Cables

Why is fibre so much faster and what difference will it make for me?

John Steele

Outline of what we will cover

- Why talk about cables?
- Copper cables
  - What types of cables are there
  - What are their limitations and why are they limited
- Fibre cables
  - What types are there and how fast are they
  - What are the benefits of fibre compared to copper
- How the telephone service has (and still is) evolved over the years

Why do we need data cables

- Computers all need data cables of one sort or another
- There are many types including
  - Cables to connect devices to your computer
    - Keyboards – now USB
    - Mice – now USB or wireless
    - Screens – now HDMI
    - Local Area Networks – Ethernet or Wireless
  - Cables for your to connect to the outside world
    - Telephone and broadband

Miscellaneous facts

- Speed of light in free space = 300,000 km/s
  - 0.3 metres per nanosecond
- Speed of pulses down a cable = approximately 0.7 * speed of light
  - 4.76 nanoseconds per metre
  - Delay for 100 metres = 476 nano seconds approximately
- Pulse lengths
  - 1 Mbps = 1 microsecond per bit or about 2 metres in a cable
  - 100 Mbps = 10 nanoseconds per bit or about 210 centimetres in a cable
  - 250 Mbps = 2.5 nanoseconds per bit or about 84 centimetres in a cable
  - 1G bps = 1 nanosecond per bit or about 21 centimetres in a cable

What type of data do we transmit down cables

- Signals sent down cables are (simplistically) one of the following
  - Audio (e.g. telephone call)
    - Multiple frequencies, limited range e.g. 75 Hz to 3500 Hz
      - Telephone originally deliberately constrained to be low frequency
      - Human hearing goes up to around 10 KHz (or perhaps 20 KHz when young)
  - Baseband Video – e.g. TV monitors
    - Signals from about 8 MHz to about 50 MHz or more
  - True digital signals – no encoding
    - Digital pulses from zero to about 100 Mbps (for short distances over copper)
  - Encoded digital signals
    - Complex encoded digital signals – more later

Types of cable in use today

- Copper cables
  - Coaxial cable – typically not used for digital data today
  - Bundles of copper wires
    - USB used for connecting devices to computers
    - HDMI used for video
    - Ethernet used to connect computers and other devices to each other
      - Four Twisted pair cables inside one sheath
- Fibre Optic cables – two fibres (transmit/receive) required
  - Bundles of fine glass strands of principally two types
    - Multimode fibre
    - Mono or Single Mode fibre

Copper Data Cables

- Generic cable types
  - Coaxial cabling used to be used for data networks
    - early Ethernet (not quite the same cable as TV Coax!)
    - still used for Television
  - Most computer cables are now Twisted pair and we will look at this type of cable in more detail
    - What happens to signals in a bundle of cables
    - What happens to signals over a long cable

The science bit!

- When you send signals along a cable
  - An electric current flows from the sender
  - It passes through a “load” at the far end
  - The current returns to the sender to form a circuit
  - An electric current always creates a magnetic field around the wire that can be detected by a device such as a compass (if the current is strong enough)
    - When the magnetic field is building it “induces” a current to flow in any adjacent wire in the opposite direction
      - This can be helpful, or a cause of interference in adjacent data pairs
  - There is also another method of interference - capacitive
    - When two metal object are close there can be a stored electrical charge which when the signals are changing can also lead to interference

Signals within cables - Interference

- A simple circuit has an outbound and return connection
  - It will create a magnetic field around each conductor when current flows
  - This magnetic field will "induce" stray signals into adjacent wires whenever the current flowing **changes**
- When you have a pair of adjacent wires for the outbound and inbound connection the magnetic fields in each conductor tend to cancel out reducing interference to adjacent circuits
  - The cancellation can be improved by twisting the pairs together reducing interference although it is never perfect
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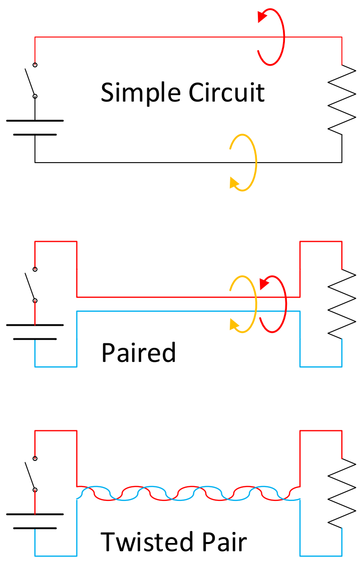
- Twisted pair Data Cables commonly have four pairs providing one connection



What happens to pulses sent down a cable

- A copper cable is actually quite a complex component
- A twisted pair cable has a property called resistance measured in Ohms
  - The signal will lose amplitude with distance
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- Each wire in a twisted pair cable also has a property called Inductance (measured in Henrys) and one called Capacitance (measured in Farads)
  - The more generic term for the effect on a signal is “Impedance”
  - The affect of impedance on the signal depends on its frequency
    - With inductance the impedance value increases with frequency
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How is binary data transmitted over copper cables

