Brief CV of Prof. L. Hanzo,
FREng, European Research Council Advanced Fellow
FIEEE, FIET, Fellow of EURASIP, DSc, Dr. Honoris Causa

http://www-mobile.ecs.soton.ac.uk/newcomms/?q=people/lh/

1. Personal Information[1]

Job Title: Chair of Telecommunications
Appointment: Head of Southampton Wireless
Distinctions/Honours/Awards: FREng, 2004; FIEE 2003; FIEEE, 2004; DSc, 2004; VC's Teaching Award, 2006; IEE Signal. Proc. Distinguished Lecture; RAEng. Vodafone Lecturer 2007; WCNC'2007 Best Paper Prize; ICC'2009 Best Paper Prize; IEEE Wireless Technical Committee Achievement Award; IET Sir Monti Finniston Award; Fellow of the European Signal Processing Association 2011; Dr. Honoris Causa 2011, Budapest; WCNC'13 Best paper award; European Research Council Advanced Fellow 2012; RS Wolfson Fellow 2013; IEEE Radio Communications Achievent Award, 2013, IEEE VTS Avant Garde Award 2014, Dr. Honoris Causa 2015, Edinburgh; IEEE VTS Avant Garde Award 2014; Foreign Member of the Hungarian Academy of Sciences, 2016; EURASIP Papoulis Award'2018; IEEE ComSoc Education Award 2018;

Previous Appointments:

Current post since 1998 Chair in Telecommunications, ECS, Univ. of Southampton, UK
2008-2012 Chaired Honorary Professor of Tsinghua University, Beijing China
1996-97 Reader, School of ECS, Univ. of Southampton, UK
1990-96 Lecturer, School of ECS, Univ. of Southampton, UK
1987-90 Teaching Fellow, School of ECS, Univ. of Southampton, UK
1986-87 Research Fellow, School of ECS, Univ. of Southampton, UK
1981-86 Senior Research Scientist, Telecommunications Res. Inst., Budapest, Hungary
1980-81 Research Fellow, Dept. of Telecomms., Univ. of Erlangen, Germany
1976-80 Research Scientist, Telecommunications Res. Inst., Budapest, Hungary

Qualifications:

2004 Doctor of Sciences, University of Southampton, UK
1983 Doctorate in Telecommunications, Technical Univ. of Budapest, Hungary; Grade: Summa Cum Laude (with Distinction)
1971-76 5-year Master Degree, Technical University of Budapest, Hungary, Grade: First Class
1966-70 European Baccalaureate, Grade: 100%

2. Research Career and Achievements:

- **Overall Research Output, Dissemination and Outreach:**
  I have published 18 highly-cited John Wiley - IEEE Press Anglo-American research monographs totalling in excess of 10 000 pages (http://www-mobile.ecs.soton.ac.uk); **I have a total of 1908 publications at IEEE Xplore:**

  http://ieeexplore.ieee.org/search/searchresult.jsp?action=search&sortType=&rowsPerPage=&searchField=Search_All&matchBoolean=t

  During my 34-year service in Southampton I published about 40 IEEE papers/year. Googlescholar shows **48 557 citations** of my research, as seen at

  http://scholar.google.co.uk/citations?hl=en&user=p0jnEW0AAAAJ&view_op=list_works&gmla=AJsN-F4D6MRIarsw8bM0Sn7Ff2jHl

  As an IEEE Distinguished Lecturer I enjoy a global research/educational influence. I acted as a non-executive Director of the Mobile VCE, Governor of both the IEEE Vehicular Technology Society and of the Communications Society. I also acted as a board-member of the Pan-European Newcom consortium directing the research of 59 academic research teams in telecommunications. I was promoted to FREng, FIEEE, FIET and was awarded a DSC as well as the VC's Teaching Award. I have recruited, funded and directed a wireless research team. **As a recognition of my research contributions, the European Research Council awarded their highest research distinction, namely their 2.5 MEuro Advanced Fellow Grant to me in 2018 for the second time.**

- **Breadth/Depth of Industrial, Academic and Social Impact:**
  The motivation of my entire research career has been to fulfill the dream of flawless wireless multimedia telecommunications (*L. Hanzo: Bandwidth-Efficient Wireless Multimedia Communications, Proceedings of the IEEE, July 1998, Vol. 86, No. 7, pp. 1342-1382.*), creating the impression of tele-presence - at the touch of a dialling key accessing immersive wireless multimedia solutions - with joy and wonder...

