Senior and Master Air Cadet

Satellite and Data Communications

Learning Outcome 1:

Know the types and roles of satellites and principles of earth orbit

Learning Outcomes

- Know the types and roles of satellites and the principles of earth orbit including;
  - Orbits
  - Uses of satellites
  - Mission phases
  - Station keeping
  - Satellite components and uses

Lessons

1. Introduction to satellites and their Uses
2. Orbits
3. Satellite mission phases
4. Satellite communications basics
5. Satellite components

Satellite & Data Communications

Lesson 1:

Introduction to satellites and their uses

Satellites and Their Uses

- In this lesson Cadets will learn about the early development, types and uses of satellites including;
  - Definition of a satellite
  - Extra terrestrial relays
  - Sputnik
  - Early experimental satellites
  - The first communications satellites
  - Types and roles of satellites

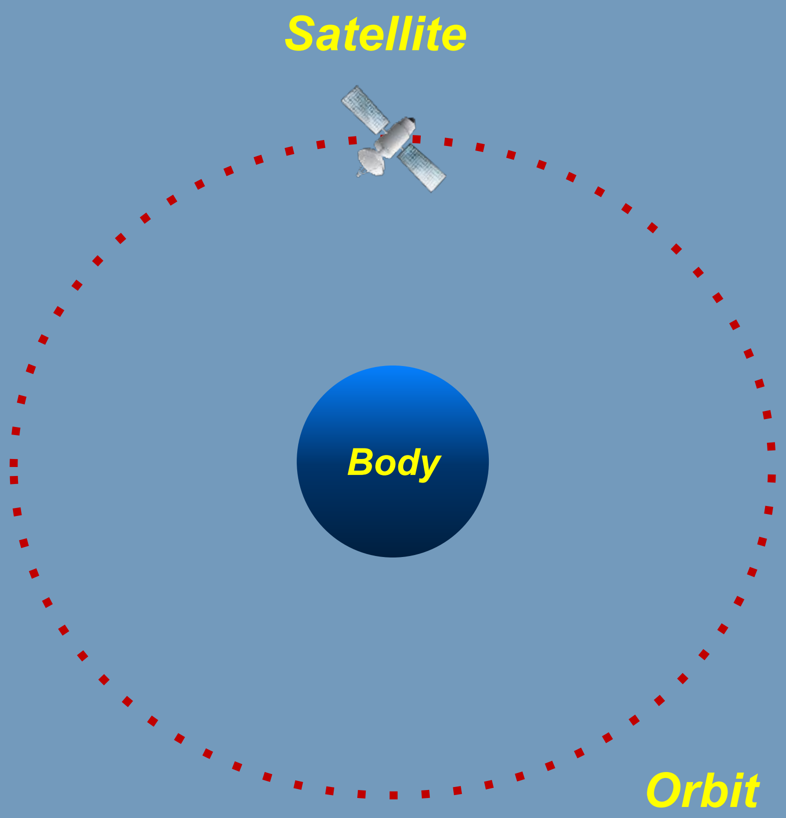
Introduction

- Man-made satellites are used extensively for a variety of specialist applications due to their many benefits over land based alternatives.
- The first artificial satellite was launched in 1957.
- There are now over 1,700 operational satellites in orbit around the Earth owned by various operators such as;
  - Treaty-based intergovernmental organisations
  - Nationalised companies and organisations
  - Private companies
  - Governments and militaries
- The oldest active satellite is the AMSAT-OSCAR 7 communications satellite launched in 1974 and used by radio amateurs

Image courtesy of Airbus

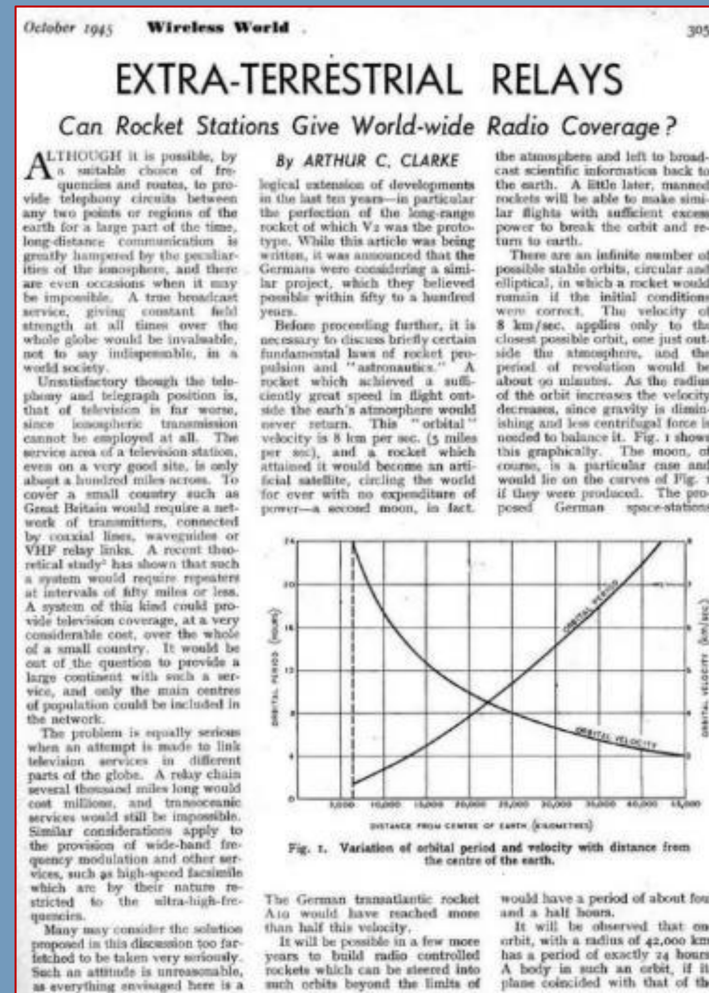
Definition of a Satellite

- A satellite is an object that moves around a larger object in an orbit.
- There are two types of satellite.
- A *natural* satellite such as a moon orbiting a planet.
- A *man-made* or artificial satellite is a machine that is launched into space and orbits the Earth or another body in space.



Extra Terrestrial Relays

- In 1945 Arthur C Clarke, a member of the British Interplanetary Society and a serving RAF radar specialist, wrote a letter to *Wireless World* magazine proposing that large rockets would be able to launch man-made satellites.
- Later that year he published an article titled “*Extra-Terrestrial Relays*”.
- He suggested that if three satellites were placed into a specific high altitude orbit over the equator, separated by 120º, they would be able to act as repeater stations and provide television and radio coverage over most of the earth.



October 1945 **Wireless World** 305

EXTRA-TERRESTRIAL RELAYS

Can Rocket Stations Give World-wide Radio Coverage?

By ARTHUR C. CLARKE

ALTHOUGH it is possible, by a suitable choice of frequencies and routes, to provide telephony circuits between any two points or regions of the earth for a large part of the time, long-distance communication is greatly hampered by the peculiarities of the ionosphere, and there are even occasions when it may be impossible. A true broadcast service, giving constant field strength at all times over the whole globe would be invaluable, not to say indispensable, in a world society.

Unsatisfactory though the telephony and telegraph position is, that of television is far worse, since ionospheric transmission cannot be employed at all. The service area of a television station, even on a very good site, is only about a hundred miles across. To cover a small country such as Great Britain would require a network of transmitters, connected by coaxial lines, waveguides or VHF relay links. A recent theoretical study[1] has shown that such a system would require repeaters at intervals of fifty miles or less. A system of this kind could provide television coverage, at a very considerable cost, over the whole of a small country. It would be out of the question to provide a large continent with such a service, and only the main centres of population could be included in the network.

The problem is equally serious when an attempt is made to link television services in different parts of the globe. A relay chain several thousand miles long would cost millions, and transoceanic services would still be impossible. Similar considerations apply to the provision of wide-band frequency modulation and other services, such as high-speed facsimile which are by their nature restricted to the ultra-high-frequencies.

Many may consider the solution proposed in this discussion too far-fetched to be taken very seriously. Such an attitude is unreasonable, as everything envisaged here is a logical extension of developments in the last ten years—in particular the perfection of the long-range rocket of which V2 was the prototype. While this article was being written, it was announced that the Germans were considering a similar project, which they believed possible within fifty to a hundred years.

Before proceeding further, it is necessary to discuss briefly certain fundamental laws of rocket propulsion and "astronautics." A rocket which achieved a sufficiently great speed in flight outside the earh's atmosphere would never return. This "orbital" velocity is 8 km per sec. (5 miles per sec), and a rocket which attained it would become an artificial satellite, circling the world for ever with no expenditure of power—a second moon, in fact.

The German transatlantic rocket A10 would have reached more than half this velocity.

It will be possible in a few more years to build radio controlled rockets which can be steered into such orbits beyond the limits of the atmosphere and left to broadcast scientific information back to the earth. A little later, manned rockets will be able to make similar flights with sufficient excess power to break the orbit and return to earth.

There are an infinite number of possible stable orbits, circular and elliptical, in which a rocket would remain if the initial conditions were correct. The velocity of 8 km/sec. applies only to the closest possible orbit, one just outside the atmosphere, and the period of revolution would be about 90 minutes. As the radius of the orbit increases the velocity decreases, since gravity is diminishing and less centrifugal force is needed to balance it. Fig. 1 shows this graphically. The moon, of course, is a particular case and would lie on the curves of Fig. 1 if they were produced. The proposed German space-stations would have a period of about four and a half hours.

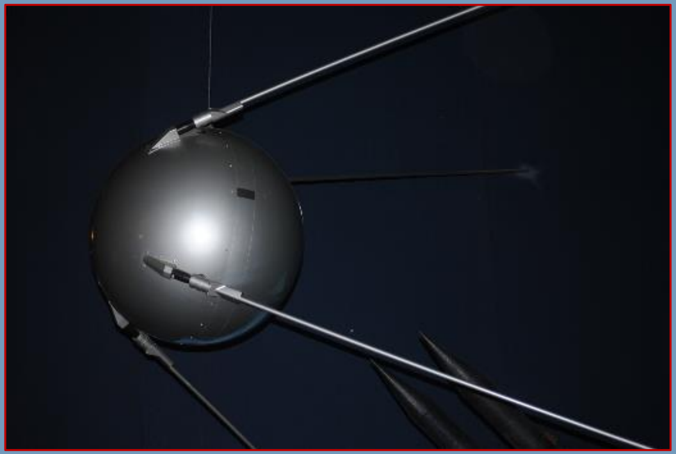
It will be observed that one orbit, with a radius of 42,000 km, has a period of exactly 24 hours. A body in such an orbit, if its plane coincided with that of the

Fig. 1. Variation of orbital period and velocity with distance from the centre of the earth.

Image source Wireless World

Sputnik

- After World War II advancements in missiles and microwave radio technology made man-made satellites a reality.
- On 4 October 1957 the first artificial satellite *Sputnik* was launched from the Soviet Union.
- Sputnik 1, a 58 cm diameter sphere weighing 83 kg, was launched by an Intercontinental Ballistic Missile into an orbit varying from 225 km and 917 km above earth.
- It transmitted a characteristic *"beep-beep"* signal for 21 days before returning to earth.



Listen to the Sputnik signal

Image source jc4i

Early Experimental Satellites

- The following years saw the launching of a series of experimental satellites;
  - SCORE (1958)
    - The first US launched satellite transmitted a wire tape recorded Christmas message from President Eisenhower.
  - ECHO (1960)
    - A 30m aluminium coated inflatable balloon from which signals were passively reflected back to earth.
  - COURIER (1960)
    - The first electronic active store and forward repeater.
  - TELSTAR (1962) and RELAY (1962)
    - The first powered relay satellites to rebroadcast live television signal across the Atlantic.
  - SYNCOM (1963)
    - The first geostationary satellite. Broadcast live pictures of the Tokyo Olympic Games in 1964.

ECHO

TELSTAR

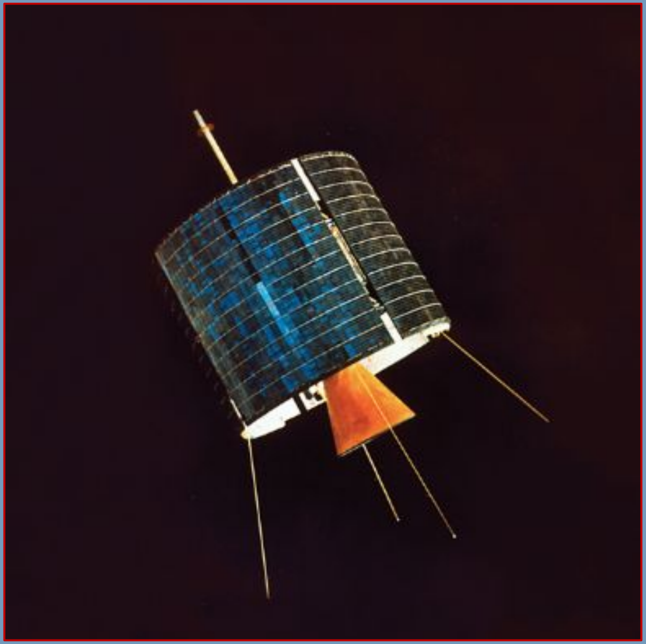
SYNCOM

Image source NASA

ROYAL AIR FORCE AIR CADETS the next generation

The First Commercial Satellites

- In 1965, the first commercial telecommunications satellite, *Early Bird,* later known as *Intelsat 1,* was launched into geostationary orbit.
- The initial services were telephone and television transmission across continents to supplement submarine cables.
- The satellite provided capacity for only 480 telephone channels and one TV channel.
- The Soviets also launched their first *Molynya* satellite in the same year.

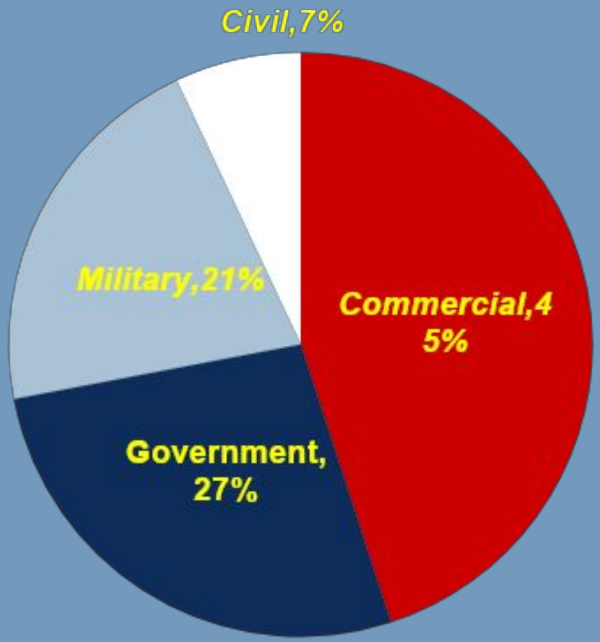


Early Bird

Image source NASA

Types and Roles of Satellites

- A satellite is launched into space to fulfil a specific job and is classified according to its role;
  - Communications
    - Broadcasting, Telecommunications, Data Distribution and Exchange
  - Radiodetermination
    - Positioning, Navigation, Timing
  - Surveillance
    - Reconnaissance, Remote Sensing, Weather Stations, Search And Rescue
  - Space Science
    - Astronomy



Satellite usage in 2017

Cadet Activity

- Cadets should now investigate the different types and roles of satellites from the Internet and other sources, comparing outcomes with the group.

Communications

- Communications Satellites, or "*COMSATS*", are the most common satellite in use with around 750 operational in 2017.
- They provide capabilities not readily available with, or which can supplement, land based communication systems.
- Commercial COMSATS are used for services such as;
  - Direct broadcasting
    - Television and radio
  - Digital telecommunications
    - Telephony, television programme exchange, mobile communications
  - Data distribution and exchange
    - Small terminal low capacity data transmission, multimedia and Internet access
- The military rely almost totally on satellites for communications with forces abroad, making it possible to;
  - direct war from 1000s of km away
  - co-ordinate widely scattered forces on sea, air and land.

Navigation

- *Global Navigation Satellite Systems* (GNSS) enable anyone with a receiver to determine their location to within a few metres.
- GNSS provide 3-dimensional *position, navigation and timing* (PNT) information to receivers on the land, sea and in the air.
- There are numerous new and innovative applications utilising GNSS being created on a daily basis.
- GNSS are now used intensively in military, industrial, commercial, public safety and consumer applications replacing existing conventional methods of navigation.
- There are currently three major GNSS systems in operation with more in development;
  - *GPS* - US
  - *GLONASS* - Russia
  - *GALILEO* - Europe

Remote Sensing

- *Remote sensing* is the process of detecting the physical characteristics of the Earth from a distance by measuring its reflected and emitted radiation.
- Special sensors on-board satellites can make different types of images of the earth using various electromagnetic frequency bands such as:
  - visible light
  - infra-red radiation
  - microwave radio
- They can observe large expanses of land where the climate is very harsh or which are virtually impossible to reach by land.
- Global environmental change that is difficult to measure on the ground, such as deforestation, polar ice cap shrinkage, spreading deserts and other large scale phenomena can be monitored.
- The Earth's resources important for humans can be monitored, such as tracking animal migration, locating mineral deposits and monitoring crops.

Reconnaissance

- *Reconnaissance* satellites are used by governments and military to;
  - spy on other countries and provide intelligence information on foreign military activities
  - detect missile launches or nuclear explosions
  - monitor electromagnetic transmissions while passing over a country
- There are three main types of reconnaissance satellites in use;
  - Optical and infrared imaging
    - Satellites with sensors that detect missile launches and observe enemy weapon systems on the ground
  - Radar imaging
    - Satellites able to observe the Earth using radar technology even through cloud cover
  - Signals intelligence (SIGINT)
    - Satellites with sensitive receivers to capture radio transmissions emitted from Earth
      - wireless communications (Communications Intelligence - COMINT)
      - other types of electronic emissions such as radar (Electronic Intelligence - ELINT)

Meteorology

- Most data used by weather forecasters now comes from *meteorology* satellites primarily used to monitor the Earth's weather and climate.
- Data is captured using on-board sensors to assist in making short and long term weather predictions.
- Typically, five sensors operating in different frequency bands give a number of images of the same scene;
  - visual imaging identifies cloud locations and weather fronts
  - infra-red and microwave sensors measure the Earth's surface and atmospheric radiation to estimate the amount of heat and energy being released, the amount of water vapour and sea temperature
- Weather satellites can also be used to;
  - monitor the movements hot or cold air masses, the amount of snow, the movement of ice fields and the depth of the ocean
  - examine crop conditions, areas of deforestation and drought
  - detect volcanic eruptions and the motion of ash clouds
  - receive environmental data from remote collection platforms

Search and Rescue

- *Search and Rescue* (SAR) satellites can be used to detect and locate emergency beacons activated on ships, aircraft, or individuals in remote or dangerous places.
- COSPAS-SARSAT (Search and Rescue Satellite Aided Tracking) is a satellite-based international, humanitarian search and rescue system.
- The system consists of a network of SAR instruments flown on remote sensing and navigation satellites, ground stations, mission control centres, and rescue coordination centres.
- When an emergency radio beacon is activated, the signal is received by a satellite then relayed via the nearest ground station to a local user terminal.
- The ground system identifies the beacon, calculates its position using Doppler techniques, and alerts the appropriate rescue coordination centre.
- A distress message can then be sent to the appropriate authorities from anywhere on Earth, 24 hours a day, 365 days a year, to instigate a rescue mission.

Astronomy

- An *astronomy* satellite is a large telescope located in Earth orbit.
- The satellites can see into space up to ten times better than a telescope of similar strength on Earth.
- This is because the satellite's vision is not impaired by the Earth's atmosphere and its infrared imaging equipment is not confused by the heat of the Earth.
- Astronomy satellites are used to;
  - map the stars in the universe
  - study unusual phenomena such as black holes and quasars
  - take images of the planets in the solar system
  - map planetary surfaces
- The *Hubble Telescope* is perhaps the best known current example.

Satellite & Data Communications

Lesson 2:

Orbits

Orbits

- In this lesson Cadets will learn about the principles of satellite orbits including;
  - Kepler's laws of planetary motion
  - How satellites stay in orbit
  - Definition of orbits
  - Popular operational orbits
  - Orbital slots
  - Space debris

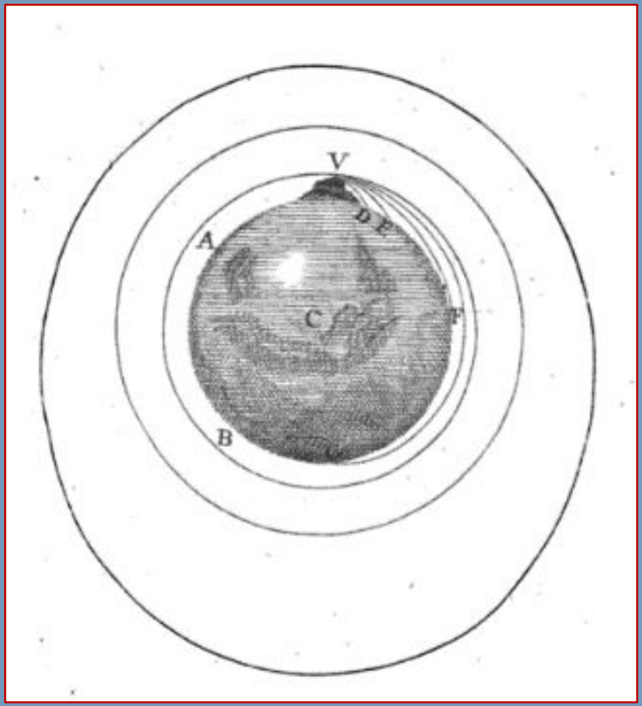
Kepler's Laws of Planetary Motion

- An *orbit* is a regular, repeating path that one object in space takes around another one.
- In the 17th century *Johannes Kepler*, a German astronomer, used accurate records of planetary observations over many years to arrive at an understanding of how planets orbit.
- He described the behaviour of a satellite in Earth orbit by his three *laws of planetary motion:*
  1. The orbit of each planet is an ellipse, with the sun at one focus
  2. The line joining each planet to the Sun sweeps out equal areas in equal times
  3. The square of the period of the planet is proportional to the cube of its mean distance to the sun

Johannes Kepler

How Satellites Stay in Orbit

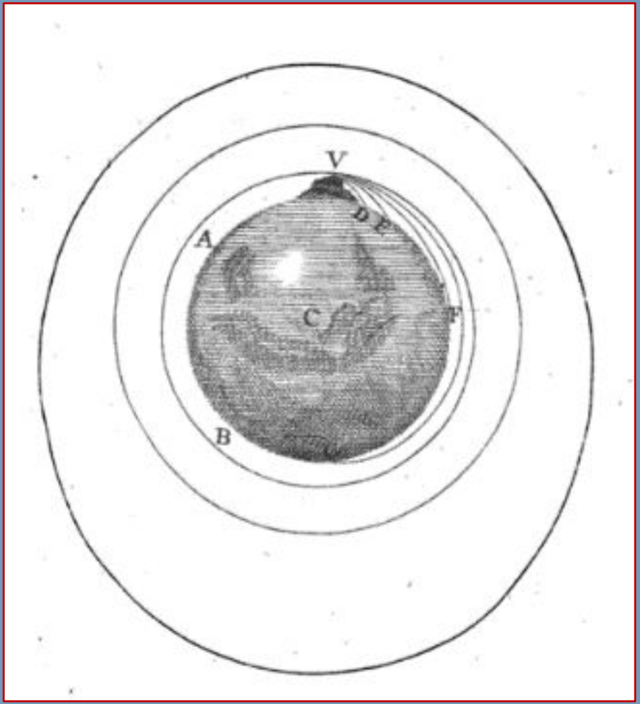
- About 70 years after Kepler, *Isaac Newton* used the newly formed principles of physics to prove that not only was Kepler correct, but to derive the physical basis of a satellite's behaviour through the *laws of motion*.
- In 1687 he devised a thought experiment known as *Newton's Cannon* to explain the nature of orbital motion.
- Newton created this diagram to explain his concept.



Newton's Cannon

Newton’s Cannon

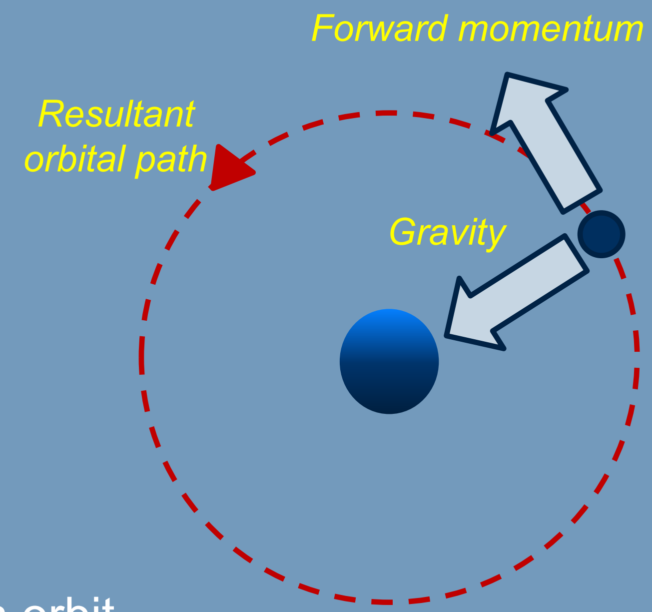
- Newton considered what would happen if a body at a very high altitude above the earth were accelerated to a sufficiently high speed enabling it to travel around the earth before falling to the ground.
- He imagined firing a large canon from a very high mountain top where;
  - The power of the cannon is increased each time it is fired.
  - Initially the shell falls to the ground.
  - Each time it is fired it travels a longer distance over the earth.
  - Eventually the shell makes a full circuit of the earth returning to the launch point then continuing in orbit for ever.



Newton’s Cannon

Newton's Laws and Orbits

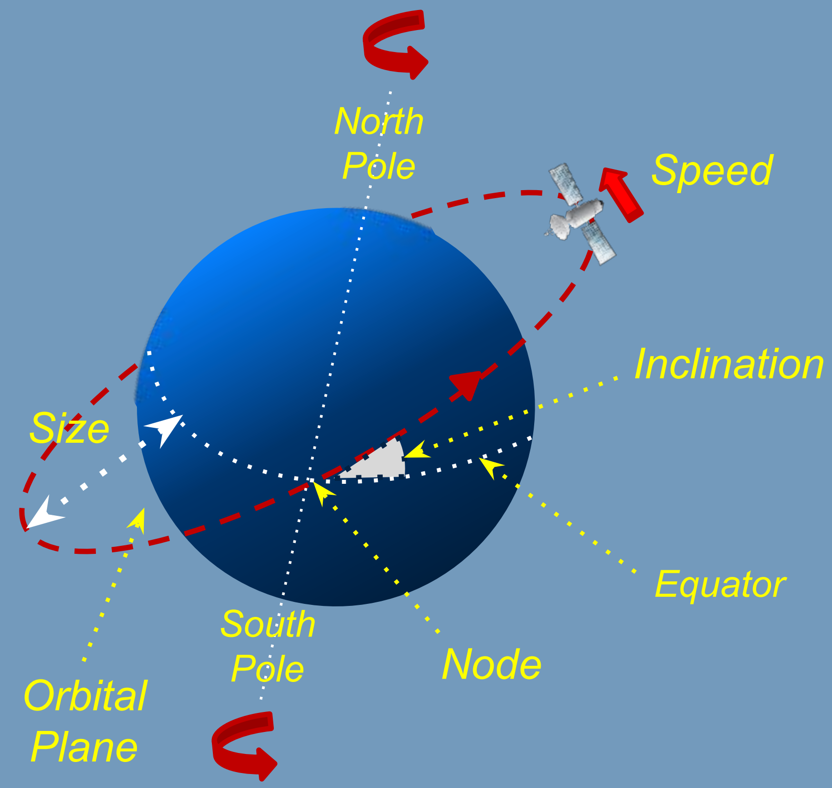
- Newton's 1st Law of Motion states that an object in motion will stay in motion unless something pushes or pulls on it.
  - Without gravity, an Earth-orbiting satellite would continue into space along a straight line
  - With gravity, it is pulled back toward the Earth
- There is an ongoing tug-of-war between a satellite's *momentum*, or tendency to move in a straight line, and *gravity* pulling it back.



- Both have to be equal for a satellite to remain in orbit.
  - If the forward momentum of one object is too great, it will go past the other object and not enter into orbit.
  - If momentum is too small, the object will be pulled into the other one.
- When the forces are balanced, the object is falling into the planet, but as it is moving fast enough horizontally, it never hits the planet.

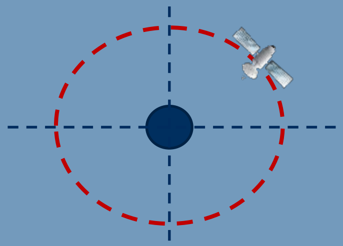
Definition of Orbits

- Consequently, satellites move predictably according to the fundamental physical laws which determine the mathematical *parameters* of an orbit.
- An orbit can be defined mathematically and has a set of key characteristics such as;
  - Shape
  - Size
  - Inclination
  - Speed
  - Period

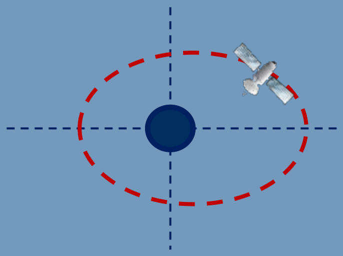


Orbit Shape

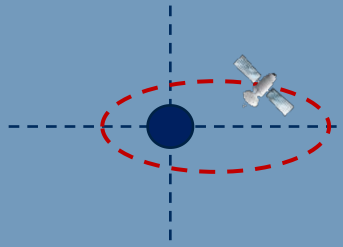
- Orbit shape is defined by Kepler's 1st Law.
- *Eccentricity* defines the shape of an orbit compared to a perfect circle.
- In other words, how much it is elongated or squashed.
- It is represented by a number between 0 and 1.
  - An ellipse with an eccentricity of 0 is a perfect circle
  - An ellipse that is almost flat has an eccentricity of close to 1
- The most common satellite orbit is *circular*.
- *Elliptical* orbits are often used when only a particular part of the Earth needs to be in view of a satellite for infrequent periods of time.



Circular orbit with zero eccentricity



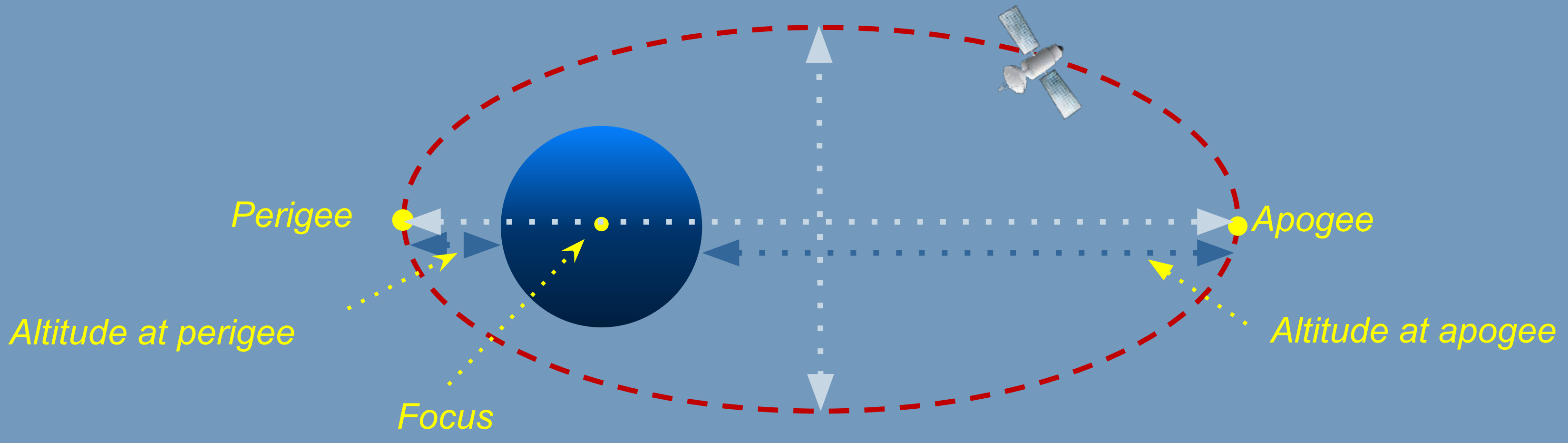
Elliptical orbit with low eccentricity



Elliptical orbit with high eccentricity

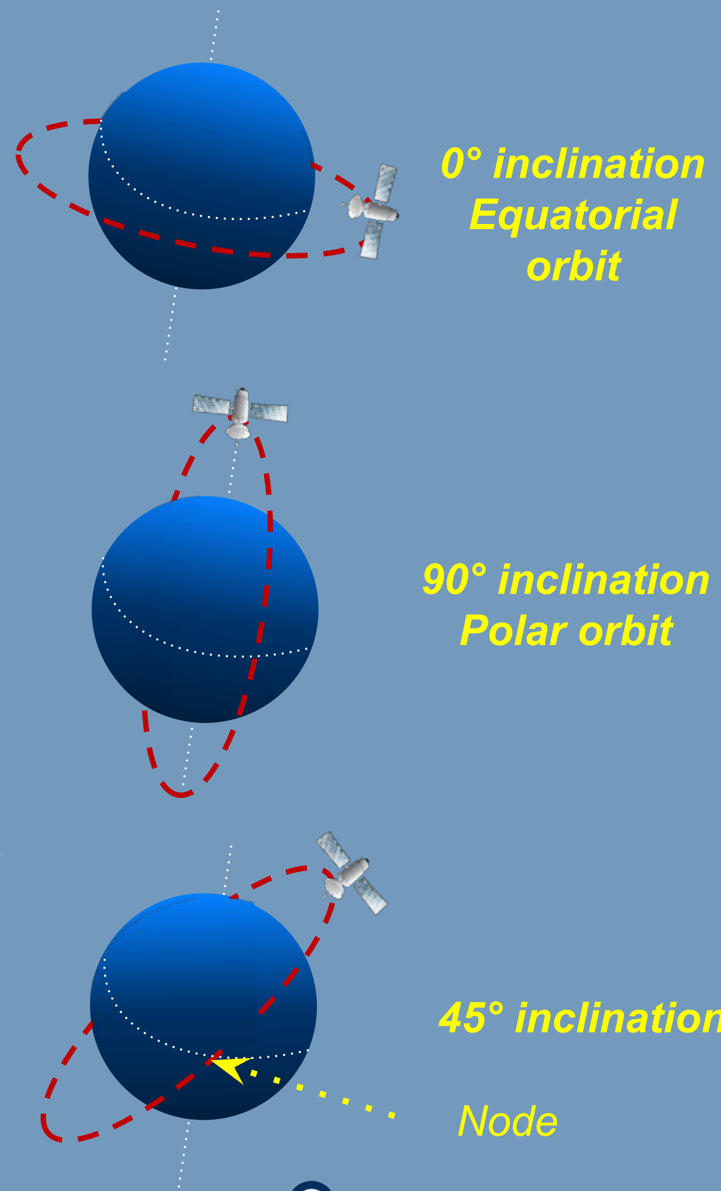
Orbit Size

- The *size* of an orbit is defined by the orbit *height or altitude,* the distance between the satellite and Earth's surface.
- For elliptical orbits, the overall size of the orbit can be defined in terms of the distance between perigee and apogee;
  - The *perigee* is the orbit point nearest to the earth's surface.
  - The *apogee* is the orbit point farthest away from the earth's surface.