- A digital signal consists of a series of high and low voltages encoded in a special way to include a timing element. The receiver needs to know when to expect a 1 or a 0
- One such encoding scheme is Manchester Encoding
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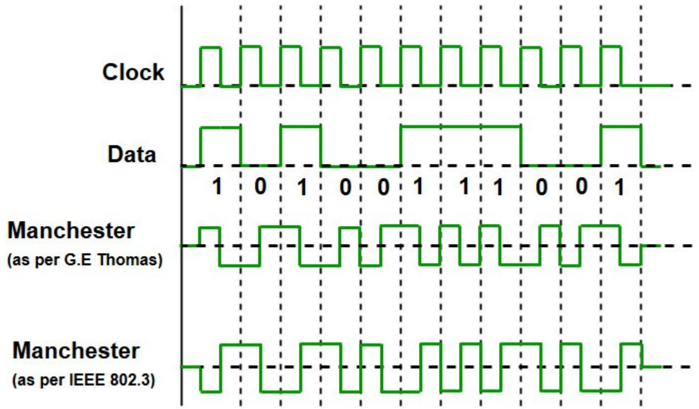
- Higher data rates use more complex encoding methods which also use the amplitude to encode more bits into each pulse



Example Data packet - Ethernet

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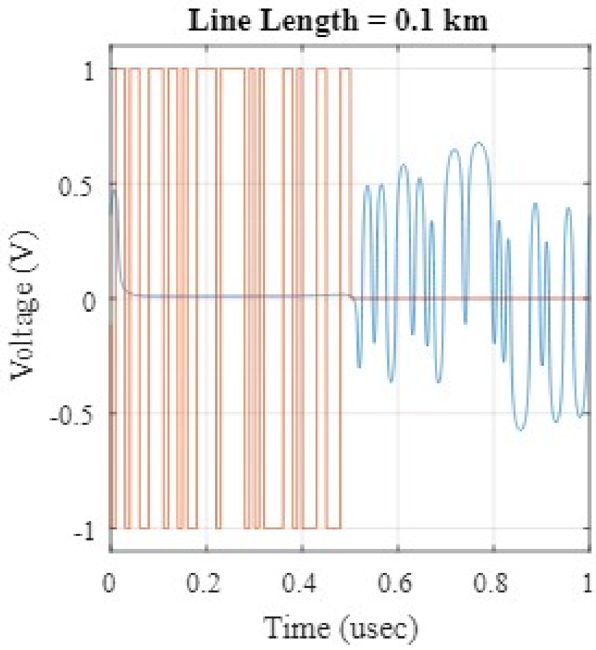
  - A self contained set of bytes
    - Preamble (7 bytes) + Start frame delimiter (1 byte)
      - receiver clock synchronisation and start of message
    - Body of message (60 to 1518 bytes)
    - Checksum (4 bytes)
      - Check message is received correctly

Cable propagation

- This simulation shows signals being sent down a 100 metre twisted pair cable at 100 Mb/s
  - Red is the signal as pushed into the cable
  - Blue is as it emerges from the other end
    - This is without any interfering signals from other adjacent cables
    - Note the propagation delay and distortion!
- I Gb/s is impossible on a single pair
  - 256 Mb/s is about the limit for 100 metres
  -



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So what about 1 Gb/s?

- The previous slide assumes that 100 Mb/s is sent down one pair and the reverse channel is down another pair
  - One pair for transmit and one for receive
- In a standard Cat 5/6 cable we have 4 pairs, With clever electronics:
  - We can can send data and receive data back on the SAME pair
  - We can use all 4 pairs to send 4 bits at a time in each direction
  - We can encode several bits into one pulse by varying its amplitude
  - We can achieve 1 Gb/s in both directions for a <u>**maximum**</u> of 100 m
- Data in wires travels at about 0.7 c (c is the speed of light)
  - There is therefore a delay of about 476 nanoseconds over 100 m
    - This equates to 476 bits delay = almost 60 bytes

But what about broadband over telephone

- The previous slide states that 100 metres is about the limit for local copper networks at speeds up to 1 Gb/s
- Telephone wires are much longer and were not originally designed for data
  - Frequency range permitted was constrained (by a set of mandatory standards) from about 100Hz to 3.5 kHz and the permitted signal strength outside this range frequencies dropped off very rapidly
  - Communicators equipment (modems) had to work within these constraints and equipment was **rigorously tested** to ensure compliance with the published standards
    - This was a serious challenge to equipment designers!
  - Modem manufactures found ways (which were standardised) to achieve initially 2400 bps half duplex (only transmit or receive at any one time with a delay changing from one to the other) and later up to 56 Kbps full duplex

How was this done?

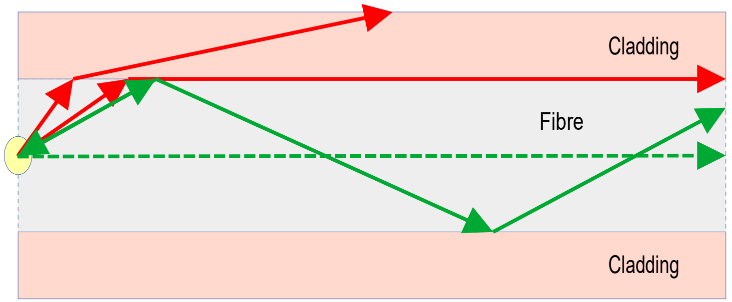
- Telephone wires are a single pair, bundled into perhaps 500 pairs from premises to exchange
  - Many were (and possibly still are) very old – 50 years and long before any data transmission was ever contemplated
  - There can be a long distance (miles) between premises and the local telephone exchange
- All equipment had to be approved by the appropriate body PO → BT → BABT
- You must only send audible tones down the wires within the legally permitted frequency range and signal strength (and provide signal isolation up to initially 4 kilovolts!)
  - Constrained from about 50Hz to 3400 Hz - not exactly HiFi
  - You can send multiple tones (signal frequencies) together
  - You can change the amplitude of each of the tones
- You can encode multiple bits by using several tones which can each have one of several amplitudes
  - Consider 16 separate tones as an illustration
    - When combined with 16 permitted amplitudes - this encodes 256 bits at a time

