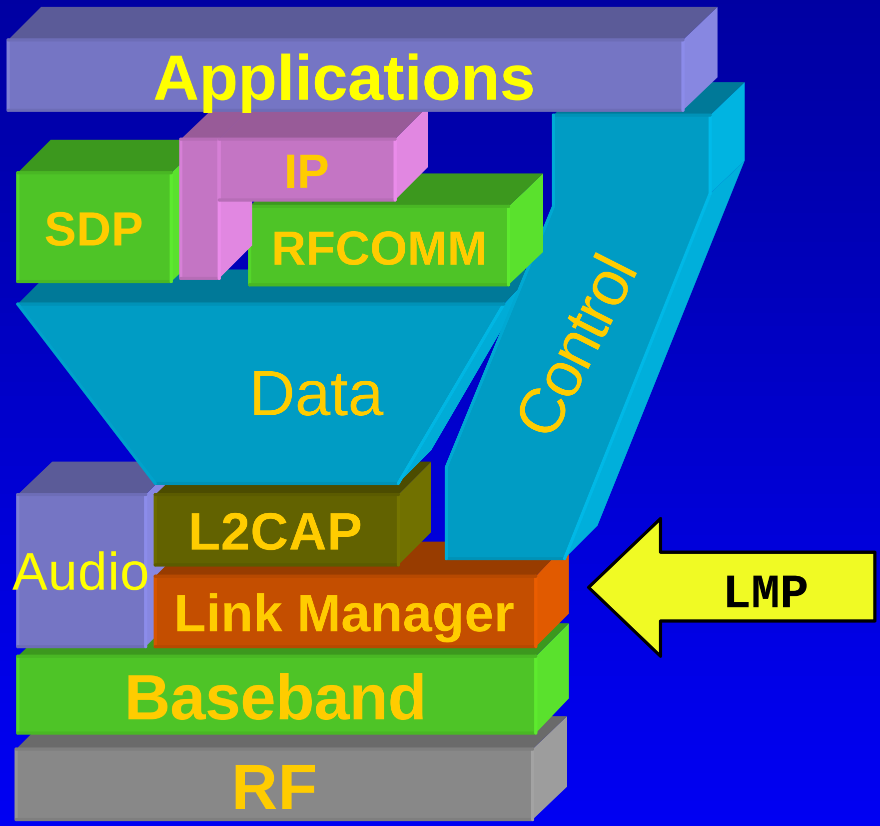


Baseband: Summary



- **TDD, frequency hopping physical layer**
- **Device inquiry and paging**
- **Two types of links: SCO and ACL links**
- **Multiple packet types (multiple data rates with and without FEC)**

Link Manager Protocol

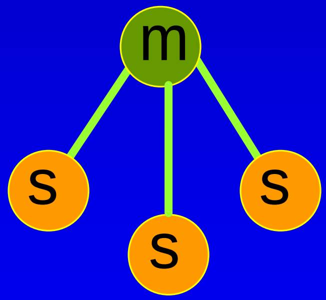


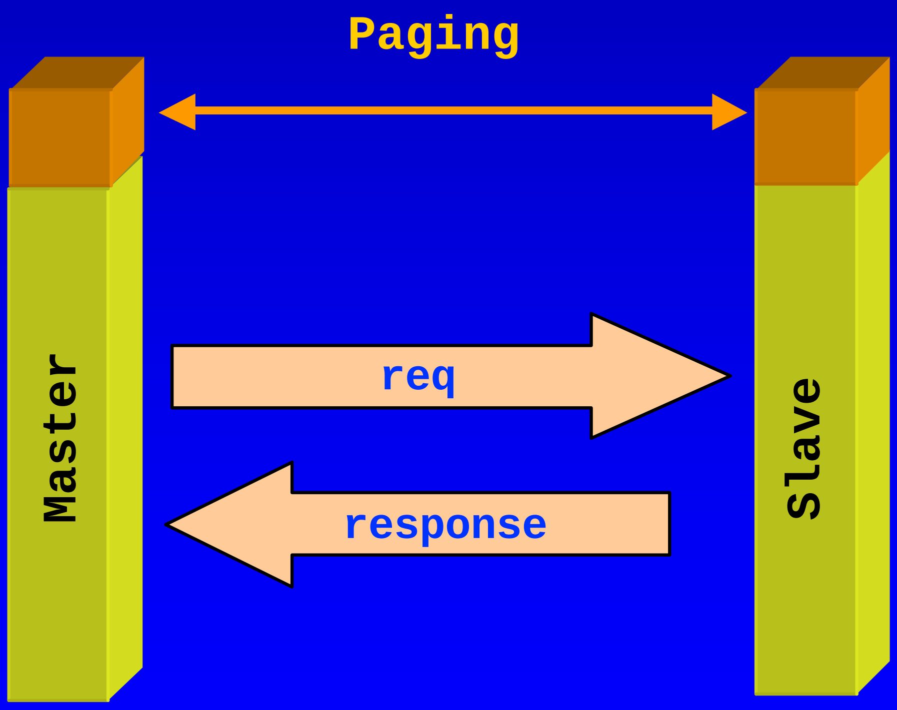
Setup and management of Baseband connections

