Institution: University of Essex		
Unit of Assessment: 11 – Computer Science and Informatics		
Title of case study: Development of 10GbE enabled technology for trains yielding commercial benefits for the rail industry and improvements to rail security and passenger experience		
Period when the underpinning research was undertaken: 2004 - 2019		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Stuart Walker	Senior Lecturer, Professor	1988-2004, 2004-present
Geza Koczian	KTP Associate	7 Jan 2013 – 6 Jan 2015
Felix Ngobigha	KTP Associate	23 Jan 2017 – 22 Jan 2020
Period when the claimed impact occurred: 2013 - 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Essex research for the rail industry resulted in **the world's first 10GbE Ethernet train backbone over copper; achieving bandwidth capacity previously considered impossible**. The 10GbE backbone was developed using rail-approved copper cable technology in collaboration with LPA Connection Systems, transforming the company's fortunes and propelling the company to become the market leader [text removed for publication]. Since the technology's launch LPA's turnover increased by 60% with 10GbE product and related sales totalling approximately GBP8,000,000. LPA sold the technology to global companies Nomad Digital and Icomera Solutions, providing transport connectivity solutions for trains [text removed for publication]. This technology enables rail operators to add new communications systems to their trains, delivering significant improvements to passenger experience and safety through better WiFi connectivity, improved passenger information systems, HD CCTV and on-demand infotainment.

2. Underpinning research

By the early 2000s, rail journey times became competitive with short haul flights, however, Internet connectivity still lagged behind in the harsher train environment. Passenger experience, security improvements (e.g., CCTV) and improved on-train communications required increased capacity however, 100MbE download rates seemed unsurpassable. Research led by Walker at Essex, developed a rail approved 10GbE Ethernet communication system, now widely installed on trains, which **exceeds the capacity the rail industry considered best possible by two orders of magnitude**.

From research commencing in 2004, Walker presented [R1] an optically remoted leaky feeder system for data transmission in hostile environments like the underground transportation networks. The 1.6Gb/s data throughput, the highest reported in this application at that time, offered future-proof provision for broadband security networks. This research in data transmission and service provision in the hostile rail environment subsequently contributed to a solution for the radio frequency (RF) cross-talk electro-magnetic field, which affects the existing train connectors, as it provided the tools to study the problem. The measured 2.4 - 6 GHz leaky feeder bandwidth allowed multi-radio, multi-band wireless mesh networking and therefore low contention Gigabit rolling stock data communications. For the in-carriage environment, especially improving in-train data distribution, as is the case here, Walker's research into full service access and edge networks [R2] demonstrated for the first time that Gigabit throughput using the emerging 5G 24-GHz frequency band is an option for future in-carriage wireless networks. Communications through copper media, widely used and considered reliable by the rail industry, and wireless transmission systems insights [R3] presented for the first time a novel implementation of 4K UHD live video encoding for streaming over a wireless network at low bitrate indoors, using GPUs for parallel

H264/AVC video encoding, in order to enhance the on-train infotainment experience.

Progress towards fulfilling expectations for increased capacity using wireless, wired and hybrid communication systems in non-trivial real-world railway applications [R1] combined with [R2], [R3] provided the foundations for collaboration with LPA, with significant and challenging requirements of achieving 10GbE networking and managing associated issues, including cross-talk; RF data transmission (particularly 2.5 - 2.7GHz range) and realising opportunities and challenges of 4G and 5Gmobile networks; fibre-optics and inter-carriage wireless systems. Consequently, Walker collaborated with LPA [G1] to enable them to design rail connectors for RF communication and Ethernet data transmission. Most importantly, [G1] enabled Walker to develop the new Ethernet backbone. Walker addressed challenges of: 1) cabling and connectorisation at gigabit data rates; 2) cross-talk issues which meant ensuring inter-pair shielding for multi-pair cables, whilst 3) retaining compliance with standard connector sizes. Though practical investigation, a new system was developed to withstand the rugged train environment [R4, G1].

