

DETAILED PROJECT REPORT (DPR)

For

**NATIONAL MISSION – INTEROPERABLE CYBER
PHYSICAL SYSTEM (NM-ICPS)**

ON

ADVANCED COMMUNICATION SYSTEM (ACS)

TIH: IIIT-Bangalore

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Annexure-II

1. Executive Summary

(i) Description of the Hub

This NM-ICPS Hub will be located at the heart of India's Silicon Valley (Bangalore).

IIT-B is a world-class research institute with a solid track record in its contribution to the Indian ICT/IT scenario, with a specific focus on education, research, entrepreneurship and innovation. The hub will be surrounded by a vibrant R&D ecosystem including MSMEs/start-ups, and will leverage the academic and industrial talent pool available locally and elsewhere in India.

(ii) Intellectual focus:

The hub has been assigned to mainly focus on Advanced Communication Systems, with respect to present and future needs of our nation as well as international dynamics. The hub will focus on enabling the design and development of fundamental technology building blocks of 5G-advanced (5G+) & 6G systems and networks. The prime focus will be on indigenous research leading to intellectual property (IP) generation that includes product IP for commercial usage and development of patents (IPR) that will not only enable product-oriented innovation but also target adoption into the upcoming 5G-advanced and 6G standards. It will also focus on other advanced communication systems R&D which have commercial potential.

(iii) Proposed activities: (Major R&D and Application Areas)

- (i) 5G is expected to usher in a new era where Indian society will benefit from large scale adoption of "Internet-of-Things" (IoT), Industrial Evolution 4.0 and Artificial Intelligence (AI). New features offered by 5G and Beyond will increase data rates, increase capacity, reduce latency, and allow massive number of users/devices to connect to the network. These features are included in the 5G NR (New Radio) specifications as three distinct services, namely, Enhanced Mobile Broadband (eMBB), massive Machine-Type-Communications (mMTC), and Ultra-Reliable-Low-Latency-Communication (URLLC). The completion of Rel-15 5G NR was announced by 3GPP (a global body that develops 5G specifications) in mid-2018. By now, 5G has undergone two releases of development (Rel-15 and 16), with a third release (rel-17) coming up soon (in mid-2022). Typically, the first three releases of a new generation of a cellular standard get deployed as a commercial solution while the further releases set

the stage for the arrival of a new generation, i.e., Rel-18 and beyond of 5G can be viewed as a pre-6G standard.

In the past three decades, each new generation of a cellular wireless standard has have evolved into a new generation roughly every 10 years, whereas the communication services have evolved every 20 years. Therefore, new 5G communication services such as IoT and URLLC which are currently in their early deployment phase can be expected to mature only in the 6G timeframe (i.e., 2028 and beyond). 6G will comprise of *advanced versions* of eMBB, mMTC and URLLC but there will be demand for much higher requirements on end-to-end latency (milliseconds), data rates (100Gbps), and universal coverage. Applications like big data, AI/ML, machine-machine communication, and human-machine interaction will begin with 5G but will reach their true potential in the next two decades through 5G evolution and 6G technology. The hub will work on addressing the aforementioned areas and enable India to become a frontier in the development of 5G evolution and 6G technology.

5G deployments are taking place rapidly in economically advanced countries like US, China and South Korea leading the rollouts. India is gearing up for 5G with spectrum auctions being planned in 2022 but large scale rollouts are expected only after 2 or 3 years. Meanwhile, the Government is giving a significant push for Indigenization in the telecom sector. Large Indian companies have announced their foray into wireless domain by bidding for the recent past BSNL 4G roll-out. However, all these new Indian players will have to develop their own 5G gear within the next 3 years and be ready for 5G deployment post 4G roll-out. In this backdrop, the R&D activities of this hub will be aligned with this national “Atmanirbhar” mission and the hub will act as a catalyst for the indigenization of telecom IPR and products. The hub will not only participate in knowledge/IPR creation but also forge linkages with industry towards commercialization. The economic benefits resulting from this project will be very high for the nation. In addition, the highly skilled manpower who are trained in this project in these complex technologies in theory and advanced communication systems development will be an asset to the nation over the next few decades. In this TIH, we will be addressing deep research and highly valued commercial problems, i.e., 5G and Beyond base station (also referred to as 5G-Advanced leading to 6G) and another one in Reconfigurable Intelligent Surfaces (RIS) to enhance wireless communication performance. In the following paragraphs we first elaborate on the base station part and its various focus areas, followed by RIS.

- (ii) 5G+ and 6G ORAN Base Station: A new type of radio access network based on an emerging technology called as ORAN (Open-Radio-Access-Network) is considered to be a strong contender as the next major disruptor in the 5G landscape. This technology allows rapid deployment of low-cost, software

upgradable 5G base stations in significantly higher volumes and larger densities than the current 4G network. ORAN is a software defined system based on open interfaces and general purpose hardware. Some operators have initiated the deployment of ORAN based software-defined network (SDN) and virtualized networks that enable self-organization, low operational cost and ease of introduction of new features and service upgrades. New use cases can be introduced rapidly on the fly using software upgrades, as opposed to costly and time-consuming hardware development cycles. ORAN is still in an early phase of development and India needs to ride this wave to make its mark by developing ORAN compliant 5G, 5G advanced, and 6G products, which will solve to a great extent India's indigenous commercial level base station needs.

Some Indian operators have announced pilots of ORAN compliant 5G base station. However, the existing efforts are in early stages and there is a lack of indigenously developed full-fledged end-to-end base station solution. This hub will take up the development of a near commercial grade base station as the key project with its indigenous research, IPR in physical layer (PHY), layer-2 (L2) MAC (Medium Access Controller) scheduling, AI/ML driven network controller, and orchestration and management. Significant resources will be directed towards this development because it has a huge R&D commercial impact. Below we have explained each of the above layers' focus in this TIH.

- (iii) Massive MIMO (mMIMO) technology is a current reality and it is included as an integral part of 5G physical layer (PHY). 5G offers a substantial capacity and coverage increase over 4G mainly by using a large number of antennas at the base station. Introduction of such large antenna systems complicates the overall network design. Especially, end-to-end mMIMO network optimization with service level guarantees is a difficult and challenging problem with few known solutions openly available. The layer-2 (L2) protocol stack has to be designed by incorporating the mMIMO based physical layer (PHY) in the design and optimization process leading to need of ML/DL based new scheduling and network slicing problems. This problem not only requires a theoretically sound solution to this difficult and challenging problem but also implementable algorithms suitable for commercial deployment.

With respect to above, this hub will develop ORAN compliant 5G Advanced technology comprising of a massive MIMO scheduler and stack that deals with large number of users, multiple service types namely eMBB, mMTC and URLLC. The technology offers an integrated PHY, stack and Core along with an intelligent network controller driven by AI/ML concepts. The entire design is driven by cutting edge algorithms developed exclusively for this new and futuristic state of the art technology. The deliverables include a near commercial grade base station including all the aforementioned components.

- (iv) AI/ML technology is beginning to emerge as a mainstream technology in industries and applications that involve rich amount of data. Wireless networks comprise of hundreds of thousands of base stations and millions of users located over a certain geographical area. The networks handle large number of different parameters associated with network elements in different parts of the network. Human engineered, hand crafted algorithms tend to be sub-optimal as the network complexity grows. This scenario is prime for AI/ML technology where access to rich amounts of data is readily available. ORAN has begun to explore creation of open interfaces at various network elements to enable “data collection” and also exchange information between AI/ML engines/layer with the network elements. The AI/ML engine will aid optimization of various parameters and algorithms associated with the network at different layers e.g., MAC (Medium Access Control), RRC (Radio Resource Control), and core network level. This is a nascent field with a vast scope but only a few players operating at the moment. India should bag this opportunity to take lead in this space for present and future evolution in these area.
- (v) The above areas deal with new trends at macro system level development that are at the crux of 5G+ and 6G technologies. Yet another area where the hub will seek proposals is applied research to target specific 5G+ and 6G research challenges is Reconfigurable Intelligent Surfaces (RIS). Recent advances in antenna technology and rise of small-distance communication applications have led to efforts that try to control and dimension this wireless environment by introducing controllable reflectors that are pre-configured for an intended wireless transmission. Hence, another area of focus will be, Smart Radio Environments (SREs), which will provide us with an alternative way to look at the wireless communications by allowing us to view the channel as a control variable, which can be optimized for performance objectives for a given pair of transceivers or more. SREs are realized using RIS and a significant body of literature pointing to potential benefits of the same are available. However, there is a need for an integrated effort that fabricates the hardware, implements the control logic, standardizes the relevant aspects, and takes the responsibility to commercialize the product with indigenous IPR. This activity has a strong focus on building an end-to-end product that, via an incubated start-up, will be taken to market. SREs are clearly useful in controlled environments, for example, in an Industrial IoT scenario and semi-public buildings and smart-home environments. It is clear that Industrial IoT (Industry 4.0) setup would benefit from having RIS in the Industrial floor, assisting communication between low-cost devices, instead of having expensive end-devices that use sophisticated signal processing algorithms.

(vi) Integration

As the hub is located in Bangalore, it has access to R&D Labs, MSMEs/start-ups, academia, and larger companies, which makes it suitable for integration of different sub-systems leading to a larger 5G+/6G trial system. The various ORAN complaint sub systems, AI/ML engines and algorithms that are developed by the academic and industrial partners will be integrated into a trial system. The hub and spoke model will also enable other academic institutes to offer their Labs/facilities for integration and technology trials.

In the short-term, the hub will focus on technology development, nurturing of start-ups/MSMEs through collaborative research efforts. There will be intense focus on development of IPs, IPR and field grade prototype-products that have high commercialization potential. The hub will also train the manpower for next generation technologies in niche areas. It will also look forward to national and international collaborations.

The hub strives to make a mark in the aforementioned 5G+ and 6G arena so that the IPs generated in the project would further aid in establishing self-sufficiency in the long-run (beyond 5-years).

2. Context/Background:

(This section should provide a brief description of the sector/sub-sector as well as the national strategy and policy framework. This section should also provide a general description of the scheme/project being posed for appraisal.)

Brief description of the sector/sub-sector as well as the national strategy and policy framework:

The advent of 4G technology has led to radical changes all over the world, especially by way of smart phones that have had a staggering impact on our lives. Far from being a mere evolutionary successor of 4G, 5G technology is slated to revolutionize the telecommunications/internet sector in the near future. 5G technology will go much beyond connecting people - 5G applications include integrating a whole range of machines into the internet, such as smart metering (electricity/water/gas), fourth industrial revolution, e-commerce, internet of things, tracking of people/assets, machined farming, agri-tech, perishable goods management, pollution monitoring, healthcare applications, video surveillance etc. Given that critical national infrastructure such as electricity grids, financial transaction, defence, and various public services offered by local Government

bodies will soon run on 5G, security considerations are crucial in the selection and ownership of such technology, as it will have a bearing on the nation's ability to control the equipment as well as secure the delivery of such critical services. On the economic front, within the next decade, 5G/IoT is expected to add business of tens of Trillions of USD to the world economy. Indian companies have not commercially participated before in any generation of (2G, 2.5G, 3G, 4G) wireless telecom product in a big way. For the first time, Low-Mobility-Large-Cell (LMLC) use case for 5G rural and some more technical works were contributed by Indian teams. The advent of 5G-Advanced and beyond is an unprecedented economic opportunity that India cannot afford to let go of, as Indian technical critical mass aligning in this direction as well as self-reliance is hour of need. So far, only a few Indian entities have begun to address such opportunities in the 5G/IoT space. Hence, *it is imperative now that as the nation needs acceleration in this direction to develop 5G-Advanced and beyond technologies to benefit financially, create jobs, entrepreneur and remain secured for various sensitive data transition through telecom-networks/Internet.*

2.1 Current 5G Research in India and Recent-Future National Alignment

The development of 5G happens through global forums, one such forum which has been active is the 3rd Generation Partnership Project (3GPP). It's a partnership between seven Standards Development Organizations (SDOs) of which Telecommunications Standards Development Society, India (TSDSI) is a member. 3GPP kick-started the 5G project in 2016 where certain Indian entities contributed to 5G New Radio (NR) technical specifications. The International Telecommunication Union (ITU), a UN body that lays down requirements for 5G, had earlier adopted the so-called Low-Mobility-Large-Cell (LMLC) use case as a mandatory 5G requirement in 2017. This requirement was adopted by ITU mainly as a result of sustained effort by the Indian Government through Department of Telecommunications (DoT) and TSDSI to address the unique Indian rural broadband deployment scenario. Several countries supported this use case as they saw a similar need in their jurisdictions as well. The LMLC based 5G technology will deliver ultra-fast, low-latency mobile internet and next-generation IoT services in both cellular and mm-wave spectral bands, common to all 5G candidate standards and an additional technological enhancement that has the ability to provide broadband connectivity to rural users using ultra-long range cell sites. This enhancement will ensure that 100% of India's villages are covered from towers located at panchayat villages, whereas nearly a third of such villages would be out of coverage otherwise. The Indian LMLC 5G submission exploits a new transmit waveform, developed by Indian entities, that increases

cell range. This indigenous technology is covered by a family of patents developed by Indian entities. Furthermore, a large 5G patent pool exists within the country that can be leveraged to shape the future course of 5G, i.e., protect indigenous products, introduce India specific requirements and features in the future releases of the standards, etc. Adoption of LMLC based 5G standards in India will enable India to leap forward in the 5G space, with key innovations introduced by Indian entities accepted as part of global wireless standards for the first time. The nation stands to gain enormously both in achieving the required 5G penetration in rural and urban areas as well as in nurturing the nascent Indian R&D ecosystem to make global impact. The current national efforts are aligned with the national digital communication policy that promotes innovation, equipment design and manufacturing out of India for the world market. As a nation we need to contribute more to take leadership in upcoming wireless technologies, as given below.

