EEENGM4221:
Broadband Wireless Communications

Framework - Terminology, Definitions and Models

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WPAN / WLAN / WMAN / WWAN

- These terms pervade the teaching material for this unit and discussion of wireless communications in general.
- Qualitative understanding of these terms is thus essential.
- Fortunately we will stick to some simple definitions for the purpose of this unit!
- The ‘W’ (Wireless) and ‘N’ (Network) parts are fairly self explanatory.
- Various connotations are sometimes applied to the PA, LA, MA and WA parts.
- However, we will consider these to simply define the scale or range of the network.

Ref: STAL 3.1

WPAN

- Wireless Personal Area Networks:
  - Typically less than 10m range
  - Commonly operating in the vicinity of the human body or within a single room
    - E.g. A wireless headset for a mobile phone or a wireless PC-printer link
    - Not normally working across substantial physical obstructions (such as walls or floors)
  - The term Body Area Network (BAN) is sometimes used but we will consider PAN to encompass this domain and not use this term
  - Distinct from a 'Personal Network' which has no implications for Physical range

WLAN

- Wireless Local Area Networks:
  - Typically refers to indoor networks with corresponding implications for range (<50m)
  - Also includes outdoor networks up to around 250m range and some large open space indoor environments
    - E.g. a network covering an office, airport departure lounge or public square
  - Typically capable of operating across one or more physical obstructions (walls, floors, etc)
  - The term Home Area Network (HAN) is sometimes used to describe a domestic deployment but we will consider the term LAN to include the HAN and not use the latter term again.