A primary issue for Ethernet cabling and connectors, as identified in [R1], is near-end crosstalk (NEXT), where cable pairs interact both capacitively and inductively to produce radiative interference [R1, R4], which degrades the data throughput, and deteriorates with increased data rate. The IEEE standard 10GBASE-T network interface card (NIC) deals with NEXT, inter alia, very effectively. Thus, NEXT is not an issue in data centres where standardised cable (CAT 7), plugs and sockets are used. In the hostile rail environment, however, severe cable flexing must be accommodated, e.g., for use in inter-carriage jumpers where CAT 7 cable fails mechanically. At the start the study [G1] in 2013, connectors, adequate for 100MbE Ethernet, were using industrial, super-flexible CAT 5 cabling. Essex's investigations with FLUKE 100MbE to 10GbE certified test equipment (which extracts sophisticated diagnostic information) revealed CAT5 cable failed beyond 1GbE. Worst still, the existing connectors failed NEXT levels at just over 100MbE. The NEXT failings of existing cabling and connectors were solved separately. For the cables, Walker's transmission line insights [R1] were applied. It was found that a short length of rugged, flexible, industrial CAT5 cable (for use in jumpers) could be attached to a much longer CAT7 cable (~ 25m, for use in carriages) to restore 10GbE cable performance.

The connector's NEXT problem was ultimately solved by research and analysis of RF systems [R1, R4, R5]. This showed that a balanced quadrupole arrangement (instead of the previous unbalanced star-quad deployment, common in the rail industry) for the connecting pins in their housing was needed. This produced cancellation of both the electric and magnetic fields in the centre of the connector pins, which were arranged in groups of four on a square template. The key result was the breakthrough realization that zero electrical and magnetic field in the middle of the connector could not generate any cross talk in the surrounding cables [R4, R5]. Initial tests with the FLUKE apparatus showed full 10GbE capability for combined 25m CAT7 and 3m CAT5 entry and exit cables through one connector, with the required wiring modification. The tests were extended to the full 10GBASE-T 100M length (four cable spans and three connectorized jumpers), again with a satisfactory result (pass certificate). Industrial 10GbE switches were then utilised for an Ethernet Train backbone (ETB) test equivalent to 10 carriages. After testing with selected rail operators, the 10GbE ETB system was successfully demonstrated. [R5, G2] also demonstrates the 10GbE ETB enhanced to 40GBE (by spatial multiplexing), shown to work with data-centre calibre PCs.

3. References to the research [can be supplied by HEI on request]

R1 S. E. M. Dudley, T. J. Quinlan, and S.D. Walker. "Ultra-broadband Wireless–Optical Transmission Links Using Axial Slot Leaky Feeders and Optical Fiber for Underground Transport Topologies" 2014 IEEE Transactions on Vehicular Technology, Volume: 57, Issue: 6, 2008, 3471 –

3476 DOI: 10.1109/TVT.2008.920055

R2 O. J. Femi-Jemilohun, T Quinlan, S. Barc, and S. D. Walker. "An Experimental Investigation into GbE Wireless Data Communication at 24GHz in Non-Line-of-Sight and Multi-Path Rich Environments." Antennas and Wireless Propagation Letters: December 2014 Volume: 13 Issue: 1, 1219-1222. DOI: 10.1109/LAWP.2014.2332236

R3 O. Adeyemi-Ejeye and S. Walker "4K UHD H264 Wireless Live Video Streaming Using CUDA," Journal of Electrical and Computer Engineering, vol. 2014, Article ID 183716, 12 pages. (Published February 2014). DOI: 10.1155/2014/183716

R4 G. Koczian, S. Walker, G. Howell, and B. Simpkin**. "**A 10 Gbit/s Ethernet Infrastructure for future-proofed railway communications." The Stephenson Conference: Research for railway, 21 - 23 April 2015. Institution of Mechanical Engineers, London.

