

Future-Ready Wireless Networks Powering Smart Connectivity

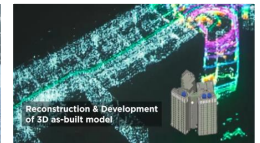
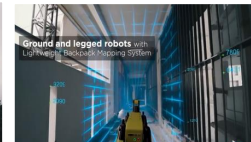
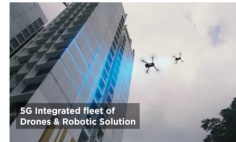
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5G-enabled Robot and Drone Assisted Construction Site Monitoring

Using 5G wireless technology for robots and drones to enhance site safety and productivity

- ✓ 3D mapping of construction site with automated progress tracking
- ✓ Wheeled + Legged robots
 - ✓ Autonomous navigation
 - ✓ 5G connectivity support
 - ✓ 3D site mapping and detection of workers' PPE and safety events



12U Satellite Bus



Ship Terminal



Comms Payload

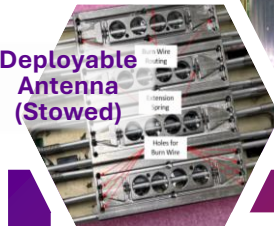


VHF Data Exchange System (VDES)

An Enabling Technology for Maritime E-Navigation

- ✓ Enables two-way communication for information exchange
- ✓ Provides larger bandwidth to accommodate larger number of maritime users
- ✓ Use of satellites to extend the terrestrial coverage

Deployable Antenna (Stowed)

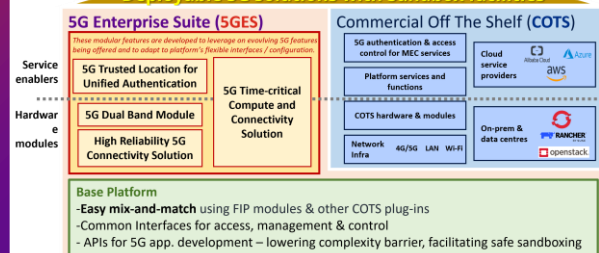


5G Enterprise Suite (5GES)

A suite of features to power 5G adoption

- ✓ Time-critical connectivity for fast closed-loop control
- ✓ Dual 5G/Wi-Fi seamless connectivity
- ✓ Reliable 5G connectivity for poor aerial and coastal coverage areas
- ✓ Trusted 3D location of assets

Deployable 5G solutions with Sandbox facilities



Portable Gateway



5G-Capable Outdoor Wi-Fi AP



Vital Sign Monitoring Watch



IoT Pervasive Connectivity Solution

Edge solutions to empower and enhance intelligent smart yard

- ✓ A secured unified connectivity architecture which is scalable and extensible
- ✓ Track and trace platform for personnel / assets and vital sign monitoring
- ✓ An integrated IIoT platform with on-premise storage

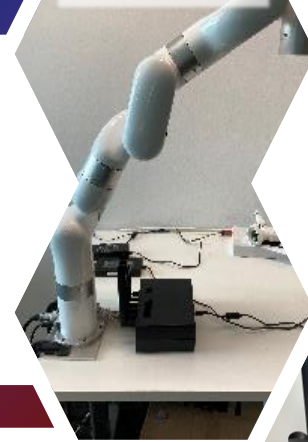
Next-Generation Connectivity Systems and Solutions

5G Edge Gateway

Enabling 5G-enabled IoT connectivity for industrial applications

- ✓ Seamless switching between 5G/Wi-Fi connectivity to deliver near-zero packet loss
- ✓ Engineered for low-latency, real-time control
- ✓ Provisioned to support dual 5G radios for carrier redundancy

Control of a robotic arm



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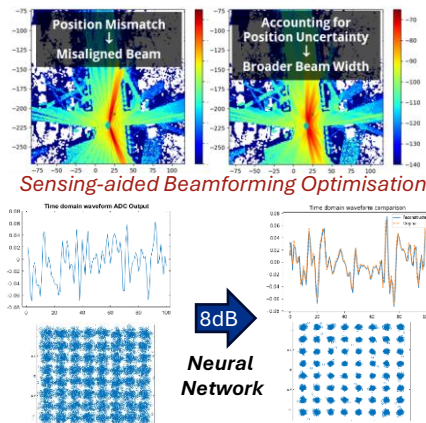
Edge Gateway



AI/ML for Next-Generation Wireless Communications

Leveraging AI/ML to address fundamental issues in communications and networks

- ✓ End-to-end solutions tackling various challenges across different layers of protocol stack
- ✓ Optimized for Real-Time Implementation
- ✓ Proven and validated in a hardware prototype under realistic environment



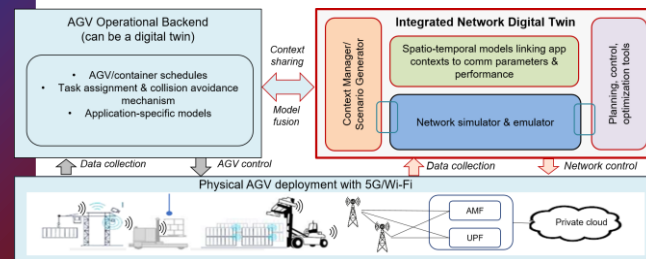
Sensing-aided Beamforming Optimisation

Deep Learning Model for Nonlinearity Compensation

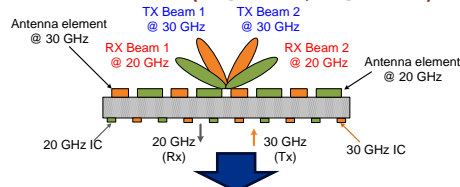
Integrated Network Digital Twins

Enabling cyber-physical convergence

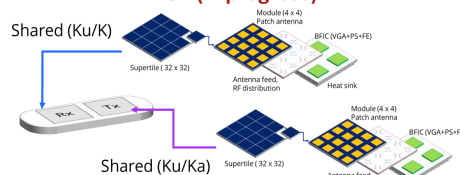
- ✓ Integration of application-domain contexts and behaviours
- ✓ Spatio-temporal prediction of comm performance based on application contexts
- ✓ Context-aware network planning and run-time control and optimisation