2.2 3GPP and TSDSI and ITU Standards

3GPP has released the first phase of 5G specifications i.e., Rel-15 of 5G in 2018 with Rel-16 specs set to be released in mid-2020. Additional features and upgrades to current specs will be part of rel-17 for which the study phase is ongoing now with specifications to be released in 2022. Also, ITU formally released the 5G specifications (those that submitted to ITU by entities such as 3GPP, TSDSI etc.) in November 2020 as IMT 2020 standards. Some early discussions on 6G have begun to take place at ITU, TSDSI etc. The timelines for 6G are not discussed yet. However, research teams in EU, China, USA have already begun to form 6G teams in their respective countries and have begun to form collaborative teams as well. Therefore, Indian entities should proactively conduct research and develop systems that aim at enhancing 5G evolution that ultimately will lead to 6G. The results of this project will not only feed into the development of specifications at 3GPP, TSDSI and ITU but also lead to systems that can be commercialized for the benefit of the country.

3. Problems to be addressed:

(This section should elaborate the problem to be addressed through the project/scheme at the local/regional/national level evidence regarding the nature and magnitude of the problems should be presented, supported by baseline data/survey/reports etc.)

3.1 5G and Beyond Disruptive Solution through ORAN Technologies

A new type of radio access network based on an emerging technology called ORAN (Open- Radio-Access-Network) is being touted as the next major disruptor in the 5G landscape. This technology allows rapid deployment of low-cost, software upgradable 5G base stations in significantly higher volumes and larger densities than the current 4G network. ORAN is a software defined 5G system based on open interfaces and general-purpose hardware. Some operators have initiated the deployment of ORAN based software-defined network (SDN) and virtualized networks that enable self-organization, low operational cost and ease of introduction of new features and service upgrades. New 5G use cases can be introduced rapidly on the fly using software upgrades as opposed to costly and time-consuming hardware development cycles. ORAN is still in an early phase of development and India needs to ride this wave to make its mark by developing ORAN compliant 5G, 5G advanced, and 6G products.

3.2 Rationale for the current project

Within the country, most of the R&D work related to 5G has picked up only in the last 2 years. The current work being executed in different institutes has focused on development of lab level prototypes and protocol stacks with minimum feature set necessary for lab demonstrations. Based on the importance attached to 5G and its evolution across the world, there is an urgent need to boost the current R&D capabilities in this area and start work on solutions and systems that are complete in nature and meet the stringent norms required for field demonstrations and network level deployment. At the same time the systems and products developed should also have enough flexibility to be utilized and deployed in diverse applications and use cases.

An approach that meets the aforementioned criterion is having the flexibility to adapt and reconfigure the system to tailor it to meet different specifications of citizen and MTC requirements for the applications. Two principles play key role in achieving the above objectives:

1. A large system or network is split into multiple layers or sub-systems and define **open interfaces** to inter-connect or inter-operate among the layer/sub-systems. The layered internet architecture that is immensely successful is an example of this principle. Although cellular radio access systems (RAN) and networks have adopted some of these principles

by defining PHY (L1), stack (L2), control, etc., the layered architecture and functional splits have not been fully utilized within the radio system or the stack of these cellular systems.

2. Given the recent advances in semiconductor technology and the large amounts computation power available with General Purpose Processor (GPPs) and FPGAs, having an ability to operate the system or sub-systems based on software designed mode allows a great degree of flexibility in adding new features or upgrades over the life cycle of the product/network. Even in the early internet-based systems, the routers and such systems have been developed based on ASICs for a long time. More recently software defined networking (SDN) has found its way into internet routers successfully reducing the overall cost. In case of radio systems, use of ASICs have largely dominated both the analog and digital section of the radio chain for several decades. More recently, software defined architectures that maximize the use of GPPs (and minimize use of ASIC for each product upgrade) are emerging as viable alternatives.

ORAN (Open Radio Access Networks) alliance has been formed recently by major operators like AT&T, Verizon, DoCoMo, Reliance Jio etc. and is gaining significant traction and is expected to be a significant disruptor in next generation wireless deployment. The rationale behind this alliance are:

- **ORAN** created to accelerate the delivery of next-gen wireless infrastructure to operators, while ensuring a broad community of suppliers driven by innovation and open market competition; In ORAN architecture the technologies part will be proprietary in each layer/sub-layer by IPR (where this TIH will work) and only the interfaces will be open to interconnect the layers/sub-layers (now the interfaces of non-ORAN architecture are mostly proprietary and belongs to a few companies across the world).
- **Open interfaces** are essential to enable smaller vendors and operators to introduce their own services, or customize the network to suit their own unique needs;
- **Open interfaces** also enable multi-vendor deployments, enabling a more competitive and vibrant supplier ecosystem;

The above flexible ORAN architecture will help Indian telecom/internet industries, academia and entrepreneurs to participate in this 5G and beyond (discussed in detail in following sections).

With the closure of Motorola networks, Lucent etc., the United States (US) has lost out its leadership in the cellular wireless infrastructure business. The US Government is now giving a significant push to ORAN compliant 5G and its evolution as a long-term strategy to encourage and nurture domestic telecom infrastructure development in the US. The US department of commerce has announced around 1 Billion USD grants directed towards ORAN development. India is in a similar situation with no clear wireless base station company ready to offer 4G/5G services on a commercial level. ORAN presents a unique window of opportunity to India as well to boost Indian start-ups, academia and telecom companies to build large telecom cyber physical system. Other countries/companies are also working on ORAN architecture. Riding on this ORAN wave, this project aims to develop and innovate:

- a. Next generation communication systems or sub-systems
- b. Advanced algorithms or systems aided by AI/ML,
- c. Tailor the ORAN complaint system to different needs and use cases demanded by Indian conditions.

3.3 Massive MIMO

In sub 6 GHz frequency bands, spectrum continues to be an expensive and scarce resource and operators are keen on solutions that maximize radio capacity without investing in additional spectrum. Massive MIMO technology that uses multiple antennas at the base station has emerged as a major differentiator in 5G. One of the significant achievements of the past few years has been the development of one of the first large scale prototypes of massive MIMO technology that operates either as an outdoor massive MIMO, or as a distributed small cell cloud RAN system out of Indian 5G development efforts. This experimental research system has been operational since 2017 in one of the IITs, where it has been used to test, analyse, and further develop many other intricate aspects of this cutting-edge technology with an aim towards commercialization.

With respect to all the above requirements, it is imperative that as a nation, we must be self-reliant through in-depth indigenous research on 5G and beyond technologies including massive MIMO capable base stations which will lead to employment, entrepreneurship as well as highly skilled manpower to take the nation to new heights in this direction.

4. Aims and Objectives (Grand Problems)

(This section should indicate the development objectives proposed to be achieved, ranked in order of importance. The outputs/deliverables expected for each development objective should be spelt out clearly).

4.1 Aim-1: Development of world-class ORAN – massive MIMO base station:

- i. Develop 5G Advanced technology comprising of a massive MIMO scheduler and stack (L2, L3, Control) that deals with large number of users, multiple service types namely eMBB, mMTC and URLLC. The technology offers an integrated Physical (PHY), stack and Core along with an intelligent network controller driven by AI/ML concepts. The entire design is driven by cutting edge indigenous algorithms developed exclusively for this new and futuristic state of the art technology.
- ii. The system supports to cloud RAN functions like, RU (Radio Unit), DU (Distribution Unit), CU (Central Unit) with Data/Control Plane, Management and Orchestration offered in a virtualized environment. The PHY, MAC algorithms and the stack will rely on highly software defined cloud native architectures which will exploit the state-of-the-art processors.

4.1.1 Open Gaps and our plans to address the gaps of 5G and Beyond Base Station

The *end-to-end network design* of cellular network has been developed in closed door standards bodies like (3GPP). While there is a mature body of literature about the physical layer concepts used in cellular systems, the same cannot be claimed of a multi-cell L2 scheduler, especially with the introduction of multiple service types namely, eMBB, mMTC and URLLC and massive MIMO based physical layer. The prime goal of this project is to put India at the forefront of this research as well as technology and emerge as a leading global design house in the 5G and 6G arena. The hub will accomplish this through development of cutting-edge systems that integrate into the full-fledged product grade stack development and the algorithms will be validated by simulations and field trials and will be incorporated into the end-to-end system. It will be the next step from the nation's point of view and may open the road to lead future generations of standards and systems in wireless communication.

4.1.2 Objectives

1. The hub will train 150 engineers/scientists over the next 5-years who will develop world's leading 5G advanced base station and RIS technologies:

The research conducted in the hub aims at solving very complex problems posed by the 5G-advanced base station technology. At the same time, the research will be steered such that the solutions developed as outcomes of the research will be commercialized for adoption in India and abroad. Maximization of a **real-world** massive MIMO capable network capacity with constraints on latency, throughput, computation, and device energy/battery life is a fertile ground for researchers. The algorithms and technologies developed with the above aims and objectives should lead to a commercial grade solution that supports eMBB, mMTC and URLLC services.

2. The hub will have a significant focus on clean-slate design of L2 scheduler and stack whereas the other components/sub-systems such as PHY, RU and Core may be developed in collaboration with partners. However, the hub is responsible for the demonstration of the technology in the form of end-to-end pilots/trials.
3. The hub will focus on Reconfigurable Intelligent Surfaces (RIS) also for wireless communication performance improvement. It needs a lot of indigenous research on hardware and software requirements to design and control the surfaces.
4. The hub will target development of 50 patents that cover the essential technologies developed in this area.
5. The hub will establish collaboration with research groups working in this area both in India and abroad. The international collaborations and connect will be strengthened through dissemination of research results in top tier conferences/journals.
6. The timeline for the development of this technology will be 3 years i.e., at the end of the 3rd year technology demonstration will be done through pilots/trials. At the same time, commercialization will be pursued based on intermediate pilots and trials.

4.1.3 Some unique features of the base station

The proposed base station solution will offer some of the following distinct features,

1. Compatibility and inter-operability with commercial devices such as 3GPP, TSDSI, and ORAN compliant systems and sub-systems.
2. Ability to support hundreds of active users simultaneously so that the system can be

stress tested under field conditions. For example, a distributed unit (DU) or a radio unit (RU) supports 3000s active users/cell.

3. Explore the optional software-hardware partitioning for DU and RU development. Develop hardware accelerators for specific physical layer functions where power consumption or computation complexity is very high for current processors.
4. The system shall support fault tolerance, self-recovery (or high immunity to errors and exceptions in the stack), high availability (up time), low-power consumption, low-cost etc.
5. The system shall support inter-operability with sub-system developed by other vendors.
6. DU has the ability to support RUs with a wide frequency range.
7. The baseband algorithms should be of low-complexity and high performance. For example, the channel estimation and equalization algorithms should support a large range of delay spreads well beyond the scope of specifications for e.g., support extremely high delay spread scenarios such as hilly Himalayan regions, communication under extremely low SNRs or over large cell radius, support for low mobility and very high mobility at the same time, ability to handle adverse interference conditions, etc.
8. Both DL (Downlink) and Uplink (UL) includes Massive MIMO integrated into the L2 scheduler (multi-user user MIMO user pairing and scheduling) with advanced PHY algorithms that support up to 16 MIMO layers in the DL and 8 layers in the UL. The UL will have inter-cell interference rejection/management ability.
9. The stack should have the ability to support complex scheduling for MAC, Control, Network slicing, and mobility management with advanced radio resource management algorithms, sleep mode management of low-power devices etc. The stack should support AI and ML driven MAC schedulers.
10. The PHY and protocol stack has enough flexibility and the design should be able to support ultra-low-latency operation, in addition to enhanced mobile broadband and provide high service reliability;
11. The system will be tested with 3rd party core network to demonstrate the ability to handle large user base with support for diverse applications with QoS support.
12. Develop data collection interfaces for the network elements such as L2, L3 and core so that AI and ML algorithms can be utilized to improve the operational efficiency of the

network.