- Piconet Management
- Link Configuration
- Security

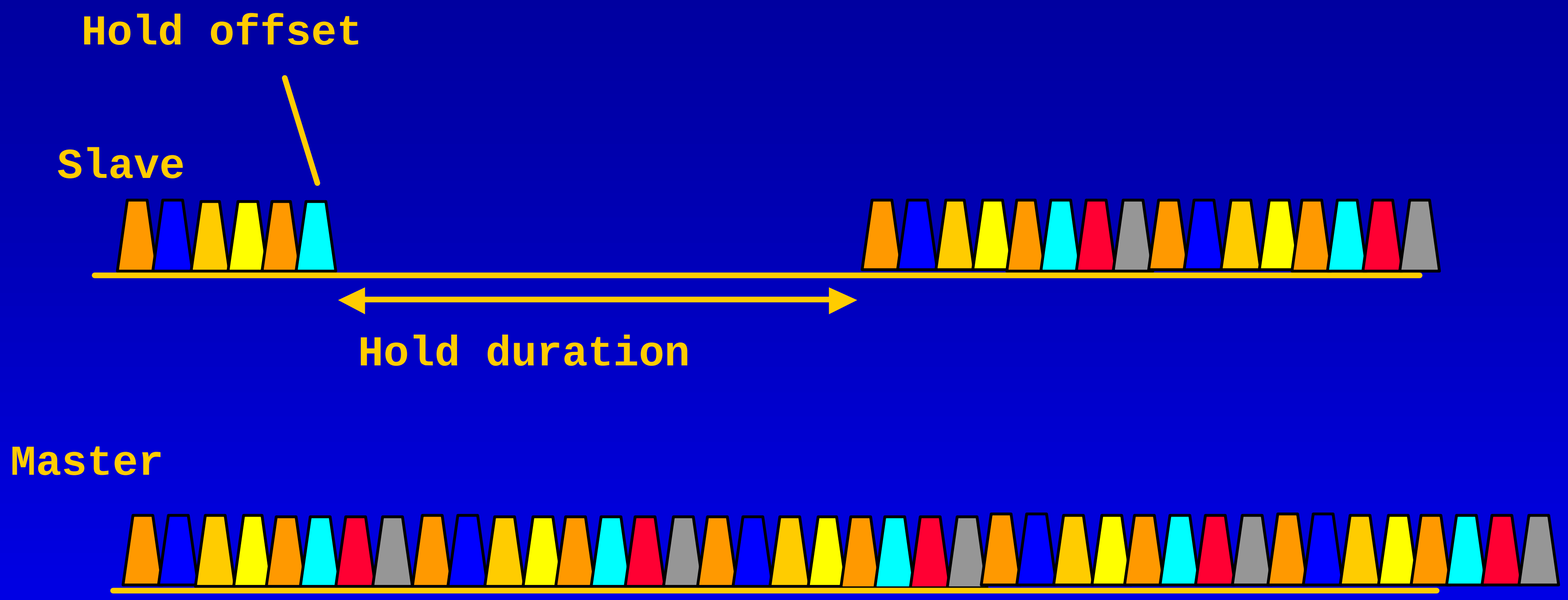
Piconet Management

- Attach and detach slaves
- Master-slave switch
- Establishing SCO links
- Handling of low power modes (Sniff, Hold, Park)

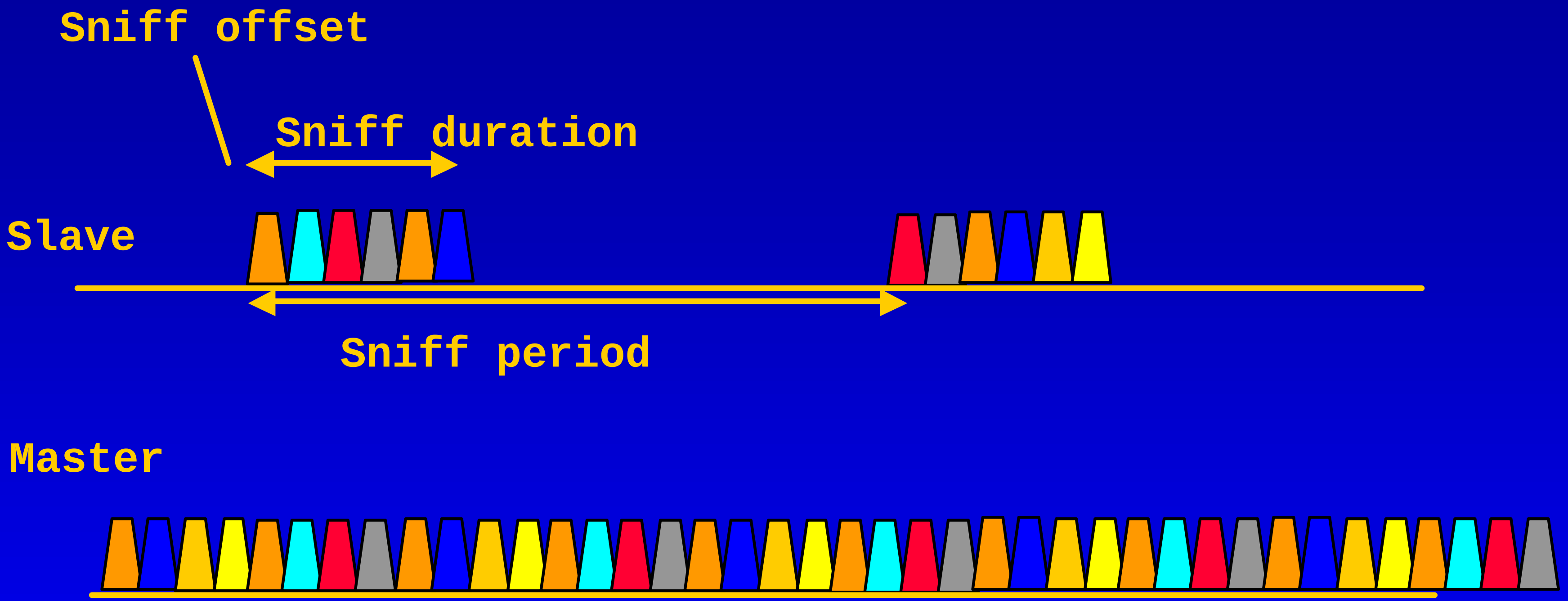




Low power mode (hold)

