

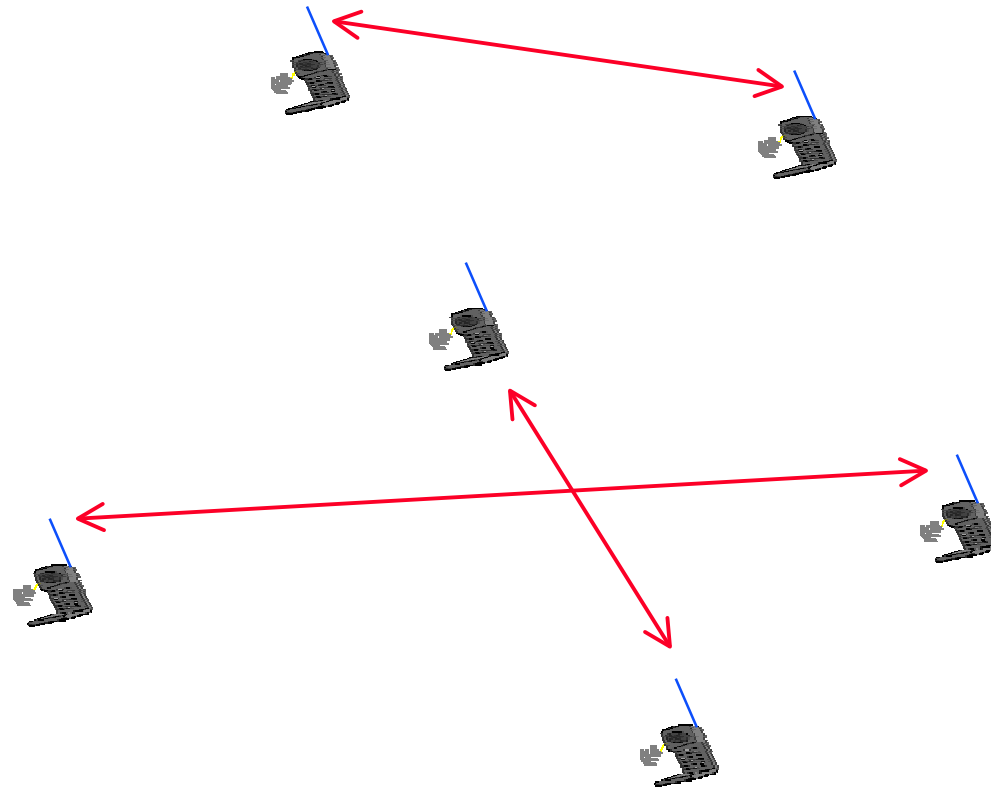
# Mobile Radio Communications

## Session 9: Bluetooth



# System classification

- Ad-hoc connectivity



# Embedded connectivity



# Core design issues

- **Ad-hoc connectivity**
- **Radio spectrum**
- **Low-cost implementation**



# Ad-hoc connectivity

**Definition:** *In an ad-hoc network, there is no (wired) infrastructure to support the connectivity of the portable units.*

**no basestations or terminals**

**no up or downlinks**

**no central controller/registration**

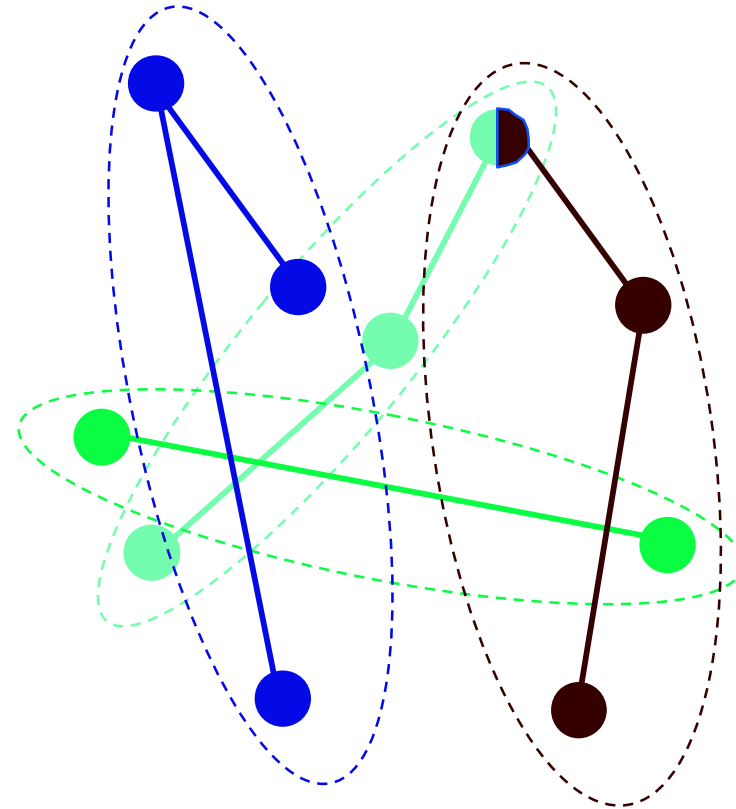
**no control channel to lock to**

## PEER-TO-PEER CONNECTIONS



# Scatternet chaos

- uncoordinated channels
- TX powers vary
- irregular traffic
- near-far problems
- non-stationary



**ROBUSTNESS**  
**GRACEFUL DEGRADATION**



# System design issues

- **Channel definition & allocation (MA)**
- **Medium access (MAC)**
- **Call setup**
- **Power management (standby)**
- **Traffic management (QoS)**

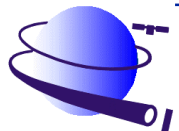


# Radio spectrum

- **Global availability**
- **Unlicensed**
- **Non-dedicated (e.g. DECT, HIPERLAN)**
- **Co-existing and sharing with other applications**
- **Regulatory bodies: FCC/ETSI/ARIB**

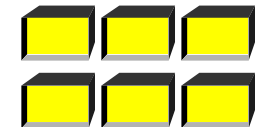
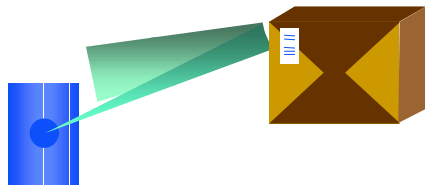
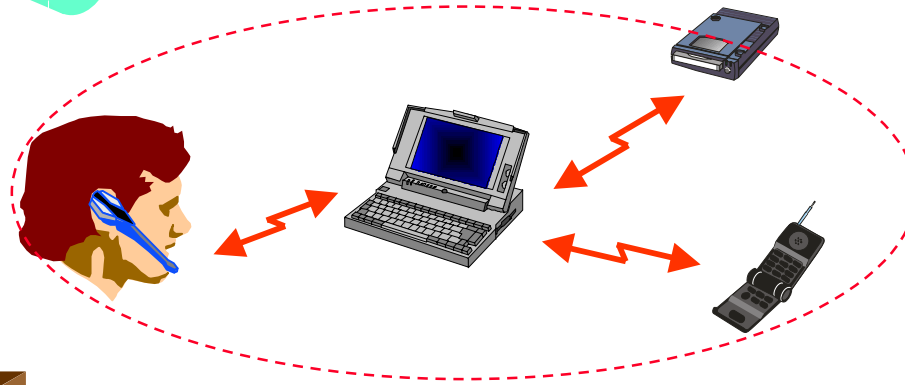
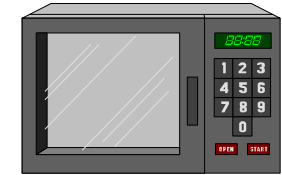
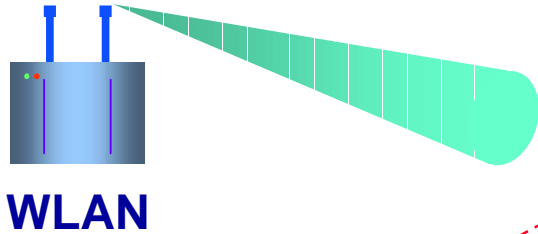
**Industrial - Scientific - Medical (ISM) band**

