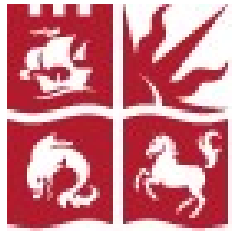
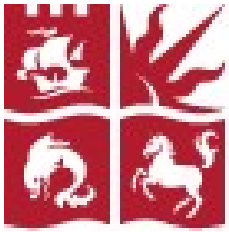


EENGM4221:
Broadband Wireless Communications

Lecture 16: Bluetooth Fundamentals

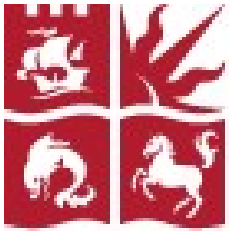
Dr Simon Armour

802.15 and Bluetooth



- Bluetooth was developed as a de-facto standard by an alliance between Ericsson, Nokia, IBM, Toshiba and Intel
  - Ericsson and Nokia came first. As a 'Scandanavian alliance' they chose the name Bluetooth in reference to a famous viking who 'united scandanavia' – here endeth the history lesson!
  - Subsequently, 802.15 adopted Bluetooth as 802.15.1 and then started creating more WPAN standards
  - We will focus only 802.15.1/Bluetooth

Bluetooth PHY



- The Bluetooth PHY is relatively simple
- Modulation is fixed to Binary Gaussian Filtered Frequency Shift Keying
  - This is a simple modulation scheme which enables low cost, power efficient modems (see EENG22000, EENGM0033)
- A few different Error Control Coding strategies are employed
- The symbol rate is 1MBaud

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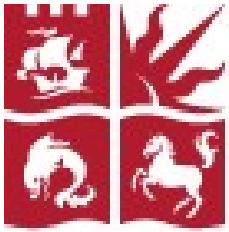
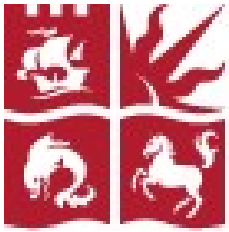
ISM Operation



- Bluetooth is designed for the 2.4GHz ISM band
  - Interference can come from many sources and is potentially severe but also probably not white
    - Hence some frequencies are better than others
    - Which ones are good and bad is unknown and dynamically varying
- Bluetooth uses Frequency Hopping as an interference mitigation strategy

Frequency Hopping



- Bluetooth divides the 2.4GHz band into 79 1MHz sub-bands
  - 1MHz acommodates the 1MBaud symbol rate
    - There will be interference with adjacent sub-bands
- A pseudo-random hopping sequence is generated to cause transmissions to hop around the different sub-bands
  - Hopping occurs 1600 times per second
  - The time spent on one hop frequency is called a slot time and is equal to 625μs
  - Over a short period of time, the interference across the entire band is averaged out
  - Later versions of Blueooth have adopted Adaptive Frequency Hopping:
    - When transmission of a packet on a sub-band is unsuccessful, interference is assumed to be present and that sub-band is avoided for a time
    - Avoided sub-bands are gradually reintroduced to the list of those used to ensure that diversity is not eroded over time

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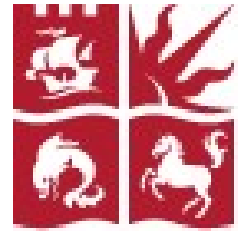
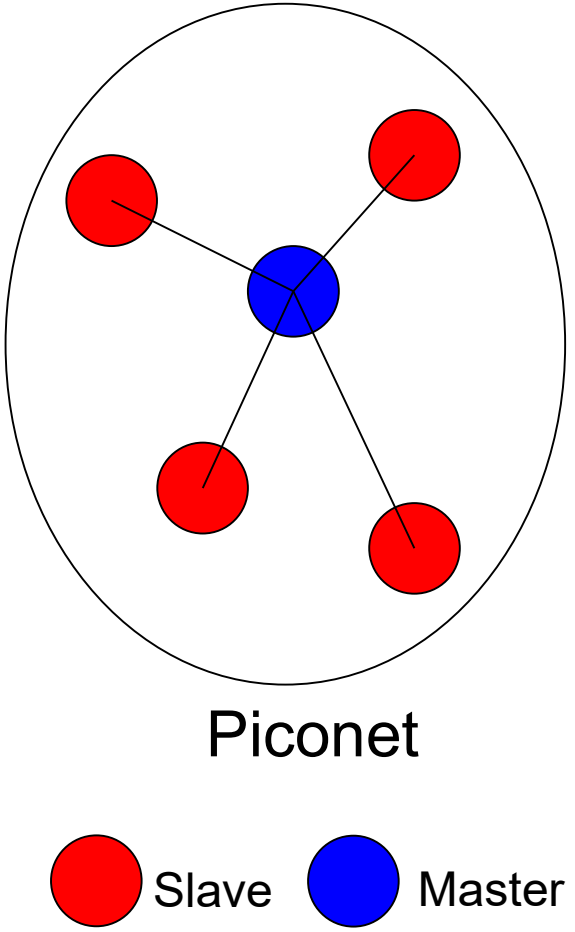
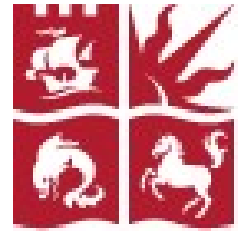
Piconets