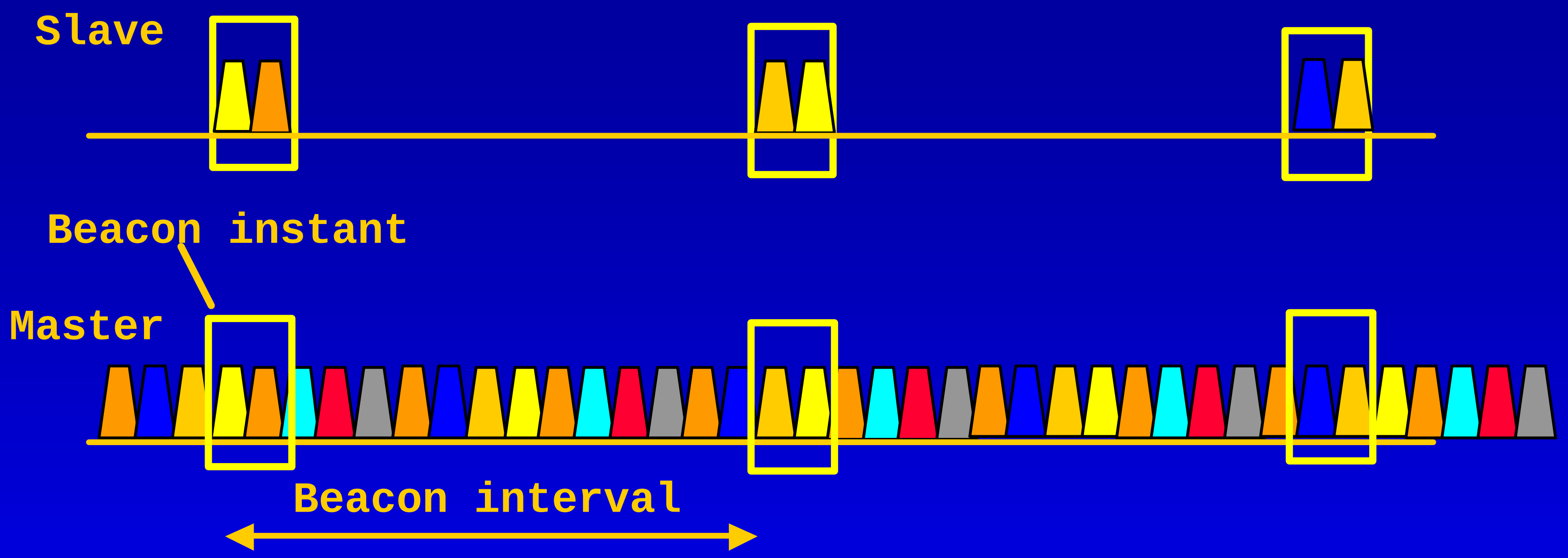


Low power mode (Sniff)



- Traffic reduced to periodic sniff slots

Low power mode (Park)



- Power saving + keep more than 7 slaves in a piconet
- Give up active member address, yet maintain synchronization
- Communication via broadcast LMP messages

Cluster Network Architecture (UCLA-WAMIS)

- **Concept**

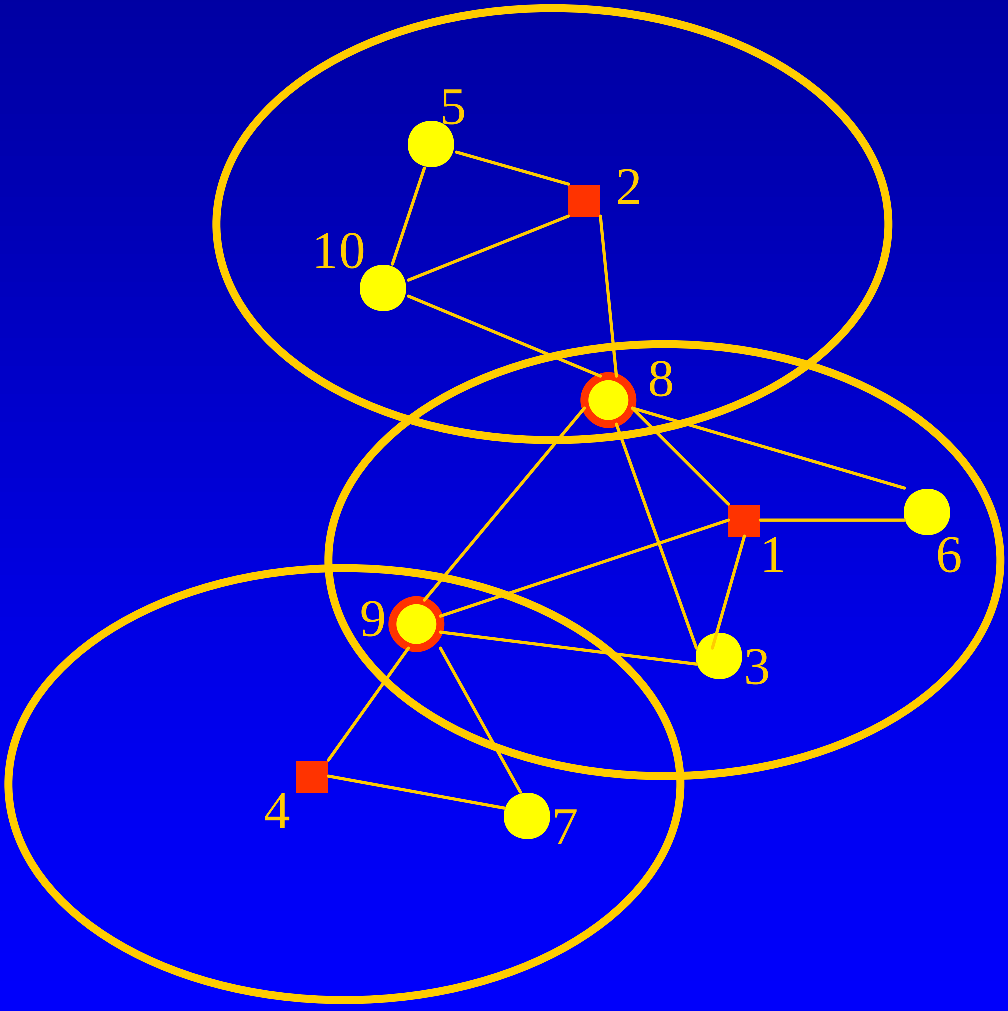
  create a cluster based TDM infrastructure which:

