

# Networks

We now move to look at a different environment: longer distance networks, in particular to the home

# Networks

We now move to look at a different environment: longer distance networks, in particular to the home

These have quite different requirements from, say, commodity Ethernet: in particular you don't always get to choose the physical layer. Sometimes you have to make do with whatever hardware is available, e.g., buried in the street

# Networks

## Analogue

Before digital networks were common, the physical layer of choice was an acoustic modem, using the existing analogue telephone network

# Networks

## Analogue

Before digital networks were common, the physical layer of choice was an acoustic modem, using the existing analogue telephone network

This used **MO**dulation and **DEM**odulation to convert bits into acoustic symbols, i.e., sounds

# Networks

## Analogue

Before digital networks were common, the physical layer of choice was an acoustic modem, using the existing analogue telephone network

This used **MO**dulation and **DE**Modulation to convert bits into acoustic symbols, i.e., sounds

The early Internet (Arpanet) ran over the existing analogue telephone network

# Networks

## Analogue

**Exercise** Read about the V series of modem standards

**Exercise** Read about *amplitude modulation*, *frequency modulation* and *phase modulation* and *Quadrature Amplitude Modulation (QAM) constellations*

# Networks

## Digital

After analogue, public telephone systems started to support purely digital networks

# Networks

## Digital

After analogue, public telephone systems started to support purely digital networks

**Exercise** Read about Integrated Services Digital Network (ISDN)



# Networks

## Digital

After analogue, public telephone systems started to support purely digital networks

**Exercise** Read about Integrated Services Digital Network (ISDN)

ISDN was the precursor to ADSL

## ADSL

*Asymmetric Digital Subscriber Line* (ADSL) was an important method of delivery, and drove the first big increase of the Internet in the home

## ADSL

*Asymmetric Digital Subscriber Line* (ADSL) was an important method of delivery, and drove the first big increase of the Internet in the home

Analogue modems are limited to 56Kb/s, the maximum speed available from a standard analogue telephone line where all frequencies apart from a 3KHz chunk centred on the human voice are filtered out and thrown away

## ADSL

*Asymmetric Digital Subscriber Line* (ADSL) was an important method of delivery, and drove the first big increase of the Internet in the home

Analogue modems are limited to 56Kb/s, the maximum speed available from a standard analogue telephone line where all frequencies apart from a 3KHz chunk centred on the human voice are filtered out and thrown away

The telephone wire — while only originally specified to be capable of sending voice — is capable of more, ADSL tries to take advantage of this

## ADSL

*Asymmetric Digital Subscriber Line* (ADSL) was an important method of delivery, and drove the first big increase of the Internet in the home

Analogue modems are limited to 56Kb/s, the maximum speed available from a standard analogue telephone line where all frequencies apart from a 3KHz chunk centred on the human voice are filtered out and thrown away

The telephone wire — while only originally specified to be capable of sending voice — is capable of more, ADSL tries to take advantage of this

It uses many blocks of frequencies simultaneously — broadband — that avoid areas of the spectrum that have interference, and to make best use of areas of the spectrum that don't

# ADSL

The data rate you get depends on the quality and length of the copper loop connecting you to the telephone exchange: the longer it is the harder it is to get a clean signal down it

# ADSL

The data rate you get depends on the quality and length of the copper loop connecting you to the telephone exchange: the longer it is the harder it is to get a clean signal down it

And the amount of interference there is along the route of the copper loop

# ADSL

The data rate you get depends on the quality and length of the copper loop connecting you to the telephone exchange: the longer it is the harder it is to get a clean signal down it

And the amount of interference there is along the route of the copper loop

ADSL2+ tops out at 24Mb/s, dropping to 2Mb/s at its longest reach (about 4km, maybe up to 8km if you are really lucky)



# ADSL

It is *asymmetric* in that it divides the available bandwidth unequally into (say) 24Mb/s downstream (towards the user) and 2Mb/s upstream (towards the Internet)

# ADSL

It is *asymmetric* in that it divides the available bandwidth unequally into (say) 24Mb/s downstream (towards the user) and 2Mb/s upstream (towards the Internet)

Which is what most home users want: a few clicks on a Web link (low bandwidth) resulting in a large page download (high bandwidth)

# ADSL

But 24Mb/s is not enough for today's video streaming, multi-occupant houses: we need to go faster and ADSL and updates to ADSL (e.g., VDSL) can't keep up