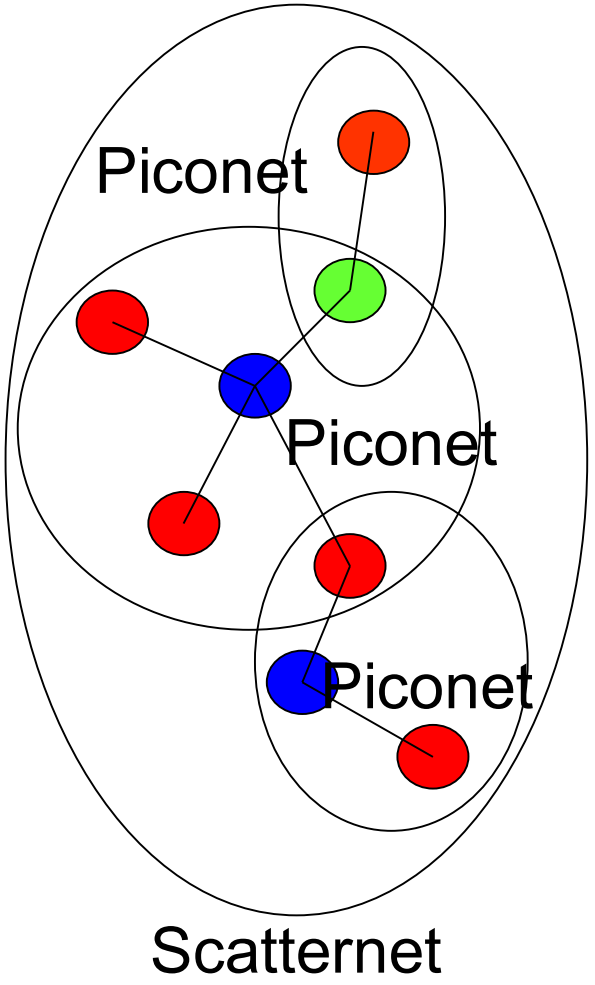
- Bluetooth networks are based upon the fundamental building block of Piconets
- A piconet consists of 2-8 nodes with a centralised network topology
- The central node is termed the ‘Master’ and the others are slaves
  - The reasons for this terminology will become obvious
- Up to 255 other slaves may be associated with the Master but only 7 slaves may actively participate in the piconet at any one time



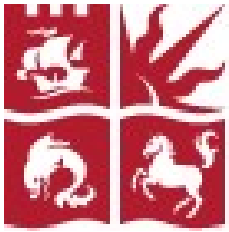
Scatternets



- Piconets may interconnect to form scatternets if one node participates in more than one piconet
- A node may be a slave to multiple masters or a master in one piconet and slave in another
- One node cannot be master of more than 1 piconet



Masters and Slaves



- Each piconet consists of one master and up to 7 slaves
- The master controls all transmissions within the piconet
- Bluetooth thus employs a centrally controlled MAC strategy
- Given that most Bluetooth networks are ad-hoc, Bluetooth and 802.11 are mutual opposites in that:
  - Bluetooth uses central control and is mostly ad-hoc
  - 802.11 uses distributed control and is mostly infrastructured
- Bluetooth uses a simple ‘ping-pong’ MAC protocol