Dual-band dual-beam shared-aperture ESA at Ka-band (TX@30GHz, Rx@20 GHz)



Dual-band multi-standard shared-aperture ESA (in progress)



Scalable and Modular Shared-Aperture Electronically Steerable Arrays (ESA)

Multiband, multibeam technology that provides flexible solutions for fast satellite tracking and communications

- ✓ Multi-standard/Multibeam allows multi-orbit/satellite connectivity (multi-operator)
- ✓ Shared-aperture allows up to 50% size reduction
- ✓ Power efficient

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Advanced Sensing and Integrated Systems

Integrated Communications and Sensing (ICAS)

Fast and robust ICAS solutions enabling sensing with communications waveform and hardware

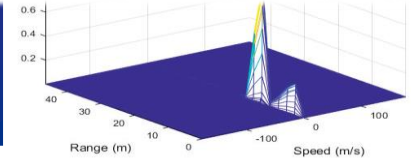
- ✓ Radar sensing algorithms with 5G signals
- ✓ Low complexity sensing algorithm achieving superlinear speed-up
- ✓ Innovative interference-cancellation methods for ICAS system



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Range and speed of the targets are estimated with single antenna



MIMO Vital Sign Radar

Comprehensive solution for touchless living body detection

(use cases: disaster relief, healthcare, safety & security)

- ✓ Human presence detection
- ✓ Multiple human body localizations
- ✓ Vital sign detections for multiple people simultaneously
- ✓ AI gesture/posture recognition



Structural Health Monitoring (SHM)

Enabling resilient infrastructures and smart city with fibre optic sensor technology

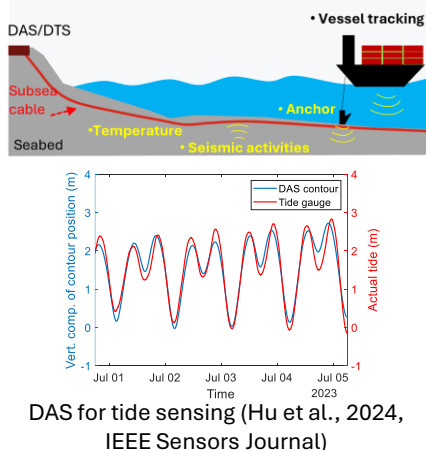
- ✓ Real-time monitoring & detection
- ✓ Strain, temperature and acceleration monitoring
- ✓ Power efficient (<1W) wireless universal interrogator



Subsea Cable Sensing

Cable anomaly detection and ocean environment monitoring

- ✓ Large-scale mapping of vibration, deformation, temperature, etc
- ✓ Subsea cable monitoring and anomaly/threat detection
- ✓ Ocean environment monitoring

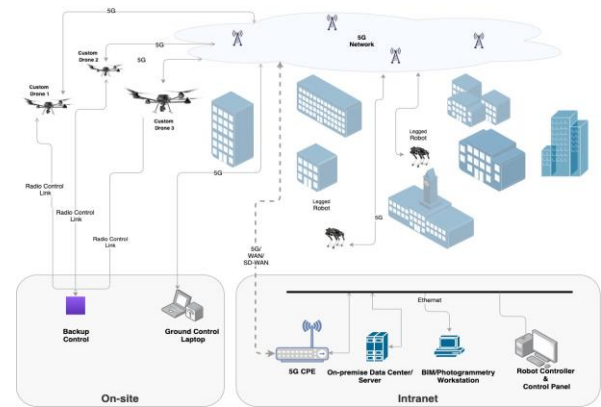


5G-enabled Robot and Drone Assisted Construction Site Monitoring

Using 5G wireless technology for robots and drones to enhance site safety and productivity

Key Features

- ✓ 3D mapping of construction site with automated progress tracking
- ✓ Wheeled + Legged robots
 - Autonomous navigation
 - 5G connectivity support
 - 3D site mapping and detection of workers' PPE and safety events



Motivation

This project aimed to help construction industry to provide remote automated construction monitoring and inspection using drones, robots and 5G technology. This will help reduce the reliance of man power and provide prompt intervention if required.

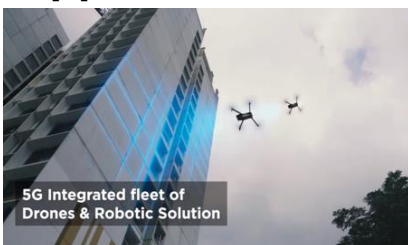
Solution

I²R 5G modem for integration with robots and drones to achieve performance of low latency and enhanced data transmission at construction site.

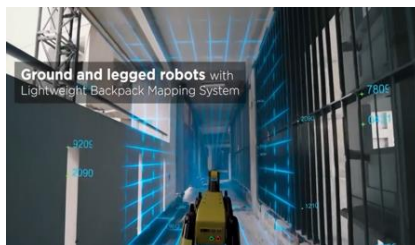
Remote tele-operation over 5G network and autonomous movement of the I²R legged and wheeled robots. The robots were mounted with Video Camera and LiDAR sensor.

