RTT TECHNOLOGY TOPIC
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Is the Past the Future?

The news this week has been dominated by two events, the assassination of Osama Bin Laden and at least for us in the UK, a Royal Wedding. Mr. Bin Laden avoided being discovered by not having telephone or internet access. The new Mr. and Mrs. Windsor by contrast managed to break a number of internet and TV viewing records. In this month's technology topic we reflect on the significance of the Wedding of the Week and what it might mean for the future of our industry.

The Royal Wedding and the twisted pair

On the 21st July 1969 five hundred million people sat in front of a television to watch Neil Armstrong step on to the moon. On the 29th July 1981 750 million people watched Charles and Diana's wedding. On April 29th 2011 more than two billion people watched William and Kate getting married and an extra 400 million or so watched via the internet. Add in the text, calls and picture messaging from the one million onlookers and 8500 journalists along the Mall and you have a new benchmark for the pulling power of linear TV along side newer forms of modern day communication.

Certainly it confounds any predictions that linear TV would disappear as a mainstream medium and or that wireless broadcast would become steadily less pervasive over time – a prediction made by **Professor Negroponte** fifteen years ago.

The British Monarchy is an apparent anachronism with no apparent purpose but few would disagree that it provides a picturesque excuse for pageantry and pomp which is quite frankly about the one thing the British still manage really well - a nation of party planners. The BBC excelled once again in building on its ninety year tradition of praising the empire and all who sail in her and quite possibly will still be doing so ninety years from now.

In telecoms the power of legacy also still applies.

TV footage of the wedding came into most households via a roof mounted antenna and then through a length of coaxial cable invented by Oliver Heaviside in 1880.

Internet footage of the wedding mostly arrived having travelled for at least some distance over twisted pair cables invented by Alexander Graham Bell in 1881.

Predictions that fibre would be everywhere by the turn of the 21st century seem as daft now as they seemed at the time.

The reason for this is that legacy technologies have the advantage of being fully amortized and supported by decades of sunk investment. Just think of all those pressure treated telegraph poles still standing after 40 years of daily exposure to the wind, rain, small insects and the woodpecker community. Legacy technologies also get better over time. This does not prevent other technologies developing in parallel, for example mobile broadband connectivity but it is wrong to assume that new technologies displace old technologies. The process is more often one of rejuvenation rather than replacement.

We can illustrate this by looking at coaxial cable and twisted pair evolution over time.

Co axial cables have an inner conductor surrounded by a flexible tubular insulating layer and an outer shield. The derivation of co axial refers to the geometric relationship between the inner conductor and outer shield. The advantage of coaxial cabling is that the electromagnetic field carrying the signal is guided through the space between the inner and outer conductors. This means that the cable is resilient to external electromagnetic interference and can be laid next to metal objects, for example gutters and metal conduit. The cable acts as an efficient wave guide at higher (RF) frequencies. Coaxial cable is more expensive than fibre on a per bit basis, cheaper than some types of fibre on a per meter basis but more expensive than copper particularly on a per meter basis.

The problem with copper pairs as a lower cost alternative to coaxial cable is that they suffer from cross talk. This is mitigated by twisting the cables at different twist rates. They can then be bundled together without the need for shielding. This is known as an unshielded twisted pair or UTP. Unshielded means the twisted pairs are unshielded from each other rather than the outside world.

UTP cables are used for indoor telephone wiring for example for phone or Ethernet connections and often grouped into sets of 25 pairs within an outer sheath.

Outdoor telephone cables can contain hundreds or thousands of pairs divided into bundles – the cables within each bundle have different twist rates and the bundles are then bundled together again using different twist rates.

Twisted pair copper cables are repurposed for data by adding a micro filter that ring fences the 3.4 KHz of voice bandwidth, leaving the higher frequencies to be used as a series of multiple carriers in the frequency and time domain. These higher frequencies suffer more aggressive impairments including Far End Cross talk (FEXT), Near End Cross Talk (NEXT) and impulse noise.

Impulse nose is typically of the order of a few microseconds and is caused by power line transients or electromechanical switches or current surges in electrical equipment. Impulse related error rates can be reduced by forward error correction.

Far end cross talk occurs when signals from the far end of a twisted pair couple with the weak received signals from the far end of another twisted pair. This is a dominant impairment in ADSL. Near end cross talk occurs when signals transmitted towards the far end couple with weak signals originating from the far end.