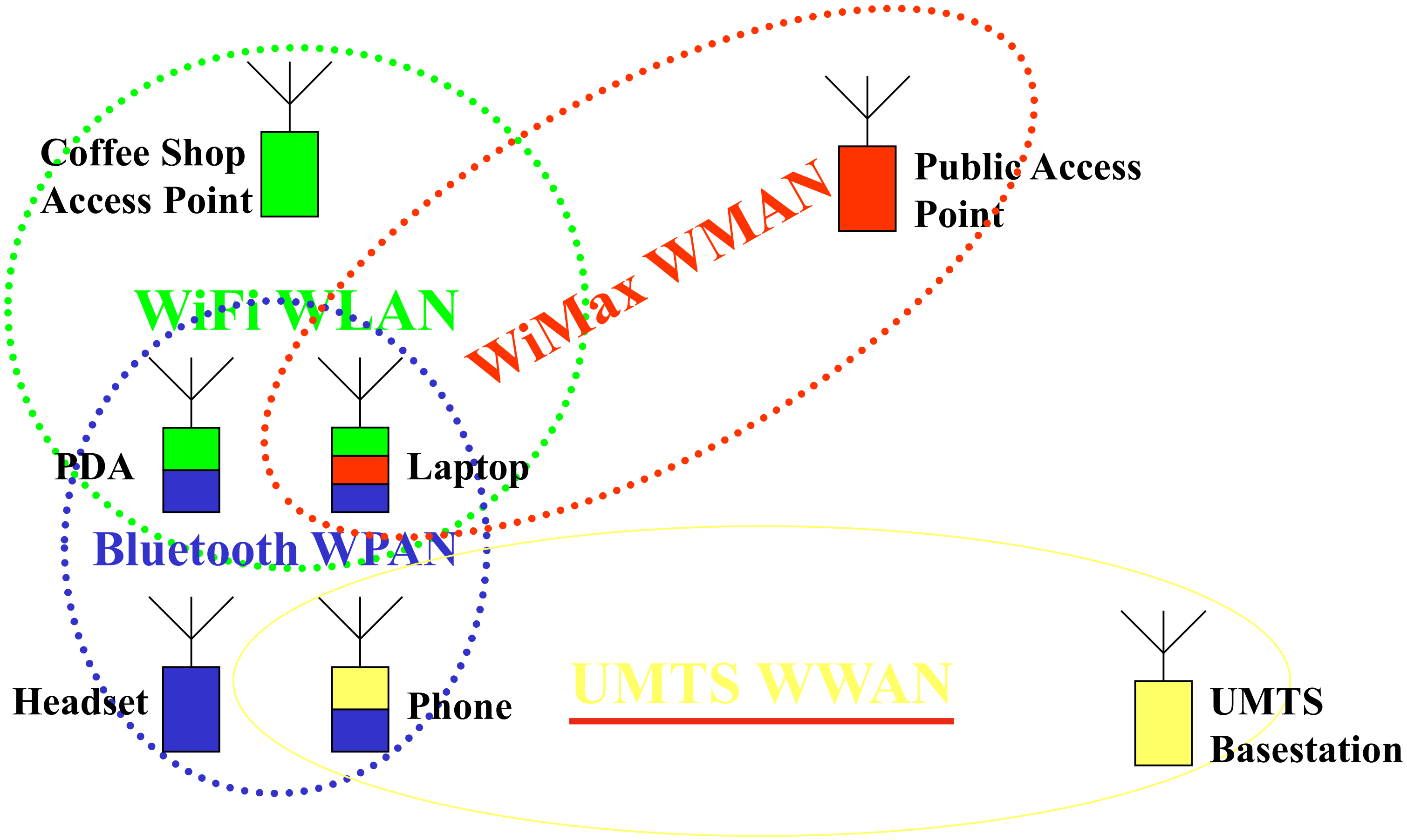
WMAN

- Wireless Metropolitan Area Networks:
  - Typically refers to networks with range up to around 1km
  - E.g. a network covering an industrial estate, business park or retail park
  - Clearly the range implies outdoor coverage but a WMAN may also include coverage inside buildings within the area
  - The term Campus Area Network (CAN) is sometimes used (e.g. spanning different buildings within a University) but this is essentially synonymous with WMAN and so we will not consider this term any further.

WWAN

- Wireless Wide Area Networks:
  - Typically refers to networks with ranges above 1km
    - A 2G or 3G macro-cell is essentially a WWAN
  - As with WMAN, may or may not be capable of providing in building coverage

Inter-working Systems (1)



Ref:

Inter-working Systems (2)

- Note that it is quite possible for devices to support multiple wireless technologies and thereby participate in multiple networks
- The WxAN term still refers to scale of network supported by a particular wireless technology. For example
  - The laptop can be simultaneously part of a WPAN, WLAN and WMAN
  - Even though the headset can potentially receive data from the internet by combination of the WPAN with one of the other networks it is nevertheless only part of the WPAN

Layered Protocol Models (1)

- Layered Protocol Models impose a structure on the functionality of communication systems
- Two established models are:
  - The Open Systems Interconnection (OSI) model
  - The TCP/IP model
- Neither is perfect or universally accepted
- Also note that description of TCP/IP model is not always consistent. (TAN pp 43 and STAL pp 77)

Ref: TAN 1.4, STAL 4

Layered Protocol Models (2)

OSI

- Application
- Presentation
- Session
- Transport
- Network
- Data Link
- Physical

TCP/IP (STAL)

- Application
- Transport
- Internet
- Network Access
- Physical

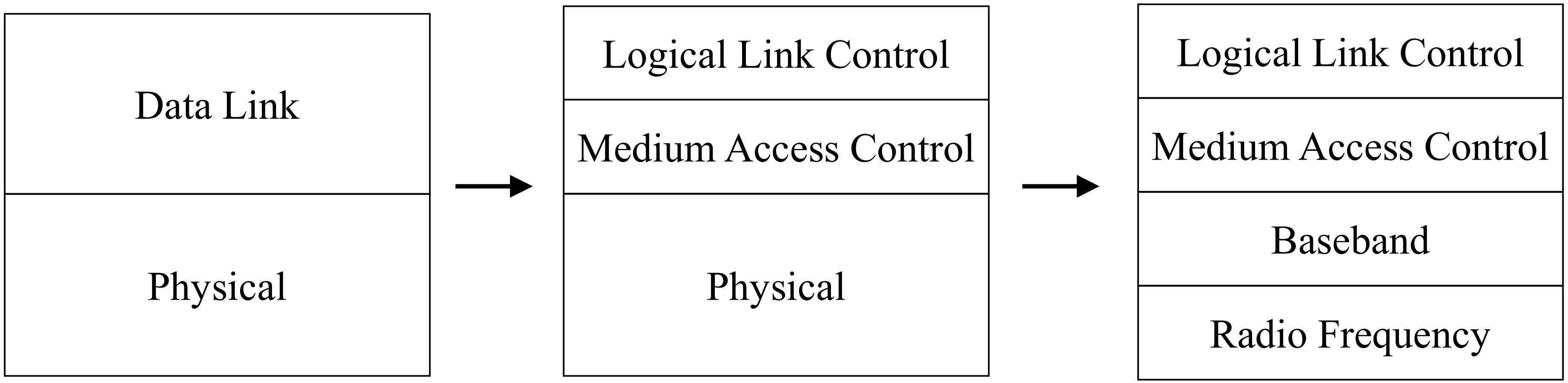
TCP/IP (TAN)

