Institution: Aston University

Unit of Assessment: 13: Electrical and Electronic Engineering, Metallurgy and Materials

Title of case study: The world's first terabit transcontinental optical communications system exploiting dispersion managed solitons

1. Summary of the impact (indicative maximum 100 words)

The world's longest high capacity terrestrial commercial communications system, now deployed worldwide, was developed from Aston University's pioneering research on the concept of dispersion managed solitons. The concepts and expertise from this research were used to develop and implement the associated system design for high capacity (1Tb/s) WDM (wavelength division multiplexing) transmission over 1000s of kilometres. Commercial development was led by Prof Doran and the core team from Aston who left the University to found Marconi-Solstis, a part of Marconi plc. Prof Doran and other key members of this team have since returned to Aston The system, now owned by Ericsson, (but still called Marconi MHL3000) has current annual sales of order $100M, and employs hundreds of people worldwide.

2. Underpinning research (indicative maximum 500 words)

Long distance high speed optical fibre communications has provided the core backbone for the internet. The research identified herein was a crucial development in that it paved the way for very long distance (3000km) transmission without the need for regeneration of the signals. This meant that systems could be operated at very high capacity for cross-continent distances and at a cost which has allowed worldwide communication at high data rate.

The key research which led to the commercial system was the concept of dispersion managed solitons and WDM transmission in long distance links. This research was led by Prof Nick Doran who co-founded the Photonics Group at Aston in early 1990s and left to join Marconi in May 2000. He returned to Aston in November 2012. Other members of the original team are also working at Aston. Specifically Dr P Harper is a Reader and has been a member of staff at Aston since March 2005. Drs I Phillips and M Stephens have been back at Aston since 2012 and Dr W Forysiak (Reader at Aston in 2000) has held a joint appointment between Aston and Oclaro as a Royal Society Industrial Research Fellow since October 2012.

A series of EPSRC grants enabled a substantial modelling and laboratory programme to explore and demonstrate the transmission capacity of soliton like pulses in an OOK (on–off-keyed) 10Gb/s and subsequently 40Gb/s symbol rate. The key breakthrough was the discovery in 1995 [3.1] that a suitable arrangement of dispersion compensation (called dispersion management) enabled soliton-like pulses to be stable over ultra-long distance. The key surprise and finding was that the dispersion compensation could allow solitons to be used over standard (lowest loss) fibre. Hitherto solitons had only been enabled over low dispersion fibre which has higher loss and not compatible with WDM. This concept was developed initially by modelling and computer simulations and was verified by detailed laboratory demonstrations. The research identified the suitable dispersion map for 10Gb/s OOK RZ (return-to-zero) modulation and showed that this modulation was superior in stability to alternative modulations such as the standard NRZ (Non-Return-to-Zero). The dispersion management used the parameters of average dispersion and dispersion map strength to match with the required signal power. The design was encapsulated in a simple map strength parameter, S, first defined by the team [3.3]. This strength parameter was used in the system design but was further refined for the final operational system.

This research not only set out the system design but also identified how the nonlinearity and dispersion of high speed systems could be mitigated. In particular for 10Gb/s systems it was shown that standard fibre with compensation was superior to the new low dispersion fibres such as

Truewave® and LEAF®. This was a counter culture concept and the system subsequently designed and operated was focussed on standard fibre. This is now accepted as the optimum transmission arrangement for all long distance high speed systems. The key concepts of dispersion managed solitons were published in a series of papers (refs 3.1, 3.2, 3.3, 3.4 and 3.5). The first work [3.1] established the stability of solitons in a lossless dispersion compensating environment. We identified the enhanced power and the Gaussian like nature of the stable solutions (3.3) and looked specifically at the situation with standard fibre as the transmission fibre with periodic dispersion compensation. In 3.6 we generalised the dispersion managed soliton concept and defined simple design rules.

The key researchers involved were:
Prof Nick Doran (Aston University 1991 to 2000 and 2012 to present) was the team leader and founder of the start-up enterprise Marconi-Solstis.
Dr Wladek Forysiak Lecturer/Reader at Aston University (1993 -2000) and since 2012 Aston/Oclaro Royal Society Industrial Research Fellow.

Students and postdoctoral fellows involved with the team at the time included: Dr P Harper, Dr S B Alleston, Dr J H B Nijhof Dr D S Govan, Dr N J Smith, F Knox (PhD student), A Berntson

3. References to the research (indicative maximum of six references)
The best 3 are indicated by * (1, 2 and 4) with a total of >800 citations (Sept 2013). These publications have had impact far beyond that of optical communications with key citations in physics and applied maths.

*3.1 - Smith, N.J.; Knox, F.M.; Doran, N.J.; Enhanced power solitons in optical fibres with periodic dispersion management; Electronics letters, Vol. 32, pp. 54-55, (1996) DOI:10.1049/el:19960062 (436 citations)

*3.2 - Smith, N.J.; Doran, N.J.; Knox, F.M.; Forysiak, W.; Energy-scaling characteristics of solitons in strongly dispersion-managed fibers; Optics Letters, Vol. 21, Issue 24, pp.1981-1983 (1996) http://dx.doi.org/10.1364/OL.21.001981 (150 citations)

3.3 - Smith, N.J.; Doran, N.J.; Forysiak, W.; Knox, F.M.; Soliton transmission using periodic dispersion compensation; Journal of Lightwave Technology, (Oct 1997) Vol. 15, Issue:10 pp. 1808–1822 doi 10.1109/50.633558

*3.4 - Nijhof, J.H.B.; Doran,N.J.; Forysiak, W.; Knox, F.M.; Stable soliton-like propagation in dispersion managed systems with net anomalous, zero and normal dispersion; Electronics Letters, Vol.33, pp.1726-1727 (1997) doi : 10.1049/el:19971128 (250 citations)