A telecoms engineer from fifty years ago would be probably surprised and certainly impressed by what can now be squeezed along two pieces of copper wire. Many of the techniques used are however based on prior art used in legacy systems and close examination of the components used would reveal more similarities than differences. So for example the challenge today is to achieve higher data rates (capacity gain) by using higher frequencies in the twisted pair local loop.

The challenge in a legacy network has traditionally been to realize more voice capacity, for example on the coaxial circuits feeding the local loop. A 9.5 mm co axial cable carrying 2700 voice channels would typically have a 6 dB per 2 kilometre propagation loss at 300 kHz and a 40 dB loss at 12.5 MHz. This required (still requires today in legacy networks) attenuation equalization and phase equalization.

Attenuation equalization is needed to avoid strong signals swamping weak signals. Phase equalization is needed to mitigate the effects of group delay caused either by the propagation medium or by filters or repeater amplifiers. Amplifiers also of course introduce noise and create intermodulation.

As with co axial cable, the capacity distance product for a twisted pair is a function of wire size and data rate. A DSL (digital subscriber line) example is shown in the table below

Wire size	Data rate	Distance
0.5 mm	1.5 - 2 Mbps	5.5 km
0.4 mm	1.5 - 2 Mbps	4.6 km
0.5mm	6.1 Mbps	3.7 km
0.4 mm	6.1 Mbps	2.7 km

The length and the quality of the local loop determine the upper limit of the frequencies that can be used which in turn increases the capacity. Distance can be increased by using repeater amplifiers.

Apparent capacity gain is also achieved by configuring the upstream/downstream to be asymmetric in the downstream direction, matching bandwidth availability to an assumed asymmetric traffic demand. Hence the term **A**symmetric **D**igital **S**ubscriber **L**ine.

The advantage of asymmetry was first observed by Joseph Leichleder, a scientist at the Bell Core laboratories in 1989 when working on options for delivering TV over the local loop to compete with cable TV. HFC networks proved to be technically and commercially more efficient than ADSL and quickly became dominant in this application domain. In retrospect this hardly mattered because ADSL proved to be just what was needed for low cost internet access. Trials in 1996 led on to implementation from 1998 onwards.

The ADSL 1standard G992.1 ratified by the ITU was finalized in 1999 with the option of deploying on an ISDN line from 120 KHz upwards or a POTS line from 25 KHz to allow for a micro filter to protect existing voice services between 300 Hz and 4 KHz.(If implemented with a legacy voice service).

An ISDN 2B+D line supports two 64 K 'bearer voice channels and a 16 K data channel. The majority of ADSL implementation in a majority of countries is on the legacy POTS network though Germany and Japan are two exceptions with high legacy ISDN investment.

The ADSL upstream bandwidth on a shared POTS line with legacy voice extends from 25.875 KHz to 138 KHz which is divided into discrete multi tones (frequency sub carriers) set at a channel spacing of 4.3125 KHz. Each tone carries information bits from a bin. A bin as the name implies is a destination for data bits that are then mapped on to available sub carriers. The mapping can be selective in order to avoid impaired sub carriers or otherwise unavailable bandwidth. Upstream ADSL1 has up to 32 bins (32 times 4.3125 KHz = 138 KHz). Downstream bandwidth is from 138 KHz to 1104 KHz supporting 256 tones at 4.3125 KHz spacing mapped to 256 bins.

Headline data rates are 1.8 M/bits/s on the upstream and 12 M/bits/s on the downstream but the practical capacity/distance constraints reduce this to 8.448 Mbps at 9000 feet, 2.048 Mbps at 16000 feet or 1.544 Mbps at 18000 feet.

The ADSL 2 standard G992.3 was ratified in 2002 and is similar to ADSL 1 except that the downstream can be extended below 138 KHz to provide an enhanced upstream of 3.5 Mbps. The ADSL2+ standard G.992.5 was ratified in 2003 with upstream bandwidth extended to 12 MHz to support 512 sub carriers. The headline data rates are 2.3 Mbps for the upstream and 24 Mbps for the downstream.

VDSL1 (**v**ery high bit rate **d**igital **s**ubscriber **l**ine) was ratified in 2003 but the more comprehensive G993.2 VDSL2 standard was completed in 2006. The various iterations of both standards are described as profiles.