- Application
- Application
- Transport
- Internet
- Host to Network

Ref:

Focus of this Unit (1)

- The focus of our interest for this unit is best represented by the PHY and DLC layers of the OSI model.
- The IEEE 802 standards we will use as case studies are similarly focussed on these layers
- Functions above the DLC in the OSI model are outside the scope of this unit.
- Given this and the inconsistent representation of the TCP/IP model we will adopt the OSI model and focus on its bottom two layers



Focus of this Unit (2)

- For the purposes of this unit we may further divide the layers
  - The data link layer can be divided into the Logical Link Control and Medium Access Control Sub-Layers
    - This is a widely accepted sub-division commonly recognised in textbooks
  - The Physical Layer may be divided into the Baseband and Radio Frequency Sub-Layers
    - This is a less conventional sub-division which we identify for the purposes of delineating the focus of this unit
    - It is also fairly obviously radio specific – not applicable to wireline, optical, infra-red etc!

Logical Link Control (1)

- The Logical Link Control (LLC) is responsible for receiving network layer packets and converting them into packets suitable for the MAC layer, known as MAC Service Data Units (MSDUs).
- This may involve:
  - Fragmentation prior to transmission - breaking one network layer packet into multiple smaller MSDUs
  - Aggregation prior to transmission – combining multiple network packets into one MSDU
  - Fragmentation after reception – breaking down an aggregated MSDU into its constituent network packets
  - Aggregation after reception – reassembling a fragmented network packet from its constituent MSDUs

Logical Link Control (2)

- Implementing Error Control strategies in a (not necessarily successful attempt) to ensure that data is exchanged error free between the network layer protocols of communicating nodes
- Implementing flow control in an attempt to avoid buffer overflow in either the sending or receiving node
- The LLC may also generate additional MSDUs for its own purposes (i.e. MSDUs which contain no data from the network layer but serve the purposes of the LLC itself)

- The LLC is considered in:
  - Networks and Protocols (EENG34200) with less emphasis on *wireless* communications
  - Coding Theory (EENGM2011) with regard to error control strategies

Ref:

Medium Access Control

- The Medium Access Control (MAC) sub-layer is responsible for ensuring that nodes share access to the physical communications medium in an effective manner. This involves:
  - Taking MSDUs from the LLC sub-layer and converting them to MAC Protocol Data Units (MPDUs) suitable for passing on to the Physical Layer
  - Determining when a node may access the physical medium
- The MAC sub-layer is considered in Networks and Protocols (EENG34200) with less emphasis on *wireless* communications

Baseband Modulation and Coding (1)

- The Baseband (BB) sub-layer is responsible for receiving a Physical Layer Service Data Unit (PSDU) and converting it into a Physical Layer Protocol Data Unit (PPDU)
- The PSDU can normally be considered synonymous with the MPDU generated by the MAC
- Unlike previous data units the PPDU is not binary data it is normally in the form of discrete complex data symbols (complex numbers)

Baseband Modulation and Coding (2)

- Baseband functionality typically includes:
  - Modulation and Demodulation
  - Error Control Coding and Decoding
  - Synchronization
- These elements are considered in:
  - Communications (EENG22000)
  - Communications Systems (EENG32000)
  - Mobile Communications (EENG32500)
  - Advanced Mobile Radio Techniques (EENGM2510)
  - Coding Theory (EENGM2011)