3.5 - Harper, P.; Alleston, S.B.; Bennion, I.; Doran, N.J.; 40 Gbit/s dispersion managed soliton transmission over 1160 km in standard fibre with 75 km span, Electronics Letters, Vol. 35, pp. 823-824 (1999) doi 10.1049/el:19991403

3.6 - Berntson, A.; Doran, N.J.; Forysiak, W.; Nijhof, J.H.B.; Power dependence of dispersion-managed solitons for anomalous, zero, and normal path-average dispersion, Optics Letters, Vol. 23, pp. 900-902 (1998) doi: 10.1364/OL.23.000900

One grant led to much of the research of this case study, namely EPSRC Grant: GR/K54908/01
Title: Ultrafast nonlinear optical transmission, processing and control,
PI: N J Doran Value: £1,090,300, Dates: 01 November 1995 to 31 October 1999.

4. Details of the impact (indicative maximum 750 words)

The key impact is through the deployment of the optical communication system in many countries, for long distance communications, enabling internet traffic and associate commercial and individual activity. The system, developed from the research at Aston, currently (2013) employs over 100 people in its development and sales/support and has annual sales in the region of $100M. The impacts are therefore **commercial for the company**, its **employees** and internet users across much of the world, ie businesses, organisations and the **public** at large.

The development of the impacts achieved later, were initiated when Marconi, a telecommunications company, approached the Aston team to lead the commercial development of a long distance, high capacity optical communication system based on their research. As a consequence of this approach, in mid-2000, Doran, Forysiak and four of the post-doctoral research assistants left Aston to start a new unit named Solstis within Marconi [5.1], with Doran as Chief Technology Officer. Extensive funding (several £10s millions) was provided by the company. Between 2000 and 2003, the team grew to about 80 staff, with a core complement of 15 photonics engineers based on and led by the original Aston team.

Field trials at 5,745 km were reported at *Optical Fiber Communications Conference, 2003.* The first version of the system was deployed across Australia in early 2003 for Amcom IP1 (Australia) Pty Ltd. This system was then created, tested and installed without regeneration across almost 3000km, from Adelaide to Perth by the team with the core leadership provided by the original Aston team. The soliton-based technology provided a cost-effective solution for long-haul networks in two key ways: first it removed the need for repeaters to convert and retransmit electronic signals over distance for clarity; and second it enabled quick and easy capacity upgrades.

The product became the world leader in the field and when Marconi was taken over by Ericsson in 2006, it was incorporated into the product portfolio of Ericsson under the name Marconi Multihaul (MHL) 3000 [5.2]. After the initial demonstration in Australia, the system was sold and installed commercially for implementation and operation worldwide [5.3].

Impact is therefore claimed since 2008, in the **sales of systems** installed across the world and the consequent employment of the staff required to develop and sell and install the system. But the impact of the system is greater than that since its role is to form the **backbone of the internet** and thus the impact could be said to **extend to all who use the internet where the system is deployed** [5.4]. The distance and capacity achieved by this system are the key features which have satisfied the ever growing internet traffic.

There is a large system in the UK now operated (and currently being upgraded) by Vodafone bought from Cable and Wireless in April 2012 as a major part of a $1Bn acquisition, providing meshed connectivity between ~30 major PoPs (Points of Presence), spanning more than 20,500km [5.5]. There are systems throughout Europe with operators such as Deutsche Telekom, Telefonica, Vodafone, Telecom Italia, and TeliaSonera. The Telstra inter-capital and national networks in Australia are dominated by this system. The networks mentioned above have all been installed or upgraded during the assessment period [5.6].

To date (2012/13) Ericsson has sold over 17,000 network elements of this system (an element would typically compose of bi-directional amplification and dispersion compensation) with total sales of approaching $1Bn. It is estimated that "*around two thirds of sales of MHL have occurred during the impact period*" [5.7]; this would amount to >$600m. The system has been deployed and is operated in 50 countries and with over 100 different buyers. Current business generated

amounts to around $100M a year and has been at that level since 2008. Ericsson has ~5% of the world market for optical hardware valued at ~$15Bn a year. This system remains a key product for the company representing about 15% of their total optical hardware sales. [5.7]. It is estimated that over 100 people are employed currently (2013) on this system worldwide in the development, testing, installation and support. Several of the founders from Aston are still employed by Ericsson (and are still working on this product), two in senior positions in worldwide development and deployment; others are involved in either the technology or further research.

5. Sources to corroborate the impact (indicative maximum of 10 references)

5.1.http://www.electronicsweekly.com/news/archived/resources/marconi-start-up-to-target-solitons-2000-06/

5.2. Current product description from Ericsson
http://archive.ericsson.net/service/internet/picov/get?DocNo=28701-FGC1010609&Lang=EN&HighestFree=Y (2010)

5.3. For confirmation of worldwide deployment since 2008
Head of Portfolio Domain Opto and Broadband
Ericsson (China) Communications Co. Ltd

5.4. For confirmation of design of current systems dependence on research
Head of Optical System design
Ericsson Telecommunicazioni SpA
PDU Optical & Metro – Systems and Technology

5.5. Vodafone purchase of C&W Worldwide

'C&WW operates 20,500km of fibre-optic cables in the UK and owning this network will give Vodafone greater capacity at a time when the increasing use of smartphones is leading to a rise in demand for mobile data.' http://www.bbc.co.uk/news/business-17810568

5.6. For confirmation of customers from a former Ericsson employee responsible for the design of the system and now working for Oclaro

5.7. For confirmation of sales and deployment figures
Ericsson Inc.
Head of Technology and Strategy
Product Line Optical and Broadband Access