



FUTURE COMMUNICATIONS R&D PROGRAMME (FCP)

JANUARY 2025



FCP 2024 AND BEYOND

As part of the Research, Innovation and Enterprise plan, IMDA and NRF invested close to S\$70M in a four-year **Future Communications Research & Development Programme (FCP)** hosted by the Singapore University of Technology and Design (SUTD) to support cutting-edge communications and connectivity research from 2021 - 2025. We are currently in the midst of preparing for the FCP next bound.

As we welcome the new year, the FCP team would like to take this opportunity to provide you with some updates and extend our best wishes for a fruitful year ahead!

FCP
NEWSLETTER

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FCP KEY ACHIEVEMENTS

- 1. Research and Development:** The FCP supports R&D in key areas such as security, network orchestration, AI-Radio Access Network (RAN) research (including AI-for-RAN, AI-on-RAN, AI-and-RAN), and non-terrestrial networks. This fosters innovation and contributes to Singapore's research capabilities, particularly in emerging technologies like AI for communications, 6G and beyond.
- 2. Talent Development:** The FCP has attracted high-calibre research fellows and engineers to work on its research and translation projects as well as Master's students under its scholarship programme and PhD students from both Singapore and overseas to build a strong talent pipeline. For FCP 2.0, there are plans to continue with Master's scholarships and also expand to offer PhD scholarships.



- 3. Collaborations:** The FCP focuses heavily on collaborations with industry partners, regulatory bodies, and international entities to help enhance Singapore's global presence and competitiveness. SUTD has been an active member, contributing to multiple 5G/6G global organizations, and have signed MOU/RCA with leading academic and industrial partners around the world.
- 4. Testbeds and Infrastructure:** The FCP focuses on developing robust communications and connectivity infrastructure, which is critical for the digital economy. The establishment of testbeds like the Future Communications Connectivity Lab (FCCLab), Future Communications Translation Lab (FCTLab) and the Asia & Pacific Open Testing and Integration Centre (OTIC) in Singapore (APOS) supports research, translation and contributes to advancing Singapore's digital infrastructure capabilities, enabling the next level of innovation in future communications and capabilities.

FUTURE COMMUNICATIONS CONNECTIVITY LAB (FCCLAB) / ASIA & PACIFIC OPEN TESTING AND INTEGRATION CENTRE (OTIC) IN SINGAPORE (APOS) @ SUTD

KEY FEATURES

Open: follows 3GPP & O-RAN standards to support easy plug-in & evaluation of research outcomes

Modular: components from multiple vendors can be easily integrated & individually upgraded

Software-defined: deployable in virtualized environment & leverage AI for intelligent orchestration

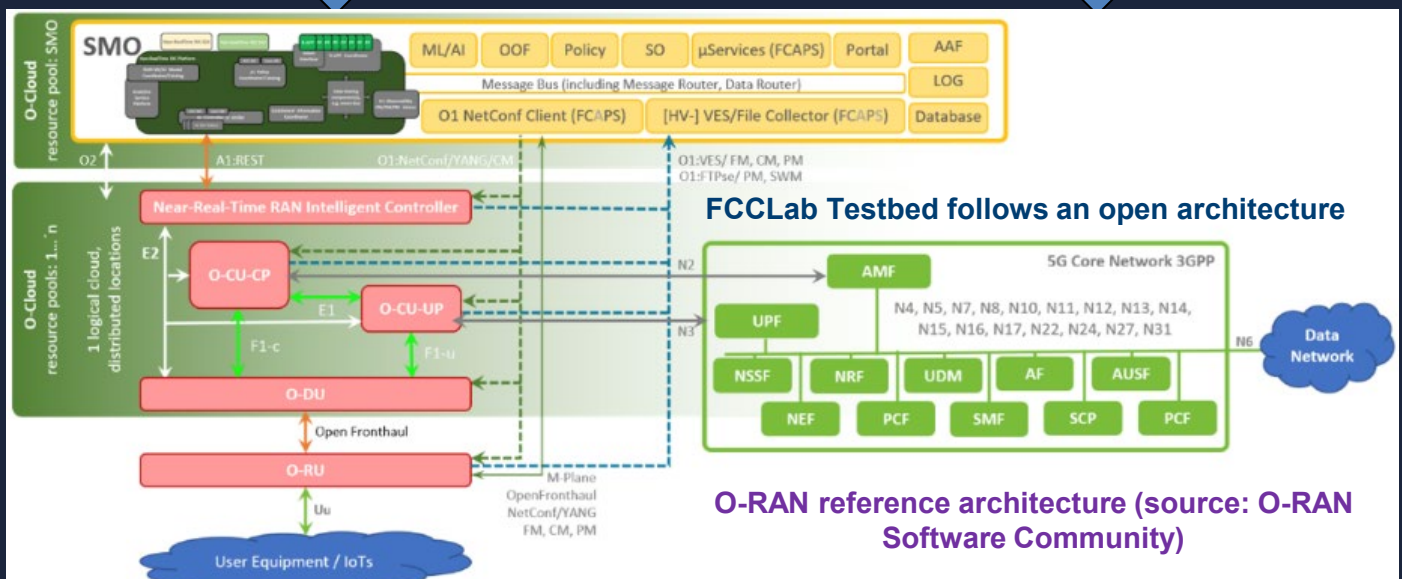
Reconfigurable: customizable for diverse use cases & adapt to changing environment / user needs

The FCCLab is setup at SUTD to facilitate research on future generations of communications technologies. It is an 5G-enabled open Radio Access Network (RAN) testbed that can provide a platform for testing and optimizing performance of different functional blocks (including both hardware and software modules that follow open interface specifications).

Leveraging on the infrastructure of the FCCLab, SUTD has also established the Asia & Pacific Open Testing and Integration Centre (OTIC) in Singapore (APOS). Both FCCLab and APOS are first of its kind in South-east Asia.

Research outcomes for individual components (e.g., CU, DU, or RIC) can be plugged into the testbed for validation

Industry collaborators can bring in their technologies for integration & testing in the testbed



FCCLAB / APOS @ SUTD



KEY ACHIEVEMENTS

The FCP team at SUTD makes outstanding contributions to 5G/6G research and innovation with over 145 publications in top 10% journals and numerous awards received.

Besides research excellence, the team has gone further to play a key role in developing the future communications and connectivity ecosystem in Singapore. Their contributions helped make Singapore a global innovation hub for 5G and future communications technologies.

The team has contributed actively in multiple global organisations in the field, including the O-RAN Alliance and the AI-RAN Alliance where FCP Director, Prof Tony Quek, chairs its AI-on-RAN working group.

Thanks to its numerous research contributions and technical leadership, the team has put Singapore on the stage of multiple international forums, including the first demos from a Singapore university in Mobile World Congress (MWC) Barcelona in 2023, the successful organisation of the first Global OTIC Summit in 2023, being selected as the global top 10 AI-based Radio Access Network (RAN) intelligence control projects (the only team from Asia) in the RIC forum 2024 organised by US government, the organisation of the first O-RAN PlugFest in Southeast Asia in 2024, where the achievement on consistent and repeatable testing is selected for sharing at the International Open RAN symposium 2024, organised by US government.