VDSL1 was specified for 8 MHz and 12 MHz operational bandwidths extended in VDSL to include frequencies up to 17 MHz and 30 MHz.

The profile number denotes the bandwidth and the letter denotes the power which is determined by whether or not the VDSL service overlaps other services. For example a reduced power is needed in some circumstances to mitigate cross coupling effects.

The 30 MHz option also supports wider channel spacing, 8.625 kHz rather than 4.3125 KHz.

The table below lists the profile and power outputs and the table after shows the ADSL and VDSL band plan.

VDSL 2 profiles

Profile	8a	8b	8c	8d	12 a	12 b	17a	30 a
Bandwidth(MHz)	8.832	8.832	8.5	8.832	12	12	17.664	30
Number of sub carriers(tones)	2048	2048	1972	2048	2783	2783	4096	3479
Carrier spacing	4.3125	4.3125	4.3125	4.3125	4.3125	4.3125	4.3125	8.625
Line power dBm	+17.5	+20.5	+11.5	+14.5	+14.5	+14.5	+14.5	+14.5

Higher power, for example over +20 dBm, will increase power consumption as the line driver will require a higher bias current to deliver the higher voltages needed on the line. The higher power outputs also require more linearity which is harder to achieve over wider operational bandwidths. For example the 8b option above with +20.5 dBm of power is downstream limited to 8.5 MHz operational bandwidth. The wider bandwidths will require higher sampling rates which create DAC/ADC performance challenges which will be compounded by the additional clock cycles needed for the IFFT/FFT transform as the number of tones increase.

But the real problem will be the cross talk created as new high bandwidth services are introduced that have to co share with legacy services.

There are effectively two constraint mechanisms – the fundamental propagation constraints of the medium and the unwanted cross talk between services co sharing the medium

The downstream data rates for VDSL derive from sub multiples of SONET (Synchronous Optical Network) and SDH (Synchronous Digital Hierarchy) data rates which presumably would imply that 155.52 mbps would be the next benchmark to aim for. VDSL is however presently configured as symmetric bandwidth.

These higher data rate channels are susceptible to channel time dispersion (CDT) and frequency dependent noise (FDN) and will degrade the performance of other legacy services sharing the medium.

Various techniques can be applied to mitigate these effects.

These can be illustrated by tracing through the processing steps in the transmit/receive chain.

In the transmitter a Reed-Solomon error-correction code is used to encode the high-speed data stream and then extracted into lower-speed data sub-streams which are then placed on each sub carrier using quadrature amplitude modulation.

The number of carriers to be used is determined during bit loading and then transformed into a time domain signal using an inverse discrete Fourier transform. (IDFT). A cyclic extension is added to mitigate channel dispersion effects.

In the receiver the time domain signal is equalized and a discrete Fourier transform brings the signal back into the frequency domain. Frequency equalization is then performed on each carrier and then demodulated and passed on to the error decoder.

Splitting the high data rate stream into lower bit rate streams reduces Inter Symbol Interference and the combination of a time domain equalizer and frequency domain equalizer provides channel throughput gain in return for additional clock cycles.

Sub carriers with low signal to noise ratios can be avoided or bit loading can be reduced. Countries like Japan with legacy ISDN for example will end up not carrying ADSL or VDSL on lower frequency sub carriers.

There will also be interference between upstream and downstream bandwidth which needs to be accommodated with guard bands although in theory the sub carriers should be orthogonal to each other and therefore should not interfere with each other.

This however depends on the length of the loop .A connection from a home or business to a fiber node a few hundred meters away will behave very differently to a medium or longer loop application of three or four kilo feet (1-1.2 km). The longer loop will require additional echo cancellation and time domain equalization and the higher frequencies in the loop will be more highly attenuated.

So there are two fundamental performance considerations. How does the individual point to point link behave and what does it do to other user's co sharing the same medium. Take for example a live bundle with a pair count of 25 twisted pairs. Once the first DSL circuit is added the amount of cross talk will drastically increase and increase further with each additional DSL circuit. There may also be T1 and E1 signals on the line. The spectral density of these services may make them incompatible with DSL circuits.

This becomes problematic when cable bundles are shared between telecommunication companies and imply a need for some form of spectral policing which in turn implies a need to measure power spectral density across all utilized frequencies.