Now for Broadband - ADSL

- ADSL (Asynchronous Digital Subscriber Line) uses frequencies above the old permitted range
  - It uses similar principles but I do have not have access to the current standards
- It is possible with modern signal processing electronics to elaborate on the earlier modem techniques
  - An ADSL connection to the telephone exchange has a dedicated device to service your line
    - DSLAM (Digital Subscriber Line Access Multiplexer) which connects you to an IP Router for data and routes voice to the telephone exchange
  - When first connected your ADSL modem and the DSLAM measure the characteristics of the line and optimise the encoding to match
    - They continue to do this even after the initial “training” session is over – this can take two weeks
      - a good reason NOT to switch off your router
- There is a distance limitation between premises and exchange of about 3 to 5 miles
- Fibre to the cabinet (FTTC) moves the DSLAM and IP routing functionality near to customer premises and onward routing is over fibre
  - It is still a copper pair to the local cabinet.
  - We can then achieve up to 80 about megabits per second over FTTC in many cases

And now for Fibre – What is Fibre

- Fibre or to be more accurate Fibre Optic Cables have been available for many years.
- Instead of using copper wires they use fine glass fibres to carry light pulses generated by a laser
- A fibre optic cable has a pure fine glass fibre surrounded by a material with a lower “refractive index”
  - When a light beam meets the boundary at less than a critical angle it it reflected back
  - This is called Total Internal Reflection (TIR)
    - When it reaches the opposite side of the fibre it again is reflected back
      - It stays within the fibre!
    - Note that the light path lengths, and transit times, for a ray straight down the middle and one that bounces are different

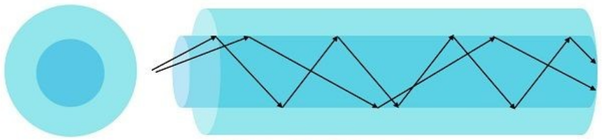


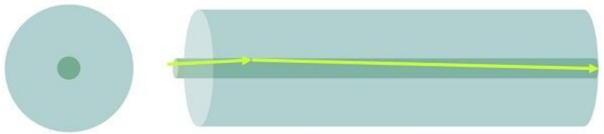
Fibre – Types of fibre

- Glass fibre has especially low loss for light travelling at several specific wavelengths
  - 850 nanometres (0.85 microns) – red visible light
  - 1300 nanometres (1.3 microns) – Infrared (not visible)
  - 1550 nanometres (1.55 microns) – Infrared (not visible)
- Fibre cables come in two versions
  - Single mode fibre is about 9 microns (or micrometres) in diameter
  - Multi Mode fibre is either 50 or 62.5 microns (62.5 most common in Europe)
- In both cases the fibre is surrounded by an optical cladding, to ensure Total Internal Reflection, and a protective external sheath
- Note that a human hair is typically between 20 and 200 microns with an average of about 100 microns

Difference between Multimode and Monomode fibre

- In a fibre the light is constrained by the fibre’s Total Internal Reflection to stay within the fibre
- With multimode fibre the light paths can vary according to the angle at which they are launched
  - Multiple paths means that light rays can take the shorter path down the middle or a longer and hence more delayed path by bouncing and being reflected
  - This “blurs” the received pulses and limits the distance that can be driven
- With Monomode (or Single Mode) fibre the diameter of the fibre is too small to allow the multiple paths and there is no dispersion of the received signal
  - Monomode fibres can transmit data at very high rates even across the Atlantic!





Comparison of Single Mode vs Multi Mode

- Multi Mode Fibres
  - Are somewhat easier to terminate and hence much lower cost to install
    - But still much more expensive that copper cabling
  - Connectors can be spliced on relatively easily and have smaller losses on a misaligned connector
  - Are limited on distance and speed for very high data rates due to the multiple paths
- Single Mode
  - Require considerable expertise and specialised, expensive equipment to terminate connectors
  - Misalignment is far more critical for connectors
  - Distance and bandwidth does not need to be an issue
    - “Dark fibres” have spanned the Atlantic for years (available in 1988) using special lasers to launch signals into cable
    - Experimentally Terabits per second have been launched through a single fibre even in 1992

Comparison of copper cables to fibre

- Fibre can support higher data rates than copper
- Fibre (particularly single mode) can pass data over much longer distances than copper
- Copper is much easier to install than fibre
  - Can be bent without damage
  - Connectors are very low cost
  - RJ45 tools for Ethernet RJ45 connectors about £15, Krone tools to terminate fixed cables cost about the same
  - Training for both types of connection takes about 5 minutes
  - Once trained connections can take less than 1 minute
- Fibre (especially single mode) is much more difficult to work with
  - Does not tolerate sharp bends – maximum 50 cm bend radius during installation
  - Connectors are expensive and need expensive precision equipment and specialised training to add a connector to a cable – the fibres are much thinner than a human hair!
  - Connections take much longer to terminate even for an expert
  - Equipment using fibre connectors is much more expensive that copper but does operate at higher speeds