4.1.4 Timelines

First 18 months: Build a team to develop a clean-slate stack with L2 scheduler (and RRC/L3) that incorporates eMBB, URLLC, and mMTC use cases along with massive MIMO (mMIMO) PHY.

4.1.4.1 eMBB Delivery

18 Months: Target a first POC based on a RU (plus UE) emulator

24 Months: Commercial UE attach with eMBB support with a mMIMO capable RU.

30 Months: Pilots with multiple base stations and UEs

4.1.4.2 mMTC

24 Months: Target a first POC based on a RU (plus UE) emulator

30 Months: Commercial UE attach with eMBB support with a mMIMO capable RU.

36 Months: mMTC pilots with multiple base stations and UEs

4.1.4.3 URLLC

30 Months: URLLC pilots with multiple base stations and UEs

4.2 Aim-2: Reconfigurable Intelligent Systems (RIS)

4.2.1 Open gaps and our plans to address the gaps in RIS

Home-grown Industry working on such a field is completely missing. Most of the enterprise wireless network management companies are offering an added layer of management plane and do not have their own proprietary hardware offerings. This activity will help in filling the following gaps and novel R&D aspects,

- i. **Control aspects:** IISc is working on Radar performance improvement using RIS and channel estimation (<https://arxiv.org/pdf/2011.00900.pdf>), BSNL is looking at RIS and MEC combination (<https://arxiv.org/pdf/2106.11784.pdf>), IIT-Delhi is looking at signal processing aspects (<https://ieeexplore.ieee.org/abstract/document/9347448>), similar is the case with IIT Jodhpur activities.
- ii. **Fabrication Aspects:** CARE in IIT Delhi is working on fabrication of meta-surfaces for mmWave communications.

In summary, though this field is promising, there seems to be no one group in India that is working on developing an end-to-end system for using RIS. Many groups are focused on signal

processing algorithms at the receiver to improve the RIS-assisted communication performance. An approach where COTS end devices are provided with a performance gain in using RIS is missing.

4.2.2 Objectives

The objectives of the hub in the RIS area will be:

- Fabrication of at least one RIS array
- Development of control capability for deployed RIS to improve communications performance between COTS devices
- Demonstration of system-level working deployment of the RIS system
- Demonstration of one security solution where the RF communication is protected from eavesdropping of signal using the developed dynamic RIS system
- Deployment of the solution for one concrete use-case and taking the so-developed product to market (identifying the customer will be part of the activity)

The fabrication of the RIS array and the solutions to the control problems are non-trivial and are of National and International importance. This will be the first such RIS system developed in India, along with significant research and standardization activity.

The detailed sub-topics that require indigenous research are detailed below. We will be seeking proposals providing promising work in addressing these problems:

1. Channel modelling and estimation for RIS-enabled networks
2. Fundamental limits of RIS-enabled networks
3. Fabrication challenges in realizing RIS
4. Performance analysis and optimization of transmission schemes for massive-MIMO RIS-enabled networks
 - a. Passive Beamforming Design Based on Imperfect Parameters
5. Performance analysis and optimization of transmission schemes for Multi-user RIS-enabled networks
6. RIS-enabled mm-wave and Terahertz communications
7. Distributed Algorithms with Low Overhead Exchange
8. Machine learning techniques for RIS-enabled networks

9. Energy- and cost-efficiency of RIS-enabled networks
10. RIS-enabled cloud radio-access networks
11. System Design for RIS-aided Frequency Division Duplex (FDD) systems
12. Mobility Management
13. Deployment Issues

5. Strategy

(This section should present an analysis of alternative strategies available to achieve the development objectives. Reasons for Selecting the proposed strategy should be brought out. Basis for prioritization of locations should be indicated (Wherever relevant). Opportunities for leveraging government funds through public private partnership or savings through outsourcing must be explored. This section should also provide a description of the ongoing initiatives and the manner in which duplication can be avoided and synergy created with the proposed scheme/project)

The key strategies that will be employed in this project are:

- a) This project will have unique and novel contributions on licensing the IPs and sub-systems where needed that will accelerate the ORAN 5G base station and supported technologies/application development, at a reasonable cost.
- b) Develop partnerships with 5G capable DSP/processor suppliers and SoC suppliers.
- c) Inter-operate with the sub-systems developed by multiple partners who will supply their sub-systems such as DU and RU for testing purposes.
- d) Develop partnership with the new breed of make-in-India systems integrators such as TCS, Tech Mahindra, Tejas Networks, etc. to integrate the 5G base station into the product ecosystem for early trials.
- e) Develop partnership with entities like BSNL and other operators to collect requirements and conduct early field trials.
- f) Conduct trials to address 5G rural use cases such as addressing the last mile wireless connectivity needs of BharatNet project. Develop partnerships with the equipment providers of BharatNet project and integrate the developed base station into the BharatNet ecosystem. It will also remain open for trial by other service providers.

g) Research, design, testing and niche manpower training as well as start-ups in the areas of wireless RIS.

There are four major aims and objectives of this hub: (i) Develop technologies as detail given below; (ii) nurture incubation and commercialization of mentioned and related technologies as well as applications through the hub; (iii) Train skilled manpower in the areas of communication; (iv) collaboration with national and international organization.

6. Target Beneficiaries

(There should be clear identification of target beneficiaries. Stakeholders analysis should be undertaken, including consultation with stakeholders at the time of scheme/project formulation. Options regarding cost sharing and beneficiary participation should be explored and incorporated in the project. Impact of the project on weaker sections of society, positive or negative, should be assessed and remedial steps suggested in case of any adverse impact.)

1. **Industry involved in network and service delivery:** Leading the industry towards open, interoperable interfaces, RAN virtualization, big data and AI-enabled RAN intelligent controller. The next generation wireless network architecture aims to specify and release a complete reference design of high performance, spectral and energy efficient white-box base station. By releasing and applying this reference design, the ecosystem can get the scale effect of hardware selection and reduce the cost of the whole industry chain. Additionally, releasing this reference design can reduce the R&D challenges and costs, which can attract more enterprises into the telecom industry and ensure innovation in India.

Target Cellular Deployments

Recent press announcements in India indicate that Indigenous base station manufacturing is gaining significant traction. It is understood that companies like TCS, Tejas Networks, Tata Communications/Sons, Tech Mahindra, L&T, ITI, CDOT and others have been working on 4G solutions. Most of these companies have a 5G roadmap and are actively seeking an indigenously developed 5G stack. With 5G spectrum auction yet to

happen, 5G device prices being high, large scale and mass adoption of 5G deployment is still a few years away. Given that this project aims to develop an indigenous 5G stack, we intend establish active collaboration with Indian companies to conduct pilots/trials/IP licensing.

Defence/Public Safety Market

Defence/Public Safety agencies world-wide (including the US and India) have been exploring use of 5G technology for defence applications. By introducing suitable frequency band support and by introducing the necessary security features (in PHY and stack), the 5G technology can be customized to address various defence and public safety use cases. We have seen interest expressed by manufacturers such as BEL and ECIL and others floating EOIs and tenders for the development of 5G technology. In this project we will explore collaboration with Indian defence manufacturers.

2. RIS Beneficiaries/Target Users

We plan to take the product developed under this category to targeted industries. The following is a list of industries that will be approached during the execution of the project so that we can tailor the offering to their needs:

- i. Enterprise Wi-Fi providers (Like, Arista, Cisco, etc.)
 - ii. Smart Home/Hospital/Building solution providers (Multiple start-ups and MSME emerging)
 - iii. Public utility providers
3. **Highly skilled manpower:** To be self-sufficient, the country's call for 'Atmanirbhar' in telecom/Internet like advanced countries, India needs much more highly skilled manpower in this direction. Furthering of knowledge through development of system models, protocols and standards to ensure improved QoS, QoE and network agility. The new standards will enable a more competitive and vibrant ecosystem with faster innovations to improve the efficiency of RAN deployments. This project will help to build that eco-system and enable self-reliance of the nation in this area over time.

4. **Government:** Important role to play in facilitating and fostering an open, diverse and secure supply chain for advanced wireless technologies, 5G and beyond. Development and deployment of appropriate policies and open, interoperable interfaces to promote wider technology usage for better cost effective and secure service delivery to Governmental agencies and also citizens. Support for research development efforts to establish an open wireless technology supply chain. Ability to introduce new services. Example: Health services, Education etc. for promoting development. Moreover, due to indigenous IPR, more control of the nation will be on data flow and security.
5. **Urban and Rural Users:** With the advent of the concept of 5G Advanced/6G wireless systems, status of the network performance and network resources will be continuously monitored with more real-time closed-loop control with little human intervention. There is a need to customize UE-centric strategies and ensure proactive optimization by predicting the network conditions and UE performance, thus improving the user experience. Even for the most complex networks, optimized resource management through closed-loop control will be performed to enhance the quality of service; Better value for the costs paid towards services; Better range and newer range of services.
6. **Weaker section of society:** 5G Advanced/6G wireless networks must reach economically weaker and rural segments of the society and should be an inclusive technology. The advanced wireless generation can unleash new economic opportunities and societal benefits giving it the potential for being a transformative force for Indian Society. For example, offering services at affordable costs to weaker and rural areas in Society.

7. Legal framework

(This section should present the legal framework, if relevant, within which the scheme/project will be implemented as well as the strengths and weaknesses of the legal framework in so far as its impacts on achievement of stated objectives.)

1. This project followed the guidelines DST has proposed for NM-ICPS scheme. That is, IIIT-Bangalore is the host institute (HI) for Advanced Communication System under NM-ICPS scheme.

2. HI has created Section 8 company, named IIITB COMET FOUNDATION. This company by Section 8 will have MoA and AoA to run it according to the company acts of Govt. of India.
3. HI will also create Technology Incubation Hub (TIH)/Technology Business Incubator (TBI), by giving space. TIH hire project staff from the project and run it.
4. HI, Mission (DST's NM-ICPS) and Section 8 company have signed the tripartite MoU.
5. The TIH HUB will have a Hub Governing Body (HGB). HGB has the overall authority and has been delegated with administrative, technical and financial powers.
6. HGB will consists of following members
 - a. Director/ Vice-Chancellor of Host Institute: Chairman
 - b. Academic representatives (not less than 2): Members
 - c. Industry Representatives (not less than 2): Members
 - d. Mission Director, Mission Office, DST: Member
 - e. CEO/Project Director, Hub: Member-Secretary
7. As mentioned above IIITB is HUB will be governed by the HGB discussion and laid rules.
8. If any other additional academic institute wants to join as spoke/spike will go through presentation and approval by HGB. It will help the new institutes to know the focus areas of the project's R&D presented during the presentation to the DST constituted committee for the award of this project. Secondly, HGB will monitor the progress of spoke and sanction the financial requirements accordingly, according to the availability of resources (finance) and without hampering the planning of HUB for the main project as well as deliverables.
9. International collaboration with right partner and area can be done. For any international travel financial support has to be granted by HGB. As HGB meeting happens once in a quarter, for any emergency international travel, one has to take permission of HGB Chairman, which later informed to the HGB board.

10. Any of the collaborative institute or spoke/spike not able to spend the money granted over the time frame given by them has to be returned back to Section 8 company of HUB. HGB can discuss and grant that balance money to collaborators/spoke/spike according their requirements by submission of proposal to HGB.
11. A Professor/faculty and others working in the related areas of project can apply for fund by submitting a proposal to HGB. If there is fund available HGB may support without hampering main goal of the project and resources required by HUB.
12. In case of any dispute among the collaborators/spoke/spikes/individuals, will be tried to sort out amicably by project director in HUB by discussion with the parties. If project director wants, may forward the issue to HGB. In this case the decision of the HGB is final.
13. Companies or individual disputes can be sort-out by Project Director of the HUB. If project director wants, may forward the issue to HGB. In this case the decision of HGB is final.
14. Any donations to HUB/Section8 company from industry, CSR, foundations, charity will be follow the rules of finance. It will be spent for purpose of present and future projects monitored under Section 8 company of the HUB. It may also be used for encouraging entrepreneurship under the HUB.
15. The start-up received seed money from the HUB as financial help, will give some % stakes or royalty to Section 8 company of the HUB or some other agreement as revenue generation to run the HUB. The % of stake will be decided by HGB.
16. Licensing of the IP or sale of equity of the any incubated start-ups will be decided by the approval of HGB.