  (a) enables guaranteed bandwidth for voice/video

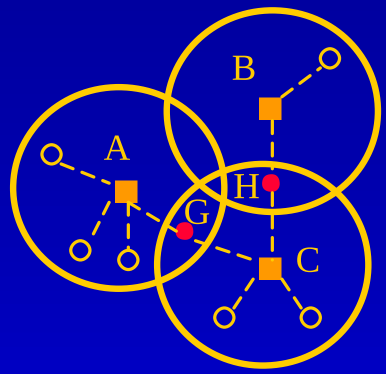
  (b) can support mobility

- **Approach**
  - distributed clustering algorithm
  - time division slotting within each cluster
  - slot reservation for real time traffic
  - virtual circuits for real traffic; datagrams for data
  - code separation across clusters
  - slot synchronization
- **Combines cellular radio and traditional packet radio features.**

Lowest-ID cluster-head election



Distributed Cluster algorithm (lowest-ID)



- **Each node is assigned a distinct ID.**
- **Periodically, the node broadcast the list of nodes that it can hear.**
  - “ClusterHead” hears only nodes with ID higher that itself (unless lower ID specifically gives up its role as CH) ® A,B,C
  - “Gateway” hears two or more CHs ® G,H
  - “Ordinary” node otherwise ®
- **Properties**
  - No cluster heads are directly linked.
  - In a cluster, any two nodes are at most two-hops away, since the CH is directly linked to any other node in the cluster.

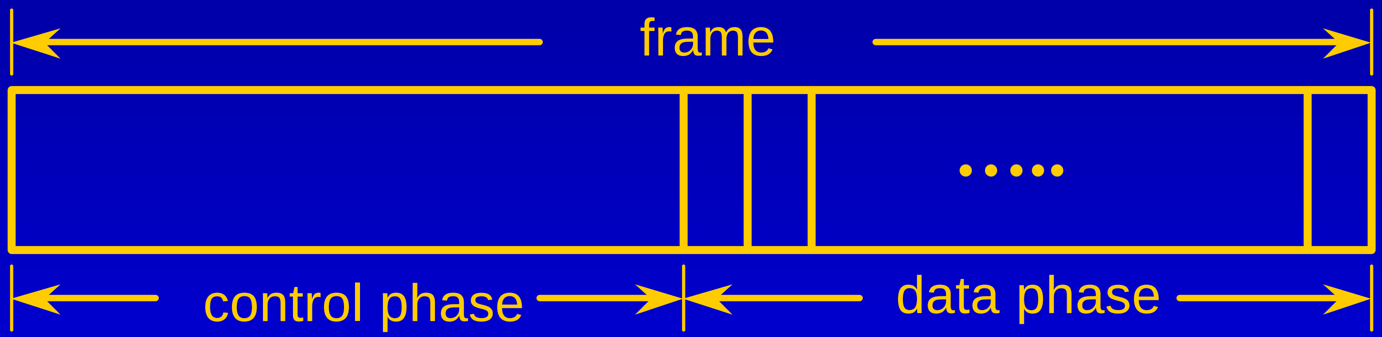
RE: Emphremides, et al “A Design Concept for Reliable Mobile Radio Networks with Frequency Hopping Signaling” Proceedings of IEEE, Vol. 75, No.1, 1987

Cluster network architecture

- **Dynamic, distributed clustering alg. partitions the system into clusters.**
- **Code separation among clusters.**
- **Local coordination provided within a cluster.**
- **Clusterhead acts as local coordinator to**
  - resolve channel scheduling
  - provide power measurement/control
  - support virtual circuit setup for real time (voice and video) traffic
  - maintain synchronization
- **Dynamic adaptation (via periodic updates)**
  - mobility
  - failures
  - Interference
  - bandwidth requirements (B/W alloc.--TDMA slot assgn.)