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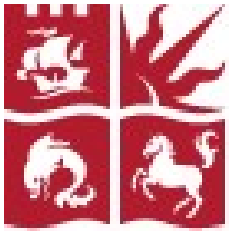
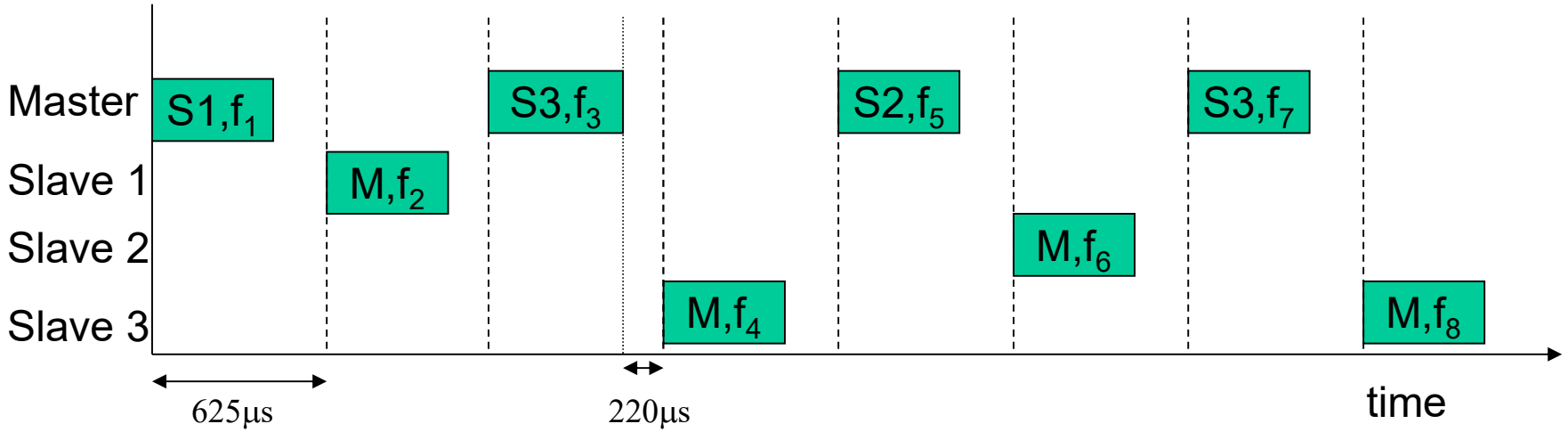
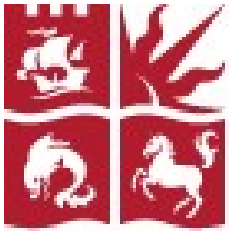
Frame Structure



- Alternate Master and Slave packets are transmitted
- The Master may transmit to any slave it wishes
- A Slave may only transmit to the Master after receiving a packet from the Master
- Frame Syntax: Destination Address, Hop-Sequence Number (frequency)

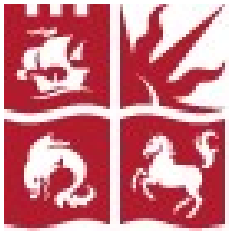


Radio Turnaround



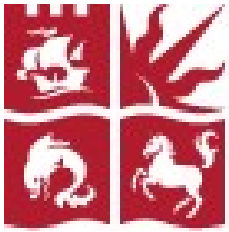
- Bluetooth can be seen to use Time Division Duplex (TDD)
- Only one radio is required if it is only necessary to transmit or receive at any one time
- Radio cost can be reduced if the radio is not required to change from transmitter to receiver or to hop to the next frequency very fast
- For this reason, Bluetooth allows a period of silence between frames during which nodes neither transmit nor receive
  - This represents an overhead
  - The radio turnaround time is fixed to 220μs which can be a substantial overhead

Frequency Hopping Revisited



- The frequency hop sequence is derived from the MAC address of the Master so all nodes in one Piconet operate according to the same sequence but all Piconets have a different sequence
  - This is essential in order to:
    - Keep all nodes within a Piconet synchronised so that for each frame the source and destination node operate on the same frequency
    - Prevent interference between Piconets in the same Scatternet or between geographically adjacent but unconnected piconets
  - Some collisions still occur but:
    - Collisions are statistically unlikely provided there are not too many piconets within range of each other
      - This is unlikely to be a problem given Bluetooth's short range
    - Sequences of consecutive collisions are highly unlikely since the sequence depends upon the MAC address of the Master and every Master has a difference MAC address

Central Control



- The importance of the Master can be seen
- The slave may not transmit to the Master until allowed too
  - The Master is in total control
  - QoS can be catered for to some degree if the Master implements effective scheduling
- The master cannot receive data from a slave without sending a packet first
- If the Slave has data to send to the Master but the Master has no data for the Slave, either:
  - The Slave must wait – may have implications for QoS
  - The Master must send a dummy packet – reduces power and spectrum efficiency
- If lots of Slaves have traffic to send but the Master has nothing to send to them, this protocol becomes either very inefficient or very poor in terms of QoS provision (or a mixture of the two)

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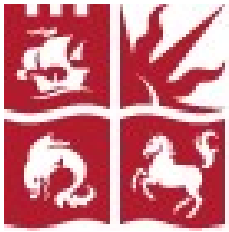
Review of Lecture 16



- We reviewed the simple PHY spec of Bluetooth
  - Modulation
  - Frequency Hopping
  - Interference mitigation
- We reviewed the basics of the Bluetooth MAC (more detail next lecture)
  - Central Control
  - 'Ping-pong' protocol
  - QoS Implications

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