Video Images and LiDAR data from the robots and drones were streamed over 5G Network to server for **safety, compliance and construction progress monitoring and inspection using AI algorithms.**

Application Scenarios



5G Modem and Drones System Prototypes



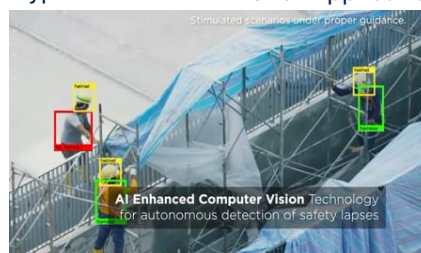
Legged and Ground Robot System Prototypes



“Digital Twin of Construction Site” Application Development



Autonomous Detection of Construction Site Safety Events



Autonomous Detection Personal Safety Equipment

VHF Data Exchange System (VDES)

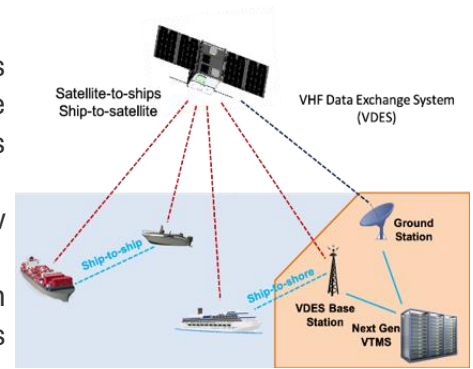
An Enabling Technology for Maritime E-Navigation

Key Features

- ✓ Enables two-way communication for information exchange.
- ✓ Provides larger bandwidth to accommodate larger number of maritime users.
- ✓ Use of satellites to extend the terrestrial coverage.

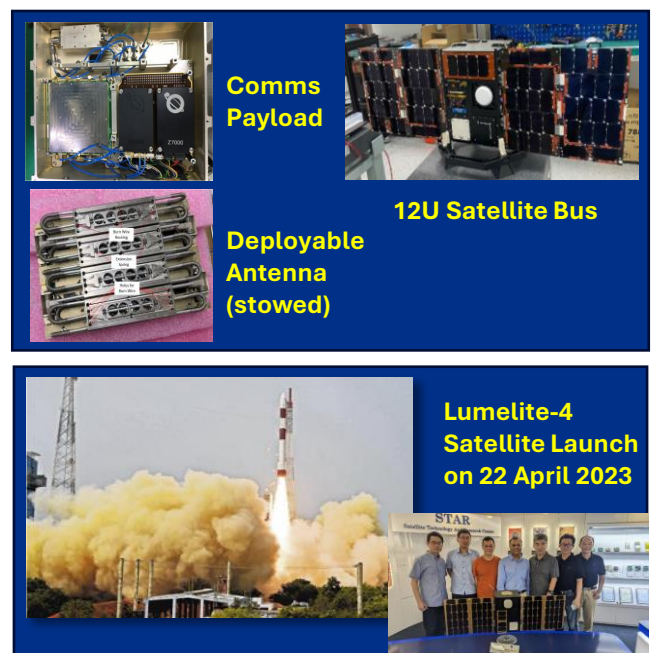
Technical Challenges

- In certain areas with a high concentration of ships such as Singapore Strait, Strait of Gibraltar, Gulf of Mexico, etc., the current Automatic Identification Systems (AIS) faces saturation problems due to the high number of users.
- Satellite AIS is uni-directional and does not allow messages to be sent by AIS satellites from space.
- AIS ship-ship connectivity is limited in open seas far from the coast or near polar regions since the maximum range is about 70 km.



Solution

The VHF Data Exchange System (VDES) is an enabling technology for maritime communications, which is going to replace the current Automatic Identification System (AIS) used for vessel tracking and navigational safety purpose. The use of VDES enables **two-way communication** with **32 times more bandwidth** than AIS to deal with increasing maritime traffic, enhance navigational safety, improve port efficiency and decarbonisation.



5G Enterprise Suite (5GES)

A suite of features to power 5G adoption

Key Features

- ✓ Time-critical connectivity for fast close-loop control
- ✓ Dual 5G/Wi-Fi seamless connectivity
- ✓ Reliable 5G connectivity for poor aerial and coastal coverage areas
- ✓ Trusted 3D location of assets

Challenge

Current connectivity solutions face major issues, including latency that fails to support time-sensitive control, inadequate coverage in aerial and coastal regions, and unreliable location tracking. For enterprises, adopting 5G is challenging due to the need for advanced technical expertise, the lack of realistic testing environments, and the absence of scalable solutions adaptable across different industries.

Solution

The 5GES comprises a base platform and a suite of features developed to address the challenges of existing connectivity solutions. The developed features include reliable, time-critical connectivity, signal booster to enhance 5G coverage for aerial and coastal areas, and trusted location-based services. The platform streamlines 5G solutioning, enabling seamless testing and validation, while also allowing the solution to be customized and adapted across various industries.

Deployable 5G solutions with Sandbox facilities

5G Enterprise Suite (5GES)

These modular features are developed to leverage on evolving 5G features being offered and to adapt to platform's flexible interfaces / configuration.

5G Trusted Location for Unified Authentication

5G Time-critical Compute and Connectivity Solution

5G Dual Band Module

High Reliability 5G Connectivity Solution

Commercial Off The Shelf (COTS)

5G authentication & access control for MEC services

Platform services and functions

COTS hardware & modules

Network Infra 4G/5G LAN Wi-Fi

Cloud service providers



On-prem & data centres



Base Platform

- Easy mix-and-match using FIP modules & other COTS plug-ins
- Common Interfaces for access, management & control
- APIs for 5G app. development – lowering complexity barrier, facilitating safe sandboxing

Pervasive Connectivity for Smart Yard

A Unified Connectivity Architecture and solution for providing secured pervasive connectivity, integrated with on-premises data storage for secured collection, storage, and retrieval of IIOT data.

