

Research Assessment Exercise 2020

Impact Case Study

University: The Hong Kong University of Science and Technology

Unit of Assessment (UoA): 13 - computer studies/science

Title of case study: Innovative location-based technologies to enable a smart city: Wherami, Streamphony and Lavinet

(1) Summary of the impact

Location-based technologies are enablers of the ‘smart city’. Professor Gary Chan’s research focuses on innovating lightweight and robust location-based technologies and deploying them for commercial impacts. His work includes an indoor localization technology, Wherami, used in Harbour City; the location-based streaming technology, Streamphony, commercialized by China Mobile Hong Kong; and a novel multi-hop WiFi technology, Lavinet, deployed in our leading port terminal to support e-logistics. These technologies have won many prestigious awards, and led to commercial products benefiting large number (millions) of users, enabling many novel business services, bringing in substantial licensing income to HKUST (in excess of HK\$2 millions), and creating immense market value (generating more than HK\$100 million investment/funding, revenue and company valuation).

(2) Underpinning research

Hong Kong aspires to be a leading world-class smart city. Location-based technologies are a critical element to enable many novel smart-city services. Chan’s team has been conducting research in the following three main areas:

A) *Wherami, a pervasive indoor localization technology for smart mobility:* GPS provides one’s location outdoors, but cannot penetrate indoors. Previous approaches to indoor localization are often based on a single signal, and hence do not perform satisfactorily due to individual signal limitations. To overcome this, our team fuses various signals existing indoors to identify locations.[1] These signals include WiFi, iBeacon, geomagnetic fields, barometers, IMU (inertial measurement unit) and pedometers.

By developing novel approaches to fuse different sensor signals to capture their strengths while overcoming their weaknesses, we created Wherami, a cost-effective indoor localization algorithm that achieves high accuracy and portability. Through algorithmic design and optimization, Wherami has been designed to be accurate, robust to sensor noise,[2] and adaptive to a changing environment [3] so that it is deployable in most general operating conditions. Its lightweight design and high computational efficiency means it can be integrated within existing phones as an app to enable many novel services. Wherami enabled *the first and only* indoor localization solution fusing WiFi and other signals on both Android and iOS platforms deployed in Hong Kong.

B) *Streamphony, large-scale location-aware multimedia streaming:* With the penetration of the Internet, OTT (over-the-top) streaming to users anywhere has become a reality, and live and interactive contents are increasingly streamed over wireless channels to mobile users. However, OTT video streaming to massively distributed users remains a critical challenge, as network resources have to be allocated on-the-fly based on user locations, sizes and mobility. This problem is accentuated as video is of high bitrate, with tight playback constraint, and sensitive to glitches and hiccups. Our design goal was to fulfil the strong need for a low-cost streaming network that accommodates user mobility, meets streaming rate requirements and offers low streaming latency.

Streamphony is a highly scalable and cost-effective protocol designed for both stored videos (by means of intelligent segment caching [4]) and live applications (by integrating IP multicast [5]). It was experimentally validated to support cost-effective and large-scale mobile multimedia

streaming.[5] The software is able to allocate network resources in cloud and edge devices (bandwidth, storage, processing power, etc.) to serve requests dynamically from different locations.

C) Lavinet, location-based mesh routing for high-performance WiFi: WiFi is a cost-effective medium to provide wireless services. Our research objective was to provide the best WiFi coverage in the most challenging environments. Providing ubiquitous WiFi coverage is challenging, because the wireless environment may be characterized with moving metallic objects that create many changing blindspots and fading. Such environments may not even allow flexible wiring and installation of routers (e.g. port terminals and plane hangars). Through the design of distributed and lightweight algorithms, our mesh network greatly enhances WiFi signals by extending its coverage. Our routers, using peer-to-peer collaboration [6], can be deployed anywhere and at any time to form a dynamic multi-hop network. Depending on their real-time locations, the routers self-configure to relay WiFi signals from gateways to users as if forming a mobile sky constellation [7].

We have researched, designed and developed this simple but effective protocol which can be embedded into any router to enable intelligent forwarding, and, substantially enhancing the signal quality by 100-fold in many settings.

(3) References to the research

- [1] H. Wu, S. He and S.-H. Chan, ‘A Graphical Model Approach for Efficient Geomagnetism-Pedometer Indoor Localization’, in *Proceedings of The 14th International Conference on Mobile Ad-Hoc and Sensor Systems (IEEE MASS)*, (Orlando, USA), pp.371–379, October 2017
- [2] S. He and S.-H. Chan, ‘Tilejunction: Mitigating Signal Noise for Fingerprint-based Indoor Localization’, *IEEE Transactions on Mobile Computing*, pp.1554–1568, June 2016
- [3] S. He, W. Lin, and S.-H. Chan, ‘Indoor Localization and Automatic Fingerprint Update with Altered AP Signals’, *IEEE Transactions on Mobile Computing*, pp.1897–1910, July 2017
- [4] W.-P. Yiu, X. Jin and S.-H. Chan, ‘VMesh: Distributed Segment Storage for Peer-to-Peer Interactive Video Streaming’, *IEEE Journal on Selected Areas in Communications (JSAC) Special Issue on Advances in Peer-to-Peer Streaming Systems*, pp.1717–31, Dec 2007
- [5] W. Jiang, S.-H. Chan, M. Chiang, J. Rexford, D. Ren and B. Wei, ‘Global 1Mbps Peer-Assisted Streaming: Fine-Grain Measurement of a Configurable Platform’, *IEEE Transactions on Multimedia*, Vol. 14, No. 5, pp.1456–1468, October 2012
- [6] M.-F. Leung and S.-H. Chan, ‘Broadcast-Based Peer-to-Peer Collaborative Video Streaming among Mobiles’, *IEEE Transactions on Broadcasting Special Issue on Mobile Multimedia Broadcasting*, pp.350–361, Vol. 53, No. 1, March 2007
- [7] W.-L. Hong, F. Long, P. Xia and S.-H. Chan, ‘Distributed Joint Channel and Routing Assignment for Multimedia Wireless Mesh Networks’, in *Proceedings of IEEE International Conference on Multimedia and Expo (ICME)*, pp.404–409, 9–13 July 2012