# ADSL

But 24Mb/s is not enough for today's video streaming, multi-occupant houses: we need to go faster and ADSL and updates to ADSL (e.g., VDSL) can't keep up

**Exercise** ADSL is just one in a series of DSL standards, collectively called xDSL. Read about these

# The Last Mile Problem

This is part of *last mile problem*: how to bridge the gap between the local telephone exchange and the final user

# The Last Mile Problem

This is part of *last mile problem*: how to bridge the gap between the local telephone exchange and the final user

Also called the *first mile problem*

## Fibre Hybrid

Currently, the most popular solution is to have *Fibre to the street cabinet* (FTTC) and then use a DSL over the existing copper wire (the copper *loop*) to the home

## Fibre Hybrid

Currently, the most popular solution is to have *Fibre to the street cabinet* (FTTC) and then use a DSL over the existing copper wire (the copper *loop*) to the home

VDSL2 is used on the copper from the cabinet to the home: with an asymmetric up to 80Mb/s downlink, 20Mb/s uplink



## Fibre Hybrid

Currently, the most popular solution is to have *Fibre to the street cabinet* (FTTC) and then use a DSL over the existing copper wire (the copper *loop*) to the home

VDSL2 is used on the copper from the cabinet to the home: with an asymmetric up to 80Mb/s downlink, 20Mb/s uplink

(The actual limits are more complex; and made even harder by legal restrictions on advertisements of speeds in marketing)

## Fibre Hybrid

VDSL (and VDSL2 etc.), another DSL standard, gives higher data rates than ADSL over short distances

## Fibre Hybrid

VDSL (and VDSL2 etc.), another DSL standard, gives higher data rates than ADSL over short distances

But the rates drop off rapidly with distance, and after about 1.6km its performance drops below that of ADSL

## Fibre Hybrid

VDSL (and VDSL2 etc.), another DSL standard, gives higher data rates than ADSL over short distances

But the rates drop off rapidly with distance, and after about 1.6km its performance drops below that of ADSL

**Exercise** Read about the various distances, performances and frequencies used by these standards

## Fibre Hybrid

With VDSL, the distance you live from the street cabinet governs what speed you actually get

## Fibre Hybrid

With VDSL, the distance you live from the street cabinet governs what speed you actually get

In contrast, ADSL uses the old copper loop all the way from the exchange to the home: this can be many kms

## Fibre Hybrid

With VDSL, the distance you live from the street cabinet governs what speed you actually get

In contrast, ADSL uses the old copper loop all the way from the exchange to the home: this can be many kms

The FTTC “Fibre broadband” hybrid represents the current cost-effective way of getting decent bandwidth to the home

# Fibre

Ideally we would each have a high-bandwidth optical fibre to our home



# Fibre

Ideally we would each have a high-bandwidth optical fibre to our home

Optical fibre is not subject to electrical interference like copper wires, and can carry huge (terabits is possible) data rates

# Fibre

Ideally we would each have a high-bandwidth optical fibre to our home

Optical fibre is not subject to electrical interference like copper wires, and can carry huge (terabits is possible) data rates

We would like *Fibre to the building/business* (FTTB) or *Fibre to the premises* (FTTP), where fibre comes to a building (business or multiple occupancy building); or *Fibre to the home* (FTTH) where fibres come to individual houses

## Fibre

It will be very expensive to provide everybody with a fibre connection: a lot of digging up the road is needed

## Fibre

It will be very expensive to provide everybody with a fibre connection: a lot of digging up the road is needed

The legacy copper telephone network was put into place over many decades

## Fibre

It will be very expensive to provide everybody with a fibre connection: a lot of digging up the road is needed

The legacy copper telephone network was put into place over many decades

Though progress on laying fibre is continuing and there are plans to decommissioning the copper network at some point in the future

## Fibre

It will be very expensive to provide everybody with a fibre connection: a lot of digging up the road is needed

The legacy copper telephone network was put into place over many decades

Though progress on laying fibre is continuing and there are plans to decommissioning the copper network at some point in the future

In 2019 the UK government announced that there will be 100% coverage of gigabit “broadband” by fibre or 5G cellular by 2025

## Fibre

It will be very expensive to provide everybody with a fibre connection: a lot of digging up the road is needed