**2400-2483.5 MHz**





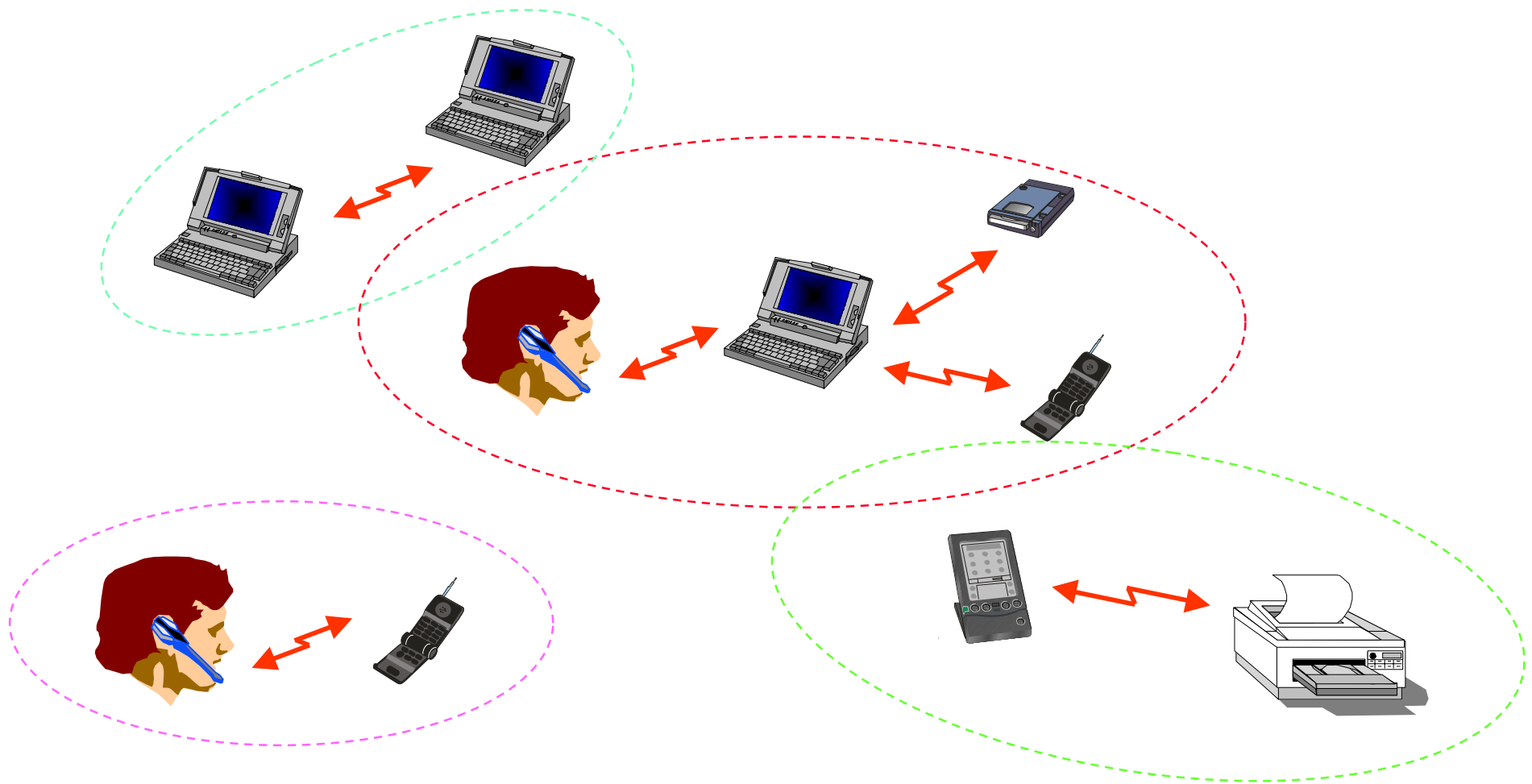
# Spectrum sharing



RF lighting

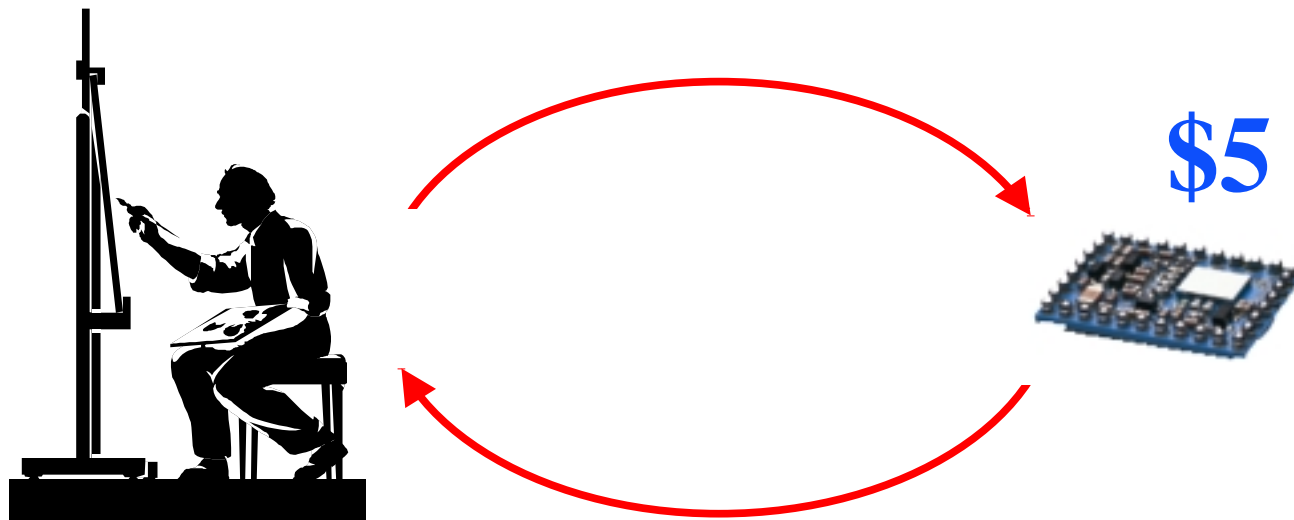


# Spectrum sharing



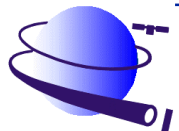
# Low-cost implementation

- Prepared for single-chip integration
- Main-stream technology



**air protocol design**

**transceiver design**



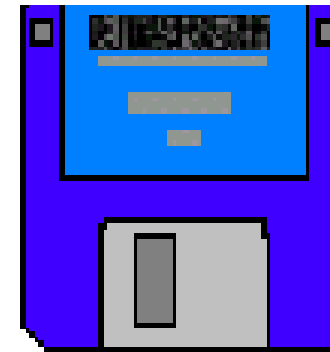
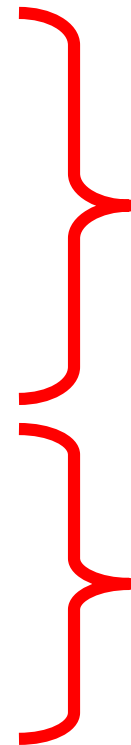
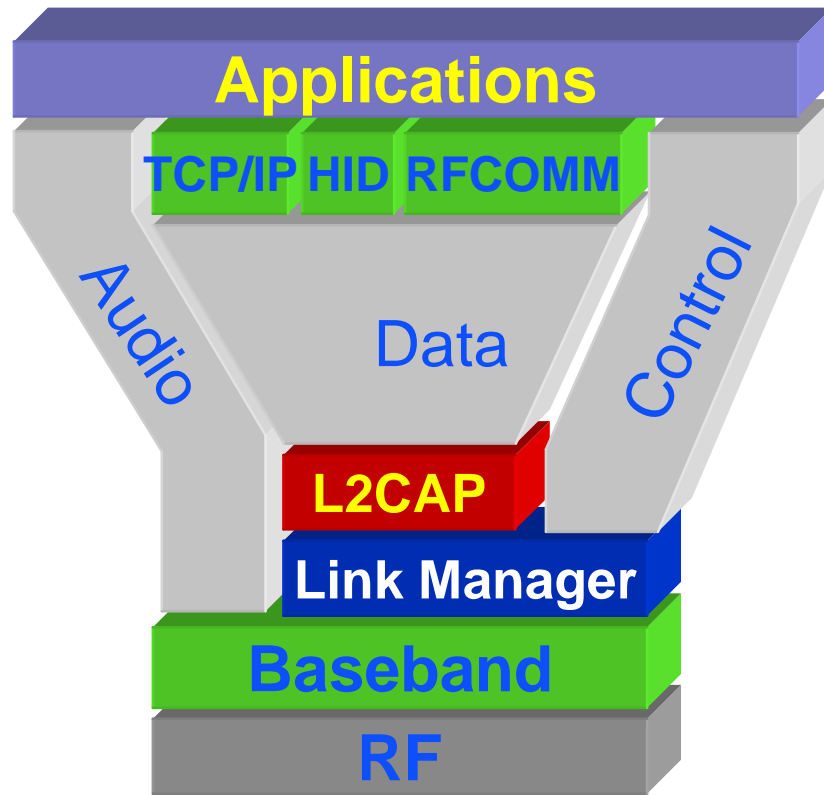
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ENGINEERING

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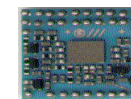
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OF  
TWENTE



# Protocol stack



an application framework



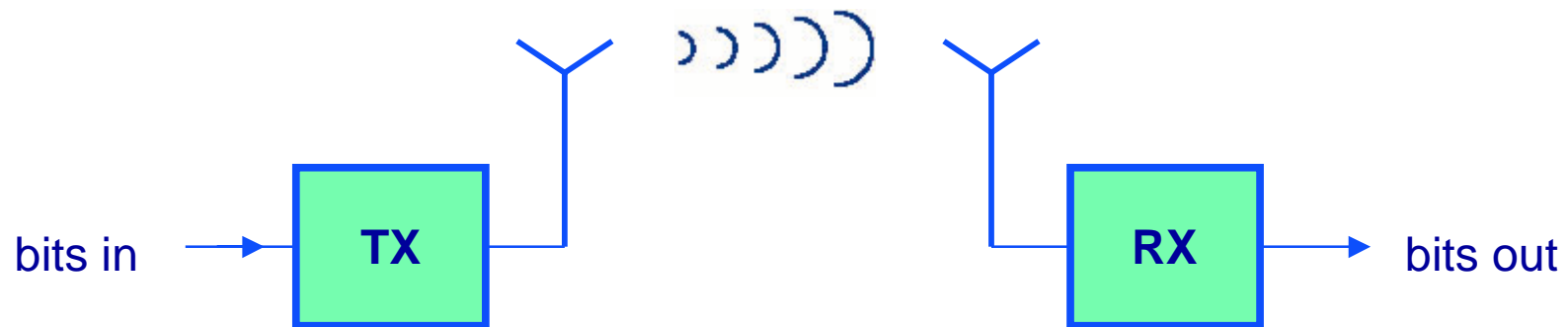
a hardware description



# RF layer

- **Basic radio functions**

- signal amplification
- frequency synthesis
- frequency up & downconversion
- modulation & demodulation
- conversion bits into symbols
- filtering & shaping



# Baseband layer

- **Real-time operations**
  - time slotting
  - frequency hopping
  - synchronization
  - packet handling
  - error correction
  - basic connection establishment



# Link Manager Protocol (LMP)

- **Non real-time operations**
  - attach/detach units
  - link handling and supervision
  - security operations
  - low-power modes



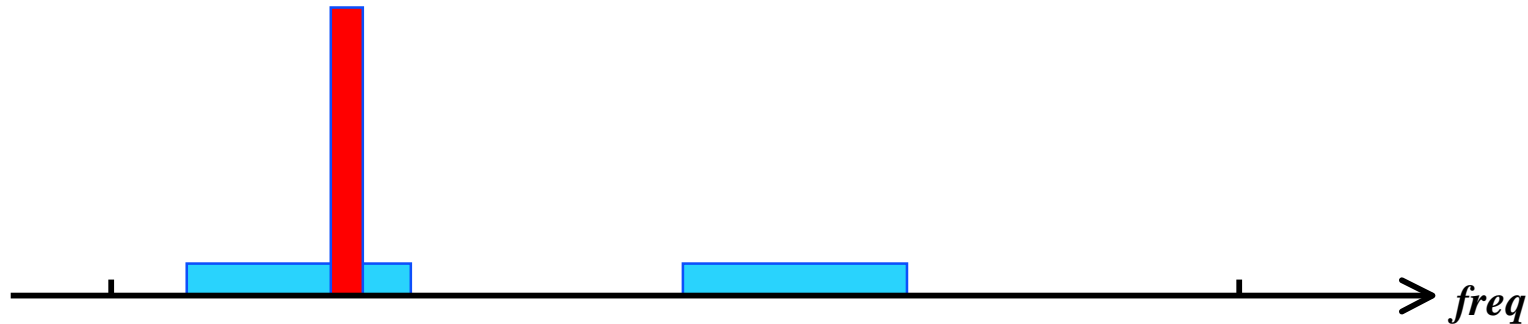
# Logical Link Control and Adaptation Protocol (L2CAP)

- **Adaptation layer**
  - link multiplexing
  - segmentation & reassembly
  - quality of service





# Radio resource management



- Varying jammer location: use entire ISM bandwidth
- Varying jammer power: use as small bandwidth as possible

~~**BROAD BAND:**~~

- near-far problems

**NARROW BAND:**

~~- dynamic frequency selection~~

- frequency hopping



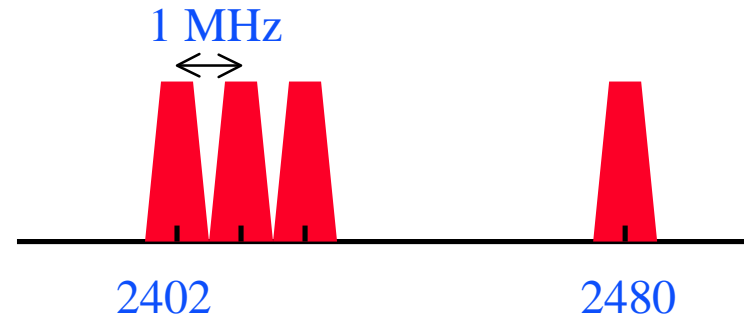
# Signal spreading

- **FH spread spectrum**
  - broadband on average / narrowband instantaneously
  - filter rejection: avoiding most of the interference
  - multiple access scheme: **FH-CDMA**

## FILTER AND SURVIVE



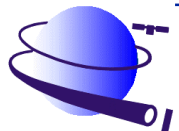
# Bluetooth FH parameters



- 79 carriers, spaced at 1 MHz

$$f = 2402 + k \text{ MHz}, k = 0, \dots, 78$$

- lower guard space: 1.5 MHz
- upper guard space: 3 MHz
- 1600 hops/s nominal hop rate

