SUBMARINE NETWORKS – THEIR GROWTH AND EVOLUTION

On 27 July 2016 in Valentia, Ireland and in Heart's Content, Canada an historical event was celebrated – the 150th anniversary of the successful landing of the first commercial transatlantic telegraph cable.

DEREK CASSIDY

Celebrating telegraphic history

The Irish and Canadian communities, aided by experts from the ITP and the IET, celebrated the significant event by recreating the first telegraph message that was sent over the 1866 cable, 150 years previously to the day.

The message was in Morse code using replica 1860s-70s telegraph instruments to transmit the signal across today's submarine systems – not a straightforward task as telegraph signals were electrical pulses in analogue waveform whereas today's submarine technology uses digital transmission over optical fibre.

The telegraph electrical pulses were manipulated so they could be transmitted via a standard telephone line via a trans-Atlantic optical cable such as Hibernia, TAT-14, AC1 or Yellow to the far side. The direction of the transmission would be from Canada to Ireland and then back again starting the conversation. At the far end, the message was received as Morse code and, via a laptop with a Morse-Analogue-Digital encoding app, was displayed as text in English for the on-looking public to read. A conversation soon took place with members of the public on both sides of the Atlantic taking part, just like 150 years previously using Morse code.

The first submarine cables

In the late 1840s there was huge interest in the development of telegraph systems and research was being carried out worldwide; Morse proved that a cable could be deployed underwater, properly insulated, to carry electrical signals. In Dublin two men, Henry Bewley and Thomas Hancock, discussed the use of a new substance called gutta percha that would aid in the design of a cork for bottles and Hancock set up the gutta percha company later that year. In Germany, a young researcher called Siemens was experimenting with the use of gutta percha as an insulator for telegraph cables and in 1847 successfully deployed a subterranean telegraph cable in Prussia. However, the invention of an extrusion machine by Bewley [1] allowed for more efficient production of insulated cables and so the stage was set for the development of submarine telegraphy.

Figure 1: An example of the 1850 Dover-Calais cable (www.atlantic-cable.com).

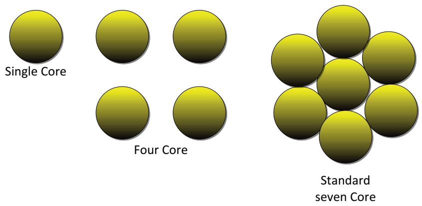

Figure 2: The increase in copper conductors increasing the cross-sectional-area.

In 1850 the first submarine telegraph cable (Figure 1) was successfully deployed by the Brett brothers between Dover and Calais with the first telegraph messages sent on 23 August, 1850. The cable design was a single copper core surrounded with gutta percha as an insulator and weighted down every 100 yards to keep the cable on the seafloor. However, the cable did not last long – it was said to have been cut by fishermen[2] believing it to be seaweed although it was more probably due to poor protection.

So now there was a new problem – how to protect submarine cables from damage. In 1851 the Brett brothers laid an armoured cable from Dover to Calais, using four copper wires insulated with gutta percha. The armour acted an as capacitor enabling better transmission of electrical signals underwater. The cable began commercial operations in November 1851 and lasted 30 years. The use of four separate copper conductors enabled increased telegraph transmission speeds and offered copper core protection. It laid the foundations for future submarine cable design.

Further cable developments saw cables with four copper cores being replaced by seven wrapped around each other (Figure 2) so as to reduce electrical resistance thereby increasing transmission speeds and yielding even better transmission characteristics and an improved copper core survival rate.

Spanning the Atlantic

A cable crossing the English Channel was one thing; crossing the Atlantic, even at its shortest distance, posed many problems, particularly the weight, flexibility and strength of the cable that would need to be laid at huge depths. The deep-sea section of the Trans-Atlantic cable of 1857 had lightweight armour of seven strands of wire in 18 bundles around the gutta percha insulation (Figure 3). The shore end included another layer of gutta percha with galvanised iron wire as its armour protection. The first attempt at laying the cable failed 380 miles from Valentia and the second failed mid-Atlantic; the armouring wire did not have sufficient tensile strength or tolerance to hold its own weight and the tension applied by the paying-out equipment on-board the two ships added to this failure [3]. Further developments in cable laying techniques (pay-out and braking) saw the success of the third attempt in 1858.