Key Features

- ✓ A secured unified connectivity architecture which is scalable and extensible
- ✓ Track and trace platform for personnel / assets and vital sign monitoring
- ✓ An integrated IIoT platform with on-premise storage

Motivation and Challenge Statement

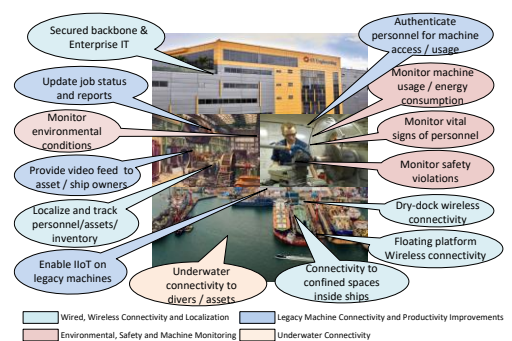
Maritime digitalization is transforming operations by collecting and analyzing sensor data to boost productivity, requiring pervasive connectivity. However, shipyard environments pose challenges for wireless communication due to **presence of metallic surfaces**, **high electromagnetic interference** from processes and equipment, and hard-to-access areas, such as **confined spaces** within ships.

Solution

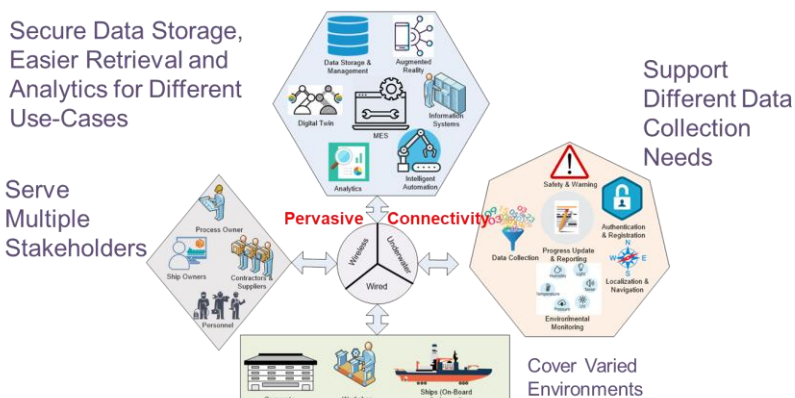
A **robust and secure unified connectivity framework** has been designed and implemented to ensure seamless connectivity across both indoor and outdoor environments of the yard. This architecture integrates wired, wireless (multi-band, multi-standard), and underwater communication technologies. By addressing the limitations of existing off-the-shelf (COTS) solutions, it enhances the performance of individual component technologies through innovative solutions.

The developed wireless mesh-based solution is used to realize a track and trace platform (TTP) for real-time asset and personnel tracking/safety/security (vital sign, zoning), identify bottlenecks and optimize workflow

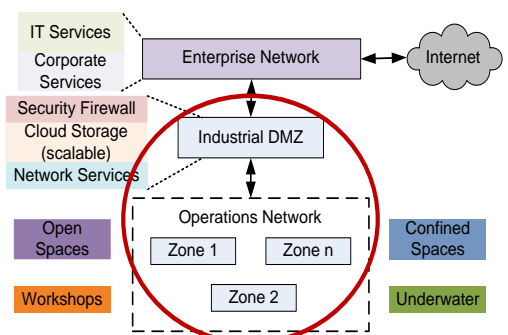
Shipyards IIoT Use-cases



Impact of Pervasive Connectivity on Smart Yard



High-level Secure Pervasive Connectivity Architecture



5G Edge Gateway

Enabling 5G-enabled IoT connectivity for industrial applications

Key Features

- ✓ Seamless switching between 5G/Wi-Fi connectivity to deliver near-zero packet loss
- ✓ Engineered for low-latency, real-time control
- ✓ Provisioned to support dual 5G radios for carrier redundancy

Challenge Addressed

Existing industrial IoT solutions face several technical challenges, including **unreliable synchronisation**, **high latency**, and **limited scalability** for time-sensitive applications. Traditional wireless networks struggle to meet the precision and real-time requirements of Industry 4.0 use cases, such as industrial control and robot coordination. Additionally, many existing platforms are **rigid** and **lack the flexibility to adapt** to diverse applications or integrate seamlessly with emerging technologies like AI/ML. These limitations hinder the widespread adoption of 5G in industrial settings, creating a need for more robust, high-performance solutions that can address these barriers.

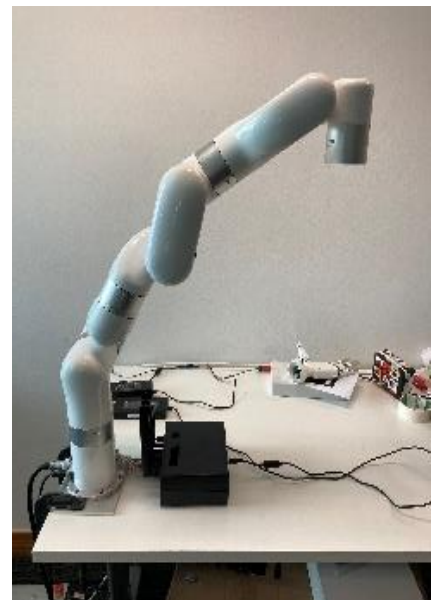
Solution

Our **5G-enabled Edge Gateway** provides a robust solution to the challenges faced by IoT and IIoT applications. With support for **5G Time Sensitive Communications (TSC)**, it ensures precise synchronisation between the gateway and infrastructure clocks, enabling real-time, low-latency capabilities for Industry 4.0 use cases. Its modular design allows seamless adaptation for various applications, such as industrial control, condition monitoring, and robotics. Enhanced with Time Sensitive Networking and optional AI/ML acceleration, this gateway is designed to break down the barriers to industrial 5G adoption and drive innovation across industries. The gateway can also be expanded to include **dual 5G radios for carrier redundancy**.

Edge Gateway



Robotic arm control



AI/ML for Next-Gen Communications

Leveraging advancements in AI/ML to address fundamental issues in communications and networks

Motivation & Opportunities

The increasing complexity of next-generation wireless networks, such as 6G, demands intelligent, adaptive, and efficient management solutions. AI/ML plays a crucial role in optimizing operations by enabling real-time decision-making, predictive analytics, and dynamic resource allocation.