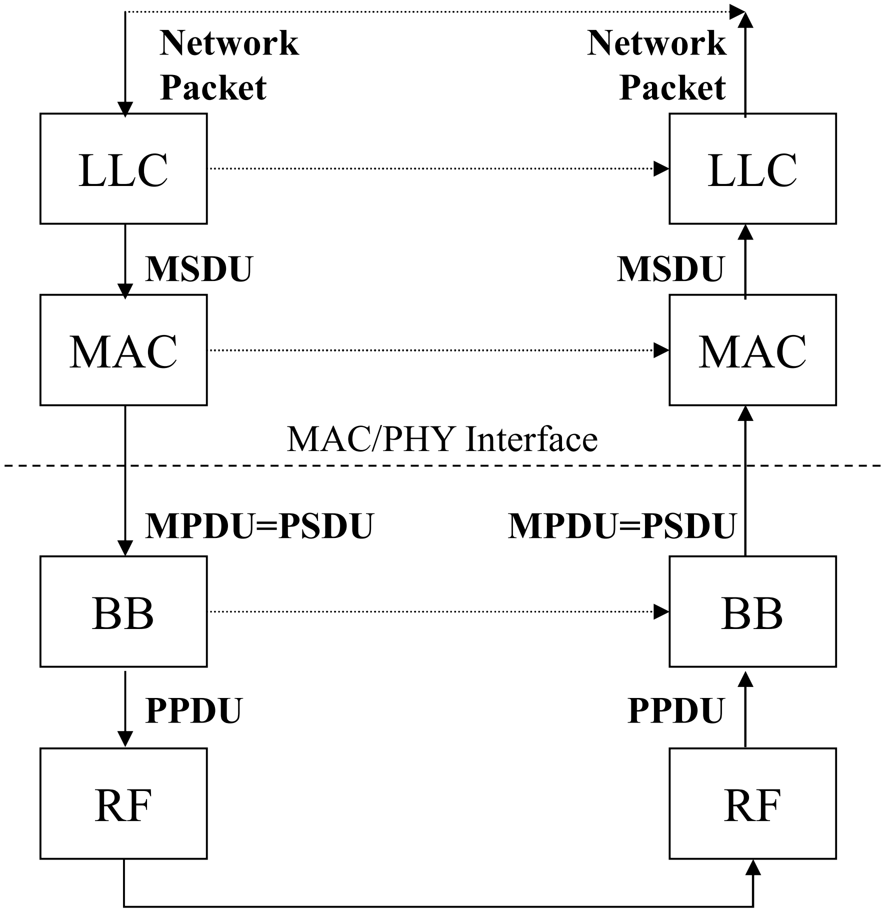
RF Sub-Layer

- The Radio Frequency (RF) sub-layer is responsible for conveying PPDU received from the baseband sub-layer as accurately as possible across the wireless medium by modulation and demodulation to/from appropriate frequencies
  - We will omit this sub-layer from detailed consideration in this course.
  - This subject is considered in more detail in:
    - Radio Frequency Engineering (EENG36500)
    - Microwave Engineering (EENGM5021)
    - Antennas (EENG35010)

Ref:

Layered Model Summary (1)

- The various sub-layers stack together to form an effective communications link between nodes at the layer above
- Actual communication takes place via the entire stack with the only Physical connections existing at the bottom of the stack
- This extends in principle all the way up through the protocol stack – whatever the model
- In the diagram, solid lines represent actual data/signal flow whilst dotted lines represent effective flow



Layered Model Summary (2)

- Of course, thus far we have only considered the responsibility of each layer or sub-layer, we have not considered *how* they achieve this functionality
- This is really what this course is about – *what* LLC, MAC and BB strategies are actually used in Broadband Wireless Communications and *why*…

Multiple Access and Duplexing

- In most communications systems it is necessary to share the channel in some way.
  - Between two communications nodes, it is often necessary to separate the signals flowing in different directions. This is known as duplexing
  - In the case of multiple nodes, it is further necessary to separate the signals of different terminals in whichever direction. This is know as multiple access

Duplexing and Multiple Access Strategies – Frequency and Time

- Frequency Division
  - Different transmitters transmit at different frequencies within the bandwidth of the overall system, without overlap, e.g. analogue terrestrial television.
  - All Signals can occupy all time.
  - Commonly used for both Duplex (FDD) and Multiple Access (FDMA)
- Time Division
  - Different transmitters transmit within different time slots within a given frame. Frame repeats cyclically. All users can occupy the entire bandwidth of the system.
  - Commonly used for both Duplex (TDD) and Multiple Access (TDMA)