R5 F. Ngobigha, S. D. Walker, G. Koczian, G. Howell, and J. Prentice. "Demonstration of 40 Gbit/s conducting media data capacity on international rolling stock," 15th Annual Conference on Wireless On-demand Network Systems and Services (WONS), January 2019. DOI: 10.23919/WONS.2019.8795504 http://dl.ifip.org/db/conf/wons/wons2019/115.pdf

G1 Walker, S. D., Woods, J.C. KTP8968 - *To enable LPA to design rail connectors suitable for RF*, LPA Industries Ltd and the Technology Strategy Board, 07 Jan 2013 - 06 Jan 2015, GBP40,613 and GBP82,456, GBP123,069.

G2 Walker, S. D., Woods, J.C. KTP010573 - *To embed a novel wireless Ethernet capability across the rail network, to support innovation in train to shore communication speed and establish LPA as a leading innovator in the sector. To increase the bandwidth of on-board copper Ethernet Backbones*, LPA Group PLC and the Technology Strategy Board, 30 Jan 2017 - 22 Jan 2020, GBP75,687 and GBP153,667, GBP229,354.

4. Details of the impact

Essex research enables company LPA commercial success to become a world leader for rail ethernet technology, achieving over 60% of the market share for advanced rail inter-car connection systems

LPA Connection Systems is a UK based company designing and manufacturing inter-connection systems and electrical control boxes for railway rolling stock. In 2013, the rail market was demanding higher data transmission rates for its Ethernet systems, capacity was previously only 100MbE, to permit faster internet access for passengers and to improve railway security by enabling HD CCTV images to be recorded centrally on the train. Essex research [R1-R5] showed how data centre copper cable technology can be applied successfully in the railway environment and via a collaborative development partnership with Essex funded by Innovate UK [G1], **LPA was** '***able to offer the world's first 10GbE bandwidth Ethernet train backbone over copper***' [S1][S2]. LPA launched this first rolling-stock approved 10GbE technology in 2014 with an order to retrofit a large UK fleet of trains and now supplies its market leading 10GbE products to customers across the world [S3]. The COO of LPA states '***Being the first to introduce 10G technology into an intercar jumper enabled LPA to sell more systems than would normally be seen'*** adding **'*Harnessing expertise in the University of Essex, the KTP enabled LPA to move into a new technology area and develop a highly successful product that has sold and continues to sell worldwide*** '[S1].

In 2010, before the collaboration with Essex, LPA's company turnover was **GBP4-6** Million p.a.,

which increased to **GBP6-9** Million p.a. (c60%) by 2017, '*largely as a result of its Ethernet technology products*', based on the work with Walker at Essex [S3]. Sales increased accordingly; LPA not only achieved direct sales of 10GbE Ethernet Inter-car Jumpers but also was able to leverage this unique 10GbE technology to sell complete LPA Inter-car connection systems to its customers [S3] and already by 2017 '***The research led by Prof Walker at the University of Essex […] provided an essential contribution to £8M worth of sales for LPA'*** [S3, S4, S5]. The development of the 10GbE technology led to LPA increasing its market share in the intercar jumper market as stated in the final KTP report ***'The demonstration of 10GbE represented a significant step change in performance for the industry and catapulted LPA to world leader for Rail Ethernet technology'*** [S2, p.2, p.4, p.8 and p.10]**.** [text removed for publication]

As a result of the Essex research, **LPA has enhanced its knowledge & capabilities in data communications which '*enabled LPA to move into a new technology area'*** [S1]. '*The company has acquired in depth knowledge in electronic testing processes and 10GbE networking and associated issues, as well as new knowledge in RF data transmission and mobile networks. The Company has acquired knowledge about the process of identifying new technologies and testing their feasibility'* [S2, p.5]. LPA established a new electronics development facility [S2, p.5] and through staff training *'the technological know-how has been embedded within the company*' [S1].