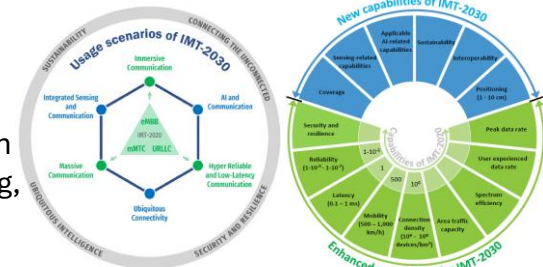
Solution

Innovations ranging from UE-side, RF Front-End, and Network Enhancements:

1. Network **anomaly detection** with Generative Adversarial Network (GAN) and sensing-aided **beamforming optimisation**
2. UE-centric prediction-based **traffic steering** with dual connectivity, achieving **90% reduction** in large delay events
3. RF Front-End **nonlinearity compensation** with DL model to support flexible carrier aggregation, achieving **8dB EVM gain**

Key Features

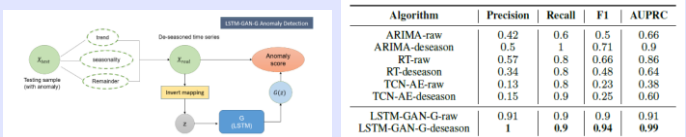
- ✓ End-to-end solutions tackling various challenges across different layers of protocol stack
- ✓ Optimized for Real-Time Implementation
- ✓ Proven and validated in a hardware prototype under realistic environment



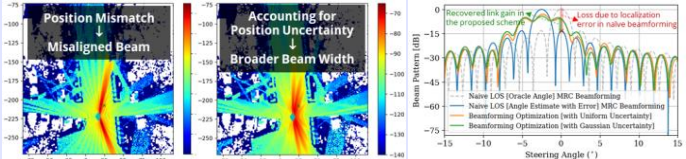
IMT-2030 Vision

Source: <https://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2030/Pages/default.aspx>

Network Enhancement



GAN-based Cellular KPI Anomaly Detection



Sensing-aided Beamforming Optimisation

UE-side Enhancement

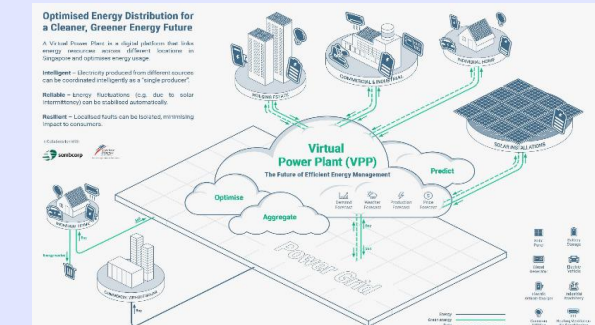
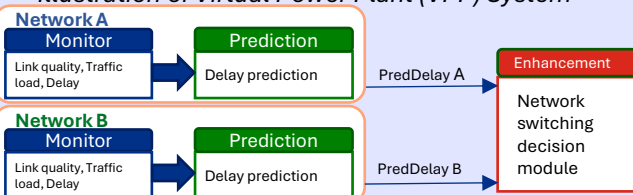
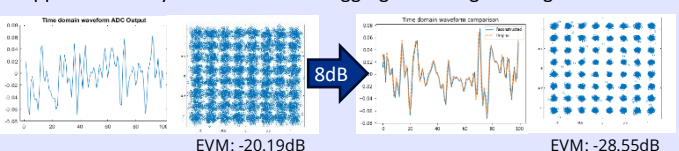
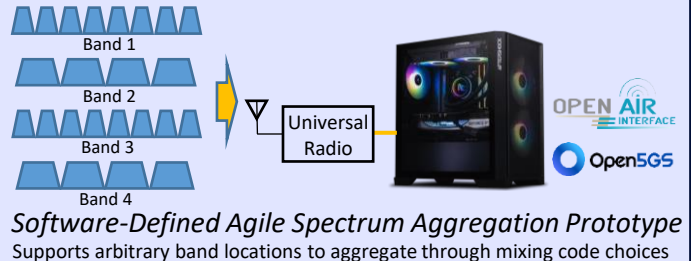


Illustration of Virtual Power Plant (VPP) System



UE-Centric Prediction-Based Traffic Steering

RF Front-End Enhancement



Deep Learning Model for Nonlinearity Compensation

Integrated Network Digital Twin

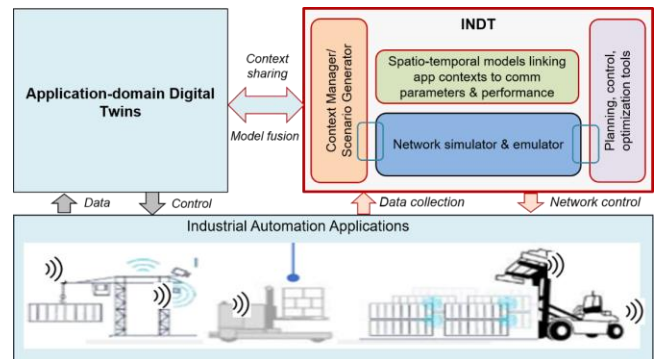
Enabling cyber-physical convergence

Key Features

- ✓ Integration of application-domain contexts and behaviours
- ✓ Spatio-temporal prediction of comm performance based on application contexts
- ✓ Context-aware network planning and run-time control and optimisation