Why is the telephone service being upgraded

- The existing telephone service is using technology that is well over 100 years old
  - It was enhanced with Subscriber Trunk Dialling in the 1970's
  - Broadband services to end user premises is now as important as voice or perhaps even more so
  - Existing telephone services now run over IP networks in the UK
    - Conversion from voice to IP takes place in the local telephone exchange
- Single mode Fibre cables can provide an almost unlimited bandwidth making it "future proof"
  - Limitations are mostly within the termination equipment and the routers that are used within the customer premises
  - The public element can easily be enhanced without updating customer equipment

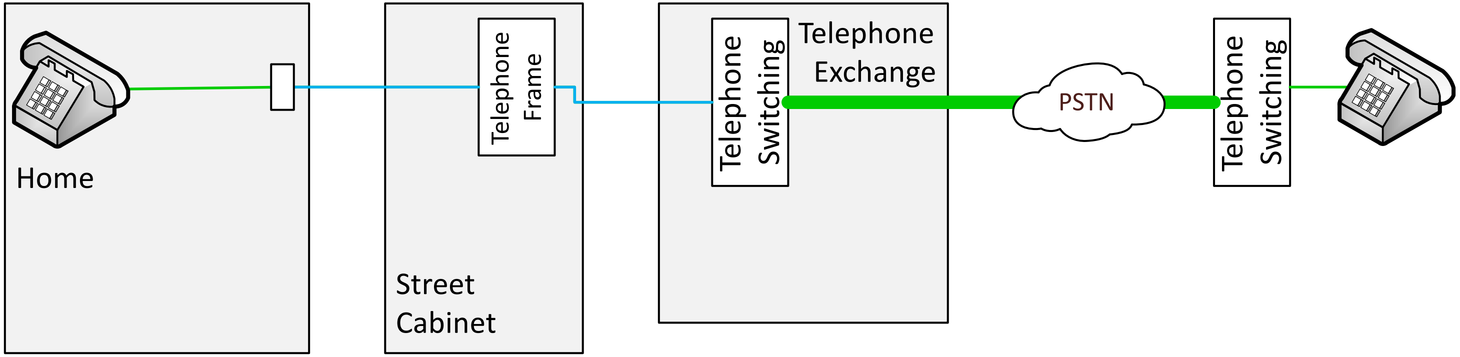
Points to note however

- Conversion of the whole telephone network to fibre is NOT directly related to the current fibre installation
- Swish (in our area) have permission to install Fibre To The Premises (FTTP) but they are not (yet) automatically providing telephone services
  - They are promising Gigabit speeds but at a cost and they become your ISP
    - Do you really need Gigabit speeds?
      - I can stream 4K TV concurrently with several HD TV streams on 34 Mbps FTTC service (accidentally tested during Wimbledon last year)
  - Swish CAN provide telephone services but this is not automatic and, I am assuming, will be additional cost
- There is an intention at some stage to migrate us all to fibre including telephone but I have seen no indication yet as to how much the consumer will have to pay

Are there any downsides?

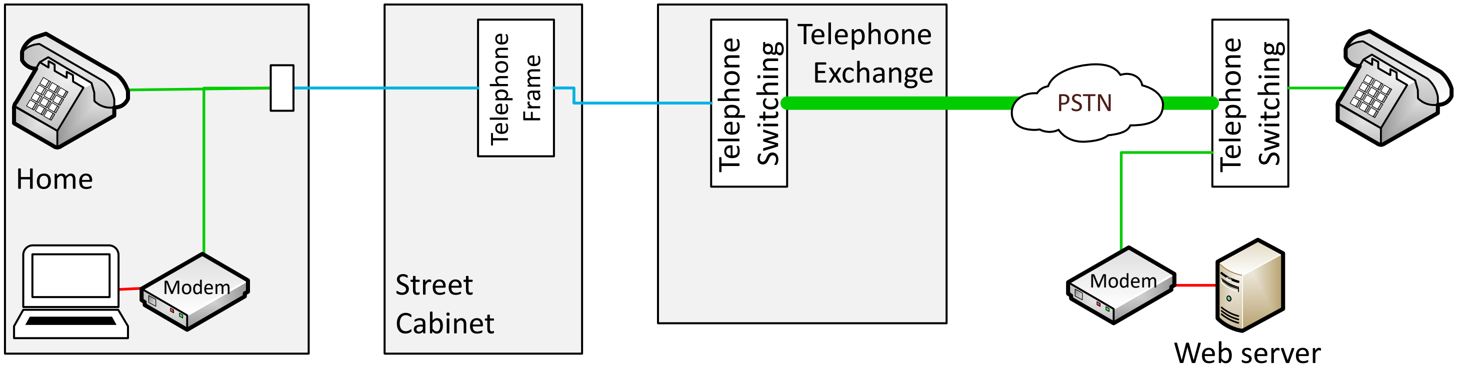
- There is the obvious disruption on roads being dug up initially
- There will be issues when the fibres are run to the home or office
  - Some equipment will not be compatible and may need to be replaced
    - Candidates include
      - Alarm systems that communicate using the telephone network
      - Medical alert systems that communicate using the telephone network
      - Possibly old telephones
  - Looking at what is being done locally they may need to dig up driveways to take the new fibre cable to the property
    - We currently have an overhead cable from a pole in my garden

