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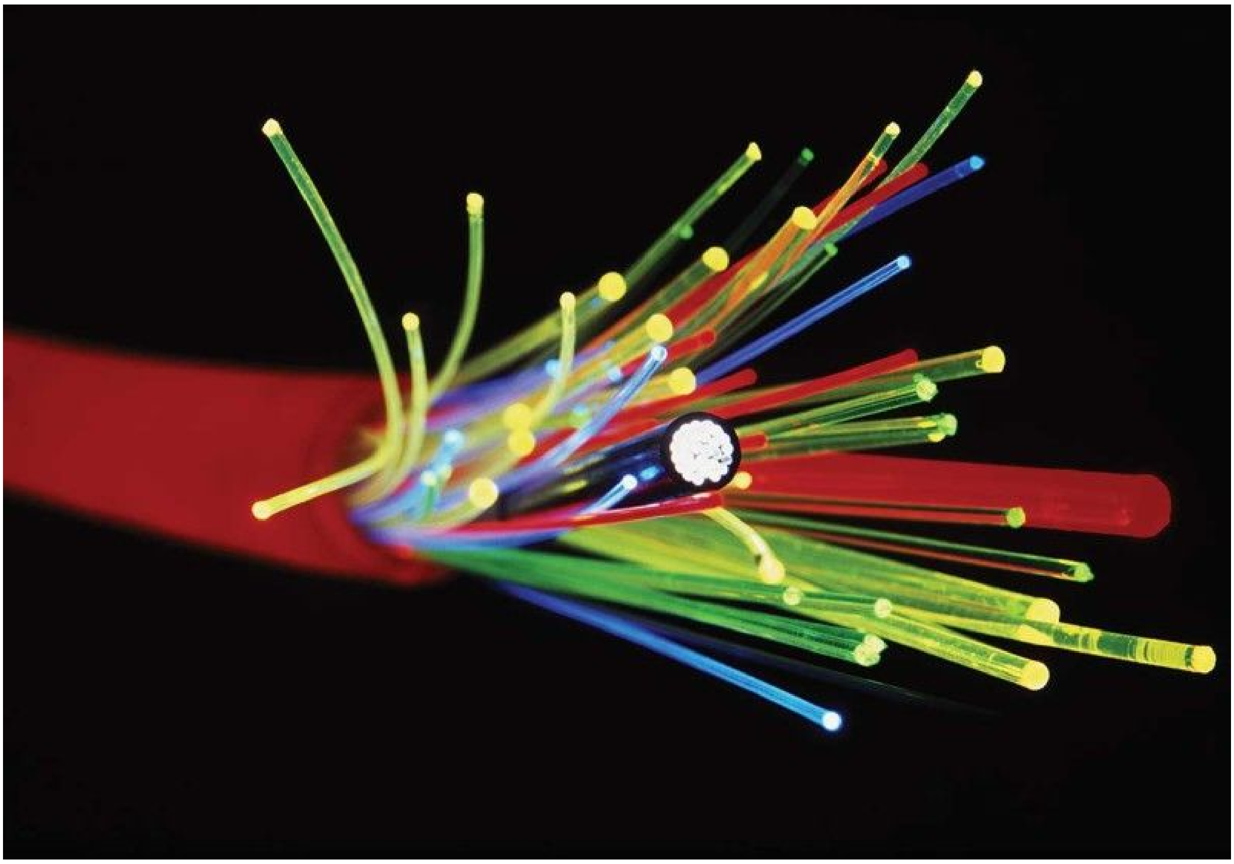
The pipes powering the internet are nearly full – what do we do?

There's only so much data you can cram down an optical fibre – unless you get rid of its insides. We need maverick solutions to save the internet



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By **Timothy Revell**

AFTER innumerable failed attempts, the first telegraph cable across the Atlantic was finally completed on 5 August 1858. At long last, people could hold direct conversations between the continents – albeit at the glacial rate of a few words per hour.

Bulky copper cables remained the status quo for over a century. And then along came optical fibres: glass cylinders the width of a human hair. Capable of transmitting information over vast distances using laser light, they enabled our modern connected world. Today, more than 2 billion kilometres of optical fibres criss-cross the globe, with more rolling off the production line at a rate nearly 20 times the speed of sound.

Light, resilient and cheap, optical fibres have stayed with us as our communication habits have transformed. In 1992, the world's internet usage was shifting around 100 gigabytes of data a day. By 2014, that amount was being transferred every 60 microseconds.

Our gargantuan appetite for data is now threatening to push the fibres to breaking point. Small improvements won't do; what's needed is nothing less than another revolution. In a surprising twist, making better optical fibres might mean dumping most of their glass – and then downgrading what remains.

The first optical fibre revolution came about in the 1970s, kick-started by our new ability to mass-produce high-quality glass that could carry light over long distances without impurities scattering it along the way. For long-distance communication, the trick was to trap light within the fibre's confines even as it bent around corners.

To achieve this, engineers clad each fibre in a glass coating, chosen to ensure that light hitting this cladding at certain angles will be completely reflected back. Instead of escaping, the light bounces along without losing much of its original intensity. Compared with old-fashioned copper cables, these optical fibres proved far better at carrying huge amounts of data over long distances – so much so that we quickly took their effectiveness for granted.

Optical fibres are glass cylinders no wider than a human hair
Dave Stock

"In the past, the data-carrying capacity of an optical fibre was almost viewed as limitless," says David Richardson of the Optoelectronics Research Centre at the University of Southampton, UK. Once the fibres themselves had been laid, improvements in transmitters, receivers and amplifiers meant data could be pumped through ever faster.

But times are changing. "We are beginning to reach the point where we hit fundamental limitations in how much data we can send through conventional optical fibres," says Richardson. There's some debate as to where this limit lies, but it is likely to be in the region of 10 times the throughput of today's fastest networks. That might seem like plenty of breathing space, but at current rates of growth we could be up against the ceiling by 2020.

By far the biggest guzzler of internet capacity is video, which accounts for around two-thirds of internet traffic today (see "Conspicuous consumption"). The rise of on-demand services like Netflix, as well as our hunger for higher-quality video, means that figure is likely to rise to 80 per cent by 2019. "If everybody gets superfast broadband tomorrow," says Polina Bayvel at University College London, "then the national infrastructure will have to be upgraded today."

That's even before you consider developments such as the internet of things, which tech companies like Cisco predict will span 50 billion smart devices by the end of the decade. The associated surge in data could lead to big downloaders paying hefty charges for clogging up the system, leaving the rest of us sharing an expensive, throttled service. This could, in turn, spell the end of the idyllic era of net neutrality, in which no user has priority in how their internet traffic is handled. If we want to avoid the capacity crunch in a way that is fair to everybody, we're going to need an upgrade.

That said, there are still a few things we can do to pump more data through existing fibres. At present, one fibre doesn't carry just one laser beam; instead, there are up to 160 beams of different colours that are merged for transmission – like putting a rainbow through a prism to form white light – then separated out at the other end. Putting more data through means increasing the intensity – but there's a snag. "The problem is that as we increase the power, the beams start to interfere with each other," says Richardson. This "non-linear crosstalk", which increases with beam intensity, is the result of each frequency bouncing off the inside of the fibre at a slightly different angle, causing the whole lot to merge in a way that makes it hard to decipher the transmission.

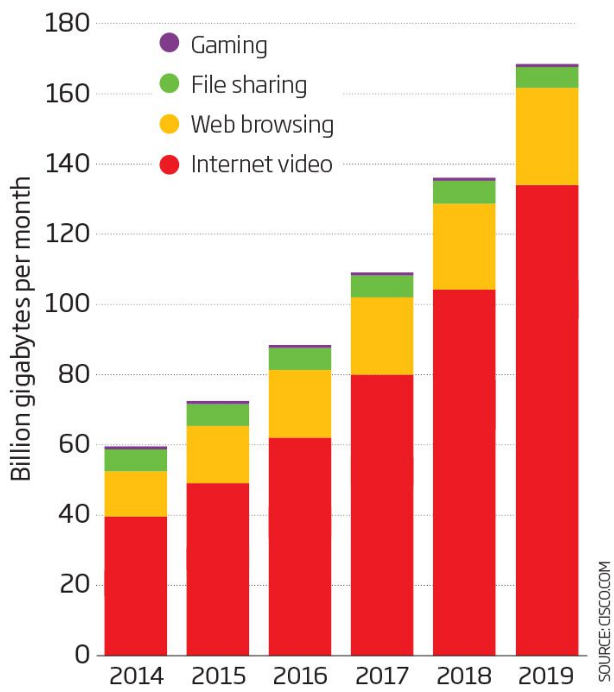
To deal with this, we program computers at each end of the fibre to correct the distortions and recover the original signal. But a better approach might be to re-engineer the light en route. Plant a device called an optical conjugator halfway along the fibre, and you can send a mirror image of the distorted waves down the fibre's second half, miraculously cancelling out the distortion by the time they reach their destination.

"In certain circumstances it's going to be a brilliant solution," says Bayvel. If there's only one route a packet of data can take – as is the case, for example, when sending a message across the Atlantic – positioning such a conjugator halfway across would be easy. But most of the time signals have thousands of routes to choose between, and so ensuring that every signal goes through a conjugator at the right point in its journey would mean a significant system redesign.

A more unusual alternative starting to find favour involves redesigning the beam sent down the fibre. "Usually when we think of light, we imagine a laser pointer creating a bright spot on the wall," says Martin Lavery at the University of Glasgow, UK. Although it might appear to be a point, that spot is actually large enough to accommodate a spatial pattern capable of encoding extra data.

Conspicuous consumption

The growth in data being shared over the internet shows no sign of slowing

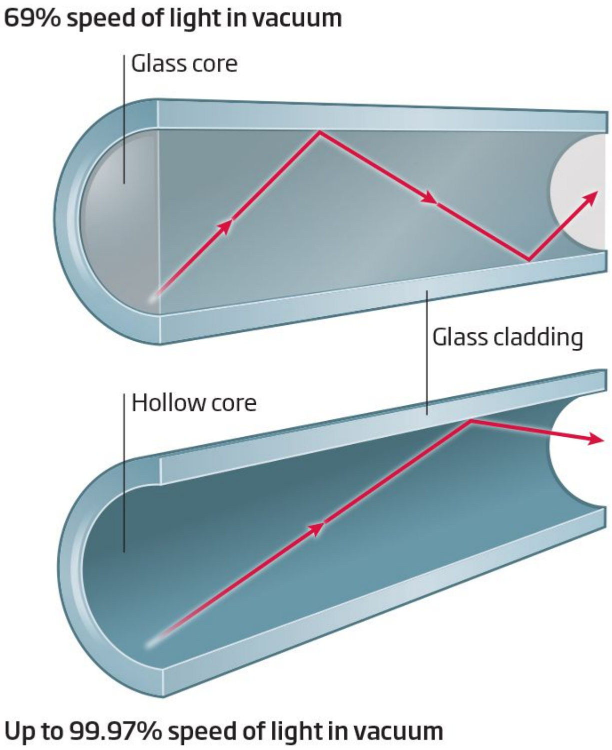


By shining the laser through a spiral, we can give the beam a twisted appearance. Then, says Lavery, like individual strings being braided together to form a rope, the twisted beams can be transmitted as one, each carrying its own signal that can be separated and read at the other end. “We can potentially have an infinite number,” says Lavery. “The only restriction is the size of the optical fibre.”

Twisted light could provide an efficient way of cramming in those extra beams, but as yet it has not managed to shine outside of the lab.

Air of superiority

Hollow-core fibres are taking over from their conventional counterparts



If we want a commercially viable system, some believe we need to rethink optical fibres completely. Walter Belardi at the University of Southampton is one of a growing number of researchers contemplating a radical idea: replacing most of each fibre with… nothing.

This gives rise to what are known as hollow-core fibres, which have an air-filled centre. "With hollow-core fibres, 99.99 per cent of the journey is done in air," says Belardi, allowing the light to travel up to 45 per cent faster. But there is a snag. When light travelling down the core hits the glass wall, it no longer gets reflected as happens in conventional optical fibres, but risks leaking into the cladding (see "Air apparent"). "Instead you have to micro-engineer the glass," says Belardi, a difficult process that involves etching intricate marks onto the fibre's inner surface.

Cue a second breakthrough, which is down to Belardi himself: if the light mostly travels through air, then the quality of the glass is no longer important. Paradoxical though it may seem, lowering the quality of the glass can even make the fibre perform better. The higher temperatures required to make purer glass also produce a rougher surface, making it more difficult to micro-engineer. Belardi has instead been experimenting with the kind of glass used in wine glasses, windows and everyday cookware. It is over 100 times cheaper than the glass used in conventional fibres, yet potentially capable of transmitting a signal over longer distances.

The superior signal speed of hollow core fibres has already sparked interest from the financial industry, for which billions of dollars' worth of trading deals depend on rapid access to information. The precious microseconds gained by a faster connection could yield a substantial return. But because hollow-core fibres suffer a signal loss around 10 times that of conventional fibres, the communications big time may still be a way off. A range of more exotic applications (see "Hollow promise") may take precedence for the moment.

Although hollow-core fibres are in need of improvements before they connect the world, Belardi can see light at the end of the tunnel. Their faster signal speeds and reduced costs could make up for their greater signal loss. And as theory starts to be put into practice, the gap between old and new technology may narrow further. The real golden age of optical fibres could be just around the corner.

HOLLOW PROMISE

Fancy a lightsaber? Just keep raising the intensity of light sent through an optical fibre. The very same techniques that underlie optical fibres can be used to produce industrial lasers – glass hosepipes capable of emitting bursts of light powerful enough to cut through sheets of solid metal.

The tremendous power and flexibility of fibre lasers means they are already being used in mineshafts and manufacturing plants around the world. But as you keep upping the intensity, conventional fibre lasers run into a problem — they become powerful enough to melt the fibre itself. So researchers are instead looking to fibres with a hollow core of air, capable of withstanding much higher temperatures (see main story).

Over a thousand of these lasers could, in principle, be combined to create an unprecedentedly powerful laser, says David Richardson of the University of Southampton, UK. "And once you get to these sorts of power levels, you are able to do some quite interesting things." Some of the most ambitious applications include a highly focusable laser that could be used to blast space debris out of orbit, causing it to disintegrate in the atmosphere rather than crashing into a satellite or space station.

Another application, already being explored, is as an alternative design for the huge accelerators used in experiments such as the Large Hadron Collider at the CERN particle physics laboratory near Geneva, Switzerland. Beaming lasers of this intensity through just a few metres of plasma can generate shock waves capable of accelerating charged particles to within a whisker of the speed of light.

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