To develop a vibrant 5G / 6G ecosystem in Singapore, the team has collaborated actively, broadly, and deeply with many world-class industrial partners and research organisations. The team's collaboration with industry spans multiple key 5G areas, from security, AI, to sustainability. The team has also successfully attracted multiple deep-tech companies like QCT, LITEON, and ALifecom to setup or expand their R&D presence in Singapore.

PARTNERS



The team has established multiple Research Collaboration Agreements with companies such as Keysight, QCT, StarHub, ST Engineering, and VIAMI. For example, the collaboration with StarHub is the first time in Singapore to integrate a multi-vendor O-RAN-based 5G radio access network with a telco grade live 5G core network and the joint team is set to demonstrate O-RAN-based end-to-end network-slicing capability to support multiple challenging 5G use cases, such as 5G drone applications. This collaboration has been shortlisted for [Best Technological Collaboration](#).

APOS: O-RAN GLOBAL PLUGFEST

SPRING 2024

The Asia & Pacific Open Testing and Integration Centre (OTIC) in Singapore (APOS) in partnership with North American OTIC in the Boston Area and Japan OTIC, hosted the O-RAN Global PlugFest Spring 2024 from 26 February to 31 May 2024.

Testing at the APOS site focused on the following high-level scope items.

- Demonstrate consistent and repeatable testing in multiple labs
- O-RAN Energy efficiency and savings testing
- O-RAN deployment templates, DevOps, and test automation
- O-RAN RIC and xApp/rApp testing

Virtual showcase: [https://plugfestvirtualshowcase.o-ran.org/2024/O-RAN PlugFest hosted by Asia and Pacific OTIC in Singapore and North American OTIC in the Boston Area](https://plugfestvirtualshowcase.o-ran.org/2024/O-RAN%20PlugFest%20hosted%20by%20Asia%20and%20Pacific%20OTIC%20in%20Singapore%20and%20North%20American%20OTIC%20in%20the%20Boston%20Area).



KEY ACHIEVEMENTS

- First time in the world to demonstrate cross-lab consistent and repeatable testing for O-RAN solutions, together with our global partners
 - O-DU testing: In both Asia & Pacific OTIC in Singapore and North America OTIC in the Boston Area
 - O-RU testing: In both Asia & Pacific OTIC in Singapore and Japan OTIC
 - We were invited by NTIA to present in the first International Open RAN Symposium (IORS), which will feature our achievements in conducting the cross-lab consistent & repeatable tests with Japan OTIC and Northeastern University
 - 2 corresponding papers are accepted in the IEEE VTC workshop on Research and Innovation in Testing and Integration for Open Radio Access Networks (RitiRAN), Washington DC, Oct 2024
- 15 O-RAN members participated, with 13 test scenarios completed successfully, including some tests that could be the first of their kinds:
 - The testing of O-RAN RIC xApp conflict mitigation solution from Capgemini
 - Repeated testing of the same LiteON O-RU using multiple test vendor solutions (Keysight, VIAVI, R&S) and achieve consistent outcomes



The Asia & Pacific Open Testing and Integration Centre (OTIC) in Singapore (APOS) hosted the O-RAN Global PlugFest Fall 2024 from 19 August to 22 November 2024.

Testing focused on the following high-level scope items.

- Demonstrate consistent and repeatable open fronthaul testing in multiple labs
 - O-RU Conformance / O-DU Conformance / WG4 IOT
- O-RAN Energy Consumption, Efficiency and Savings Testing
 - O-RU Energy Savings / O-DU Energy Savings / E2E Energy Savings
 - Non-RT RIC / Near-RT RIC

APOS: O-RAN GLOBAL PLUGFEST

FALL 2024



SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN



KEY ACHIEVEMENTS

- Demonstrated consistent and repeatable testing in multiple labs with Japan OTIC on WG3 E2 Conformance Test (for Rakuten Symphony's Near-RT RIC).
- Integrated Delta O-RU with NVIDIA AI Aerial 5G on NVIDIA A40 GPU, which is a new configuration that has not been integrated together before.
- Completed pre-certification O-RAN WG4 O-RU conformance testing for Viettel High Tech (VHT) macro mMIMO O-RU. VHT is the key research and production unit of Viettel Group, the largest telco in Vietnam. The tested O-RU has been deployed in multiple sites in Vietnam and the pre-certification tests validated the readiness of the O-RU for going through more thorough O-RAN O-RU certification testing.
- Completed pre-certification O-RAN WG4 O-RU conformance testing for Zenlynx O-RU. Zenlynx is a Singapore-based company founded in 2023, which develops advanced high-quality electronic products with a special focus on radio designs, including O-RAN products.
- Complete energy saving testing for multiple systems, including VHT mMIMO O-RU, G REIGNS O-DU/O-CU, and SynaXG O-DU/O-CU with Metanoia SoC based O-RU.

FUTURE COMMUNICATIONS TRANSLATION LAB (FCTLAB)

Testbeds at FCTLab

The FCTLab is uniquely positioned to provide a comprehensive environment for 5G translational research and development (R&D). Two 5G testbeds have been established at the SIT@Dover campus in collaboration with industry partners: one based on a multi-vendor Open RAN solution and the other on a single-vendor solution with traditional RAN.

The single-vendor testbed offers a stable and tightly integrated platform for benchmarking performance and exploring vendor-specific innovations. In contrast, the multivendor testbed promotes interoperability and flexibility, enabling researchers to access open interfaces, analyze traffic data, and develop solutions that align with Open RAN standards.








Multivendor Testbed

We are proud to announce the successful setup of our multivendor Open RAN testbed, marking a significant step forward in advancing open and interoperable 5G technologies. This achievement supports industry-academic collaboration to pioneer next-generation connectivity solutions.

The multivendor testbed integrates components from multiple vendors, including Open RAN-compliant Radio Access Network (RAN) solutions, a 5G Core, and Multi-access Edge Computing (MEC) infrastructure, creating a robust and interoperable 5G platform. Its open architecture facilitates research in areas such as network slicing and edge computing, while fostering collaboration with industry partners to tackle real-world connectivity challenges.

Building the testbed presented challenges, as integrating network components from different vendors required rigorous testing, troubleshooting, and continuous coordination. Close collaboration between FCTLab, Hewlett Packard Enterprise (HPE), and partners was essential to overcome technical hurdles and align system functionalities. This shared effort has driven the success of the testbed, providing a platform for innovation in open RAN 5G technologies.

Category	Partners
Overall System SI & MEC	 Hewlett Packard Enterprise
Core Network SI	 IP-TRIBE
RAN SI	 SOON POH
RAN Software	 Radisys
Radio Units (RUs)	 Benetel

The core software solutions are powered by Microsoft and ENEA, with indoor RUs supplied by Foxconn and outdoor RUs supplied by Benetel.