Basic Telephone



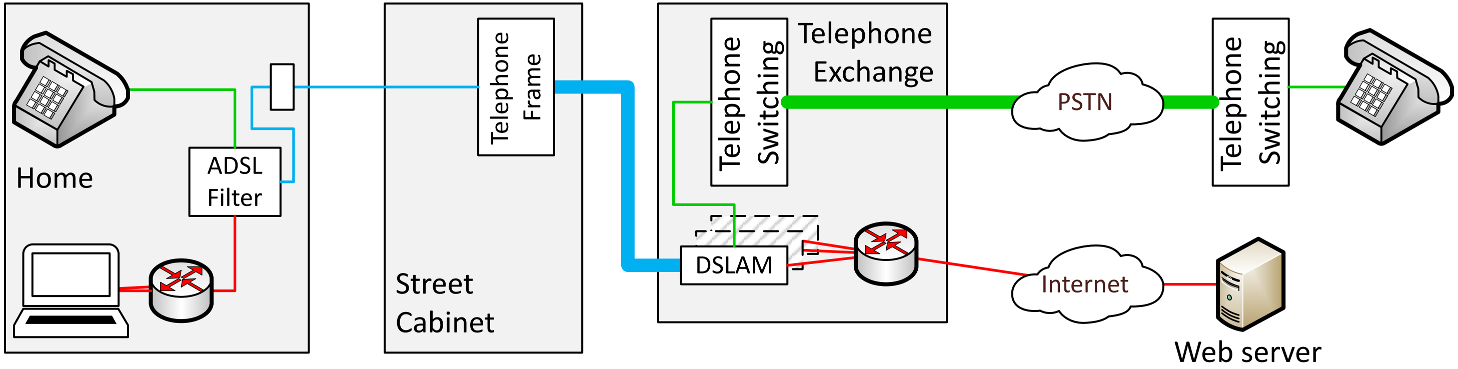
- A basic telephone system before any data services are added

Adding Internet access via modem



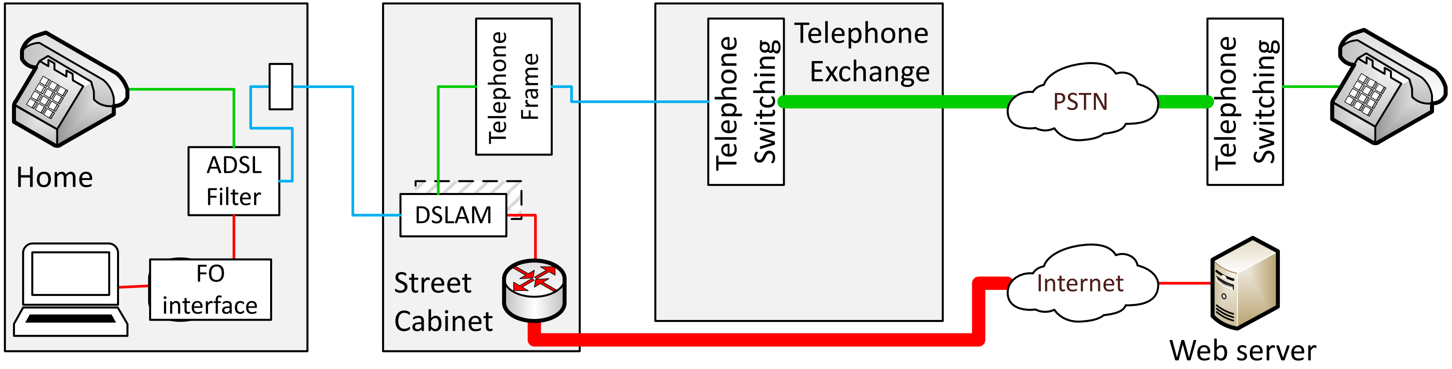
- We add a standard modem to basic the system
  - Can be external or an interface mounted inside a PC (desktop) or built into a laptop
- Routed via voice switching to the server where a modem decodes the data and passes to the server

Adding ADSL broadband



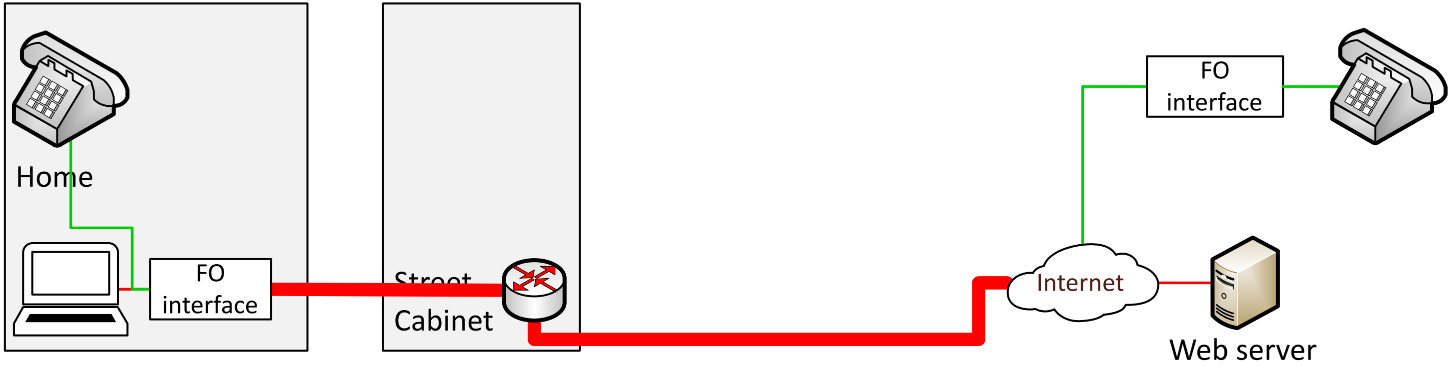
- The router takes IP data from local network and encodes in a ADSL packets
- The ADSL filter merges the ADSL data with voice to pass both to the Exchange
- The DSLAM module in the exchange splits the voice and data
- The data is routed to the Internet
- Voice is passed to the existing telephone exchange

