Audio file

118758-21StcenturyComsJohnMitchell.mp3

Transcript

Well, thank you. I'll take the introduction. So as said, my name is John Mitchell. I'm now the head of Department of Electronic Electrical engineering. And great to see you all here and say hopefully some of you will be joining us next year. A bit of luck. So this is an example of a lecture I give this at one of our first year comms course. Actually. I've also given a version of this for our in the induction for our Mscs talking about a bit about the department, a bit about the history of comms. So it's quite a quite a general general lecture. It's not going into too much technical detail. But give you an idea of some of the things we do. Some of the things we're interested in. So communications, communications, research is a very big topic for electronic engineers and a lot of what we do is is focused around these sorts of things, predominantly in a, you know, communications is a real core part of what it is to be human. Many say it's what differentiates us from many of the animals, our complex communications. Activities and you know, I quite like this because the Internet has now surpassed.

And.

Things. Communications of all forms, from smoke signals from light signals on the top, you know, date back two 3000 years where we have evidence of people sending signals to communicate various activities. Often it might be the arrival of ships. I was just just out in South Africa in Cape Town and one of the things I saw on Signal Hill, which comes about because they had big cannons there and they was a a relay of cannons that would fire when the ships came in because Cape Town was originally founded in South Africa as a refuel. Stop for the local farmers to come and sell produce to the ships and that sort of thing. So the ability to communicate, the ability to send signals are something that. The. Technology has has has looked to enable for a long time as far as electronic engineering is concerned, and electronic signals of communication. We date back to 1844 with the Telegraph, where signals dots and dashes were transmitted. And cables were being laid to try and send signals. Yeah, given the time, this is 1891. You can see a lot of it is based. Around the empire and around the various empires that were in place at the moment. So from Spain to southern America to South America. From the UK, Round Africa into India and places like this. So again, one of the things you're doing as science and society course to acknowledge is that these technologies are often based on the political, political era. And so these technologies are about. A form of control and a form of linking governance centres around the world. Because they're incredibly expensive to to put in, we now assume that communications technologies are are something that we would use, but in this time, you know, to send a Telegraph 10 telegram. Would have cost someone the you know, the average weekly wage of of of working class Person so it's not something that most people did. They were about about control, about governance and you can see the map sort of developed much around. The. The empires of the time and the need to communicate between them. And at the time, they were just very simple messages. They're actually very much like the text message of of of its time, partly because you were paying by the letter for your telegram. So you were, you know, you you didn't write long essays by telegram. You had to be very concise because you were paying by the letter to send it. By 1876, we had the invention of the telephone, the ability to send voice signals. Alexander Graham Bell, who did study at UCL although he studied vocal anatomy, not electronic engineering, there was an electronic engineering at the time, but it didn't do much communications. I suppose you could argue we hadn't really invented it yet, so it's fair that he didn't study that. But they actually sold telephones in pairs and connected them, connected them up through really very manual technology. So the thing you'll notice on this very early telephone is there's no dial, no control, no way of signalling who you wanted to talk to. You would lift this receiver up and versions of this that were in local exchanges. These were called doll's eyes, switchboards. These are basically the lights that would a little flap would open up when someone picked up their receiver and the person working here would plug in. To where the light was and ask who you wanted to talk to. Surprisingly, a very intelligent system because you could follow follow people around, you know.

I.

I need to talk to the doctor. Well, I know that the Doctor play cards in the local saloon that on a Tuesday night I can follow him around. And it was, you know, these link lines here would connect your phone to the person you you wanted to to talk to very manual. Umm. And ironically, that was our core form of telephony for a very long time. We moved away from these. We moved to mechanical switching in the 1950s. Probably none of you are old enough to ever remember the term. The term telephones used to have to turn a dial and it would click back and each one of those clicks was a wheel turning. Interesting technical story on that, but it was invented by a man called. A German who was actually an undertaker and the reason he invented an automatic telephone switching system was he was convinced that he was losing business to his competitor because his wife worked on the switchboard. And whenever they called for the Undertaker that she would connect to his rival rather than him, and so he tried to develop a system for to get rid of the the exchange personnel who used to connect calls and automate it. And that's where that came from. So. Key feature we see of engineering there's a necessity, a problem that is identified in a solution. Telecommunications and the the way we communicate really changed in the 1990s. A couple of things happened. One big one was the the boom in mobile mobiles telephony and mobile communications. And I show this graph over this region because really we saw an unprecedented rise over the course of a decade. From mobile phones being relatively niche, relatively few people having them in the in the mid 90s.