So in many respects copper is similar to wireless. As data rates have increased power spectral density has increased and this is increasingly causing user to user interference which has to be actively managed.

The use of OFDM allows an individual user's bandwidth to be sub divided down into frequency sub carriers that are orthogonal to each other or in other words theoretically at least do not interfere with each other. Each individual sub carrier has a relatively low symbol rate which minimizes problems with inter symbol interference. Different users are however not orthogonal to one another and the result is an increasing amount of cross talk. This complicates access economics.

Supplying a high data rate service to an individual user, for example a VDSL2 connection has a direct cost, for example a VDSL line card and modem. This cost can be easily accounted. However implementing the service will have a direct impact on all other users' co sharing the delivery medium. This cost is not easily accountable and the users who suffer service degradation may be supported by another service provider.

Thus we have a conundrum. The copper access network has been progressively unbundled on the basis that allowing competing providers to share access bandwidth encourages market efficiency. This has unfortunately coincided with technology innovation that makes this co sharing less rather than more efficient unless firm spectral policies are developed and enforced.

The assumption is often made that OFDM provides additional user to user interference resilience. This is not the case. What actually happens is that the modem will avoid using sub carriers that are badly impaired. There is therefore a direct physical layer capacity cost suffered by other users whenever a new high data rate service is deployed in a local loop. This is physical layer contention loss expressed in the frequency domain. There will also be MAC layer contention loss expressed in the time domain.

In terms of access economics copper has the advantage over fibre in that it is usually already deployed and fully amortized. The problem is that the income from a user is not directly coupled to the cost which will be born by other users in the form of a degraded service offering. The problem has been exacerbated by competition policy that has encouraged service unbundling in the belief that this will improve market efficiency and a relaxed regulatory environment that has failed to take into account potential spectral interference issues.

Thus theoretical improvements in market efficiency are dissipated by the technical inefficiency that is consequent on the competition policy that was introduced on the assumption that overall delivery efficiency would improve. This is not necessarily the case and a strong argument could be made that artificially created competition in the local loop will prove to be an expensive experiment which will fail in the longer term.

In next month's Technology Topic we explore why mobile broadband seems, at the moment at least, to be defying logic in a similar way.

Three Kings and a Queen

If you are not completely overwhelmed with royal wedding euphoria then RTT has more joy in store for you in terms of a free download of a short heritage article tracing the impact of ninety years of broadcast innovation on the British Monarchy and British Political System.

This includes a unique recording of George V's speech at the Empire Exhibition in Wembley in1924 which as far as we know you will not find anywhere elsewhere on the internet but which is reproduced here with joint permission of the British Library and the BBC sound archive department. George V was William's great great grandfather in case you didn't know.

The article can be downloaded **HERE** but if you cannot suppress your excitement any longer go direct to the **George V on Empire Radio live.**

If you are interested in how Public Service Broadcasting shaped British national identity we recommend an excellent new book The BBC and national identity in Britain, 1922-53 by Thomas Hajkowski, Manchester University Press ISBN 978 0 7190 7994

Study from RTT
RTT has produced a 70 page study on LTE user equipment and LTE network economics. The study is written by RTT with statistics and economic modelling from **The Mobile World** and is sponsored by **Peregrine Semiconductor** and **Ethertronics.**

The study, 'LTE User Equipment, network efficiency and value' is available free of charge from the linked web site **www.makingtelecomswork.com**

Makingtelecomswork.com

An additional level of detail on this topic and related topics can be accessed via the **Resources section** of our linked web site **www.makingtelecomswork.com**

www.makingtelecomswork.com provides a cost and time efficient way in which telecommunication engineers, product managers and policy makers can access **technical information and advice not readily available elsewhere in the public domain.**

The web site also provides information on RTT workshops, **Making Telecoms Work Europe**, **Making Telecoms Work Asia** and **Making Telecoms Work in the US.** The workshops demonstrate how engineering issues can be practically resolved and how performance gains and cost savings can be achieved. European work shops are held at the Science Museum in Kensington West London. **Information on the next workshop is available here.**

A number of sponsorship opportunities are available linked to the web site and related Science Museum telecom industry educational initiatives.

If you would like more information on these opportunities please e-mail **geoff@rttonline.com** or phone **00 44 208 744 3163**

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