  Indeed, I have conceived solutions that facilitated in excess of a 1000-fold bit-rate increase over the years, whilst approaching the theoretical capacity limits, albeit these sophisticated turbo-transceivers inevitably imposed an increased complexity and power-dissipation. As a result, I created reduced-complexity Pareto-optimum wireless solutions and ventured into fully parallel Quantum-Domain (QD) solutions, as detailed below. These popular immersive wireless multimedia solutions fuelled the demand for more bandwidth, which I mitigated with the aid of social media assisted content dissemination, radically new Visible-Light

[1] For further details on current research please refer to http://www-mobile.ecs.soton.ac.uk

Communication (VLC) based Optical Wireless (OW) as well as Free-Space Optical (FSO) solutions, as discussed in *L. Hanzo, et al., "Wireless myths, realities, and futures: From 3G/4G to optical and quantum wireless,"* Proceedings of the IEEE*, vol. 100, pp. 1853 –1888, 13 2012,* **Invited Paper in the Centennial Issue**. In a little more depth:

- The research of wireless video telephony was stimulated by one of my IEEE Transaction papers published as early as 1993, albeit in this era it was deemed to be bordering onto SciFi. Eventually **wireless video telephony became a commercial reality, enjoyed by many both in the UK and globally. These advances were summarized in my Anglo-American monograph**: *L. Hanzo, P. Cherriman, J. Streit: Wireless Video Communications: Second to Third Generation and Beyond, IEEE Press - John Wiley, February 2001* [2] **1092 pages**. Given my three decades of video compression and video streaming experience, I am one of the best-cited authors in this field. I have a holographic display, which facilitates goggle-free 3D viewing and in recent years I have conceived a large variety of proovably optimal video dtreaming solutions based on the successive generations of video codecs.
- My research on near-instantaneously adaptive quadrature amplitude modulation (AQAM) has also substantially influenced the standardization of the **third-generation (3G) and 4G mobile phone systems, which facilitated the introduction of the Wireless Internet. AQAM is now used in more than 2 Billion 3G/4G mobile phones at the time of writing and in virtually all WiFi-aided Wireless Internet links. The relevant technical solutions were documented in a series of my Anglo-American monographs, such as:** *L. Hanzo, C.H. Wong, M.S. Yee: Adaptive Wireless Transceivers: Turbo-Coded, Turbo-Equalised and Space-Time Coded TDMA, CDMA and OFDM Systems, John Wiley, March 2002, ISBN 0-470-84689-5* **752 pages***; J.S. Blogh, L. Hanzo: Third-Generation Systems and Intelligent Wireless Networking - Smart Antennas and Adaptive Modulation, John Wiley, April 2002, ISBN 0-470-84519-8* **430 pages** *and L. Hanzo, L-L. Yang, E-L. Kuan and K. Yen: Single- and Multi-Carrier DS-CDMA: Multi-User Detection, Space-Time Spreading, Synchronisation, Standards and Networking, IEEE Press - John Wiley, August 2003,* **1060 pages**
- The above-mentioned 3G/4 AQAM principles are so powerful that they will also be invoked in the emerging 5G systems based on Orthogonal Frequency Division Multiplexing (OFDM), as detailed in *L. Hanzo, M. Münster, B.J. Choi and T. Keller: OFDM and MC-CDMA for Broadband Multi-user Communications, WLANs and Broadcasting, John Wiley - IEEE Press, July 2003,* **980 pages** *and in L. Hanzo, J. Akhtman, L. Wang, M. Jiang: MIMO-OFDM for LTE, WIFI and WIMAX: Coherent versus Non-Coherent and Cooperative Turbo-Transceivers, IEEE Press - John Wiley, March 2010,* **591 pages**.

- **PhD Supervision & Nurturing the Next Generation:**
  119 PhD students have successfully graduated under my supervision and 41 of them are now Professors across the globe. Currently I direct the research of about 50 scientists.