For a full list of references and 11 related patents see *Appendix: Supplementary information*

(4) Details of the impact

Our research tackles imminent and practical deployment challenges for a smart city, so that their implemented solutions can be directly transferred to industry. We focus on location-based technologies, whose challenges include fast signal sensing, lightweight software design, robust to noisy environment, efficient computations, deep location analytics, and cost-effective deployment. We have built powerful mobile systems to enable or enhance novel smart-city applications, and worked intensively with industry to narrow the theory–practice gap. Our research impacts are in the areas of rigorous innovation (R&D projects with market significance) and serial technopreneurship (three technology start-ups with staff and graduates to commercialize the research results). Through technology transfer to the startups co-founded by the PI, our research results have been successfully commercialized to operate in real industrial settings with substantial market tractions in terms of reach and significance. With commercial adoptions and enabled novel services, our research has won many awards and visibly impacted and shaped our industries, transforming our living. Overall, HKUST has reaped more than HK\$2.2 million from transfers and licensing agreements of our technologies. Highlights of the impacts of our technologies are:

A) *Wherami for indoor localization:* HKUST Wherami research has been commercially deployed in Harbour City, a premium mall in Hong Kong, where tens of thousands of users enjoy its service. Currently, its impacts are expanding beyond Harbour City as other leading malls in Hong Kong (Moko and Yoho), Macau and Guangzhou implement the system. Wherami enables visitors to navigate the malls and receive timely and personalized location-based recommendations while shopping. It is the first and only commercial deployment in Hong Kong fusing WiFi on both iOS and Android platforms, with more than 20,000 downloads (as in 2018 only). For businesses, our technology also enables new services and insights into customer profiles and mall layout/design, and provides analytics to understand customer behaviours and preferences, crowd analysis, and flow control. All these were virtually impossible before the design of Wherami.

Initially backed by both industry and government with funding exceeding HK\$22 million, the technology has been undergoing research and enhancement since 2013. Wherami achieves its high performance by using the patented and patent-pending algorithms proposed and studied in [1]–[3]. Through innovations and technology transfers, Chan co-founded three companies in 2015 (app-based indoor localization), 2017 (IoT-based people sensing) and 2019 (sensor-based asset tracking) to commercialize the research results. These companies engage with different industrial sectors to deploy the technologies. In the companies' business with other end-users, they have attracted significant external investments in excess of HK\$5 millions, and the technologies have enabled the companies to win several prestigious industrial and entrepreneurship awards (see *Appendix*).

B) *Streamphony for massive multimedia streaming:* Streamphony is a cost-effective OTT (Over-the-top) platform supporting high-quality live and interactive streaming to a large number of distributed wired and mobile users on the Internet. Its development has been enthusiastically supported by industries and government from inception to deployment, with total funding of more than HK\$20 million. Fully developed within HKUST and tested in various industrial settings, it was commercially deployed in 2013 as UTV, Hong Kong's first mobile TV channel led by China Mobile Hong Kong (listed in HKSE: 941) and Mei Ah Digital Technology (HKSE: 0391). Streamphony enabled the first cross-platform cross-network multimedia streaming in Hong Kong.

Streamphony is rooted in Chan's extensive research on effective video caching [4], scalable island multicast [5], and experimental study [5]. Chan co-founded a start-up with his staff in 2013 to commercialize Streamphony. The company works with various companies to roll out the technology. It has won several awards, demonstrating the innovative nature, commercial impacts and technological leadership of Streamphony in the market (see *Appendix*).

C) Lavinet for high-performance WiFi: Lavinet offers seamless WiFi connectivity and remarkable signal quality to enable smart mobility despite a dynamic wireless environment. Backed by government and industry funding of more than HK\$10 million, Lavinet software development started in 2007. It combines Chan's research results and patented technologies on dynamic routing, distributed algorithm, and channel assignment [6-7]. Through technology transfer, Chan co-founded a start-up with his staff and students in 2013 to commercialize the technology with initial investment from an SI (system integrator) of more than HK\$2 million. The startup has been working closely with industry on different commercial deals. Since 2014 Lavinet has been commercially deployed in Modern Terminals Ltd, one of the top two busiest port terminals in Hong Kong, to support its 24x7 mobile logistics operation in a timely and seamless manner for supply chain management. Lavinet's industrial impact is evident from the awards it has received (see *Appendix*).

(5) Sources to corroborate the impact

1. Wherami: International Exhibition of Inventions; Hong Kong Awards for Industries: Technological Achievement; HK ICT Smart Mobility Award (Smart Tourism); Hong Kong Awards for Industries: Innovation and Creativity; etc.
 2. Streamphony: Best SME ICT (Cloud Solution) Award; etc.
 3. Lavinet: Asia-Pacific ICT Awards, Research and Development category; Silver Award, Boeing Research and Technology; etc.
 4. Appendix: Supplementary information for illustrations, references/patents, and awards
 5. Corroboration letter from Compathnion Technology Ltd
 6. Corroboration letter from iST Company Ltd
 7. Corroboration letter from Openplatform Technology Co. Ltd
- For a complete list of awards see *Appendix: Supplementary information*