BEAM-ME-UP: FROM CLASSIC RF TO QUANTUM COMMUNICATIONS

The Beam-Me-Up Project of Southampton University, UK, introduces radio frequency, giga-bit optical and quantum-wireless communication

Sixty years of research following Claude Shannon's pioneering paper has led to telecommunications solutions operating arbitrarily close to the channel capacity – 'flawless tele-presence' with 'zero' error is available to anyone, anywhere, anytime across the globe. This is a myth. The reality is that the popularity of smartphones and tablet computers has led to tele-traffic congestions in public places having a high user density, hence failing to support 'flawless tele-presence' quality.

For this reason, Beam-Me-Up has expanded the horizon of classic radio frequency (RF) systems to the hitherto rarely used 30-60GHz mm-wave spectral bands and to optical wireless frequency bands, where plenty of bandwidth is available for circumventing the looming spectrum crunch.

Following fifty years of Moore's law, contemporary semi-conductor technology is approaching nanoscale integration and the 'traveller' enters the world of quantum physics, where many of the physical phenomena are rather different from those of classical physics.

A feasible design option is to simply make the chip area larger in an attempt to accommodate more sophisticated signal processing on a single chip, but without dense integration. This option has many disadvantages, but above all the 'yield of fault-free chips' is dramatically reduced.

Beam-Me-Up therefore opted for the more radical option of contributing to making quantum communications an engineering reality by exploring the elements of the 'quantum jigsaw puzzle', with special emphasis on the following elements.

Given the vulnerable nature of quantum circuits, the tiniest environmental interference perturbs their quantum state, which is collapsed back into the classic world and all benefits of parallel processing in the quantum domain evaporate. Beam-Me-Up conceived near-optimal quantum error corrections codes for correcting both the bit-flips and phase-flips inflicted by the quantum decoherence phenomenon. At the current state-of-the-art, these codes are vital for extending the coherence interval of all quantum circuits and computers.

The second line of research contributed to making the perfectly secure ubiquitous quantum internet a reality, which requires numerous radically new components such as quantum-repeaters and quantum-key-distribution (QKD) solutions, which also require quantum memory. Chinese scientists established quantum entanglement distribution over a record-distance of 1,200km, therefore QKD may be deemed the most mature quantum technology, and the closest to commercial reality.

Beam-Me-Up contributed a suite of new network-coded QKD solutions, as well as to the conception of large-scale repeater networks with the aid of quantum-network-coding and entanglement swapping investigations.

Beam-Me-Up also exploited the formidable computing power of quantum-search algorithms (QSAs) conceived by the computer science-oriented quantum community for solving numerous, large-scale search problems found in wireless communications. This future-proof research simulated a future quantum computer with a classic parallel computer. For example, large-scale multi-user detection problems were solved at the base station (BS), where all K users supported in the mobile-to-BS uplink were simultaneously detected by using as few cost-function evaluations as possible.

This search problem becomes extremely challenging for a large number of users, especially when the system relies on high-throughput, multi-level modulation schemes, as required by today's systems.

An even more grave challenge is when the base stations are interlinked by optical fibres and, after exchanging their received information, make a joint decision about all the users' information in all cells.

Further cutting-edge solutions were conceived for other large-scale search problems such as joint data and channel estimation and for transmit pre-processing where the knowledge of the downlink channel is exploited for eliminating the potential inter-user interference that would be encountered in the hostile dispersive downlink channel. As a benefit, the mobile user would receive a clean, flawless signal and, therefore, low-complexity, single-user reception can be invoked.

Finally, Beam-Me-Up also designed new QSAs for futuristic localisation-aided wireless services, which were used for solving large-scale routing problems such as those involved in aeronautical *ad hoc* networks.

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