- **Research Grants/ Contracts:**
  Since my appointment to the Established Chair in 1998 I have grown my team from about 10 **to about 50 and the funding of the team** required substantial grants and close collaboration with industry.

- **Global IEEE Distinguished Lecture Series:**
  I was awarded the title of **IEEE Distinguished Lecturer,** hence the IEEE funded my global lecturing tours. A few examples are: **2002** - Australia and New Zealand: Perth, Adelaide, Melbourne, Canberra, Sydney, Brisbane, Townsville, Australia; Auckland and Christchurch, NZ; Vancouver, Canada. **2003** - Pacific Rim: numerous venues in Beijing, Shanghai in China; Taipei and Kaohshiung in Taiwan; George Town in Malaysia; Hamburg, Germany. **2003** - USA: Orlando, Palm Beach and Tampa; **2004** - California, San Diego. **2005** - German Aerospace Research Centre, Oberpfaffenhofen; Copenhagen, Aalborg in Denmark; **2006** - Montreal, Canada; **2007** - Hong Kong. My **2008** DLT took place in May 2008 in Singapore and Beijing, China, while in **2009** in Cape Town, Johannesburg and Pretoria in South-Africa; **2012** Shanghai, Chengdu, Beijing; **2014** Four locations in Korea; **2014** Hanoi, Vietnam; **2015** Shanghai, Nanjing, Wuhan and Hefei, China; **2016** Montreal, Waterloo & London, Ontario, Canada; **2017** Bangalore & Chennai, India; **2018** China; **2019** China;

- **Research Courses at IEEE Conferences:**
  ICCS'94 in Singapore; ICUPC'95 in Tokyo; ICASSP'96 in Atlanta, USA; PIMRC'96 in Taipei, Taiwan; ICASSP'96 in Atlanta; ICCS'96 in Singapore; VTC'97 in Phoenix, USA; PIMRC'97 Helsinki, Finland; VTC'98, Ottawa, Canada; Globecom'98 Melbourne, Australia; VTC'99 Spring Houston, USA; EURASIP Conference'99, June, 1999, Krakow, Poland; VTC'99 Fall Amsterdam, The Netherlands; VTC'2000 Spring Tokyo, Japan; VTC'2001 Spring Rhodes, Greece; Globecom'2000 San Francisco, USA; Globecom'2001 San Antonio, USA; ATAMS'2001 Krakow, Poland; Eurocon'2001, Bratislava, Slovakia; VTC'2002 Spring Birmingham Alabama, USA; VTC'2002 Fall Vancouver, Canada; ICC'2002, New York, USA; Wireless'02, Calgary, Canada; WPMC'02 Honolulu, Hawaii; ATAMS'2002, Krakow, Poland; WCNC'03 New Orleans, USA; VTC'2003 Spring, Jeju Island, Korea; PIMRC'2003, Beijing, China; VTC'2003 Fall Orlando, USA; European Wireless Conference'2004, Barcelona, Spain; ICC'2004, Paris, France; EUSIPCO'2004, Vienna, Austria; VTC'2005 Spring Stockholm, Sweden; VTC'2005 Fall, Dallas, USA; WPMC'2005 Aalborg, Denmark; VTC'2006 Spring Melbourne, Australia; ICC'2006 Istanbul, Turkey; WCNC'2006, Las Vegas, USA; ISSSTA'2006, Manaus, Brazil; VTC'2006 Fall, Montreal; VTC 2007 Spring, Dublin; ICC 2007, Glasgow; IST' 2007, Budapest, Hungary; VTC 2007 Fall, Baltimore, USA; ColCom'2007, Bogota, Colombia; ICSPC'2007, Dubai; WCNC'2007, Hong-Kong, China; ICC'2008, Beijing, China; VTC'2008 Spring Singapore; WCNC'2008, Las Vegas; VTC'2008 Fall, Calgary, Canada; Globecom'2008, New Orleans, USA; VTC'2009 Spring, Barcelona, Spain; ICC'2009, Dresden, Germany; VTC'2009 Fall, Anchorage, USA; Globecom 2009, Hawaii, USA; NCC'2010 Chennai, India; VTC 2010 Spring, Taipei; ICC 2010 Cape Town; VTC 2010 Fall Ottawa, Canada; ICC 2011 Kyoto, Japan; WCNC 2011 Cancun, Mexico; VTC 2011 Fall San Francisco, USA; GC'2011 Houston, USA; ICC'2012 Ottawa, Canada; VTC'2012 Quebec City, Canada; GC'2012 Anaheim, USA;