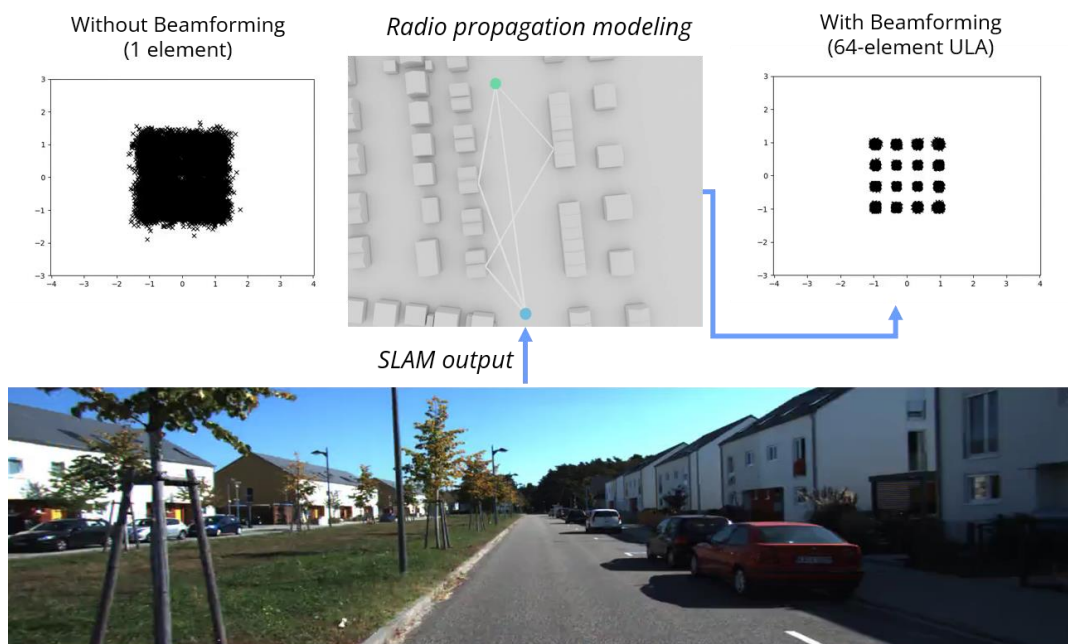
Motivation & opportunities

Future mobile communication networks are vertical-driven, with the challenge of meeting requirements of specific use cases, e.g., IoT, industrial automation, or XR. In many of these verticals, there has been a strong momentum to employ digital twins that enable faithful representation, real-time update, and performance optimisation. These digital twins can provide critical contexts for planning & optimizing their enabling mobile communication networks.



Solution

An integrated network digital twin (INDT) that allow interaction with application-domain digital twins in order to enhance network performance through **context-aware planning, control, and optimisation**.



KITTI Vision Benchmark Dataset from Visual Odometry Benchmark [Snippet from KITTI Scene 6]

Using SLAM-based positioned from vehicle digital twin to improve beamforming performance.

Scalable and Modular Shared-Apertured Electronically Steerable Arrays (ESA)

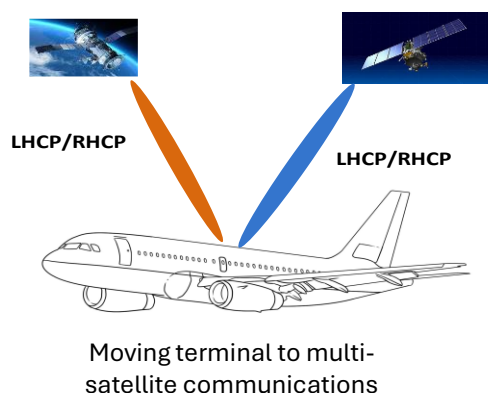
Enabling for satellite-on-the-move (SOTM) systems by offering multiband, multibeam technology that provides flexible solutions for fast satellite tracking and communications

Key Features

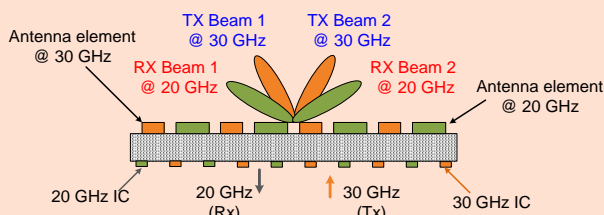
- ✓ Multi-standard/Multibeam allows multi-orbit/satellite connectivity (multi-operator)
- ✓ Shared-aperture allows up to 50% size reduction
- ✓ Power efficient

Motivation & Technical Challenges

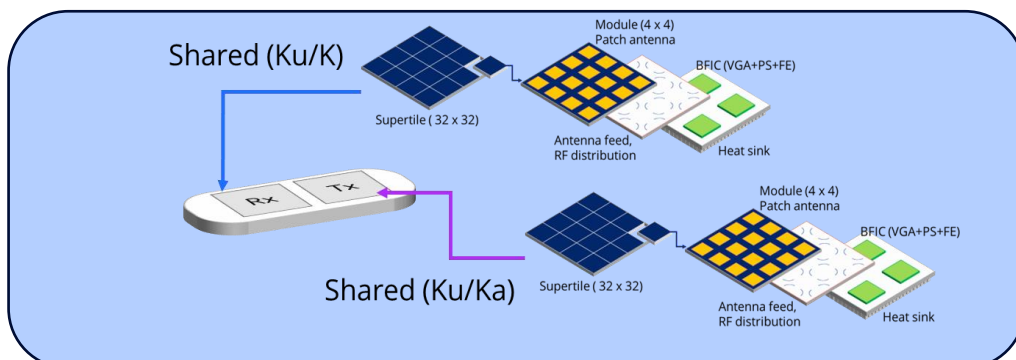
- ✓ Latest satellite constellations (LEO/MEO/GEO) are looking for new features, including multi-orbit connectivity, multi-standard operability, satellites handovers. These features needs the ESA to be equipped with **multiband and multibeam** capability.
- ✓ A compact, power efficient, and cost-effective ESA is always a MUST for SOMT systems, in particular, for small satellite platform. The **shared-aperture** ESA is desired solution.
- ✓ **Modular design** offer the great flexibility for system design for different applications to achieve required EIRP for Tx or G/T for Rx.