Fibre to the Cabinet – FTTC concept



- ADSL connection now processed in nearby street cabinet
  - Reduces distance that broadband signals travel
- An equivalent to the exchange DSLAM splits the internet data and voice
  - Voice is passed to telephone exchange for routing
  - All Internet data traffic routed to the Internet from the cabinet

Full Fibre to Premises – eventually? - FTTP



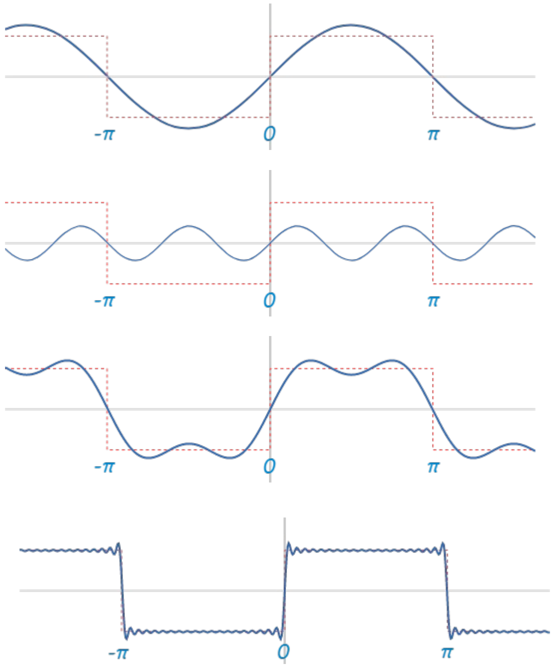
- Phone is now converted to IP in the home
- All Internet and voice traffic is routed via the Internet

Some concerns

- It is currently unclear to me what will happen in an emergency situation where there is a power cut
- At present your telephone is provided with a 50 volt supply from the exchange
  - The telephone exchange is obliged, by law, to have a battery to provide this power so that telephone calls can be made in an emergency
    - This battery does NOT supply power to cordless telephones, These need to be plugged into the mains and do not work on power failure
    - That is why you are currently recommended to have an old fashioned (not cordless) telephone plugged into your home phone system as well
    - The new legislation requires the telephone provider to provide a battery pack **on request** but that will only provide power for 1 hour
    - The justification is that everyone has cell phones these days
      - OK if you can get a signal!

But what happens to these pulses over the cable

- A pulse train can be analysed into a series of “harmonics”. Musicians may be familiar with that term
- This is called Fourier Analysis and consists of:
  - A series of “pure” (I.e. sinusoidal) frequencies.
    - Each is a multiple of the original bit rate
    - The amplitude of each frequency depends on the input wave shape
      - A “square wave” where each high and low are the same interval consists of
        - sin(x) + sin(3x)/3 + sin(5x)/5 + ... (infinitely)
        - x is 2 * π * f where f is the frequency



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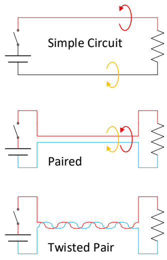

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The drawings were produced in Visio

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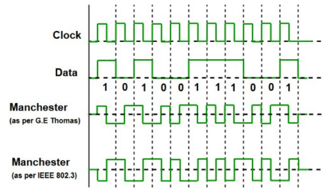

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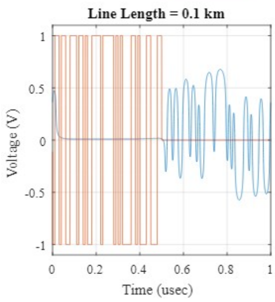

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- The previous slide states that 100 metres is about the limit for local copper networks at speeds up to 1 Gb/s
- Telephone wires are much longer and were not originally designed for data
  - Frequency range permitted was constrained (by a set of mandatory standards) from about 100Hz to 3.5 kHz and the permitted signal strength outside this range frequencies dropped off very rapidly
  - Communicators equipment (modems) had to work within these constraints and equipment was **rigorously tested** to ensure compliance with the published standards
    - This was a serious challenge to equipment designers!
  - Modem manufactures found ways (which were standardised) to achieve initially 2400 bps half duplex (only transmit or receive at any one time with a delay changing from one to the other) and later up to 56 Kbps full duplex

How was this done?

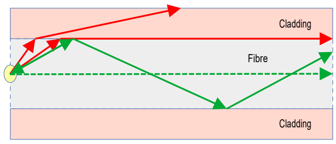
- Telephone wires are a single pair, bundled into perhaps 500 pairs from premises to exchange
  - Many were (and possibly still are) very old – 50 years and long before any data transmission was ever contemplated
  - There can be a long distance (miles) between premises and the local telephone exchange
- All equipment had to be approved by the appropriate body PO → BT → BABT
- You must only send audible tones down the wires within the legally permitted frequency range and signal strength (and provide signal isolation up to initially 4 kilovolts!)
  - Constrained from about 50Hz to 3400 Hz - not exactly HiFi
  - You can send multiple tones (signal frequencies) together
  - You can change the amplitude of each of the tones
- You can encode multiple bits by using several tones which can each have one of several amplitudes
  - Consider 16 separate tones as an illustration
    - When combined with 16 permitted amplitudes - this encodes 256 bits at a time