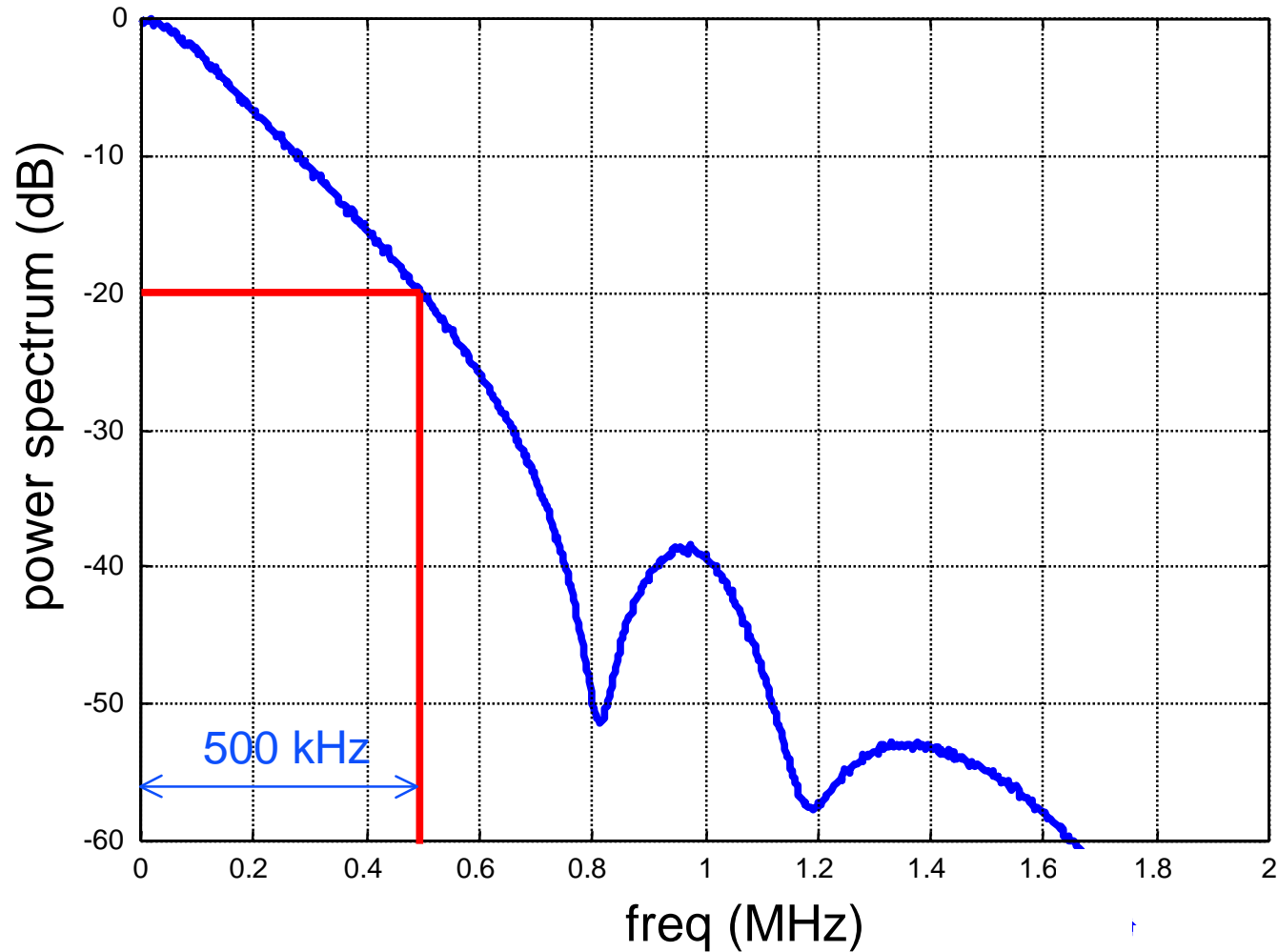


# Bluetooth modulation parameters

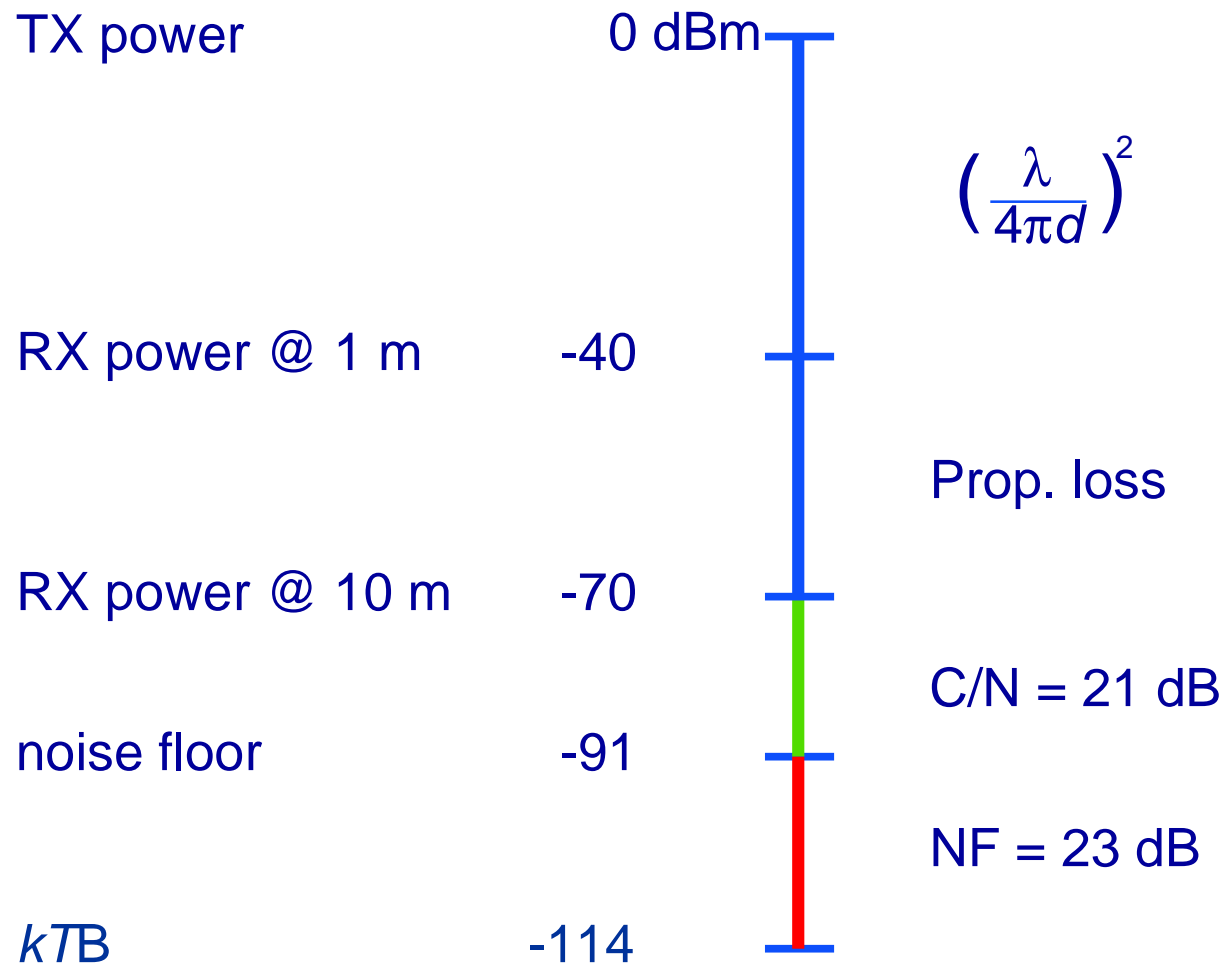
- 1 Ms/s FSK modulation:  $0.28 < h < 0.35$
- Gaussian shaping:  $BT = 0.5$
- nominal bit rate  $R_b = 1 \text{ Mb/s}$
- 20dB spectral bandwidth: 1 MHz



# Radio transmit spectrum



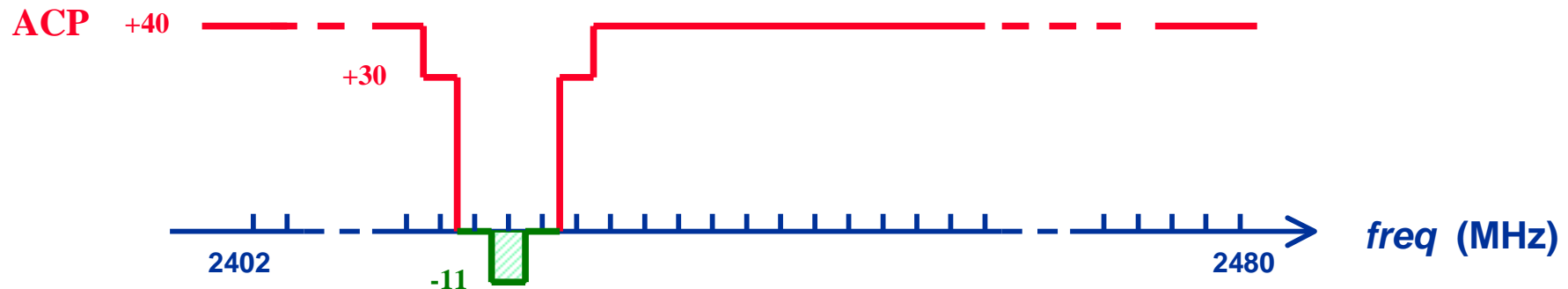
# Link budget



# Receiver selectivity

- **Channel filter requirements**

- 0dB protection ratio 1st adjacent (30 and 40dB for 2nd and 3rd, resp.)
- 9dB protection ratio image (20dB @ 1MHz from image)



## FILTER AND SURVIVE



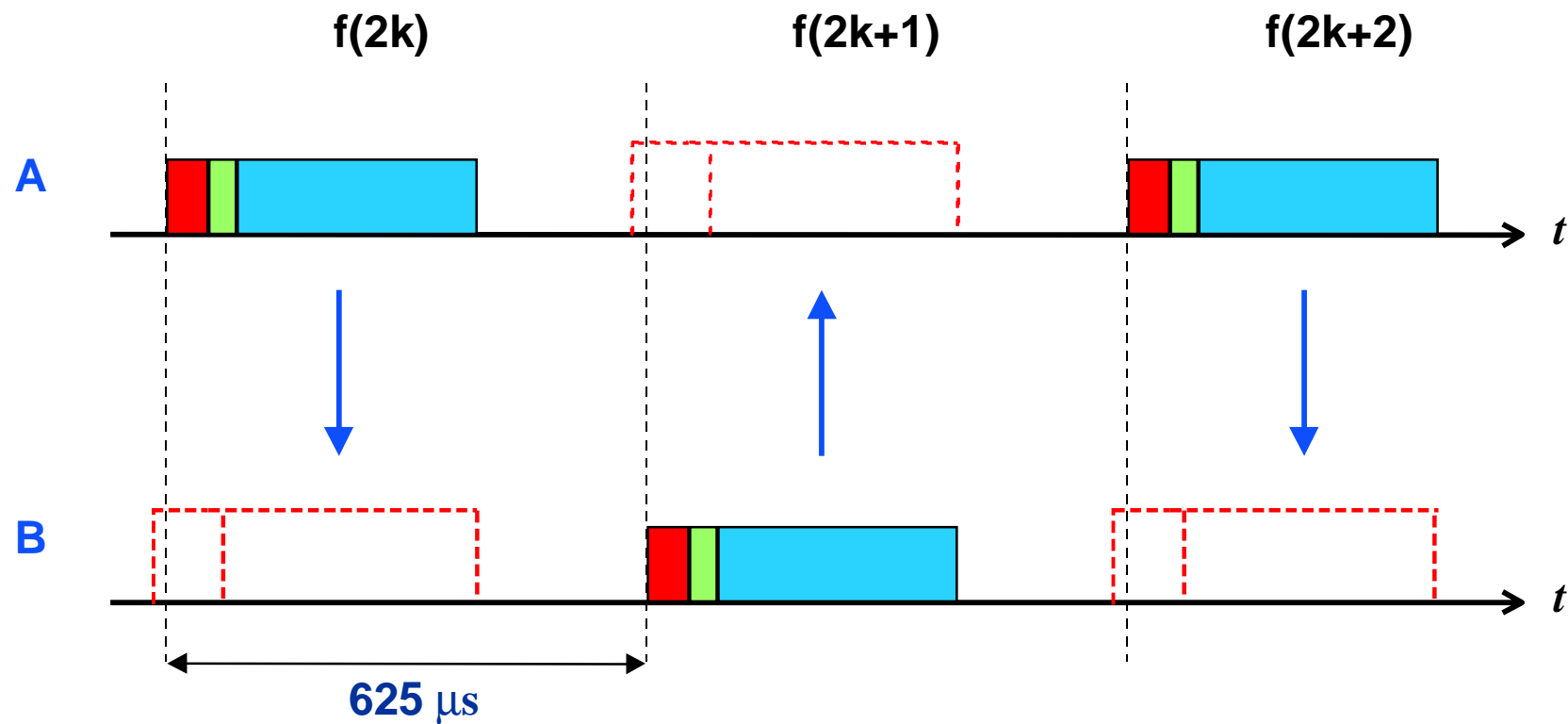
# The bluetooth channel

- Time slotted
- Time division duplex (TDD)
- $T_{\text{slot}} = T_{\text{dwell}}$



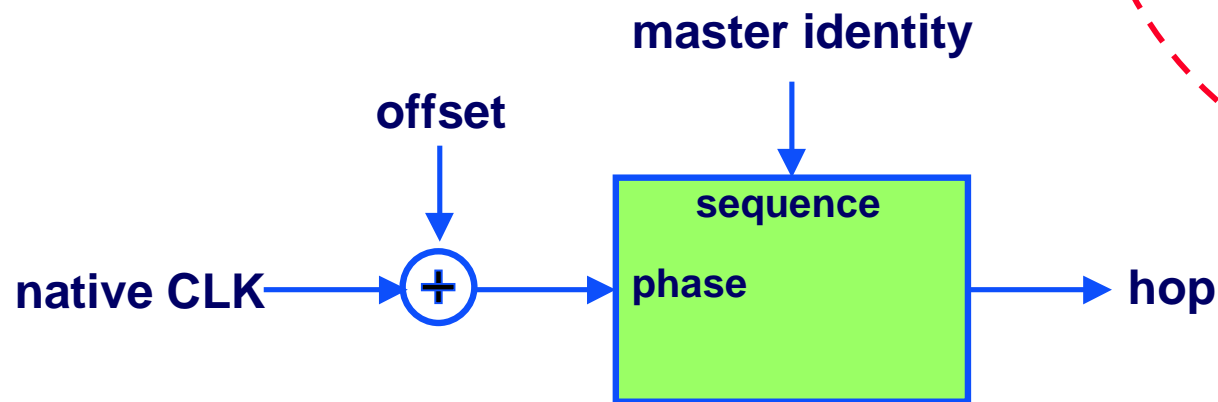
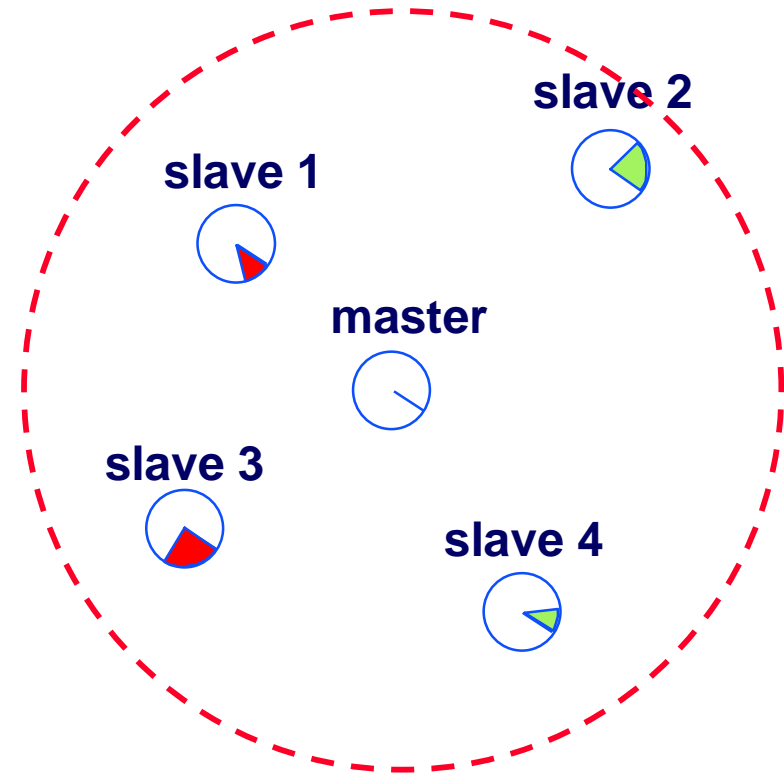