Duplexing and Multiple Access Strategies – Code (1)

- Code Division
  - Each transmitter spreads is signal according to a unique code.
  - Ideally, all codes are orthogonal
  - Each transmitter's signal is allowed to occupy all time and the entire system bandwidth. However, since an increase in bandwidth is implicit in the spreading process, no improvement in capacity is achieved
  - Receiver can extract the wanted signal from the total signal by utilising knowledge of the appropriate spreading code. If codes are orthogonal, no interference occurs

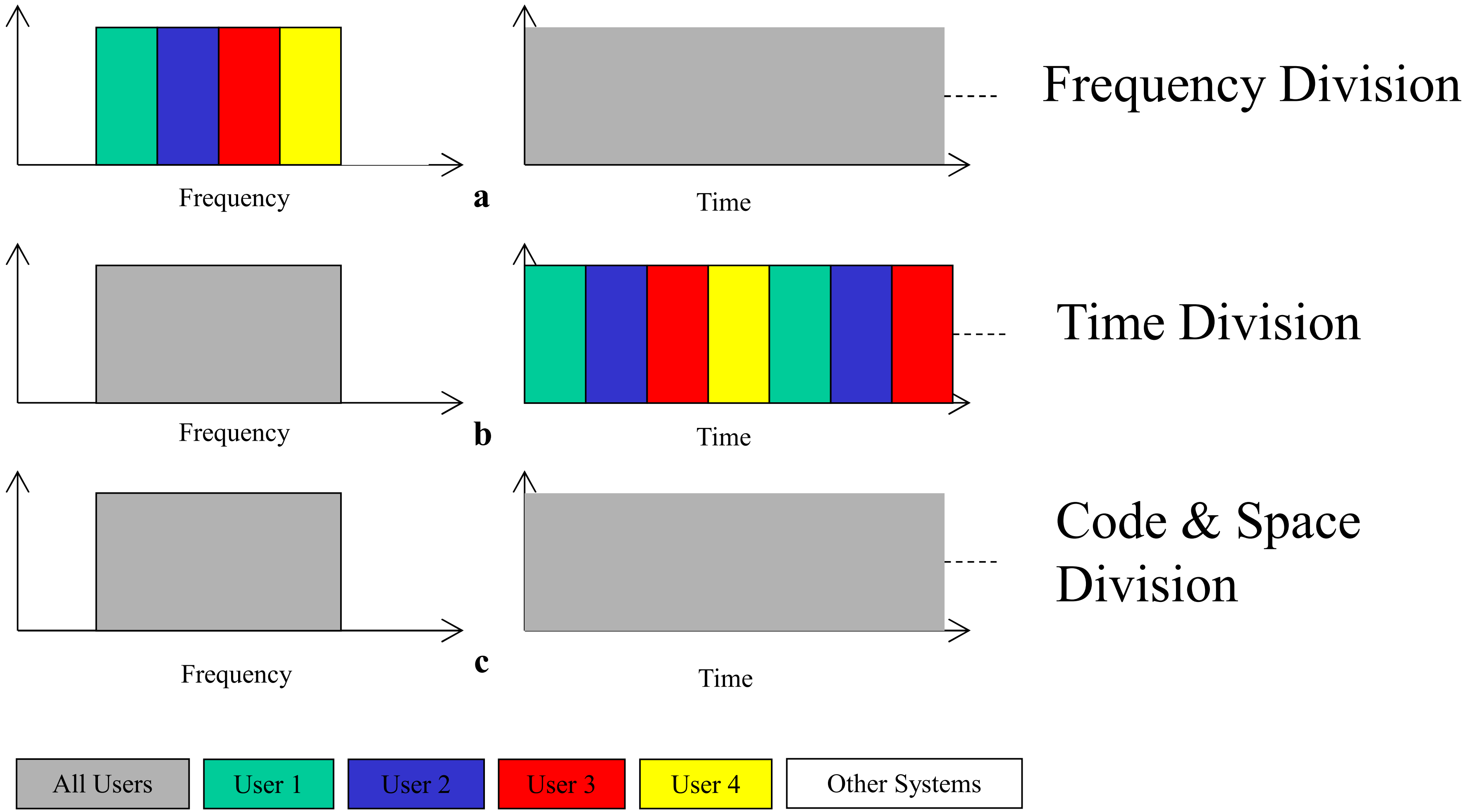
Duplexing and Multiple Access Strategies – Code (2)