Now for Broadband - ADSL

- ADSL (Asynchronous Digital Subscriber Line) uses frequencies above the old permitted range
  - It uses similar principles but I do have not have access to the current standards
- It is possible with modern signal processing electronics to elaborate on the earlier modem techniques
  - An ADSL connection to the telephone exchange has a dedicated device to service your line
    - DSLAM (Digital Subscriber Line Access Multiplexer) which connects you to an IP Router for data and routes voice to the telephone exchange
  - When first connected your ADSL modem and the DSLAM measure the characteristics of the line and optimise the encoding to match
    - They continue to do this even after the initial "training" session is over – this can take two weeks
      - a good reason NOT to switch off your router
- There is a distance limitation between premises and exchange of about 3 to 5 miles
- Fibre to the cabinet (FTTC) moves the DSLAM and IP routing functionality near to customer premises and onward routing is over fibre
  - It is still a copper pair to the local cabinet.
  - We can then achieve up to 80 about megabits per second over FTTC in many cases

And now for Fibre – What is Fibre

- Fibre or to be more accurate Fibre Optic Cables have been available for many years.
- Instead of using copper wires they use fine glass fibres to carry light pulses generated by a laser
- A fibre optic cable has a pure fine glass fibre surrounded by a material with a lower “refractive index”
  - When a light beam meets the boundary at less than a critical angle it it reflected back
  - This is called Total Internal Reflection (TIR)
    - When it reaches the opposite side of the fibre it again is reflected back
      - It stays within the fibre!
    - Note that the light path lengths, and transit times, for a ray straight down the middle and one that bounces are different

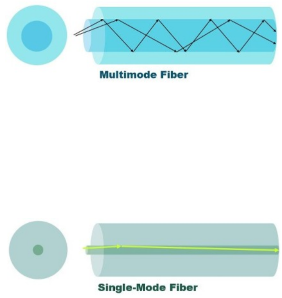


Fibre – Types of fibre

- Glass fibre has especially low loss for light travelling at several specific wavelengths
  - 850 nanometres (0.85 microns) – red visible light
  - 1300 nanometres (1.3 microns) – Infrared (not visible)
  - 1550 nanometres (1.55 microns) – Infrared (not visible)
- Fibre cables come in two versions
  - Single mode fibre is about 9 microns (or micrometres) in diameter
  - Multi Mode fibre is either 50 or 62.5 microns (62.5 most common in Europe)
- In both cases the fibre is surrounded by an optical cladding, to ensure Total Internal Reflection, and a protective external sheath
- Note that a human hair is typically between 20 and 200 microns with an average of about 100 microns

Difference between Multimode and Monomode fibre

- In a fibre the light is constrained by the fibre's Total Internal Reflection to stay within the fibre
- With multimode fibre the light paths can vary according to the angle at which they are launched
  - Multiple paths means that light rays can take the shorter path down the middle or a longer and hence more delayed path by bouncing and being reflected
  - This "blurs" the received pulses and limits the distance that can be driven
- With Monomode (or Single Mode) fibre the diameter of the fibre is too small to allow the multiple paths and there is no dispersion of the received signal
  - Monomode fibres can transmit data at very high rates even across the Atlantic!



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Comparison of Single Mode vs Multi Mode

- Multi Mode Fibres
  - Are somewhat easier to terminate and hence much lower cost to install
    - But still much more expensive that copper cabling
  - Connectors can be spliced on relatively easily and have smaller losses on a misaligned connector
  - Are limited on distance and speed for very high data rates due to the multiple paths
- Single Mode
  - Require considerable expertise and specialised, expensive equipment to terminate connectors
  - Misalignment is far more critical for connectors
  - Distance and bandwidth does not need to be an issue
    - “Dark fibres” have spanned the Atlantic for years (available in 1988) using special lasers to launch signals into cable
    - Experimentally Terabits per second have been launched through a single fibre even in 1992

Comparison of copper cables to fibre

- Fibre can support higher data rates than copper
- Fibre (particularly single mode) can pass data over much longer distances than copper
- Copper is much easier to install than fibre
  - Can be bent without damage
  - Connectors are very low cost
  - RJ45 tools for Ethernet RJ45 connectors about £15, Krone tools to terminate fixed cables cost about the same
  - Training for both types of connection takes about 5 minutes
  - Once trained connections can take less than 1 minute
- Fibre (especially single mode) is much more difficult to work with
  - Does not tolerate sharp bends – maximum 50 cm bend radius during installation
  - Connectors are expensive and need expensive precision equipment and specialised training to add a connector to a cable – the fibres are much thinner than a human hair!
  - Connections take much longer to terminate even for an expert
  - Equipment using fibre connectors is much more expensive that copper but does operate at higher speeds

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Why is the telephone service being upgraded

- The existing telephone service is using technology that is well over 100 years old
  - It was enhanced with Subscriber Trunk Dialling in the 1970's
  - Broadband services to end user premises is now as important as voice or perhaps even more so
  - Existing telephone services now run over IP networks in the UK
    - Conversion from voice to IP takes place in the local telephone exchange
- Single mode Fibre cables can provide an almost unlimited bandwidth making it "future proof"
  - Limitations are mostly within the termination equipment and the routers that are used within the customer premises
  - The public element can easily be enhanced without updating customer equipment

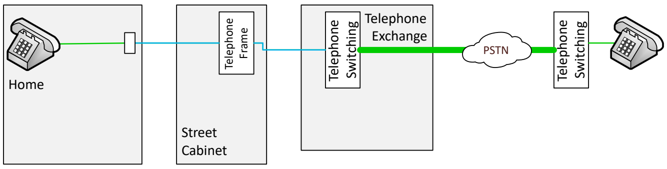
Points to note however

- Conversion of the whole telephone network to fibre is NOT directly related to the current fibre installation
- Swish (in our area) have permission to install Fibre To The Premises (FTTP) but they are not (yet) automatically providing telephone services
  - They are promising Gigabit speeds but at a cost and they become your ISP
    - Do you really need Gigabit speeds?
      - I can stream 4K TV concurrently with several HD TV streams on 34 Mbps FTTC service (accidentally tested during Wimbledon last year)
  - Swish CAN provide telephone services but this is not automatic and, I am assuming, will be additional cost
- There is an intention at some stage to migrate us all to fibre including telephone but I have seen no indication yet as to how much the consumer will have to pay

Are there any downsides?