# FH/TDD channel

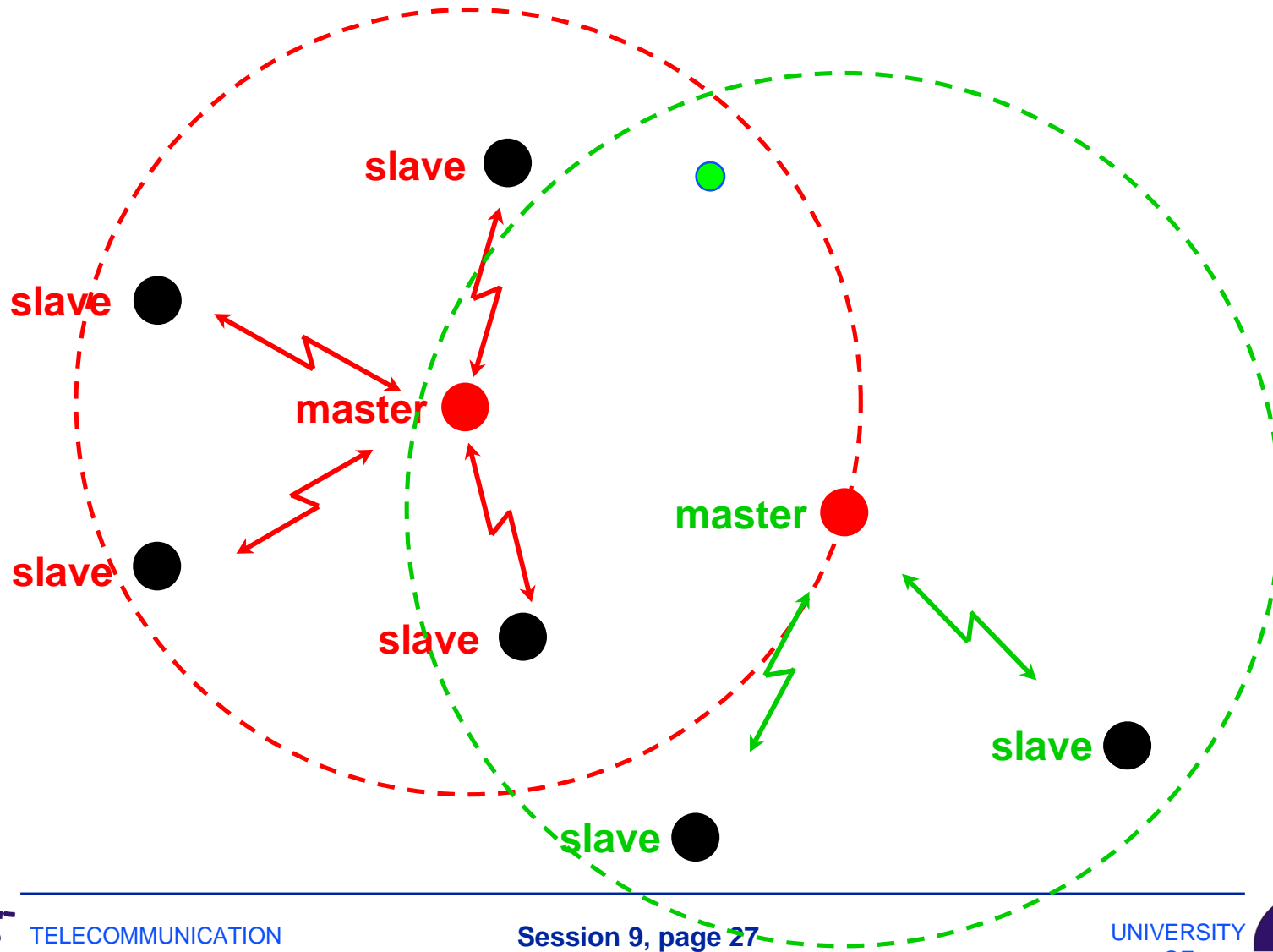


# Keeping FH synchrony

- Master identity → sequence
- Master clock → phase
- Free-running clocks



# Piconet concept

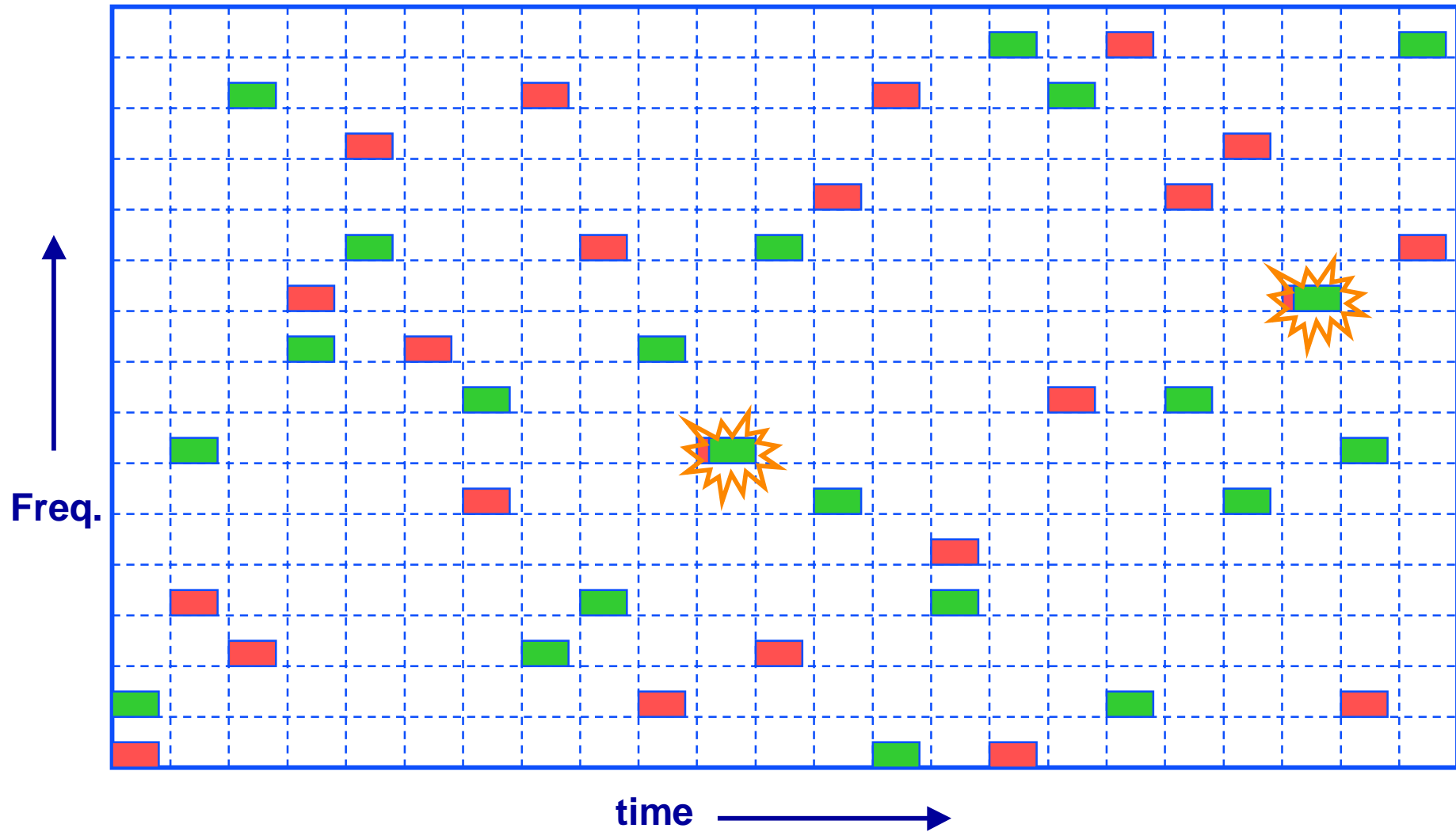


# Master-slave concept

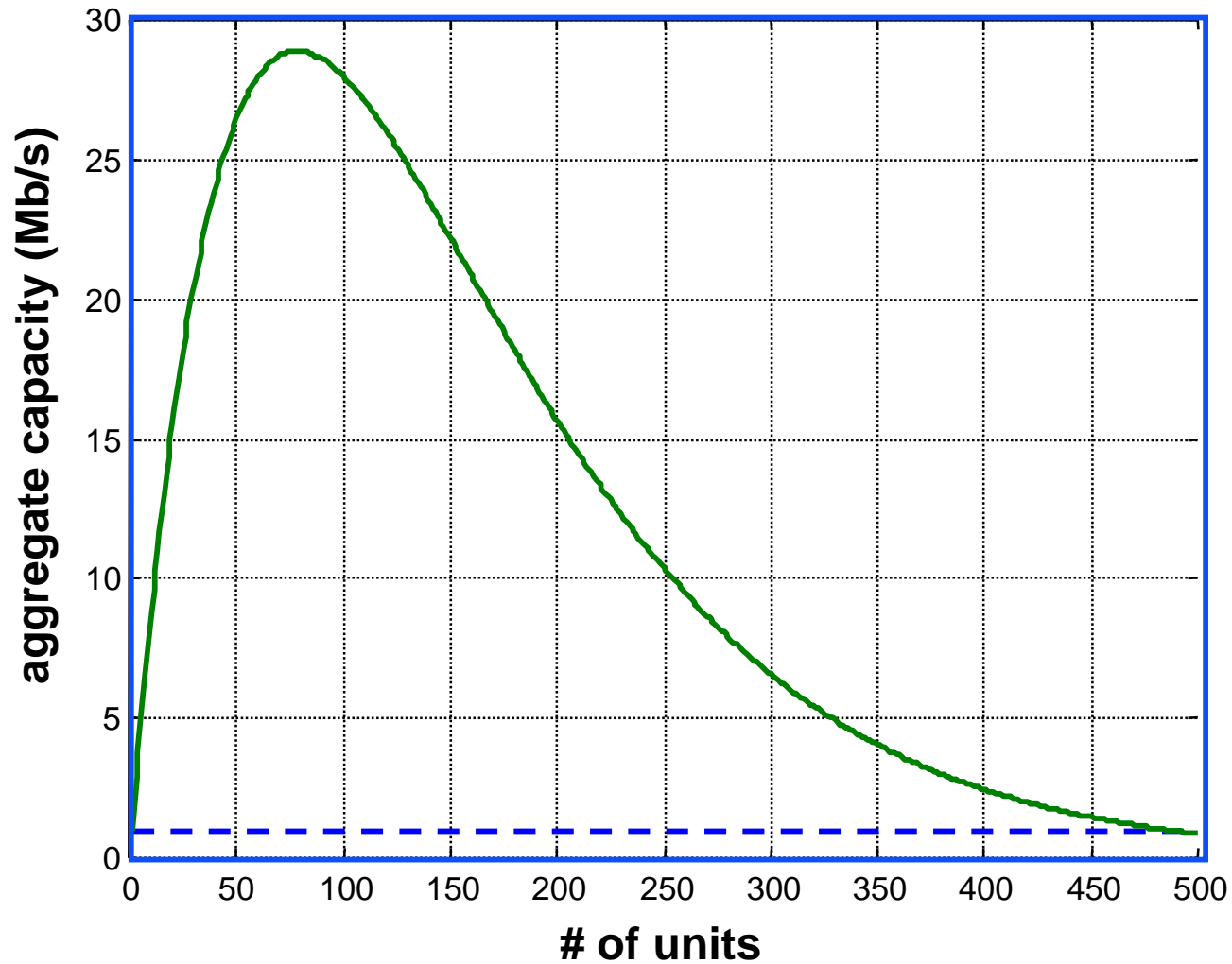
- **Only roles during piconet existence**
- **Any unit can become master, but only one per piconet**
- **Master defines piconet channel**
- **Master controls traffic on channel**
- **Master provides QoS**