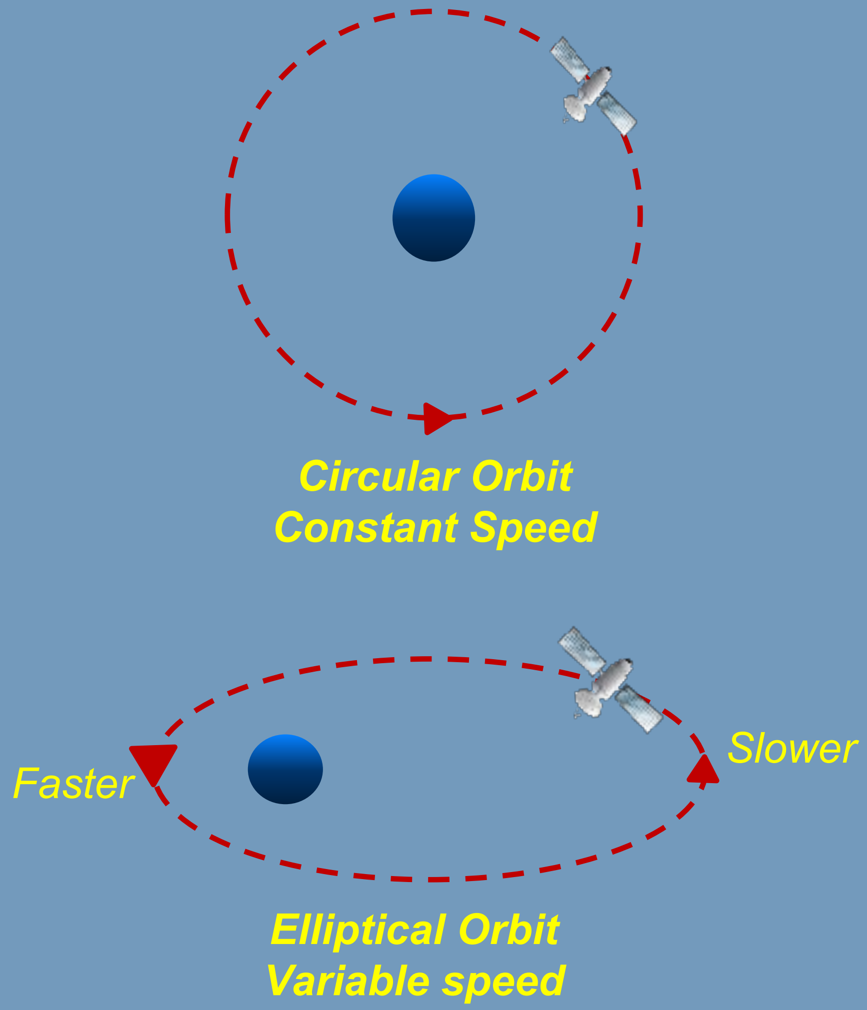
Orbital Inclination

- *Inclination* is the angle a satellite orbit makes when compared with the Earth's equator from the southern to the northern hemisphere.
- By convention, it is measured anticlockwise from the equator to the orbital plane at the point where the satellite crosses passing north.
- An *equatorial orbit* is directly above the equator with a 0° inclination
- A *polar orbit* travels directly over the north and south poles with a 90° inclination.
- Other inclined orbits make an angle of greater than 0° and less than 90° to the equator.
- The point at which the spacecraft crosses the equator is called a *node.*



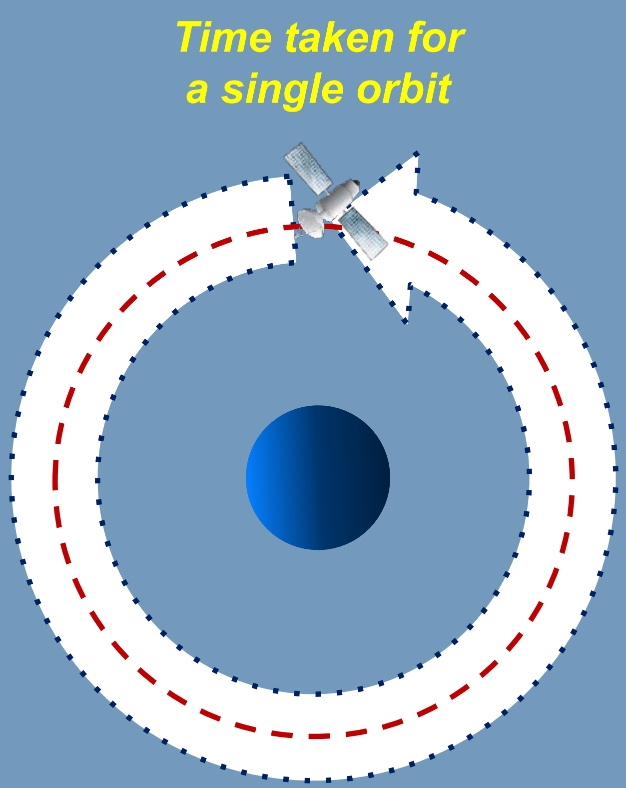
Orbital Speed

- *Orbital speed* is the speed needed to stay in orbit and is determined by the shape and size of the orbit.
- It is defined by Kepler's 2nd Law.
- An object in circular orbit at a particular height will travel at a defined constant speed at all points on orbit.
  - However, the higher the orbit, the slower the speed.
- An elliptical orbit is more complicated;
  - As orbit height increases travelling from perigee to apogee, the orbit speed decreases.
  - As orbit height decreases travelling from apogee to perigee, the orbit speed increases.



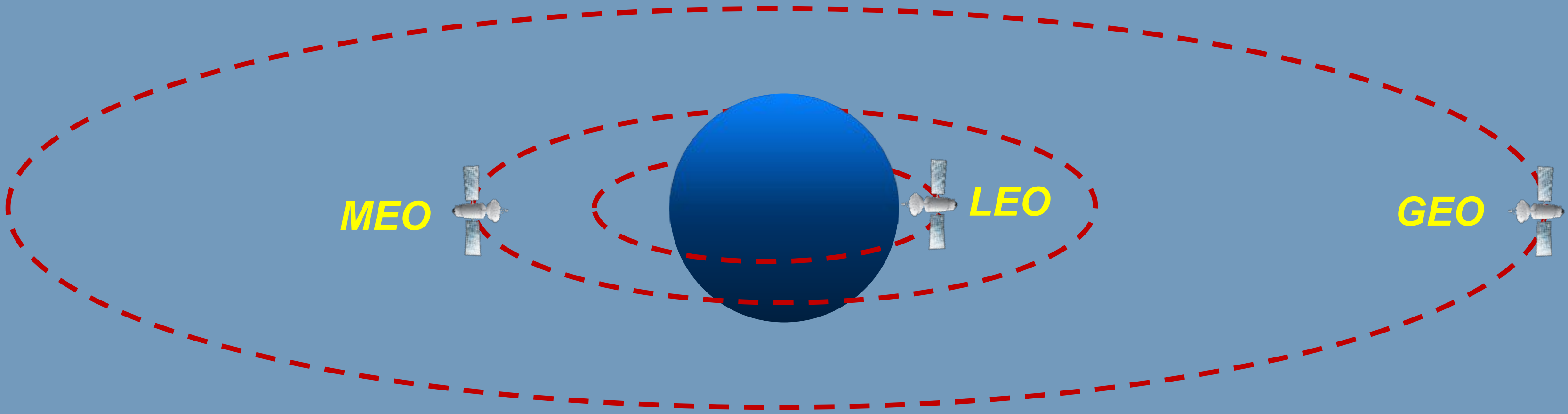
Orbital Period

- *Orbital period* is the time it takes a satellite to make one full orbit.
- It is defined by Kepler's 3rd law.
- Only the height of the orbit determines the period, not the size or mass of the object.
- As the height of the orbit increases, the time taken for the satellite to orbit increases.
- At a height of 35,786 km it takes exactly 24 hours for the satellite to orbit and it is synchronised with the speed of the earth's rotation.
- This type of orbit is known as a *geosynchronous orbit.*



Popular Operational Orbits

- There are many different types of orbits used by satellites.
- The choice of orbit is determined by the application and function the satellite needs to perform.
- The most common circular earth orbit schemes are;
  - Low Earth Orbit (LEO)
  - Medium Earth Orbit (MEO)
  - Geostationary Earth Orbit (GEO)



Not to scale

Low Earth Orbit

- LEO is restricted to the first 150km to 2,000 km of space, just above the earth's atmosphere.
- It is the easiest orbit to reach and remain in.
- The orbital period is between 90 and 120 minutes with the satellite travelling at over 27,000 km per hour.
- A LEO satellite is in view from only a small percentage of the Earth's surface.
- With a near-polar inclination close to 90°, a LEO can overtime provide worldwide long term coverage due to the combined motion of the satellite and the Earth's rotation.
- A constellation of several tens of satellites in LEO orbits, such as the *Iridium* system, can provide real-time worldwide personal communications.
- Most scientific satellites and many weather satellites are in a nearly circular, low Earth orbit.
- In 2017 over 60% of satellites were in LEO.

Medium Earth Orbit

- MEO satellites have an altitude above 2,000km and below 35,786km.
- Their orbital period is between 2 and nearly 24 hours.
- 5% to 15% of the Earth's surface 44% is visible from a MEO satellite.
- Most operational MEOs have an inclination of about 50°
- With constellations of 10 to 15 satellites, continuous global coverage is possible.
- MEO is used by satellites requiring slow sweeps of large areas of the Earth such as search and rescue, navigation and mobile communications satellites.
- Constellations of satellites in MEO at various inclinations, in which at least one will be in view of any point on the earth, are used for global mobile communications.
- The most common altitude is around 20,000 km which has an orbital period of about 12 hours and is used by the Global Positioning System.
- In 2017 nearly 6% of operational satellites were in MEO.

Geostationary Earth Orbit

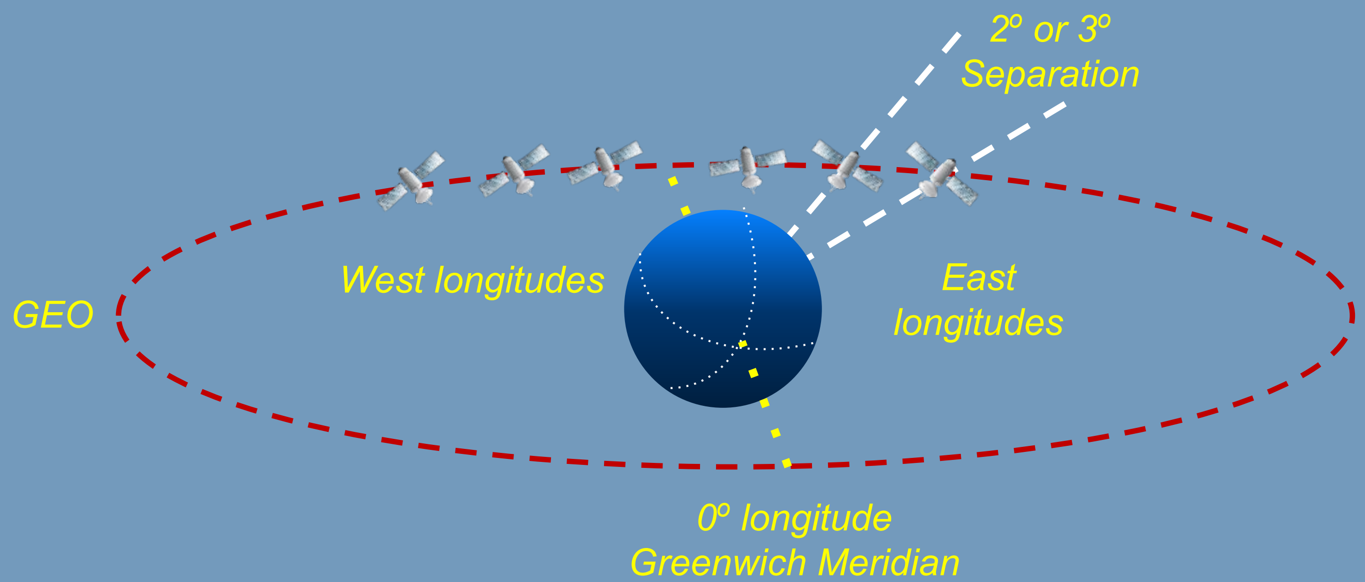
- GEO is a special case of a circular geosynchronous with zero inclination
- There is only one unique GEO at a height of 35,786km
- A GEO satellite orbits once every 24 hours at a speed of 11,100 km/hour, from west to east maintaining precise synchronisation with the Earth's rotation.
- From Earth the satellite appears to be stationary since it is always above the same location.
- 44% of the Earth's surface is visible from a GEO
- Three satellites separated by 120° of longitude can communicate with almost all inhabited portions of the Earth, except the poles.
- GEOs are mostly used for communications, scientific and earth observation.
- They are ideal for telecommunications and broadcasting because the ground station does not need to track the satellite and they can provide large areas of coverage of the earth.
- In 2017 over 30% of operational satellites were in GEO.

Choice of Operational Orbit

- A COMSAT's orbit is determined by the *mission objectives*, typically the communications capacity and coverage based on the operator's markets, customers and user needs.
- Therefore a satellite needs to be in the correct location, at the correct time.
- Choice of orbital characteristics is a compromise between;
  - the power required for transmission against total coverage on Earth
  - the period when a point on the Earth's surface remains in view of a satellite's antenna
  - the interval between repeat visits to specific points on the Earth
- The orbital altitude and inclination of the satellite controls the coverage and the elevation angles of the satellite and ultimately determines the satellite's orbit position.
  - 0° inclination orbits provide good equatorial coverage, but no polar coverage.
  - 90° inclination orbits provide global coverage and will pass over a greater part of the Earth depending on their inclination, with the earth spinning below them, eventually returning over the same point after several orbits.

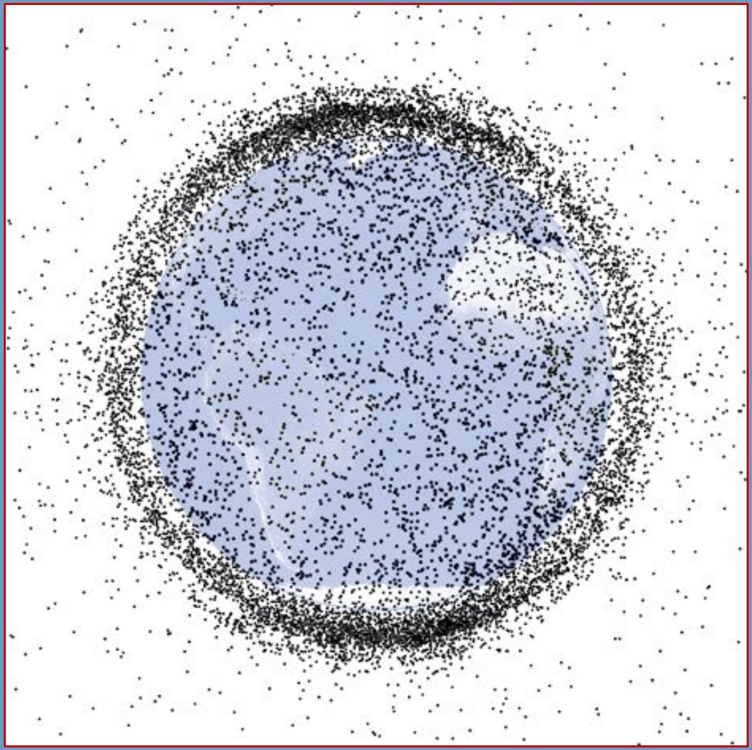
Orbital Slots

- GEO satellites are assigned a unique *orbital slot,* the position in longitude where a satellite remains stationary above Earth.
- This is to prevent unwanted radio interference occurring between satellites spaced too close together, rather than to avoid collisions.
- A slot separation of 2° or 3° of longitude is common, equating to distance between satellites of 1,500 and 2,250 km at orbital height.



Space Debris

- Space debris can be a hazard to orbiting satellites.
- *Natural debris* are pieces of rock and dust called meteoroids mostly originating from asteroids and comet tails.
- *Man-made debris* are non-functional spacecraft, rocket parts, mission related and fragmentation debris as a result of
  - Launches and failures
  - Intentional military destruction
  - Spacecraft collision



Each black dot shows a functioning satellite, an inactive satellite, or a piece of debris.

Image source NASA

Risk of Space Debris

- The total amount of orbiting space debris is estimated at over 100 million objects, most too small to be detected.
- Over half a million pieces are being tracked as they orbit Earth.
- Thousands of manmade objects, many larger than 10cm, occupy low Earth orbit, and 95% of them are “space junk”,
- Some debris is travelling at thousands of kilometres per hour.
- Such a relatively large amount of fast moving debris is a significant hazard to operational satellites and it is constantly increasing.
- Even very small debris can travel fast enough to collide with a satellite damaging critical components.
- Furthermore, a chain reaction can occur as debris collide with each other, continuously creating even more fragments of debris.

Satellite & Data Communications

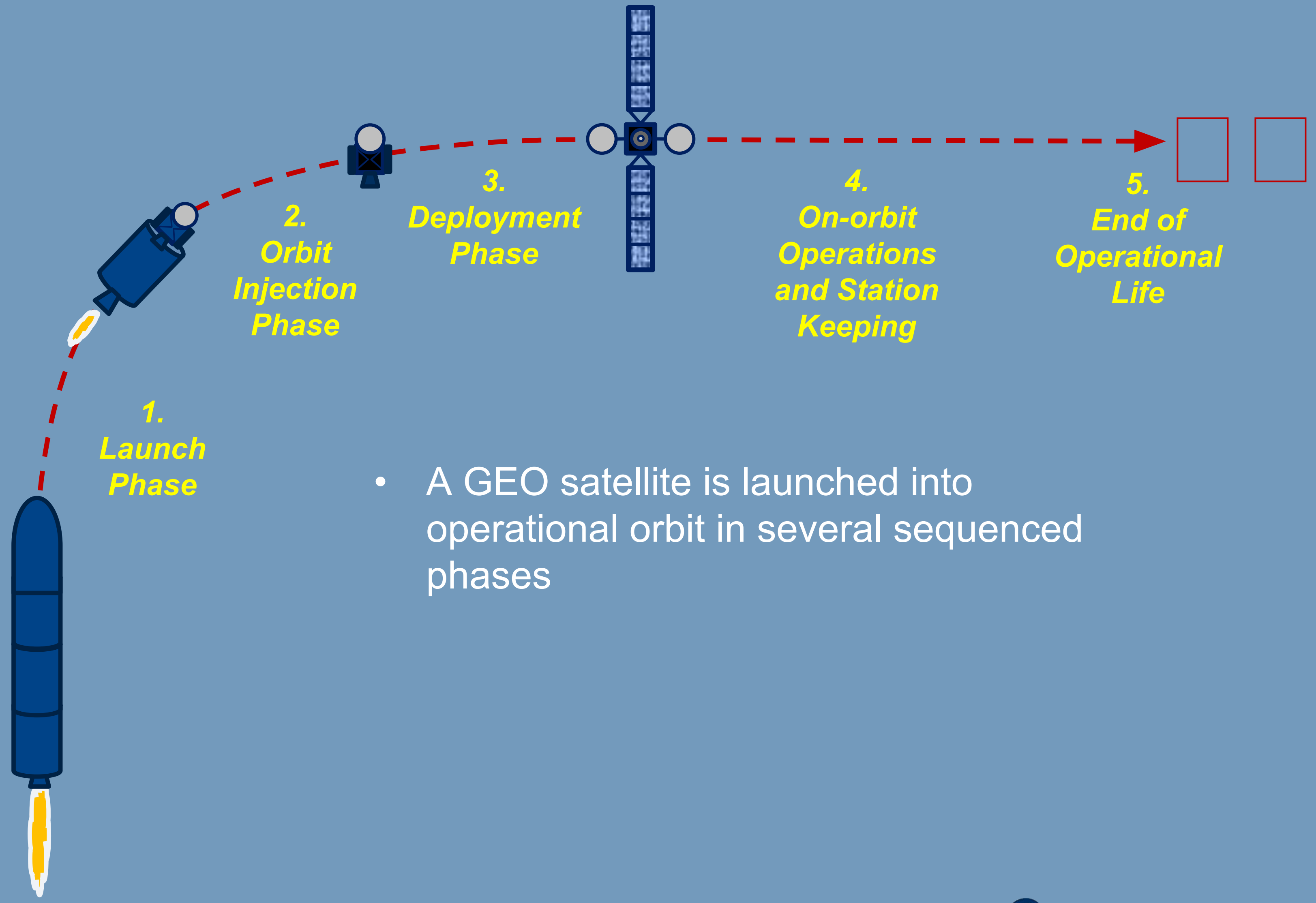
Lesson 3:

Satellite Mission Phases

Satellite Mission

- In this lesson Cadets will learn about the various phases in the lifecycle of satellite's mission including;
  - Launch phase
  - Orbit injection phase
    - Parking orbit
    - Hohmann transfer
  - Deployment phase
  - On-orbit operations
    - Station keeping
  - End of operational life

Mission Phases



- A GEO satellite is launched into operational orbit in several sequenced phases

Launch Phase

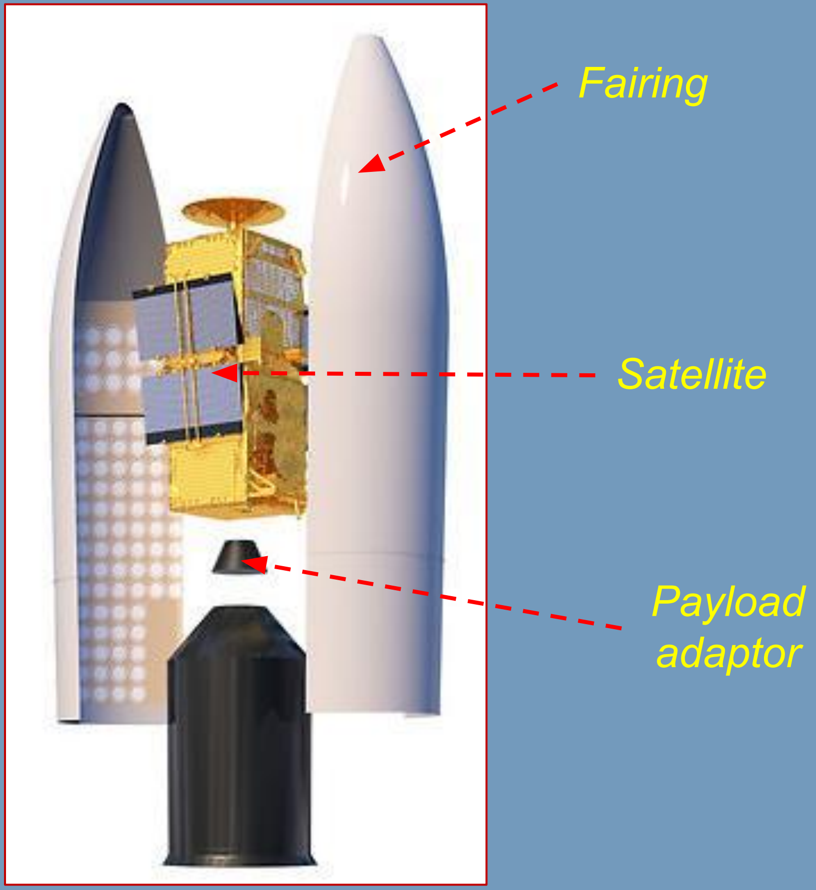
- A satellite mission begins with the Launch Phase when a *Launch Vehicle (LV)* containing the spacecraft leaves the launch pad.
- The task of the LV is to release the satellite;
  - at the correct height
  - with the proper speed and direction.
- The LV is typically an expendable ballistic rocket consisting of several stages stacked on top of one another.

Arianne 6 Launch Vehicle

Image courtesy of Airbus

Launch Vehicle Payload

- The satellite is located inside the launch vehicle in a protective nose cone called a *fairing* at the top of the rocket stack.
- A *payload adaptor* connects the satellite to the Launch Vehicle.

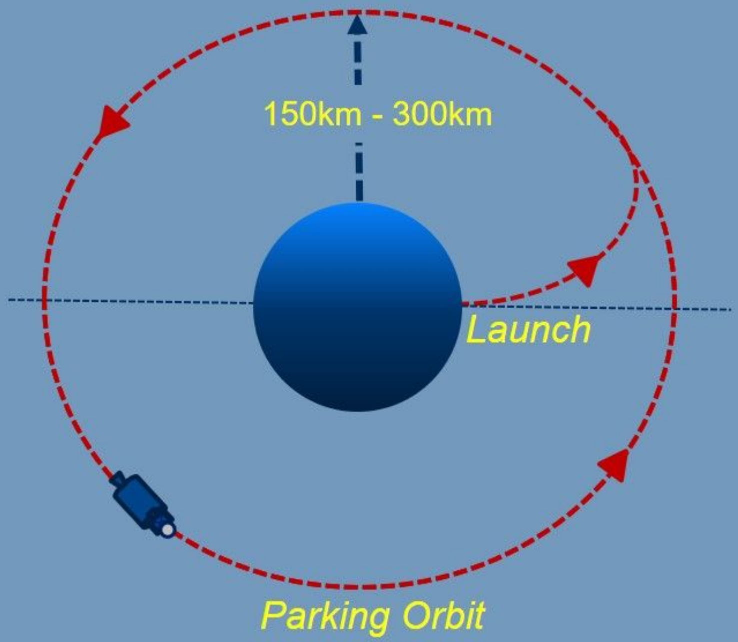


Arianne 6 Satellite Payload

Image courtesy of Airbus

Parking Orbit

- After lifting off from the launch pad, LEO and MEO Satellites are usually delivered by the LV directly into these orbits.
- For GEO satellites, the LV delivers the spacecraft to a temporary circular *parking orbit* at an altitude between 150km and 300km.
- A LV second stage booster rocket burn pushes the spacecraft into the parking orbit.
- The LV makes an orbit around the earth in about 1.5 hours.
- When the atmospheric pressure is low enough for safe deployment, the fairing is jettisoned.



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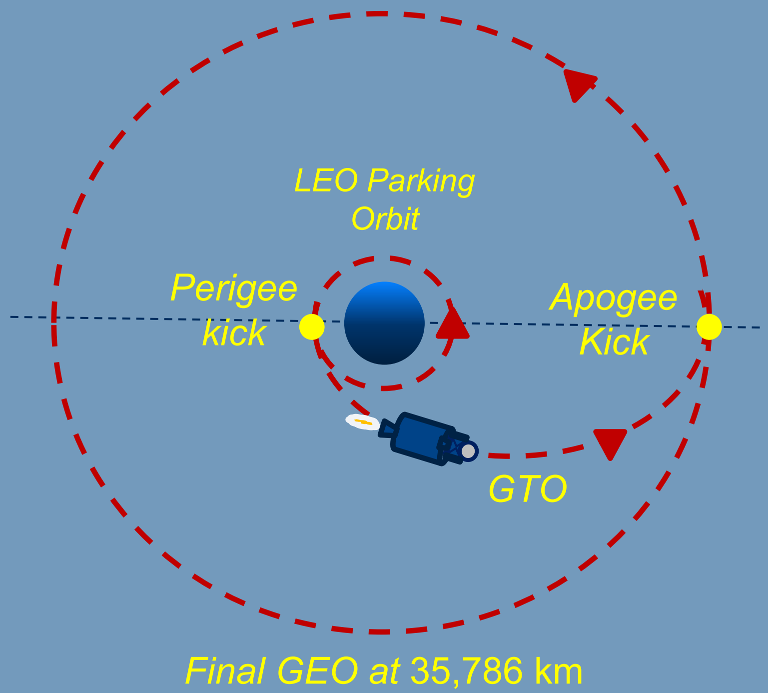
Orbit Injection Phase

- The *Orbit Injection Phase* is when the spacecraft is transferred from a parking orbit into the final operational GEO.
- The simplest approach is using a *Hohman Transfer.*



Hohman Transfer

- A Hohman Transfer is attractive because it consumes the least amount of fuel.
- The method is to use an intermediate elliptical *Geosynchronous Transfer Orbit* (GTO) where;
  - the perigee is at the same altitude as the parking orbit
  - the apogee is at or near the geosynchronous altitude
- A LV third stage, high thrust, solid fuel rocket provides a *perigee kick* to move the spacecraft from parking orbit into GTO.
- At the GTO apogee, circularisation of the orbit is achieved by reorienting the satellite and firing the on-board *Apogee Kick Motor.*

Deployment Phase

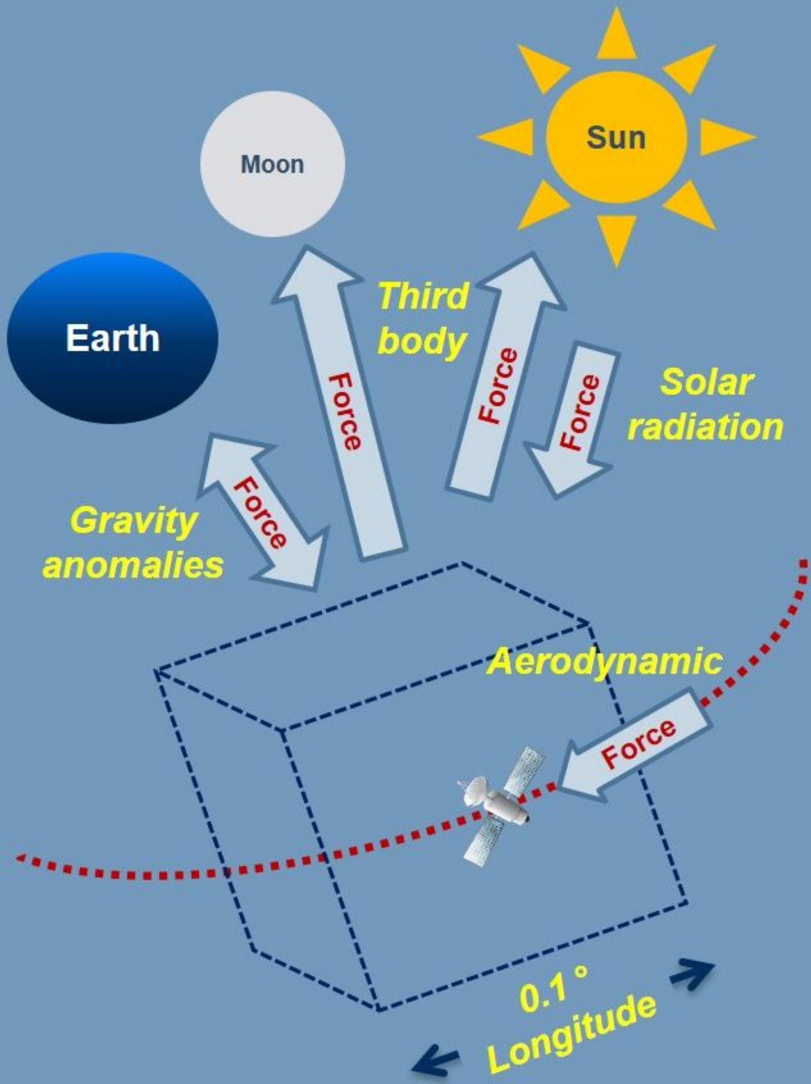
- In the deployment phase, having reached GEO, the satellite is prepared for operation.
- The satellite drifts to its assigned *orbital slot*.
- When *on-station* it is oriented to the correct attitude.
- External appendages such as the solar panels and antennas are deployed.
- All the satellite's bus and payload systems are tested which can take a few days to several weeks.