8. Environmental Impact

(Environmental Impact Assessment should be undertaken, wherever required, and measures identified to mitigate the adverse impact, if any issues relating to land acquisition,

diversion of forest land, wildlife clearances, rehabilitation and resettlement should be addressed in this section.)

This project will not do any activities which will impact the environment.

9. Technology

(This section should elaborate on the technology choices, if any, evaluation of the technology options, as well as the basis for choice of technology for the proposed project.)

9.1 ORAN Compliant 5G-advanced System Development including AI/ML support

9.1.1 Background on the Design of an O-RAN compatible Base Station

Traditional RAN architectures typically looked as a collocated architecture as below -

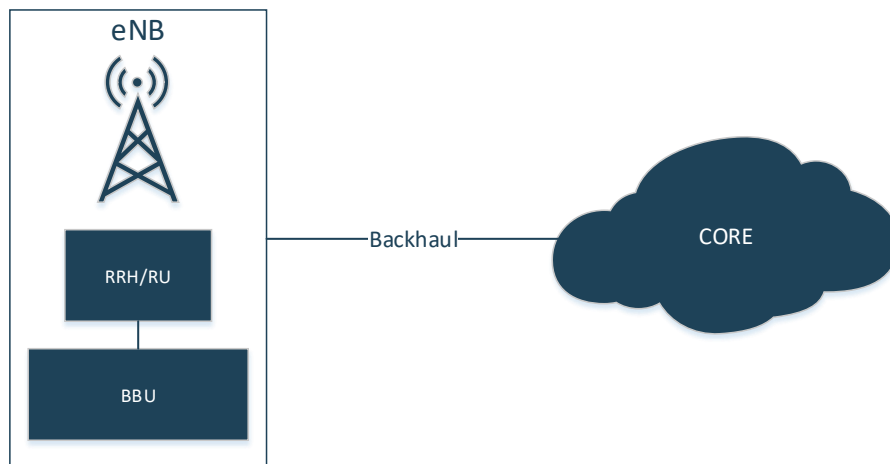


Figure 1: Traditional RAN architecture

where the radio unit (RU) comprising of the amplifiers, filters and the analog front end components of a transceiver, and the base band unit (BBU) were collocated either at the top or bottom of the cellular tower. When located at the bottom of the tower, RF cables from the antenna feeds at the top of the tower were used to connect to the units at the bottom of the tower. These methods typically had significant losses due to these RF cables and warranted special solutions.

Soon, the architectures became centralized as shown below –

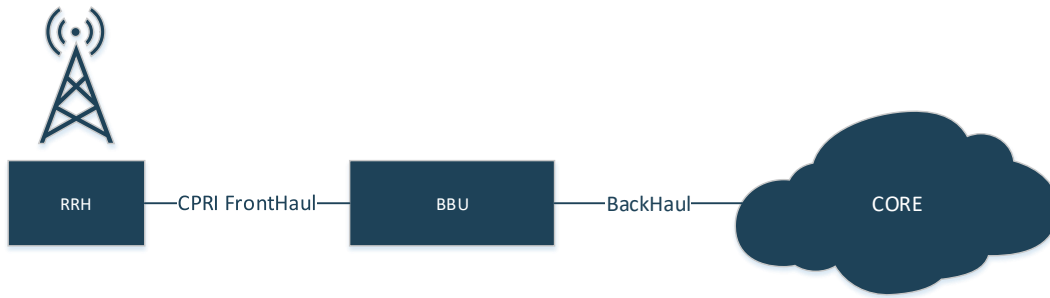


Figure 2: Centralized RAN architecture

wherein, the CPRI: Common Public Radio Interface, a protocol for IQ data transmission between RU and BBU via optical fiber was used. This architecture also allowed the BBU unit to be located at a distant location from the cell tower in which case the CPRI cables had to be long such as few kilometers (kms) to support a centralized deployment.

This centralized RAN deployment further evolved to support a cloud-RAN deployment as shown below.

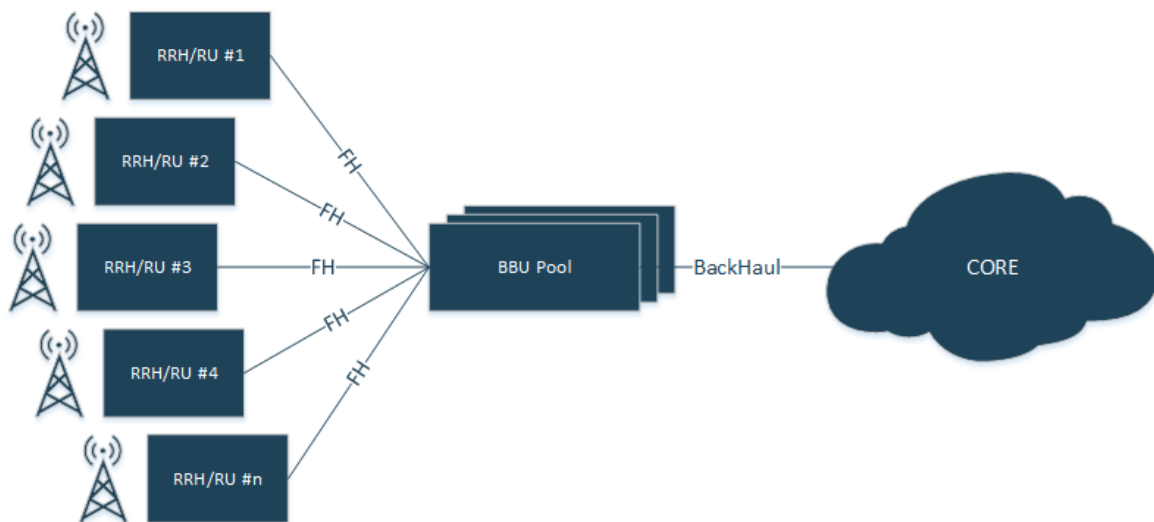


Figure 3: centralized RAN to support a cloud-RAN deployment

which allowed the BBU to coordinate radio units across multiple sites, better coordinate interference across multiple sites and improve overall network throughput. The fronthaul (FH) was supported initially supported by CPRI. However, it was soon realized that CPRI has too much overhead and lot of bandwidth wastage even during idle times. Quickly, this was replaced by eCPRI standard (enhanced CPRI) which supports Ethernet based IP packet flows only when traffic is present (not point-to-point like CPRI). This architecture also allowed for the BBUs to be virtualized to be able to support on-demand services.

The cloud-RAN could support more splits as shown below -

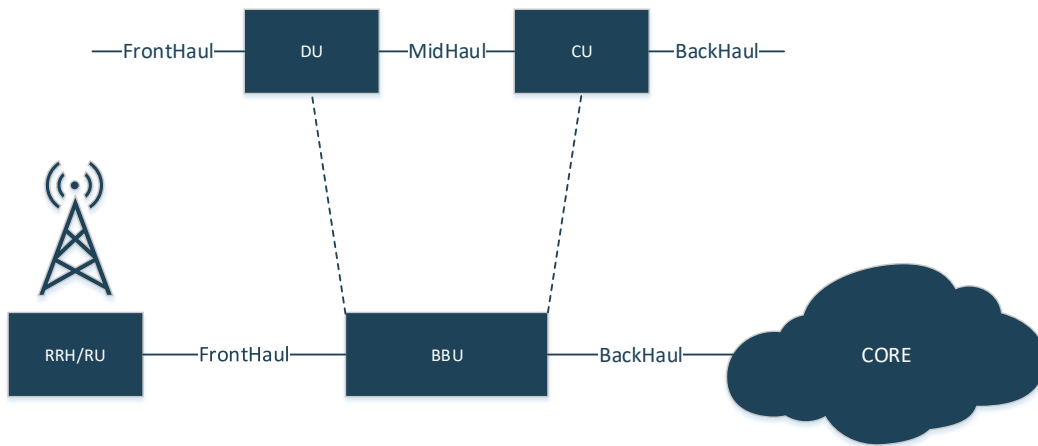


Figure 4: Cloud-RAN with splits

The BBU itself is split into a real-time distributed unit (DU) and a non-real-time control unit (CU); where a single DU can source multiple RUs and a single CU can source multiple DUs.

However, there is not a single place where the split between RU, DU and CU can be done in the entire protocol stack of a wireless network such as 4G and 5G. Some of the possible splits are shown in the figure below using the various components of a wireless stack –

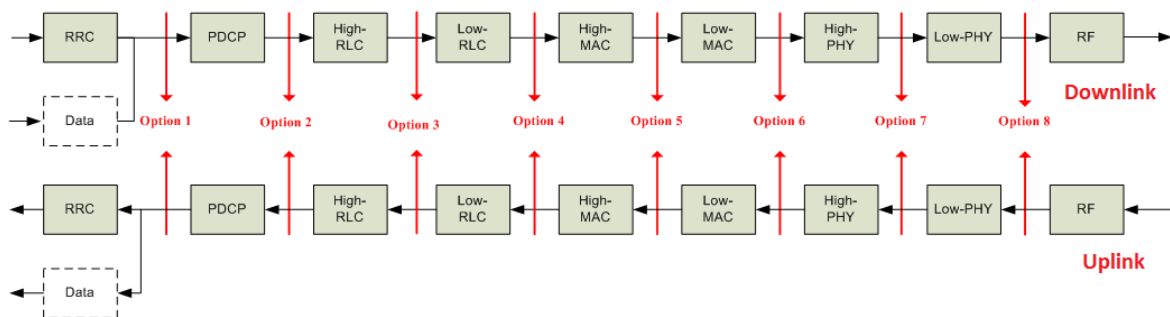


Figure 5: possible splits using the various components of a wireless stack

Depending on the splits between the CU-DU and DU-RU, the bandwidth and latency requirements change in the entire design. This problem especially aggravates with the introduction of the massive MIMO solutions to enhance capacity and coverage. For example, in the figure 6 shown below is the DU-RU split with 5 potential split points. The Fig. 6 is more granular representation of Fig. 5 from option 6 to option 8 elements.

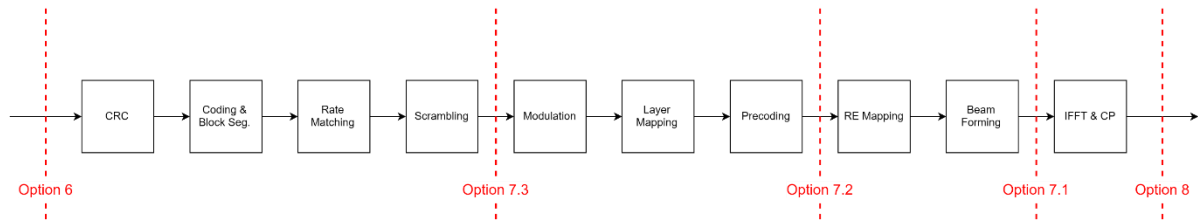


Figure 6: DU-RU split with 5 potential split points

The bandwidth requirements on the DU-RU interface change from a mere 100 Mbps at split 6 to 250 Gbps at split 8 when multiple antennas, higher order modulations and 100MHz bandwidth systems are considered. Hence, this requires a careful analysis and design of the entire wireless system.

Owing to these challenges, despite the fact that splits were defined, most networks today source components from a single vendor for RU and BBU with proprietary CPRI interface. However, telecom operators are now transforming their networks to cater to the needs of the ever-growing digital community. Typical method of operations had been to approach end-to-end equipment vendors such as Nokia, Samsung, Ericsson and Huawei to procure the telecom equipment and also rely on these vendors for operations and maintenance. However, to manage to growing opex and capex costs with the dense network deployments, the operators have now found renewed interest in venturing for open source and white-box hardware solutions from multiple vendors that is potentially bringing in new players. While the core network of the telecom equipment has predominantly been a software solution where several players have already made their mark by providing virtualized solutions using container frameworks etc., the radio access network (RAN) is yet to undergo such a transformation.

The X-RAN and CRAN alliances which were formed in the 2016-time frame have now merged to create an operator backed ORAN alliance in 2018. This alliance was formed with the basic motive to make RAN an open space and move away from the above mentioned big-4 vendors. This alliance focuses on white box hardware, open interfaces across various portions of the RAN, open software, among others. Specifically, this group advocates for the following architecture where every component is now termed as Open, such as open DU, open RU among others.