# Exploiting 79 MHz of spectrum

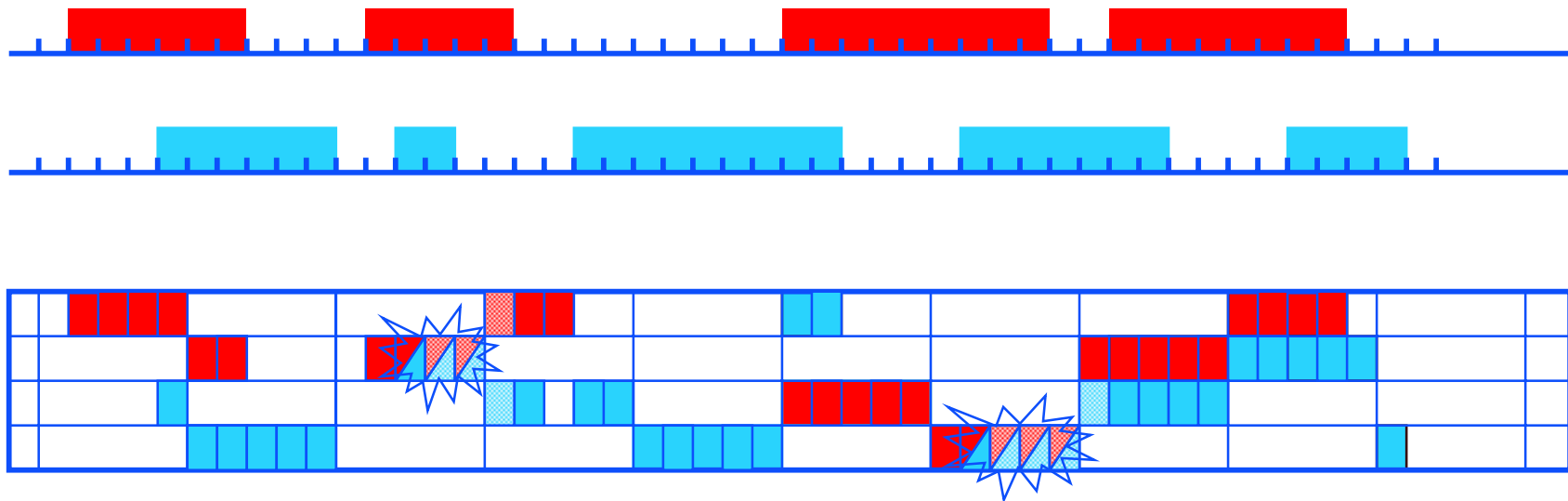


# Aggregate capacity



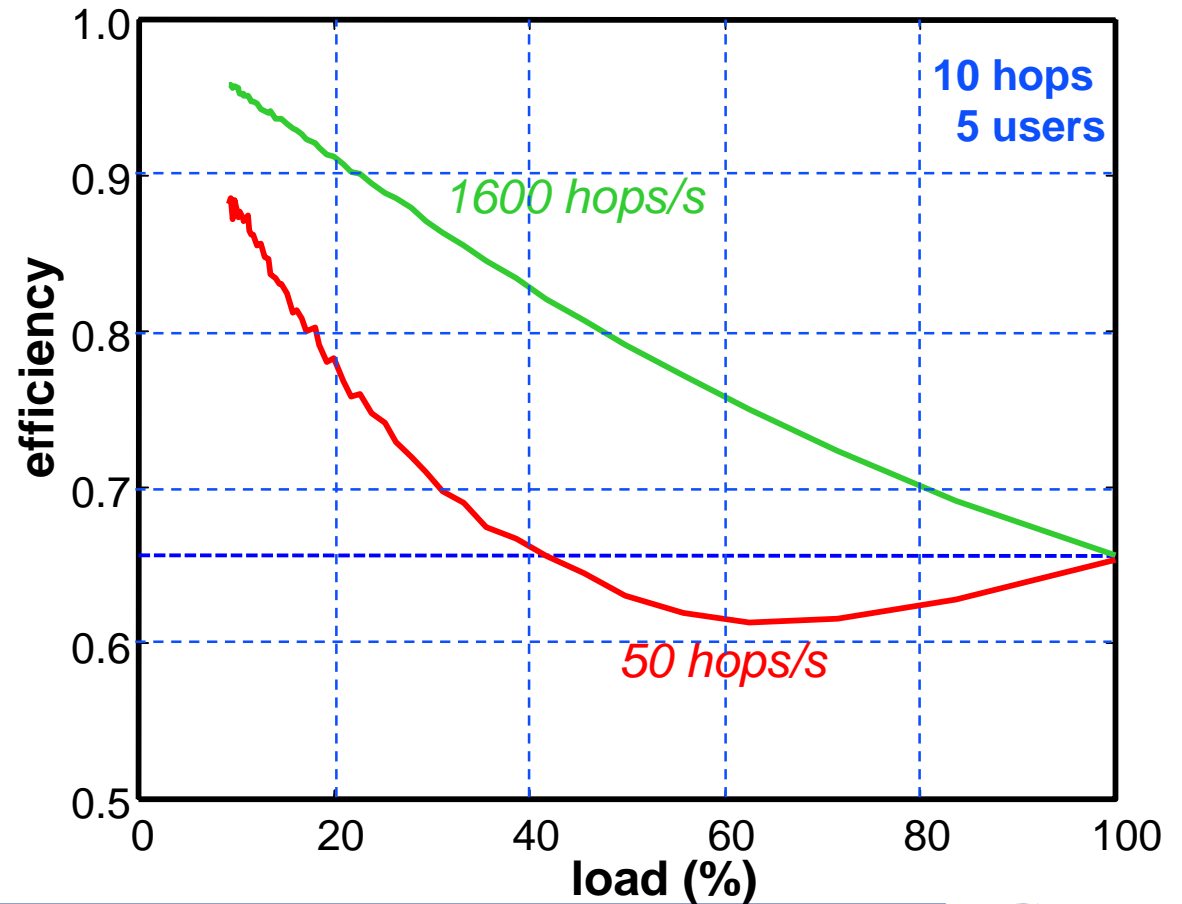
# Hopping rate

- **Datagrams:** length uniform distribution with 10 slot average
- **Inter-arrival:** exponential distribution with average variable



# Hopping rate

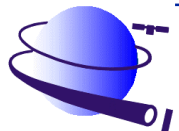
- short voice segments
- statistical data multiplexing
- retransmit “diversity”





# Addressing

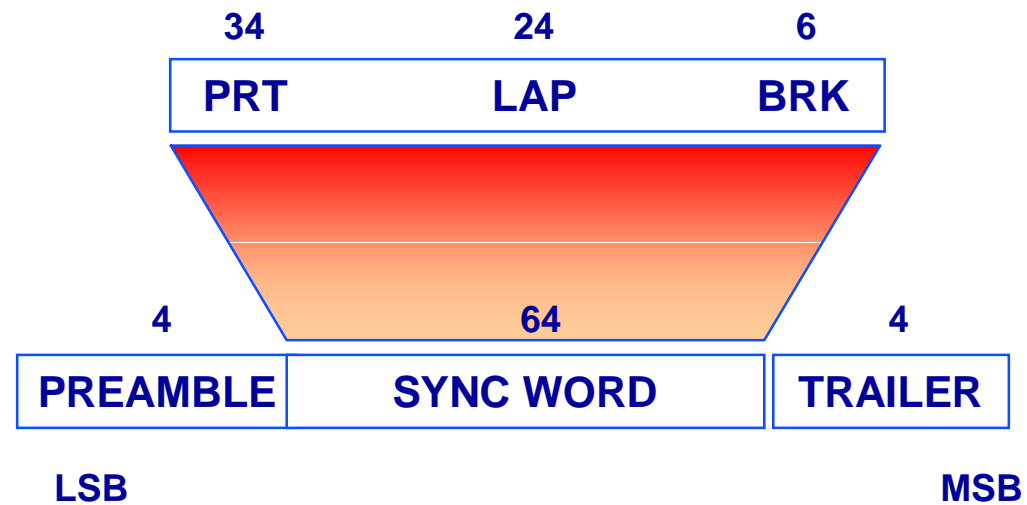
- **Bluetooth Device Address (BD\_ADDR)**
  - 48-bit IEEE 802 address
  - 24-bit lower address part (LAP)
  - 8-bit upper address part (UAP)
- **Active Member Address (AM\_ADDR)**
  - 3-bit active slave address
  - all-zero broadcast address
- **Parked Member Address (PM\_ADDR)**
  - 8-bit parked slave address



# Packet format



# Access code



# Access code types

- **Channel Access Code (CAC)**

- preceding all packets on piconet
- master LAP
- 72-bit sync & ID



- **Device Access Code (DAC)**

- used during call setup
- device LAP
- 68-bit message

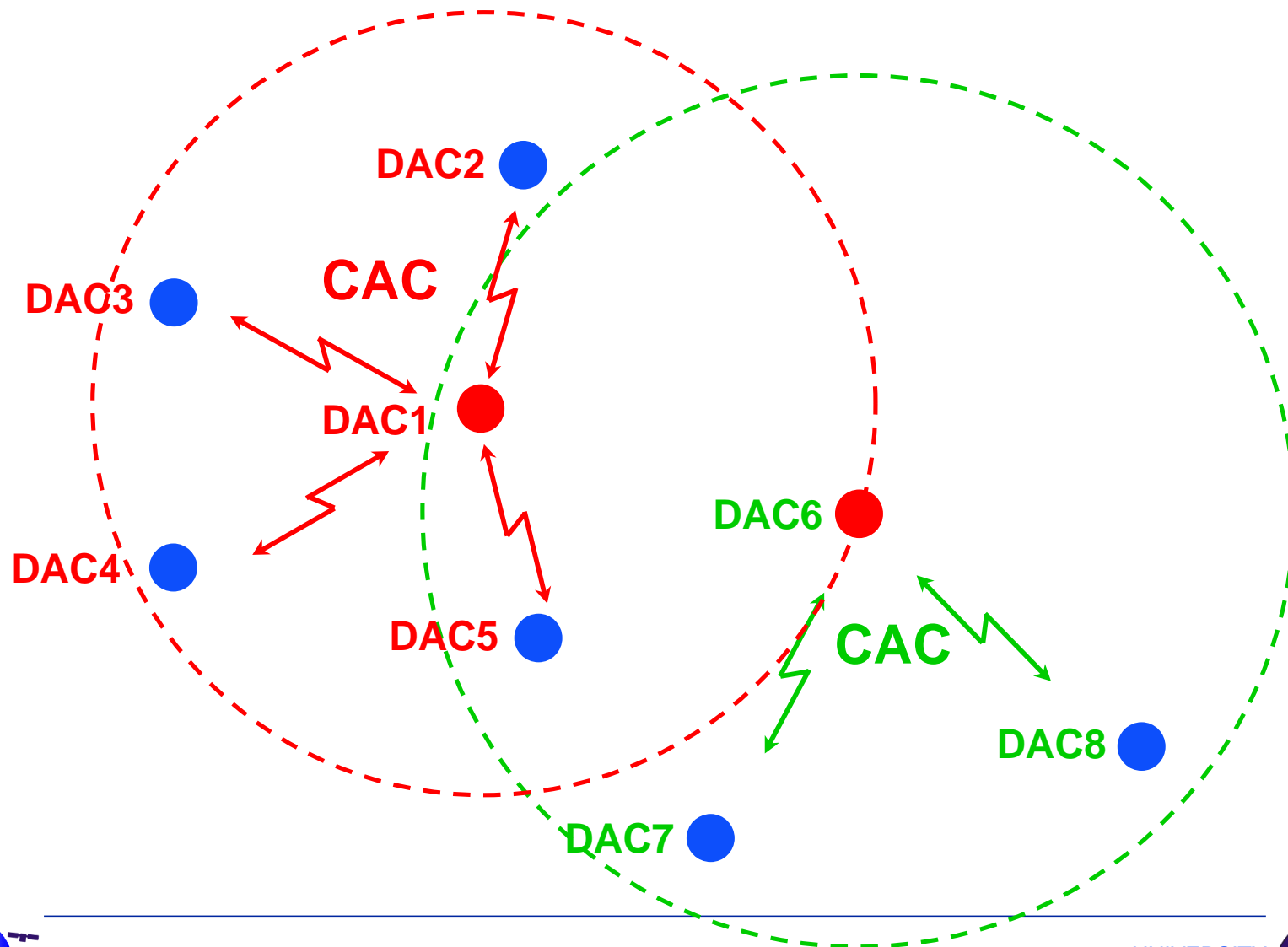


- **Inquiry Access Code (IAC)**

- used for discovery
- common LAP
- 68-bit message



# Access code types



# Packet header



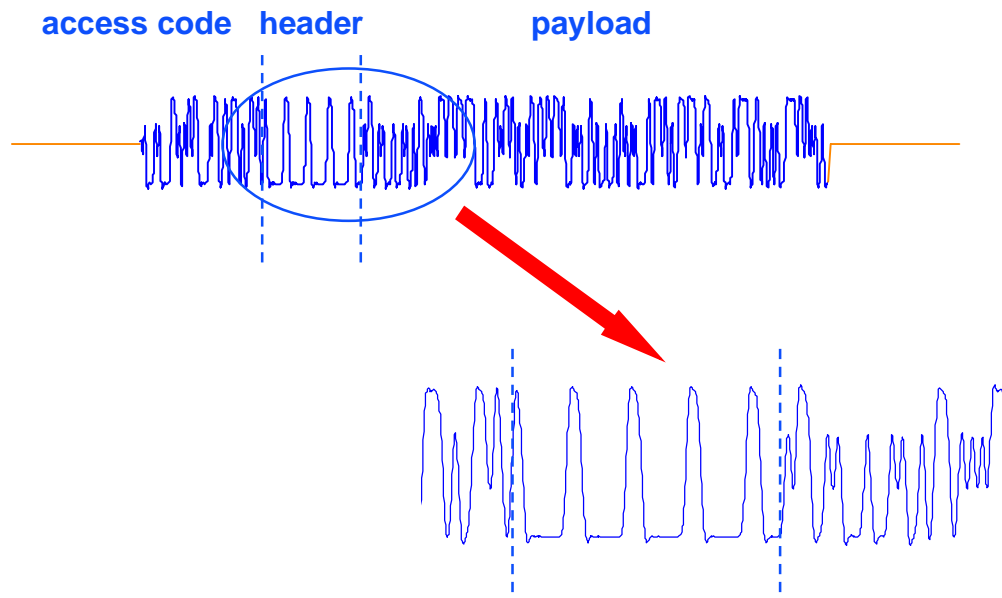
parameter	information
AM_ADDR	slave active member address
TYPE	payload type
FLOW	LC flow control
ARQN	ACK/NAK
SEQN	retransmit ordering
HEC	header error check