On-orbit Operations Phase

- When fully functional the satellite begins *on-orbit operations* and service can commence.
- However, in operational orbit, a satellite can be affected by disturbing forces called *perturbations* which can take the form of:
  - *Gravity anomalies* caused by the earth not being spherical causing and its gravitational pull varying as the satellite orbits.
  - *Third body forces* caused by the gravitational influence of the moon and sun.
  - *Solar radiation pressure* caused by the force of light particles (photons) striking the satellite.
  - *Aerodynamic forces* caused by atmosphere drag in low earth orbits.
- These forces vary the satellite's speed, moving it away from its ideal location.
- This compromises the satellite's ability to fulfill its mission objectives.
- Therefore, changes in orbit due to perturbations must be corrected by *station keeping* manoeuvres

Station Keeping

- GEO satellites are typically kept within 0.1° of their orbital slot longitude.
- *Sensors* on board the satellite measure whether the satellite is in its correct orbital position.
- The results are sent back to the *Satellite Control Station* (SCC).
- If the satellite has moved too far out of position, commands are sent from the SCC to the satellite to fire the *reaction control thrusters* and produce a small change in velocity to correct the orbit.
- Station Keeping is planned and carried out periodically over the operational lifetime of the spacecraft.



End of Operational Life

- The *operational life* of a satellite is determined by its ability to remain at its assigned orbital slot and oriented correctly by station keeping.
- Therefore when the thruster fuel has nearly run out, the satellite reaches the end of its active life, even though the satellite's other systems and payload often remain fully functional.
- A GEO satellite is then repositioned to a *graveyard orbit,* a few hundred kilometres higher than GEO.
- The satellite avoids becoming another piece of space debris and a collision hazard and makes room for new operational satellites.
- The useful lifetime of GEO satellites averages about 15 years.
- LEO satellites may have even shorter lifespans caused by the increased atmospheric drag and friction to which they are subjected reducing their orbital height.
- Satellites in LEO are usually repositioned so that they will re-enter the earth's atmosphere in a controlled descent and burn up.

Satellite & Data Communications

Lesson 4:

Satellite Communications Basics

Satellite Communications Basics

- In this lesson Cadets will learn about the principles of satellite communications and the concepts of;
  - Satellites in telecommunications
  - Satellite networks
  - Space, control and ground segments
  - Earth stations
  - Satellite footprint
  - Transmission systems
  - Uplinks and downlinks

Satellites in Telecommunications

- Satellites are one technology of many within the field of telecommunications.
- They provide an alternative method of transmission to terrestrial copper cable, optical fibre or microwave radio.
- Satellites may, or may not, satisfy all criteria demanded by a user for a specific telecommunications task.
- However, satellites have still prospered as they fill niche roles very cost effectively.
- Recent technology advances have led to smaller, lower cost, more sophisticated satellites with higher capacity and more capabilities, allowing operators to expand their services.

***Eutelsat** is the longest standing COMSAT operator with a fleet of 37 GEO satellites serving users across Europe, Africa, Asia and the Americas.*

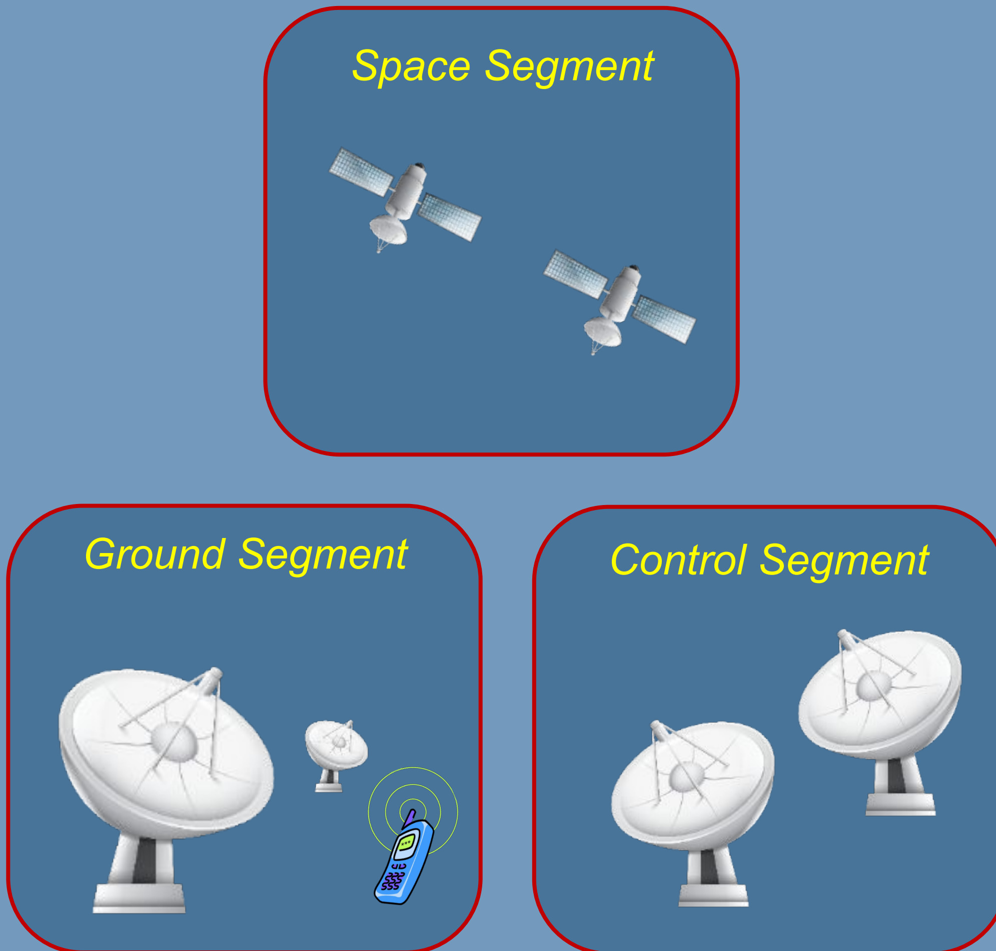
Image courtesy of Airbus

Satellite Communications Benefits

- Telecommunications is the most common use for satellites due to the many benefits such as:
  - Wide area of coverage
    - The altitude of a satellite means large areas of the Earth can be reached by a single global network provider serving a large population
  - Remote communications
    - Service is independent of terrestrial infrastructure
  - Mobility
    - Mobile communications is independent of location
  - Wide bandwidth and capacity
    - Applications such as HDTV are feasible
  - Instantaneous deployment
    - Set up is rapid and reconfiguration is simple
  - Back-up
    - Provides an alternative to existing infrastructure in case of failure or emergencies

Satellite Networks

- A satellite communications system is divided into three generic *segments* which are required to provide a complete operational *network*
  - *Space* segment
  - *Ground* segment
  - *Control* segment
- Typically an end-to-end satellite telecommunications network consists of
  - a *transmitter* on the ground
  - a *satellite payload* on orbit
  - a *receiver* on the ground.



Space Segment

- The *Space Segment* contains one or more operational, and sometimes spare, orbiting communications satellites, or COMSATS, arranged into a *constellation*.

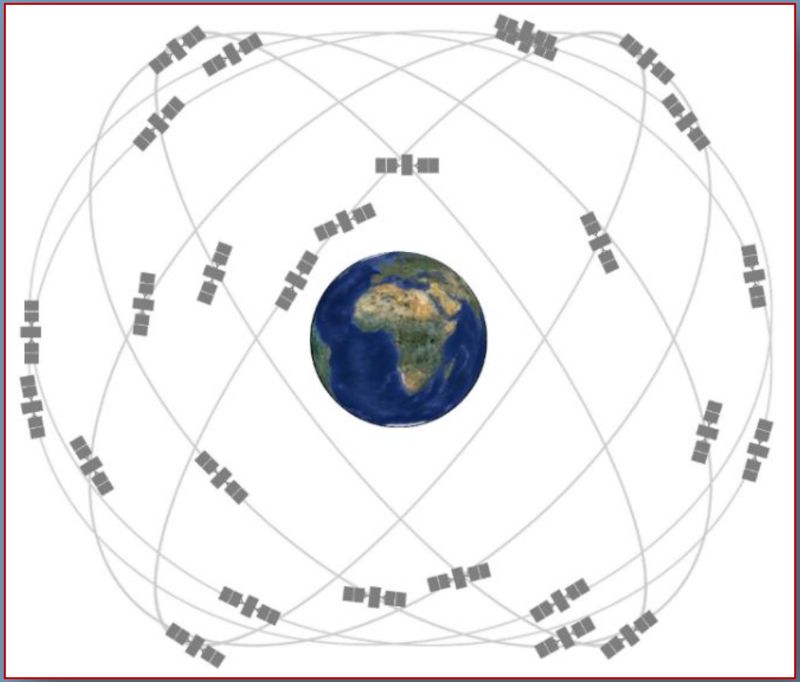


Image source US Government

Control Segment

- The *Control Segment* consists of all the ground facilities required to;
  - control and manage the satellite's function and orbit
  - manage the satellite payload equipment
  - manage the telecommunications traffic
- *Satellite Control Centres (SCC)* use *Telemetry, Tracking and Command (TT&C) Earth Stations* to;
  - monitor the health of the satellites
  - control the satellite remotely from the ground
- Often a separate *Network Operations Centre (NOC)* controls the operation of the satellite's payload handling the telecommunications traffic.

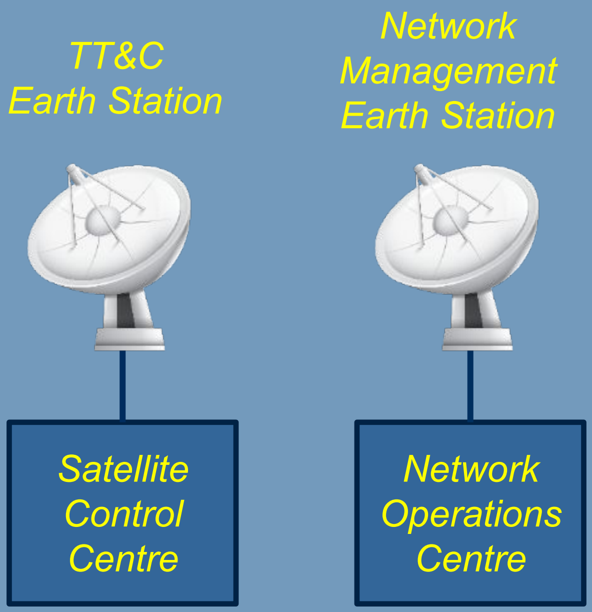


Image source MOD

Ground Segment

- The *Ground Segment* consists of all telecommunications Earth Stations which access the space segment and interconnect users.
- It is a diverse collection of facilities, users and applications that includes terminals located on land, sea and in the air
- Earth Stations are connected to the end-user's terminal either directly or to terrestrial networks such as the public telephone network and the Internet.
- Antenna sizes differ according to traffic type and quantity;
  - Historically, the largest used 30 m diameter antennas.
  - Currently, the smallest have 0.6 m antennas, such as receiving stations for satellite TV or even smaller 10 cm antennas on personal handsets.
- Some Earth Stations both transmit and receive, whilst others only receive, e.g. a satellite TV station.

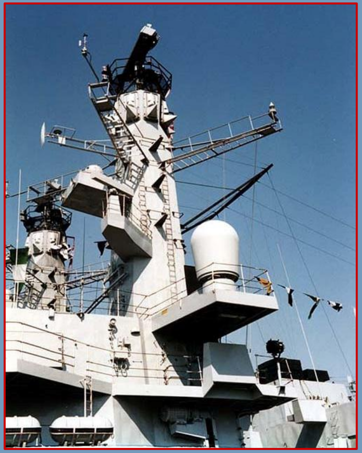
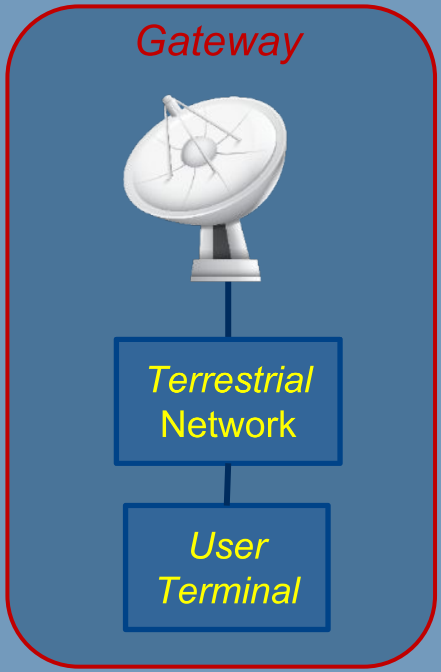
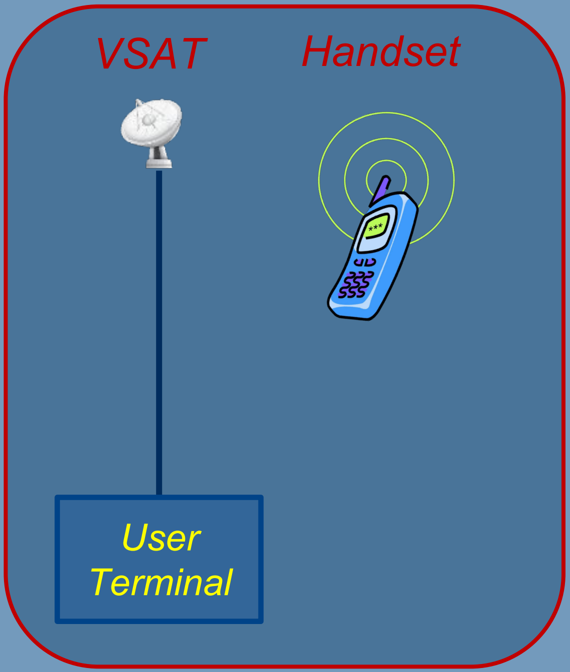


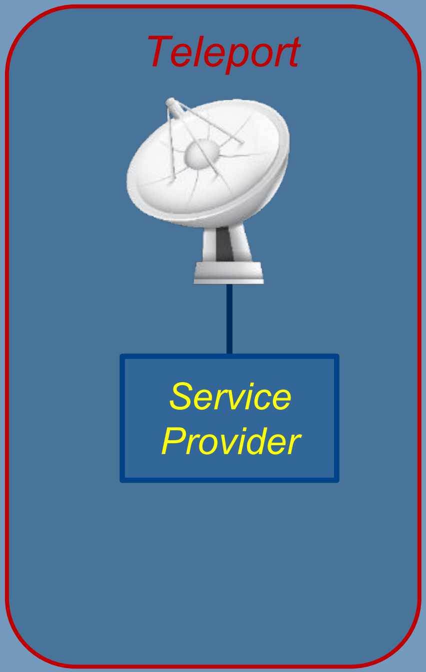
Image source MOD

Earth Station Types

- *Interface Stations*
  - *Gateways* connecting with other terrestrial or satellite networks.
- *Single-purpose User Stations*
  - *Very Small Aperture Terminals (VSAT)* located at user premises.
  - Personal *handsets*.
- *Service Stations*
  - *Teleport* hub and feeder stations for users requiring point-to-point communication.

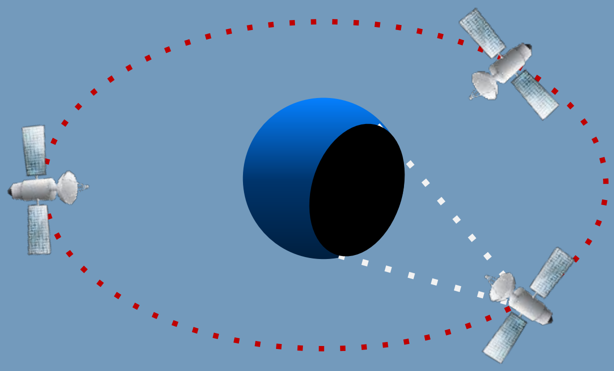




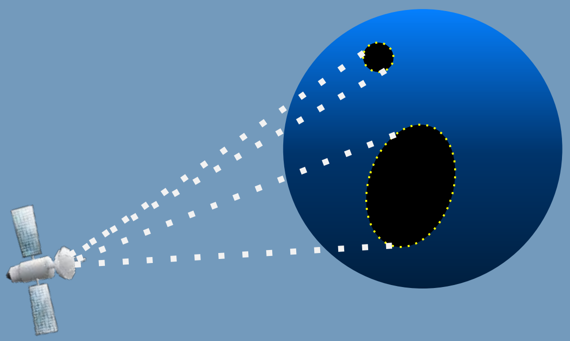


Satellite Footprint

- The satellite's *footprint* is the ground segment signal reception area on the Earth's surface.
- An Earth station must be within the footprint and visible to the satellite to be able to communicate with it.
- The footprint shape and position depends on;
  - distance from the satellite to the horizon
  - shape of the antenna beam
  - time of overflight determined by orbital speed
- Different antenna systems can create different footprints:
  - GEO satellites can cover 44% of the Earth using *a global beam* pattern.
  - A *regional beam* or *spot beam pattern* will limit the part of the Earth served.



GEO Global Beam



Spot or Regional Beam

Transmission Systems

- Transmission of information occurs between Earth stations and the satellite, and the satellite and Earth stations.
- The information is digitally encoded and combined to produce a *baseband* signal, a bit stream of 1s and 0s, which is sent to the transmitter.
- The baseband signal can convey information from a single source, or several sources produced by *multiplexing* (combining) signals from individual sources.
- It may contain a mixture of telephone, data or television signals.
- A microwave radio frequency carrier is *modulated* with the baseband signal at the Earth Station and transmitted to the satellite.
- The carrier is received at the destination satellite and the signal is retransmitted on a different carrier frequency back to the Earth Station.
- The original bit stream is recovered at the Earth Station by *demodulating* the carrier and *decoding* the digital bit stream to reveal the original information.

Traffic Uplinks

- Transmission of baseband signals from an Earth station to a satellite is called the *uplink*.
- Satellite transmissions use microwave radio frequency carriers, typically between 1GHz and 45 GHz depending on their mission.
- The signal need only be just strong enough to reach the satellite in a useable form, although it may be affected by atmospheric and other interference sources.

Traffic Downlinks

- Transmission of baseband signals from the satellite to the Earth Station is called the *downlink.*
- The downlinking transmitter sends the signal from the satellite back down to earth;
  - either to a single receiver
  - or by broadcasting to multiple receivers
- As the downlink transmitter must rely on the satellite's limited power supply, there are greater constraints on the downlink signal power than for fixed ground stations.

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Satellite & Data Communications

Lesson 5:

Satellite Components

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Main Components of a Satellite

- In this lesson Cadets will learn about the main components of a COMSAT and their uses including;
  - Satellite bus
    - Structural housing
    - Propulsion system
    - Electrical power system
    - Tracking, telemetry and command system
    - Attitude control system
    - Thermal control system
  - Communications payload
    - Transponders
    - Antennas

Main Components of a Satellite

- A satellite is a complex, interconnected, mechanical and electrical system designed and constructed to support the specific mission and functions for which it is designed.
- A COMSAT incorporates two major modules;
  - The *payload* is the most important part of the satellite and is there to fulfil the mission objective using appropriate hardware.
  - The *bus* consists six major subsystems which are there only to support the payload in its operation

Inmarsat-4A ALPHASAT Satellite under construction

Image Courtesy of Airbus

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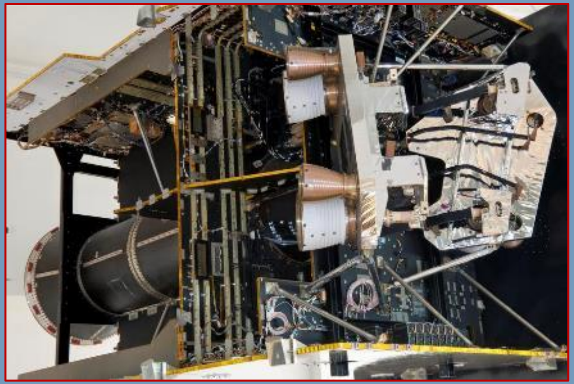
Satellite Bus

- Satellite manufacturers usually have a standard bus to carry a variety of payloads.
- The bus has several different subsystems incorporating different functional components.



Airbus Eurostar 3000 Bus

Bus System	Typical Components
Structural Housing	*Panels*
Propulsion	*Apogee Kick Motor, Thrusters, Valves, Fuel Tanks*
Electrical Power	*Solar Arrays, Batteries, Distribution and Control*
Telemetry, Tracking & Command	*Transmitter, Receiver, Antennas, Sensors, OBDH*
Attitude & Orbit Control	*Sensors, Controls*
Thermal Control	*Heaters, Radiators, Thermal Blankets*

Image courtesy of jc4i

Structural Housing

- The *housing* provides the mechanical base structure of the satellite which;
  - supports all the on-board payload and bus equipment
  - is designed to survive and operate in the harsh environments encountered from launch through to orbit
  - acts as a shield cage to protect the sensitive electronics from space radiation and electrostatic discharge.
- It is a rigid framework of panels usually constructed of lightweight aluminium *skins* bonded onto a sandwich filling of aluminium honeycomb making them very light, strong and stiff.
- The form of the housing is determined by the satellite *stabilisation* mechanism.
- The size of the housing is limited by the launch vehicle.

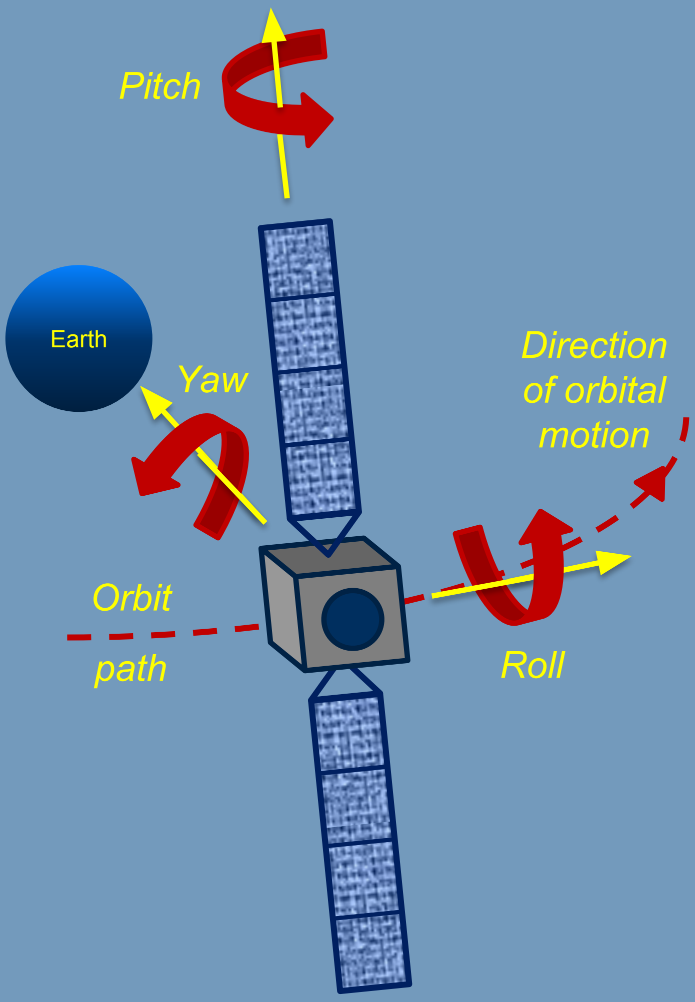
Aluminium panels

Honeycomb skin

Image Courtesy of Airbus

Stabilisation

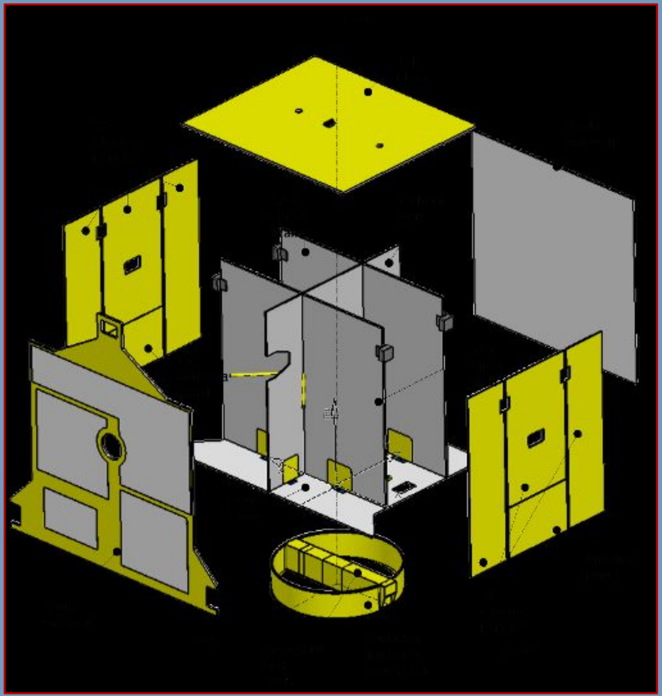
- The satellite antennas, solar panels, thermal radiators and rocket engines must be correctly oriented on orbit.
- To achieve this a stabilisation mechanism is required of which there two main types:
  - Spin stabilisation
  - 3-axis (or body) stabilisation
- 3-axis stabilisation is the most convenient form for supporting a communications payload function.
- A satellite can achieve any attitude by changing the direction of the 3-dimensional axes using the *Attitude Control System*.
- *Attitude* describes the position of a satellite in a rotational sense and changing attitude implies rotation.



3-D rotational movement of a satellite in space

Configuration

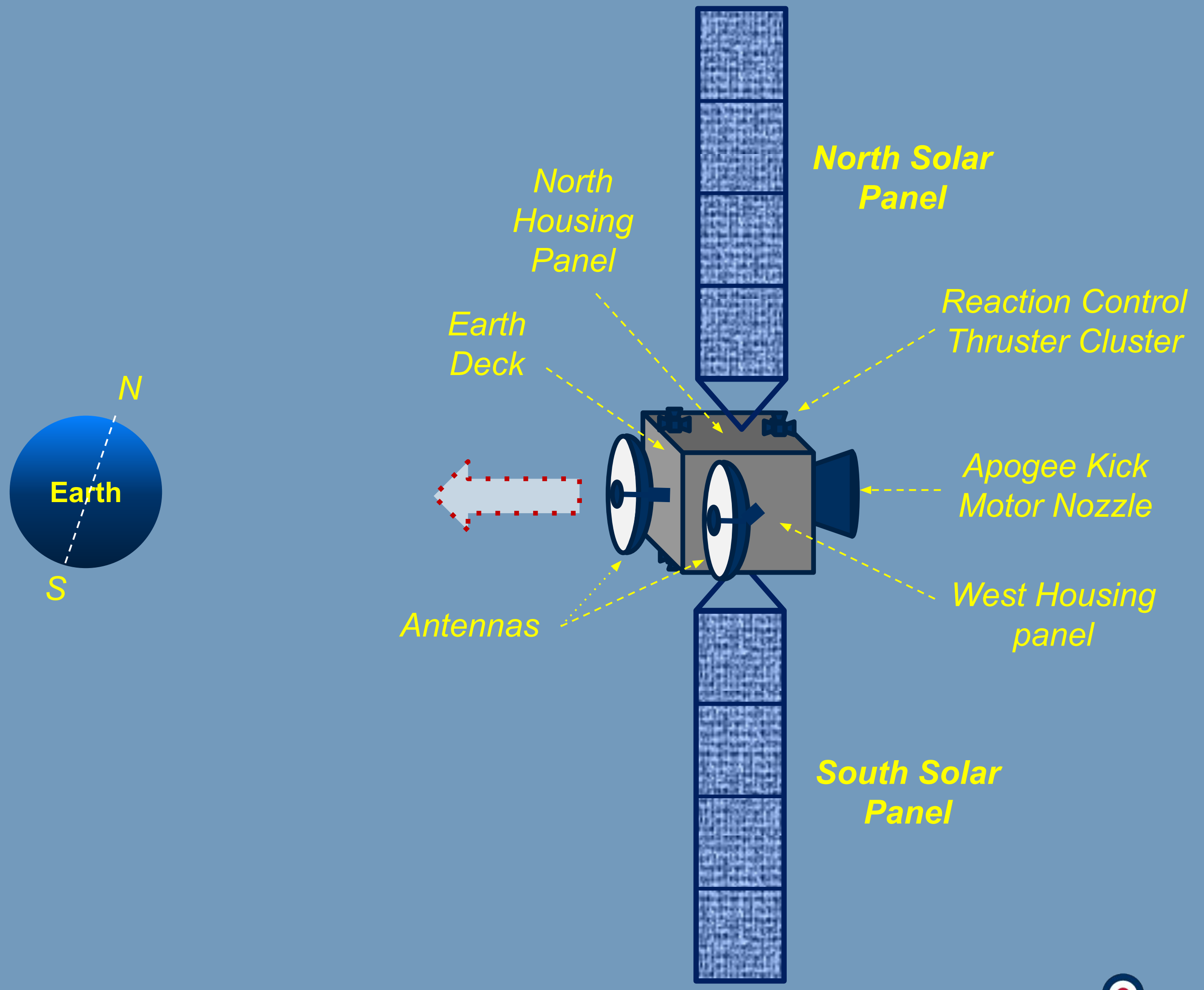
- 3-axis stabilised satellites do not have a specific shape.
- However, a box-shaped, body-mounted structure facilitates the attachment of major equipment directly to the external panels of the housing including;
  - Solar Arrays
  - Communications Antennas
  - Propulsion System
- Batteries, fuel tanks and the payload are usually contained within the box.



Exploded view of structural housing panels on a typical modular 3-axis satellite

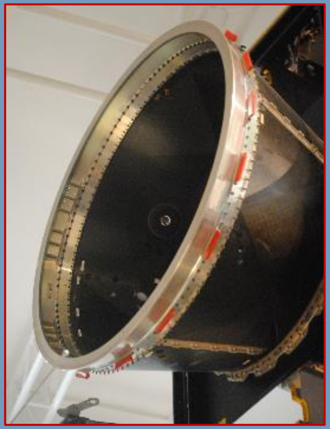
Image Courtesy of Airbus

Design Features



Propulsion System

- Satellites are equipped with two types of propulsion systems;
  - A *Primary propulsion system* is used for GEO orbit transfer using a larger rocket engine.
  - A *Secondary propulsion system* is used for controlling orientation and operational orbit position using smaller rocket engines.
- A commonly used combination is;
  - A primary *Apogee Kick Motor* (AKM)
  - Secondary *Reaction Control Thrusters*
- This approach benefits from a relative simplicity and remains of interest for small satellites.



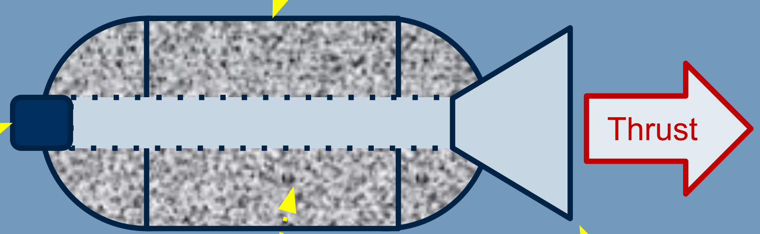
A Primary Propulsion Nozzle

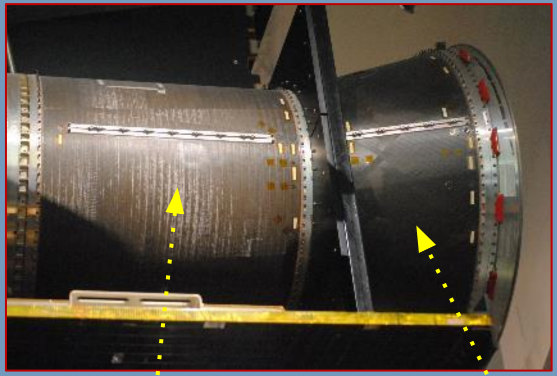
A Secondary Propulsion Nozzle

Image courtesy of jc4i

Apogee Kick Motor

- The AKM is installed in the *central thrust cone* within the housing.
- One type of AKM uses a *solid propellant rocket motor* which when ignited produces thrust.
- The shape of the AKM's external *nozzle cone* is critical to producing thrust.
- It is designed to expand and accelerate the gases to supersonic speeds.
- The nozzle is made from mixtures of carbon and other materials capable of surviving the heat and erosion by the particles in the combustion products.