The multivendor testbed demonstrates exceptional performance with optimized bandwidth allocations for both indoor and outdoor environments. The indoor setup, utilizing 50 MHz of bandwidth, reaching a downlink throughput of 700 Mbps (4T4R) and an uplink throughput of 65 Mbps (2T4R). With a low latency of 7.3ms, it ensures robust performance for high-demand applications.

FUTURE COMMUNICATIONS TRANSLATION LAB (FCTLAB)

Technology Translations with Industry Partners

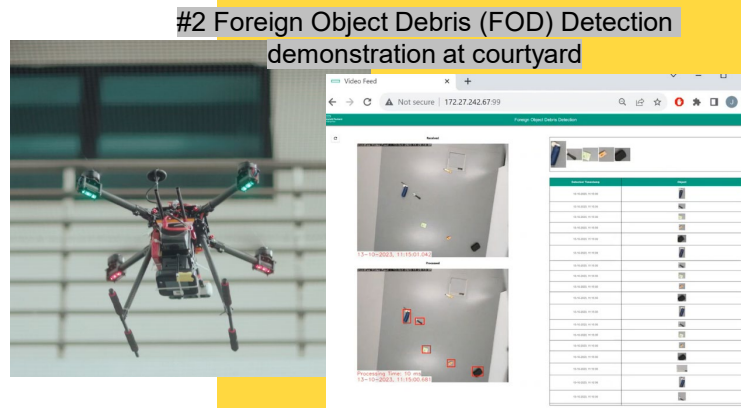
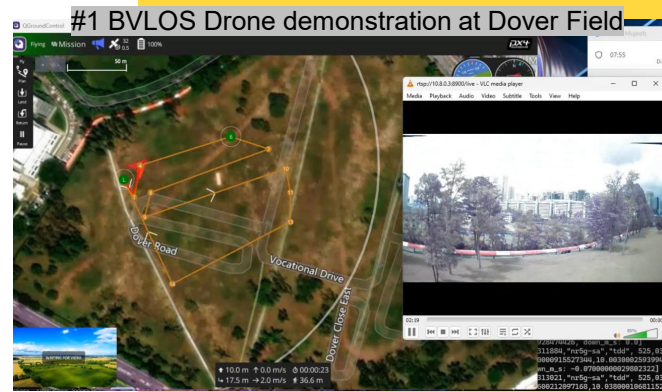
FCTLab's comprehensive indoor and outdoor 5G infrastructure provides a robust platform for collaboration with industry partners to explore and test innovative solutions. To date, we have successfully demonstrated over 20 use cases using public network and our dedicated testbeds, addressing a wide range of real-world challenges. In this newsletter, we feature four key use cases which have been tested together with our industry partners.

#1 In collaboration with **Cavill Pte Ltd**, FCTLab has demonstrated Beyond Visual Line-of-Sight (BVLOS) drone operations at Dover Field for perimeter patrols over a public 5G network. This innovative use case enhances responsiveness and security, integrating 5G-enabled drone control into facility management for more efficient and comprehensive operational oversight.

#2 In collaboration with **HPE**, FCTLab has demonstrated a 5G-enabled Foreign Object Debris (FOD) detection solution using drones and advanced zero-shot object detection models. By leveraging high bandwidth and low latency features, live video streaming replaces fixed-time image capture, while AI processing is redistributed to the Multi-access Edge Computing (MEC) at the gNodeB. This reduces latency, speeds detection, and minimizes runway inspection times, significantly enhancing operational efficiency and responsiveness.

#3 Autonomous Ground Vehicle (AGV) use case has been successfully demonstrated by **ST Engineering**, showcasing how 5G-enabled remote monitoring enhances plantation operations. With real-time video feeds supported by low latency and high throughput, the AGV reduces reliance on physical monitoring, minimizes operational disruptions, and improves safety and productivity in large-scale environments.

#4 **HPE and Hiverlab** have demonstrated a 5G-enabled digital twin solution for rolling stock operation monitoring. Leveraging high bandwidth, low latency, and network slicing, the solution enables real-time monitoring of service trains and debris trucks during debris removal operations. Hiverlab's digital twin platform, hosted on MEC infrastructure, integrates video streams, telemetry data, and visual positioning information, providing a seamless virtual representation of on-site activities.



FCP PROJECT

Towards Secure and Resilient Open RAN Systems: From Continuous Attestation to Real-Time Adaptation

The architectural design of 5G/6G systems emphasizes reconfigurability and intelligent/automatic operations. Open radio access networks (open RAN) architecture is a promising way to achieve these objectives. It offers open interface design, visibility and control of RAN, and flexibility to adopt AI-based intelligent solutions. These can help mitigate emerging security risks for 5G/6G systems, but at the same time they could also enlarge the attack surface and introduce new security risks.

This research project studies how to mitigate some new risks introduced by open RAN to make them more secure and resilient. It also studies how to leverage the open, flexible, and intelligent design of open RAN to detect and respond to new attacks. As such, our research results can help support the assessment and adoption of O-RAN technology in telco industry and some critical Enterprise 5G network use cases.



Lead PI: Chen Binbin (SUTD)

KEY ACHIEVEMENTS

- We have been working closely with the FCCLab team to setup and experiment with multiple O-RAN experimental platforms, including both commercial and open-source implementations. The team has designed a new framework to enhance the security of software-intensive systems from the design phase, which was published in ACSAC 2022 conference. Our further work on the security assessment framework, which is in collaboration with Keysight and QCT, has been demonstrated in Mobile World Congress (MWC) Barcelona 2023. The work also contributed to the successful application of the Asia and Pacific O-RAN OTIC (Open Testing and Integration Centre) in Singapore, which is the first and only OTIC in Southeast Asia and the first OTIC hosted by a university.
- We have published several work in NRF-approved top 10% venues, including:
 - DNAttest: Digital-twin-based Non-intrusive Attestation under Transient Uncertainty, in IEEE/IFIP International Conference on Dependable Systems and Networks (DSN) 2023.
 - One Pass is Sufficient: A Solver for Minimizing Data Delivery Time over Time varying Networks, in IEEE Infocom conference 2023.
 - 5G-Muffler: Covert DoS Attacks over Open Fronthaul Interface of O-RAN 5G Network, to appear in IEEE Infocom conference 2025.
- We also collaborated with several leading companies in the RAN Intelligent Controller (RIC) domain, including VIAVI, Broadcom (VMWare), and Capgemini, regarding RIC and xApp/rApp testing. Our team has supported the successful demonstrations of two RIC and xApp/rApp demos in MWC Barcelona 2024, as well as an rApp for interference management demo at the USA National Telecommunications and Information Administration (NTIA) RIC forum 2024 --- we are the only team from Asia among the top 10 teams selected globally by NTIA for the presentation. The collaboration has also resulted in several successful demonstrations on RIC / xApp / rApp in the Global PlugFest 2024 hosted by Asia & Pacific OTIC in Singapore.