# Packet header

- **Protection**

- 1/3-rate Forward Error correction (FEC)
  - 3-repeat coding
  - majority decoding
  - Inter Symbol Interference (ISI) reduction



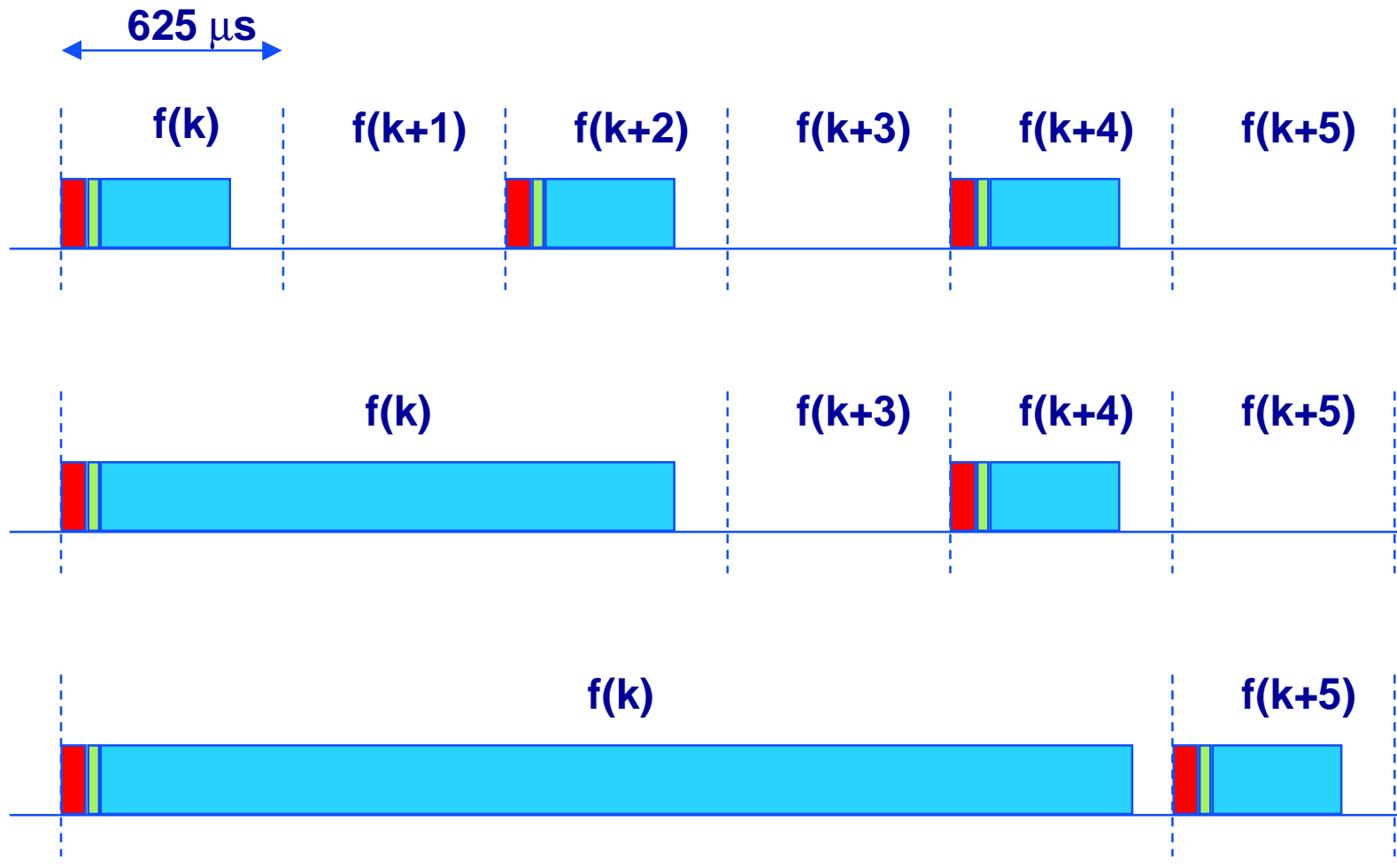
# Packet types

- **4-bit payload type indication**
  - 16 different packets
  - 4 “control” packets
  - 6 single-slot packets
  - 4 three-slot packets
  - 2 five-slot packets

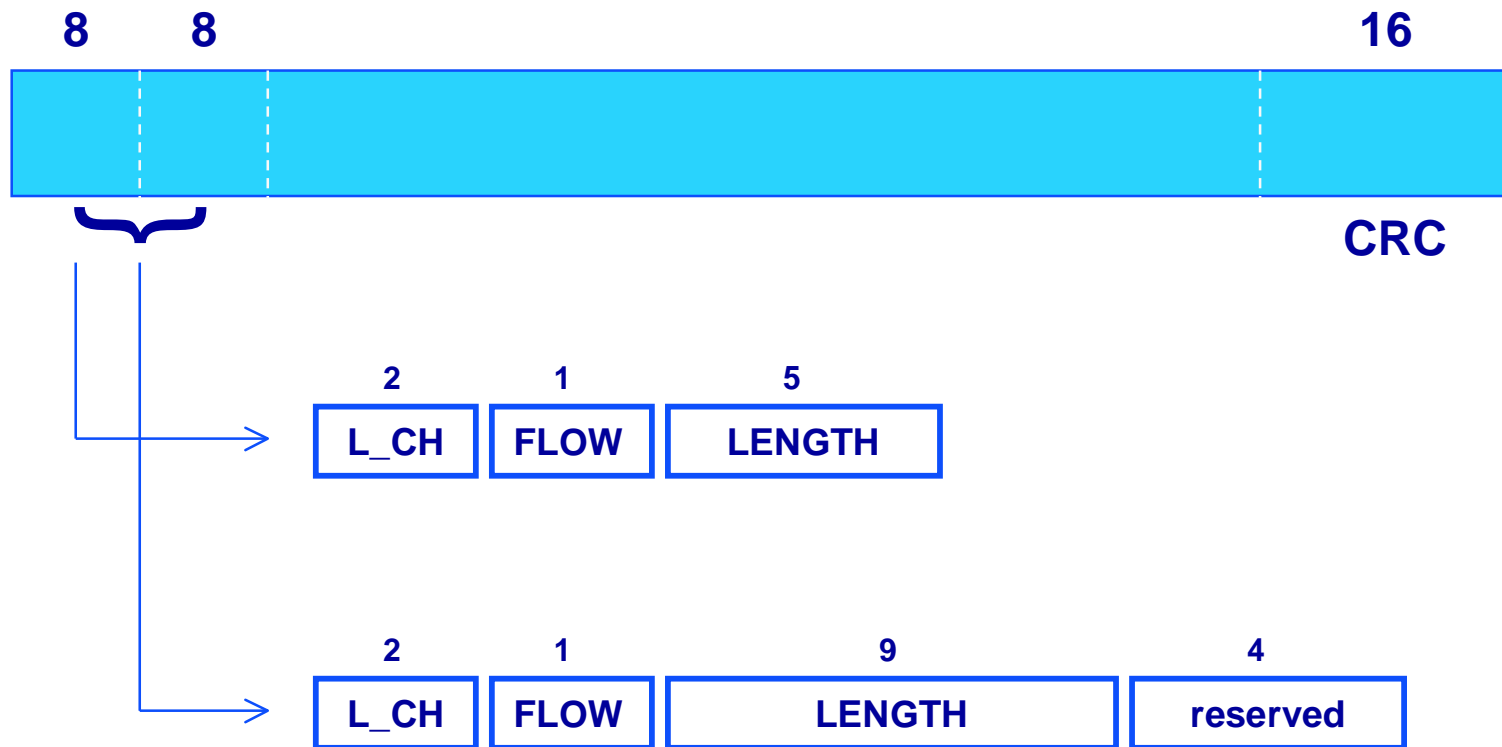




# Multi-slot packets



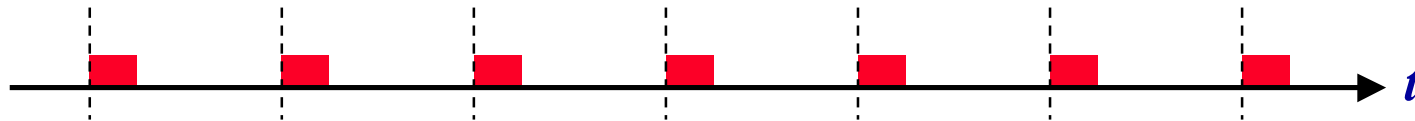
# Payload format



# Physical links

- **Multi-media support**

- synchronous services



- asynchronous services



- isochronous services



# Physical links

- **Synchronous services**
  - circuit switching
  - point-to-point
  - no delay variations, error tolerant
- **Asynchronous services**
  - packet switching
  - point-to-multipoint
  - delay tolerant, no errors
- **Isochronous services**
  - point-to-point
  - delay & error tolerant

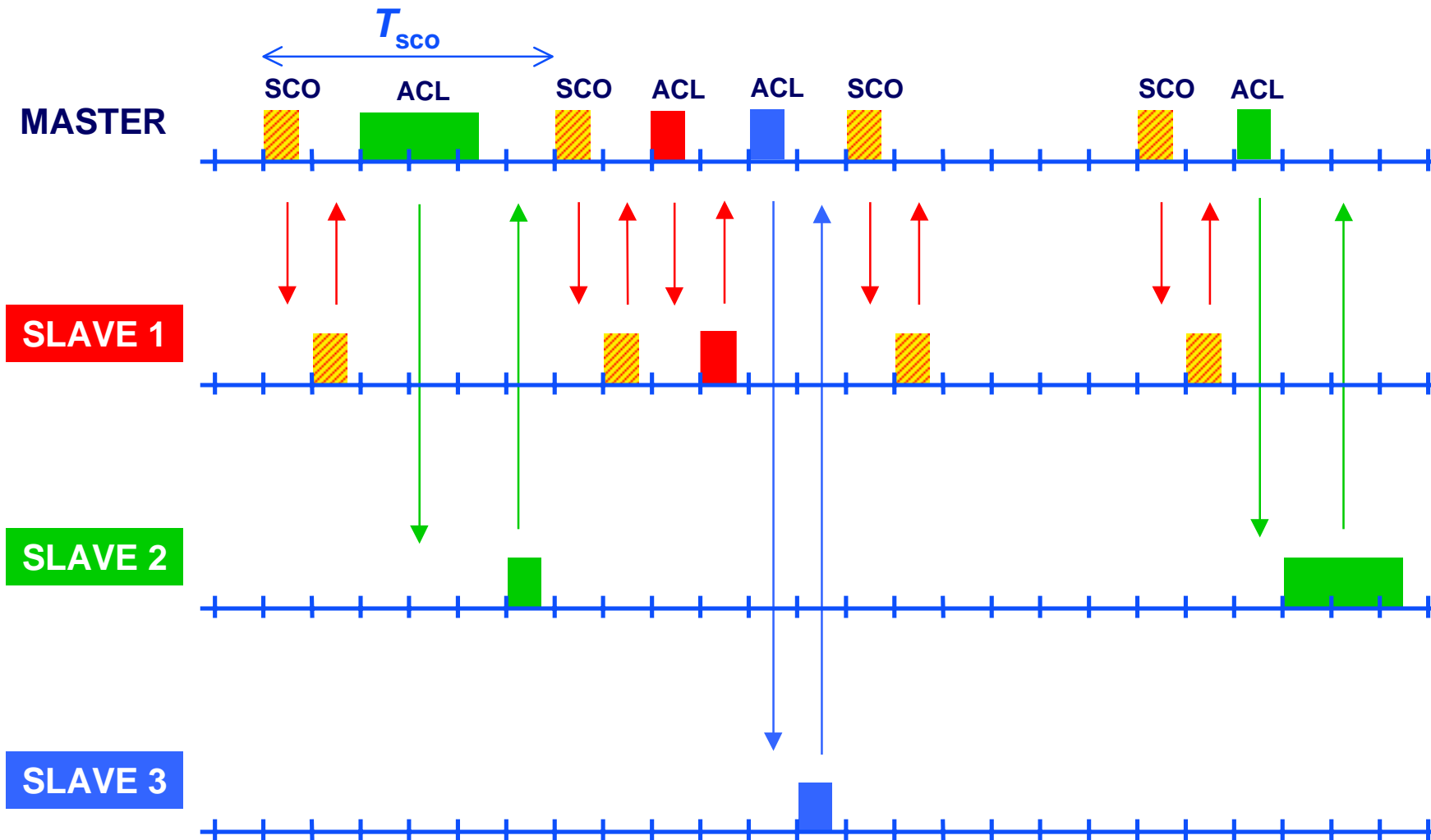


# Physical links

- **Mixing services on air interface**
  - time slotted channel
  - packet scheduling by master
  - control over quality of service
- **Synchronous Connection-Oriented (SCO) Link**
  - symmetric, synchronous services
  - slot reservation with fixed interval
- **Asynchronous Connection-Less (ACL) Link**
  - (a)symmetric, asynchronous services
  - polling access scheme
  - isochronous service via master scheduling