The legacy copper telephone network was put into place over many decades

Though progress on laying fibre is continuing and there are plans to decommissioning the copper network at some point in the future

In 2019 the UK government announced that there will be 100% coverage of gigabit “broadband” by fibre or 5G cellular by 2025

Previously it had an “aspiration” to have 100% optical fibre by 2033 — much more realistic

## Fibre

It will be very expensive to provide everybody with a fibre connection: a lot of digging up the road is needed

The legacy copper telephone network was put into place over many decades

Though progress on laying fibre is continuing and there are plans to decommissioning the copper network at some point in the future

In 2019 the UK government announced that there will be 100% coverage of gigabit “broadband” by fibre or 5G cellular by 2025

Previously it had an “aspiration” to have 100% optical fibre by 2033 — much more realistic

**Exercise** Find out what the current Government target is



## Fibre

The current big push is to install FTTP and there is a lot of engineering works across the country digging up streets to install it

## Fibre

The current big push is to install FTTP and there is a lot of engineering works across the country digging up streets to install it

Big companies like Openreach (BT) and Virgin as well as smaller *altnets*, like Truespeed and City Fibre currently digging up Bath

## Fibre

The current big push is to install FTTP and there is a lot of engineering works across the country digging up streets to install it

Big companies like Openreach (BT) and Virgin as well as smaller *altnets*, like Truespeed and City Fibre currently digging up Bath

Offering up to gigabit speeds: usually advertised as 900Mb/s (rules on advertising, again)

## Fibre

The current big push is to install FTTP and there is a lot of engineering works across the country digging up streets to install it

Big companies like Openreach (BT) and Virgin as well as smaller *altnets*, like Truespeed and City Fibre currently digging up Bath

Offering up to gigabit speeds: usually advertised as 900Mb/s (rules on advertising, again)

With an eye to the future, some altnets are installing hardware that can provide up to 10Gb/s

## Fibre

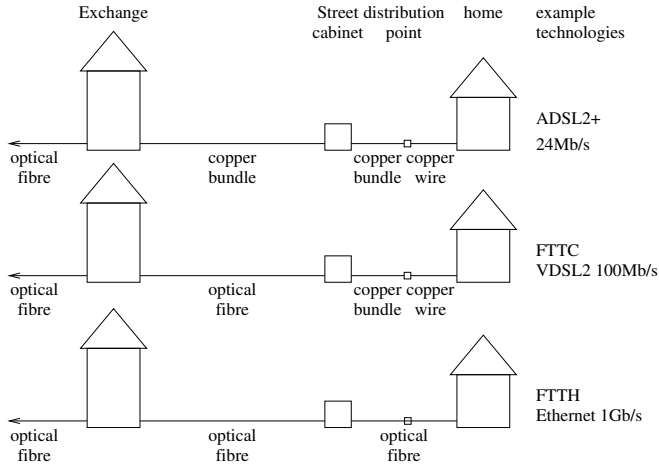
The current big push is to install FTTP and there is a lot of engineering works across the country digging up streets to install it

Big companies like Openreach (BT) and Virgin as well as smaller *altnets*, like Truespeed and City Fibre currently digging up Bath

Offering up to gigabit speeds: usually advertised as 900Mb/s (rules on advertising, again)

With an eye to the future, some altnets are installing hardware that can provide up to 10Gb/s

FTTH/P is being marketed as “full fibre” to distinguish it from FTTC



Current common connections in the last mile

## FTTx

A street cabinet is where a bundle of wires or fibres for several streets (say) split into smaller bundles going to the respective streets

## FTTx

A street cabinet is where a bundle of wires or fibres for several streets (say) split into smaller bundles going to the respective streets

A distribution point is a place (another cabinet or underground beneath a manhole or on a telegraph pole) where the bundles split into the individual connections to their destinations



## FTTx

A street cabinet is where a bundle of wires or fibres for several streets (say) split into smaller bundles going to the respective streets

A distribution point is a place (another cabinet or underground beneath a manhole or on a telegraph pole) where the bundles split into the individual connections to their destinations

For example, a FTTH might have multiple fibres to a street cabinet; a single shared fibre to the DP where the signal is split optically on to individual fibres to the homes

## FTTx

A street cabinet is where a bundle of wires or fibres for several streets (say) split into smaller bundles going to the respective streets