- In reality, although the spreading codes may be designed to be orthogonal, features of a wireless channel often compromise this orthogonality resulting in interference between Code Division signals
- Complex signal processing techniques are often required to mitigate this interference
- Code Division is used for Multiple Access and has only receive academic consideration as a Duplexing Strategy

Duplexing and Multiple Access Strategies – Space

- Space Division
  - Each transmitter's signal is allowed to occupy all time and the entire system bandwidth
  - Knowledge of the spatial environment in which the system operates is exploited at the receiver (and perhaps at the transmitter as well) to enable the extraction of the wanted signal from the total signal
  - The interference between signals can be typically substantial and very strong signal processing techniques may required to mitigate it
  - Note that since there is no implicit bandwidth expansion in the space division process, this does allow for an increase in spectral efficiency beyond the conventional Shannon limit – it is the only strategy which enables this
  - Space Division can only be applied as a Multiple Access technique (SDMA)

Signal Occupancy



Architectures, Control Strategies and Infrastructure versus Ad-Hoc

- We will now define and revise some terminology for wireless networks which does occasionally give rise to confusion and ambiguity. Wireless networks can be classified in terms of the following:
  - Topology
  - Single-Hop vs Multi-hop
  - Control
  - Infastructure vs Ad-Hoc

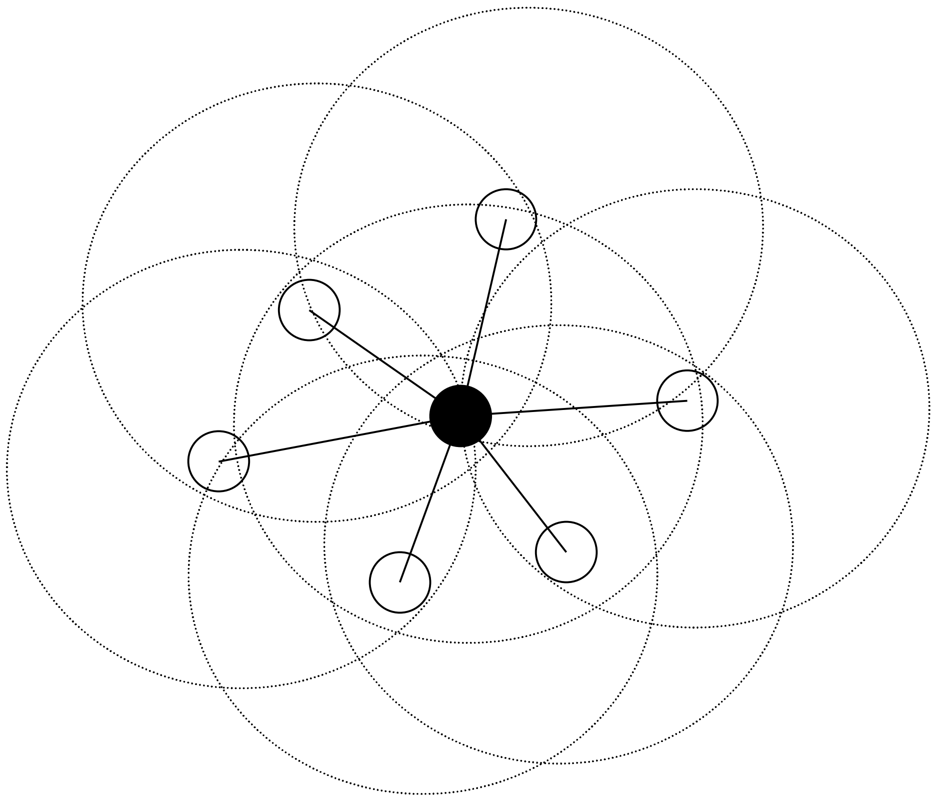
Network Topology

- A variety of network topologies may be identified in the general (not wireless specific) context:
  - Star
  - Mesh
  - Bus
  - Ring
  - Etc
- The nature of the wireless medium makes some of these more relevant than others for wireless communications, so we will focus on Star and Mesh network architectures