[2] For detailed contents and sample chapters please refer to http://www-mobile.ecs.soton.ac.uk, ISBN 0-7803-6032-x,

VTC'13S Dresden, Germany; GC'13 Atlanta, USA; VTC13F Las Vegas, USA; WCNC'14 Istanbul, Turkey; VTC14S, Seoul, Korea; ICC'14 Sydney, Australia; GC'14 Austin, USA; VTC'15 Spring, Glasgow; VTC'15F Boston, USA; VTC'16S Nanjing, China; VTC'16F Ontreal, Canada; Globecom'16, Washington, USA; VTC'18F Chicago; GC'2019 Hawaii; ICC'2020 Dublin; ICASSP'2020 Barcelona;

- **Recent Keynote Lectures:** Links to these keynotes can be found at http://www-mobile.ecs.soton.ac.uk;
  Asia-Pacific Communications Conference'2003, George Town, Malaysia; The Finnish Wireless Conference, Tampere, Finland, 2004; Signal Processing in Wireless Communications Conference (SPWC) in 2003; SPWC'2004, SPWC'2005, SPWC'2006, SPWC'2007, SPWC'2008, London, UK; The Benelux Vehicular Technology Society's (VTS) Conferene, 2004, IMEC, Leuven, Belgium; IWT'2003 Long Island, USA; Hungarian Telecomms' Research Conference, 2004, Budapest, Hungary; IEEE Sympotic'2004, Bratislava, Czech Republic; MUCS'2004, Dublin, Ireland, 2004; The Benelux VTS Conference'2005, Twente, Belgium; URSI'2006, Poznan, Poland; Global Telecommunications Congress, 2006, Budapest, Hungary; IEEE ISSSTA'2006, Manaus, Brazil; IEEE SiPS'2007, Shanghai, China, IEEE ICSPC'07, Dubai; WPMC'07 Jaipur, India; MobiMedia 2008, July 2008, Oulu, Finland; CNSR'2009, Moncton, Canada; IEEE SSP'2009 Cardiff, UK; NCC'2010 Madras, India; ELMAR'2010, Zadar, Croatia; Globecom'2010, Miami, Florida; WiAD'2010, London, UK; WCNC'11 Cancun, Mexico; WiAD'2011, London, UK; Mobiware'2011, London; UltraCom'2011 Budapest; WiAd'2012, London; 2012 Rome; EUSIPCO'2012, Buchurest; MSWIM'2013, Paphos; ICT'2013 Casablanca; IWCMC'2013 Cagliari, Italy; WiMOB'2013 Lyon, France; ATC'2014 Hanoi, Vietnam; WCSP'2014 Hefei, China; SCC'2015, Hamburg; WCNC'2015 New Orleans, ICC'2015 London; VTC'15F Boston; Qatar, Doha; Next-GWiN 2016, Dublin; WiSPNET'17 Chennai, India; VTC'17F Toronto; IWCS'19, Oulu, Finland, ICC'2009 Shanghai; ICOIN'20 Barcelona, Spain;