Central thrust cone

Nozzle

Image courtesy of jc⁴i

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Reaction Control Thrusters

- Small *Reaction Control Thrusters* are located around the satellite housing in *clusters*.
- When fired, the thrusters work together to maintain the satellite in the correct orientation and orbital position.

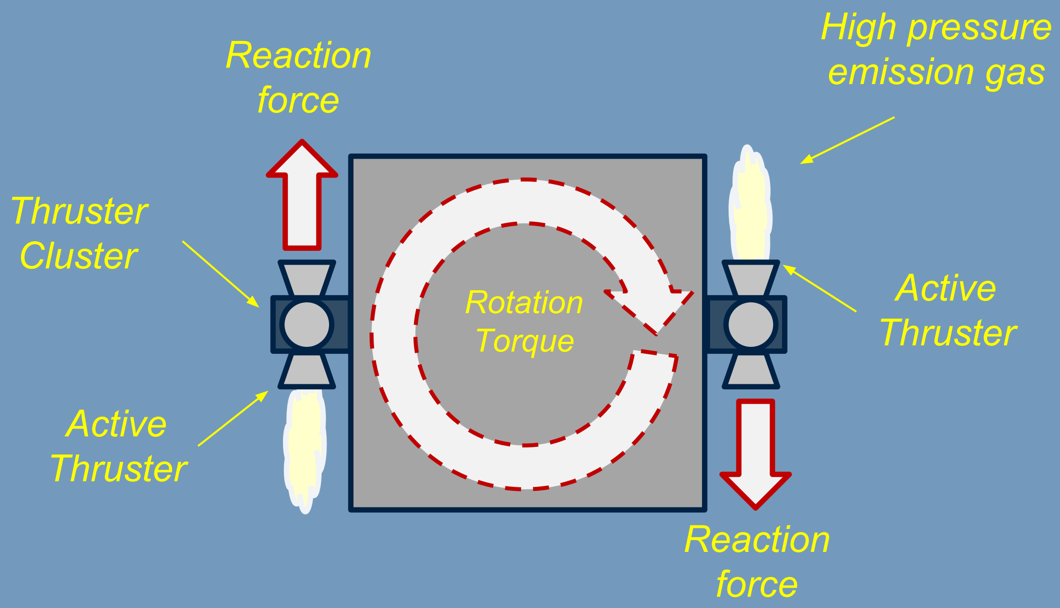
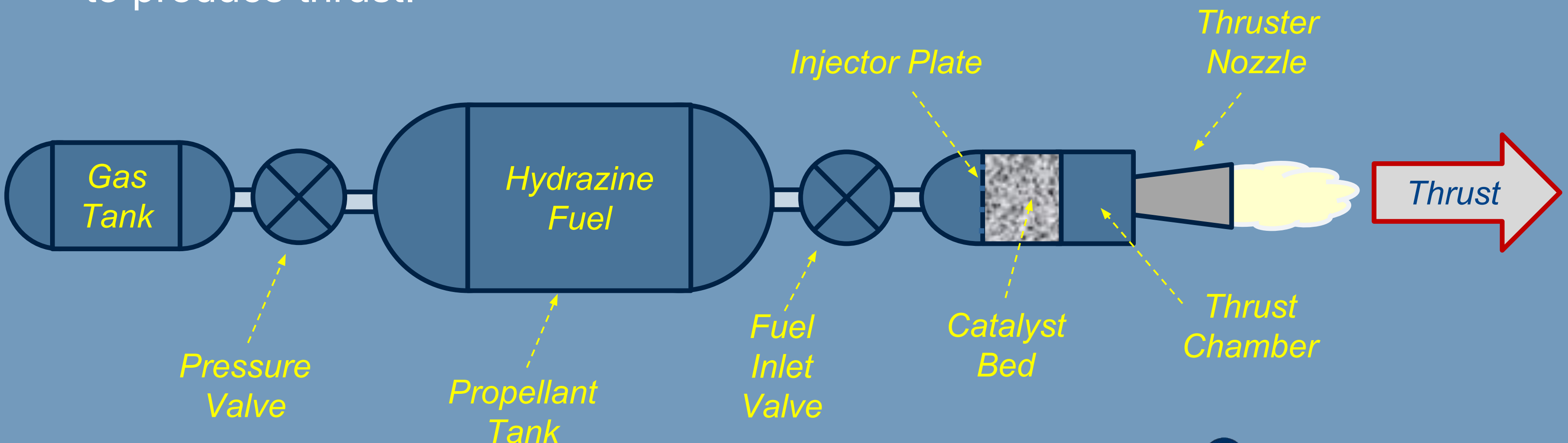


Image courtesy of jc[4]i

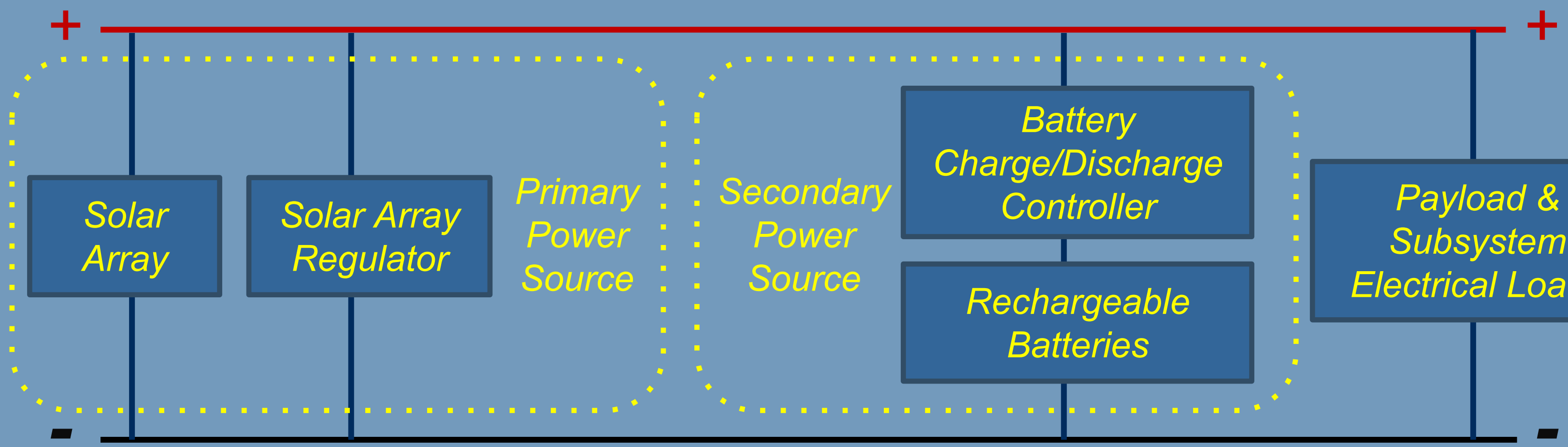
Liquid Mono-propellant Thrusters

- One type of thruster uses liquid mono-propellant *hydrazine* fuel.
- Fuel is stored in a cylindrical, pressurised, sealed tank with rounded ends, typically made from welded titanium.
- To fire a specific thruster, the fuel inlet valve is opened and high pressure gas forces hydrazine through a bed of chemicals, causing a heat producing *exothermic* chemical reaction.
- The hydrazine decomposes into hot, high pressure hydrogen, nitrogen and ammonia gasses which are exited at supersonic speed through the nozzle to produce thrust.



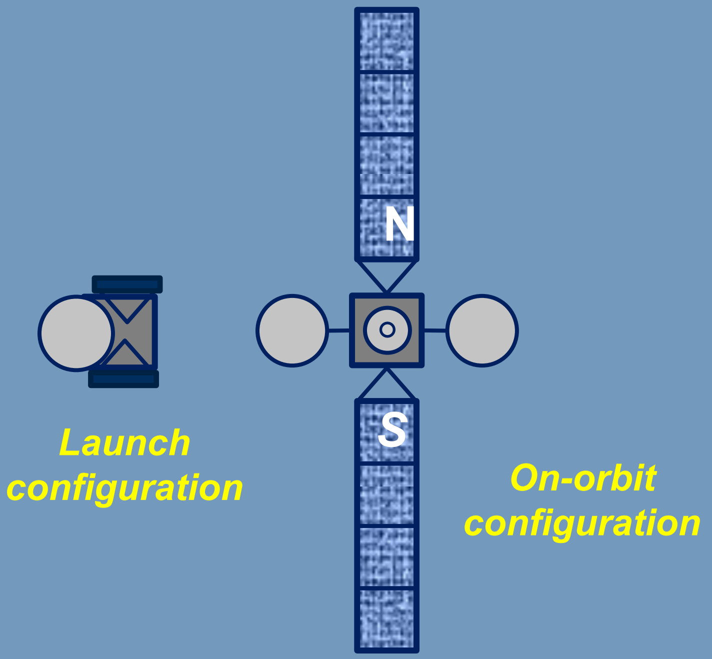
Electrical Power System

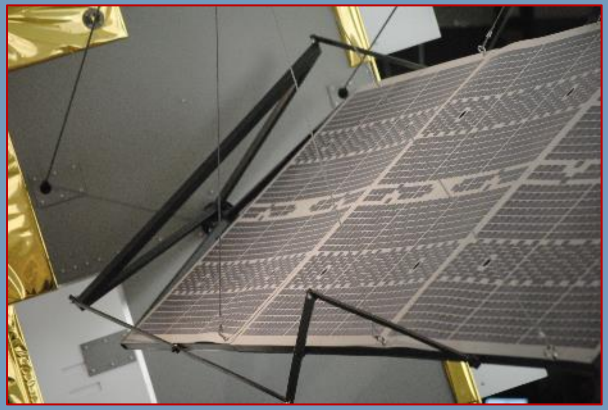
- The electrical power subsystem provides *generation*, *storage* and *conditioning* of a reliable electricity source to operate the payload and bus.
- The only feasible external *primary* source of energy for an Earth orbiting COMSAT is from the conversion of sunlight into electricity.
- When the *primary* solar power source is unavailable, a *secondary* power source is required.
- The most common arrangement is a solar array and battery combination.



Solar Array

- *Solar arrays are* attached to the north and south panels of the housing.
- A typical array consists of semi-rigid hinged panels.
- As room on the launch vehicle is limited, the arrays are folded up against the sides of the satellite during the launch phase.
- Once in orbit, the arrays are extended by a deployable mast until flat and positioned above and below the housing.
- The arrays are rotated in orbit to point towards the sun regardless of the direction the spacecraft is facing.



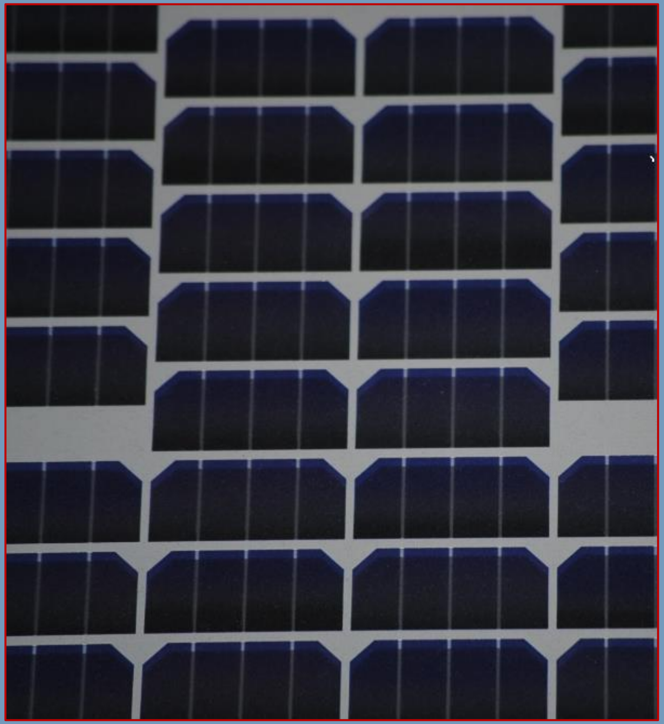


GPS Satellite Solar Array

Image courtesy of jc[4]i

Solar Cells

- The solar arrays consist of panels containing a large number of individual *solar cells* interconnected in series, in vertical *strings*, bonded to panels with a glass cover on the front surface.
- The cells are made from semiconductor materials such as silicon or gallium arsenide.
- When the cells are illuminated by the sun, electricity is generated by a process called the *photovoltaic effect*.
- By connecting different numbers of strings together in parallel *circuits*, the amount of electricity available can be adjusted to suit the power needs of the satellite.



GPS Satellite Solar Cells

Image courtesy of jc4i

Limitations of Solar Power

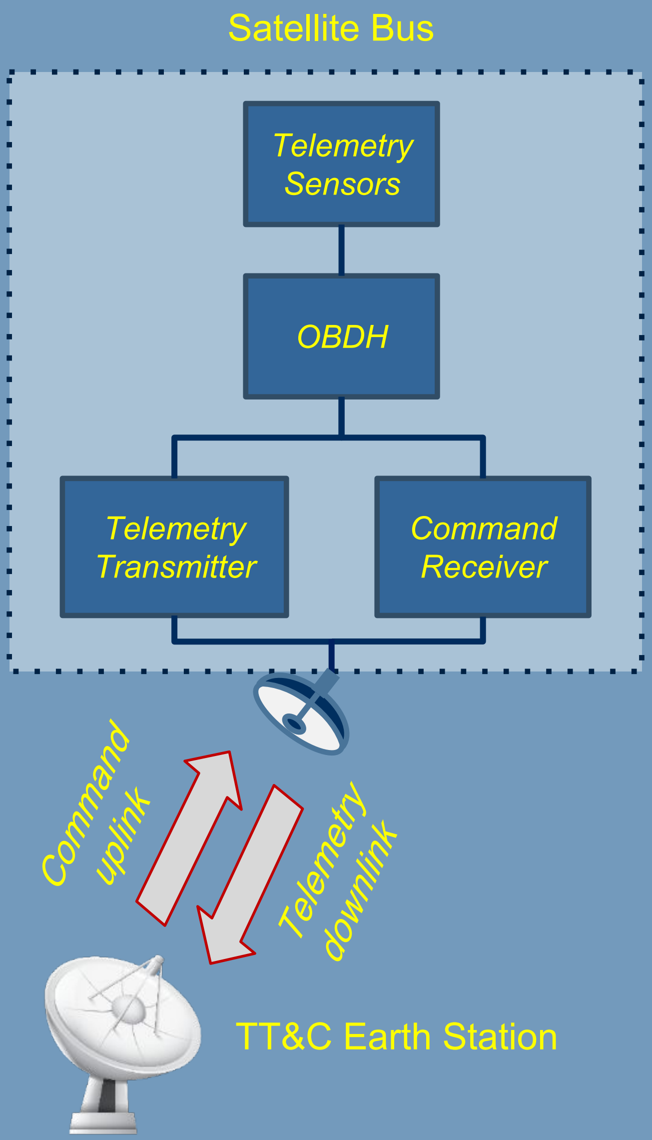
- Without batteries a satellite would shut down entirely during eclipses of the sun by the earth and might not activate properly after re-entering sunlight.
  - For GEO satellites, eclipses occur on 90 days per year for up to 70 minutes.
  - For most LEO satellites eclipses occur every day and orbit, for up to 30 minutes
- Solar Arrays are inefficient with only about 10-20% of the sun's energy falling on the array generating useful electrical power.
- The available output of the array also deteriorates over its lifetime.
- The array output is constant at a particular moment, but varies over time, whilst the electrical loads supplied continuously vary over time.
- *Power distribution control* helps to manage some of these limitations ensuring the correct voltage and current is delivered to equipment when needed.
  - If the batteries are fully charged or the satellite requires less power, the solar arrays can be turned away from the sun.
  - Any excess electrical energy generated and not used, but cannot be stored in the batteries, is vented of and dissipated as heat into space.

Batteries

- High performance *electrochemical* batteries are generally used as a secondary power source to;
  - store surplus energy from the solar array not being used by the payload when it is illuminated by the sun
  - return the stored energy when the solar array is in the earth's shadow
- The battery storage capacity must be adequate enough to continue to operate the satellite during an eclipse.
- Following an eclipse the batteries must be fully charged for the next occurrence.
- About 10% of the solar power is used to charge the batteries.

TT&C System

- The on-board *Telemetry, Tracking and Command* system allows the Satellite Control Centre computers and operations support personnel to;
  - determine the status of the satellite
  - determine the location of the satellite
  - control the various subsystems of the payload and bus.
- The TT&C subsystem consists of several components;
  - Telemetry sensors
  - An On-Board Data Handling System (OBDH)
  - A telemetry transmitter
  - A command receiver
  - Antennas

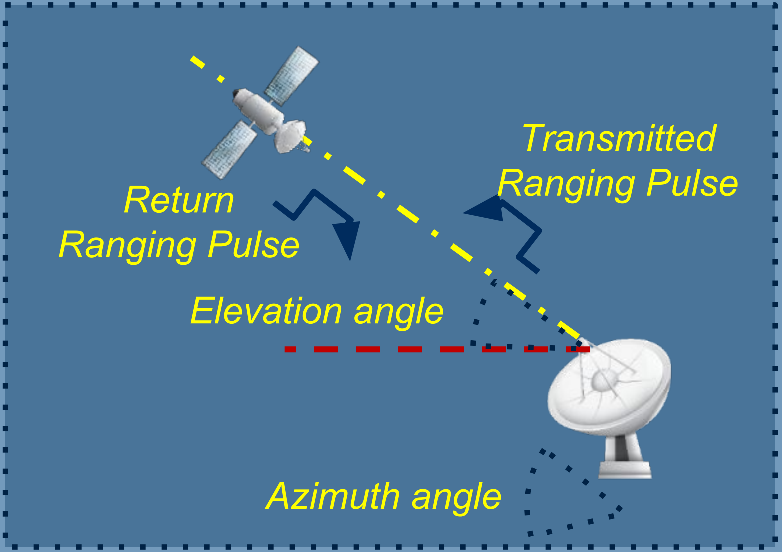


Telemetry Function

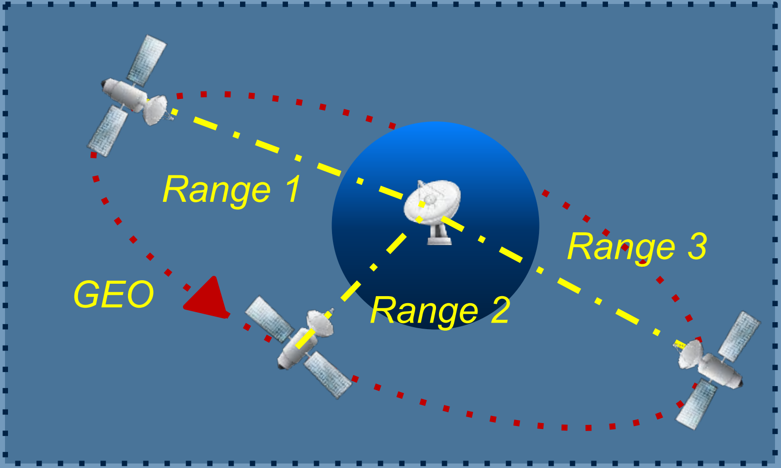
- *Sensors* placed around the spacecraft monitor the status and health of the payload and bus.
- They provide *housekeeping data* by measuring important parameters such as temperature, electrical voltage and tank pressure.
- The operational status of equipment is also monitored as to whether it is switched on or off.
- Housekeeping data is processed by the OBDH, converted into a digital bit stream and transmitted to the ground segment using the telemetry downlink.
- The data is received at the Satellite Control Centre, processed by a computer to provide a current picture of satellite health, and displayed on computer monitors in the operations room.
- When any parameters move out of specification, warning signals alert the operations team and potential problems can be identified and corrected by the engineers.

Tracking Function

- To *track* a satellite is to know its position in space.
- The precise *range* can obtained by measuring the time delay at the TT&C station between transmission of a reference signal and its reception after being delayed by the distance and satellite.
- The *direction* can be fixed by measuring the azimuth (bearing) angle and elevation angle of the Earth station antenna when its beam is aligned to receive the maximum *telemetry beacon* signal.
- Knowing range and direction, the *position* of the satellite can be determined.



Ranging view from the ground



Ranging view from orbit

Command Function

- The *command* function allows ground operators at the Satellite Control Centre to control all aspects of the spacecraft's operation to optimise and maintain the service.
- Command functions include;
  - powering subsystems on/off or changing operating modes
  - controlling spacecraft guidance and attitude control
  - deploying antennas and solar cell arrays
  - uploading computer software
- Commands are received by the satellite through the command uplink, interpreted by the *On-board Data Handling System* and then passed on to the satellite subsystems.
- The commands are checked before execution to ensure that they have been received correctly.
- The OBDH finally confirms the uplinked commands have been executed correctly by using the telemetry downlink.

Satellite Command and Control

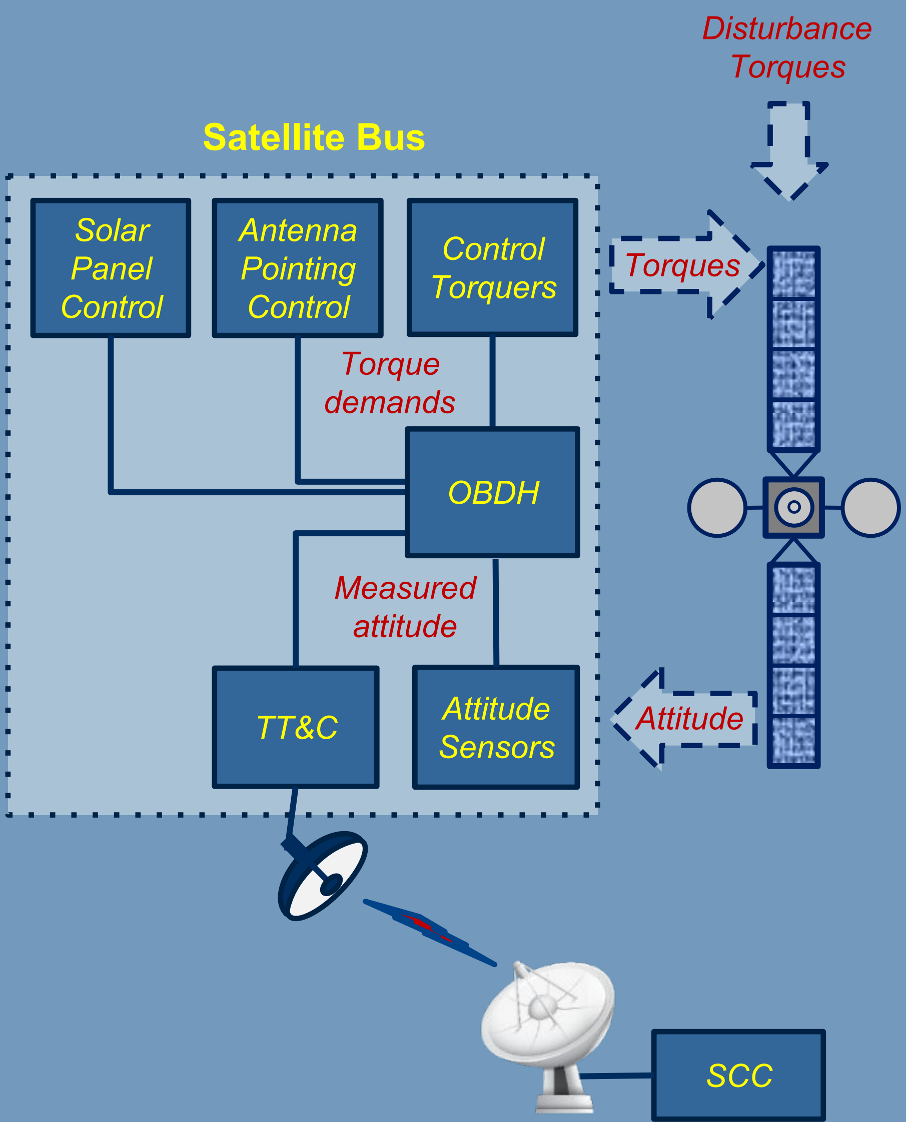
- The OBDH is the satellite's main computer system and is distributed throughout the spacecraft.
- The function of the OBDH is to;
  - Exchange command and control data between the various subsystems,
  - Monitor and control all of the satellite's operations,
  - Provide storage and processing of payload and other data,
  - Transfer payload data to the communications system ready for download to the Satellite Control Centre.
- Overall command and control of a satellite is carried out from the SCC.
- SCC personnel monitor the health and status of all the onboard systems from the telemetry downlink.
- This is the only way to observe and control the spacecraft's functions and condition from the ground.

System Priority

- It is important that commands are executed at the correct time and in the correct order or the satellite could drift out of control.
- Depending on the mode selected, commands can be handled in one of two ways;
  - The most important commands are executed immediately when received by the OBDH.
  - Alternatively the commands can be stored in memory and executed;
    - either on receiving a command
    - or at a given time determined by a signal from the ground or the OBDH
- Built-in *failsoft* procedures control the computers in case contact between the satellite and Satellite Control Centre is lost.

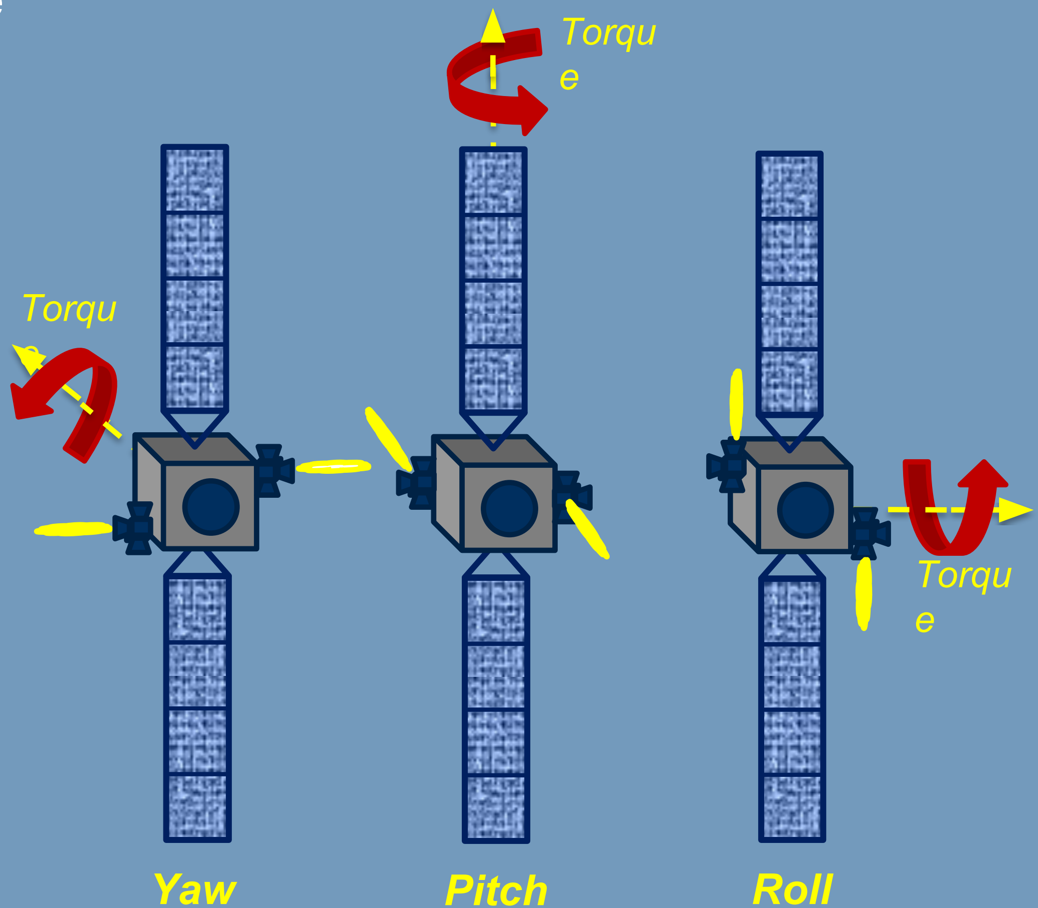
Attitude Control System

- The ACS addresses the pointing or rotation of the satellite.
  - Rotation is detected and measured by *attitude sensors.*
  - OBDH control software processes sensor measurements to calculate the satellite's current attitude.
  - The estimated attitude is compared to the required attitude for the desired orientation.
  - If different, the control software determines the *torques* to correct the attitude.
  - The *Reaction Control Thrusters* are fired to act as *control torquers.*
- The ACS is also used for orbit control when station keeping



Control Torques

- 12 nozzles provide thrust in the 6 degrees of freedom;
  - Up-down
  - Left-right
  - Forwards-backwards
  - Roll
  - Pitch
  - Yaw
- The firing of two thrusters in opposed pairs produces torque.
- This allows the satellite to be rotated in any direction returning the spacecraft's attitude to the desired orientation.



Thermal Control System

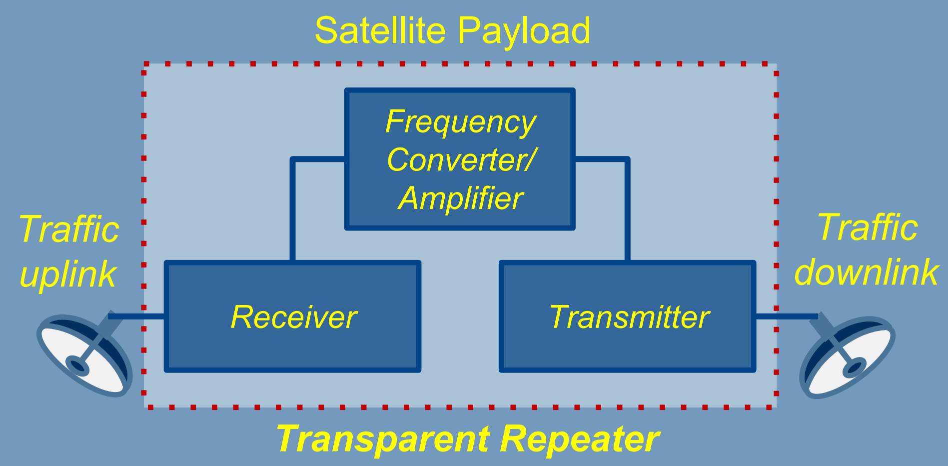
- The Thermal Control System provides an appropriate thermal environment onboard the satellite to ensure reliable operation of the payload and subsystems.
- A satellite absorbs heat from sunlight and generates heat from internal electrical equipment and this must be radiated away into space.
- When in the Earth's shadow, the satellite must not be allowed to get too cold.
- Various techniques are used to maintain the temperature within the satellite's operating limits;
  - *Thermal blanket* composed of a multi-layered insulation of thin plastic film with a gold coating acts as a thermal barrier.
  - External mirror-like *radiator* surfaces attached to internally mounted electrical equipment encourage the escape of dissipated heat.
  - *Heat pipes* transfer heat from the interior to the outside.
  - *Heaters* prevent the batteries weakening and the onboard fuel freezing.

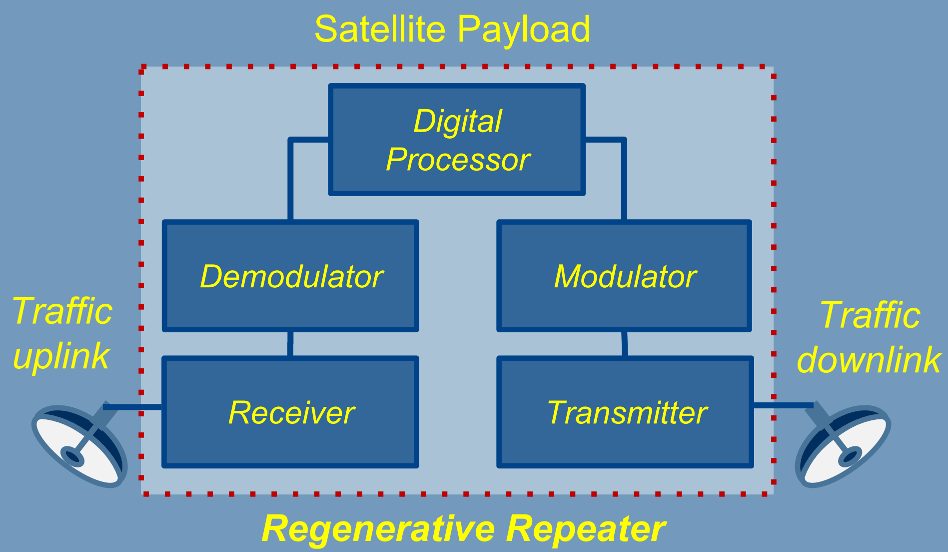
Communications Payload

- A COMSAT's communications *payload* delivers the telecommunications *services*.
- Most communications payloads are *radio relay* stations in orbit that carry on-board electronics called *transponders*.
- The term transponder is a contraction of "***trans****mitter-res****ponder"*** and is used to identify one complete microwave radio channel of transmission from a satellite.
- The basic function of the transponder is to:
  - receive signals from an Earth Station on the uplink frequency
  - change the signal to another downlink frequency
  - amplify the signal
  - rebroadcast the signal back down to another Earth Station
- Rebroadcasting on a different downlink frequency prevents the uplink receiver and downlink transmitter interfering with each other.