FCP PROJECT

Investigations on Synergy of Semantic Communications and Edge Intelligence

The project explores the synergy between semantic communication (SemCom) and edge intelligence for future communications. SemCom aims to break out of "Shannon's trap" by focusing on the semantic and effectiveness levels of communication, leveraging AI to filter out irrelevant information and transmit only valuable data. Edge intelligence, driven by AI, brings sensing, communication, AI model training, and inference closer to data sources, reducing latency and improving service orchestration. Both technologies aim to enhance the performance and resource management efficiency of 6G networks. The project seeks to understand how these technologies can benefit from each other and jointly contribute to the implementation of a high-efficient intelligent Internet of Things in 6G.



Lead PI: Xiong Zehui (SUTD)
Co-PI: Dusit Niyato (NTU)
Collaborators: Sun Sumei (I²R, A*STAR), Jiang Wenchao (SUTD)

KEY ACHIEVEMENTS

- Clarivate's annual list of Highly Cited Researchers™ (HCR) gives recognition to individuals whose research have demonstrated significant and broad influence in their respective fields. Prof Xiong Zehui is among the 108 awardees from Singapore for 2024: <https://www.sutd.edu.sg/About/happenings/News/2024/11/SUTD-Faculty-Highly-Cited-Researchers>.
- **SemCom Enabled Edge Intelligence:** The proposed G-SemCom framework and ADD algorithm effectively reduce bandwidth consumption while ensuring high-quality AI-generated images in mobile AIGC.
- **Edge Intelligence enabled SemCom:** The simulation results demonstrated promising performance gains in terms of energy saving, semantic transmission reliability, and semantic energy efficiency. The benefits of KG-based semantic communication in terms of the flexibility it brings to resource allocation are well documented.
- **Resource Management for Synergy of SemCom and Edge Intelligence:** The semantic-aware rendering capacity allocation scheme, has shown improved performance compared to random and uniform allocation schemes. The scheme achieved a maximum of 25.5% improvement in Meta-Immersion (MI) compared to the uniform allocation scheme.
 - Furthermore, the performance of the proposed SemCom framework in the simulation was evaluated using mean recall as the metric. The results showed that the system performed almost as well as the original model for the top 20 predictions. The performance of the system was tested under different wireless channel conditions. The performance of the system increased steadily with increasing SNR and was stable for SNR of 9 dB and above. The proposed auction mechanism was evaluated and found to adapt to different numbers of VSPs, with consistent average utilities for the seller and winning VSPs. The proposed greedy algorithm outperformed the random algorithm in terms of average seller's utility and average winning VSPs' utility. The image utilization rates were consistently above 50%. The data size of image transmission was greatly reduced by using the semantic communication system for scene graph transmission, improving the efficiency of the communication system for the Metaverse.
- **Prototype Development:** The self-supervised learning-based decoding method allows for the recovery of source messages to support multiple different tasks, overcoming the limitations encountered in semantic communications. The effective semantic hash sampling algorithm achieves a mean squared error (MSE) between the ground truth and the 2D angles-of-arrival (AoA) estimation results that is 67% lower than that of typically used uniform sampling schemes. The RIS hardware design also enhances security by utilizing the amplitude response matrix of the RIS for data encryption.

FCP PROJECT

Towards Differential Fuzzing of 5G and Beyond 5G Communication

This project aims to design an open security testing platform as a first step to comprehensively investigate and explore the security issues in Open Radio Access Network (Open RAN) components.



Lead PI: Sudipta Chattopadhyay (SUTD)

KEY ACHIEVEMENTS

- To the best of our knowledge, we have created the first over-the-air fuzzing technology that could automatically test arbitrary commercial-off-the-shelf (COTS) 5G devices (e.g., smartphones and 5G USB modems). The technology does not require any instrumentation or reverse engineering, hence, applicable to any 5G baseband modem architecture.
- We have evaluated our architecture and released [5Ghoul](#) (520+ github stars), a total of 16 security vulnerabilities (12 CVEs, seven with high severity), of which 12 affect commercial off-the-shelf (COTS) edge devices employing 5G modems from Qualcomm and MediaTek.
- 5Ghoul discovery was featured widely in technology media in Singapore and beyond. Notable coverage includes [Channel News Asia \(CNA\)](#), HackerNews, SecurityWeek, BleepingComputer, Hackaday, Heise (German), ZDnet (French), Edge Singapore, etc.
- The discovery of 5Ghoul has been awarded by Qualcomm and MediaTek with a bug bounty of 36,000 USD. Moreover, a Qualcomm spokesperson had publicly commended the research team in this [SUTD Media Release](#).
- 5Ghoul was accepted to be presented as a 2-hour demonstration at DEFCON32 at Las Vegas, USA. DEFCON is the largest industry conference on hacking and security.
- We have also made our over-the-air fuzzing technology generic, and currently, the technology is able to fuzz arbitrary protocols supported by Wireshark. This is important, as one of our key milestones is to apply the technology in a generic fashion as ORAN technologies evolve. However, as our state mapping technique is designed in a generic fashion, the evolution of ORAN protocols are not going to instigate changes to the stateful fuzzing. This technology (named U-Fuzz) has been publicly released here: <https://github.com/asset-group/U-Fuzz>.
- The U-Fuzz technology was accepted to be presented at the International Conference of Software Testing, Verification and Validation (ICST) 2024 in Toronto, Canada in May 2024. ICST is a flagship conference (Core Rank: A) in the area of Software Testing and Verification.
- The U-Fuzz tool (75+ github stars) was also accepted to be presented as a testing tool at the International Conference of Software Testing, Verification and Validation (ICST) 2024 in Toronto, Canada in May 2024. In contrast to the full presentation of the technology, the tool presentation focuses on mature tools that have been used by the community and have been proven useful to find bugs/vulnerabilities in real-world software. Indeed, the U-Fuzz tool has found over 11 new security vulnerabilities (11 CVEs) across a variety of protocols, two within 5G NR implementations. However, since the tool is generic, it has also found nine other vulnerabilities in CoAP and Zigbee protocol implementations as well. Thus, the tool has a strong potential for extension in ORAN compliant protocols.

FCP PROJECT



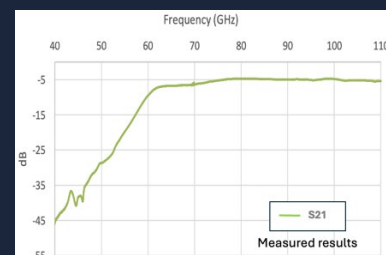
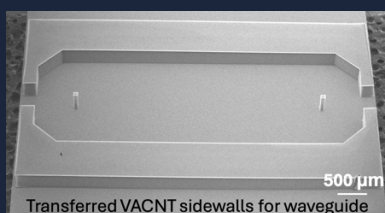
Lead PI: Dominique Baillargeat (CNRS@CREATE)
Co-PI: Tay Beng Kang (NTU)

Advanced Technology for Sub-THz Waveguides based on Carbon Nanotubes

This project focuses on the development of passive components operating at high frequencies up to 300GHz. This development is essential for 3D heterogeneous integration and requires innovative circuits such as waveguides that are easy to integrate in a 3D approach, compact, cost-effective to manufacture, and designed for low loss to improve connectivity. To address these needs, we are focusing on the development of alternative and disruptive technologies based on carbon nanotube (CNT) growth and transfer for the experimental demonstration of a CNT-based air-filled waveguide in the sub-millimeter wave range.