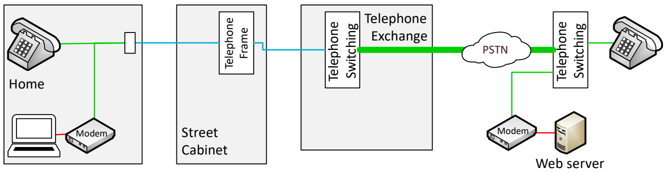
- There is the obvious disruption on roads being dug up initially
- There will be issues when the fibres are run to the home or office
  - Some equipment will not be compatible and may need to be replaced
    - Candidates include
      - Alarm systems that communicate using the telephone network
      - Medical alert systems that communicate using the telephone network
      - Possibly old telephones
  - Looking at what is being done locally they may need to dig up driveways to take the new fibre cable to the property
    - We currently have an overhead cable from a pole in my garden

Basic Telephone



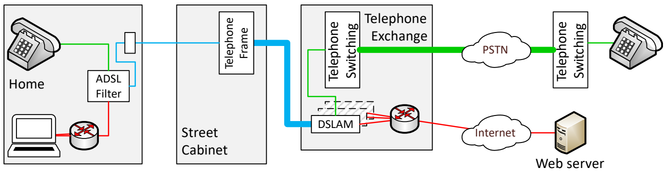
- A basic telephone system before any data services are added

Adding Internet access via modem



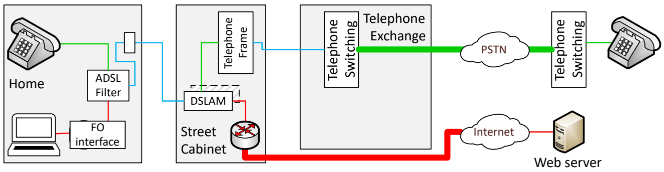
- We add a standard modem to basic the system
  - Can be external or an interface mounted inside a PC (desktop) or built into a laptop
- Routed via voice switching to the server where a modem decodes the data and passes to the server

Adding ADSL broadband



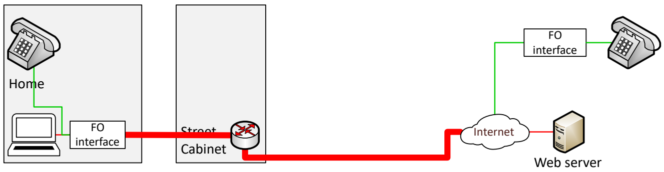
- The router takes IP data from local network and encodes in a ADSL packets
- The ADSL filter merges the ADSL data with voice to pass both to the Exchange
- The DSLAM module in the exchange splits the voice and data
- The data is routed to the Internet
- Voice is passed to the existing telephone exchange

Fibre to the Cabinet – FTTC concept



- ADSL connection now processed in nearby street cabinet
  - Reduces distance that broadband signals travel
- An equivalent to the exchange DSLAM splits the internet data and voice
  - Voice is passed to telephone exchange for routing
  - All Internet data traffic routed to the Internet from the cabinet

Full Fibre to Premises – eventually? - FTTP



- Phone is now converted to IP in the home
- All Internet and voice traffic is routed via the Internet

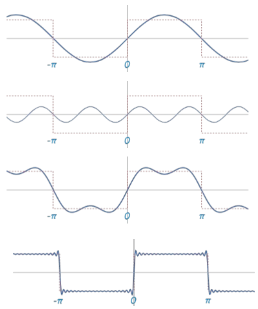
12 May 2022 30

Some concerns

- It is currently unclear to me what will happen in an emergency situation where there is a power cut
- At present your telephone is provided with a 50 volt supply from the exchange
  - The telephone exchange is obliged, by law, to have a battery to provide this power so that telephone calls can be made in an emergency
    - This battery does NOT supply power to cordless telephones, These need to be plugged into the mains and do not work on power failure
    - That is why you are currently recommended to have an old fashioned (not cordless) telephone plugged into your home phone system as well
    - The new legislation requires the telephone provider to provide a battery pack **on request** but that will only provide power for 1 hour
    - The justification is that everyone has cell phones these days
      - OK if you can get a signal!

But what happens to these pulses over the cable

- A pulse train can be analysed into a series of “harmonics”. Musicians may be familiar with that term
- This is called Fourier Analysis and consists of:
  - A series of “pure” (I.e. sinusoidal) frequencies.
    - Each is a multiple of the original bit rate
    - The amplitude of each frequency depends on the input wave shape
      - A “square wave” where each high and low are the same interval consists of
        - sin(x) + sin(3x)/3 + sin(5x)/5 + ... (infinitely)
        - x is 2 * π * f where f is the frequency



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