Channel Access

Within each cluster: time-slotted frame



fixed TDMA

on common code at full power

- **<u>Control Phase:</u>**
  - clustering algorithm
  - routing
  - power measurement and control
  - code and slot assignment
  - VC setup
  - acknowledgments

- **<u>Data Phase:</u>**
  - voice/video (PRMA)
  - data (Random Access)

Virtual Circuit support in WAMIS

Multimedia Traffic (eg, voice, video):

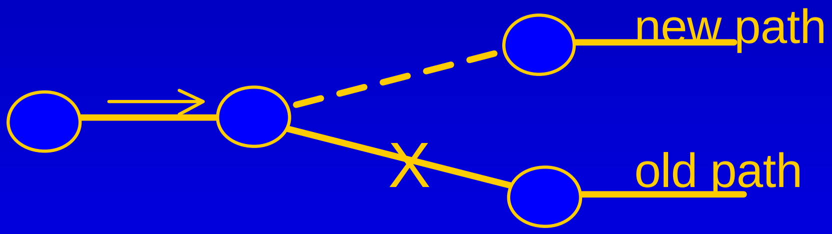
- connection oriented;
- QoS based admission control
- VC based bandwidth allocation

We need:

- robust, QoS enabled routing
- “elastic”, reconfigurable VCs

VC reconfiguration in Mobile Environment

- Conventional VC setup does not work (path breaks up too frequently)
- Proposed approach: Fast Reservations, like in PRMA (Packet Reservation Multi Access)



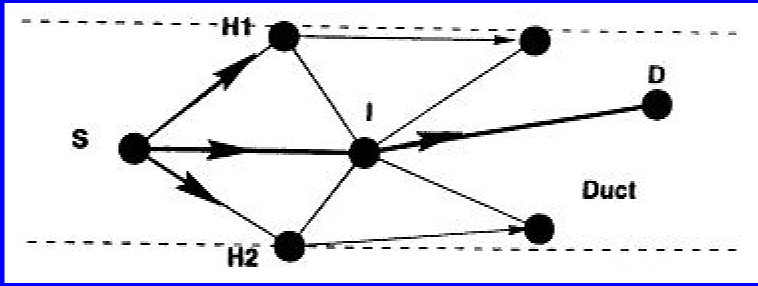
- Packet follow shortest path
- First packet reserves the slot(s) along the path
- When path changes, first packet competes again for slots on new path (voice/video rate reduced by low priority pkt drop)
- If no path, packet is dropped
- reservation released if slot is unused

Case study: compare Random Access and TDMA in Multimedia

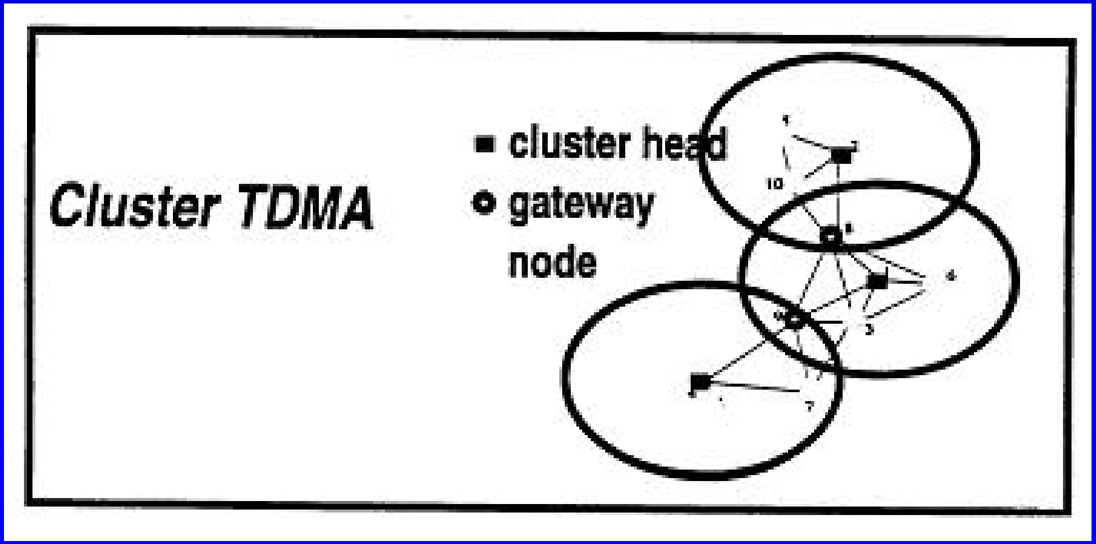
C. Richard Lin and Mario Gerla
Computer Science Department
University of California, Los Angeles

CSMA : DARPA PRNET (1970's)

- **Single channel**
- **Spatial reuse**
- **CSMA**
- **Implicit ACK (echo ACK)**
- **Retransmission (for datagrams only)**
- **Duct routing (for voice traffic)**
  - Based on Bellman-Ford routing
  - Alternate routing: multiple paths used to carry multiple copies of a real-time packet to improve reliability
  - Carrier sense will limit the fan-out



- **Limitation of PRNET**
  - no bandwidth reservations; no access control (for voice)
  - “hidden terminal” problem
- **Enter Cluster TDMA (1994)**
  - different codes in each cluster
  - TDMA type MAC access in each cluster
  - QoS routing; bdw reservation; access control
  - Fast VC set up (soft state)