KEY ACHIEVEMENTS

1. A significant milestone by successfully designing and fabricating CNT-based waveguides in the W band (70GHz-110GHz), demonstrating excellent transmission performance with a wide bandwidth, a flat transmission response over the full W band, an insertion loss around -4dB.



2. A first experimental validation of a wideband digital modulated channel transmission at 60GHz using the fabricated CNT-based waveguide.
3. The potential of CNT-based waveguide technology has been shown to extend into the sub-THz band, offering promising opportunities.
4. Design and optimization of CNT-based waveguides for the D band (around 150GHz) and up to 300GHz have been accomplished. Device fabrication is currently in progress.
5. Design and optimization of other CNT-based passives, including cavities and filters, for three different central frequencies: 80 GHz, 145 GHz, and 285 GHz have been completed. Fabrication of these components is also ongoing.
6. One conference paper was presented at the European Microwave conference EuMW 2024 in Paris, France, in Sept. 2024 and another one at the Asia Pacific Microwave Conference 2024. Three conference papers, including a keynote presentation, have been accepted for presentation at INEC 2025 in Taiwan in Jan 2025.

FCP PROJECT

SD-PAR5ER Security Framework for Smart Drones Video Surveillance Applications using P4 Tofino

Lead PI: Purnima Murali Mohan (SIT)
 Co-PIs: Vivek Balachandran (SIT), Peter Loh Kok Keong (SIT)

The SD-PAR5ER security framework for smart drones video surveillance applications has achieved significant milestones in cybersecurity and network optimization. It strengthens defenses against cyber threats, enhances access controls, and improves QoS in high-volume networks such as smart drone surveillance, which operates at traffic volumes of about 80 Mbps with a round-trip time (RTT) latency of ~15 ms. Collaborating with the Industry – Starview Technologies, the project successfully filed a Singapore patent (No.: 10202403003W) and contributed to 5G cybersecurity by identifying and blocking malicious traffic, aiding network forensics, and supporting lawful investigations. Key findings were presented at the IEEE Conference on Communications and Network Security (CNS '24), and the project has trained 1 research engineer, 10 undergraduate students, and 1 industry master's student, driving innovation and real-world impact.

https://www.linkedin.com/posts/fctlab_future-communications-translation-lab-sit-activity-7229313153669459969-zy1y/?utm_source=share&utm_medium=member_desktop



prototype our new technologies for potential commercialisation

Security Threat	Description	Risk level
Phishing attacks	Malicious UEs (drones) gaining access to the MEC interfaces	High
CPS attacks	Attacks on the SDN/NFV infrastructure (less likely to happen with strong defenses in place)	Low
DoS/DDoS	RAN network due to malicious AP's with service requests targeting the RAN and/or MEC leading to service disruptions	High
Interoperability issues	When integrating different cloud technologies that are not compatible (e.g., version gaps), issues due to lack of standardized security.	Low

FCP PROJECT

Hybrid Terahertz/ Free Space Optics (THz/FSO) for 6G Communication Networks

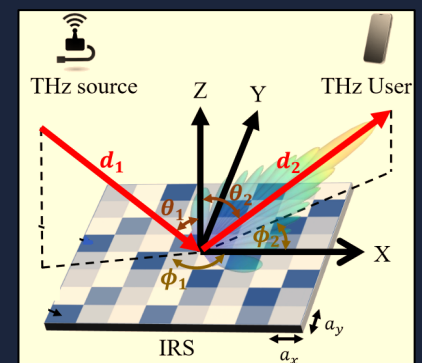
KEY OBJECTIVES

- To improve coverage and spectral efficiency of THz access links using **intelligent reflective surface (IRS)** and using **hybrid terahertz/free space optics (THz/FSO)** for ultra-high data rate network.
- Deployment of IRSs in **hybrid** wireless network: Stochastic geometry-based analytical framework.
- To achieve reliable link performance by exploiting **spatial diversity and spatial modulation (SM)** for hybrid THz/FSO communication.
- **Deep learning (DL)**-based channel estimation in ultra-massive multiple-input multiple-output (**UM-MIMO**) Communications.



KEY ACHIEVEMENTS

- **IRS-assisted THz Access Systems:** Designed IRS-aided THz access frameworks and rigorously characterized THz and FSO communication links by accounting for critical factors such as atmospheric attenuation, fading, spreading losses, statistical parameters, and misalignment effects.
- **RIS-enhanced Hybrid FSO/RF Systems:** Proposed an innovative hybrid backhaul network integrating free-space optical (FSO) and terahertz (THz) technologies, leveraging reconfigurable intelligent surfaces (RIS) to enhance performance and reliability.
- **Resilient High-Bandwidth Backhaul Solutions:** Developed robust and high-bandwidth backhaul networks by seamlessly incorporating RIS into hybrid FSO/THz systems, addressing challenges in resilience and throughput.
- **Enhanced Spectral Efficiency with SM-Based THz MIMO:** Introduced a spatial modulation (SM)-based array-of-subarrays (AoSA) structure to significantly improve spectral efficiency in MIMO-THz systems.
- **Advanced Channel Estimation for UM-MIMO THz:** Investigated uplink hybrid-field THz ultra-massive MIMO (UM-MIMO) channel estimation (CE) techniques by utilizing THz channel sparsity and Bayesian learning, achieving robust and accurate CE with reduced pilot overhead.
- **Deep Unfolding-Based Sparsity-Aware CE:** Developed a deep unfolding-aided sparsity-aware framework to enable adaptive and efficient channel estimation, specifically optimized for wideband THz UM-MIMO transmission scenarios.