Success was short-lived; the cable only lasted 30 days after the breakdown in insulation, due to its mishandling and bad storage methods.

In 1865 a new attempt was made. The armouring was much more solid with three armouring wires in 12 bundles. Even so the cable snapped just 600 miles from its destination in Newfoundland. Finally, in 1866 with an improved armouring design (Figures 4 and 5) and better cable laying techniques, the trans-Atlantic submarine cable was finally laid. The laying team even managed to recover the snapped end of the 1865 cable and splice it to complete that cable; two cables for the price of one [4, 5]. Messages could now be sent across the Atlantic in minutes rather than two weeks by ship.

Expansion of telegraphy globally

This heralded a new era in telegraph technology; submarine cables were laid across the globe with cables from France to Canada, across the Indian Ocean and across the Pacific enabling a growth in telegraph communication (Figure 6). New technologies allowed for the increase in word speed from eight words a minute in 1866 to hundreds of words a minute in the 1890s.

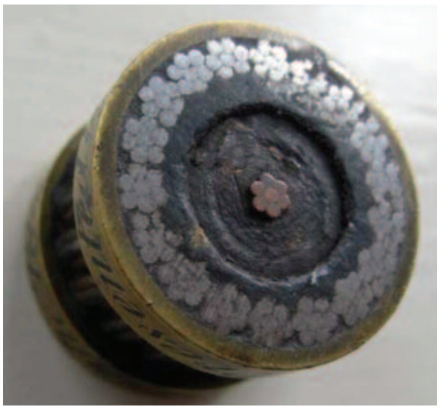

Figure 3: An example of the deep-sea section of 1857-58 trans-Atlantic submarine cable (www.atlantic-cable.com).

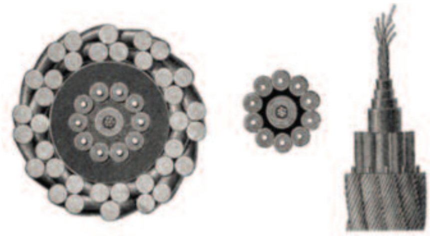

Figure 4: 1865 cable cross sections for shallow and deep water. (www.atlantic-cable.com).

Figure 5: A presentation case of the 1857/8-1865 and 1866 submarine cables (www.atlantic-cable.com).

From telegraphy to telephony

The invention of the telephone in 1876 was seen by many telegraph network operators as a threat to their livelihood but also as a potential way of increasing revenue. It was a slow process of innovation adoption with only the wealthy being able to afford a telephone. In 1884 the first telephony submarine cable was laid across San Francisco Bay although it only allowed for one call at a time and it was consequently expensive.

In Britain and Europe, the telephone began to make its appearance in the houses of the upper classes,whereas in the US it was seen as a way for the masses to communicate. Nevertheless, telephony was appearing more frequently on both sides of the Atlantic but the long oceanic distances and consequent attenuation of signal power meant that telephony could only be used for shorter distances; telegraph networks retained their place in long distance communication.

In the early 20th century with improved telegraph submarine cable designs (albeit broadly in line with the original designs) and technical advances in the telegraph equipment, transmission speeds improved. The next significant improvement was the introduction of loading coils which improved the transmission characteristics of submarine cables at telephony voice frequencies over relatively short distances – a few tens of miles. In 1910, a submarine cable with loading coils was laid across Chesapeake Bay and further developments led to the first international telephone cable – the 90 miles between Havana, Cuba and Key West, Florida in 1921. What made these milestones important was that the cables were of a standard telegraph submarine cable design but with the addition of loading coils which helped to decrease the electrical impedance at voice frequencies. Even so, only one telephone circuit at a time could be supported.

Military uses

During World War 1 and the years up to and including World War 2, the military authorities in the US and Great Britain turned to the old 'out of service' telegraph submarine cables and used them to detect the movement of submarines and ships[1]. By passing a small electrical current along the cable, it would become an electrical inductor; a large metal object (i.e. a ship) passing over the cable would change the inductance and hence the electrical current which could be detected. The

[1] www.indicatorloops.com/loops.htm

Figure 6: The global telegraph network around the turn of the 20th century (www.atlantic-cable.com).

technique proved so successful that the military laid new submarine cables with the same design as the standard telegraph submarine cables across the mouths of most major naval bases and was the forerunner of Sosus system[2] and other systems in use today.