A distribution point is a place (another cabinet or underground beneath a manhole or on a telegraph pole) where the bundles split into the individual connections to their destinations

For example, a FTTH might have multiple fibres to a street cabinet; a single shared fibre to the DP where the signal is split optically on to individual fibres to the homes

**Exercise** Read about (the now defunct) FTTdp that took fibre all the way to the DP

## The Last Mile

In the UK we have:

5500 exchanges	ADSL	copper	24Mb
10,000s street cabinets	VDSL FTTC	fibre + copper	80Mb
1,000,000s distribution points	G.fast FTTdp	fibre + copper	300Mb
30,000,000 premises	Ethernet FTTP	fibre	1GB

## The Last Mile

In the UK there is a legal requirement: the *universal service obligation* (USO) of a connection of at least 10Mb/s down, 1Mb/s up

## The Last Mile

In the UK there is a legal requirement: the *universal service obligation* (USO) of a connection of at least 10Mb/s down, 1Mb/s up

BT (or other large provider, like KCOM in Hull) have to provide this at a reasonable cost

## The Last Mile

In the UK there is a legal requirement: the *universal service obligation* (USO) of a connection of at least 10Mb/s down, 1Mb/s up

BT (or other large provider, like KCOM in Hull) have to provide this at a reasonable cost

It can be wired/fibre or even wireless

## End of Analogue

BT wants to turn off all analogue (*Public Switched Telephone Network* (PSTN)) networks by 31 Dec 2025

## End of Analogue

BT wants to turn off all analogue (*Public Switched Telephone Network* (PSTN)) networks by 31 Dec 2025

Meaning the voice network, i.e., telephone



## End of Analogue

BT wants to turn off all analogue (*Public Switched Telephone Network* (PSTN)) networks by 31 Dec 2025

Meaning the voice network, i.e., telephone

Voice will be replaced by digital (*Voice Over IP* (VOIP)) over copper or fibre to a modem in your home; your phone plugs into the modem

## End of Analogue

BT wants to turn off all analogue (*Public Switched Telephone Network* (PSTN)) networks by 31 Dec 2025

Meaning the voice network, i.e., telephone

Voice will be replaced by digital (*Voice Over IP* (VOIP)) over copper or fibre to a modem in your home; your phone plugs into the modem

In the long run they want to remove the copper, but this means building fibre (or wireless) everywhere first

## Cable TV

The cable TV system, where available, is another solution to the Last Mile

## Cable TV

The cable TV system, where available, is another solution to the Last Mile

Newer installations are full fibre, but there is also a lot of another fibre/copper hybrid, with fibre to cabinets and then copper to the home

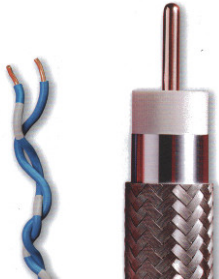
## Cable TV

The cable TV system, where available, is another solution to the Last Mile

Newer installations are full fibre, but there is also a lot of another fibre/copper hybrid, with fibre to cabinets and then copper to the home

However, the copper wires used is good(ish) quality coaxial cable that is well screened against interference and crosstalk, and so the data rates it supports are much higher

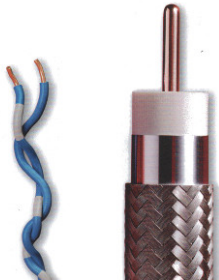
# Cable TV



Telephone wire and coaxial cable

Picture from Virgin Media

## Cable TV



Telephone wire and coaxial cable

Picture from Virgin Media

**Exercise** *Read up on Data Over Cable Service Interface Specification (DOCSIS)*

# Wireless

Next: cellular networks, as used by mobile phones for the Last Mile



## Wireless

Next: cellular networks, as used by mobile phones for the Last Mile

The first important digital system was *Global System for Mobile Communications* (GSM)

## Wireless

Next: cellular networks, as used by mobile phones for the Last Mile

The first important digital system was *Global System for Mobile Communications* (GSM)

Retrospectively named *2G*

## Wireless

Next: cellular networks, as used by mobile phones for the Last Mile

The first important digital system was *Global System for Mobile Communications* (GSM)

Retrospectively named *2G*

(1G was the preceding analogue system)

# Wireless

Next: cellular networks, as used by mobile phones for the Last Mile

The first important digital system was *Global System for Mobile Communications* (GSM)