# Mixing services



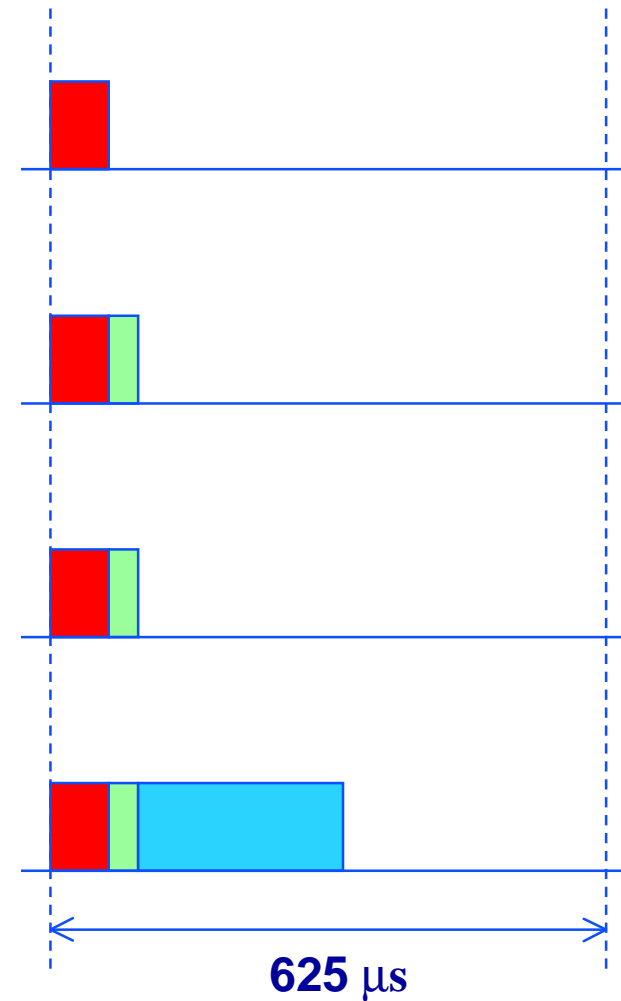
# Control packets

- **ID packet: DAC, IAC**

- **NULL packet**

- **POLL packet**

- **FHS packet**



# Frequency hop sync (FHS) packet

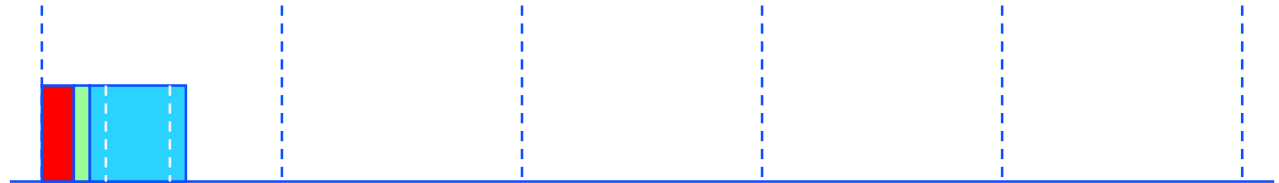
- **BD\_ADDR**
- **DAC**
- **AM\_ADDR**
- **class of device**
- **paging class**
- **real-time clock**





# ACL packets

• **DM1\*, DH1\*\***



• **DM3, DH3**



• **DM5, DH5**



← 625 μs →

\* DM1 is a common packet

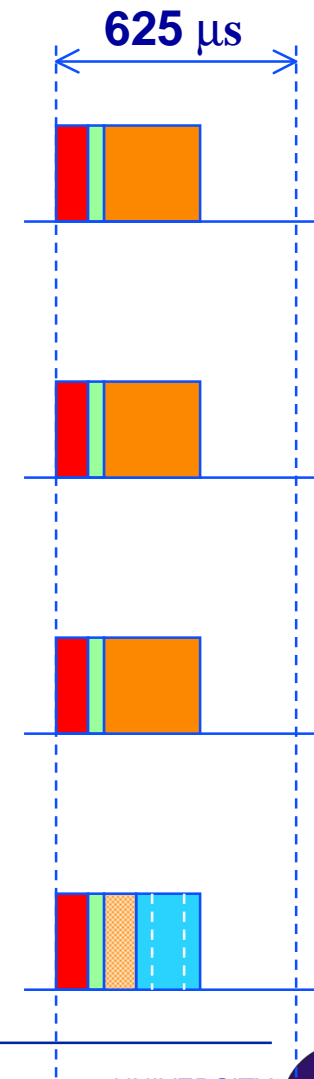
\*\* DH packet: uncoded

DM packet: 2/3-rate coded; shortened (15,10) Hamming code



# SCO packets

- **HV1: 1/3-rate repeat code**
- **HV2: 2/3-rate, short Hamming code**
- **HV3: uncoded**
- **DV: data/voice**



# Data rates (in kb/s)

PACKET TYPE	symmetric	asymmetric	
DM1	108.8	108.8	108.8
DH1	172.8	172.8	172.8
DM3	258.1	387.2	54.4
DH3	390.4	585.6	86.4
DM5	286.7	477.8	36.3
DH5	433.9	723.2	57.6
HV1	64.0		
HV2	64.0		
HV3	64.0		



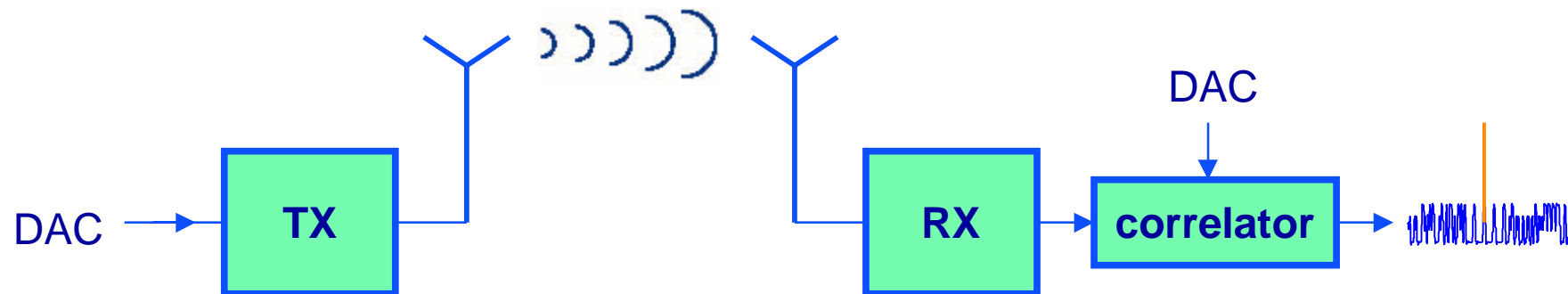
# Call setup

- **Floating units**
- **Discovery**
- **Standby current (always on)**
- **Response time**
- **Robustness**
- **Regulations**