Post WW2 developments leading to TAT-1

In 1928 Bell Labs started research and development into a new design of submarine cables aimed at transatlantic transmission of voice circuits. The economic downturn in 1929 delayed the project but in 1933 another revolutionary cable design was developed; the coaxial cable (Figure 7). It allowed for faster and better transmission of signals thereby enabling telephony voice to be transmitted over a longer distance. Coaxial cable induces its own current or reduces impedance by the capacitance and induction effect created by the coaxial design of the metallic core and metallic shielding/inner armouring.

The outbreak of World War 2 delayed the deployment of these new cables for general use although they were deployed to further the war effort including communications across the English Channel during and after D-Day. Such deployments gave telecom operators the chance to undertake live testing, research and field trials aimed at finding a solution that would enable long distance communications.

The development of amplifiers [6] enabled signals to be transmitted over longer distances. By having many such amplifiers (or repeaters) spaced along the cable, significant distances could be achieved. Another development was that of multiplexing which allowed for several voice channels to be transmitted over the same electrical conductor. The combination of coaxial cable, repeating amplifiers and multiplexing led to a new era in voice telephony and opened the way for a new transatlantic cable that was deployed by the GPO and AT&T in 1956 – TAT-1 (Trans-Atlantic Telephone cable #1). At this stage in multiplex design, only one direction of transmission could be supported and therefore two cables had to be deployed, one transmitting west to east and the other east to west.

Expansion of telephony globally

The drive to communicate by telephone and the technology developments that led to TAT-1 [7] soon resulted in the deployment of a global voice network that would equal the old telegraph networks. By 1966, telegraph networks around the UK and Ireland began to decline as the ever-increasing number of long distance submarine coaxial telephony cables increased. The strategically important telegraph station in Valentia, County Kerry closed that same year. The telephone had the capability to carry voice and data (such as facsimile) and enabled telegrams to be sent quicker, faster and cheaper. The advancements in communication systems, submarine cable design and underwater amplifiers allowed the number of voice circuits to be increased from 32 in 1956 to over 4,000 in 1976 with the introduction of TAT-6.

Since the original design of the submarine cable in the 1850s through to the 1970s, only a relatively small number of changes

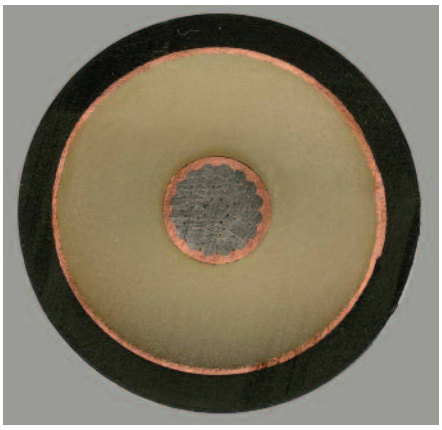

Figure 7: Coaxial cable (www.atlantic-cable.com).

Figure 8: Coaxial submarine cable (www.atlantic-cable.com).

[2] www.nytimes.com/1985/06/06/us/spy-case-is-called-threat-to-finding-soviet-submarines.html

Figure 9: The optical fibre submarine cable of BT-TE-1 on the left and the 1947 Eire P&T submarine cable on the right.

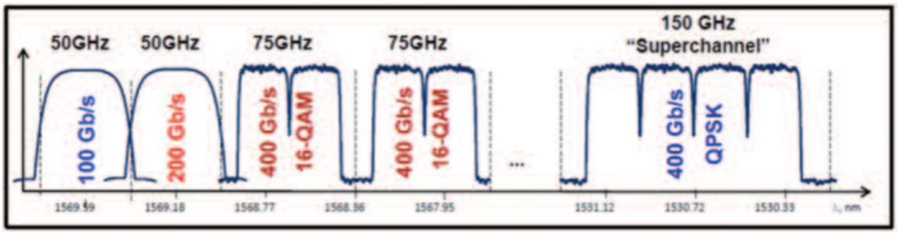

Figure 11: Flexi-grid optical spacing for dense wave division multiplexing. (Image courtesy of Viavi; www.viavisolutions.com).