FCP PROJECT

Integrated Sensing and Communication in Millimetre-Wave and Terahertz Bands for B5G and 6G



Lead PI: Chen Xudong (NUS)
Co-PIs: Zeng Yonghong (I²R, A*STAR), Sun Sumei (I²R, A*STAR)

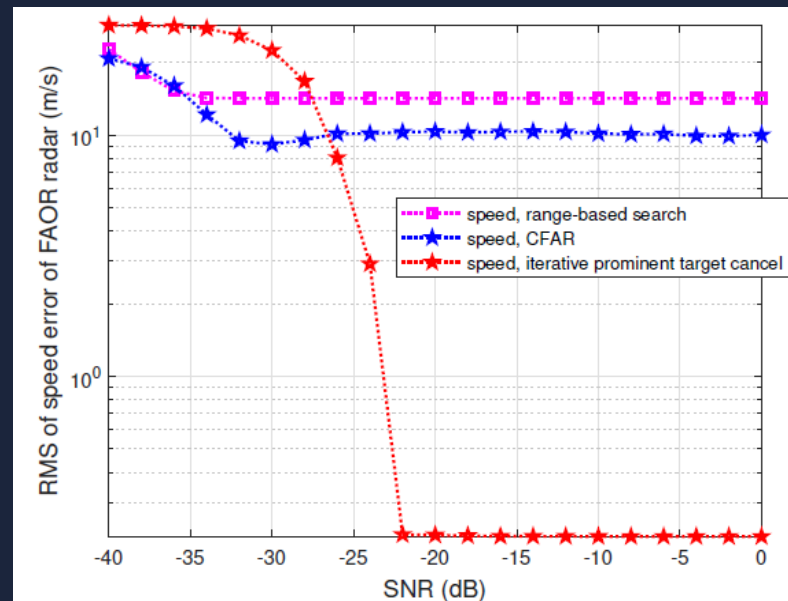
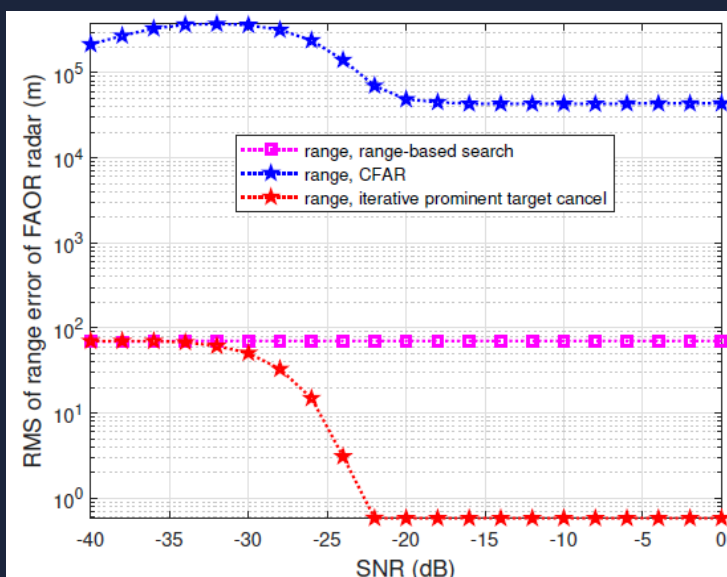
Integrated sensing and communication (ISAC) with OTFS signal
Orthogonal time frequency space (OTFS) modulation has been proposed to handle the high Doppler spread or fast time varying channel. It has been shown that OTFS indeed have much better performance than the orthogonal frequency division multiplexing (OFDM) for high mobility channels, which is a promising for the 6G communication.

KEY ACHIEVEMENTS

- **Fast algorithm OTFS radar (FAOR):** algorithm for sensing with OTFS signal with low complexity (patent)
- **Iterative prominent target cancellation (IPTC):** enable multi-target detection by iteratively canceling the impact of strong target (patent)
- **Sensing aided channel estimation, pilot design, and target detection for OTFS**
 - The same pilot for channel estimation and target detection
 - The pilot design dramatically reduces the PAPR compared to the single symbol pilot design (multiple-tens of dB reduction), while has comparable channel estimation performance

Method	Complexity
FAOR	$O(NM \log_2(MN))$
Method in [2]	$O((MN)^2)$
Matched filtering [1]	$O((MN)^2)$

1. P. Raviteja, K. T. Phany, Y. Hong, and E. Viterbo, "Orthogonal Time Frequency Space (OTFS) Modulation Based Radar System", IEEE Radar Conference (RadarConf), April 2019
2. K. Zhang, W. Yuan, S. Li, F. Liu, F. Gao, P. Fan, and Y. Cai, "Radar sensing via OTFS signaling: A delay Doppler signal processing perspective". IEEE ICC, May 2023.



With the proposed IPTC, the range and speed of the weak target are estimate accurately, while conventional methods do not work well

FCP PROJECT

Integrated Sensing and Communication in Millimetre-Wave and Terahertz Bands for B5G and 6G



Lead PI: Chen Xudong (NUS)
Co-PIs: Zeng Yonghong (I²R, A*STAR), Sun Sumei (I²R, A*STAR)

Integrated sensing and communication (ISAC) with Compressed Sensing

Automotive radar imaging has garnered widespread attention in the field of ISAC for V2X. TPSSI is proposed, an unfolded deep network that project compressed sensing and AMP algorithms into the network structure to achieve high-resolution, low-clutter imaging, which provides a powerful tool for vehicle communication and perception in 6G V2X scenarios.

KEY ACHIEVEMENTS

- Robust Super Resolution:** Traditional algorithms (AMP, ISTA-Net, etc.) Specific parameters are limited to specific scenarios, making multi-scenario super-resolution challenging. Deep unfolding methods address this by learning and optimizing hyperparameters from training data, enabling robust super-resolution across diverse conditions.
- Fixed Threshold Limitation:** Fixed thresholds cannot adapt to varying noise and scattering intensities.
- TPSSI-Net Advantage:** TPSSI-Net uses dynamic threshold matrices, enhancing strong targets while suppressing noise, ideal for automotive radar imaging.