3. Leadership and Management Achievements:

- **Conference Chair/Vice-Chair, Invited Speaker:** WCNC'2003, New Orleans, Louisiana, USA, 17-19 March, 2003; COST Workshop, 2004, Budapest, Hungary; Sympotic'2004, Bratislava; European Wireless Conference'2004, Barcelona, Spain; PIMRCs since 1997; ICC'2004, Paris, France; Turbo Symposium'2003, Brest, France, Sept, 2003; IEEE ISSSTA'2006, Manaus, Brazil; IWCT'2005, Oulu, Finland; IEE 3G & Beyond both in 2004, 2005; IEEE VTC since 1994 - recently: IEEE VTC'2004, Spring 2004, Milan, Italy; IEEE VTC'2005 Spring, Stockholm, Sweden; IEEE VTC'2005, Fall, Dallas, USA; IEEE VTC'2006 Spring, Melbourne, Australia; IEEE VTC'2006 Fall, Montreal, Canada; IEEE VTC'2007, Dublin, Ireland; IEEE VTC'2007 Fall, Baltimore, USA; WCNC'2009, Budapest, Hungary; Mobimedia'2009, London, UK; CNSR'2009 Moncton, Canada; VTC'2010 Spring, Taipei, Taiwan; VTC'2010 Fall, Ottawa, Canada; VTC'2011 Spring Budapest, Hungary; VTC'2012 Fall, Quebec City, Canada; Globecom'2012 Anaheim, USA; ICC'2013 Budapest Hungary; WCNC'2013 Shanghai, China; VTC'2013S Dresden, Germany; VTC'2013 Las Vegas, USA; Globecom'2013 Atlanta, USA; ICC'14, Sydney; Globecom'14 Austin, Texas; WCSP'2014 Hefei; VTC'2015, Glasgow; ICC'2015, London; EUSIPCO'2016, Budapest; VTC'16 Montreal; PIMRC'17, Montreal; WCSP'2018, Hangzhou, China; ICASSP'2019, Brighton; VTC'2019 Hawaii; IEEE Quantum Week'20, Denver, USA;

- **External Assessor and Project Evaluator:**
  EPSRC; ERC Consolidator Panel; the European Commission; Brussels; Hong-Kong; Italy; Singapore; Australia; Ireland; Norway; Cyprus; Germany; Finland; The Netherlands; Canada; Qatar; European Research Council - just to name a few;

- **Editorships:**
  various high-impact **IEEE journals, such as the Proceedings of the IEEE**, the Wiley Journal on Wireless Communications and Mobile Computing, Elsevier PhyCom. **I was the EIC of the IEEE Press during 2008-2012, I spearheaded the digitazation of all IEEE Press books, which made the Press more profitable than ever before.**

- Governor of the IEEE Vehicular Technology Society, USA, 2005 - to date;

- Governor of the IEEE Communications Society, USA, 2007 - 2010; 2017 - 2020;

- IEEE VTS Fellow Award Committee 2004 - 2019;

- Non-Executive Director of the VCE, 2003-2012;

- Executive Board Member for the EU Network of Excellence NEWCOM 2004 - 2007, managing a team of 500+ academics and their PhD students from 59 EU Universities;

- IEEE COMSOC Awards Chair (2014 - 2018) and IEEE-level Edison Medal Committee, 2018 - 2020

4. Interdisciplinary Research Highlights:

- **BREADTH OF RESEARCH:** My wireless research dates back to the mid-1980s, hallmarked by contributions to GSM system studies, leading to the research of EDGE 3G/3.5G HSDPA/HSUPA, 3GPP LTE, WIFI, WIMAX and DVB/DVB-H systems. In terms of technical solutions, these systems led to the unprecedented evolution of QAM, time-domain (TD) frequency-domain (FD) and spatial-domain (SD) spread MC-CDMA, OFDM, new multi-functional MIMOs, generalised turbo-detection and networking. I contributed right across these topics [1] - [18].

- **AQAM/3.5G HSDPA:** To elaborate further on QAM, [1,2,3] my research has been highly cited, referring to seminal contributions of the BER evaluation of QAM, to novel pilot-symbol-assisted modulation (PSAM) solutions, to low-complexity differential-QAM requiring no channel estimation, adaptive-QAM (AQAM) leading to the 3.5G HSDPA-mode. Three teams were globally influential, providing sustained contributions on QAM research, including the Japanese Ministry of Post/Telecomms - leading to an AQAM 3G-proposal, Prof. Goldsmith at Caltech/Stanford and our team in Southampton [1,2,3].

- **OFDM/MC-CDMA USING TD, FD AND SD SPREADING FOR 4G LTE, WIFI, WIMAX:** My highly-cited AQAM research strongly influenced both the ensuing OFDM and CDMA [8,10,11,12] standardization, again, in the 3.5G HSDPA mode, in WIFI and WIMAX. The crest-factor problems of AQAM/OFDM were solved in [10], along with the grave challenge of joint turbo-detection and decision-directed channel estimation (DDCE) for MIMO-OFDM [11,12,16], where potentially 8x8=64 MIMO-channels may have to be estimated. As a benefit of this joint turbo-DDCE, the perfect-estimation-based single-user/single-stream performance was achieved by multi-user MIMO-OFDM [10], demonstrating the benefits of TD, FD and SD spreading under time-variant propagation conditions, when no fixed-mode transceiver performs well. Our team also characterized CDMA, SDMA and MIMO scenarios with the aid of a unified channel matrix [10,11,12], which allows the plausible joint physical interpretation of CDMA and SDMA/SDM systems [16,17], where the latter techniques exploit the unique, user-specific dispersive channel impulse responses (CIRs) for differentiating the users instead of orthogonal CDMA spreading sequences.