LPA's customers benefit from futureproofed 10GbE systems for trains enabling improvements to rail security and passenger experience

LPA's 10GbE products were sold to a range of rail industry customers operating globally [S3]:

- **Systems integration companies** such as Icomera, the world's leading provider of wireless internet connectivity and application platforms for passenger transport and Nomad Digital which operates widely across Europe, North America and Australia [S6] [S3].
- **Rolling stock operators** [text removed for publication] operating in 38 countries worldwide [S6]; [text removed for publication]
- **Rail operators**: In the UK LPA 10GbE products are used by almost a third of the UK's rail operators [S6]: [text removed for publication]

Between 2014 and 2019, over 1,000 train cars were fitted with 10GbE technology [S1]. By enabling LPA's customers to purchase and install 10GbE-ready jumpers and fixed harnesses to their trains for the same price as a 100MbE system, they have been able to futureproof their rolling stock and avoid the large cost and fleet disruption associated with fitting upgraded jumpers when data demand on-board trains overloaded their 100MbE capability. '***These systems have enabled operators to futureproof their vehicles and ensure adequate data capability for any systems that may be added at a later point***' LPA COO [S1]. The Technical Manager of Angel Trains, one of Britain's leading rolling stock companies, which leases stock to 20 UK rail operators [S6] states '*With the development and launch of LPA's 10GbE-Ready Jumpers, the justification for retrofitting of 10GbE-Ready Inter-car Jumpers was made easier',* adding '***With the future-proofed Ethernet Jumpers, further increases in data transmission demands in the future can be accommodated without another expensive retrofit programme being carried out on trains*** *- both expensive (>>£1M) and necessitating trains to be taken out of service one-by-one*' [S7].

Rail passengers increasingly require high-speed on-train connectivity that supports entertainment, social media engagement and business activity and identify WiFi as a reason for choosing a

particular rail operator. As a result '***Train operators continue to invest in next generation hardware platforms and upgrades to the on-train network, including migration to a 10GbE backbone***' according to Nomad Digital's Head of Product Management [S8]. This continued investment allows operators to benefit from services such as CCTV, passenger WiFi and sophisticated fleet management solutions and enables a new raft of entertainment services to be deployed [S8]. The Angel Trains Technical Manager confirms the benefits to the rail operators and their passengers: '***The LPA 10GbE-ready backbone enables our customers [rail operators] to exploit the future-proofed data capacity to enable new communications systems to be added to their trains to deliver significant improvements to passenger experience; for example, Wi-Fi, improved Passenger Information Systems, on-demand infotainment, passenger counting, digital HD/4K CCTV and Big Data analytics***' [S7]. Rail operators and passengers also benefit from more reliable trains through the use of the 10GbE enabled technology '*Improved train reliability initiatives benefit from preventative maintenance regimes that exploit data from sensors all over the train, for instance to flag up a potential bearing failure before it occurs. Angel Trains' Class 357/2 fleet was upgraded with McLaren's "Intelligent Train" system, with the objective of using McLaren's Big Data analytics to monitor the train sensors and report for any abnormal outputs. This 1GbE system communicates over an LPA 10GbE-Ready backbone*' [S7]. Angel Trains concludes that: '*In the rail industry, 10GbE was a leap in data transmission capability and the resulting bandwidth benefits that these technical innovations have since bought to Angel Trains, the Train Operating Companies and their passengers would otherwise not have been possible*' [S7].

5. Sources to corroborate the impact

[S1] Testimonial from the Chief Operating Officer, LPA Connection Systems
[S2] Final Report KTP: KTP8968
[S3] Testimonial from the MD, Rail innovations Ltd (former MD of LPA 2009-2019)
[S4] Article from Rail Engineer 2017
https://www.railengineer.co.uk/innovation-conference-gets-bigger-and-better/
[S5] E mail testimonial MD, Rail innovations Ltd (former MD of LPA 2009-2019)
[S6] Scale of Operations of LPA's customers (complied pdf)
[S7] Testimonial from the Angel Trains Product Technology Manager.
[S8] Article, Head of Product Management Nomad Digital
https://nomad-digital.com/articles/passenger-expectations-in-todays-connected-world/