Retrospectively named *2G*

(1G was the preceding analogue system)

Rates of 9.6Kb/s to 14.4Kb/s (similar to old analogue wired modems)

# Wireless

Next: cellular networks, as used by mobile phones for the Last Mile

The first important digital system was *Global System for Mobile Communications* (GSM)

Retrospectively named *2G*

(1G was the preceding analogue system)

Rates of 9.6Kb/s to 14.4Kb/s (similar to old analogue wired modems)

*High Speed Circuit Switched Data* (HSCSD) takes this up to 57.6Kb/s

# Wireless

*General Packet Radio Service* (GPRS), packet based, up to 171.2Kb/s

## Wireless

*General Packet Radio Service* (GPRS), packet based, up to 171.2Kb/s

Uses several GSM channels

## Wireless

*General Packet Radio Service* (GPRS), packet based, up to 171.2Kb/s

Uses several GSM channels

*Enhanced Data rates for GSM Evolution* (EDGE) uses better encodings to get up to 384Kb/s, again using several channels



## Wireless

*General Packet Radio Service* (GPRS), packet based, up to 171.2Kb/s

Uses several GSM channels

*Enhanced Data rates for GSM Evolution* (EDGE) uses better encodings to get up to 384Kb/s, again using several channels

EDGE used by Third Generation (3G) systems

## Wireless

*General Packet Radio Service (GPRS)*, packet based, up to 171.2Kb/s

Uses several GSM channels

*Enhanced Data rates for GSM Evolution (EDGE)* uses better encodings to get up to 384Kb/s, again using several channels

EDGE used by Third Generation (3G) systems

*High-Speed Downlink Packet Access (HSDPA)* ups this to 42.2Mb/s

## Wireless

*General Packet Radio Service (GPRS)*, packet based, up to 171.2Kb/s

Uses several GSM channels

*Enhanced Data rates for GSM Evolution (EDGE)* uses better encodings to get up to 384Kb/s, again using several channels

EDGE used by Third Generation (3G) systems

*High-Speed Downlink Packet Access (HSDPA)* ups this to 42.2Mb/s

*Evolved High-Speed Packet Access (HSPA+)* will do 168Mb/s

# Wireless

4G is well established

# Wireless

4G is well established

Using *Long Term Evolution* (LTE) with the promise of 300Mb/s

# Wireless

4G is well established

Using *Long Term Evolution* (LTE) with the promise of 300Mb/s

LTE, marketed as “4G”, originally did not meet the proposed 4G standard as it did not satisfy the proposed technical specifications of a 4G system

# Wireless

4G is well established

Using *Long Term Evolution* (LTE) with the promise of 300Mb/s

LTE, marketed as “4G”, originally did not meet the proposed 4G standard as it did not satisfy the proposed technical specifications of a 4G system

In particular, a 4G network should support 1Gb/s for a stationary host

# Wireless

4G is well established

Using *Long Term Evolution* (LTE) with the promise of 300Mb/s

LTE, marketed as “4G”, originally did not meet the proposed 4G standard as it did not satisfy the proposed technical specifications of a 4G system

In particular, a 4G network should support 1Gb/s for a stationary host

The ITU (who say what “4G” is supposed to mean) actually gave in to commerce and retroactively changed the definition of 4G to allow for LTE



# Wireless

LTE is data traffic only, and does not have a voice channel

# Wireless

LTE is data traffic only, and does not have a voice channel

Currently on many LTE systems if you want to make a voice call it has to drop back to 3G (or even 2G)

# Wireless

LTE is data traffic only, and does not have a voice channel

Currently on many LTE systems if you want to make a voice call it has to drop back to 3G (or even 2G)

Some phones and systems support *voice over LTE* (VoLTE) using a suitable digital encoding of sound over the data channel

# Wireless

LTE is data traffic only, and does not have a voice channel

Currently on many LTE systems if you want to make a voice call it has to drop back to 3G (or even 2G)

Some phones and systems support *voice over LTE* (VoLTE) using a suitable digital encoding of sound over the data channel

**Exercise** Some systems support “Wi-Fi calling”, which is using your Wi-Fi (rather than the cellular network) to connect to the telephone system. Read about this