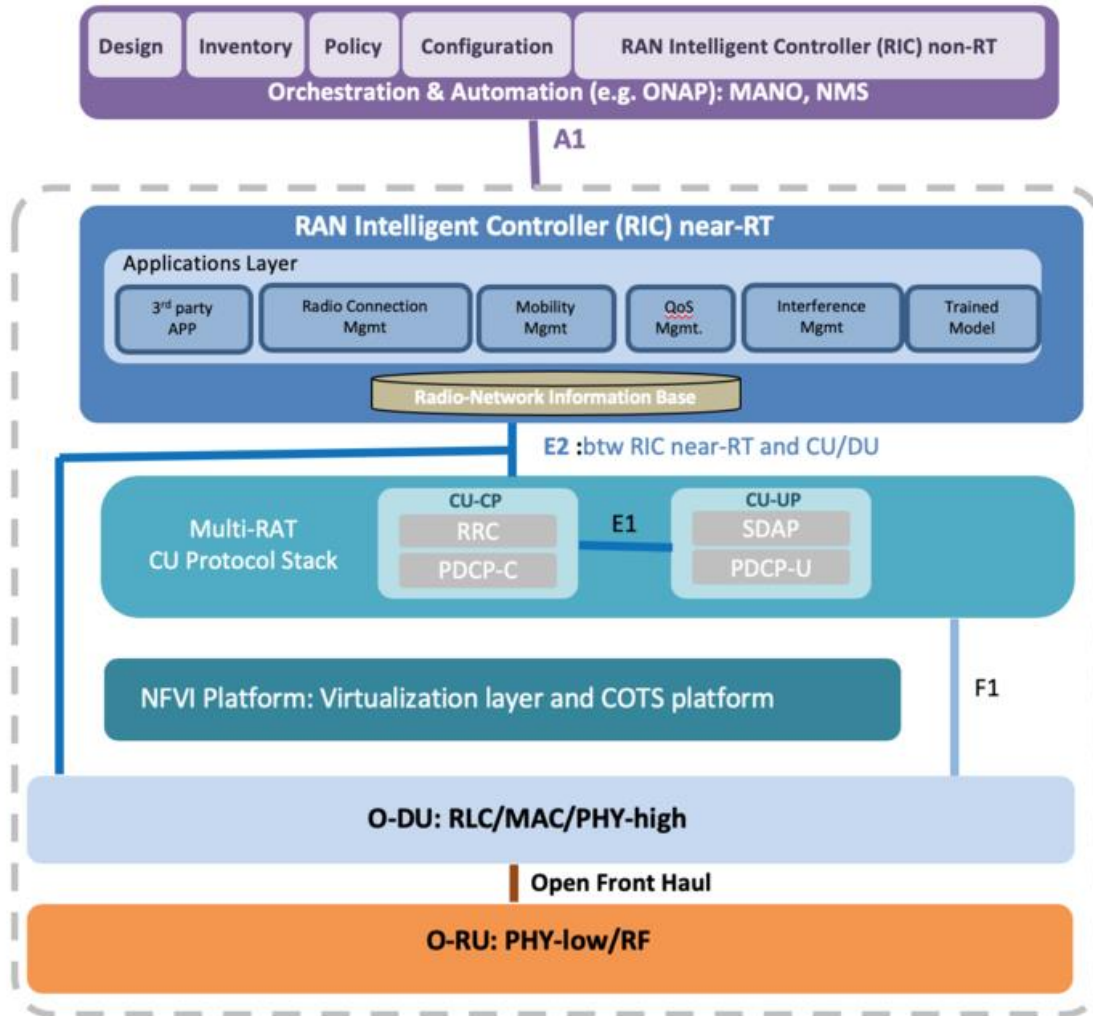


Figure 7: ORAN alliance

This architecture supports a vertical split along the various protocol layers and horizontal splits within a protocol layer to support control plane and user plane traffic separation. Several open interfaces such as,

- Open FH between O-DU and O-RU
- F1 between O-DU and O-CU
- E1 between CU-CP and CU-UP
- E2 between RIC RT and CU/DU
- A1 between NMS and RIC RT

have been introduced and made open. Now, any company can make any of these various boxes and prescribe to these open interfaces and be a player in this vast telecom market.

They only have to ensure that their open devices are compliant to these open devices. However, interoperability is still a challenge in this method of operation.

The ORAN alliance, has narrowed down to split 7.2 shown (Figure 6) earlier between DU-RU and split 2 between CU and DU. They allow 2 variants of the devices in the 7.2 split based on where digital beamforming is performed. This design depends on the deployments chosen by a telecom operator. To support this deployment, the ORAN alliance uses eCPRI protocol and has created various types of messages as shown in the figure below –

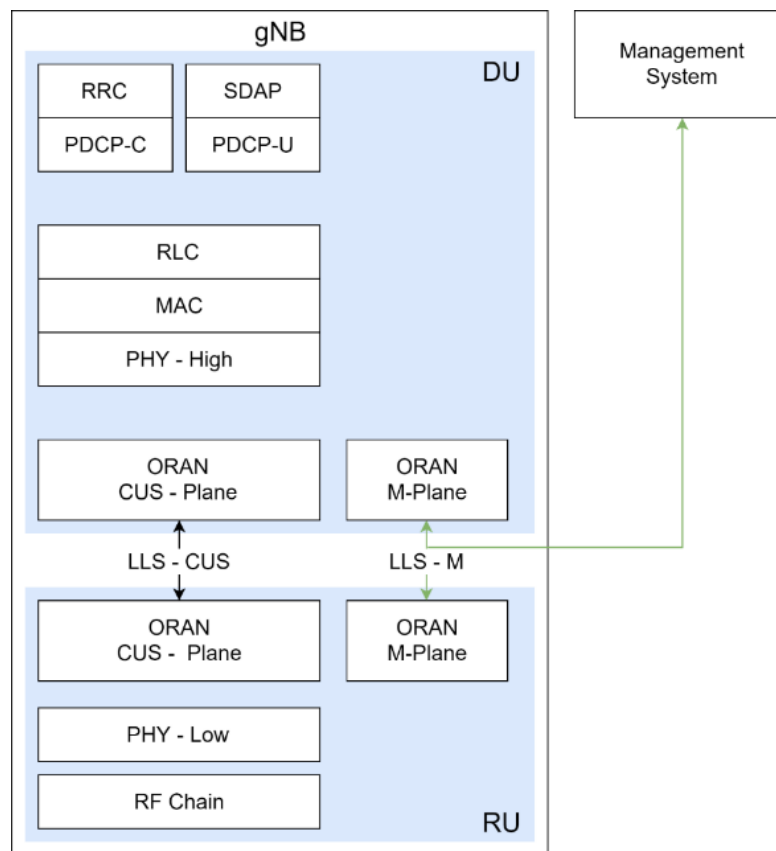


Figure 8: ORAN Stack

They are control plane, user plane, synchronization plane and management plane. Their functions are described below,

CUS Plane: Control / User / Synchronization (CUS) Plane

- Covers real-time control-plane communications between the DU and RU
- Covers user plane traffic in DL and UL between DU and RU

- Covers synchronization of the RU generally sources from the DU
- Uses Ethernet transport and eCPRI/IEEE 1914.3 radio application transport

M-Plane: Management Plane

- Covers management of the Radio Unit (RU) as governed by the DU
- Provides all non-real-time control of the RU (Real time control uses the C-Plane)
- Uses Ethernet (UDP/IP) transport

While this covers the open interfaces portion, the actual stack portion between DU and RU is shown below with the 7.2x split by ORAN which shows in detail the various blocks in the downlink physical chains followed by the uplink physical chain. It shows the low-level components such as modulation, scrambling, FFT, etc. and where each operation will be performed in an ORAN compatible RAN design.

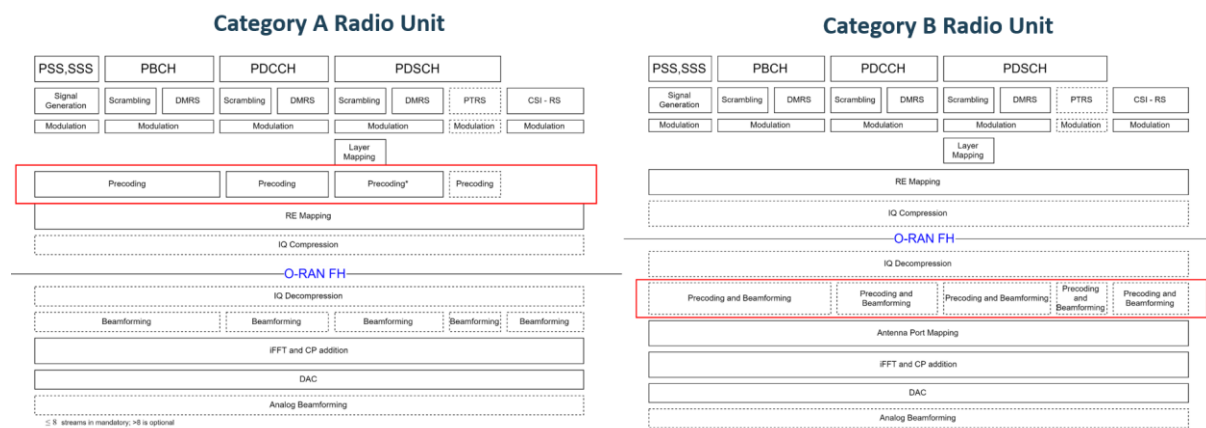


Figure 9: Downlink splits as per ORAN for category A and B

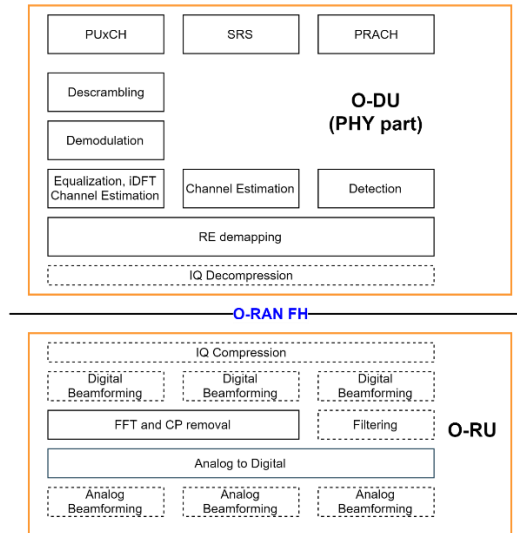


Figure 10: Uplink splits as per ORAN

9.1.2 ORAN Base Station Objectives

(for detail deliverables please see Timing and Deliverable Section)

1. O-DU and O-RU hardware development based on a mix of GPPs and FPGA and ASICs
2. Develop hardware accelerators for specific PHY functions
3. O-DU and O-RU L1/2/3 and ORAN based software development for the above hardware;
4. Realization of small/large cells with conventional radios and massive MIMO systems based on the developed systems;
5. Define new Interfaces where necessary and re-use ORAN interfaces where applicable at different layers to implement novel AI/ML algorithms/engines to aid network performance enhancement;
6. Contributions to ORAN, 3GPP, TSDSI, and ITU
7. Develop algorithms and Patents
8. Inter-operability tests and field trails under live network conditions

The outputs of the project will be in the form of Software/Hardware IP that will be licensed to commercial entities that will further develop this technology and take it to field deployment. Patents generated in the project will feed into ORAN, 3GPP, TSDSI specifications and standards.

9.1.3 Further Details of ORAN technical proposal

We propose to develop ORAN compatible DU and RU systems with the functionalities mentioned in the WP1 objectives. The proposed design is explained in more detail in the following. Figure 11 shows the block diagram of the proposed O-DU and O-RU design with an RF transceiver. Figure12 shows further details of RU functions. Figure13 shows ORAN specific implementation.

9.1.4 O-RU design:

As shown in Figure11, RU comprises of ORAN compliant interface to the DU, lower PHY functions, the RF section that includes ADC/DAC section, RF front-end (RFFE) that comprises of PA/LNA/switch, and the antenna array. The low PHY portion of the downlink including channel generations for PDSCH, PDCCH, SS block and the associated control for interactions with higher layers. It also includes the necessary ORAN modules such as CUS plane, M-plane and the IQ compression portion to reduce the front haul bandwidth. The low PHY implementation typically goes into an FPGA. The RF section needs to be able to support large BWs, multiple carriers, and an array of PAs with total power output that ranges from 1 Watt/carrier (small cell) to 40 Watts/carrier (Macro cells). In a carrier aggregation mode, the total power output may reach 100s of Watts. The output power requirements will be decided based on local operator needs. Standard implementations include 4-RF-paths with 4-antennas (either Omni antennas or sectoral Macro antennas). However, massive MIMO requires special considerations such as support up to 64 antennas to allow active beamforming or TDD/FDD based precoding operations. Digital pre-distortion (DPD) plays an important role in controlling overall PA cost. FPGA based DPD implementation will be considered. We also consider design of hardware accelerators to increase power efficiency of specific RU modules by accelerating the computationally expensive low-PHY functions.