Transponder Operation

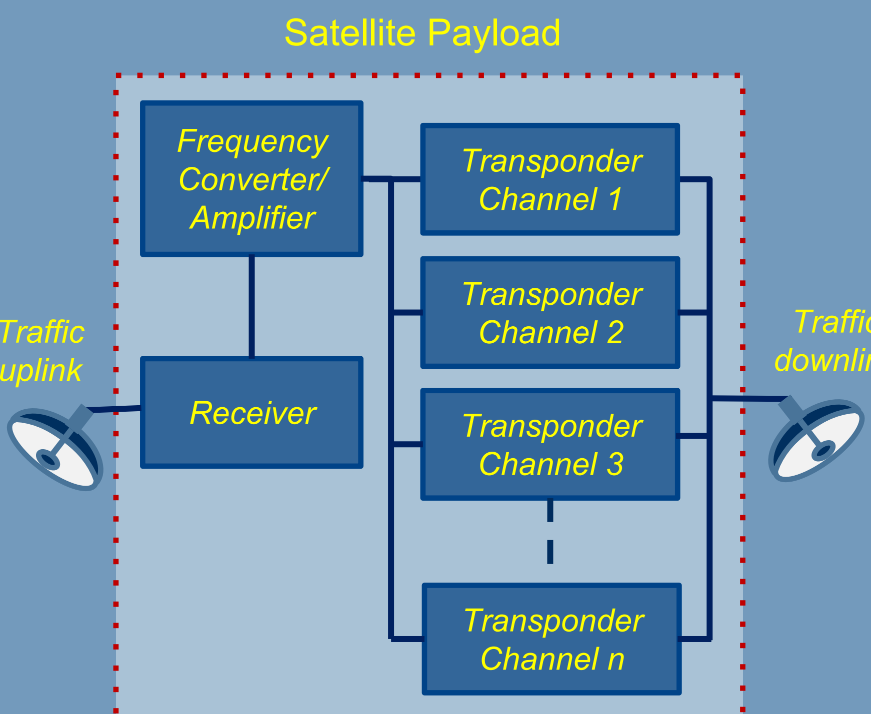
- Most COMSATs operate as a *transparent* (often called a "*bent pipe*") transponder;
  - The received uplink signal is retransmitted back to earth with amplification and frequency shift.
- Some modern satellites have more complex *regenerative* transponders;
  - The received uplink signal is demodulated to reveal the original bitstream.
  - On-board digital processing cleans up the signal and remove noise and extracts routing information, before retransmitting the signal back to Earth.





Number of Transponders

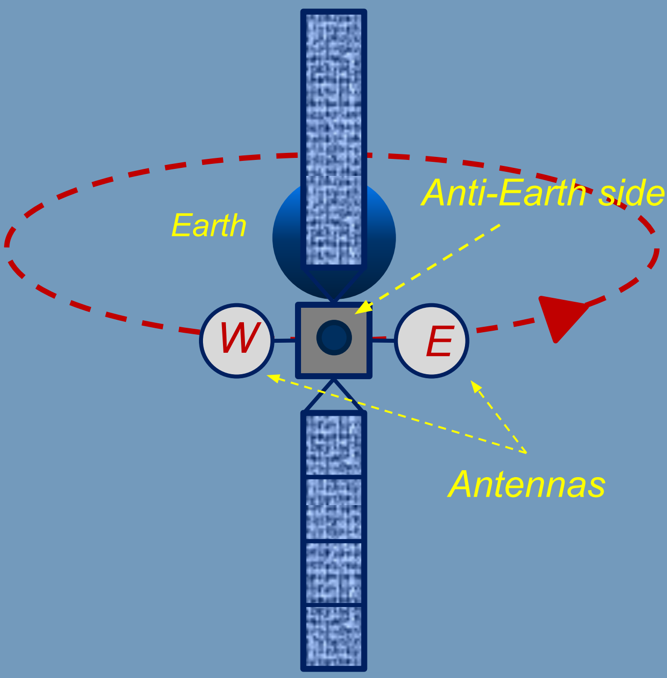
- The *transponderized* design breaks up the downlink bandwidth into a range of individual channels.
- The number of transponder channels varies greatly depending on the satellite's role.
- Depending on the mission, a satellite will often contain multiple transponders, sometimes 20 to 30 or more, to provide redundancy and increased capacity.
- Individual transponders can be assigned to different uses.

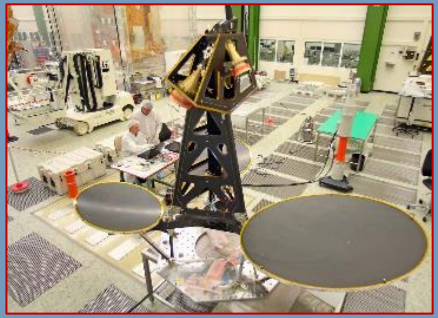


Transponderized Transparent Repeater

Communications Antennas

- Antennas are used to;
  - collect uplink telecommunications traffic and TT&C signals from earth stations
  - direct downlink telecommunications traffic and TT&C signals to earth stations
- They can be mounted on the Earth facing side and the adjacent east and west side panels of the structural housing.
- Most antennas are attached to the housing by short or long booms.
- The satellite must be continuously oriented so that the antennas always point correctly towards the Earth.





Typical Antenna Assembly

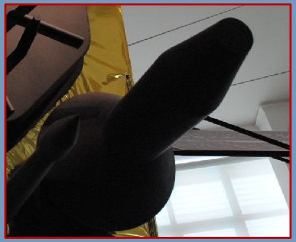
Image Courtesy of Airbus

Antenna Types

- Different types, sizes and numbers of antennas may used depending on the communications payload requirements.
- *High gain* directional antennas are mostly used to project a narrow *beam* to create the desired footprint on the Earth.
- More sophisticated types of antennas can;
  - form multiple individual spot beams at any one time across the surface of the Earth
  - be steered either physically with motors, or electronically, to point at a specific location on the Earth when required

Parabolic reflector

Horn



Helical

Image Courtesy of jc^{4}i

Summary of Learning Outcome 1

- Having studied lessons 1 to 9 Cadets should now know the types and roles of satellites and the principles of earth orbit including;
  - Orbits
  - Uses of satellites
  - Satellite mission
  - Station keeping
  - Satellite components and uses

Senior and Master Air Cadet

Satellite and Data Communications

Learning Outcome 2:

Know the components and principles of the Global Positioning System

Learning Outcomes

- Know the components and principles of the Global Positioning System including:
  - How GPS works
  - The Components of GPS
  - Constellation of GPS satellites
  - Ground stations
  - GPS in the military
  - GPS in everyday life

Lessons

6. Introduction to GPS
7. GPS System Components
8. How GPS Works
9. GPS in Everyday Life

Satellite & Data Communications

Lesson 6:

Introduction to GPS

Introduction to GPS

- In this lesson Cadets will be introduced to GPS and learn about:
  - Global Satellite Navigation Systems
  - The History of the Global Positioning System
  - GPS Positioning Services
  - Basic Method of GPS Operation

Global Navigational Satellite System

- The *Global Positioning System* (GPS) was the first *Global Navigational Satellite System* (GNSS) to be put into service.
- GPS is a space-based *radio-navigation* system providing;
  - 3-dimensional positioning, in latitude, longitude and altitude, to about a metre of accuracy
  - nanosecond precise timing information
- A GPS receiver connected to a GPS antenna can be used to determine any user's position;
  - continuously
  - anywhere in the world
  - under any weather conditions
  - at no direct cost to the user
- The United States Government owns the infrastructure and the United States Air Force develops, maintains, and operates it.

The History of GPS

- In the early 1970's during the cold war, the US Department of Defense (DOD) wanted to ensure a robust, stable, satellite navigation system would be available to more accurately target Intercontinental Ballistic Missiles launched from submarines.
- The DoD launched its first *NAVSTAR* (**Nav**igation **S**atellite **T**iming **A**nd **R**anging) satellite in 1978.
- The system became known as the Global Positioning System (GPS) and was fully operational in 1993.
- In the 1990s GPS had a *Selective Availability* (SA) feature that intentionally degraded civilian accuracy for US national security reasons.
- In 2000, the US Government ended its use of SA to make GPS more responsive to civil and commercial users worldwide.
- The range error of the GPS signals in space is now actually the same for the civilian and military GPS services.

GPS Positioning Services

- A GPS receiver can determine;
  - the time
  - its distance from GPS satellites
  - its own position
- GPS provides two levels of positioning accuracy;
  - The *Standard Positioning Service* (SPS) is available to all users for peaceful civil, commercial, and scientific use.
  - The *Precise Positioning Service* (PPP) is reserved for military use and authorised government and civilian users
    - Users receive encryption keys from the US DOD to access the PPS and obtain the maximum accuracy from GPS.
    - Should a PPS receiver have not been fed with valid keys, it could still behave as an SPS receiver.

Basic Method of GPS Operation

- The principle of GPS satellite navigation is that of one-way *passive ranging* by time difference and is based on:
  - radio wave propagation
  - precision timing
  - knowledge of each satellite position above the earth
- A constellation of satellites transmits microwave radio signals containing their position and timing information towards the earth.
- The signals can be picked up by ground based or airborne GPS receivers.
- After decoding the signals from several satellites, the receiver can then begin to accurately determine its position.
- If the precise time and distances from the GPS receiver location to at least four GPS satellites are known, along with the satellite locations, then the 3-dimensional location of the receiver can potentially be calculated to metre accuracy.

Satellite & Data Communications

Lesson 7:

GPS Systems Components

System Components

- In this lesson Cadets will learn about the components of a GPS System including:
  - The Space Segment
    - Satellite Constellation
    - Satellite Orbits
    - GPS Signal in Space
  - The Control Segment
    - Master Control Stations
    - Ground Antennas
    - Monitor Stations
  - The User Segment
    - GPS Receiver Types

GPS Segments

Space Segment

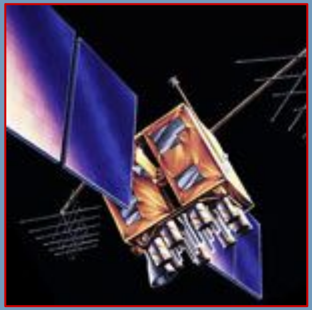
Control Segment

User Segment

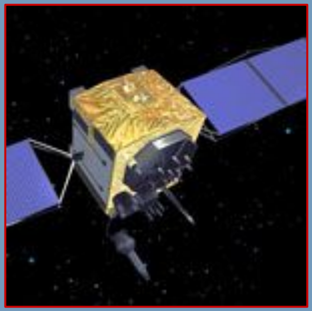
Image source: US Government

Space Segment

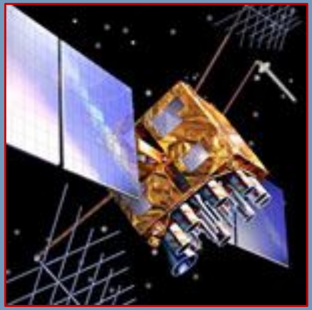
- The GPS space segment is a *constellation* of satellites transmitting microwave radio signals to the Earth.
- At the end of 2017, there were a total of 31 operational satellites, not including the decommissioned and on-orbit spares.
- The constellation is a mix of old and new generations of satellites;
  - 12 Legacy Block IIR ("Replenishment")
  - 7 Block IIR-M ("Modernized")
  - 12 Block IIF ("Follow-on")
- New Block III satellites are being launched to replace aging ones when needed and offer upgraded accuracy and reliability.



Block IIR Satellite



Block IIR-M satellite



Block IIF Satellite

Image source: US Government

Satellite Constellation

- The baseline operational constellation of 24 satellites is arranged into six *orbital planes*.
- This arrangement ensures that as the satellites orbit, receivers can view at least four satellites from virtually any point on the planet at any one time.
- Additional satellites are flown to maintain coverage whenever the baseline satellites are serviced or decommissioned.
- The extra satellites may increase GPS performance but are not part of the core constellation.

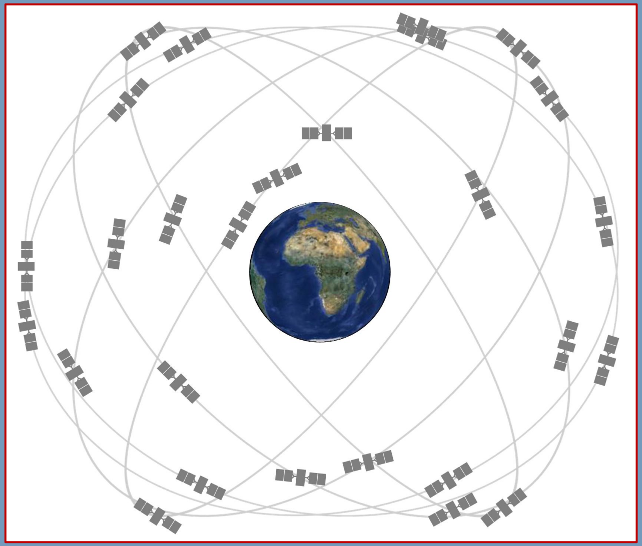


Image source: US Government

Satellite Orbits

- GPS satellites fly in Medium Earth Orbit at an altitude of 20,233 km.
- This provides optimum ground coverage with the least number of satellites.
- The eccentricity of the orbit is so small it is almost circular.
- Satellites are distributed evenly in six planes spaced 60° apart.
- Each plane contains four orbital slots occupied by baseline satellites.
- The satellites rise over the equator at a 55° inclination.
- Each satellite has an orbital period of 11 hours 58 minutes.

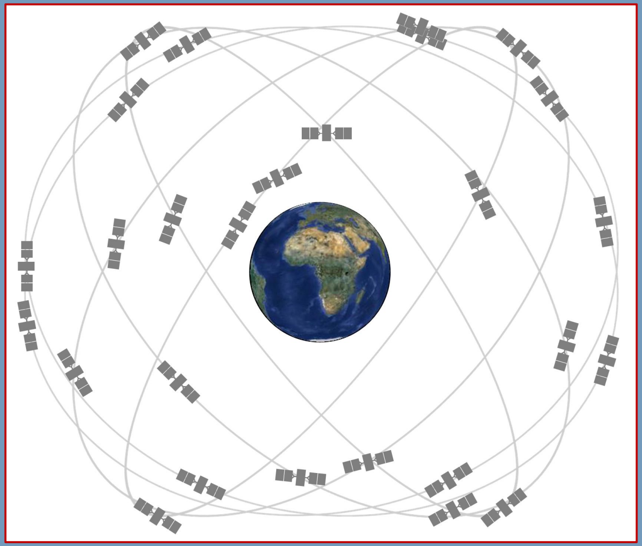


Image source: US Government

Signal in Space

- Each satellite transmits a microwave radio carrier called L1 at 1575.42 MHz
- L1 is modulated by a number of signal components which provide information to GPS receivers on;
  - satellite locations
  - satellite status
  - the precise time from on-board atomic clocks
- Two of these components are accessible by all GPS receivers;
  - a *Coarse Acquisition* (C/A) *code*
    - A known, time referenced, complex digital code unique to each satellite, that appears like random electrical noise and is used for ranging.
  - a *Navigation Message* composed of*;*
    - *Almanac data* containing a set of orbital parameter status defining the approximate positions of all the satellites in the constellation used by the receiver during initial acquisition of satellite signals.
    - *Ephemeris data* containing the current predicted satellite position and timing information.
- More carriers and codes are being added over time to improve accuracy and security

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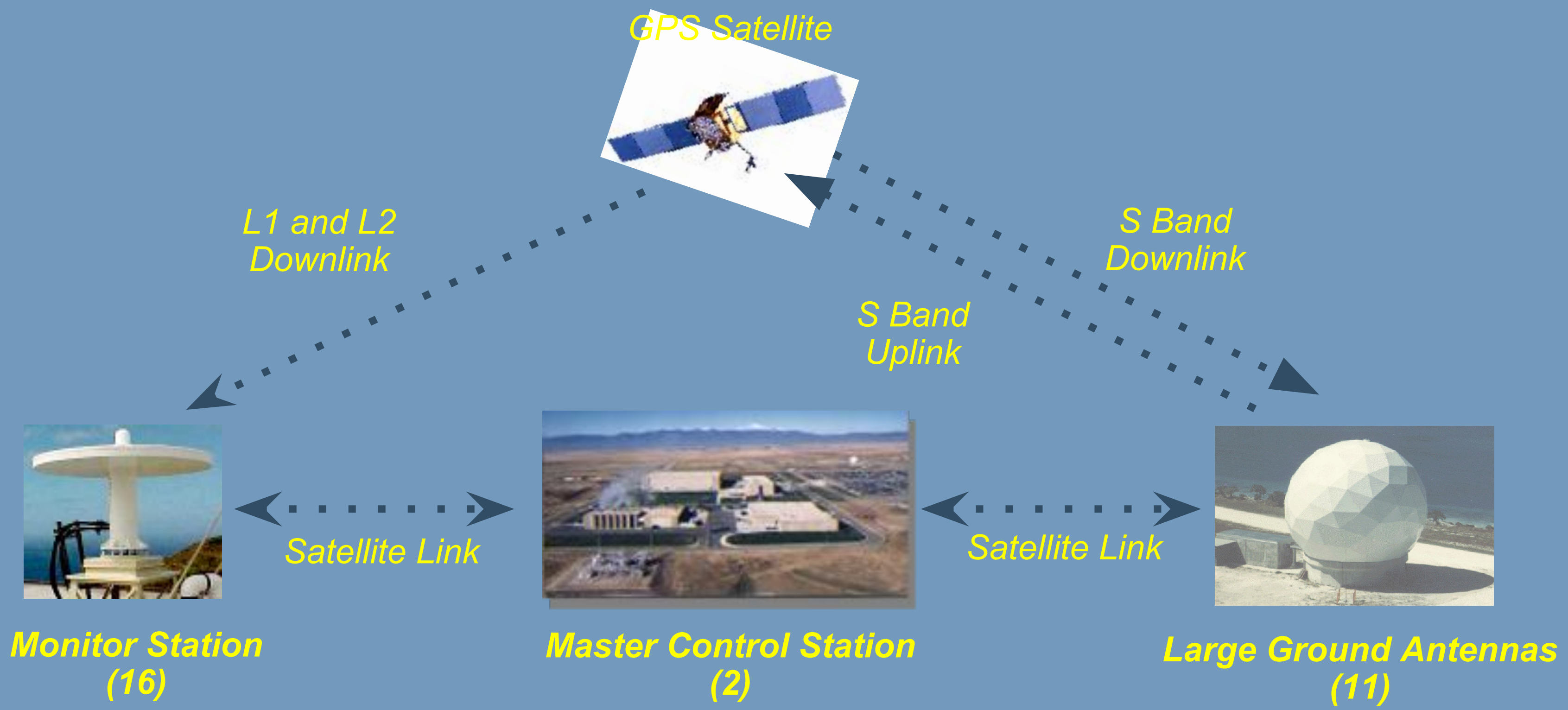
Control Segment

- The Operational Control Segment is a global network of satellite ground stations comprising 2 Master Control Stations, 11 Large Ground Antennas and 16 Monitor Stations



Control Segment Locations

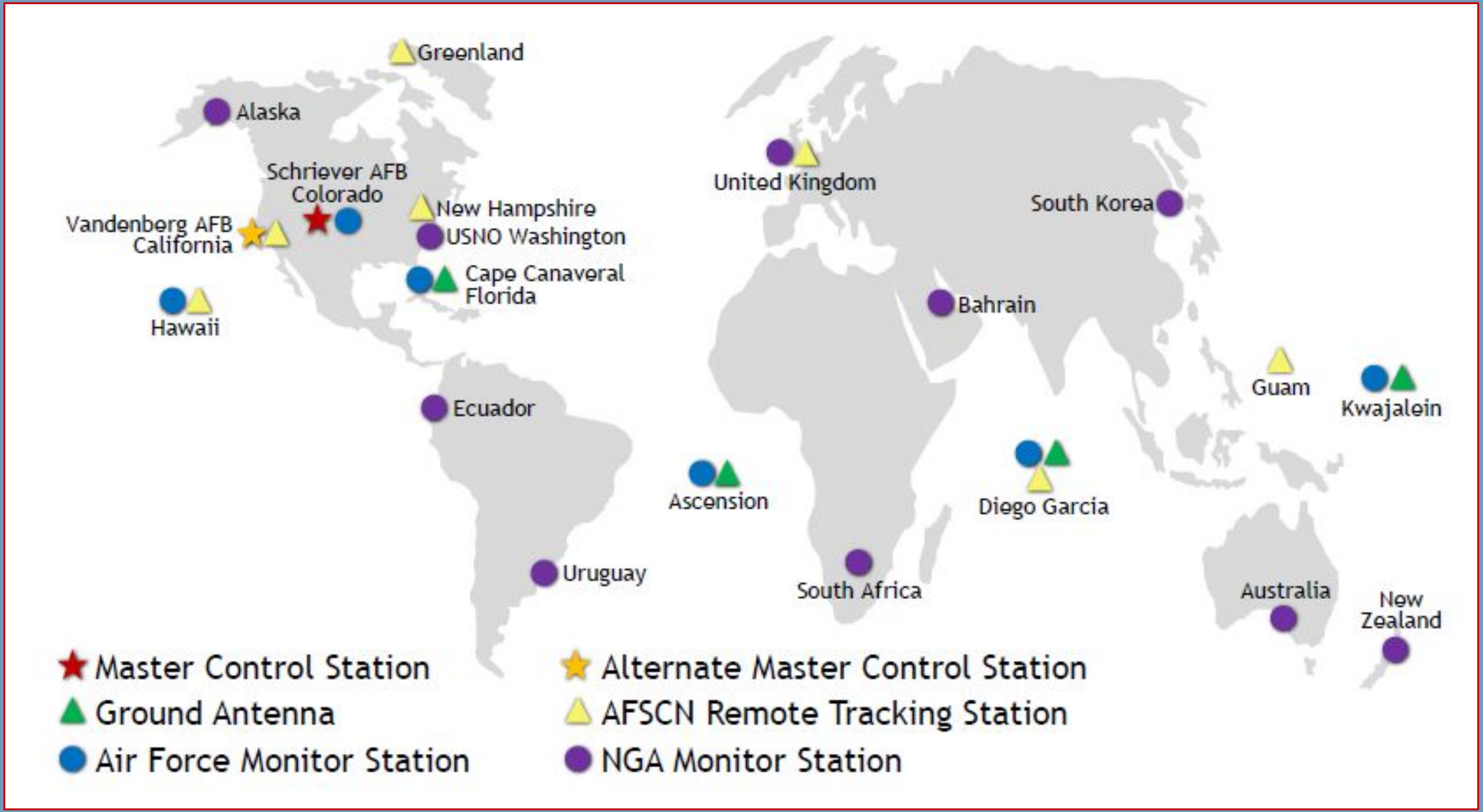


Image source: US Government

Control Segment Elements

- *Master Control Stations* command and control the GPS constellation to;
  - compute the precise satellite locations
  - generate navigation messages for upload to the satellites
  - monitor satellite health and accuracy
  - perform satellite maintenance, problem resolution and station keeping
- Unstaffed remote *Monitor Station* receivers located around the Earth provide continuous ground visibility to monitor each satellite in order to;
  - track GPS satellites as they pass overhead
  - monitor the GPS signals and atmospheric data
  - feed the observations to the MCS
- Large *Ground Antennas* provide Telemetry, Tracking and Control by;
  - sending commands, navigation data and software uploads to the satellites
  - collecting telemetry from the satellites
  - performing ranging on the satellites

Control of the GPS System

- GPS accuracy relies on the accuracy of the receiver's clock and knowledge of the satellite's orbital parameters and their atomic clock errors.
- The Operational Control Segment essentially acts as a control loop.
- It measures the satellite orbit and clock errors as accurately as possible and broadcasts the accurate data to the user receivers via the GPS satellites
- Monitor stations receive the two navigation signals from each satellite and pass the data back to the MCS.
- The MCS takes the data from each satellite and updates its estimates of each satellite's orbital parameters and clock errors.
- The new information is passed to the Ground Antennas for upload to the satellites.
- When each satellite receives the updates, it will incorporate the new data in subsequent navigation messages.

User Segment

- The *user segment* contains all users in possession of a GPS receiver which includes the antenna, receiver hardware and software that processes the navigation signals from the GPS satellites.
- GPS receivers are manufactured in various forms and can be embedded in other devices for many uses including:
  - Aviation
    - Enables 3-dimensional position determination for all phases of flight from departure, en-route and arrival, to airport surface navigation.
  - Maritime
    - Provides the fastest and most accurate method for mariners to navigate, measure speed, and determine location while in open sea, congested harbours and waterways
  - Automotive
    - Used in vehicles such as cars, trucks and public transport for navigation, location and tracking purposes.
  - Personal
    - Available as dedicated handheld navigation devices, or embedded into portable devices such as smartphones.

Satellite & Data Communications

Lesson 8:

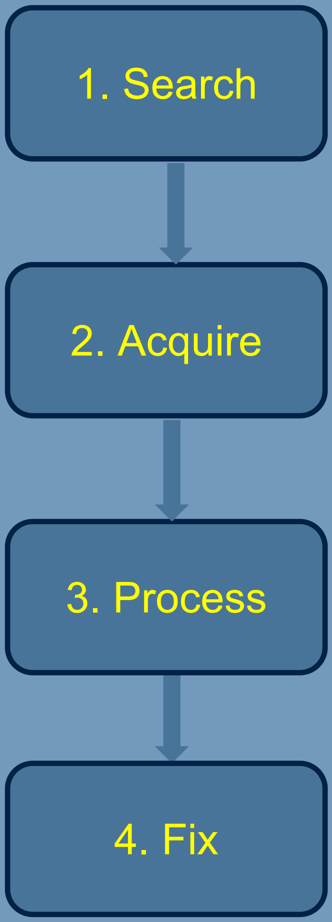
How GPS Works

How GPS Works

- In this lesson Cadets will learn how the GPS System works including:
  - GPS receiver operation
  - Measuring time
  - Measuring distance
    - Pseudoranging
  - Measuring position
    - Trilateration
    - Use of four or more satellites
  - GPS co-ordinate system
  - Military GPS

GPS Receiver Operation

- There are four sequential activities at work in a GPS receiver.
  1. When switched on, the receiver will *search* for GPS signals.
     - This can take about 15 to 45 seconds depending on the type of receiver.
  2. The receiver will examine the signals and *acquire* lock with as many GPS satellites as possible.
     - Receivers with multiple channels can acquire satellites much quicker by processing several satellite signals in parallel rather than in sequence.
  3. The receiver will *process* each signal using built in software, the outcome of which is;
     - the synchronisation of the receiver clock with the satellite precision atomic clock
     - the distances to the satellites from the receiver
  4. The receiver will then *fix* the user's position by calculation
     - Generally receivers provide a fresh navigation fix every second



GPS Receiver Satellite Fix

Receiver's longitude, latitude and altitude

Received signal strength

Satellite ID number

Visible satellite positions

Receiver position

- The display shows a typical vehicle GPS satellite navigation receiver with a a 3-D position fix
- The receiver has acquired 7 from 11 visible satellites; ID numbers 5, 7,13,15, 27, 28 and 30

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Measuring Time

- Each GPS satellite is equipped with multiple *atomic clocks* that add extremely precise time data called *Co-ordinated Universal Time* (UCT) to the GPS signals.
- The clocks typically maintain accuracy to 3 nanoseconds (3 x 10^{-9} seconds) per day, however the relative timing between satellites drifts over time and needs to be monitored and corrected by the MCS.
- GPS receivers decode the signals transmitted from the satellites, noting their exact arrival time.
- The signal's travel time is the difference between the time broadcast by the satellite and the time the signal is received, about 0.07 seconds.
- Using this information each receiver can synchronize their internal clocks to the atomic clocks of the satellites.
- This enables receivers to determine the time to within billionths of a second, without the cost of owning and operating atomic clocks.
- Therefore GPS is also an extremely accurate timing system which can be used for clock synchronisation.

Measuring Distance

- To calculate its distance from a satellite, a GPS receiver applies a simple formula to the satellite's radio signal:

  distance = speed x time

- Radio signals travel through space at the constant *speed of light*; 299,792 metres per second.
- The receiver therefore only needs to know the time the radio signal takes to reach the receiver from the satellite in order to calculate the distance to the satellite:

  range to satellite = speed of light x signal travel time

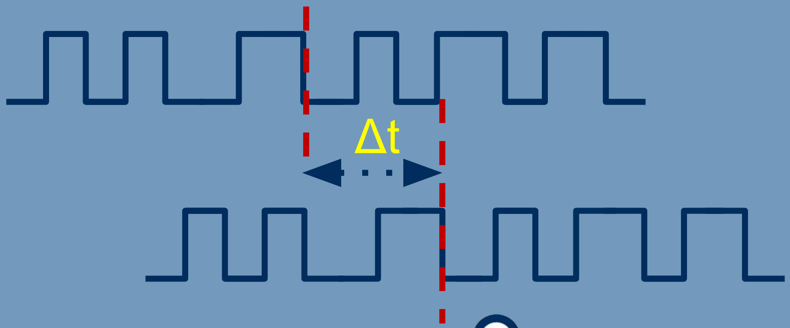
- The value derived from this method of computing distance is called a *pseudorange* because:
  - it is not a direct measurement of distance but a measurement derived from time
  - not all the errors in the measurement are taken into account

Pseudoranging

- Starting at exactly the same point in time, the satellite and receiver generate identical *pseudorandom* binary sequences (the C/A code).
  - The codes are unique to each satellite and repeated constantly every 1023 bits.
  - GPS receivers match the C/A code of each satellite with an identical copy of the code contained in the receiver database.
- The satellite transmits its code, but the received version of the code lags behind due to the time taken for it to travel to the receiver.
- The receiver compares its own and the received code to determine how many seconds to shift the codes to match the sequence.
- The shift (Δt), multiplied by the speed of light, determines the distance from the satellite to the receiver.

Synchronously running C/A code at satellite transmitter and receiver

Delayed C/A code received at the receiver

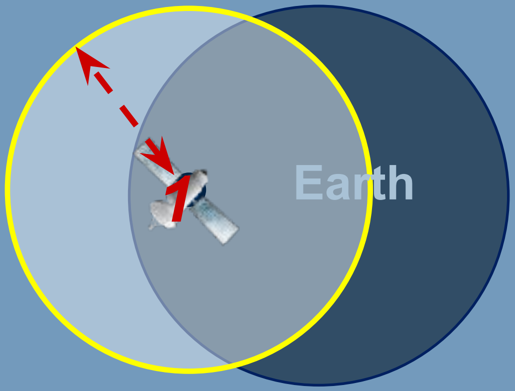


Measuring Position

- Theoretically, to determine the GPS receiver's position at any time, the satellite coordinates of a minimum of three satellite ranges are required.
- The received GPS navigation message includes the *broadcast ephemeris* containing information on the orbit parameters of the satellites.
- Knowing the satellite's orbit parameters and the current time, it is possible to calculate the exact 3-dimensional co-ordinates (longitude, latitude, altitude) of the satellites at any point in time.
- By knowing each signal's point of origin and its arrival time, the GPS receiver can compute its own co-ordinates.
- It does this by using a technique called *trilateration* that exploits the geometry of circles and spheres.
- The GPS receiver performs the trilateration computation by constructing imaginary spheres.
- Using this method, GPS can give an instantaneous, real-time position to within approximately 5-10 metres for 95% of the time for civilian users.

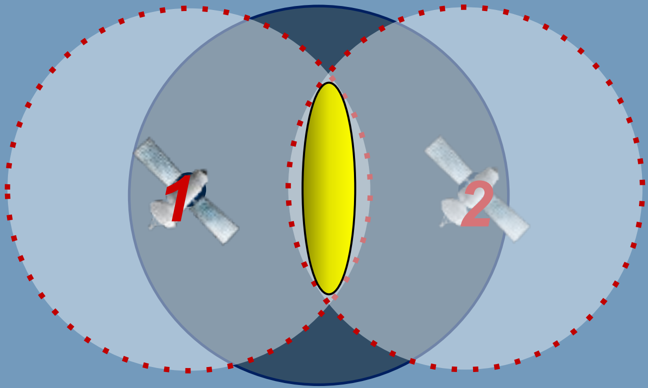
Trilateration - 1st Satellite

- The first GPS satellite signal pseudoranging tells the receiver how far it is from that satellite.
- The satellite is at the center of the sphere and radius is equal to the measured distance or *pseudorange*.
- The location of the receiver could thus be anywhere on the surface of an imaginary sphere, whether on land, in the air or even in space.