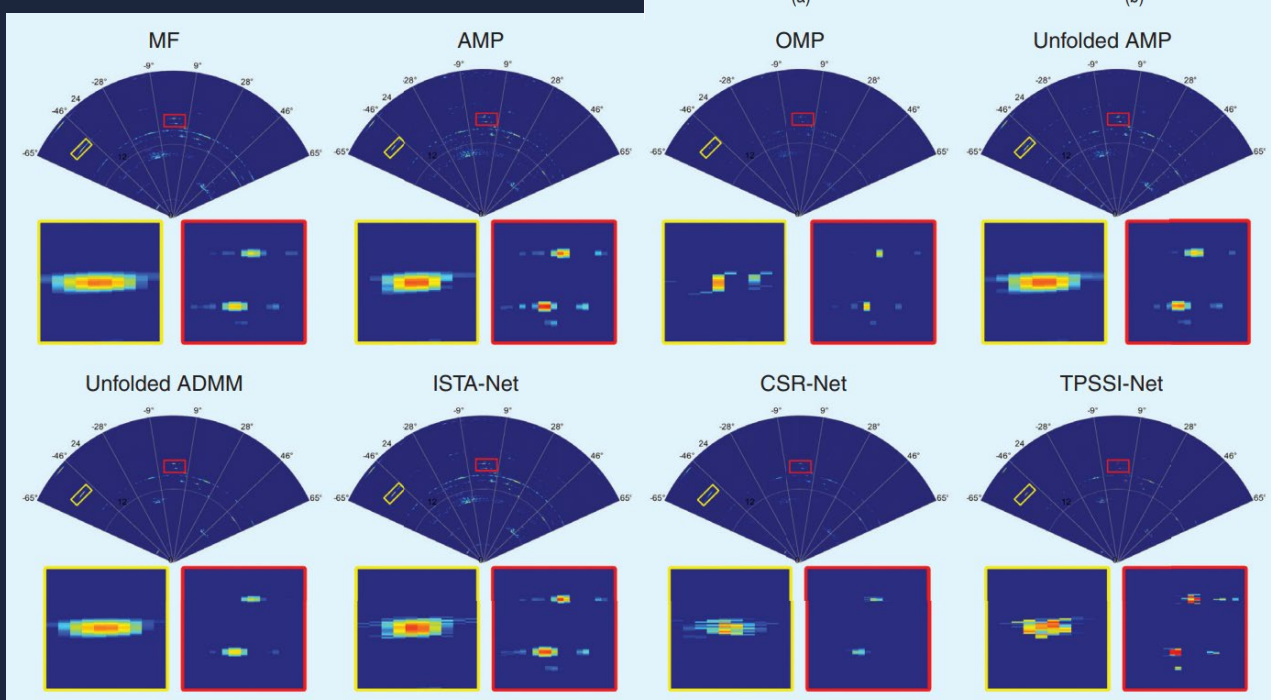


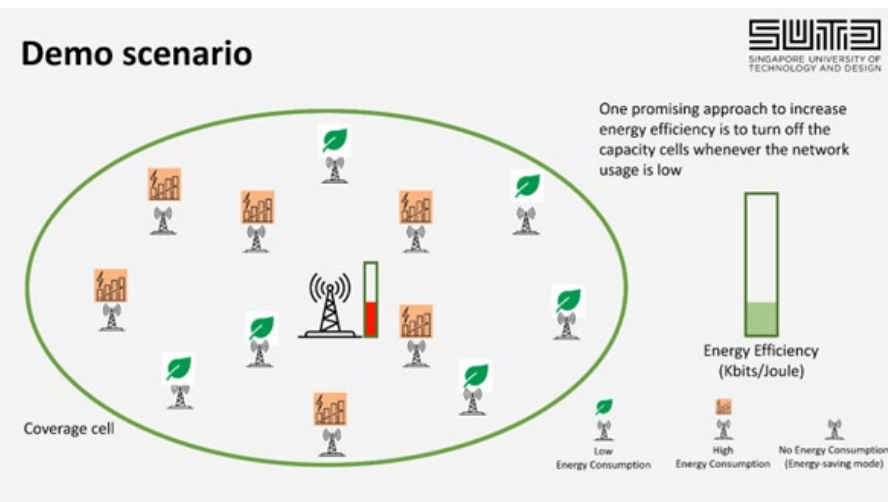
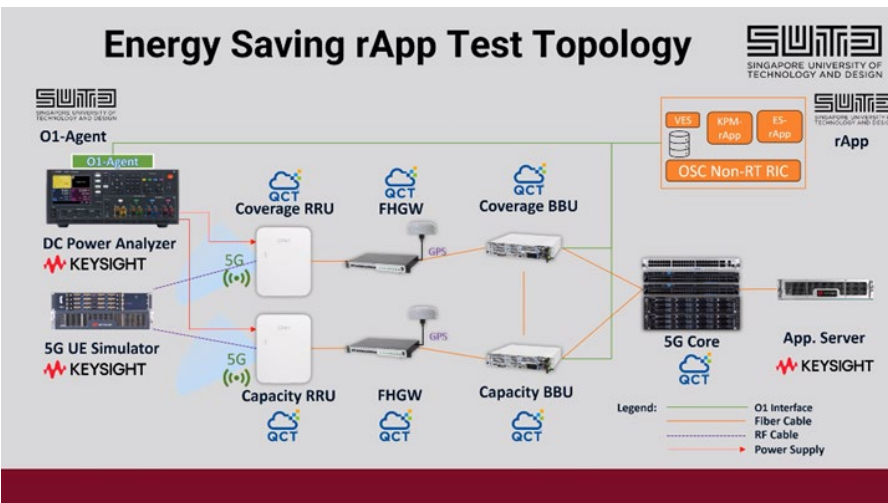
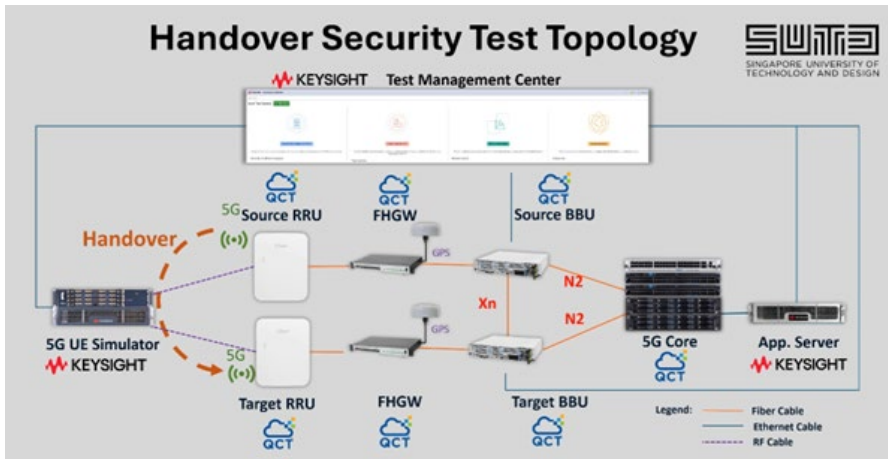
Fig.1. Imaging results by different algorithms in frame 5, where the boxed figures are the enlarged views of the local strong scattering areas