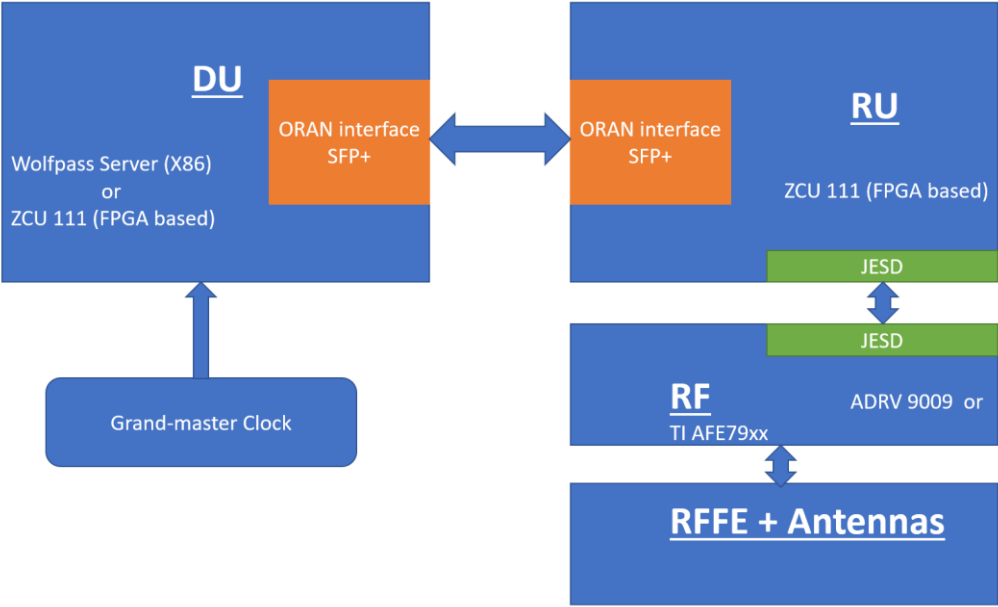


Figure 11: Proposed ORAN compatible DL design for DU

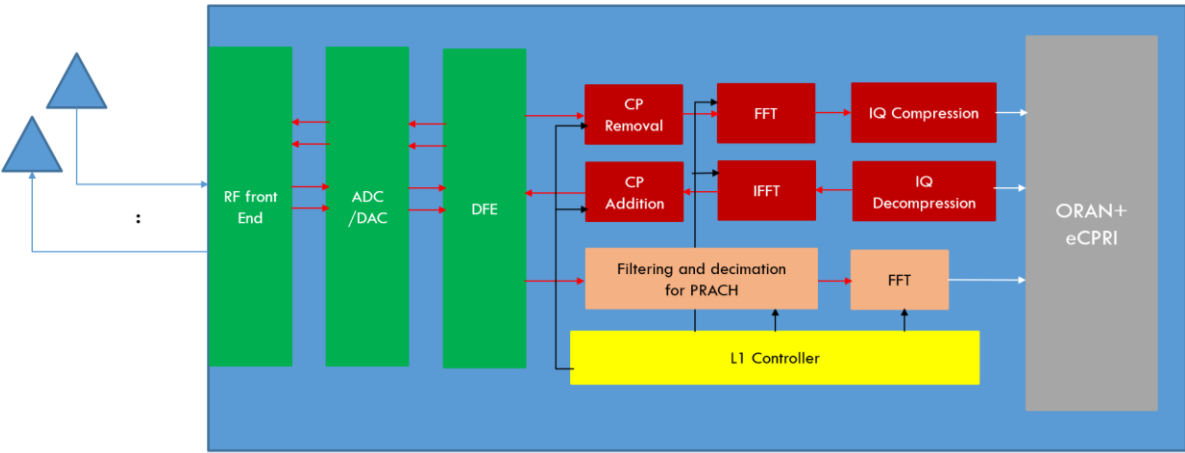


Figure 12: Proposed ORAN compatible design for RU

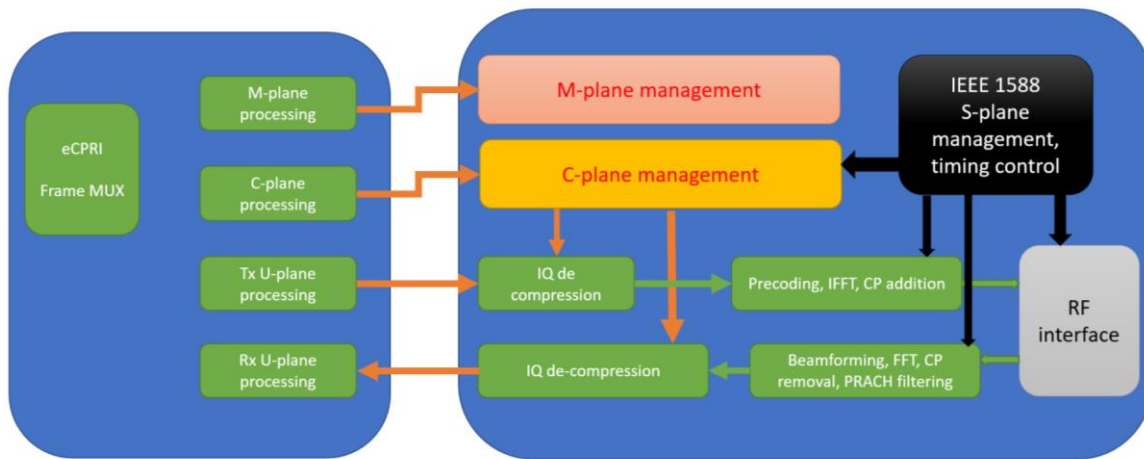


Figure 13: ORAN IP on the DU-RU

9.1.5 O-DU Design:

O-DU comprises of ORAN compliant interface to RU, a combination of GPPs, FPGA/ASIC to enable L1 and parts of L2 or L3 processing based on supported functional split. The L2/L3 stack can run on ARM or x86 whereas parts of the physical layer (high PHY) may run on x86/ARM/DSPs and other parts that involve computationally intensive processing may use FPGAs/ASIC for off-load. Based on the combination of GPPs/FPGA/ASIC split we will design and optimize the high PHY software specific to the selected platform. The O-DU computational capacity needs to be dimensioned for the number of cell sites it should support. These parameters as well as the functional split that need to be supported will be determined based on operator requirement. The interfaces to the CU or the core network will also be determined based on the selected functional split. We also consider design of hardware accelerators to increase power efficiency of the DU by accelerating the computationally expensive high-PHY functions.

The physical layer IPs and software will be designed as per the 3GPP or TSDSI rel-15 specifications e.g., TR 38.211, 212, 213 and 214. The relevant ORAN specification will be followed for implementation of the ORAN IP blocks.

9.1.6 WP1: Implementations to support AI/ML optimizations in the network

The below figure shows the proposed AI/ML integrated open RAN compatible base station. This figure is from the ORAN specifications.

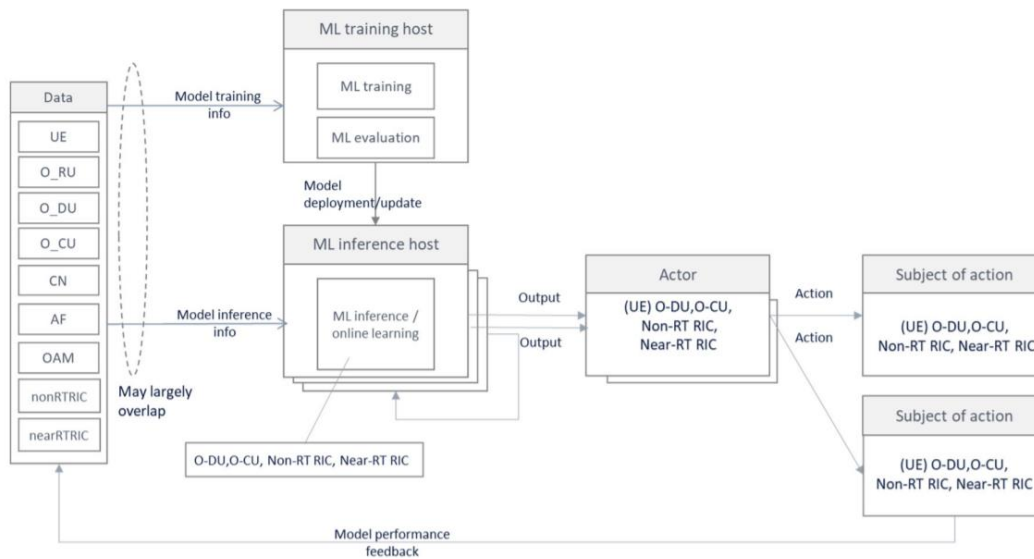


Figure 14: AI/ML integrated ORAN compatible base station architecture

ORAN base stations must be open and also be intelligent. Intelligence in the base stations is quickly becoming critical in due to the complexity of the upcoming wireless networks, number of devices that are connected to the network, higher data rates requirements among others. To support all of this, the network must be scalable enough instead of deploying new base stations physically. The single hardware of a deployed base station must have intelligence to support 1000s of users. To this end, the ORAN alliance defined new protocol layers defined as ran intelligent controllers, real and non-real time ones. Furthermore, ORAN also proposes self-organizing networks that can scale, heal and optimize their operations.

Radio intelligent controllers, real time (RT-RIC) and non-real time (NRT-RIC) are main components to achieve this. The RT-RIC interfaces with the control plane and user plane in the lower level stack of the base station and sits close to the real deployments. It takes care of the real time decisions, stores data, does number crunching at a faster time scale. For instance, it has some already trained machine learning models which use the new data such as RSRP, cell load etc. and sue this ML model to give some new scheduling decisions for the base station, or advise the base station to perform WIFI offloading, or create new cells for cell splitting among others. These decisions from RTRIC are then forwarded to the non-real time RIC which collects data from 100's of RT-RIC's and makes a global model and makes more

informed decisions. The radio connection management, mobility management, interference management are some examples of problems handled by RT-RIC.

Several interfaces must be developed along with hardware to support these machines learning enabled base stations. For instance, GPU type processors are needed to enable fast learning and fast number crunching for Machine learning purposes. The GPP/FPGA/ASIC design must be tuned to support the same. Software to support A1 interface for communicating with the NRT-RIC is also to be created. The designed system should be capable to create generic ML models that are therefore adaptable for dynamic cell and/or carrier aggregations.

O-RAN arises from the key principles of virtualization, it should also account for the security challenges of the virtualized deployments. For example, authentication, authorization of virtual machine (VM) orchestration, etc. are some of them. The shared design of ORAN across multiple cells may pose risks for user privacy which must be accounted for and new security-based protocols are also needed to be ensured for these deployments. This will again entail deployment of specialized hardware to support high throughput encryption.