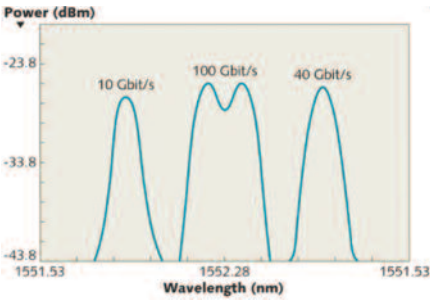

Figure 10: 10, 40 and 100Gbit/s optical channels (http://www.ethernetalliance.org).

were made to the actual cable design. The metallic core of the telegraph cable changed from one to four, then to seven strands and then, with the development of the coaxial cable, back to a single core. Gutta percha insulation gave way to polyethylene. The central conductor was still copper or alloy surrounded by an insulator and then a copper or alloy sheath or shielding which also acted as a power conductor with the outer armouring being the earth (Figure 8). However, that was to change. During the early part of the 1980s the potential of optical fibre as a transmission medium for submarine cable was being studied.

Optical fibre cables and capacity innovation

Trials into the use of optical submarine cables were carried out in Loch Fyne and in 1986 the first international optical submarine cable was laid between the UK and Belgium, UK-Belgium-5. It was soon followed by other systems including the first optical cable between the UK and Ireland called BT-TE-1 (Figure 9) in 1988. In the same year, another transatlantic milestone was reached; TAT-8 – an optical fibre system laid between the UK, France and the US capable of carrying over 40,000 voice circuits. Optical fibre allowed for the transmission of multiple times the capacity of TAT-6 or TAT-7 and was capable of long distance transmission with the use of the newly developed underwater optical amplifier.

Although signals transmitted over optical fibre attenuate with distance, the attenuation is far less than with coaxial cable which meant that amplifiers could be placed further apart thereby improving reliability. Also, because the optical systems use digital transmission, regenerators could be used in conjunction with the amplifiers, to clean-up and restore the digital signal to its original form thereby avoiding the degradation in signal-to-noise with distance that ultimately limited the analogue systems.

The development of dense wave division multiplex (DWDM) systems with multiple wavelengths across the fibre pairs resulted in massive increases in capacity [8]. Further developments in fibre design and optical systems increased this further. 40Gbit/s and 100Gbit/s wavelengths were being deployed on submarine cable networks as required to meet the capacity demand (Figure 10).

With the ever-increasing growth in data-rich video and Internet traffic, the need to increase bandwidth is ever-present [9]. The recent standardisation of optical channel spacing allows for capacity increases to be achieved by upgrades rather than replacement with the advantage of a significant reduction in expenditure especially when it comes to long distance submarine systems. The introduction of a flex-grid system (Figure 11) allows DWDM networks to incorporate a variety of optical channels. Even with these advances, it is a case of running just to stand still in the relentless demand for more capacity.

Other applications of submarine cables

A proposal being investigated is the re-use of out-of-service submarine cables to connect smaller island or coastal communities to the broadband and next generation networks where the expense of laying a new cable or delivery via terrestrial cable is prohibitive or impossible. An existing out-of-service optical submarine cable could, at the fraction of the cost of a new cable, be taken up and re-laid to connect the island community.

The use of submarine cables, including out-of-service-cables, is being used to support research into wave energy, tsunami warning systems, sensor demonstration and validation, environmental monitoring and climate change (Figure 12). The Smartbay marine and renewable energy test site hosts an underwater observatory within Galway Bay where the Marine Institute has laid a new submarine cable to provide power to and receive high volumes of data from an underwater observatory within the test site.

AUTHOR'S CONCLUSIONS

Submarine cables have come a long way from being a single copper core conductor insulated by gutta percha and transmitting three to four words a minute. These days they are the global backbone of the Internet and they will continue to develop and play a vital role as global telecommunications develops along with the ever-increasing demand for bandwidth. With the development of the Internet of Things and video, which uses up as much as 65% of the world's communication bandwidth and rising, there is a need to develop faster systems with larger capacity with wavelengths in the 400Gbit/s and 1Tbit/s region.