Ref:

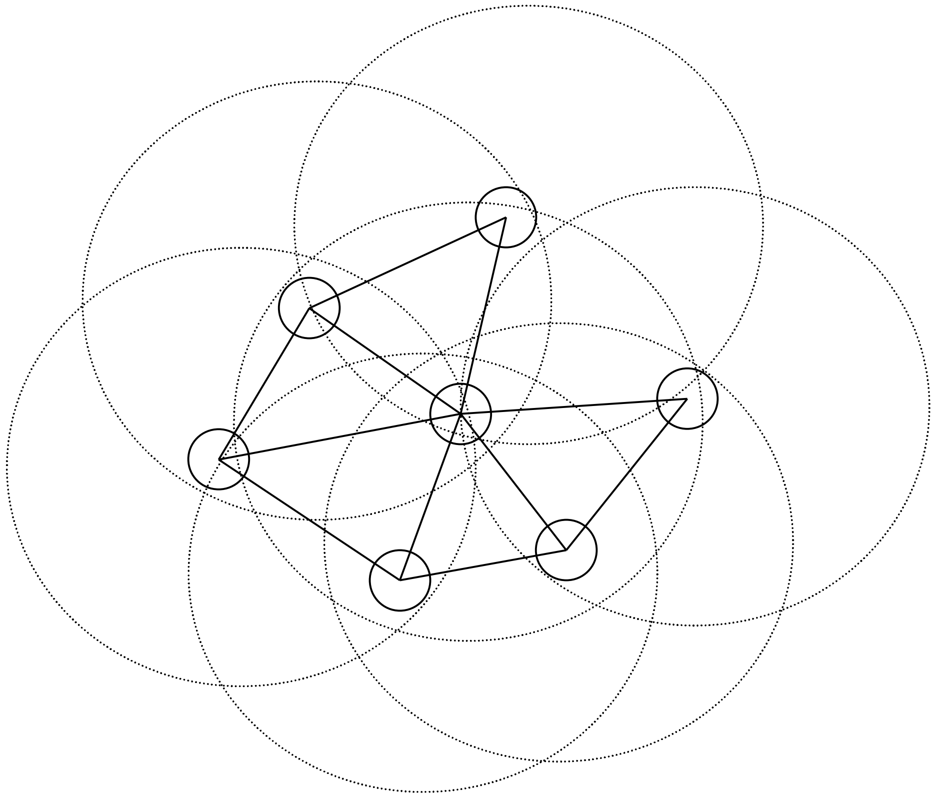
Star Topology

- A 'central' node (shown in black) communicates with all other non-central nodes (in white)
- Non-central nodes do not communicate directly with each other, even when they may have viable radio links between them
- A common topology in modern wireless communications, e.g.
  - Bluetooth, GSM, '3G', WiFi (in infrastructure mode)



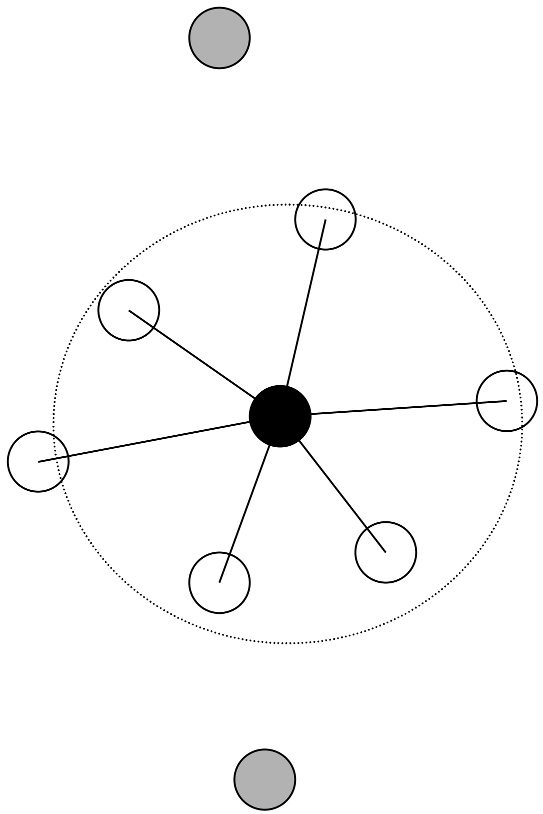
Mesh Topology

- There is no ‘central’ node
- Each node may communicate with any other node within range
- A less common topology but still used
  - E.g. WiFi in ‘ad-hoc’ mode