FCP SCHOLARS

- A copyright owned by NTU, is obtained in collaboration with NTUitive, for a **progress monitoring algorithm** that monitors the building construction progress of Prefabricated Prefinished Volumetric Construction (PPVC) for HDB flats. FCP scholar **Chua Wei Png** contributed to the development of the copyrighted software, the drafting and reviewing of the copyright.
- FCP scholar **Khor Kai Sherng**, together with his research supervisor Prof Cheah Chien Chern, **devised a different way to use machine learning algorithms for robot grasping**. With these remarkable results, they have written a paper, and the paper has been **published by a journal under MDPI called Sensors**.
- FCP scholar **Loh Guo-Yang** has **[filed a Defensive Publication \(SAFE-SEND\) on secure methods to protect payments](#)**. It relates to a method of performing a Safe-Send transaction that may allow a sender to recall money transferred to a receiver even after the transaction is completed.
- FCP scholar **Foo Feng Lin** is a **team lead for a major software development project at DBS Bank**. She was responsible for overseeing the project's progression, coordinating with various stakeholders, and ensuring that the team met all technical and strategic goals. The specific goals of the project included enhancing the speed and reliability of transaction processing within the bank's digital platform, strengthening security measures to protect sensitive customer data, and redesigning the user interface to make it more intuitive and user-friendly. DBS bank achieved more efficient transactions, enhanced data security, and a more accessible interface. As a result, customers enjoyed smoother interactions with the digital banking platform, which led to increased user satisfaction and contributed to the bank's ability to retain and attract clients. Additionally, the project contributed to more effective internal workflows for employees who interacted with the system daily.
- Feng Lin has also been actively involved in championing diversity and inclusion within the industry. She served as a **panel speaker at DBS's Women in Tech events** to share her experiences and insights on navigating the tech field as a woman. This provided her with the opportunity to advocate for greater gender diversity in technology, contribute to meaningful discussions on the subject, and inspire other professionals to pursue and excel in tech careers.
- FCP scholar **Ngan Weida** actively participated in the **development of advisories and standards at the national level**, focusing on both current and emerging technologies.
- FCP scholar **Justin Koh Shang Rong** joined Singlife as a Third-Party Information Security Specialist and developed an **information security centric supply chain risk management framework** which has been operationalised from the ground up.
- FCP scholar **Wang Junhao** was an **invited speaker** on topics related to Internet-of-Things security at events hosted by Cyber Security Agency of Singapore (CSA), Nanyang Polytechnic (NYP) and Infineon. He also **drafted and piloted an extension of the Cybersecurity Labeling Scheme (CLS)** known as CLS-Ready, a security evaluation scheme meant for integrated circuit (IC) manufacturer to facilitate end-user product manufacturers to achieve CLS Tier 4 more easily.
- Junhao together with his supervisor (Daryl Koh) had provided the initial draft of the CLS-Ready scheme documentation to CSA. Using the draft scheme documentation as baseline, Junhao **piloted CLS-Ready himself in collaboration with Infineon Technologies**. Infineon Technologies offered one of their products, Optiga Trust M, for the pilot evaluation. As a result, Infineon's Optiga Trust M became the **[first to receive CLS-Ready certification from Cyber Security Agency of Singapore](#)**.
- During the pilot, an NYP senior lecturer also worked alongside Junhao to learn about how the CLS-Ready scheme is executed; this was intended to grow the competency of the senior lecturer to build a pre-evaluation lab in NYP.

HIGHLIGHTS OF 2024

- FCP showcased the following demos at **Mobile World Congress Barcelona, 26 - 29 Feb 2024**



1) Security Tests of QCT OmniRAN's Handover Procedures by the Asia & Pacific Open Testing and Integration Centre (OTIC) in Singapore (APOS) using Keysight Test Solutions

APOS conducted rigorous security tests with support from Keysight to validate the handover procedures implemented by QCT's O-RAN-based OmniRAN 5G solution. The testing, involving multiple OmniRAN cells, achieved significant test automation, ensuring consistency and repeatability.

2) O-RAN Energy Saving Demonstration using rApp (from SUTD), OmniRAN (from QCT), and E-Plane Test Suite (from Keysight)

FCP showcased its AI-based Energy Saving rApp, designed to manage QCT's O-RAN-based OmniRAN system optimally. Leveraging AI for traffic predictions and energy saving RAN control, this breakthrough, verified with Keysight's E-plane test suite, underscores AI's pivotal role in telecommunications.

3) O-RAN Energy Saving Demonstration using rApp (from SUTD), non-RT RIC (from VMware), and RIC Tester (from VIAVI)

FCP presented an integration of its Energy-saving rApp with VMware's Non-RT RIC and VIAVI's RIC test solution. Employing state-of-the-art AI technologies, the rApp optimizes cell control, achieving significant energy savings without compromising service quality in realistic scenarios.

HIGHLIGHTS OF 2024



- FCP's efforts attracted the US National Telecommunications and Information Administration's (NTIA) attention and was **selected as one of the 10 main presenters** for their radio access network **(RAN) Intelligent Controller (RIC) Forum**, 26 – 28 March 2024, in Dallas-Fort Worth, Texas.

IEEE INFOCOM 2024  

The 2nd Workshop on Next-generation Open and Programmable Radio Access Networks (NG-OPERA)

Best Demo Paper Award

presented to

Nguyen Bao Long Tran; Mao Van Ngo; Yong Hao Pua; Thanh Long Le; Binbin Chen; Tony Q. S. Quek

for the paper entitled

AI-Driven rApps for Reducing Radio Access Network Interference in Real-World 5G Deployment

Nakjung Choi, Workshop Co-Chairs,
Tao Han, Workshop Co-Chairs
21 May 2024

- FCP team won the **best demo paper award** at the 2nd Workshop on Next-generation Open and Programmable Radio Access Networks **(NG-OPERA)**.

HIGHLIGHTS OF 2024

- FCP Director, **Professor Tony Quek**, was awarded **2024 WWRF Fellow** in recognition of his leadership and contributions in the field of wireless communications and networking.
- He was also awarded the **IIT Bombay International Award For Excellence in Research in Engineering and Technology** in Oct 2024. This award was established in 2022 through generous donations by alumnus Mr. Shantanu Rastogi (B.Tech., M.Tech., EE, Nanotechnology, 2002) and Mr. Sandeep Naik (Managing Director, Head of India and Asia Pacific, General Atlantic). The award acknowledges Prof Quek's stellar research and publications in the areas of wireless communications, particularly in ultra-reliable low-latency communication (URLLC) and network intelligence.



- Dr Tung Chen-Yuan from the Taipei Representative Office in Singapore led a **delegation of business leaders** for a visit proudly hosted by Prof Tony Quek, Sector Lead of the SUTD AI programme and Director of the Future Communications R&D Programme (FCP). Our cutting-edge **advancements in AI**, particularly in communications and robotics, **were showcased**.

HIGHLIGHTS OF 2024

- FCP Deputy Director, **Associate Professor Park Jihong**, has been elected as one of the twelve new **Technical Committee members** for **Machine Learning for Signal Processing (MLSP)**. This is a testament to Jihong's dedication and significant contributions to the MLSP community.



- The Future Communications Connectivity Lab (FCCLab) / Asia & Pacific OTIC in Singapore conducted a **RIC Development Workshop** for participants from **the Philippines' Asia Open RAN Academy (AORA)** at the SUTD campus. The workshop, co-hosted with VIAVI Solutions Inc, was held on 3-5 September 2024 and the participants had practical sessions on installing a RIC-enabled testbed from scratch and training materials were co-developed.

HIGHLIGHTS OF 2024



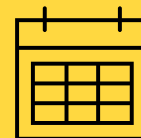
- FCP Deputy Director, Associate Professor **Chen Binbin**, participated in two of the panels at **CommunicAsia 2024** on “AI-Driven Networking with 6G: Envisioning the Next Frontier” and “Open RAN: What’s next for APAC?”



- Assistant Professor **Xiong Zehui** and his collaborators won the IEEE Communications Society (**ComSoc**) **Outstanding Paper Award** and **Best Paper Award** from IEEE International Wireless Communications and Mobile Computing (**IWCMC**) in 2024.

UPCOMING ACTIVITIES

- 1st O-RAN Certification from APOS
- MWC Barcelona, 3 - 6 Mar 2025
- Expo 2025, Osaka
- MWC Shanghai 2025
- OAI Workshop, Oct 2025
- MWC Las Vegas 2025



For the latest information on the FCP, do visit us at our website at: <https://fcp.sutd.edu.sg/>