- **3G/3.5G HSDPA-STYLE NETWORKING [9,15]:** We quantified [9, 15] the overall network-layer benefits of the abovemwentioned AQAM physical-layer performance improvements using novel cross-layer optimization techniques, when instead of dropping a call under hostile channel conditions, only the AQAM rate is dropped temporarily, leading to a factor of two user-load improvements. We also demonstrated [9, 15] that the widely-known Gupta-Kumar scaling-law of large ad hoc networks cannot be circumvented by AQAM, but as the benefit of AQAM, their effective throughput can be improved. In [15] both AQAM and MIMOs were proposed for improving the otherwise poor TDD performance of 3.5G TDD networks, approaching that of the correspondiong FDD system. We also improved the TDD performance by GA-based optimization [9,15].

- **AD HOC NETWORKS:** Given the high expense of GPS-based synchronization techniques in low-cost ad hoc networks and the lack of central power control, we proposed the employment of Large Area Synchronised (LAS) codes [15], which exhibit a finite-duration interference-free window (IFW) and hence are capable of facilitating operation in the ideal noise-limited, rather than interference-limited scenario. Hence they approach the single-user Gaussian performance even without multi-user detection (MUD) [15].

- **AERONAUTICAL AD HOC NETWORKS:** The engineering vision of relying on the "smart sky" supporting air traffic and the "Internet above the clouds" for in-flight entertainment has become imperative for the future aircraft industry. Aeronautical *ad hoc* Networking (AANET) constitutes a compelling concept for providing broadband communications above clouds by extending the coverage of Air-to-Ground (A2G) networks to oceanic and remote airspace via autonomous and self-configured wireless networking amongst commercial passenger airplanes. The AANET concept may be viewed as a new member of the family of Mobile *ad hoc* Networks (MANETs) in action above the clouds. However, AANETs have more dynamic topologies, larger and more variable geographical network size, stricter security requirements and more hostile transmission conditions. These specific characteristics lead to more grave challenges in aircraft mobility modeling, aeronautical channel modeling and interference mitigation as well as in network scheduling and routing, as documented in my related papers.

- **NON-LINEAR MUDs FOR HIGH-THROUGHPUT RANK-DEFICIENT MIMO-OFDM SCENARIOS [16,17]:** In the presence of a high number of uplink (UP) WIFI transmitters it is unrealistic to expect the UL receiver to have a sufficiently high number of receiver MIMO-elements, which renders the channel matrix rank-deficient. Since the received signal constellation becomes rank-deficient, only powerful non-linear Maximum Likelihood (ML), Bayesian or low-complexity near-ML Sphere-Decoders (SD) [10,12,16] can avoid catastrophic BER degradations. We also proposed powerful Radial Basis Function (RBF) aided MUDs [8], new Genetic Algorithm (GA) aided MUDs [11] and radically new Minimum Bit Error Ratio (MBER) MUDs, which directly minimize the BER, rather than the classic MSE. They perform extremely well, conveying 2-3 times the user load at the cost of a higher complexity. Hence it may be expected that in the future these MBER designs become dominant. This rank-deficient scenario is also often encountered in the down-link, since the mobile receiver's size is limited and hence cannot accommodate many MIMO-elements.

- **NON-ORTHOGONAL TURBO TRANSCEIVERS for 5G:** I have been an advocate of non-orthogonal multiples access (NOMA) and signalling for at least two decades and in the 5G-era finally my solutions have found favour also in the 3GPP standardization committee. During this period I have designed dozens of NOMA solutions.