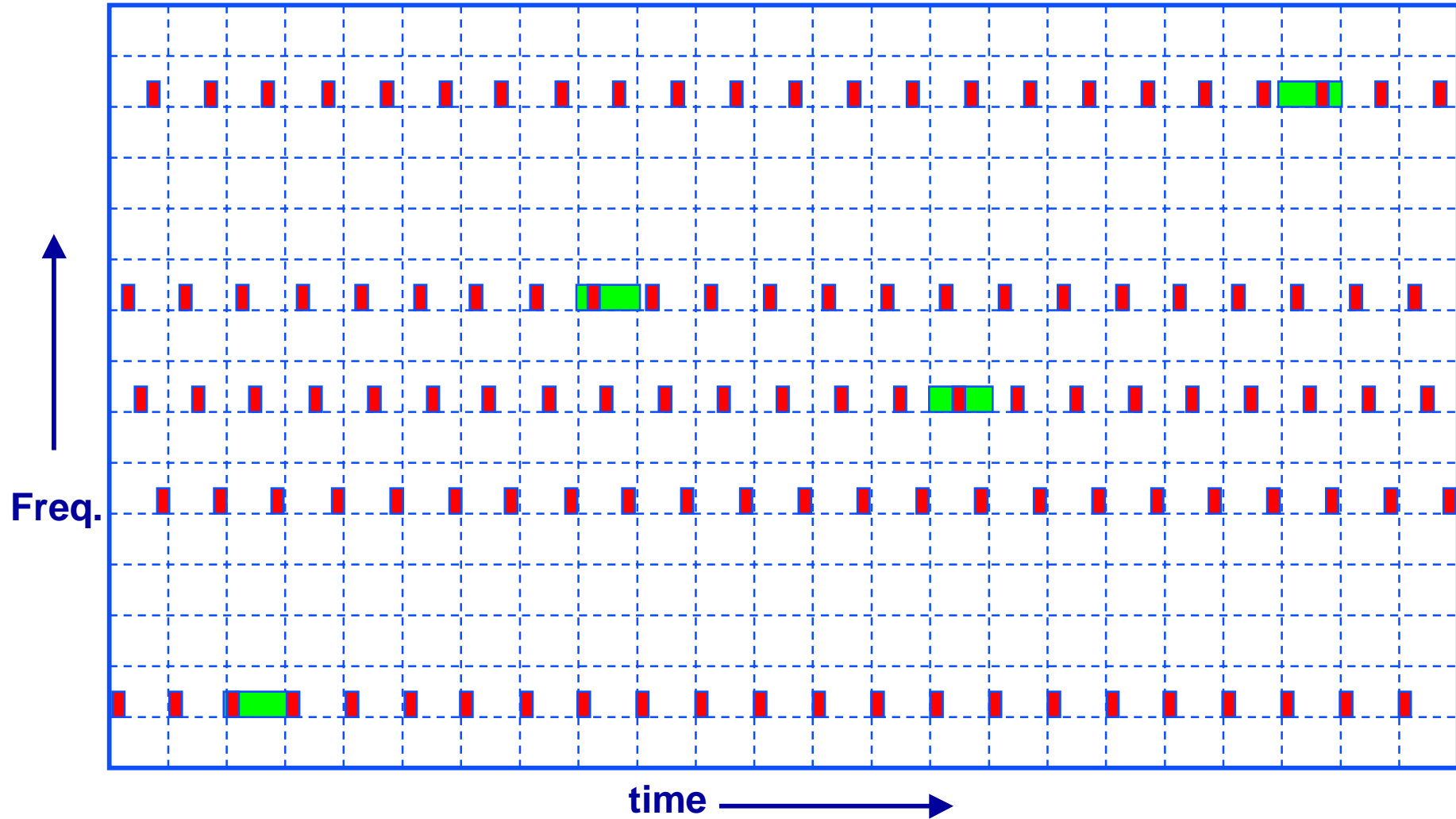


# Call setup: basic elements

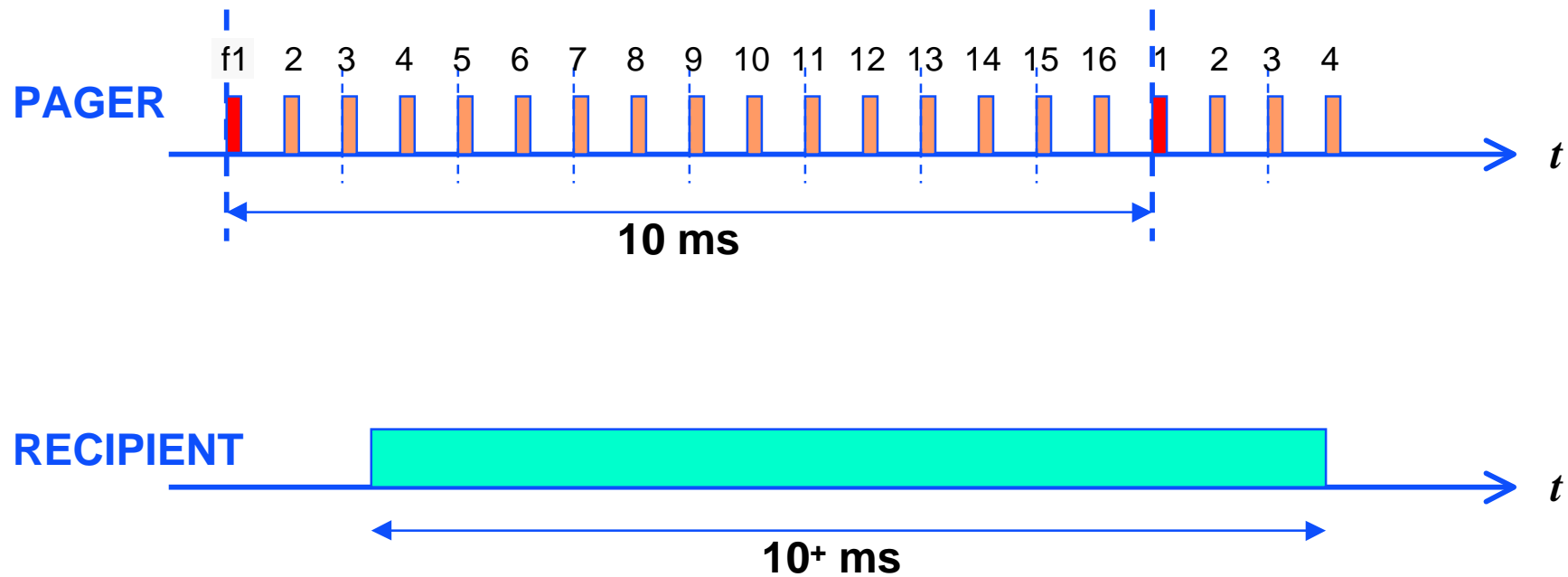
- Page message = DAC of recipient ( $LAP_{RX}$ )
- Page hopping sequence: 32 carriers ( $LAP_{RX}$ )
- Hybrid FH/DS mode with 17 dB PG



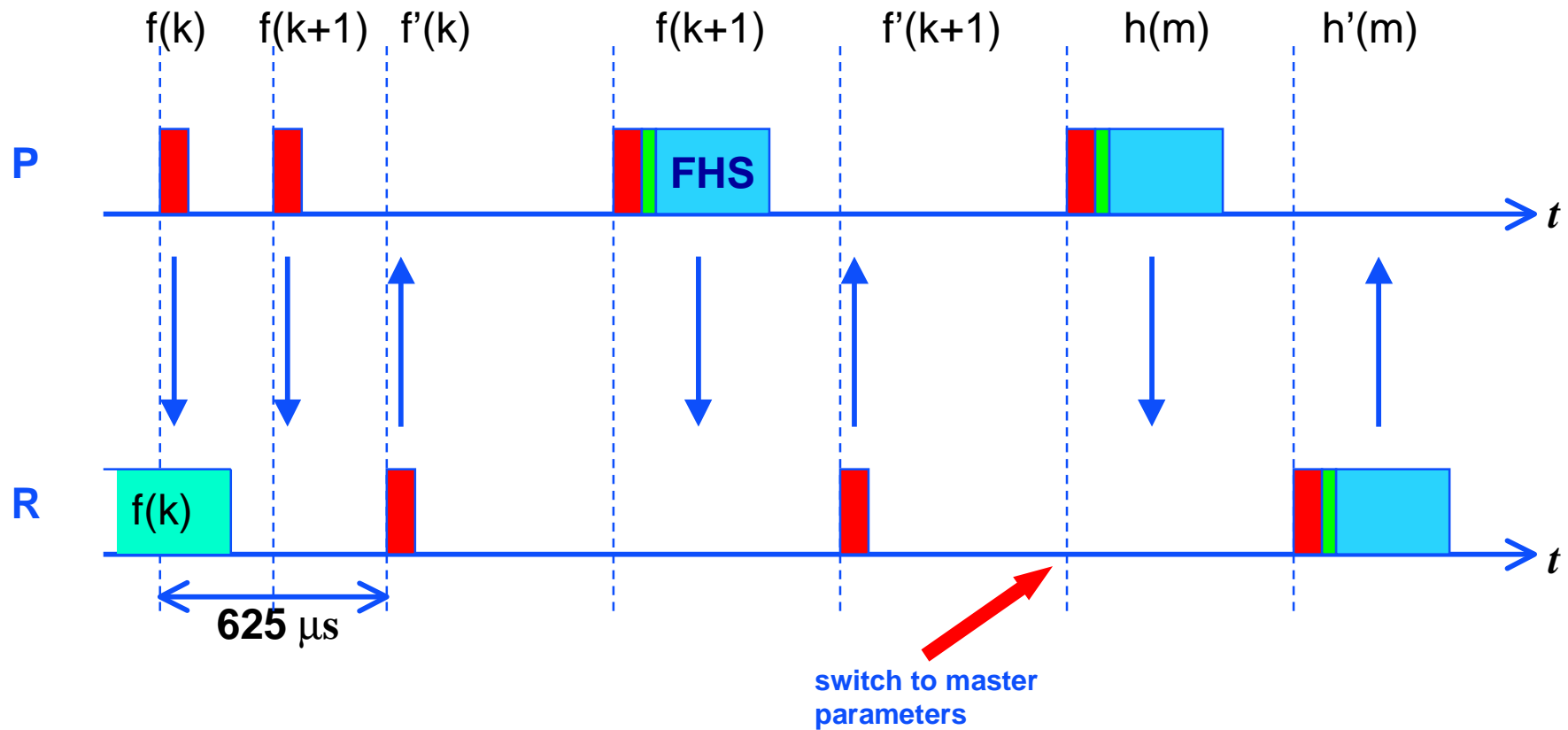
# Call setup: time-frequency uncertainty



# Call setup: paging scheme

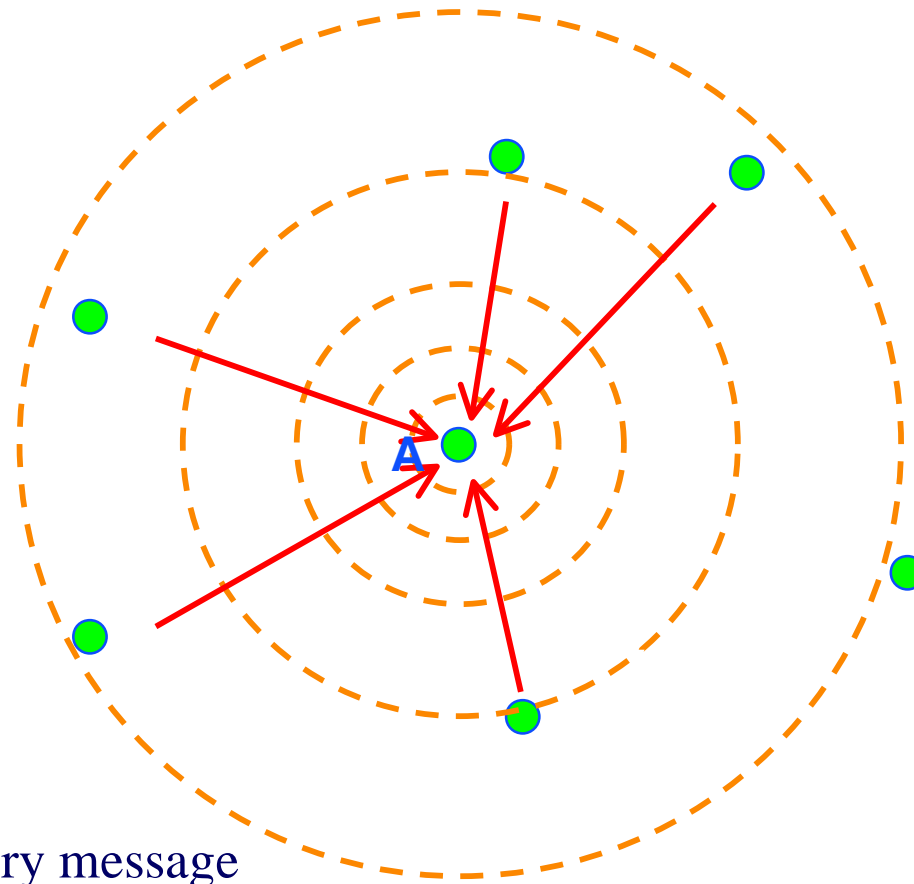


# Call setup: page response





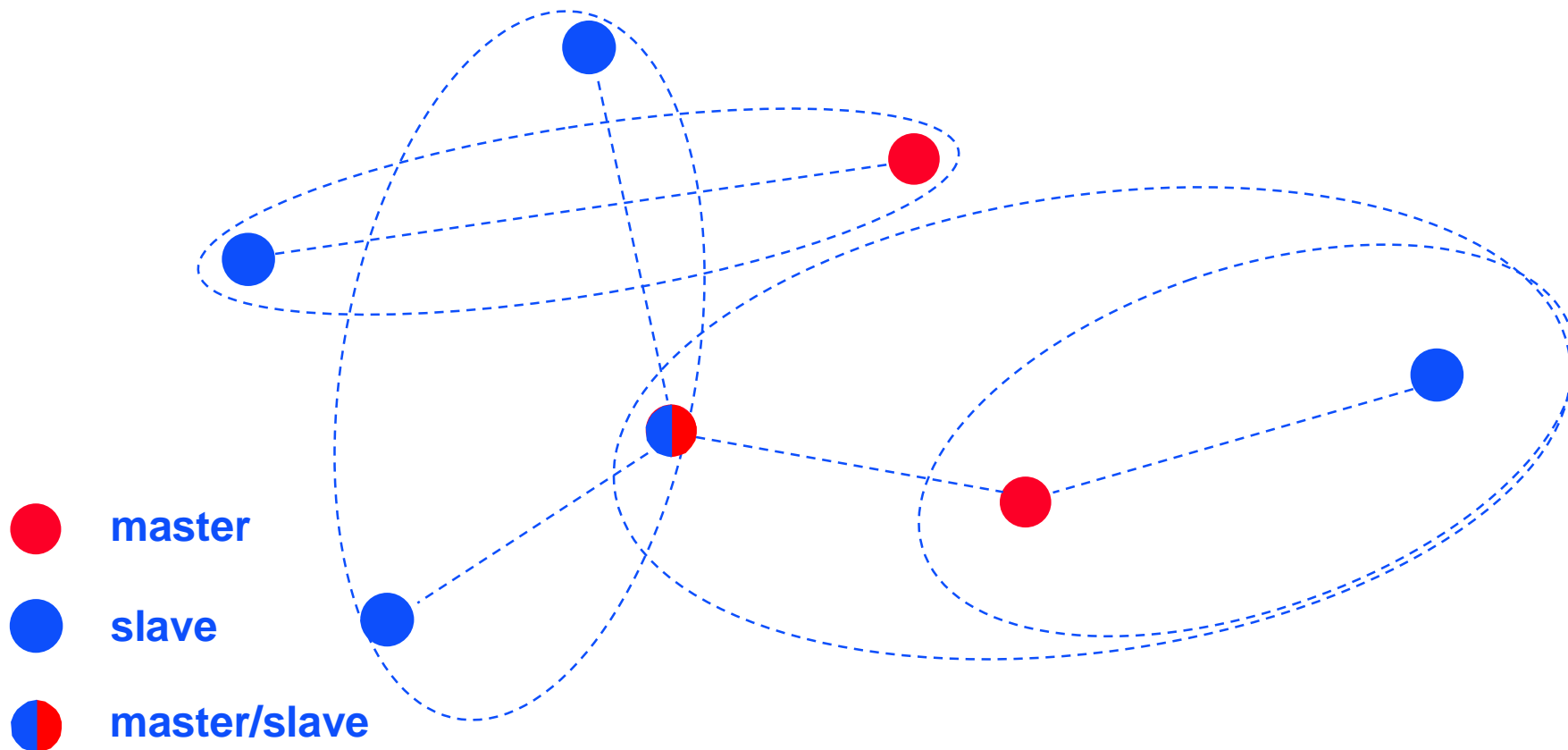
# Inquiry



- broadcast inquiry message
- return FHS with random delay



# Scatternet



# Scatternet: piconet switching