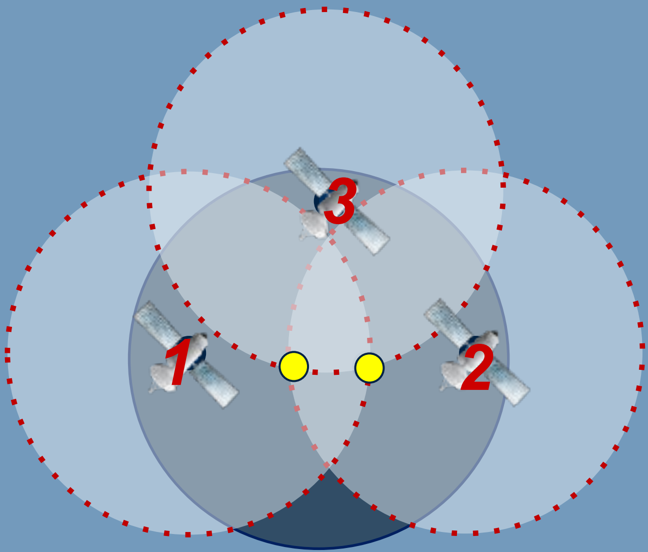
Trilateration - 2nd Satellite

- The second GPS satellite signal pseudoranging creates a second sphere centered on the second satellite
- This narrows down the location of the receiver to somewhere on the circle where those two imaginary spheres intersect.



Trilateration - 3rd Satellite

- The third GPS satellite signal pseudoraning creates a third sphere centered on the third satellite.
- This further which narrows down the receiver location to two points on the circle where those three imaginary spheres intersect
- One point is obviously wrong as it is usually well above the surface of the Earth, or deep within the Earth, and so can be discarded.

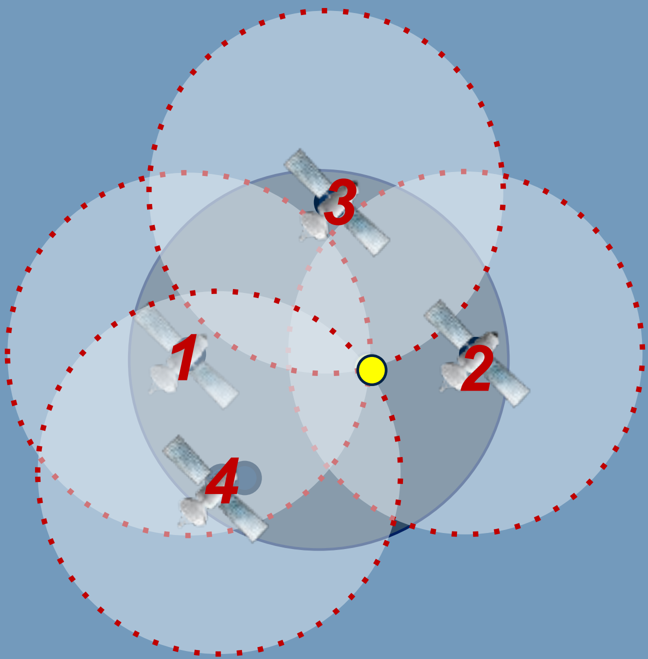


Use of Four or More Satellites

- In practice, GPS positioning requires four, rather than three satellites, to determine accurate 3-D positioning information.
- Receiver's use small, low cost oscillator clocks that are insufficiently accurate to stay perfectly synchronized with the satellite clocks and hence identify a precise location with three satellites.
- A fourth satellite accounts for the receiver clock offset causing timing errors, as well as correcting for other errors in the system.
- More than four satellite signals received simultaneously would improve the GPS position precision even further, particularly in the vertical position.
- The receivers process the extra signals using special statistical techniques to correct for any remaining errors.
- This brings the receiver's clock back into synchronisation with the satellite's precise atomic clock.
- Most modern receivers consist of 12 separate channels which track and process data from 12 satellites in parallel to acquire them more quickly.

Trilateration - 4th Satellite

- If all the pseudoranges were absolutely precise based on accurate time measurements, then a fourth satellite measurement would coincide with the single point of intersection from the other three, but in reality it rarely does.
- The receiver makes an adjustment by searching for a single correction to all four timing measurements such that the 4th satellite measurement gives the same position as the other three.
- The receiver clock can then be synchronized to the satellite atomic clock.



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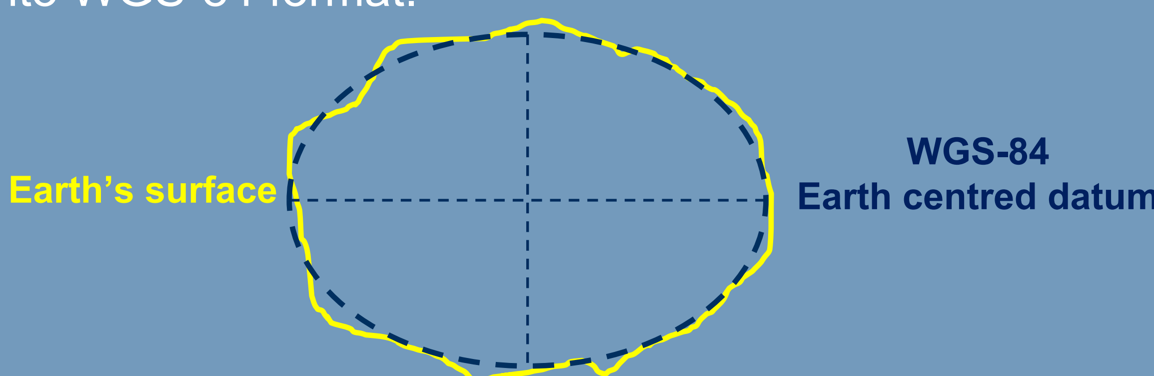
GPS Co-ordinate System

- The earth is not a perfect circle; it bulges at the equator and is somewhat squashed at the poles.
- To account for this, GPS uses the US National Geospatial Intelligence Agency model of the Earth called the *World Geodetic System 1984* (WGS-84) as the reference coordinate system to determine latitude and longitude.
- The model provides a description of the shape of the earth and overcomes the problem of using many different geodetic datums worldwide.
- The GPS receiver employs an algorithm in the receiver to transform the orbit parameters of the GPS satellites received from the broadcast ephemeris into WGS-84 format.



Military GPS

- Military GPS is used where accuracy and reliability is highly important, such as improved situational awareness to locate friendly forces and precision munitions guidance.
- Military receivers use the *Precise Position Service* (PPS) to work around vulnerabilities such as;
  - *Spoofing;* imitating the GPS signal to cause false readings
  - *Jamming;* interference to prevent GPS signal reception
- To prevent spoofing, an alternative encrypted *P[Y] code*, is transmitted on the L1 carrier to ensure that an authentic signal is being received.
  - Only US and approved allied armed forces and governments have access to the encryption keys to decode the P[Y] signal.
- To prevent jamming, the P[Y] code is also transmitted on an additional carrier called L2 at a frequency of 1227.6 MHz

Precision Lightweight GPS Receiver (PLGR)

Image courtesy of jc^{4}i

Satellite & Data Communications

Lesson 9:

GPS in Everyday Life

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GPS in Everyday Life

- In this lesson Cadets will learn about how GPS is used in everyday life works including:
  - Public Safety
  - Surveying, Mapping, and Geodesy
  - Geophysics
  - Land Transportation
  - Earth Environmental Sciences
  - Scientific Research and Exploration
  - Recreation

Positioning, Navigation, Timing

- GPS receivers are employed by a wide range of users to meet their daily needs.
- The term *PNT* is commonly used to describe the services that GPS provides, or to denote the various methods and technologies by which navigation is supported.
  - *Positioning* is the ability to accurately and precisely determine location and orientation for mapping and tracking purposes.
  - *Navigation* is the ability to determine current and desired position and apply corrections to course, orientation, and speed to attain a desired position anywhere around the world, from sub-surface to surface and from surface to space.
  - *Timing* is the ability to acquire and maintain accurate and precise time from a *Universal Time Clock* (UTC) anywhere in the world and within user-defined parameters.

Cadet Activity

- Cadets should research and discuss what they know about the GPS system and its many uses, both from their own experiences and using the Internet.

Public Safety

- GPS serves as a facilitating technology to assist *public safety* and *disaster response* teams as they respond to emergencies and prepare for the unexpected.
- First responders such as law enforcement, fire fighters and emergency medical personnel rely on GPS to provide critical instant location and route information.
- Knowing the precise location of landmarks, streets, buildings, and emergency service resources shortens travel times, allowing quicker responses often meaning the difference between life and death or significantly mitigating property damage and loss.

Surveying, Mapping and Geodesy

- GPS provides many advantages for *surveying,* compared to traditional mapping and surveying techniques by not requiring a line of sight between adjacent surveyed points;
  - accuracy is improved
  - unaffected by weather
  - collection is much faster and the amount of equipment and labour required is reduced, leading to cost savings.
- *Geographic Information Systems* (GIS) can be used to;
  - display features, store, manipulate, and display geographically referenced data measured with GPS on maps
- *Geodesy* is the science of accurately measuring and understanding the Earth's geometric shape, orientation in space, and gravity field, as well as the changes of these properties with time.
  - By using GPS, the movement of a site can be continuously and accurately monitored.

Land Transportation

- All modes of land transportation, including trains, trucks, automobiles, all terrain vehicles have applications in which safety, position-location, and navigation are important.
- *Automatic Vehicle Location* (AVL) using GPS is a means for determining the location of a vehicle and transmitting this information to a point where that data can be used to manage vehicle fleets, public transportation, delivery trucks and courier services.
- *Tracking* can provide an historical record of driving habits or events providing benefits such as routing efficiency, fuel efficiency and maintenance costs, driver monitoring, safety and security and asset monitoring
- *Automatic guidance* of farm vehicles allow farmers to apply precise amounts of fertilizer and pesticide to exact field locations based on crop type planted and soil composition, potentially improving both the efficiency and cost-effectiveness of these operations.

Vehicle Navigation

- Vehicle *navigation* systems use a *moving map display* which is a type of navigation system output.
- Instead of numerically displaying coordinates from the GPS receiver, or a heading and distance indication of a certain waypoint, it displays the receiver's current location at the centre of a map
- As the receiver moves and new position coordinates are determined, the map moves to keep its position at the centre of the display
- The display portrays the receiver's physical movement, typically showing a simulated overhead view of the location on a moving map.
- Some devices also simulate a 3D view from the perspective of the receiver.

Earth Environmental Sciences

- The ability to measure the Earth, including its atmosphere, ocean and land surfaces, has been greatly enhanced by GPS.
- In *meteorology* GPS receivers are mounted on weather *sounding balloons* used to;
  - measure atmospheric water vapor.
- In *atmospheric science* GPS receivers are mounted on *Ozonesondes,* lightweight, balloon-borne instruments used to;
  - monitor holes in ozone layer.
- In *oceanography* GPS receivers are mounted on *buoys* used to;
  - observe the effects of ocean tides
  - track the movement and spread of oil spills
- In *geodynamics* GPS receivers are used to;
  - study relative motions on the surface of the Earth to monitor earthquakes.

Scientific Research and Exploration

- GPS is used for many different scientific research and exploration purposes requiring accurate and reliable positioning.
- In *archaeology* fieldwork GPS receivers may be used to;
  - map find-spots, earthworks and other archaeological features without the need of conventional techniques.
- *In biology* animals can be equipped with GPS technology to;
  - obtain accurate locations that can be combined with sensor data to study animal behaviour and ecology.
  - track and map the migratory patterns of endangered species as they migrate to another habitat for a season, move in search of food or shelter, or are forced out of their ecosystem by human activity such as construction, thus helping to preserve and enhance declining populations.
- *Explorers* can carry GPS receivers to;
  - easily locate themselves and their findings
  - navigate in remote, uncharted territory.

Recreation

- Personal GPS receivers are used mostly for transportation-related activities involving both vehicles and pedestrians
- In *recreation*, GPS can be used for;
  - "off-roading" with four-wheel drive vehicles, back-country skiing, mountain climbing, bicycling, hiking, boating and even golfing.
- For those activities in which the potential for getting lost is high, and search and rescue services are often required as a result, GPS is much more than a useful gadget; it is a potentially life-saving device.

Cadet Activity

- Cadets should experiment with as many types of GPS equipment as possible; for example, mobile phones, in-car navigation, walking handsets.
- Cadets should discuss how they operate and are used and identify the advantages and limitations of their use.

Summary of Learning Outcome 2

- Cadets should now know the components and principles of the Global Positioning System including;
  - How GPS works
  - Components of GPS
  - GPS satellite orbits
  - Ground stations
  - GPS in the military
  - GPS in everyday life

Senior and Master Air Cadet

Satellite and Data Communications

Learning Outcome 3:

Know the principles of data communications

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Learning Objectives

- Learners should know the principles of data communication including
  - The protocols used in data communications
  - The different types of data networks
  - Computer network servers

Lessons

10. Basic Principles of Data Communications
11. Transfer of Data
12. Protocols
13. Types of Networks
14. Servers

Satellite & Data Communications

Lesson 10:

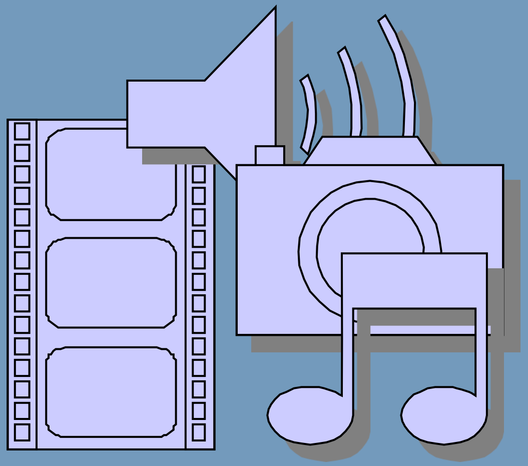
Basic Principles of Data Communications

Data Communications Basic Principles

- In this lesson Cadets will learn about the basic principles of data communications including:
  - Data and information
  - Bits and encoding
  - The roles of data communications
  - Data communications elements

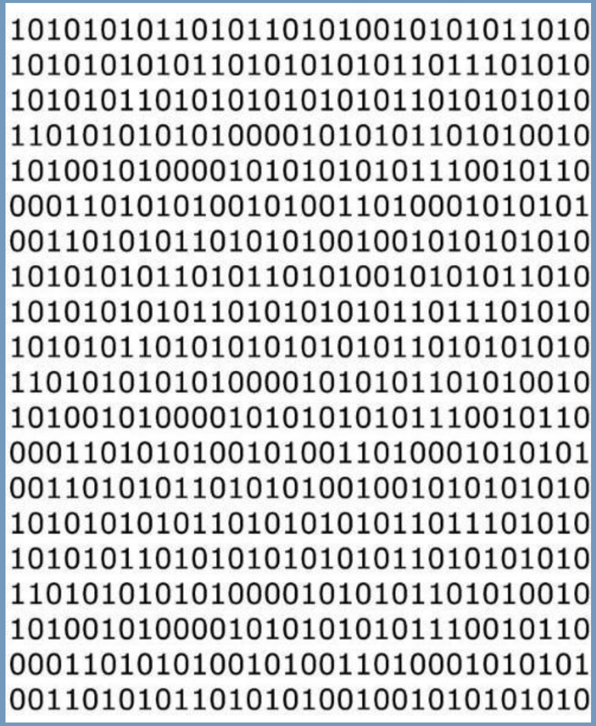
Data and Information

- *Data* describes numbers, character strings, etc. that are a representation of information so that it can be stored, processed and communicated.
  - It temporarily takes the place of information in such a way that the original information can be recovered from it.
  - It does not by itself represent anything meaningful.
- *Information* is the meaning that people give to data in particular contexts.
  - Data cannot be considered information until given meaning and interpreted.
- Information may exist in many forms, referred to as *multimedia,* derived from many different sources such as;
  - Text
    - Words, numbers
  - Audio
    - Human language, music
  - Static Images
    - Symbols, pictures, facsimiles
  - Dynamic Images
    - Video



Bits and Encoding

- Data represents information within computers and networks by a collection of *bits.*
- A bit is an abbreviation for a ***bi****nary digi****t.***
- A bit can have just one of two values, either **1** (one) or **0** (zero).
- Any type of information can be represented with bits using special *coding* methods and *file formats*, for example;
  - Numbers by binary bytes
  - Text by a 7-bit ASCII characters
  - Pictures by JPEG
  - Sound by MP3
  - Video by MPEG



Roles of Data Communications

- A data communication system enables the *exchange of information* electronically between;
  - Users; i.e. *Person to Person*
  - Users and devices; i.e. *Person to Machine*
  - Devices; i.e. *Machine to Machine (m2m)*
- The objective of a data communications network is to provide services to users connected to the network thereby allowing them to:
  - Share hardware resources
    - For example printers and scanners
  - Share data
    - Data needs to be accessible from more than one location
  - Communicate with each other
    - This is particularly relevant for organisations with people in different offices and different countries

Data Communications Elements

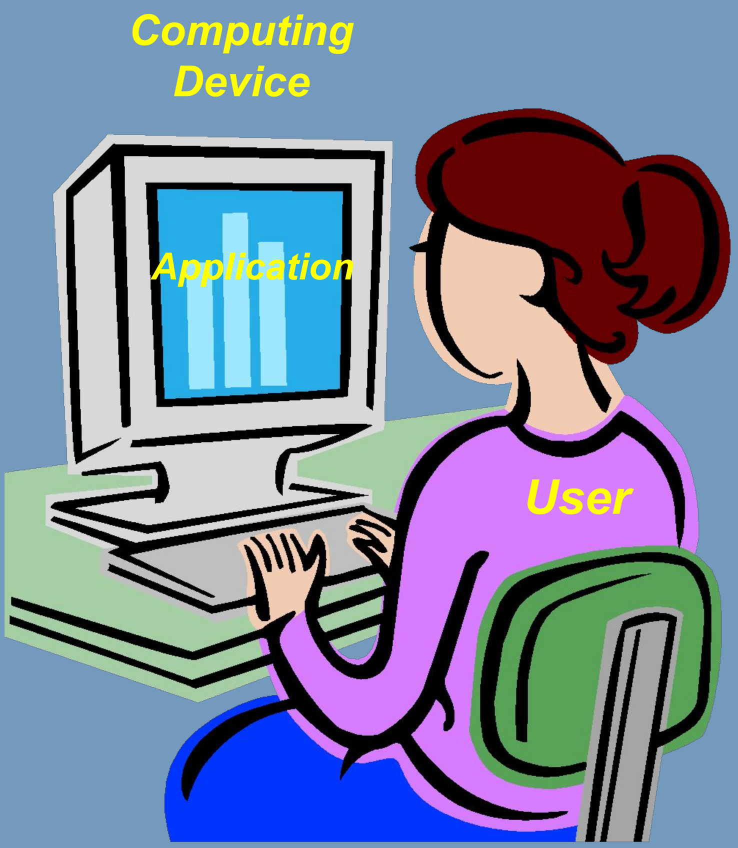
- Data communications is the process of using computing and communication technologies to transfer data from one place to another, and vice versa.
- It enables the movement of electronic digital data between two or more devices, regardless of geographical location, technological medium or data content.
- Distributed data communications is built around three elements:
  - Applications
  - Computers
  - Networks

Application

- In computing, information is exchanged between applications.
- An *application* is the use to which something is put.
- Application *software* is the program running on a computing device realising application functionality for both organisational, personal or home use, for example;
  - Resource and information sharing
    - collaborative working, databases, wikis, World Wide Web
  - Communications and connectivity
    - messaging, email, social networking, IP telephony, desktop sharing
  - Business and electronic commerce
    - on-line financial transactions, purchasing goods and services
  - Entertainment
    - media players, game playing
  - Education
    - information publishing and delivery
  - Monitoring and control
    - remote devices

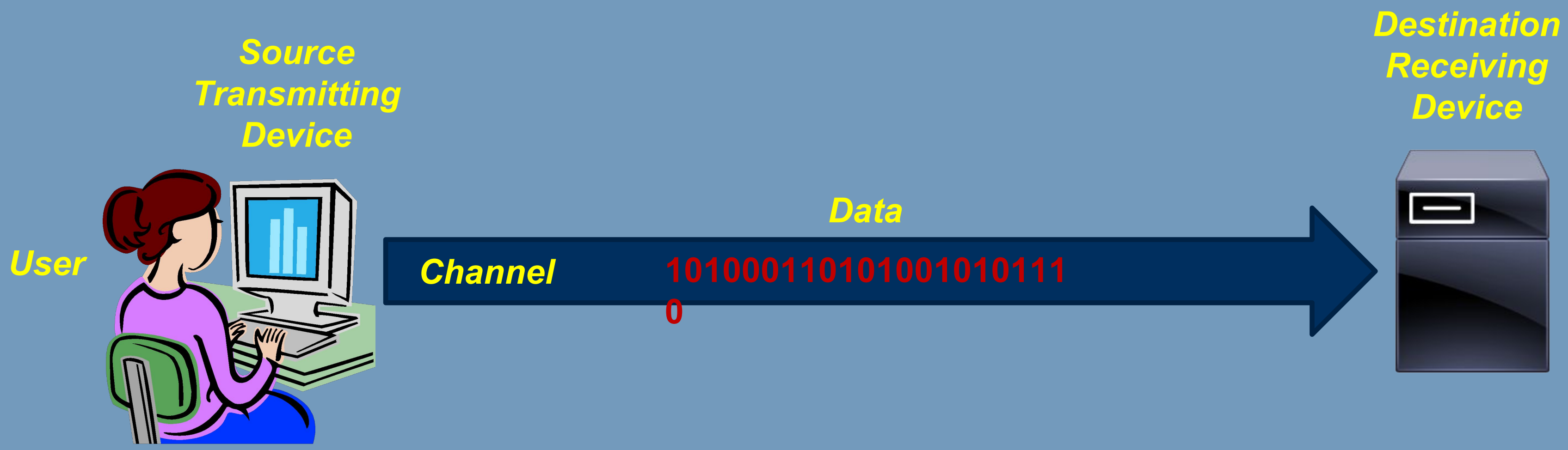
User

- These applications execute on *computers* that typically support multiple simultaneous applications.
- A *user* is a person who interacts with and derives benefit from a computer application.
- The user captures, enters or retrieves and directs its processing.
- The user may be the source of the information, such as the content of an email message.



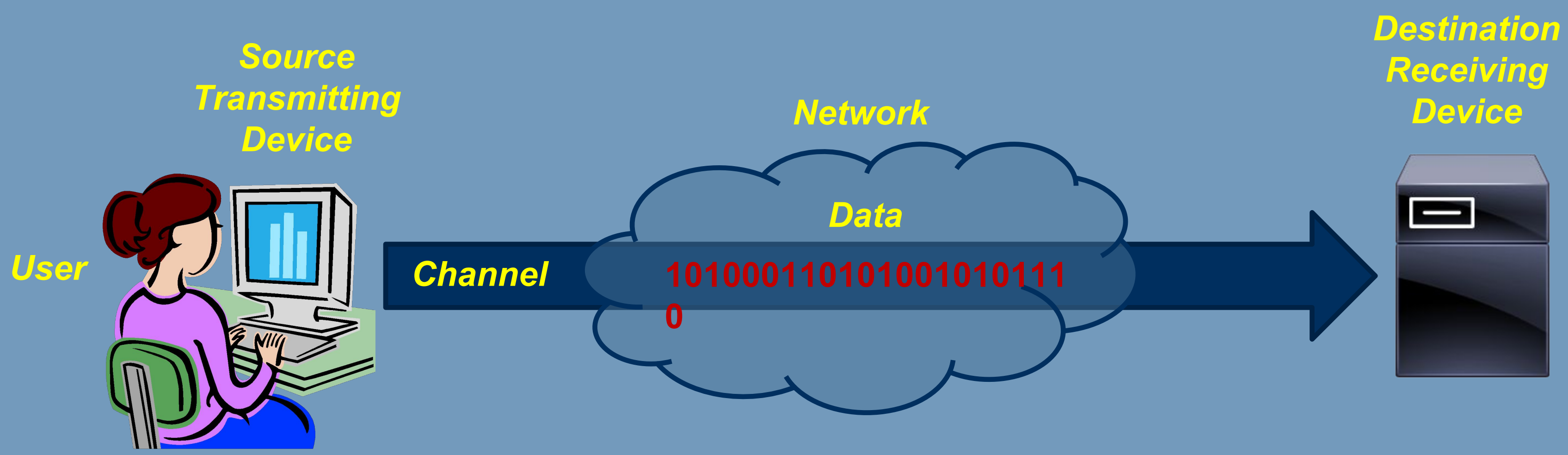
Channel

- When exchanging data between devices, the transmitting device receives data from a user application or other external sources.
- The transmitter then processes the data into a format that can be sent to a communication *channel* which conveys data from a source transmitter to a destination receiver.



Network

- If the two or more devices in different locations some distance apart need to exchange information, then some form of *network* will be required.
- A network is the communications *infrastructure* connecting the computer devices running the applications.
- Networks are often represented in diagrams as a *cloud*.



Satellite & Data Communications

Lesson 11:

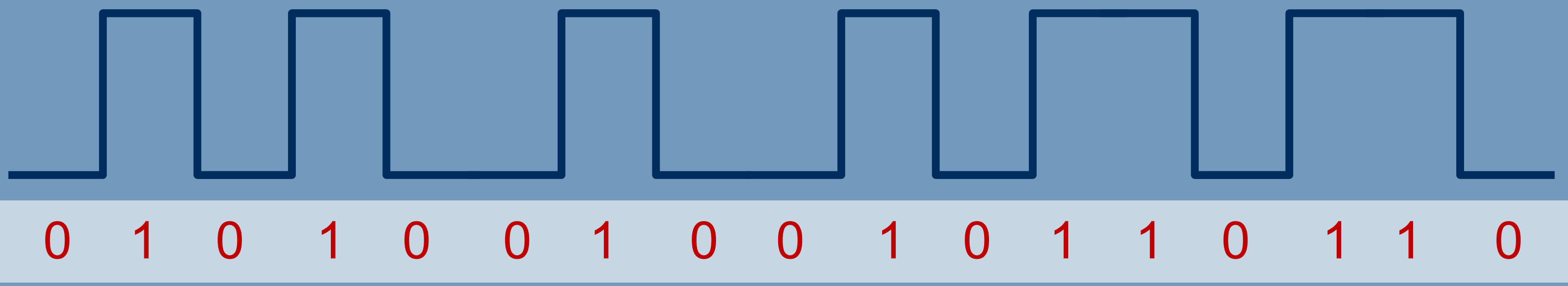
Transfer of Data

Transfer of Data

- In this lesson Cadets will learn about the method of transfer of data in a data communications network and the concepts of:
  - Bits streams
  - Channel capacity
  - Nodes and links
  - Data packets
  - Switching and routing
  - Data preservation

Bit Streams

- All forms of information can be represented by electrical signals.
- Binary data can be transmitted by encoding each data bit into signal elements.
- Data communications networks exchange bits using electrical pulses.
  - 1 is represented by a pulse being present.
  - 0 is represented by a pulse not being present.
- When a data message is sent from a transmitting device to a receiving device, streams of these bits are conveyed across the communication channel as a signal consisting of a series of digital pulses.



Channel Capacity

- Data can be transmitted across a communication channel at various speeds called the *data rate* expressed as the number of bits transmitted per second, often abbreviated as *bit/s* or *bps.*

Data Rate Number Form	Exponent	Prefix	Unit
1 bits per second	1×10^{0}	-	bps
1,000 bits per second	1×10^{3}	kilo	kbps
1,000,000 bits per second	1×10^{6}	Mega	Mbps
1,000,000,000 bits per second	1×10^{9}	Giga	Gbps
1,000,000,000,000 bits per second	1×10^{12}	Tera	Tbps

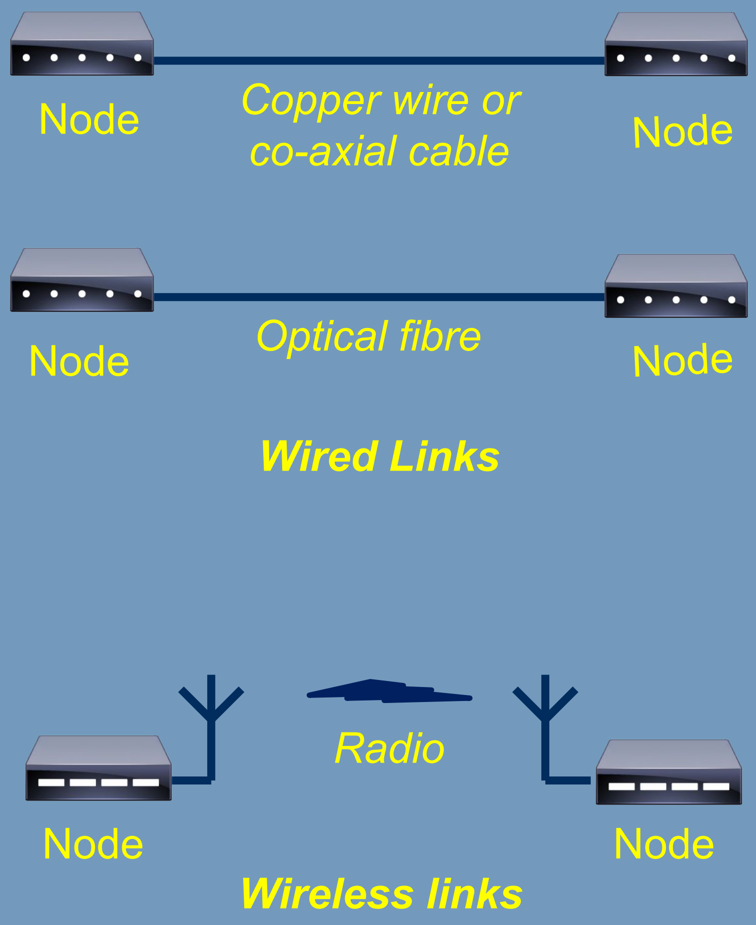
- A data communication channel must have the capacity to be able to both;
  - handle the amount of data messages that it has to exchange
  - transfer them as quickly as they are arriving from the sender
- A measure of the ability of a link to transfer data is known as *bandwidth*, which defines the maximum data transfer rate a link can support.
- Video contains a lot of information and transmission requires a very high data rate and hence bandwidth.

Nodes

- A networked computing device is often referred to as a *node.*
- A node is any device connected to a network;
  - either as an end point where the communication link finishes
  - or some point which lies in the middle of a communication link
- Every node contains a *Network Interface Card* (NIC) which;
  - provides the physical interface between the node and the communications link
  - controls the flow of data over the network
- Each node has a unique identity number known as its *Media Access Control (MAC)* address which is assigned to the hardware device when manufactured.
- A standard format for printing addresses is six groups of two hexadecimal digits (0-10, A,B,C,D,E), separated by colons(:) - For example: **01:23:45:67:89:ab**

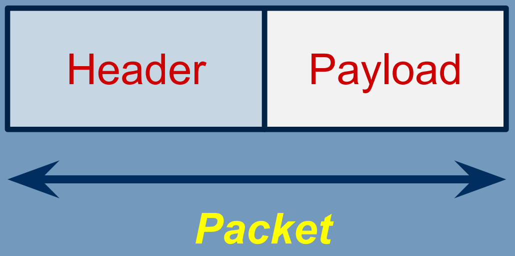
Links

- To send data between nodes there must be some kind of communication *link* or path between them.
- The network conveys data from transmitter to receiver over some form of *transmission media.*
- There are two classes of links;
  - *Wired* networks use physical cables such as copper wire, co-axial cable or optical fibre to connect nodes.
  - *Wireless* networks use electromagnetic waves such as radio to connect nodes.



Data Packets

- Data is passed over a network as a sequence of *packets* which are chunks of data that an application wants to deliver to another device.
- A packet is organised in a pre-determined structured format.
- The data has information added to the front and back containing instructions for where the data needs to go and what the destination system should do with it once it arrives.
- The *header* contains all the information sufficient for routing from the originating node to the destination node.
- The *payload* is the data to be transported from source to destination.
- The addition of this routing and usage information is called *encapsulation*.



Packet Switching

- The network needs to select the most appropriate route for the data packets to travel through the network.
- Most modern networks use *packet switching* which establishes a *virtual circuit* rather than a dedicated physical circuit for the connection between sender and receiver.
- Each transmitting device's data stream is divided into number sequenced data packets which are;
  - sent to the network
  - mixed with all of the other user's packets
  - relayed through the network to the correct receiver
- Packets are directed to the destination device
  - independently
  - in any order
  - using different routes to their final destination
- The received packets are rearranged into the correct number sequenced order to reconstruct the original data stream.

Routing

- A node needs to identify other nodes on the network it wants to communicate with.
- This is achieved by assigning each node an *address.*
- When a source node wants the network to deliver a message to a certain destination node, it specifies the address of the destination node.
- The addresses are carried in the header of the data packets.
- If the sending and receiving nodes are not directly connected, then the switches of the network use this address to decide how to forward the message toward the destination.
- The process of determining systematically how to forward messages toward the destination node based on its address is called *routing*.
- Devices called *routers,* which hold information about the structure of the network, make decisions about how the data should be routed through it.