You know the First mobile phone was released in the 8 late 80s, but at the time they were, you know, we've got one in the department which comes with its own shoulder bag. It used to sort of slot into your car and charge and you'd take it out and put it in a shoulder bag to carry it around. It's a, you know. This sort of size thing. This is when they really started becoming, becoming small and portable, and over the course of this 10 years we saw. Mobile phones reach pretty much, certainly in the developed world, almost total penetration. We actually now see that it's about 110% of the population, if you count the number of people and the number of phones. So people have far more phones than people out there at any one point in time with people having more than one licence, it's continued to increase. We also saw. A surprising rise in parts of the developing world. And this was interesting because many of these areas did not have the fixed landlines I've talked about. There wasn't telephone technology. Even the wired telephone technology, the sort that sits on the cable and sits, would sit by people's front door was a common sight in the 80s that wasn't common in many parts of the world. And mobile telephony has essentially given telephony where it's not old technologies would spread, a new technology came along and lots of people, people adopted it. In parallel, we saw the growth, the explosion of of the Internet, so. The Internet as sort of we know it really started 1990 three, 1994 with the 1st. Web browser, Netscape. That came out, I think, came out in 1993. Up until then, there were connected computers, but they were generally in universities, they were in specialist establishments and if you wanted to get information from anywhere. At the command line you were typing typing commands, you needed to know what you were. For and. The World Wide Web and the very first search engine, a thing called Alta Vista, started to revolutionise that over the 90s, where people could post, people could find information and we started to see, you know, the the rapid, rapid expansion of of the Internet. Now where we have a total population of nearly 8 billion. We have over 5 billion mobile phone users, nearly 5 billion Internet users, the vast majority of which are now. Content posting content on social media in in in one way or. So again, in in a not dissimilar time, we've seen almost complete world penetration of of the Internet and the and the technologies. So that's a a bit of a history and some of the things that have have led, I'm gonna go through some, some, some of the things that were behind that that led to it and also some of the key technologies that we've we've discovered. So. This. Chat my department talks a lot about him. He's well, famous. Founding Father Sir John Ambrose Fleming. Two things. He's mostly known for if you've ever. If you studied physics, you'll know the left and right hand rules. He was one of the first to teach that he fancied himself as an artist. Fingers are always difficult. It's not too bad. His drawing of that. He also really invented the first electronic devices, so he was seeking a way to support radio transmissions. He'd mainly worked in high power and did a lot about lighting cities, but he invented a device that could detect radio waves. And so he was. Part of the he was one of the consultants to Marconi, who?

Built.

This first transmitter station and receiver station to try and transmit across the Atlantic. At the time, there was a great debate. People thought you couldn't transmit across the Atlantic. They believed that radio waves travelled in straight lines. And so with the curvature of the earth you they expected that you wouldn't be able to transmit over the horizon. Which the the Atlantic would be so from from Poldu in Cornwall to a place called. Signal Hill in Newfoundland Signal Hill's everywhere. And in 1901, they sent the first successful transmission. It was the letter S in Morse code to Marconi, who was sitting in this in this Hut in Newfoundland, near big antennas. You can see this is the transmitter of the antennas there and a very simple system that creates that created huge pulses of energy. To send. This information across across the Atlantic. Interestingly, and this is something that we sort of forget a little bit about engineering and science and its relationship, there seems to be a modern view that scientists discover things and then engineers might use them. That's, you know, now sort of we we think of that as the way the world works. You know, there'll be a scientific discovery, graphene or whatever, and then down the line someone else finds out how, how, how to use it to do something useful. Interestingly, if you go back through much of history, that's not the case. Quite often, we've discovered things by accident. And only later really worked out how they work. The theory to practise paradigm is not always that way around. This proved that you could transmit across the horizon. But for a long time, we knew no reason why that might be, and many thought it was a fake and they couldn't work out why it was we now know it's a layer of the atmosphere, the ionosphere, what was called the Heaviside layer at the time. It's a layer of charged particles that sits in the upper atmosphere and actually acts like a guide to the work to radio wave so they bounce off it because of the charge that's in them.

But that wasn't.

Something we knew we didn't think. Oh, well, we can transmit across Atlantic because we know that's there. We only discovered it was there in theory or looked for it because we saw this this happening. So we said in the 90s there was a big change in communications from those early days. What what really changed? Well, the big drive is that we moved from the previous technology, which was predominantly what was an analogue technology. To a digital technology that is pretty much everything we do in terms of communications today. So. Just to say a bit about the difference between the two, this is an. Waveform. This is sort of an example of of speech, an example of. What might what might speech signal might look like, and the early telephones, the early mobile phones 1st and 2nd generation mobile phones? Transmitted signals that look like this. And there's a few problems with them. One, it can take any value and changes all the time, which means we don't know that much about it. So if it gets corrupted by noise or distorted by other signals, it's very different, very difficult to turn it back into the signal we first wanted to send. Whereas digital signals have much better immunity to noise because we limit them to only have a certain number of levels and they have immunity to distortion because we only let them change at certain times. Now usually we think of digital as ones and zeros. That's a common parlance. Technically, binary is a special sort of particular sort of digital. Digital just means that it has. Discrete things. Digits, I guess, comes from the same as the the fingers that there are only set levels of the signal. Therefore, what can happen when I transmitted if there's some noise and there's noise on this signal? I know it should be at this level. If it's between here and here, I can guess that what I was sending was here and I can get rid of my noise and recreate it. So digital allowed us to send much higher quality signals.

That's.

Why in the 80s there was sort of the the rise of digital music and the CD? You can get much higher quality, much better immunity to noise, and you can do a thing called compression and I'll come back to compression in a minute. So the first thing we have to work out is we know that our signals are analogue to start with. How do we get them to be digital. So if we have an analogue signal, the first thing we do is we do what's called sampling. We look at it very regularly and we take a value. You at a periodic, so we take that analogue signal and we're going to sample it at each each stage. So now we have a signal that only changes at certain times, but it can still take any sort of level, and so the second thing we do is something that's called quantizing. And so here we say, well, actually our signal can only take a few levels.

I.

It'll depend what level L, so anything between this band we will say is this value. Anything between this band is another value, and that's what we'll transmit. And that's one way of reducing our band. At the receiver, our best guess is that if I say it was in this level, so I send M nought to say I'm in the zero level. My best guess is it will be in the middle and then my guess will be in the middle. So I create a signal at the receiver that look. Books rather like the signal that I sent, but it's not an exact copy because I'm I'm I'm losing some of this subtlety. I don't know the difference between here and here. Anything in this band looks the same to me. So we have to be very careful. To to create a signal that is is high quality. And you can effectively trade the number of samples you need or the number of levels you have, which is a longer string of ones and zeros. You need to send with with the data you see. Send and so in this example we might send 00 to represent this level, 01 to represent this level 010 and so.

I.

And that means we send a code and as long as both ends, understand the code we can. That signal. So we could ask the question how many signals we need, how many levels we need. So if this works, if the speakers, let's see. This is on. I'll turn it down, because sometimes it. Come in a bit loud.

I went to an argument.

Well, let's try that again. Are there speakers in here is? Coming out the screen.

I went to an Ivy League.

School. That's not good, is it? Is there a speaker system in this room? Let's see.

Sound.

New questron that's what we should be. OK, it looks like it's just coming out this speaker here and not in the room speakers. So. Alright, it's not not the best way of doing it, but it will work.

I'm very honest. I know that that's fun.

So this is taking a voice signal which you may or may not recognise. Someone quite well known. And is just sampling with three levels, so one level 2 levels enough.

OK.

Anyone got a guess who that was? Most people don't get it there. Once when you've heard or heard it enough times, it becomes. So let's try a few more levels. Let's go to 5 levels.

I'm very likely I don't really have the best part.

So that's 5 levels. So we've now got a bit more subtlety, but you know.

I went to an iue school.

Who? Oh, it's jumped ahead. Ruined.

Thank you.

I'm very high witted. I know who I am the best word.

You wouldn't want to listen to that over and over by 15. It starts becoming sort of acceptable.

I'm very highly educated. I know words and the best words.

Yeah, so very minimal. If we go for 3231.

I'm very. Educated. I don't worry. I have the best words.

So by 5 bits, 31 different levels. Do the two things you need with a voice signal. You can tell the person you're. You may well guess who it is and you can roughly tell what they're. They're saying. I should probably update this. This is from from. 1st President soon.

Right, I'm very highly educated. I know words. I have the best words.

There are plenty more of those sound bites I could use, so the gift that keeps giving. So this is 200 and 5655 levels. This is what was typically used in telephony. Yeah. So this was a sort of telephone level signal. For very high quality for music, we tend to go to a lot more levels. The CD used 16 bits which still today is probably the height of a. The height of quality music, MP3 S generally compress. You'll find a lot of people will tell you that the quality of CDs was much better than than the MP3 S you get on Spotify these days, which is true because of the compression levels, but that uses 65,000 levels to give you very high quality. So that's one thing about creating quality, but obviously quality takes a lot of bits. We've got a lot of information then to. So one of the other big drivers that certainly is probably the biggest thing that enables the mobile phone to work in the is an idea of compression. Now compression is not new. Compression in its basic form is you use something about your knowledge of the signal to send less information. If you know nothing about it, you have to send everything. But if you know something, you can send it. So this is a really, really early version of compression. So this is the more Morse code. So this is what they would have sent with with the Telegraph, a series of dots and dashes that spelt out the. But what do you notice about this? Some. Letters. Have a number of dots and dashes. Some have much less. Why do you think that might be? Any guesses? Yeah, to do with the frequency. So certainly in the English language, E and I and T and a are very common letters. If you take an average piece of text, you're going to be sending those letters. More often. Than you might be Y or Z. They're just more common in typical English text. So what this allows you to do is if I'd created a system where every letter had, this was the same length, I would always have the same the same length. Here I've got the ones that occur more often being much shorter than others. So there's one way I know something about the signal. I know it's going to be text. I know it's going to be in English so I can adapt my code depending on what I do. There's a similar version of this with voice compression, so this is what your mobile phone will use if you make a make a. Call. OK, these are. These are test signals. So they're they're they're funny sentences that are used to test each of the different sounds. So this is the standard that was used for fixed telephony. So if you had a phone like this over the digital network, you would use this.

If a dead's crown in the to the stage landings.

The fruit of.

A fig tree is apple shaped. So.

It's not great on these speakers, but that's that was the compression. What your mobile phone does is it tries to make a model of your voice of your voice box how it works using some some the the sort of the impulse, the air that's going through it and a long term prediction which is about the sounds that come. And so, because it knows it's going to be voice, it can compress. So this first one is about 1/4 of the data needed.

If the dense crowd in two distinct ways, the.

Fruit of a fig tree is apples.

So it's we've lost a lot of data, but it still sounds roughly the same. It doesn't sound much worse, doesn't sound. Doesn't sound you can still tell it was a man and a woman. You could tell what they're saying. This one was one of the very early ones that was used in Skype. If people ever remember Skype, it sort of predated zoom and such. And it was the lowest form, and it was often quite amusing for those who used it back then. Occasionally, if your bandwidth dropped, you'd end up sounding like this.

Two distinct varieties, all ********.

So by the time you get to here effectively what this is doing is not sending your voice, it's effectively picking it apart and trying to recreate it at the other end. Which is why these start sounding slightly robotic when you get down to these very low layers. But you could still tell it's a man and a woman. You could tell what they were saying. It's not particularly nice to listen to, but it's a tenth of the bit rate needed for that higher rate. So we're reducing the amount of information we send all the time. The other thing that comes about is that once we've reduced that information, what we send becomes very valuable. And so the other big piece of technology that came about to enable this communication was a thing called error correction coding. And So what error correction coding does is it adds a certain amount of redundancy, so it adds some extra information. That means if I get my any one of my ones and zeros wrong I can. Work out there's something wrong and I can fix it. CDs did this a lot. If you can find anyone who still has ACD player, you can actually put a strip of black tape on a CD and it will still play. Go up to about sort of five or six mil. Do it with someone else's CD player because they're probably expensive now if they've. One, but it would work. Because there's enough redundancy that it can make up, it can fill in the gaps if there are gaps. We do this a lot of the time, you know, we can specifically do it in. In speech, so this is an example effectively of error correction coding. So this is the phonetic alphabet that some of you might be familiar with, and the idea here is effectively rather than just say the letter. Which might sound like another letter, so N&M often get confused. You know, some sound like similar. These are deliberately chosen words that don't sound like any of the other words, but that start with the letter that you're you're putting forward.

OK, So what?

If you're seeing cop shows, they'll sort of talk about WH Victor. WHV. WHV might you know, in a noisy environment, you might get that wrong, whereas this is specifically designed now. Obviously saying hotel takes more time than saying. Which I've added redundancy to.

Good.

But I'm doing that to make sure that that I get it across. And all of our natural language and natural speech has an awful lot of redundancy, OK? I'll leave that there for a second. So this is an example of that. What it's saying, we do not read letter by letter and then work out what the word is. Our minds are very highly skilled at picking together pieces from the information we have and not having to take everything in. So we read by the shape of words quite often and the context that surrounded it's.

You're.

In a, you know, a noisy club, a noisy environment. You can pick up conversations. In part through the way the other person speaking hearing bits, you build up the sense from everything that's around and we do the same with letters and effectively that's because there is redundancy in here. This is uncompressed. We could compress that down. But in which case our minds wouldn't be able to do it. And so our minds are are are very good. Sort of thing, OK. So all of these technologies compression error correction, have all enabled us to move from analogue communications or phone like this to things like this. You know there's mathematics behind it. And then there's also the problem of. Actually developing the computing power to do it, we knew how to do error correction since the 1950s. It wasn't till the 1990s that we had the silicon, the computing power, to actually implement that in a phone. Very very complicated error corrections. The Internet. Again, being a big boom. If people know a bit of the history, it started as a defence network with the idea that compared to traditional communications where there were fixed locations where everything was centred on. That the Internet would be entirely distributed. So you've got to remember this is the 1980s. This is the middle of the Cold War between the US and Russia. Fear of nuclear strikes and all such things. And they wanted a network whereby if you took out any part of the network, it would work out how to reconfigure messages, would go through other forms, whereas the telephone network, every link was very carefully designed. And so the network would know if I went to go from here to here. I would have to follow this particular path and every telephone call went that way. With the Internet, it's broadcast out and the network works from works out from what? Paths it can see how to get information to an endpoint. Started in the US, actually, no way. A Norwegian and London were the first two, nor saw and UCL. There was a piece of land in the corner of the quad that was supposedly designated American territory, so the story goes to have the first exchange on the Internet outside. And then by the by the 90s. In Berners, Lee started the web. We saw the Internet huge, huge rise as I say now to figures, figures like this where we've got 5 billion users. You know, the vast majority of the population. With people spending a significant part of their day on the Internet or accessing it via mobile phones and now mobile phones are by far become the biggest. Device for accessing to the mobile phone. So what enables it? And there is an interesting piece around the the Internet in that, you know, we now sort of feel that the Internet is wireless we generally. Generally, use it in a wireless sense. Your laptops are not connected by a wire you know. Actually, if you have to come and plug in, it seems prehistoric. But actually the vast majority of where your information is going is still down down cables of one sort or another. You know my phone at the moment is connected to the Wi-Fi, so it's talking, I guess, to that thing up there on the roof. And as you see out the back of that, there's cables that's probably copper cable that goes down to. A server room. Probably there's one on this floor. There'll be a cabinet that all those cables go back to. There'll probably be an optical fibre that runs from this building back to Central UCL in Torrington Place where the main server rooms are. And from then it will go out. Fibres, probably to the London Internet exchange down in Docklands and out wherever the information needs to go. So actually it's only this bit, this sort of 10 metres at most, that is wireless, even if I was outdoors on the on the. On the standards standard mobile network, I'm probably only going. I'm in central London, I'm going 100 metres or so. There's a big base station just on Mallet Mallet St on where where the farmers market is. It's probably the nearest one to here or someone buildings. If I was out in the country, I might be a kilometre at most, away from from. But still it's only that.

OK, so I'm going to go back to some physics. To understand how this is, this is all working. Snell's law. So Snell's law basically says if you've got an interface between 2 medium with different refractive indices, light coming in will be bent. Yeah. If you want to prove this, take a pencil, take a glass of water. And if you put the pencil into a glass of water, you will see that it. Look straight anymore. Yeah, it looks like it's curved like that at the interface between the wall that snail's law, the light you're seeing off in the pencil. Follows this no pencil's not. By water it's just. Well, we can then do is say, well, if I've got two different mediums. In, in a case of an optical fibre, two different types of glass I could get light so that it can't exit.

By.

Fire at a steep enough angle I get total internal reflection. The light bounces around within the glass.

Now, like a lot of.

Things. This is something that we discovered much later. How to utilise. But was known for a long time. I used to do this with a bucket and a laser pointer. You can do that, but you can show that light will be guided in water. I don't know how we manage this with the sun and a bucket because I've never managed it. But a laser pointer, it works all. And so you can fire a laser pointer into the beam of water and you'll see the light will follow the water's path rather than just come straight out. Then you can put the put your hand in. And get the light. So we knew that. Welcome to the 1960s, Charles Cow, who started here. Came up with this idea of a fibre. Two different types of glass. So you they actually grow this? We deploy superheat glass and then deposit it to create one and then change the type of glass and deposit an outer side and then stretch it, stretch it, stretch it to its very very thin. We create these little tubes of glass. Now the main optical fibre we use is about 125 micrometres across. That's about the third of the thickness of the human hair. It's a very. Fine strands of glass that we shine the light into this middle part and it reflects around, and so we can guide it. So as long as we don't bend it very tightly, we can, we can bend it. And despite being glass, it's actually remarkably strong. We normally put some sort of coatings on it and things to give it additional strength, but you try pulling it, it doesn't. Doesn't doesn't break if you crack it on something, it will crack and will snap, but actually it's it's surprisingly strong. And now following for the Telegraph, the communications of the 1840s. Now we're getting into the 21st century. We have this network of optical fibre that goes all around the globe. Connecting up various areas. And is now a. Battleground Amazon and Google are replacing a lot of this, putting in their own networks now is common, particularly Cos some parts weren't that well connected. And that's really what is what has been driving. So one of those individual strands. Let me go back. So if you think about how much information one individual strand, well, one telephone call requires 84,000 bits of data every second, so 84,000 ones and 0. Typical Internet connections. Probably I should update this when I wrote this, it was about 8 megabits. People are probably 50 megabits if you think about what you're sending. Actually, most houses now, even if they've got fibre, are getting. 500 megabits down, but probably not that much. Back up. It assumes you're not sending that much back up, so maybe 50 megabits. But even if we think about what a a DVD concerns, so DVD quality film is about 5 gigabytes of information in total. A bite is 8 bits, so 37,000 bytes. The current record for a single strand of optical fibre. He's a bit more than a DVD. It's currently 170 terabits, which is about 265 billion telephone calls. Given that's about 15 times the population of the planet, who's talking to who is a bit difficult to tell, but it is, you know, the entire back catalogue of Netflix in a second pretty much down down a single fibre. So this is all by light. And so these are the sort of technologies we work on. We have a very big group at at UCL and this is sort. My background. That we look at sending lots of different colours of light. Sending different sets of information, a thing called wavelength division multiplexing. We send multiple colours of light and we receive multiple colours of light and this allows us to send multiple channels digital data. What the ones and zeros that I talked about. We create lots of different colours of light, put them all together and send them down a fibre and then separate them all out again to the different channels and these might be 40 gigabytes per second hundred gigabits per second. Now's becoming common. A few years back, we held the world record. It's one of these things. It doesn't last long. Someone else speaks you every six months or so. I think we might have had one since I've need to check. But that 170 terabytes. Colleague here, Lydia gardeno's. Was part of the team that that showed that 170 terabits per second as the world record. We've recently had a world record for wireless, one of the team have put a near nearly a TB per second.

What?

Sadly they got 9. I think it was 978 gigabits per second over a short wireless wireless link, which is a a world record. So these are the sorts of sorts of things we do. So hopefully that's. You some ideas of some of the things electrical engineers do, particularly in the field of communications. As I say, communications has grown massively, but in the last 20-30 years it has really exploded with the forms we have. All underpinned by some of these digital technologies. The ability to create faster and faster silicon that allows us to implement some of these mathematical solutions as well as coding, compression and many of the things that we sort of take for granted and that are happening all the time in our mobile phone when we're accessing the Internet or trying to send signals. Across the world, on an on an optical. So thank. Very much for your attention and.

Good to see you all.