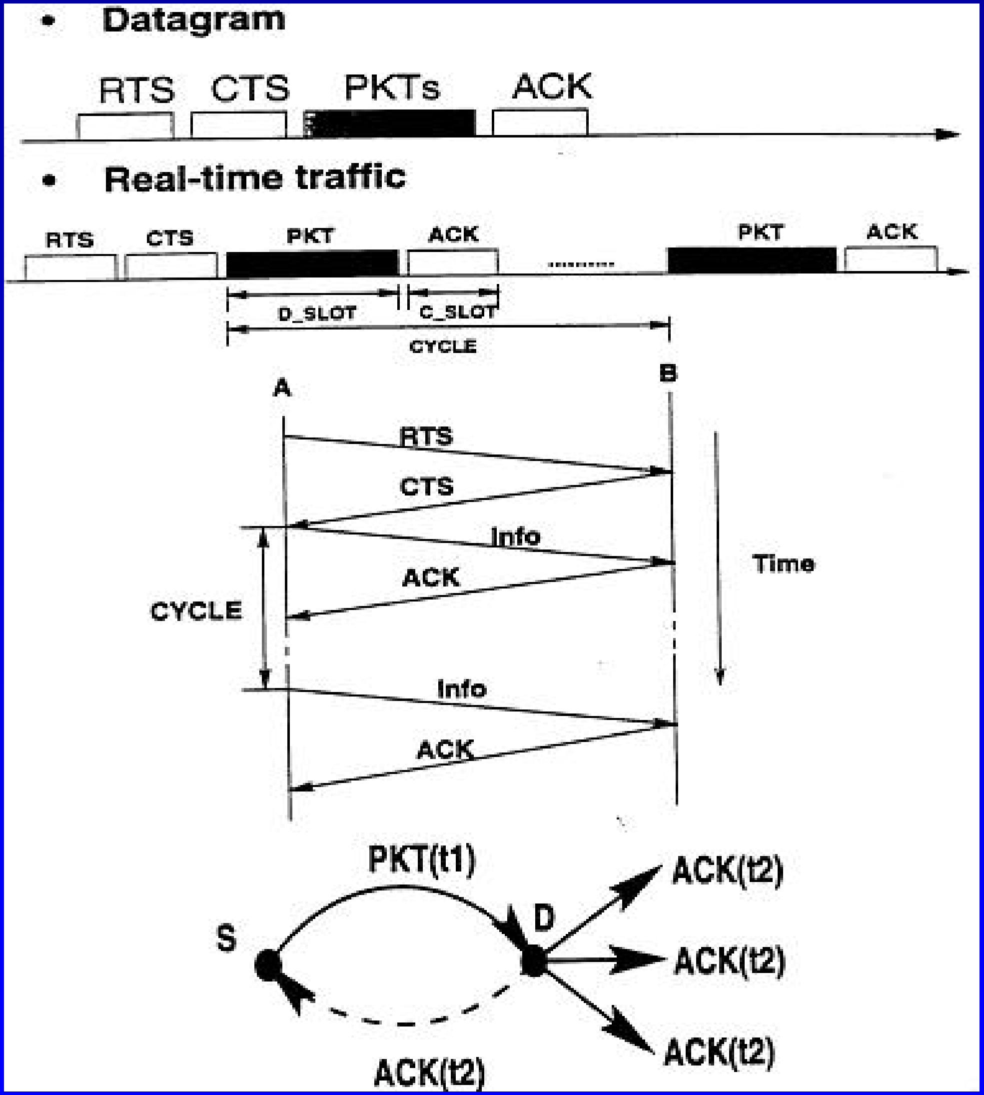
- **Problems of CLUSTER TDMA: cost and complexity**
  - global slot synchronization
  - multiple codes
  - initialization

- **Enter MACA/PR (1996)**

(Multiple Access Collision Avoidance/Packet Reservations)

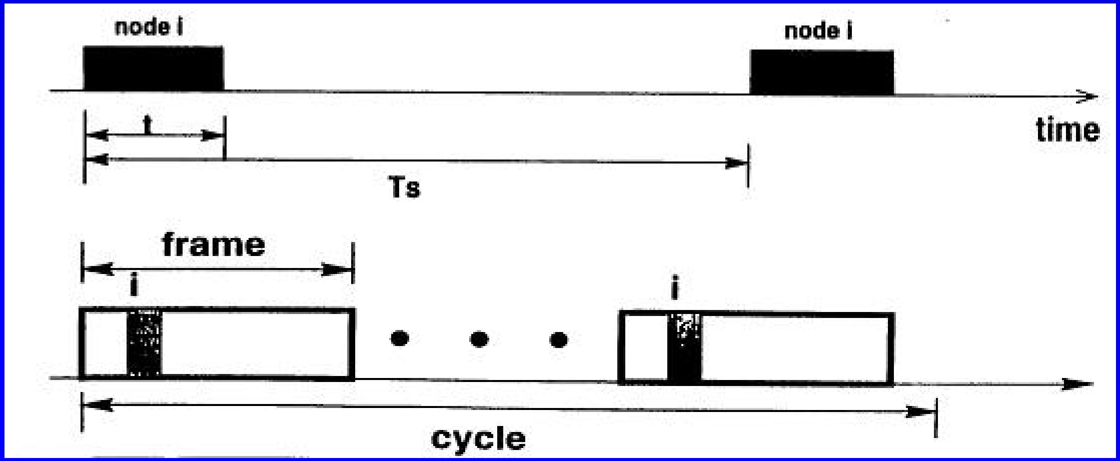
  - no clustering; single code; easy initialization
  - RTS/CTS dialog (to prevent “hidden terminal” problems)
  - Packet Reservations (to support real time traffic)
  - QoS routing; “standby” routs (for dynamic rerouting)

MACA/PR (cont'd)



Real Time Traffic Support: Bandwidth Reservation

- 1st packet is treated as a datagram packet
- After 1st successful transmission: piggyback reservation is honored for subsequent packets
- Bounded delay and no collision
- Real -time Traffic and datagram traffic are interleaved (with datagram deferring to real-time traffic)



Performance Comparison (parameters)

- A 100X100 feet area
- Number of radio station=20
- Frame size =100ms
- Tx range =40 feet
- VC end-to-end hop distance=3
- Maximum speed=8 feet/sec
- Data rate=800kbps
- Pkt size=4kbits; pkt acquisition=500bits
- Multiple VCs,datagram background traffic
- Tx rate = 1pkt/frame
- Call duration=180 seconds.