- **WIRELESS MULTIMEDIA TURBO TRANSCEIVERS [5,6,13,14]:** In 1993 I co-authored one of the first papers on wireless video telephony and coauthored the first dedicated monograph on the subject, where the overall channel-impaired video quality is optimized, instead of designing error-sensitive compression for a perfect channel. Now this is commercial reality, as seen on TV. It is argued in [5,6,13,14] that the Shannonian source- and channel separation theorem derived for AWGN channels and lossless entropy-based source codecs has limited applicability for psycho-acoustically or psycho-visually optimized lossy codecs communicating in bursty wireless channels. It is demonstrated that near-capacity operation is achieved by exchanging extrinsic information between the source decoder and channel decoder by exploiting the new concept of soft speech and video bits.

- **SIGNAL PROCESSING IN THE REDUNDANT RESIDUE NUMBER SYSTEM (RRNS) [7,11]:** A unique feature of our research is the employment of radically new ideas for designing wireless signal processing algorithms operating in the RRNS. This has numerous benefits, in particular when designing mobile phones for sub-1Volt operation, where the electromagnetic compatibility (EMC) problems become dominant, because RRNS allow the correction of errors, regardless, whether they were imposed by channel errors, or by EMC-induced errors. This is expected to lead to substantial future applications, since they have already been adopted for arithmetic units of SUN computers.

- **BIO-INSPIRED OPTIMIZATION IN WIRELESS COMMUNICATIONS [11,12,15]:** My research has uniquely bridged the knowledge-gap between the optimization and telecommommunications research community with the objective of conceiving near-capacity wireless systems.

- **PARETO-OPTIMIZATION OF WIRELESS SYSTEMS:** Following Shannon's pioneering paper in the late 1940s the research community has spent a period of about 60 years in developing near-capacity solutions. My teams has been one of the main contributor to the design of near-capacity turbo transceivers. However, inching closer to capacity tends to require long channel codes and high-complexity receivers, which imposes a high delay. Hence there is a performance vs. complexity vs. delay trade-off. Therefore in 2011 I have coauthored a paper on 'green, i.e. power-efficient radio' solutions, which heralded the 'green radio' era and led to the creation of a new IEEE journal for disseminating power-efficient solutions. Unfortunately, power-efficient solutions often fail to approach the system capacity.

  In order to strike a compelling compromise in the design of wireless systems, I have conceived the new design paradigm of Pareto-optimal systems, as detailed in my recent Proceedings of the IEEE paper entitled "Thirty Years of Machine Learning: The Road to Pareto-Optimal Wireless Networks" and in "Aeronautical Ad Hoc Networking for the Internet-Above-the-Clouds". To elaborate briefly, the Pareto-front of optimal solutions represents a collection of all optimal solutions, where for example the error probability cannot be improved without degrading the power-efficiency or the delay.

- **OPTICAL WIRELESS SYSTEMS:** As part of my European Research Council Advanced Fellow Grant, I have conceived radically new near-capacity visible-light communications (VLC) solutions as well as Free-Space Optical (FSO) solutions, with special emphasis on Color Shift Keying (CSK), which may be viewed as the dual pair of RF MIMO systems operating in the visible-light frequency domain, where substantial hitherto unused spectral bands are available. Another radically new VLC solution developed by our team is constituted by near-instantaneously adaptive Layered Asymmetrically Clipped Optical Orthogonal Frequency Division Multiplexing (LACO-OFDM).

- **USER-CENTRIC OPTICAL WIRELESS NETWORKING:** Although the advantages of VLC down-link transmissions are multi-fold, some challenges arise when incorporating VLC into the classic RF HetNet environments, which requires new system architectures. Hence we have conceived user-centric (UC) VLC networks, where the LED light providing coverage are organized into amorph clusters, each containing a potentially different number of LED supporting a similar number of VLC users. As a benefit, near-perfect load-balancing may be achieved. Hence the entire classic WiFi band may be used for up-link transmission.

- **SECURE JOINT INFORMATION AND POWER DISTRIBUTION NETWORKS:** In order to satisfy the power-thirsty of wireless devices, I have conceived sophisticated wireless charging techniques, which are also capable of avoiding eavesdropping. My solutions tend to rely on high-gain RF power-beamforming.