To support all of the said above, ORAN prescribes control loops as shown below –

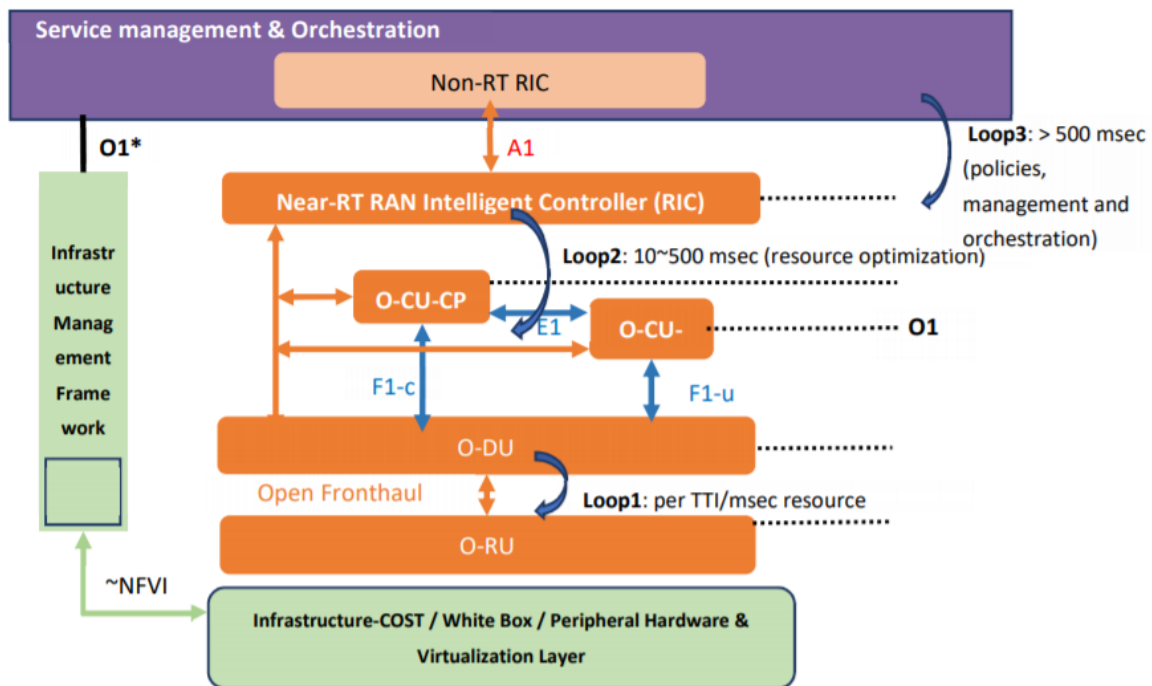


Figure 15: control loops in ORAN designs

“AI/ML related functionalities can be mapped into the three loops. The location of the ML model training and the ML model inference for a use case depends on the computation complexity, on the availability and the quantity of data to be exchanged, on the response time requirements and on the type of ML model. For example, online ML model for configuring RRM algorithms operating at the TTI time scale could run in O-DU, while the configuration of system parameters such as beamforming configurations requiring a large amount of data with no response time constraints can be performed in the Non-RT RIC and Orchestration and management layer where intensive computation means can be made available [ORAN specification]”.

The general procedure is shown below which must be implemented in the hardware that will be developed. Specifically, it shows where the various functions of the ML/AI capable base station have to be implemented. While designing the hardware, we will ensure the following architecture will be supported.

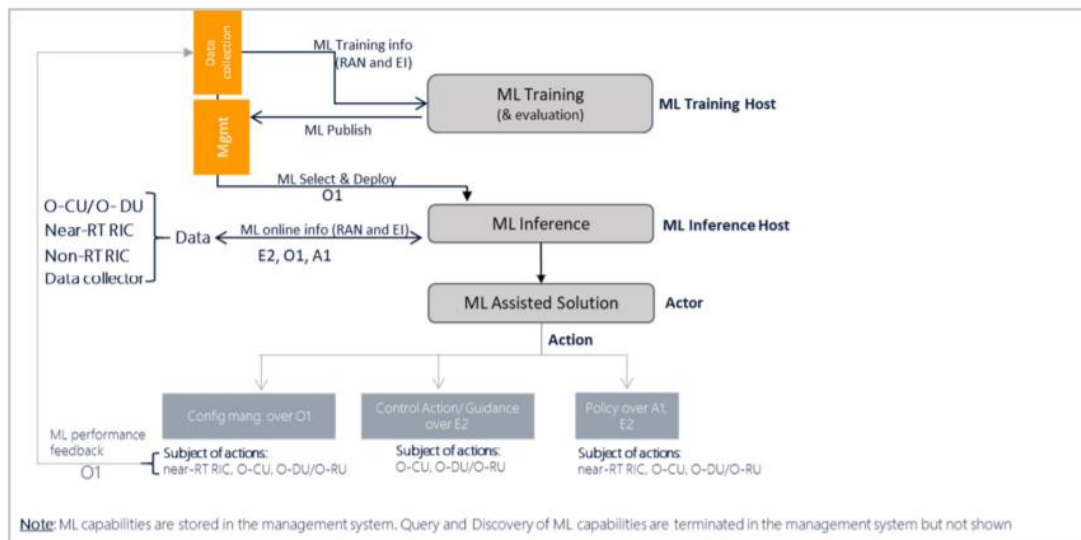


Figure 16: ML training host and inference locations

9.2 AI/ML-based MAC Scheduling and Network Slicing for 5G and Beyond Base Station

9.2.1 Context:

Future wireless systems, i.e., 5G Advanced and beyond will present significant challenges and complexity due to network densification and highly demanding applications. As a result, the evolution towards 5G wireless for an architectural transformation required to support service heterogeneity, coordination of multi-connectivity technologies and on-demand service deployment. An emerging idea that enables such a transformation using the concepts of virtualization, flexibility and intelligence is open radio access network (O-RAN). As mentioned before, the main objective of O-RAN is to enhance the RAN performance with focus on two fundamental pillars, Openness and Intelligence. Openness aims to build more cost effective and agile RAN through open source and open interfaces enabling efficient multi-vendor interoperability. Intelligence to meet the requirements for increasingly complex, denser and richer networks through deep learning and embedded intelligence in every layer of the RAN architecture. Thus, machine learning (ML) and AI back end policy-driven optimization modules are required in medium access control (MAC) protocols to empower network intelligence through standardised interfaces to meet the requirements of 5G Advanced and 6G systems.

9.2.2 Problems to be addressed:

The networks will become increasingly complex with the advent of 5G, densification and highly demanding applications. Such traffic intensive and highly interactive applications are generated by user interactions and fluctuating radio transmission capabilities. Hence, the service Quality of Experience (QoE) cannot be always guaranteed, except by over-provisioning Quality of Service (QoS) during peak traffic demand. To reduce the complexity, the traditional human intensive means of deploying, optimizing and operation cannot be applied. The networks should be self-driving and be able to leverage new learning-based technologies to automate the network functions and reduce the operational costs. Embedded intelligence applied at both component and network levels will enable dynamic radio resource allocation and optimized network efficiency. In view of this, one such challenging area to be addressed is:

To propose novel ML-based system-level Optimization models and MAC Scheduling algorithms for ORAN-Compliant 5G and beyond systems.

1. Designing the 5G RAN requires planning for multiple features, such as, MIMO antennas, large spectrum bandwidth and multi-band carrier aggregation. This poses a challenge for the growth and maintenance of networks, which would need to support multiple generations of connectivity, scalability and flexibility to meet the increasing data demands.
2. Identifying set of use-cases, services, functions and application programming interfaces to utilize closed-loop learning-based ML/AI technologies.
3. Development of adaptive multiple access protocols that can dynamically change type of multiple access depending on the application/traffic needs and network status.
4. Design of proactive and dynamic handover and signaling mechanisms to cope with different mobility patterns posed by 5G Advanced systems.
5. The future generation of wireless networks will comprise of RAN components, i.e., Central unit, distributed unit and radio unit supported by multiple vendors. This multi-vendor setup makes it more challenging to identify and isolate issues in the network. In view of this, there is a need to study as to how to deliver the best possible service when optimizing the configuration of the control plane. The above complexity may impact the performance of the 5G-NR base station under high load conditions

9.2.3 Technology:

It has been envisioned that 5G Advanced systems will take network softwarization towards a next level, i.e., network intelligentization. In 5G, the “non-radio” aspect has become more and more crucial, and has been the key driver behind the recent concept of “softwarization”. More specifically, the two key 5G technologies that have moved modern communications towards software-based virtual networks are Software-Defined Networking (SDN) and Network Functions Virtualization (NFV). The above concepts enable the concept of network slicing, where multiple virtual networks are created on top of a single shared physical infrastructure. Nevertheless, as the network is becoming more complex and more heterogeneous, softwarization will not be sufficient for Beyond 5G. In particular, to support AI-based applications, there is a need for an architecture that is flexible, adaptive, and more importantly, intelligent. Future (5G Advanced) network architectures, will be built on

foundations of advanced network technologies that fully embrace the principles of intelligence and openness. Using the above concepts, a particular application/service/use-case can be implemented which involves three major functional loops. Following Fig. 17 depicts an overall view of the O-RAN architecture for implementation of a specific 5G/Beyond use-case/application.

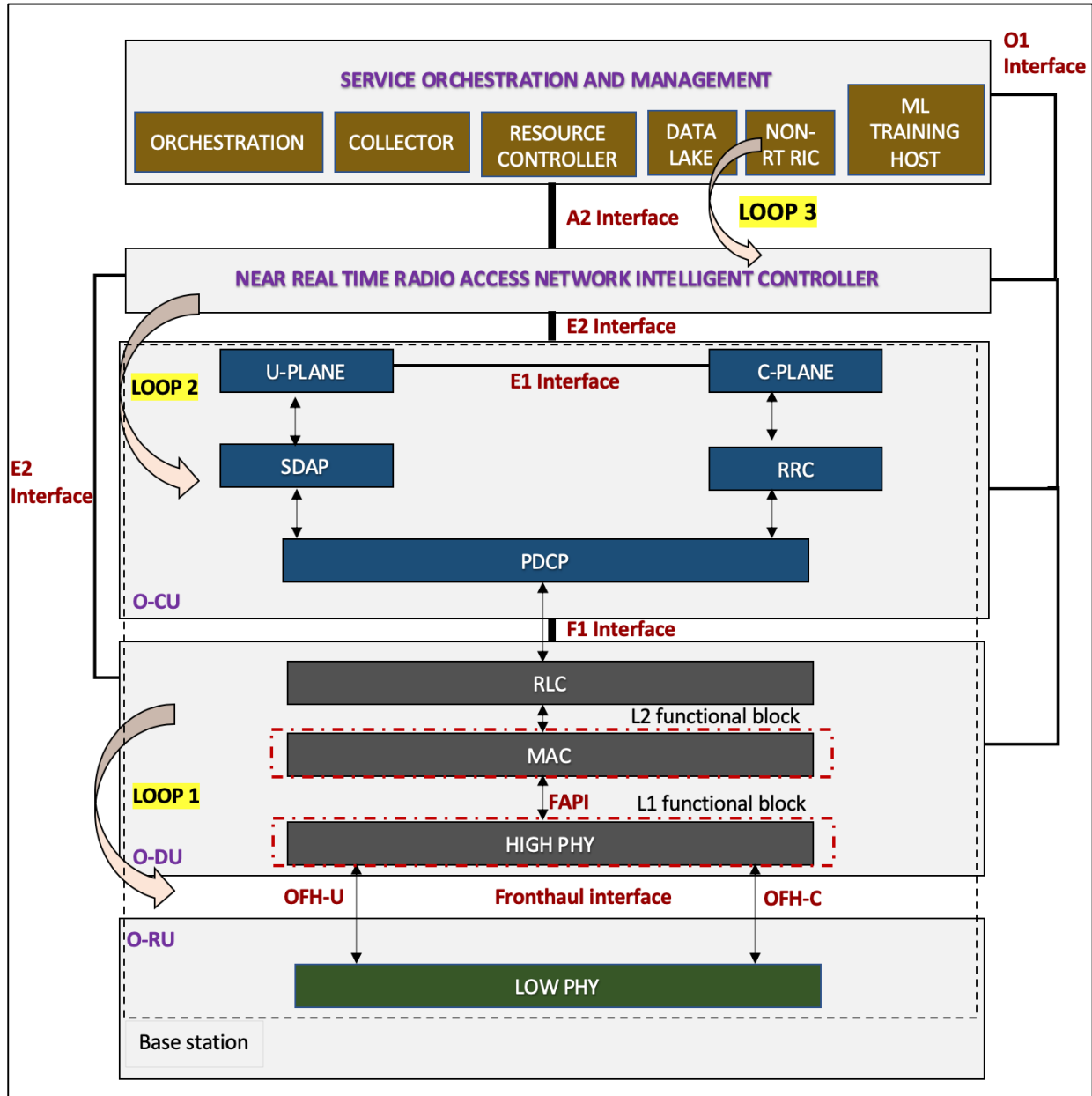


Figure 17: Overall view of O-RAN architecture for implementation of 5G and Beyond applications

1. **LOOP 1:** Per transmission time interval scheduling which involves interaction between the distributed unit (O-DU) and radio unit (O-RU) functional blocks.

2. **LOOP 2:** Resource optimization in the Near-RT RIC.
3. **LOOP 3:** Policy management, ML model management: Interaction between the Non-RT RIC and Near-RT RIC. Non-RT RIC provides policies to the Near-RT RIC for updating AI/ML models to obtain the near-real time information for the given 5G and Beyond use-case/application scenario.