Router symbol

Data Preservation

- Data packets can often be corrupted by noise and other flaws when sent through a communications link.
- Some bits may be “damaged”; 1s become 0s or 0s become 1s
- To prevent this from happening additional *error control* bits are added;
  - At the receiver a mathematical function called *error detection* is performed to identify incorrect bits
  - The receiver can then request the corrupt data packets be retransmitted until received correctly
- More complex mathematical functions can be used to go one step further and perform *error correction;*
  - The correct message is recovered directly from the incorrect bits that were originally received

Satellite & Data Communications

Lesson 12:

Protocols

Protocols

- In this lesson Cadets will learn about data communication protocols and the concepts of:
  - Software Communications Layers
  - Protocols
  - Standards
  - TCP/IP

Software Communications Layers

- The transfer of data from source to destination involves;
  - first getting the data to the source computer in which the application resides
  - then passing it to the intended application within the destination computer.
- For a message, file or any other data to travel through a network, it must pass through several software communications *layers.*
- A layer is designed to offer certain services to the layers above, shielding the layers below.
- Each software layer carries out a different function associated with data transfer and has its own set of protocols designed to make sure the data gets through accurately.

Protocols

- Information exchange in a network involves many interacting functions.
- When software on two devices carry on a conversation, the rules and conventions used are known as a *protocol*.
- A protocol is an agreement between those communicating with each other on how to proceed.
- It can be explained using an analogy with the way people talk to each other.
  - People don't just put words together in a random way.
  - They have a set of rules (grammar) that determines the order of words and how sentences are formed
  - They also need to have a common understanding of the meaning of different words
- Data communications protocols operate in a similar way.
- A list of protocols, one operating at each layer, is called a *protocol stack.*
- A complete set of layers and protocols is called a *network protocol architecture.*

Standards

- Fortunately, a number of organisations have taken responsibility for ensuring that many communication protocols are clearly stated, recorded and made available to others.
- These organisations agree on and produce the necessary *standards.*
- Standards are a kind of technical specification that sets out the rules and requirements to ensure interoperability.
- A standards *document* is usually drawn up with the involvement and agreement of all interested parties including representatives of users, manufacturers and government agencies.

TCP/IP

- *Transmission Control Protocol/Internet Protocol (TCP/IP)* is the almost universally adopted network protocol architecture standard and is used with the Internet.

Layer	Functions	Example Protocol
Application	• Runs programs that make use of the network	Hyper Text Transfer Protocol (HTTP) *used by web browsers*
Transport	• Ensures reliability of data communication across the network without errors • Controls the sequencing and flow of data	Transmission Control Protocol (TCP)
Internet	• Deals with how to combine multiple communications links into networks combine networks together send packets between remote devices • Finds the path along which to route packets	Internet Protocol (IP)
Network Access	• Provides the software interface between host devices and communications links	Ethernet *used by LANs*

Cadet Learning Activity

- Using devices Cadets have authorised access to, search through the device settings, identify and note down some examples of the following parameters;
  - E-mail address formats
  - Port numbers for any applications
  - Device IP address
  - Device MAC address

- Using the settings of the device, identify the following information about your data connection
  - Device MAC address
  - Device IP address
  - Data rate

Satellite & Data Communications

Lesson 13:

Types of Networks

Types of Networks

- In this lesson Cadets will learn about data communication networks and the concepts of:
  - Networked computing
  - Types of networks
    - Personal Area Networks
    - Local Area Networks
    - Wide Area Networks
  - Internetworking
    - Intranet
    - Extranet
    - The Internet
  - The World Wide Web
  - Wireless networks
  - Network security

Networked Computing

- Two devices are *networked* if connected in some way and able to exchange information.
- Networks come in different sizes, shapes and forms and are usually interconnected together to make larger networks.
- In forming a network, there are choices to be made depending on;
  - where the computers are located in relation to one another
  - how they need to interact with each other
- Data networks can be classified by the type communications link used to connect devices (wired or wireless) and the geographical range of coverage.

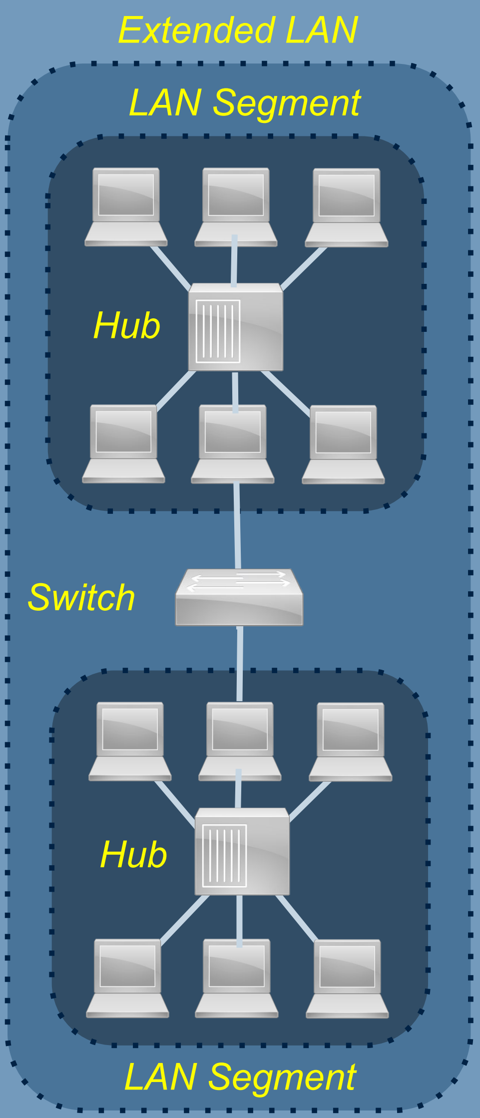
Network Type	Typical Reach	Coverage
Personal Area Network	1 m	Person, Vehicle
	10 m	Room
Local Area Network	100 m	Building
	1 km	Campus
Wide Area Network	10 km	City
	100 km	Country
	1,000 km	Continent
The Internet	10,000km	Planet

Personal Area Networks

- *PANs* are used for close communication, typically a few metres apart such as;
  - on a person, in a single room or a car
  - among personal devices themselves
  - for connecting to a higher level network and the Internet
- They are aimed at low power, low cost implementations and are used in applications such as;
  - industrial control
  - public safety
  - automotive sensing
  - home networking and automation
- Wireless PANs use wireless technologies such as *Bluetooth*

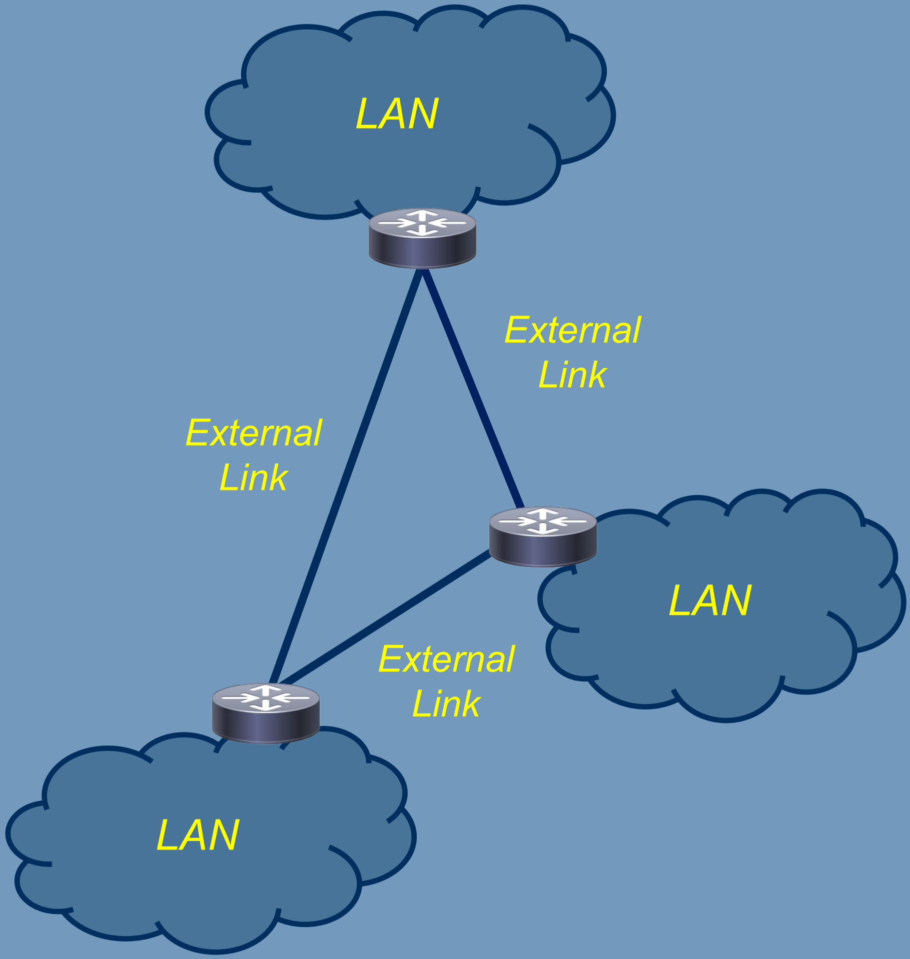
Local Area Networks

- *LANs* connect together as few as two or hundreds of nodes in a single building, or group of buildings near each other, such as a home, office or factory.
- LANs are usually privately owned or belong to a single organisation.
- Ethernet was the first and is the most universal LAN type conforming to the IEEE 802.3 standard.
- Each LAN node connects to a device at the centre of a star configuration, called a *hub* or *switch.*
- They act as policemen to move and route data to the correct node, as well as stopping unwanted intruders or data entering the LAN.
- LAN segments can be extended or joined together using switches to form an extended LAN.
- A single Ethernet LAN can connect 1024 devices.



Wide Area Networks

- An organisation can interconnect its LANs located at different geographic locations into a single *Wide Area Network (WAN).*
- A WAN typically consists of a number of interconnected switching nodes connected to an external telecommunications provider's links.
- A transmission from any one device is routed through these internal nodes to the specified destination device.
- The nodes that interconnect the networks are *routers*.

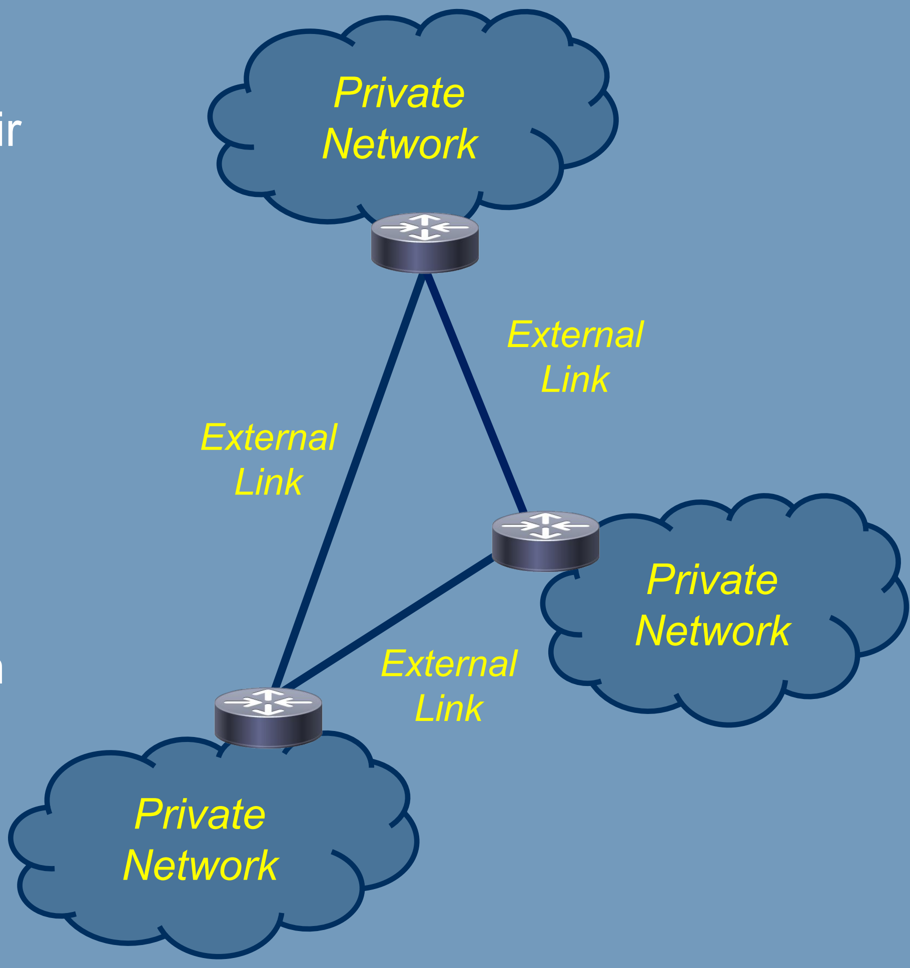


Internetwork

- Networks, often using different technology, can be further interconnected to form a ‘network of networks’ called an *internetwork.*
- An internetwork is set of interconnected networks using the IP protocol.
- It is usually limited in scope to a single organisation and appears to the user to be a single, seamless data communication system.
- Additional hardware and software systems are used to interconnect the individual networks together securely.
- There are three forms of internetwork:
  - Intranet
  - Extranet
  - The Internet

Intranets

- An *intranet* is an internetwork limited in scope to a single organisation.
- Organisations often interconnect their existing and separate internal networks together securely to form a larger private network called an *Enterprise Network*.
- It is really a large WAN and is concerned with ownership, control and administration rather than technology.
- Intranets facilitate cross-organisation communications and collaboration.
- They are made inaccessible by anybody from outside the organisation by special security features called a *Firewall*.



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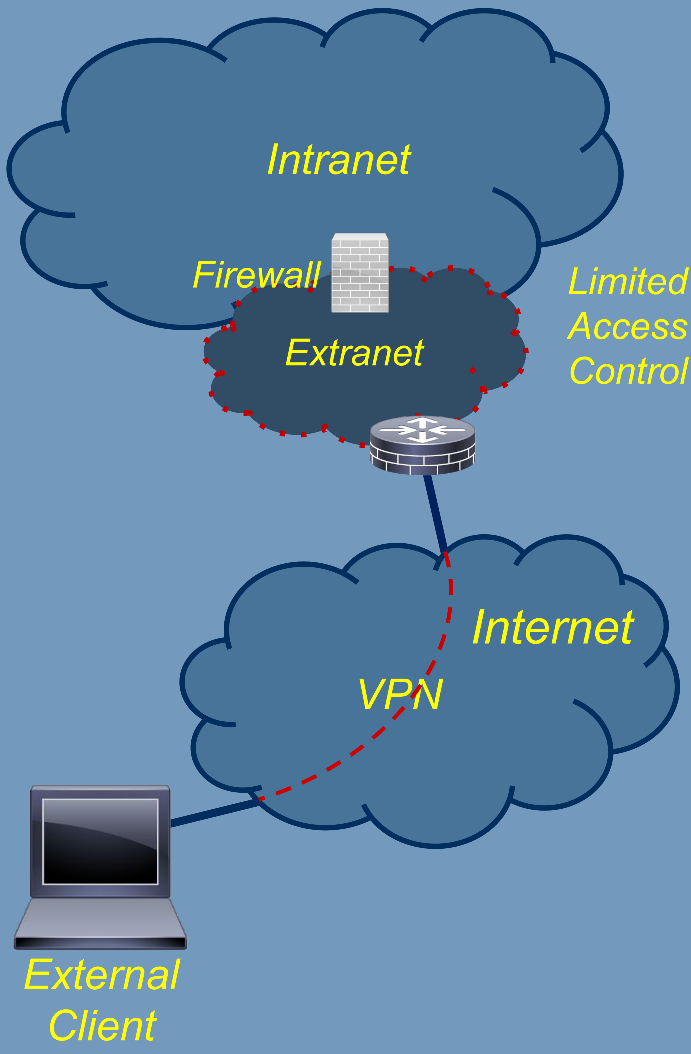
Extranets

- An *extranet* is an intranet that is made partially accessible to users outside an organisation.
- It is an effective and secure way for organisations, external customers, partners and suppliers to share information and do business.
- External users connect to the network through the Internet using a secure *Virtual Private Network* (VPN) connection.
- Access is restricted to a compartmentalised area of an intranet without granting access to the entire network using firewalls.



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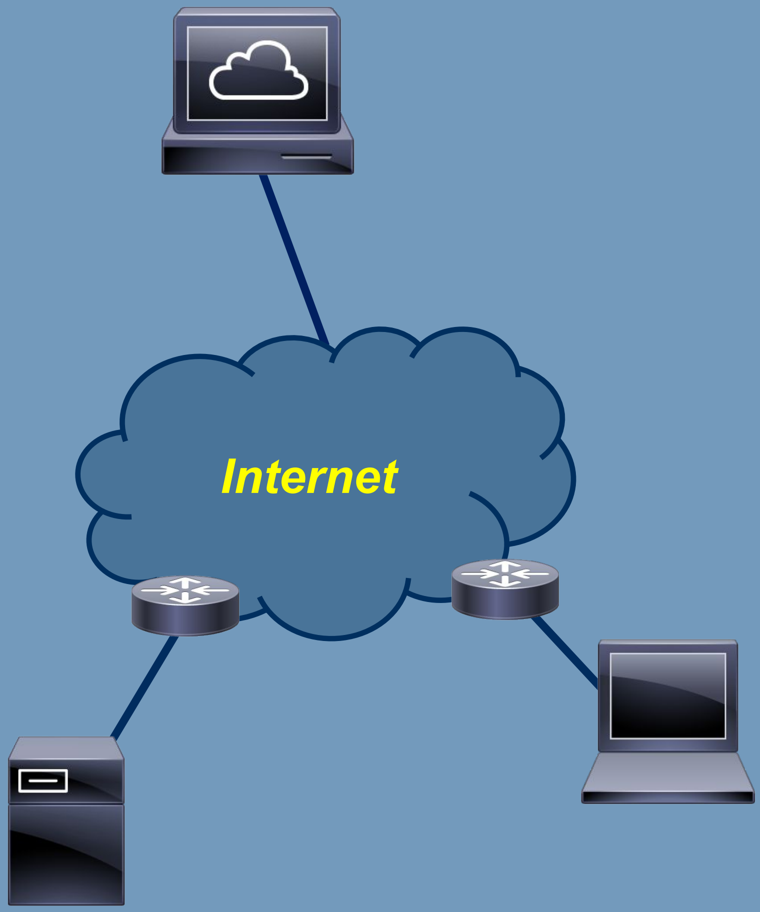
The Internet

- The *Internet* (with capital letter **I**) is a specific and unique internetwork, the very large one with global reach and accessible to all; it is not really a network at all but a vast collection of devices and interconnected networks.
- The Internet evolved from a US government supported computing infrastructure research project called ARPANET launched in 1969.
- In the 1980s commercial applications were allowed on the Internet and it was gradually privatised and made accessible to everyone.
- It is unusual in that it is not planned or centrally controlled by anyone.
- Users purchase Internet access or connectivity from an *Internet Service Provider* (ISP) which allows the computer to exchange data with all the other accessible computers on the Internet.
- A device or network can connect to the Internet by several different means;
  - a phone line with a broadband modem
  - a cable television system with a cable modem using unused cable TV channels
  - mobile networks
  - wireless access points

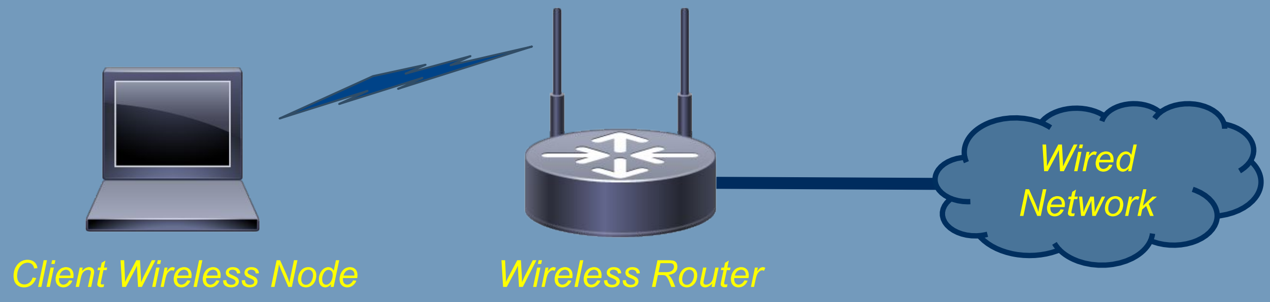
The World Wide Web

- The *World Wide Web* (WWW) is not strictly a network but a loose collection of Internet computer servers.
- It is a way of accessing linked information content spread across millions of computers over the Internet.
- The WWW consists of a vast, global collection of content in the form of Web Pages generally viewed with an application called a browser.



Wireless Networks

- *Wireless* networks are an alternative to fixed wired networks enabling devices to connect to a network and communicate
  - without connecting cables
  - using radio signals as a communicating medium
  - typically covering a range of up to 100m
- They provide advantages over wired networks in terms of mobility and ease of installation and configuration.
- However, wireless LANs cannot match the speed of wired LANs and are limited by their range.
- WLANs are available for use in many public areas, workspaces and the home.



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Network Security

- *Network security* refers to the proper safeguarding of everything associated with a network including data, media and equipment.
- It involves administration functions, vulnerability assessment and uses special technical tools and facilities.
- Network *administrators* need to be sure that network resources are used appropriately, in accordance with a prescribed policy, and only by people who are authorised to have access.
- A difficulty with network security is determining how much security is really necessary.
- To determine this, an assessment is made of potential *threats* and *attacks*.
- Threats and attacks can be prevented by appropriate *security responses* which can be implemented using specialised network security technology and applications.

Security Applications

- Encryption
  - This ensures a message can only be read by the intended recipient by transforming data into an unreadable cipher using a secret key.
- Authentication
  - This enables a message recipient to verify the identity of a sender by
    - Sharing a secret; e.g. password and challenge response (question and answer)
    - Possessing a physical device or token; e.g. swipe card
    - Detecting a physical attribute or biometric; e.g. iris scan, voice recognition
- Digital Signature
  - This ensures a message hasn't been modified since originated by a sender by binding a user's identity to a message making it unfeasible for an attacker to copy or making it difficult for a user to deny sending.
- Firewall
  - This prevents unauthorised network access by monitoring and protecting critical network resources and restricting access to authorised authenticated users.

Satellite & Data Communications

Lesson 14:

Computer Network Servers

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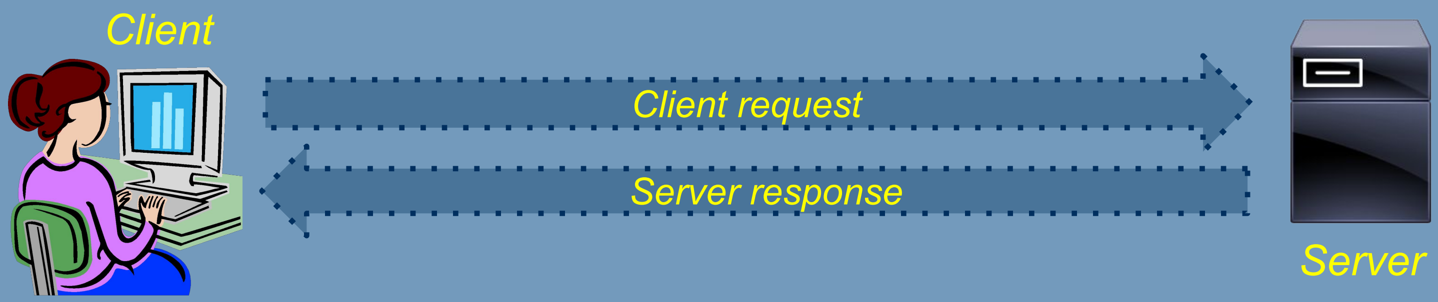
Computer Network Servers

- In this lesson Cadets will learn about computer servers and the concepts of:
  - Client-server computing
  - Server types
  - Server farms
  - Data Centres

Client-Server Computing

- Data is often stored on powerful, centralised, networked computers called *servers*.
- The primary role of a server is to respond to data requests, typically from *clients*.
- Clients are simpler computing devices that directly support the user to access the remote data on the servers.
- The client device;
  - accepts instructions from the user
  - makes requests of the server
  - displays responses from the server for the user.
- This arrangement is called a *client-server* computing model.

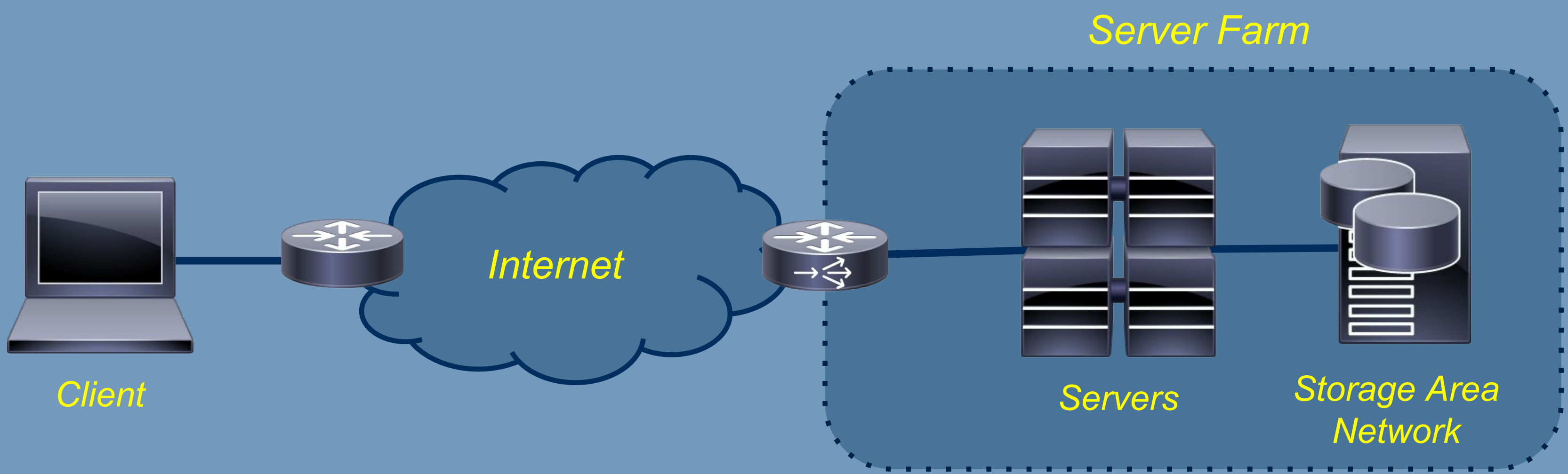


Server Types

- *Servers* can be just PCs or very powerful computers often with multiple-processors, gigabytes of memory, terabytes of hard disk space, and high-speed networking capability which;
  - contain programs and data files that can be accessed by other client computers in a network;
  - provide services ranging from computation, logic and storage to networked applications
  - specialise in specific functions such as file storage, printing, databases, communications, mail or web applications.
- Some servers can handle thousands of transactions per second.
- They are often centrally housed, far apart and connected by the Intranet.
- For example, websites are stored on web servers;
  - a web browser is the client which makes a request to the server, and the server sends the website to the browser.

Server Farms

- Under most conditions, one server can handle a large number of clients, but it can only serve so many requests before the load is too great.
- Organisations that provide a lot of content use *Server Farms*.
- A server farm provides a set of servers that look like a single server or web site to its clients.
- Each server has access to a copy of the content which is often stored on a *Storage Area Network* (SAN).



Data Centres

- Server Farms are housed in secure remote Data Centres that are well connected to the rest of the Internet
- Clusters of computers are housed in a large room, entire building or group of buildings.
- Today's data centres are likely to have thousands of very small but powerful servers running continuously, 24 hours a day, 7 days a week.
- The computers are staked in racks that are place in rows.

Summary of Learning Outcome 3

- Cadets should now know the basic principles of data communications including;
  - The protocols used in data communications
  - The different types of data networks
  - Computer network servers

Senior and Master Air Cadet

Satellite and Data Communications

Learning Outcome 4:

Know the type and roles of mobile communications

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Learning Outcomes

- Know the types and roles of mobile communications including:
  - Mobile communications
  - Bluetooth
  - WiFi

Lessons

15. Principles of Mobile Communications
16. Principles of WiFi
17. Principles of Bluetooth

Satellite & Data Communications

Lesson 15:

Principles of Mobile Data Communications

Mobile Communications

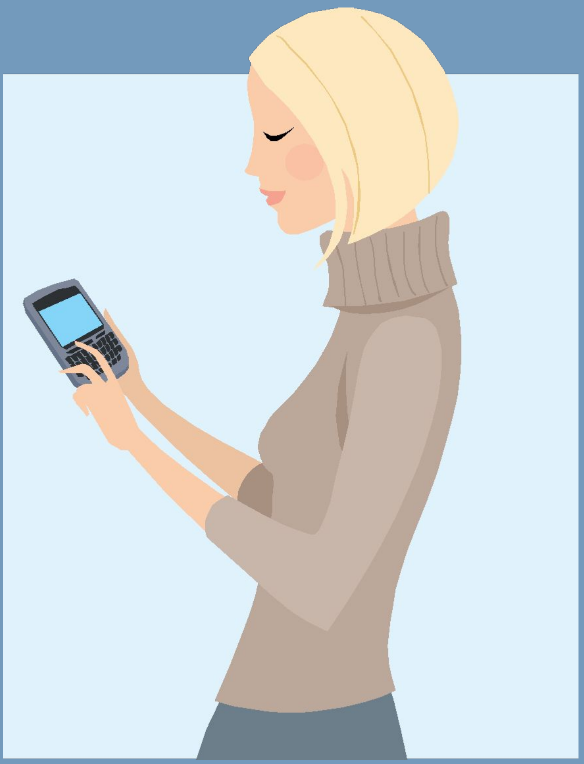
- In this lesson Cadets will learn about the basic principles and technical concepts of mobile data communication including:
  - Mobile computing
  - Cellular mobile data networks
    - UK mobile data network evolution
    - Mobile network elements
    - System access, radio coverage and handoff management
    - Mobile data devices, services and applications

Wireless and Mobile Data Networking

- As networked computing applications became more widely deployed, network access became important, not only through fixed access at home or at work, but also while travelling.
- For example, mobile workers need easy remote access to their organisation's intranet.
- There are two means of providing wireless data connectivity for users on the move;
  - *mobile computing*
  - *nomadic access*

Mobile Computing

- *Mobile computing* provides network access whilst a user is "on-the-go",
  - when walking or in a vehicle
  - using portable devices
- It has evolved from voice based *cellular* mobile telecommunications technology.
- A mobile network uses *mobility management* to maintain a continuous session as the user moves around, by seamless handover of the session between one radio base station and the next.



Cellular Mobile Data Networks

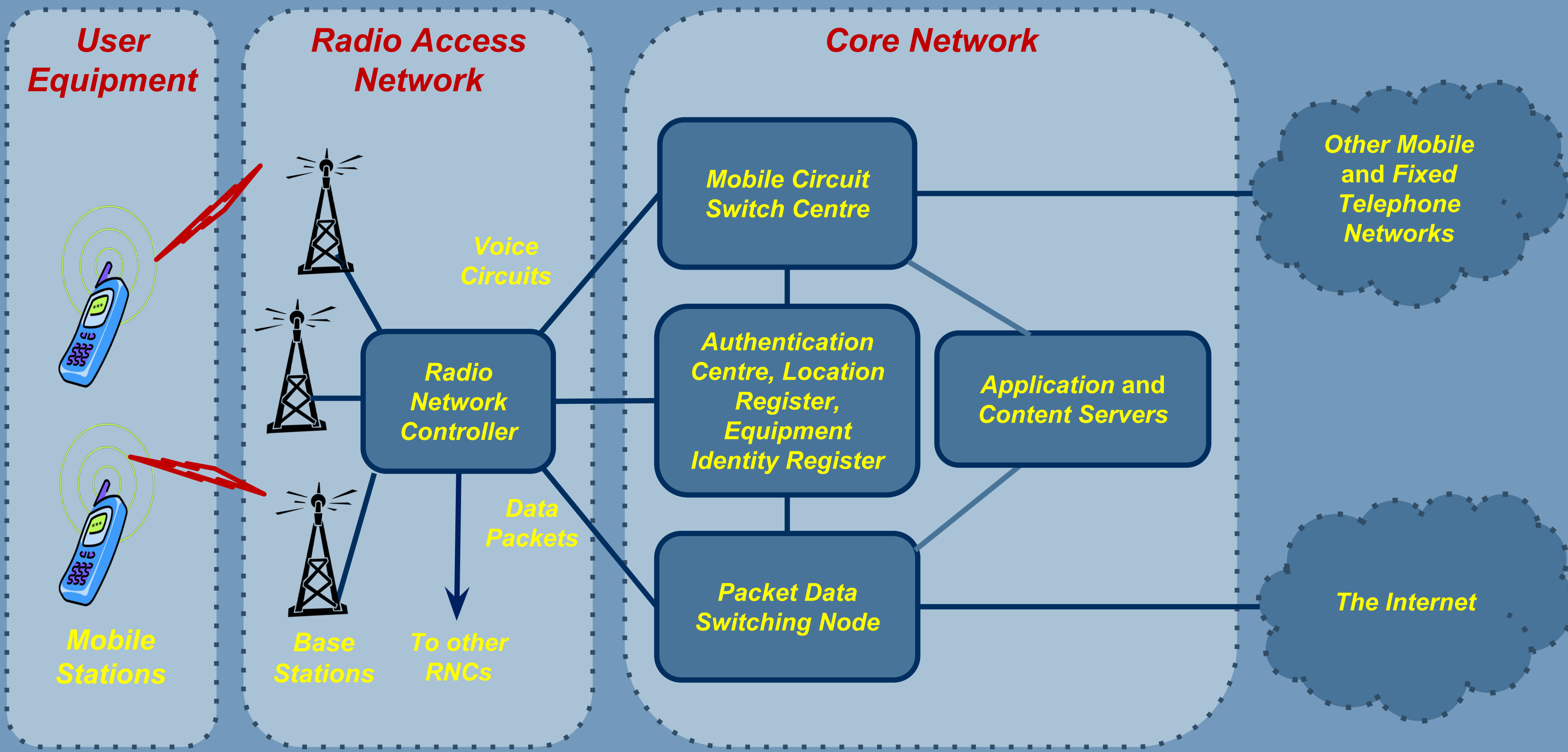
- Since the start of the first public mobile telephone networks in the UK in 1985, data communications technology has evolved rapidly through a series of generations.
- Each *generation* data networking capabilities have increased to meet demand.
  - *1G* systems were *analogue* and designed only to make telephone calls
  - *2G* Global System for Mobiles (*GSM)* system were *digital* and supported mobile data communications at low bit rates.
  - *3G* systems allowed greater mobile data rates and simultaneous voice and data.
  - *4G* systems began to address the demand for access for high speed broadband mobile data.
  - *5G* system implementation is underway supporting broadband on the move providing data rates comparable to wired connections.
- There are many different standards of competing technologies that support data traffic in different ways and at different speeds.
- These technologies are loosely categorised by generation.