Dual-band dual-beam shared-aperture ESA at Ka-band (TX@30GHz, Rx@20 GHz)



Dual-band multi-standard shared-aperture ESA (to be developed)



Integrated Communication and Sensing(ICAS)

Fast and robust ICAS solutions enabling sensing with communications waveform and hardware

Key Features

- ✓ Radar sensing algorithms with 5G or OTFS signals
- ✓ Low complexity sensing algorithm achieving super-linear speed-up
- ✓ Innovative interference-cancellation methods for ICAS system

Motivation

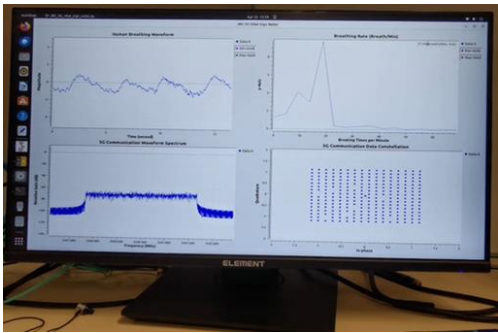
ICAS has been formally included in the “Framework and overall objectives of the future development of IMT for 2030 and beyond” by ITU in Nov. 2023, which will be part of the 6G.

- By adding the sensing to the communication network, ICAS has great potential to provide ubiquitous sensing and communication everywhere anytime to enable strong situational awareness, intelligence and low-latency cloud-like computing.
- ICAS can also provide real-time information for the optimisation of comm. network.
- ICAS can save spectrum, energy & cost, and enable new applications that need communication and sensing at the same time.

ICAS Prototype

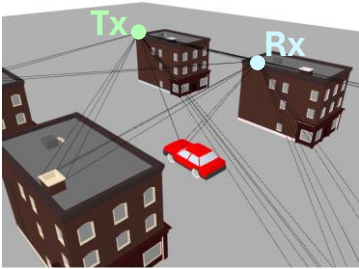
- It transmits 5G signal or OTFS signal, while at the same time use the signal for sensing.
- It achieves communication and radar sensing with the same device, same spectrum, and at the same time.
- The radar sensing can detect the range, speed, angle, and vital sign (for human being only), of the targets.

Human breath rate detected

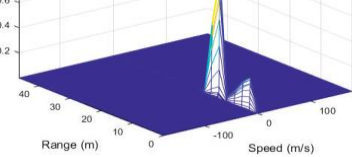


Key Innovations

- Tailored radar sensing algorithms with 5G signal
- Innovative interference cancellation methods (patent)
- Fast sensing with the OTFS/ODDM signal and interference cancellation (patent)
- Human vital sign detection (breathing rate and heartbeat) with the ICAS system
- Super-resolution localisation and feature extraction for multiple targets with communication network
- Sensing assisted communication for network performance optimisation
- Bistatic radar sensing algorithms with 5G signals
- Moving target localisation via multi-static sensing
- Sensing aided channel estimation, pilot design, and target detection for OTFS/ODDM



Range and speed of the targets are estimated with single antenna



Fast algorithm OTFS radar (FAOR): low complexity sensing with OTFS signal

Method	Complexity
FAOR	$O(NM \log_2(MN))$
SOTA Method 1	$O((MN)^2)$
SOTA Method 2	$O((MN)^2)$

MIMO Vital Sign Radar

Comprehensive solution to touchless living body detection for

- Disaster relief
- Healthcare
- Safety & Security

Key Features

- ✓ Human presence detection
- ✓ Multiple human body localisations
- ✓ Vital sign (VS*) detections for multiple people simultaneously
- ✓ AI gesture/posture recognition

Problem Statement

Sensing human body presence, location, vital sign and even condition are widely desired in disaster relief, smart home, healthcare, safety and security applications. However, how to wirelessly get it is challenging.

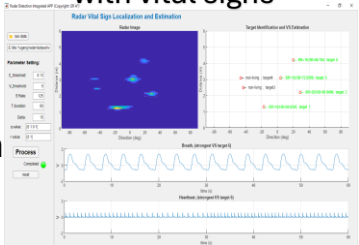
Solution

- Unique MIMO radar algorithms for multi living body identification, localisation
- Unique vital sign detection algorithm with body movement effect compensation
- Joint estimations of vital sign and body location changing speed
- Deep learning (DL) based human body gesture/posture recognition.
- High resolution algorithm for radar imaging

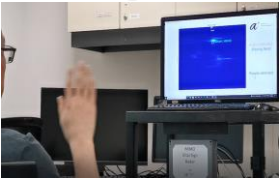
Prototypes:



Multi-people localisation with vital signs



AI gesture recognition



Benchmark:

Technology		SISO FMCW**	IR-UWB***	I²R's
Functions	VS detection	Multi-people VSs	Multi-people VSs	Multi-people VSs
	Multi-target localisations	NA	NA	Yes
	Multi-target type identifications	Yes	Yes	Yes
	Critical condition recognition	NA	NA	Yes

**SISO FMCW refers to single-input single-output frequency modulated continuous wave radar

***IR-UWB refers to SISO impulse-radio ultra-wideband radar

Structural Health Monitoring (SHM)

Enabling resilient infrastructures and smart city with fiber optic sensor technology

Key Features

- ✓ Power efficient (<1W) wireless universal interrogator
- ✓ Strain, temperature and acceleration monitoring
- ✓ Real-time monitoring & detection

Problem Statement

Engineering structures and infrastructures such as buildings, bridges, tunnels, pipelines, aerospace and maritime structures are subjected to ageing and deterioration, which decreases their quality, reliability and increasing risks in safety. High power consumption and proprietary interrogator needed for different sensors limit the deployment of existing SHM solutions.