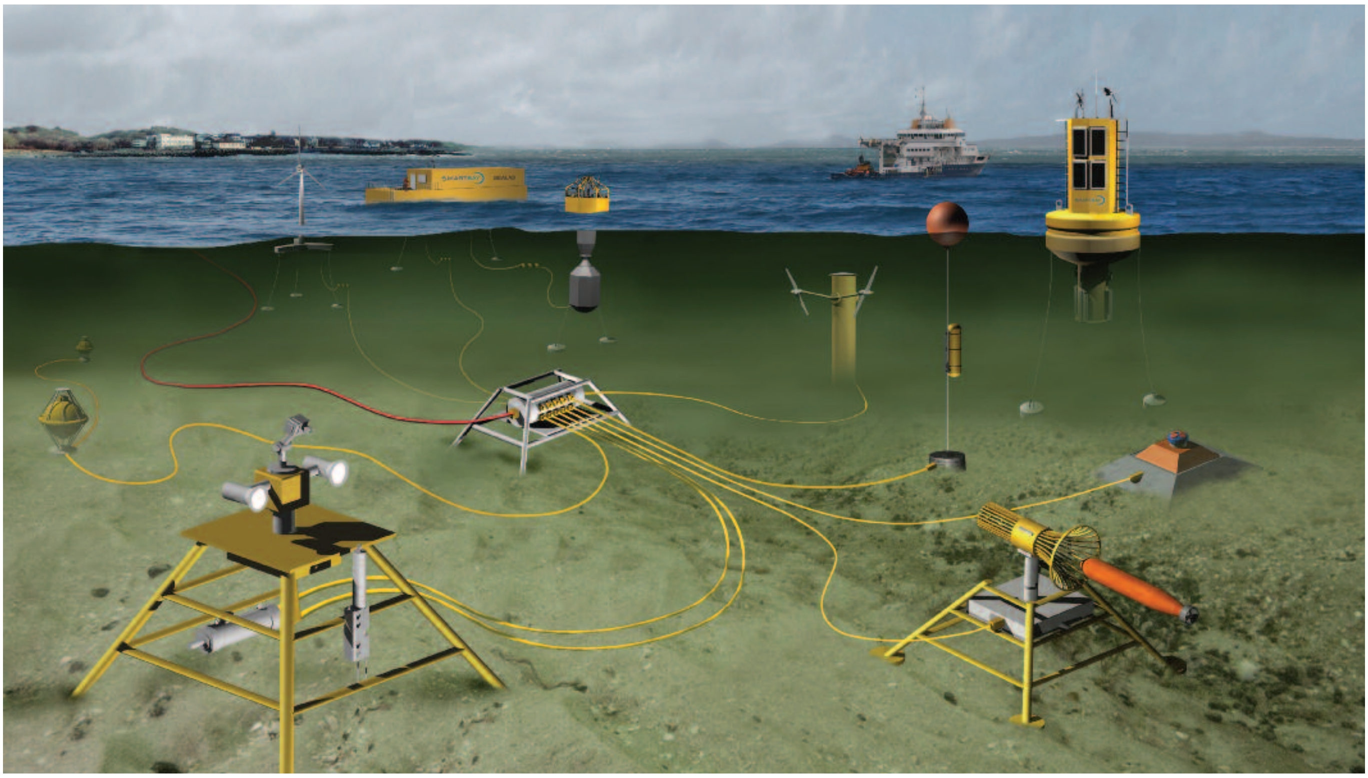

Figure 12: An impression of the many different uses of submarine cable technology in use. (Image courtesy of Smartbay; www.smartbay.ie).

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ABOUT THE AUTHOR

Derek Cassidy is a Chartered Engineer with the IET and he has worked for 23 years in the telecommunications industry of which 18 years have been working for BT in their Field Engineering division. He is Chairman of IET Ireland; Chairman of the Irish Communications Research Group, an organisation dedicated to the promotion, protection and research of Ireland's communication heritage, and is also a member of the IEEE, holding a position of Head of the IEEE (Ire) Entrepreneur Network and a member of Engineers Ireland.

Derek holds the following Degrees; BSc (Physics/Optical Engineering), BEng (Structural/Mechanical Engineering) and BSc (Engineering Design) and has a Masters Degrees MEng (Structural, Mechanical, and Forensic Engineering) and a Masters Degree MSc (Optical Engineering).

He is currently researching the Communication History of Ireland and is doing a PhD in the field of Optical Engineering and wavelength manipulation with UCD.

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