# Wireless

5G is currently being deployed

# Wireless

5G is currently being deployed

It uses the available spectrum much more efficiently than 4G, and employs frequencies up to 86GHz (LTE uses up to 6GHz)

# Wireless

5G is currently being deployed

It uses the available spectrum much more efficiently than 4G, and employs frequencies up to 86GHz (LTE uses up to 6GHz)

Projections indicate users connected to a base-station will share 20Gb/s download and 10Gb/s upload rates

# Wireless

5G is currently being deployed

It uses the available spectrum much more efficiently than 4G, and employs frequencies up to 86GHz (LTE uses up to 6GHz)

Projections indicate users connected to a base-station will share 20Gb/s download and 10Gb/s upload rates

And base-stations will support “millions” of devices per square mile (enabling the *Internet of Things*)



# Wireless

5G is currently being deployed

It uses the available spectrum much more efficiently than 4G, and employs frequencies up to 86GHz (LTE uses up to 6GHz)

Projections indicate users connected to a base-station will share 20Gb/s download and 10Gb/s upload rates

And base-stations will support “millions” of devices per square mile (enabling the *Internet of Things*)

A device will be able to connect even if it is moving at 500km/h (e.g., in a plane); latencies will be 1ms, compared to the current 20ms on LTE

# Wireless

Current sticking points over the adoption of 5G are:

# Wireless

Current sticking points over the adoption of 5G are:

- lack of support in “old” mobile phones

# Wireless

Current sticking points over the adoption of 5G are:

- lack of support in “old” mobile phones
- phone 5G chipsets currently suck a lot of power

# Wireless

Current sticking points over the adoption of 5G are:

- lack of support in “old” mobile phones
- phone 5G chipsets currently suck a lot of power
- the need to build a lot more base stations (using higher radio frequencies means the range of a cell is smaller)

# Wireless

Current sticking points over the adoption of 5G are:

- lack of support in “old” mobile phones
- phone 5G chipsets currently suck a lot of power
- the need to build a lot more base stations (using higher radio frequencies means the range of a cell is smaller)
- or upgrading old ones and re-purposing existing frequencies used by 3G

# Wireless

6G? A new “G” appears roughly every 10 years, so maybe 2030, but this is uncertain as 5G has significant improvements planned. Maybe a standard will be published in 2025

# Wireless

6G? A new “G” appears roughly every 10 years, so maybe 2030, but this is uncertain as 5G has significant improvements planned. Maybe a standard will be published in 2025

With targets of 100Gb/s to 1Tb/s using 100GHz to 1THz (terahertz) frequencies



## Wireless

6G? A new “G” appears roughly every 10 years, so maybe 2030, but this is uncertain as 5G has significant improvements planned. Maybe a standard will be published in 2025

With targets of 100Gb/s to 1Tb/s using 100GHz to 1THz (terahertz) frequencies

THz is between microwaves and infrared, not ionizing; current mobile is MHz and GHz. The tech to generate THz waves is still very new

## Wireless

6G? A new “G” appears roughly every 10 years, so maybe 2030, but this is uncertain as 5G has significant improvements planned. Maybe a standard will be published in 2025

With targets of 100Gb/s to 1Tb/s using 100GHz to 1THz (terahertz) frequencies

THz is between microwaves and infrared, not ionizing; current mobile is MHz and GHz. The tech to generate THz waves is still very new

(The base-stations will need really good onward connectivity!)

# Wireless

2G and 3G signals are due to be phased out by 2033 so their frequencies can be reused by 4G and 5G

Probably 3G will go first, as 2G is widely used in things like Smart Meters, and as a low-power, long-range fallback, particularly in rural areas

# Wireless

2G and 3G signals are due to be phased out by 2033 so their frequencies can be reused by 4G and 5G

Probably 3G will go first, as 2G is widely used in things like Smart Meters, and as a low-power, long-range fallback, particularly in rural areas

Many companies are looking at dates like 2025 for 3G removal

# Wireless

2G and 3G signals are due to be phased out by 2033 so their frequencies can be reused by 4G and 5G

Probably 3G will go first, as 2G is widely used in things like Smart Meters, and as a low-power, long-range fallback, particularly in rural areas