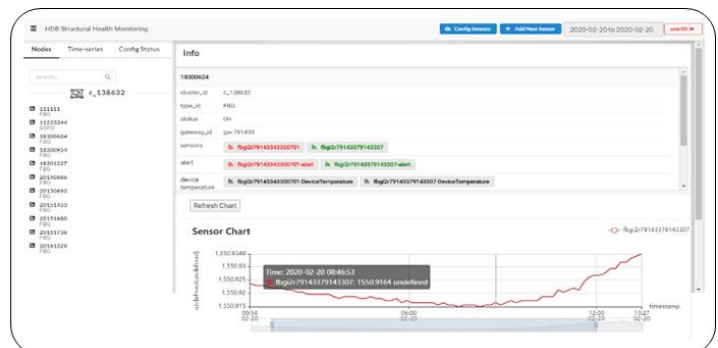
Solution

I²R integrated SHM system, including SHM Universal Interrogators, sensors and backend system, automatically captures, analyses and visualizes the strain, temperature etc. information about the structure. The Universal Interrogators can retrieve and analysis SHM information from wavelength modulation based fiber optic sensors regardless of their types and configurations. Compared to conventional FBG sensing system, our solution offer higher deployment flexibility and lower cost, and open optical interface (software definable) for various fiber optic sensors.



Universal Interrogator

SHM backend System



The research/project are funded by Cities of Tomorrow R&D Programme (COT), Translational Research and Development for Application to Smart Nation (TRANS) Grant, and sponsored by Housing & Development Board (HDB).

Subsea Cable Sensing

Cable anomaly detection & ocean environment monitoring

Key Features

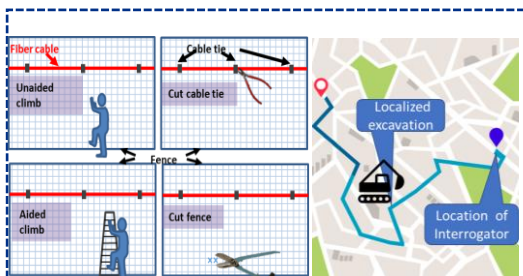
- ✓ Large-scale mapping of vibration, deformation, temperature, etc
- ✓ Subsea cable monitoring and anomaly/threat detection
- ✓ Ocean environment monitoring

Motivation & Opportunities

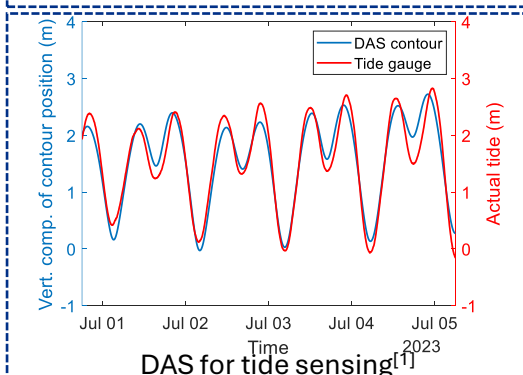
As the global hub for submarine cables, Singapore presently hosts 26 submarine cables across three landing sites, with plans to double the number of sites within the next 10 years. DAS transforms existing subsea cables into vast sensor networks, enabling real-time monitoring of seismic activity, environmental changes, and human activities such as vessel movement and cable tampering. This technology enhances subsea security, environmental surveillance, and early-warning systems, making large-scale ocean monitoring more feasible and cost-effective.

Solution

DAS on subsea cables turns optical fibres into continuous sensors, detecting acoustic, thermal, vibration, and strain disturbances in the sea. By using existing telecom fibres, DAS provides a cost-effective and versatile solution for monitoring subsea assets and environments.



Earlier version of DAS was adopted in *Fence intrusion and Excavation detection*



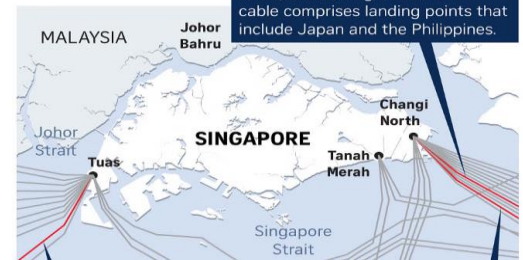
[1]. Hu, D.J.J. et al. 2024. Submarine cable based distributed acoustic sensing for tide monitoring. IEEE Sensors Journal.

Submarine cables on our shores

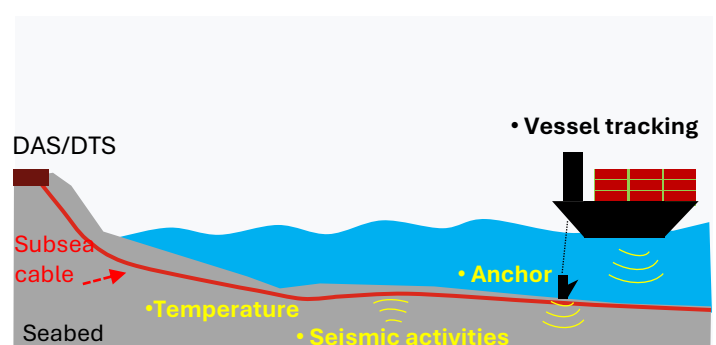
Within the next decade, Singapore will double the number of landing stations to build more network cables, which send data rapidly across countries.

EAC-C2C cable

At 36,500km long, this subsea cable comprises landing points that include Japan and the Philippines.



Reference: <https://www.straitstimes.com/tech/tech-news/singapore-to-double-capacity-for-subsea-cable-landings-to-enhance-digital-connectivity>



Use cases in maritime applications for innovations in safety, operational efficiency, productivity improvement, measurements, automation

- Large scale mapping of vibration, deformation, temperature, etc.
- Submarine cable monitoring and anomaly/threat detection
- Vessel tracking
- Ocean environment monitoring