Performance Comparison of Various Schemes

Synchronous ⟷ Asynchronous

Cluster TDMA	Cluster Token	MACA/PR	PRNET
Global synchronization	Cluster synchronization	Session synchronization	No synchronization

Overall Performance Comparison

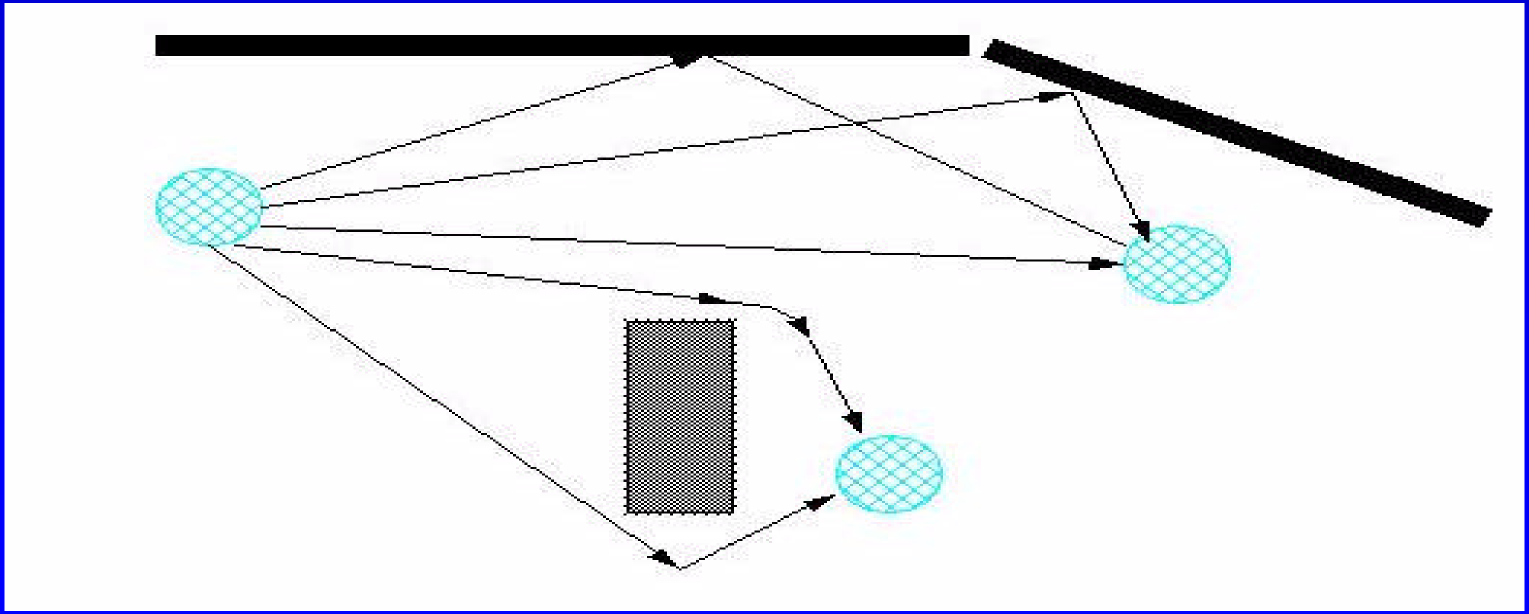
	PRNET	MACA/ PR	Cluster Token	Cluster TDMA
avg VC thrput (pkts/sec)	4.6	9.69	9.88	9.97
total thrput (pkts/sec)	14.54	34.45	95.34	107.70
end-to-end delay (ms)	73.05	66.50	298.80	302.13
avg pkt loss per VC	64.30%	3.07%	1.18%	0.02%

- **PRNET**
  - No bandwidth reservation
  - No acceptance control
  - In heavy load: duct routing generates excessive number of "requests for alternate routes" (congestion)
- **MACA/PR**
  - total VC throughput limited by lack of cluster/code separation
- **Cluster TOKEN and TDMA**
  - high end to end delay due to token/TDMA latency

Channel Propagation Models

Radio channel propagation is characterized by three main parameters:

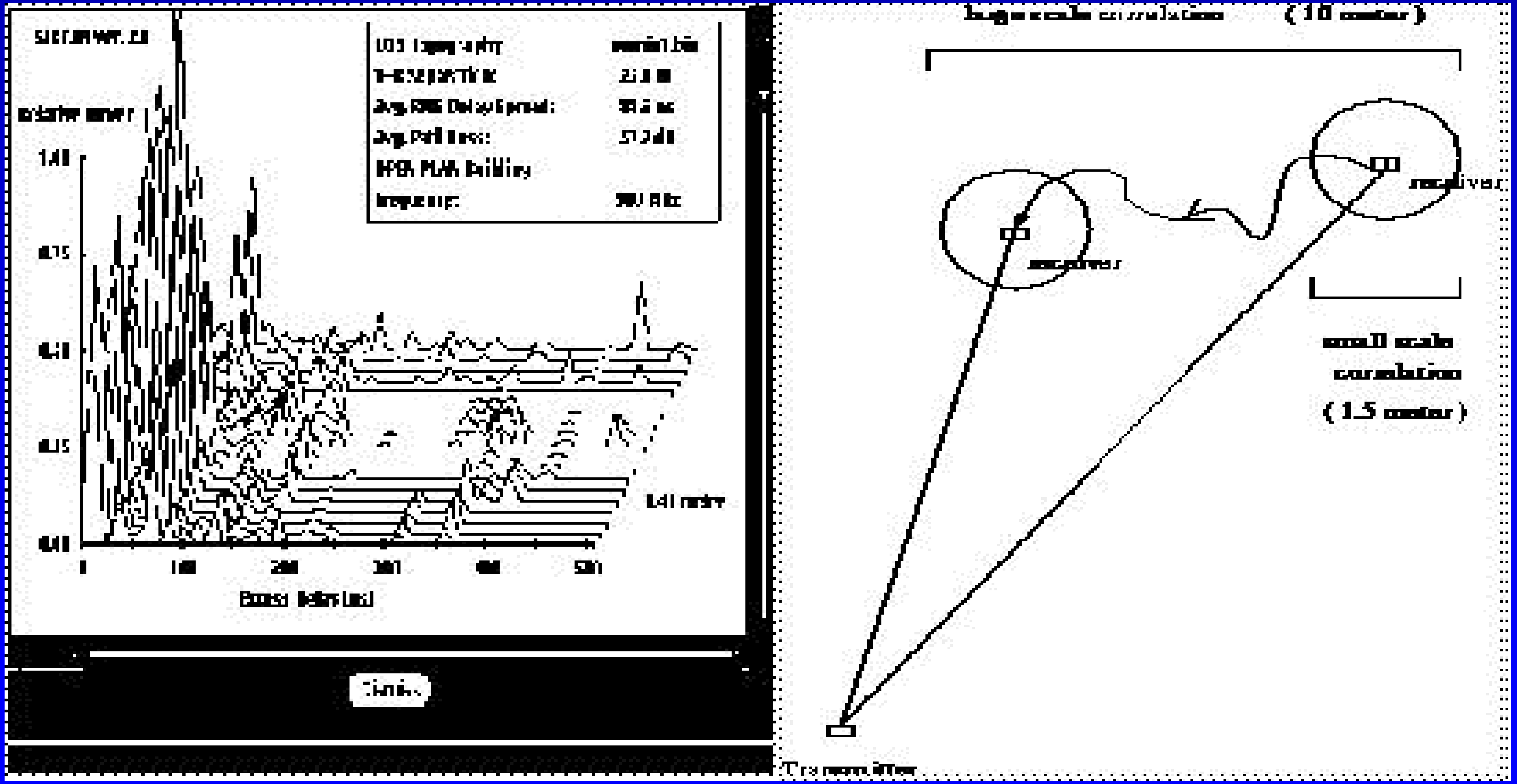
- Attenuation: free space loss, absorption by foliage, partitions
- Shadowing: obstacles between transmitter and receiver
- Multipath: due to the different phases on different paths



Simulator : Glomosim Channel Model

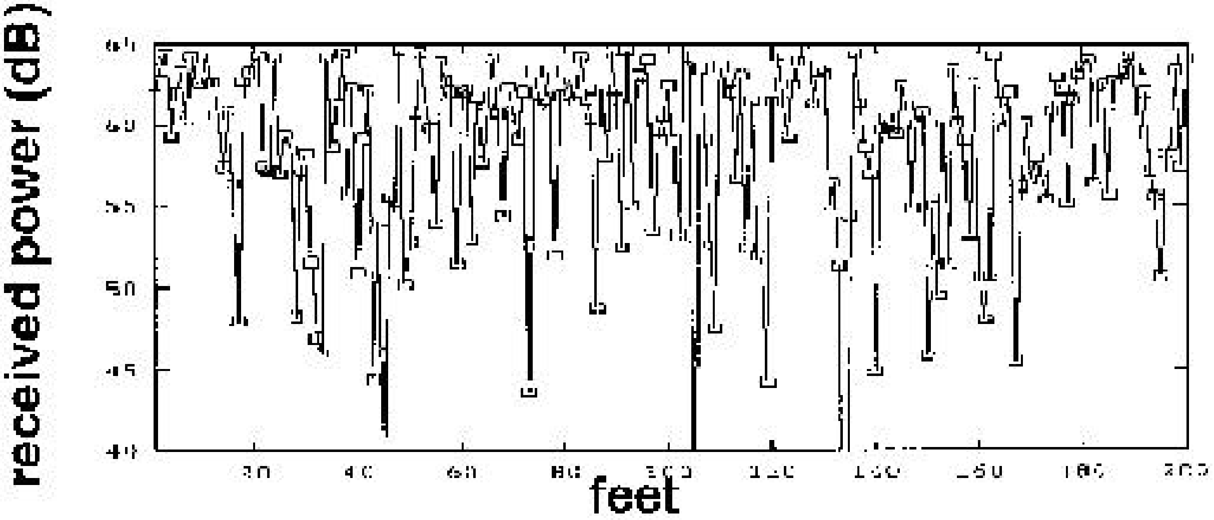
Channel Fading Model in Glomosim Simulator

- the Simulator utilizes the SIRCIM impulse response parameters to characterize the radio propagation model, i.e.: multipath, shadowing effect, spatial correlation



Radio Channel Simulation

- Effect of channel fading on received power and on cluster changes



models	free space	fading
CH changes	0.013	0.538
Cluster Switches	0.047	1.087

20 nodes in 300m x 300m square; tx range = 150 m
max speed = 22 km/hr, avg speed = 2.2 km/hr

VC Performance: free space vs fading model

propagation model	loop free + rate ctrl free sp.	loop free + rate ctrl fading	no rate ctrl free sp.	no rate ctrl fading	no loop free free sp.	no loop free fading
pkts rcved	99.8%	89.4%	81.2%	45.9%	99.6%	85.7%
pkts dropped	0.2%	10.6%	18.8%	55.1%	0.4%	14.3%
out of seq	1.0%	18.4%	0.6%	6.0%	0.7%	19.8%
fraction of time when rate was reduced by half	0.7%	16.4%	N/A	N/A	1.1%	16.3%
mean delay	1.17	2.70	3.11	9.22	1.03	2.47

20 nodes in a 300m X 300m square; tx range = 150 m
max speed = 11 km/hr, avg. speed = 1.1 km/hr