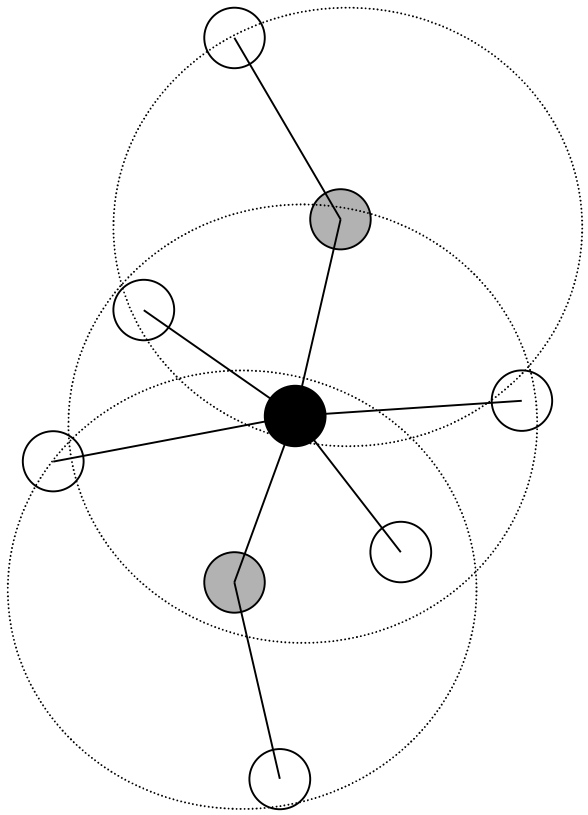
Single-Hop Networks

- Networks may also be classified as single-hop or multi-hop in terms of the number of wireless links (hops) allowed to link a non-central node to the central node
- Clearly, this terminology is not compatible with Mesh topologies
- The star topology example considered already is a single-hop case
- It can be seen that range of the network is fundamentally limited to within one hop of the central node
- Any nodes (illustrated in grey here) outside of the one hop range cannot be connected



Multi-hop Networks

- The network illustrated here extends its range beyond that of the single hop network by use of ‘relay’ nodes (shown in grey)
- This range extension is achieved at the expense of the additional complexity required to enable the use of relay nodes
- Repeat transmissions also reduce spectral efficiency
- The relay node might belong either to the network operator or to a customer
- Clearly other nodes in the network can act as relays and the principle can be extended to more than the two hops shown here
- Multi-hop strategies are NOT commonly employed in existing wireless networks but are seen as interesting for the future



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Control Strategies (1)

- Networks may be classified in terms of their control strategy as either:
  – Centralised or
  – Distributed
- In this context, control refers specifically to Medium Access Control
- A network using a centralised control strategy will have one node which dictates to all other nodes when they may access the physical medium. This node will contain an entity known as the Central Controller (CC)

Control Strategies (2)

– Often, in a network with a star architecture, it will be convenient for the central node of the star to contain the CC
– For this reason, star topologies and central control are sometimes deemed synonymous. This is not accurate
  • Central Control may be employed in a Mesh architecture
  • A node other than the central node of the star may be the CC of a star topology network
  • These examples are obviously not as convenient as the case of locating the CC in the central node of a star topology network but they are valid and the terminology should not be confused

Ref:

Infrastructure and Ad-Hoc Networks

- The terms Infrastructure and Ad-Hoc refer to whether or not the network contains a node which has a connection to a communications 'backbone' – typically a wireline link back to a very large scale network such as the internet
  - Infrastructure networks have such a node
  - Ad-Hoc networks do not
  - Cellular phone networks are a good example of an infrastructure network. Each cell is a wireless network in which the basestation is wired to the wired backbone network of the service provider
  - Bluetooth is an example of an ad-hoc network in which for example a mobile phone, PDA, headset and printer might link together to form a network in which none of the nodes is connected to a backbone
- These terms do occasionally give rise to confusion – Ad-hoc in particular is often wrongly taken to be synonymous with Mesh, Distributed control or multihop

Ref: