RTT	**RTT TECHNOLOGY TOPIC February 2012**
	The new carbon economy

On February 2nd 2012 the UK government announced that £50 million of funding would be available to support the Graphene Institute, a **graphene research programme at Manchester University.**

Graphene was discovered at the University in 2004 and in 2010 the Nobel Prize for Physics was awarded to Professors Geim and Novoselov for their **pioneering research work** on 'the world's thinnest material'.

In this month's technology topic we review the potential impact that graphene could have on the telecoms industry, but first some historical context.

The invention of Facebook

30,000 years ago some unknown Neanderthals picked up a piece of charcoal from the cold remains of a fire and began drawing on the wall of their damp and gloomy cave, prehistoric Facebook had arrived.

Charcoal is activated carbon, carbon that has been processed to make it porous with a large surface area available for adsorption, the ability to make atoms, ions, biomolecules or molecules of gas, liquid or dissolved solids adhere to a surface. The word carbon is derived from the Latin 'carbo' meaning coal or charcoal.

For Neanderthal families charcoal was a tool that allowed them to express themselves in a new way. For mankind it was the moment when carbon started its career as a component of a communications and memory storage system.

Fast forward to the early 16^{th} century and some unknown village folk discovered a large deposit of graphite close to the hamlet of Seathwaite in Borrodale in Cumbria.

All natural carbon based materials are produced from decayed plants and animals and are transformed by heat and pressure into peat, lignite, coal, anthracite and diamonds. Graphite is formed from diamonds crushed by rock movements close to the surface of the earth.

Graphite is named from the Greek 'graphos' meaning 'to write'. The Borrodale deposit was soft and malleable and good for **pencils, invented in 1565.** The role of carbon as a communications enabler had taken a step forward.

Lars Magnus adds carbon to his phone

Fast forward 450 years and a group of telecom engineers are gathered in the Science Museum admiring the Ericsson magneto telephone designed and manufactured by Lars Magnus Ericsson in 1890.

The phone is one of 300,000 objects owned by the museum of which 30,000 are on display .It was there as the star of Next25, an event which amongst other things set out to demonstrate that the Museum has objects and case study resources that document with great detail why some innovations succeed and some fail, how the past predicts the future.

Lars Magnus Ericsson started a mechanical repair shop in central Stockholm in the 1870's with his friend Carl Johan Andersson. In 1878 they were given a contract to modify telephones from the Bell company to make them compatible with the local telephone network. Ericsson had been an apprentice at Siemens and decided to acquire some Siemens phones to see how they were built. The first Ericsson phone was produced in 1879.

Magneto telephones generated the current for ringing the bell at the called subscriber's end or for calling the operator. In the Ericsson phone the permanent magnets for the generator were made to form the base and support of the telephone itself giving the phone an open skeletal appearance.

A skeleton from a cupboard in the Science Museum.
Ericsson 'skeleton' phone, 1890.
Image used with permission of the Science Museum, London/ SSPL
With thanks also to John Liffen and the curatorial team.

The phone remained popular in many countries until central battery working gradually supplanted magneto exchanges in the first half of the twentieth century.

But the main point is that the device used a carbon microphone.

Elisha Gray and Alexander Graham Bell had both filed patents for a telephone on the same day, February 14 1876. Gray had produced a steel diaphragm transmitter receiver in 1874 but it didn't work well. Bell's version of the same thing was better, sufficient to send intelligible sound over several miles of telephone cable.

In 1877 Thomas Edison developed an improved microphone using compressed carbon. The English inventor Henry Hummings produced a similar device in 1877. Whatever its provenance, Ericsson's use of this new 'component' achieved a big improvement in voice quality and power efficiency. An example of engineering applied to improve existing technology to achieve market advantage.

The carbon microphone works as a sound to electrical signal transducer with two metal plates separated by granules of carbon. Sound waves striking the plate increase the pressure on the granules which then change the electrical resistance between the plates. A direct current is passed from one plate to another and the changing resistance results in a changing current which is then passed through the telephone system. Crucially a carbon microphone continues to work down to a fraction of a volt which meant that substantially longer line lengths could be supported. Given that Ericsson was also now in the switch and telephone network business this improvement in user equipment efficiency could be translated into reduced network cost. Because carbon microphones vary the current passed through them rather than generate a signal voltage they could also be used as amplifiers and were widely deployed as repeaters to make long distance calls possible before the introduction of vacuum tube devices. Carbon in the phone, carbon in the network.

Even when all-electronic telephones became common, carbon microphones continued to have a number of unique advantages. An all-electronic telephone needs at least 3 volts of DC to function. The ability of a carbon transmitter telephone to work down to a fraction of a volt meant the devices would work at the end of a very long telephone line but could also be used in mining and chemical applications where the low voltage reduced the risk of explosion. The natural resistance of carbon microphones to damage from high voltage transients from lightning strikes and electromagnetic impulses from nuclear explosions means they are still maintained for back up communication systems in present day military communication systems.

Carbon in the twentieth century

The applications for carbon and or the derivations or 'allotropes' of carbon continued to broaden through the 20^{th} century, from charcoal used in gas masks through to carbon fibre used in racing cars and aeroplanes.

In 1985 a group of scientists at Rice University discovered another allotrope, a hollow cluster of 60 carbon atoms shaped like a soccer ball and named after an architect R Buckminster Fuller who had designed a geodesic dome with a similar structure. 'Bucky Balls as they became known had many surprising chemical and physical properties including being an efficient organic superconductor. The discovery of Bucky Balls prompted an explosion of research into similar molecular structures leading indirectly to the discovery of graphene.

Carbon in the 21st century

Graphene is graphite rearranged in hexagons one atom thick. Potentially a replacement for silicon and a basis for ultra-fast transistors, graphene has direct relevance to the computer and consumer electronics industry and therefore by default to the telecoms industry.

Mid-way through last year and to mark their 100th anniversary **IBM Research scientists announced** that they had built an integrated circuit fabricated from wafer-size graphene applied as a broadband frequency mixer operating at frequencies up to 10 GHz. Potentially this solves a number of contemporary problems presently exercising multi band cellular phone design teams including noise and insertion loss in broad band devices across present allocated bands and a need to maintain efficiency at higher frequencies and across broader bandwidths in the very near future.

In September 2011 the **University of California and Samsung** announced work on the use of graphene as a storage layer within a silicon substrate.

With silicon based flash, as memory gates get smaller the transistor gates have to be thicker relative to the rest of the circuit in order to store enough charge and the thick gated cells start to interfere with their neighbours. Gates made from graphene are ultra-thin and therefore do not interfere with one another. They also hold more charge than silicon with lower leakage. Graphene based devices would scale down to about 10 nm. Conventional flash scales down to about 22nm below which they become unstable.

In January 2012 the **University of California and the University of Texas in Austin and Dallas and Xiamen University in China** announced work on structurally modified graphene with very high thermal conductivity which could be used in mobile phones and lap tops to improve heat dissipation.

These nanoscale scale devices are structures sized between 1 and 100 nanometres in at least one dimension. A nanometre is a billionth of a metre. Fingernails grow at the rate of about one nanometre per second.

Graphene as a conductor of electricity performs as well as copper at potentially a fraction of the cost. As a conductor of heat it out performs all other materials. As a transistor it is faster and more efficient.

Lars Magnus Ericsson built a business based on efficient user equipment that used carbon to improve voice quality and to deliver enhanced range in terms of supportable line length. The same technology applied to repeaters meant that long distance telephone calls were not only technically possible but also commercially viable.

Today it is becoming progressively more obvious that the efficiency of user devices particularly mobile devices needs to be improved to support present user experience expectations. Conversely as data rates at the edge of the network increase there will be a need for faster more efficient switching which means that next generation router hardware will need to be more efficient. Memory efficiency both in user equipment and in the network will need to improve in parallel in order to realise a return on present and future spectral and network investment.

In 25 years' time it is reasonable to expect that we will be using graphene as the basis for a new generation of RF components that deliver a step function improvement in efficiency and gigabytes of delivery bandwidth capability. In 25 years' time it is reasonable to expect that we will be using graphene based components in terabit routers providing access to graphene based server farms delivering exabytes of storage capability - a new carbon economy as an enabler of a low carbon economy.

Lars Magnus would be impressed but not necessarily surprised.

Ends

More detail on this topic can be found in our new book 'Making Telecoms Work – from technical innovation to commercial success.' Chapter 1 is available as a **free download** from the John Wiley web site but the best bits are in the other twenty chapters and you can buy the whole book on Amazon by going to the **RTT book shop**

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RTT, the Jane Zweig Group and **The Mobile World** are presently working on a number of research and forecasting projects in the mobile broadband, two way radio, satellite and broadcasting industry. If you would like more information on this work then please contact
geoff@rttonline.com

00 44 208 744 3163