Many companies are looking at dates like 2025 for 3G removal

**Exercise** Read about how this conflicts with the limited support for VoLTE in 4G

# Wireless

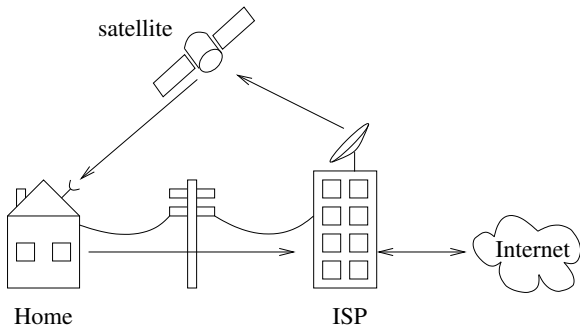
Satellite networks can be used outside of well-connected urban areas for the Last Mile

# Wireless

Satellite networks can be used outside of well-connected urban areas for the Last Mile

There are two main variants

# Wireless



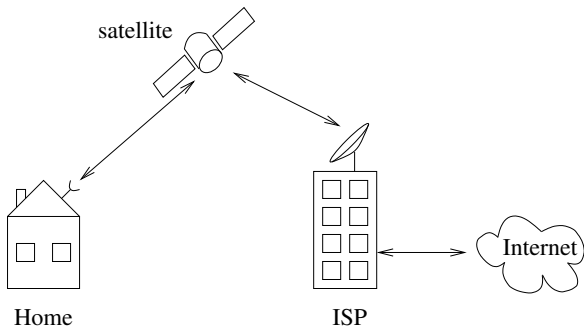
One Way satellite

One way satellite

One way satellite: this employs the usual asymmetry. Data away from the home travels by telephone wire; data towards the home travels through a satellite connection



# Wireless



Two Way satellite

Two way satellite

Two way satellite: satellite connections both ways. More expensive in equipment in the home, but not reliant on a telephone network

# Wireless

Satellites are very expensive to put up and to run

# Wireless

Satellites are very expensive to put up and to run

They cover a large area with a reasonably good bandwidth

# Wireless

Satellites are very expensive to put up and to run

They cover a large area with a reasonably good bandwidth

They are good for remote and undeveloped areas with no other local infrastructure

# Wireless

Geostationary satellites have a large latency: about 1/10 sec, which can be very noticeable in highly interactive applications (games)

# Wireless

Geostationary satellites have a large latency: about 1/10 sec, which can be very noticeable in highly interactive applications (games)

So lately providers are putting satellites into low orbits, but this means they are forever moving (from the perspective of someone at ground level)

## Wireless

Geostationary satellites have a large latency: about 1/10 sec, which can be very noticeable in highly interactive applications (games)

So lately providers are putting satellites into low orbits, but this means they are forever moving (from the perspective of someone at ground level)

This is fixed by having a large number of satellites so there is always one overhead

# Wireless

Geostationary satellites have a large latency: about 1/10 sec, which can be very noticeable in highly interactive applications (games)

So lately providers are putting satellites into low orbits, but this means they are forever moving (from the perspective of someone at ground level)

This is fixed by having a large number of satellites so there is always one overhead

Lower latency  $\implies$  lower orbit  $\implies$  faster moving satellites  
 $\implies$  more satellites needed to maintain coverage



# Wireless

Starlink (amongst others) are currently building a low orbit satellite network

# Wireless

Starlink (amongst others) are currently building a low orbit satellite network

Targets are 300 Mb/s at 20ms latency

# Wireless

Starlink (amongst others) are currently building a low orbit satellite network

Targets are 300 Mb/s at 20ms latency

But this will need 10s of thousands of satellites (a problem for astronomers!)

# Wireless

Starlink (amongst others) are currently building a low orbit satellite network

Targets are 300 Mb/s at 20ms latency

But this will need 10s of thousands of satellites (a problem for astronomers!)

Due to the cost, this may turn out to be a “top up” service for the hard to get at places; not a general connection for all

# The Physical Layer

We have seen some implementations of the physical layer

# The Physical Layer

We have seen some implementations of the physical layer

There are very many more

# The Physical Layer

We have seen some implementations of the physical layer

There are very many more

There are many implementations as there are many physical requirements of networks (distance, speed, power, etc.)

# The Physical Layer

We have seen some implementations of the physical layer

There are very many more

There are many implementations as there are many physical requirements of networks (distance, speed, power, etc.)

Fortunately, as we go up the layers, the amount of variety decreases!