UK Mobile Data Network Evolution

Generation	2G				3G		4G
Network Standard	Global System for Mobiles (GSM)				Universal Mobile Telecoms System (UMTS)		Long Term Evolution (LTE)
UK Launch Date	1990's	2002	2000	2006	2003	2006	2012
Data Service Type	CSD	HSCSD	GPRS	EDGE	WCDMA	HSPA	LTE
	Circuit Switched Data	*High Speed Circuit Switched Data*	*General Packet Radio Service*	*Enhanced Data Rates for GSM*	*Wideband Code Division Multiple Access*	*High Speed Packet Access*	
Max Data Rate	10 kbps	10's of kbps	~100 kbps	~300 kbps	~300 kbps to 2 Mbps	~5 to 15 Mbps	~1 to 20 Mbps

Mobile Network Elements

- A typical 3G mobile network is built around three major elements
  - User equipment, Radio Access Network and Core Network



User Equipment

- *User Equipment* (UE) are devices used to access the mobile network.
- The User Equipment contain all the hardware and software needed to;
  - connect to mobile networks through a device's internal *radio modem*
  - provide the interface to the user
- Every User Equipment is allocated a unique *International Mobile Equipment Identity* (IMEI) used by a network to;
  - identify valid devices
  - stop unauthorised or stolen phones from accessing a network if necessary
- Different types of devices are used for mobile data services;
  - Mobile computing equipment
  - Smartphones
  - Dedicated data terminals

Mobile Data Devices

- Mobile phones were first used primarily for making and receiving telephone calls.
- Subsequently, suitably equipped laptop computers or notebooks obtained Internet access through the mobile network using an external *radio modem* module or 'dongle'.
- However mobile network operators focused on handheld devices for mobile internet access.
- Initially there were dedicated mobile data devices without voice capabilities, such as *Personal Digital Assistants (PDA) and feature phones.*
- These have since evolved into more complex *Smartphones* which entered the market later.
- Dedicated data devices also exist which are used for many different specialised business applications.

Smartphones

- *Smartphones* are small multimedia computers that also function as phones.
- A key feature of a smartphone is the ability to install and run applications.
- They use special mobile software operating systems such as;
  - Android
  - iOS
  - Blackberry
- Many different types of mobile *data services* provided by the network operators, can be accessed using smartphones depending on device features and software.

Subscriber Identity Module

- User Equipment house a removable smartcard chip called *a Subscriber Identity Module (SIM)*.
- The card is usually swappable between User Equipment.
- It is uniquely identified by its *Integrated Circuit Card Identifier* (ICCID)
- The SIM stores;
  - information to connect to the network
  - passwords
  - additional user information such as contact lists and text messages

Radio Access Network

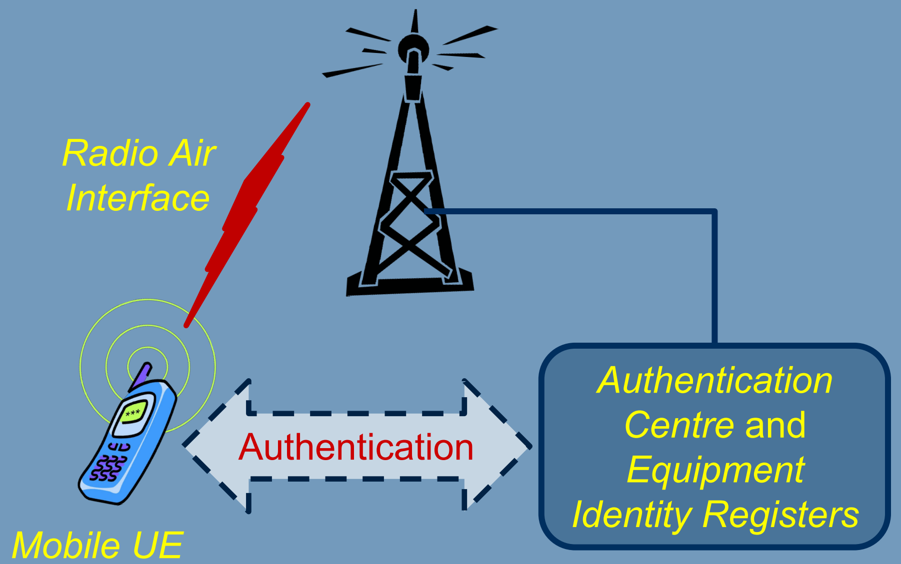
- User Equipment communicate with a network of *Base Stations,* called *Node B,* consisting of;
  - Radio transmitters
  - Radio receivers
  - Antennas
- *Radio Network Controllers (RNC)* connect to, co-ordinate and control groups of base stations.
- The function of the RNC is to;
  - allocate radio channels used by user equipment communicating with base stations.
  - determine how the radio channel is used.
  - manage transfer of calls between base stations.

Core Network

- A 3G *Core Network* contains the fixed infrastructure to operate the entire network comprising.
- Two types of switches are used to route voice and data traffic;
  - *Mobile Circuit Switch Centre*;
    - routes voice traffic around the network
    - routes voice traffic to other external mobile and telephone networks;
  - *Packet Data Switching Node*;
    - routes voice traffic around the network
    - routes voice traffic to the Internet
- There are a number of additional supporting database systems;
  - The *Authentication Centre, Equipment Register and Location Register*;
    - control user access to network
    - track mobile locations
    - route calls and data
    - work out billing charges
  - The *Application Servers* and *Content Servers;*
    - deliver additional network services

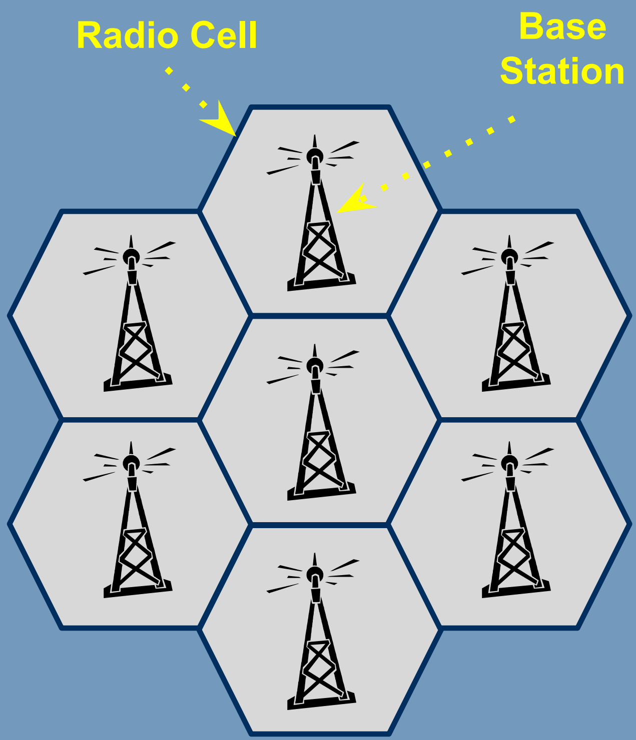
System Access

- When a mobile device is first switched on, it registers with the network through the nearest base station.
- *Authentication* takes place to prove that the UE is genuine and allowed to access the network.
- A protocol called the *Radio Air Interface* is used by mobile devices and base stations to;
  - communicate using *microwave frequencies* allocated exclusively to a specific network operator.
  - share the radio channel between many mobile devices simultaneously.



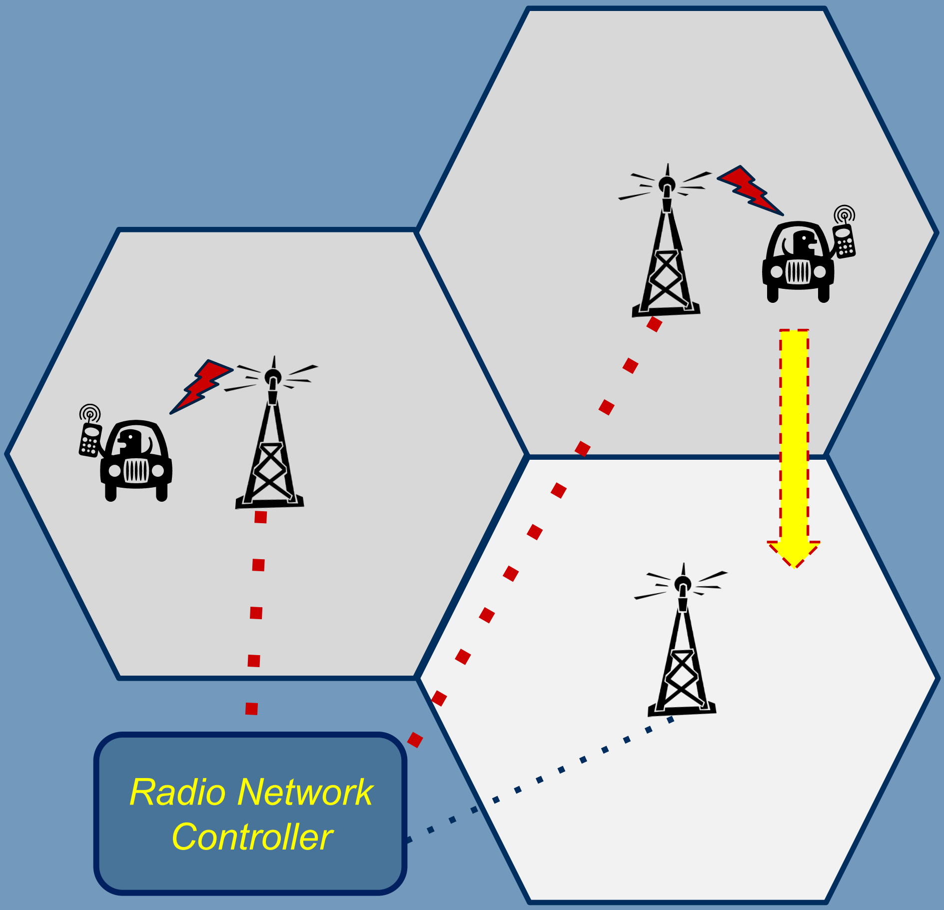
Radio Coverage

- Uninterrupted radio coverage is achieved by dividing the network's geographical area into a collection of adjacent *cells.*
- A cell is the defined geographical radio coverage area of a single base station.
- In a national mobile network thousands of cells are deployed across the country.
- Mobile devices move around a network and access services via the base station belonging to whichever cell the mobile is located within.



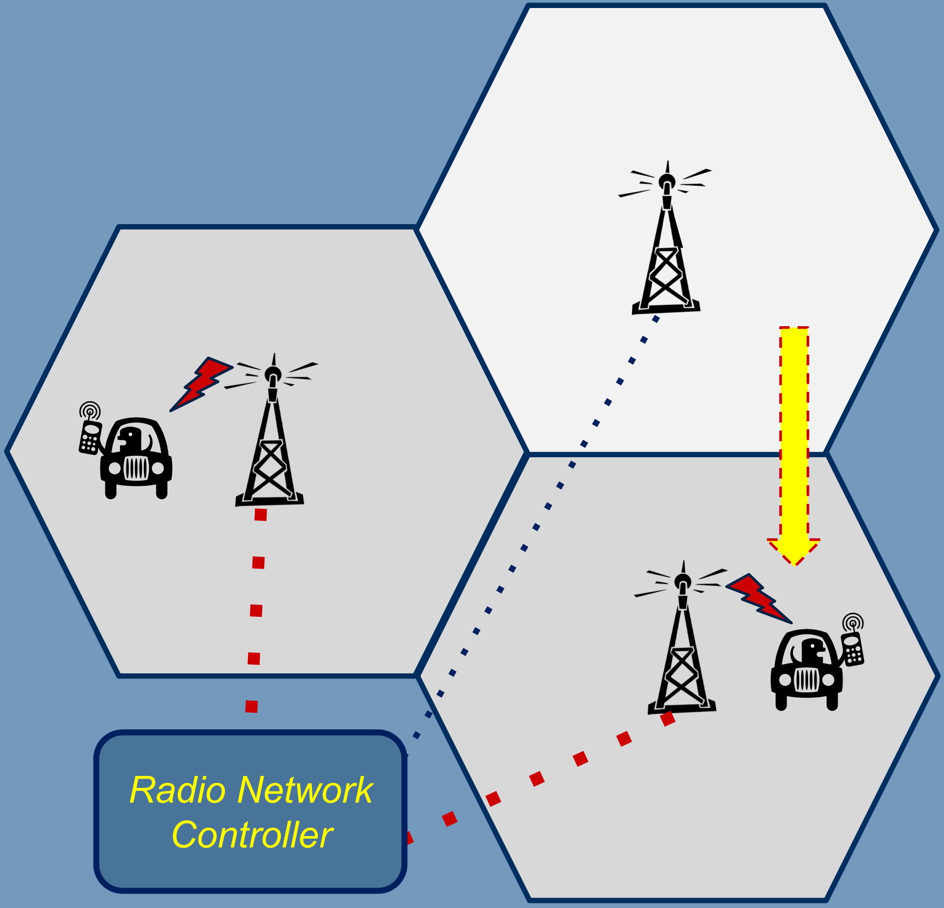
Handoff Management

- As a mobile device moves between cells, there needs to be a way to transfer the call to the new cell.
- As the mobile device moves to the edge of the cell
  - the received signal gets weaker
  - then eventually reaches a point where it can no longer receive data reliably
- Meanwhile the surrounding cells have been monitoring the signal strength on all frequencies.



Handoff Management

- When the signal from a surrounding cell becomes stronger than the signal from the current cell, the mobile device's frequency is switched to the channel of the adjacent cell.
- The flow of data is now re-routed seamlessly from the old to the new base station.
- The connection continues without a break in service with the user being unaware of any change.



Mobile Data Services

- Mobile network operators offer several types of *mobile data services* to meet different user needs;
  - *Short Messaging Service (SMS)*
    - Allows 160 character text messages to be sent
  - *Multimedia Messaging Service (MMS)*
    - Permits still pictures, video clips and audio messages to be sent
  - *Streaming Service*
    - Presents audio-visual content for buffering and immediate replay
    - Content is not stored permanently on the device
    - Two types; Mobile TV and Content on Demand
  - *Download Service*
    - Allows content to be downloaded and replayed
    - Some providers limit the number of times or specify an expiry date
  - *Internet Access Service*
    - Allows access to the Internet and World Wide Web
    - Web servers can detect whether to return a desktop or mobile version of the web pages

Mobile Applications

- Using these mobile data services, users can run applications on the WWW using a mobile data device in one of two ways:
  - A mobile content browser
  - Dedicated mobile applications hosted on the user equipment
- Applications are available to support many uses, the most popular being:
  - Messaging
  - Email
  - Web browsing and downloads
  - Social networking
  - Gaming
  - Entertainment
  - On-line commerce
  - Navigation and location based services

Cadet Learning Activity

- Cadets should discuss the mobile devices you use for wireless mobile data communications in your everyday life, then compare and contrast the different applications.
- Identify the mobile data services you have access to on your mobile device and discuss what you use them for with your device.
- Using these devices, access the settings menu and discover as much information about the device's wireless networking:
  - the device type
  - the mobile operating system
  - the user equipment SIM card IMEI (if accessible) and ICCID
  - the network service provider
  - the network type and generation
  - signal strength
- Search for and identify the locations of mobile base station near to your squadron.

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LO4 Lesson 16:

Principles of WiFi

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WiFi

- In this lesson Cadets will learn about WiFi and the concepts:
  - Nomadic access
  - WiFi technology
    - Infrastructure networks
    - Access Points
    - Range
  - Internet hotspots
  - Voice over IP

Nomadic Access

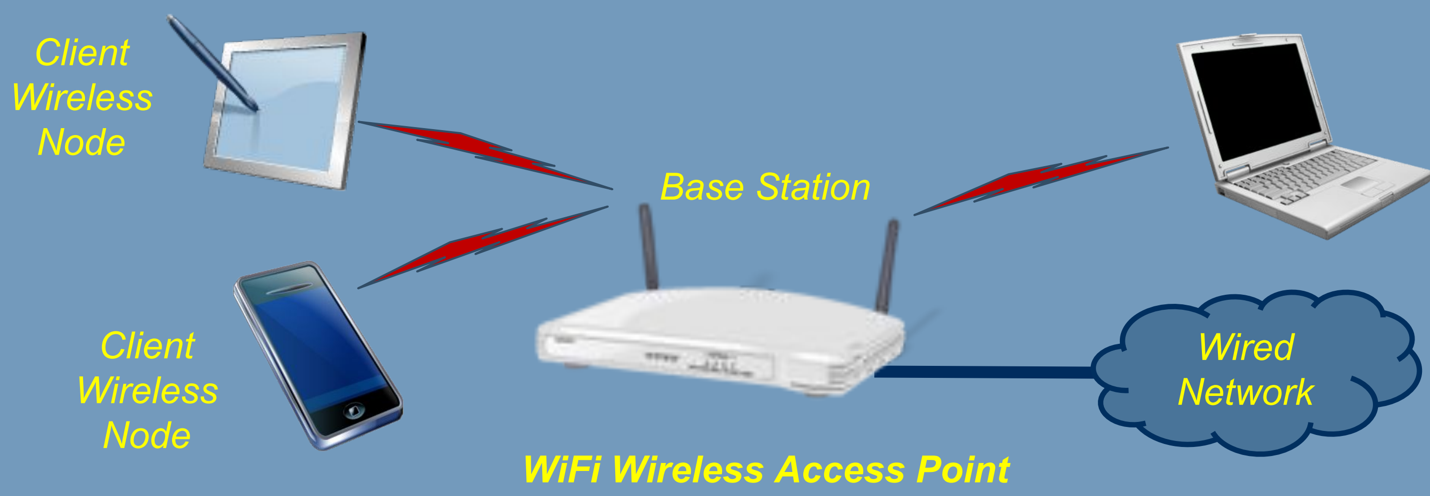
- *Nomadic access* provides data network access whilst a user is semi-portable when;
  - travelling but operating from a fixed stationary location
  - using semi-portable devices such as laptops.
- It uses wireless networking which has evolved from wired LAN technology.
- A user can log-on whenever they are within radio range of an accessible *Wireless Local Area Network (WLAN)* station.
- If the user subsequently moves on to the coverage area of a different WLAN station, the session is terminated and the user has to log on again.

WiFi Technology

- *WiFi,* meaning '*Wireless Fidelity',* is a wireless LAN networking technology which provides a user with *nomadic access*.
- WiFi networks are accessed by a wide range of consumer devices incorporating *radio modems.*
- The modems operate in the unlicensed Industrial, Scientific and Medical bands at frequencies of 2.4 GHz and 5 GHZ.
- Certified products conforming to the IEEE 802.11 technical standard produced by WiFi Alliance are guaranteed to be interoperable.
- Various versions of the standard exist and new ones are evolving over time.
- Versions IEEE 802.11a and IEEE 802.11g provide theoretical data transfer rates of 54 Mbps.

WiFi Infrastructure Network

- A WiFi *Infrastructure Network* is used as an extension to wired networks.
- Stations connect wirelessly to an *Access Point, a* radio base station that controls station communications and connects to a router.
- The router in turn connects to a wired LAN or to a broadband connection linked to the Internet.
- Access Points are usually located on the wall or in the ceiling of a building or communal area.



Access Point Connection

- When in range, a WiFi enabled station learns through the radio channel the identity or *Service Set Identifier* (SSID) and capabilities of the Access Points.
- The station can send a request to *associate*, which the Access Point may accept or reject.
- If a network is open or unsecure, everyone is allowed to use it.
- Otherwise a security access password is needed to *authenticate* before data can be exchanged.
  - *WPA2* is the recommended security method
  - *WEP* was an earlier method but use is discouraged because of design flaws that make it easy to compromise

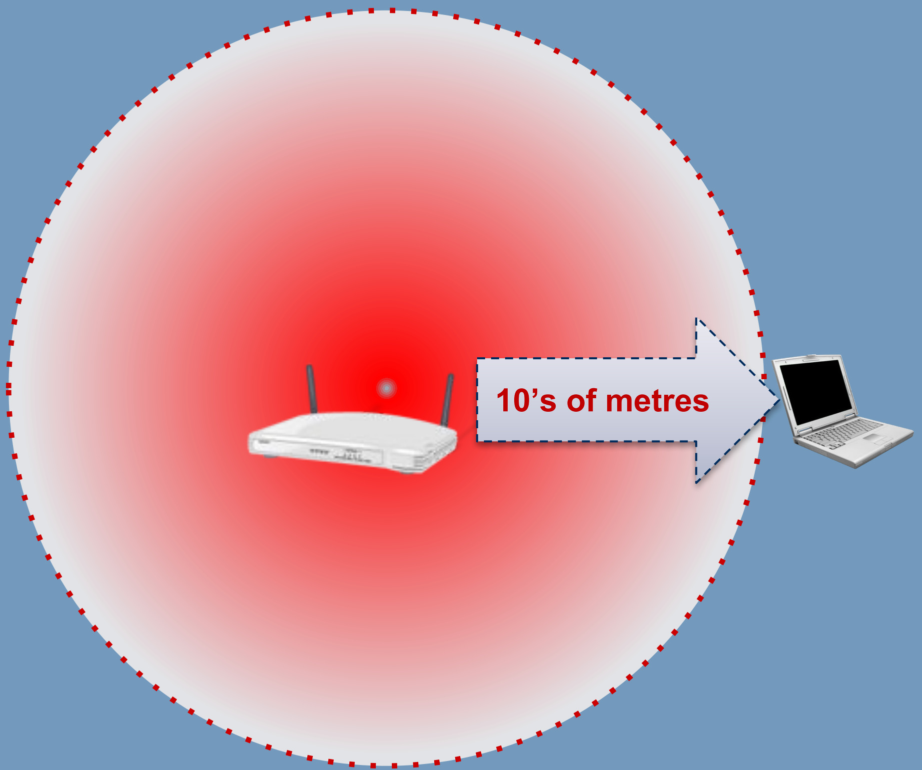
Access Point Operation

- All stations in a WiFi network share the same channel.
- Only one station at a time can be allowed to send data.
- WiFi standards do not define how many stations can join a network, but some equipment may have a limit.
- As the number of communicating stations increases, the channel capacity for each station decreases.
- A point will eventually be reached when the network becomes too congested to provide an adequate service

Wall mounted office Wi-Fi Access Point

WiFi Range

- Any form of wireless communication is limited by how far the signals can travel.
- Typical WiFi range is 10's of metres
- Physical barriers such as walls will reduce the data rate and distance further.
- WLANs in larger organisations may use several Access Points to cover a larger area.
- Access Points within range of each other must be set to use different frequencies or channels so that they do not interfere with each other.



Typical Range of a Wi-Fi Access point

Internet Hotspots

- *Hotspots* are where WiFi internet access is open to the public.
- Some require you to register or pay for access.
- Others are free as a marketing ploy, as a public service or from an Internet user who opens up a connection.
- Hotspots have sprung up everywhere people go, resulting in a patchwork of coverage.
- The geographical area served by a WiFi hotspot is typically only 10’s of metres across and unlike mobile phone networks, coverage areas are generally not adjoining.
- For many users on the move, this level of mobility is an acceptable alternative to mobile phone networks.

Voice Over IP

- *Voice Over Internet Protocol (VoIP)* allows wireless telephone calls to be made using WiFi through the Internet;
  - either to other VoIP users of the system
  - or sometimes to conventional telephones
- Typically you pay for calls to a landline or mobile phone, whereas calls to users of the same VoIP service are at no additional cost.
- Many VoIP software applications are available free from the Internet.
- The most popular VoIP application is *Skype.*

Cadet Learning Activity

- Using a wireless enabled device, Cadets should turn on WiFi and identify any Networks or Access Points within range of your device, noting down;
  - the network names (SSID)
  - which networks are open and which have security enabled
- Connect to a WiFi network which you are authorised to access.
- Using the device WiFi settings, explore as much information about the WiFi connection as possible, for example
  - Security and encryption type
  - Speed
  - Channel number and frequency
  - Signal level
  - Client MAC and IP addresses
- Physically locate the Access Point and using your device estimate the maximum range and the effect of the environment on the signal reception.

Unit 19: Data Networking

LO4 Lesson 17:

Principles of Bluetooth

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Bluetooth

- In this lesson Cadets will learn about Bluetooth including:
  - Technology
  - Operation
  - Applications

Bluetooth Technology

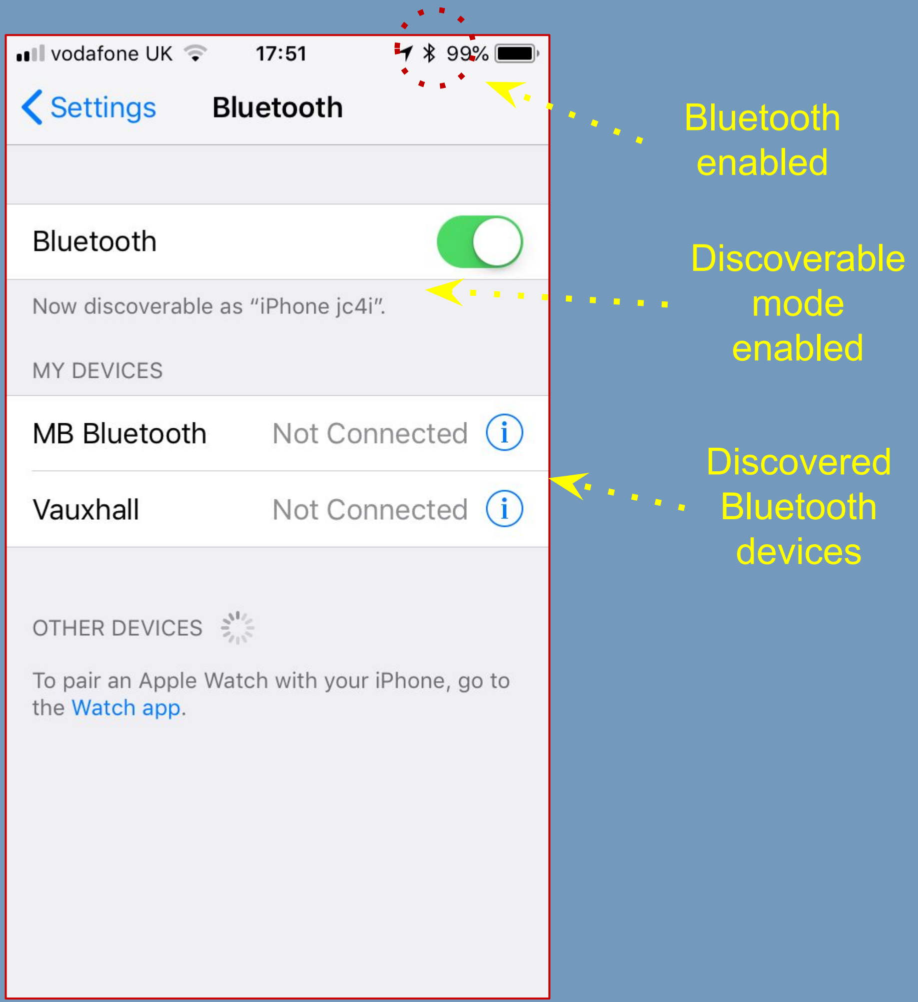
- Bluetooth® is a type of wireless Personal Area Network technology used with very short range, low power, inexpensive radio devices.
- It was originally intended to be a convenient alternative to cables when interconnecting local computing devices.
- Products conforming to IEEE 802.15.1 Bluetooth technical standard are interoperable with the specification version for which they are designed.
  - Version 1.0 of the standard was released in 1990 and has seen many revisions.
  - Version 2.0 allow users to exchange data wirelessly between paired devices up to 2 to 3 MHz.
- Devices operate in the 2.4 GHz ISM band reserved for unlicensed users and can therefore be used without restriction around the world.
- The name originates from the 10^{th} century King of Denmark, Harold Bluetooth, who was famous for uniting Scandinavian tribes.

Class and Range

- Manufacturers of Bluetooth devices can provide the communication range needed to support uses for their solutions.
- Depending on the application, range may vary depending on class of radio transmitter used in a device;
  - *Class 3* transmitters have a range of up to 1m
  - *Class 2* transmitters, most commonly found in mobile devices, have a range of 10m
  - *Class 1* transmitters, used primarily in industrial applications, have a range of 100m
- Range can be further reduced by physical obstructions between devices.

Discoverability

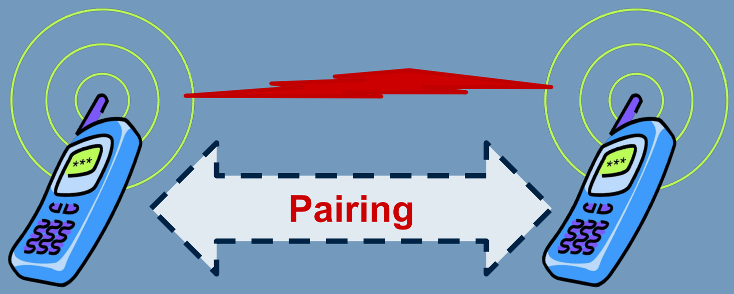
- Every Bluetooth device has a unique MAC *address.*
- When switched on, the Bluetooth protocol lets devices discover each other by transmitting a message alerting other Bluetooth devices nearby.
- A user selectable security feature determines whether or not the device is visible to others within the area.
- If several Bluetooth devices are set to discoverable mode, they can all search for and locate each other as long as they remain within range.



iPhone Bluetooth settings

Pairing

- Pairing is a procedure followed to determine if two Bluetooth devices can communicate on discovering each other.
- Using the original method, both devices are configured with the same 4-digit PIN code called *passkeys*.
- A new simple secure pairing method was later introduced whereby;
  - users either confirm that both devices are displaying the same 6-digit device generated passkey or observe the passkey on one device and enter into the other
  - devices negotiate the use of 128 bit AES encryption to secure communications
- On establishing a link, both devices can exchange short bursts of data in packets.



Bluetooth Device Applications

- Bluetooth is used in an ever increasing range of application;
  - Automotive
    - hands-free calling, music, smartphone apps, navigation units, monitoring vehicle diagnostics, traffic, driver health
  - Consumer Electronics
    - game boxes, watches, music players
  - Health and Wellness
    - activity sensors to monitor medical parameters
  - Mobile Telephony
    - smartphones, hands-free calling systems, headsets, speakers
  - PC and Peripherals
    - laptops, headsets, printers, keyboards, mice
  - Sports and Fitness
    - sensors to measure pace, pulse, distance, other workout information
  - Smart Home
    - home automation, security, smart energy, entertainment

Cadet Learning Activity

- Cadets should list all the Bluetooth enabled devices they use for wireless mobile data communications in their everyday life and discuss the different applications.
- Using some of these devices, turn on the Bluetooth connection and identify any devices within range of the device, noting down any information about the devices e.g. the device names, MAC addresses, etc.
- Pair with another Bluetooth device you are have permission to connect to and identify and explore the following;
  - the type of devices
  - the device applications
  - the pairing method for the connection
  - the maximum communications range (and hence the class of Bluetooth device)
  - the effect walls, buildings, trees, vehicles etc. on communications

Summary of Learning Outcome 4

- Cadets should now know about the types and roles of wireless mobile data communications including:
  - Mobile networks
  - WiFi
  - Bluetooth