- **BEAMFORMING- AND AI-AIDED MM-WAVE COMMUNICATIONS:** The millimeter wave (mmWave) radio frequency (RF) band spanning from 30 GHz to 300 GHz has substantial spectral resources for next-generation wireless systems. However, its propagation characteristics are less favourable owing to its high pathloss and due to its poor multipath diversity, which limits the maximum cell-size. Hence it critically relies on the high-gain hybrid analogue/digital beamforming techniques we designed for mitigating the pathloss.

- **QUANTUM CODES FOR MAKING QUANTUM-COMPUTING A REALITY:** As part of my ERC Advanced Fellow Grant, we have conceived powerful new quantum codes for mitigating the decoherence-induced qubit errors of the emerging quantum computers. We have also conceived new quantum search algorithms for solving large-scale search problems in wireless communication systems. By exploiting the inherent parallelism of quantum computing, we have designed new quantum search algorithms for approaching the optimal performance of classical wireless processes, despite their reduced number of cost-function evaluations in multi-user detection, localization, routing in *ad hoc* networks, beamforming etc.

- **QUANTUM KEY DISTRIBUTION FOR ULTIMATE INFORMATION SECURITY:** We conceived a simultaneous quantum and classical communication regime for amalgamating continuous variable quantum key distribution and classical coherent optical communication by using the same communication infrastructure. This relies on both two-way classical communication and on measurement-device-independent quantum key distribution, in which the superposition modulation based coherent states depend on the information bits of both the secret key and on the classical communication ciphertext, which are measured by an untrusted relay node. A beneficial error rate vs. secret key rate trade-off was demonstrated for transmission over dozens of kilometers.

- **PHYSICAL-LAYER SECURITY FOR WIRELESS:** In the interest of realistically comparing quantum-domain and classical physical-layer security (PLS), we have investigated numerous solutions by considering a variety of realistic hardware impairments. Similarly, beneficial secret key generation and authentication techniques were devised by our ERC team in the presence of a multiplicity of eavesdroppers, such as untrusted relays for example.

- **JOINT DESIGN OF CHANNEL CODING SOLUTIONS AND NANO-ELECTRONICS CHIPS:** Whilst much of my research is dedicated to long-term frontier research, I also maintain a strong interest in industrially relevant proof-of-concept activities. In this context, I have had several successful joint algorithm and chip-design projects, which have led to a spate of innovative practical channel coding solutions.

References

[1] W.T. Webb, L. Hanzo: Modern Quadrature Amplitude Modulation: Principles and Applications for Fixed and Wireless Channels, IEEE Press-John Wiley, 1st edition, 1994, ISBN 0-7273-1701-6, **557 pages**.

[2] L. Hanzo, W.T. Webb, T. Keller: Single- and Multi-carrier Quadrature Amplitude Modulation: Principles and Applications for Personal Communications, WATM and Broadcasting; IEEE Press-John Wiley, 2nd edition, June 2000, ISBN 0-471-49239-6, **762 pages**.

[3] L. Hanzo, S-X. Ng, W.T. Webb, T. Keller: Quadrature Amplitude Modulation: From Basics to Adaptive Trellis-Coded, Turbo-Equalised and Space-Time Coded OFDM, CDMA and MC-CDMA Systems, IEEE Press-John Wiley, 2nd edition, September 2004 **1105 pages**.

[4] R. Steele, L. Hanzo (Ed): Mobile Radio Communications: Second and Third Generation Cellular and WATM Systems, John Wiley-IEEE Press, 2nd edition, July 1999, ISBN 0-471-97806-x, **1060 pages**.

[5] L. Hanzo, P. Cherriman, J. Streit: Wireless Video Communications: Second to Third Generation and Beyond, IEEE Press, February 2001 [3], ISBN 0-7803-6032-x, **1092 pages**.

[6] L. Hanzo, F.C.A. Somerville, J.P. Woodard: Voice Compression and Communications: Principles and Applications for Fixed and Wireless Channels; IEEE Press-John Wiley, August 2001 [4], ISBN 0-471-15039-8, **672 pages**.

[7] L. Hanzo, T.H. Liew, B.L. Yeap: Turbo Coding, Turbo Equalisation and Space-Time Coding, John Wiley, August 2002, ISBN 0-470-84726-3, **766 pages**.

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