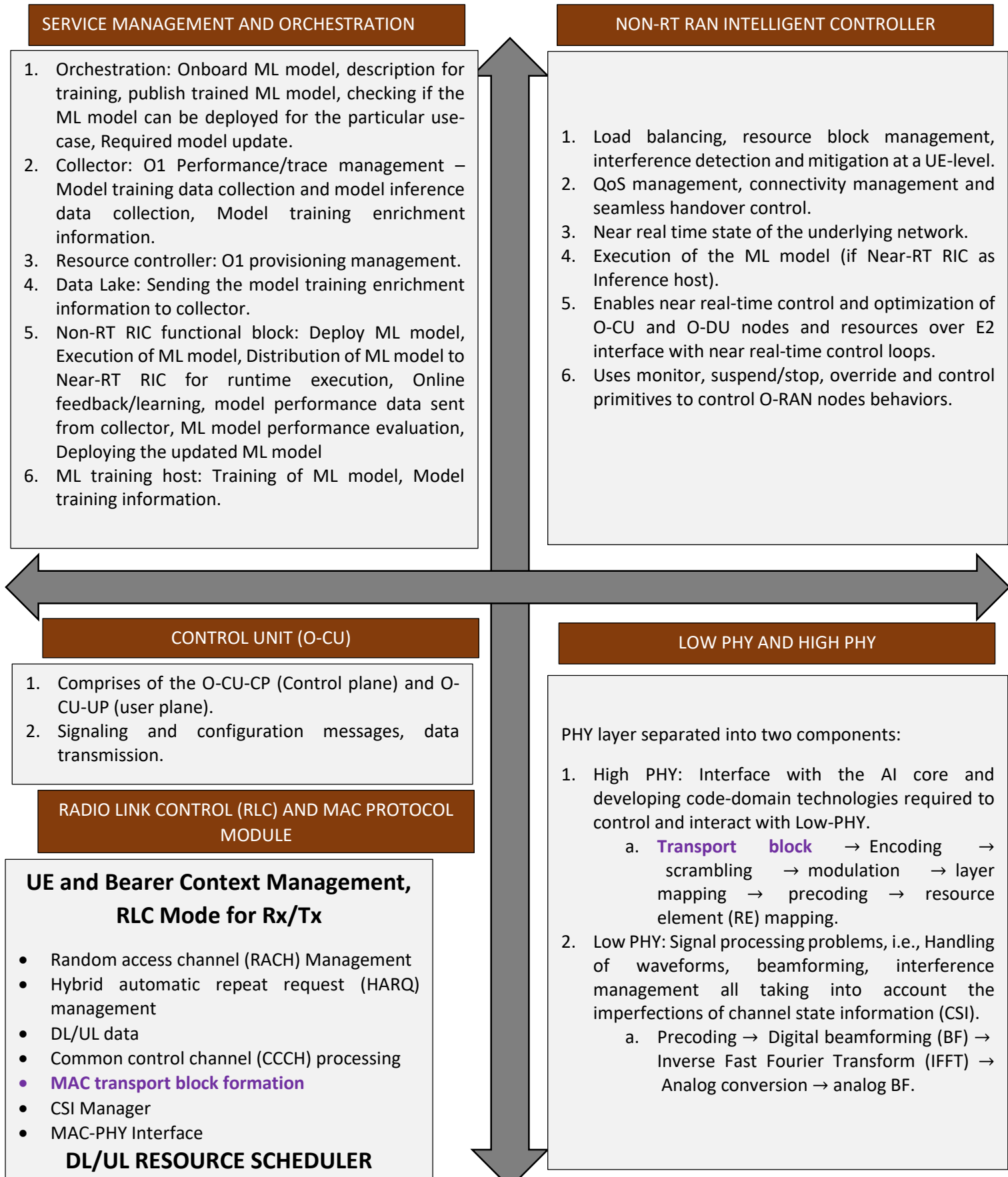


Figure 18: AI/ML based MAC Scheduler

O-DU AND O-RU: MAC-PHY FUNCTIONALITY: LOOP 1

The O-DU comprises of the L1 and L2 functional blocks which interface through the functional application platform interface (FAPI), as shown in Figure 1. O-DU L1 functional block comprises of the Physical Uplink Control channel (PUCCH); Physical Uplink Shared Channel (PUSCH) and Physical Downlink Control channel (PDCCH); Physical Downlink Shared Channel (PUSCH). Considering an uplink (UL) flow use-case/application, the below steps would be implemented,

1. O-DU L1 **PUCCH** block conveys uplink control information. The control message comprises of: Hybrid automatic repeat request-acknowledgement (HARQ-ACK), Scheduling request (SR) and channel state information (CSI). **PUSCH**: The frequency domain orthogonal signals received by the fronthaul module are sent to L1 PUSCH processing functions and the output is user bit stream.
2. PHY-MAC: Receive and transmit the L1-L2 interface messages.
3. Configuration of CSI and informing the CSI feedback from UE to scheduler in MAC. The MAC scheduler comprises of the Downlink Uplink (DL)/ Uplink (UL) resource scheduler, UL/DL link adaptation, UL Tx power control and Timing assistant (TA) manager.
4. Creation of the MAC transport block based on the input from the scheduler. Interfaces with RLC to get RLC PDUs.
5. Resource assignment based on resource allocation schedule from the scheduler.
6. HARQ management by keeping track of HARQ feedback, HARQ timer and providing free HARQ processes information to scheduler.
7. Demultiplexing the transport block containing MAC control elements and RLC packet data units (PDUs) and sends for respective tasks. MAC layer indicates UL data by sending RLC PDUs. RLC forms the Service data units (SDUs) by reassembling the PDUs and transmits it to the upper layer through F1 interface.
8. Handles CCCH message and corresponding HARQ.

9. RACH resource management.
10. RLC layer stores the semi-static information on air interface resources for UE. Keeps QoS related information for the scheduler.

F1 INTERFACE FUNCTIONALITIES AT O-DU

1. F1 user plane interface module consists of tasks related to tunnel management, UL data packets transmission for packets received from RLC and header encapsulation.
2. F1 control plane interface module consists of tasks related to cell management, UE management and semi-static air interface resource management for UE (at cell-level). Interacts with the O-CU-CP to control communication setup.

CONTROL UNIT: DATA TRANSMISSION

1. Control unit responsible for data transmission, signaling and configuration messages (gNB procedure management, Cell procedure management, UE procedure management (access control and signaling procedures)).
2. The control unit collects the performance counters and faults at O-CU-CP and O-CU-UP and reports to the performance and fault management entities (explained below).

CASE 1: NON-RT RIC ACTS AS ML INFERENCE HOST

For a given 5G/Beyond use-case application, Near-RT RIC, O-CU and O-DU collect the following below information(s) and send it to the Collector (Figure 1) which is sent to the Non-RT RIC. Depending on the SMO platform, different entities would be responsible for data collection.

1. O1 network provisioning management

- a. Processing capabilities, such as CPU, memory, bandwidth, resources available that can be allocated for model inference.
- b. Architecture support in ML inference host to run ML model.
- c. Supported ML model formats and ML engines.
- d. Data sources available to run and support the ML pipeline.
- e. Apps for collection of near real-time information to provide value added services.

2. O1 Performance/Trace management → Model training data collection (Metadata).

- a. Information such as type of 5G/Beyond use-case application and traffic related information, data rate associated with the service, mobility of UE, location and patterns, resource requirements for use-case application, channel information, network status and conditions, radio conditions, historical data.

3. O1 Performance/Trace management → Model inference data collection.

- a. Checking the accuracy of model (e.g. Confusion matrix, specificity, F1 score).
- b. Advanced troubleshooting, malfunction, optimization of resource usage, quality, radio frequency (RF) coverage control.
- c. Location updates, counters, such as packet loss/drop rate, radio resource control (RRC) connection release, handover failure, RRC connection establishment, RACH usage, enhanced counters for mobility robustness optimization and so on.

4. O1 fault measurement performance

- a. Comprises of the knowledge base and inference engine for decisions.

5. O1 Software management

6. O1 Performance/Trace management → Model performance data collection

- a. Envisaged 5G/Beyond KPIs performance.

Based on the above information(s) received from O1 interface, Non-RT RIC provides policy-based guidance/AI/ML model management to the Near-RT RIC depending on the use-case - **(LOOP 3)**.

CASE 2: NEAR-RT RIC ACTS AS ML INFERENCE HOST

(Case 2) E2 interface is used to feed data from O-CU and O-DU to Near-RT RIC. The data includes RAN measurements to facilitate radio resource management **(LOOP 2)**, configuration changes/realization of policies on O-CUs/O-DUs. The Non-RT RIC provides model inference enrichment information as in a reference to the Near-RT RIC using the A1 policies. This information is either collected from non-network data sources or from network functions itself.

9.3 Work-Smart Radio Environments to improve performance for 5G and beyond use-cases

In continuation with above, an increasing maturity in antenna technology and penetration of small-distance communication applications, we see an increase in efforts that attempt to *control and dimension* the unpredictable wireless environment by introducing controllable reflectors that are pre-configured for the intended wireless transmission. Smart Radio Environments (SREs) provide us with an alternative way to look at the wireless communications by allowing us to view the *channel* as a control variable, which can be optimized for performance objectives for a given pair of transceivers or more will increase small cell 5G and beyond networks performance further. SREs are realized using Reconfigurable Intelligent Surfaces (RIS) and a significant body of literature pointing to potential benefits of the same are available. However, a lot of work is required to be able to make a usable product from the above technology. SREs are clearly useful in controlled environments, for example, in an Industrial IoT scenario. Several survey papers in the references list of this document provide detailed list of activities happening in this emerging field. There are several thoughts, for example, showing the limitations of RIS for SREs and the need for being careful before jumping to conclusion on relative advantages of RIS over other conventional techniques for improving system performance. An RIS can be realized by employing different technologies and it is known that they can be designed based on conceptually different approaches. One set of such RIS elements in the environment can serve multiple devices, even though the devices are too small to have an individual large antenna array. This points towards possibility of investing more in having the smart radio environment instead of having each end-device equipped with an increased signal processing and RF circuitry.

Smart Radio Environments (SREs) are expected to change the way we look at wireless communications by allowing us to view the *channel* as a control variable, which can be optimized for performance objectives for a given pair of transceivers or more. This is depicted in Figure 21 below.

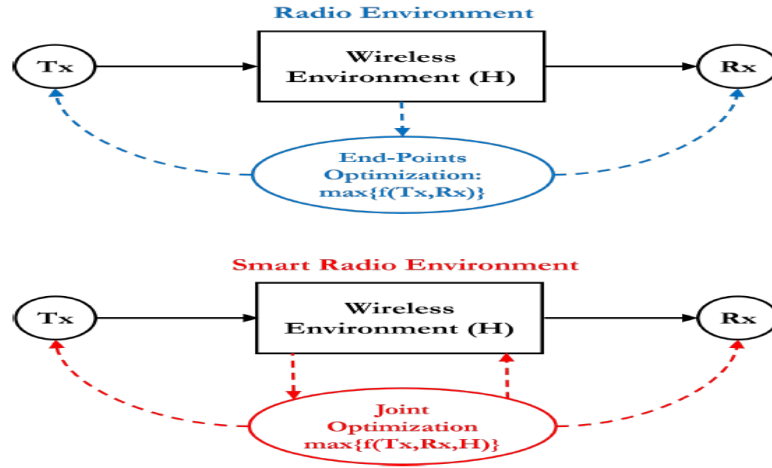


Figure 21: The new control available in SREs.

We wish to point out here that given so much aggressive work from multiple credible wireless research groups around the world, the benefits of achieving SREs via the use of RIS is not free of technical debates and challenges. We point out in particular a recent reference paper, and the work done by the group in showing the limitations of RIS for SREs and the need for being careful before jumping to conclusion on relative advantages of RIS over other conventional techniques for improving system performance. The authors claim that one may compare a decode-and-forward relay and a large RIS surface is required to achieve performance better than relaying. Further, one of the reference argues that if we use realistic physics-driven models, an RIS would not act as a specular reflector, giving out plane waves when fed with plane waves. The work of this group is certainly promising, and we should be cautious in our excitement about using this emerging technology. We can gain from the research of this group as their approach is of open-sourcing the code used for scientific studies as referred in one of the references. We wish to point out that the criticism of SREs using RIS are more on performance limit grounds and not on feasibility. Given that the technology is relatively new, we believe that more work and smarter algorithms developed in this field would be able to address some of the performance concerns.

As explained in a reference, we provide a view of an every-day communication scenario with multiple users within a physical environment. We reproduce the figure from a reference.

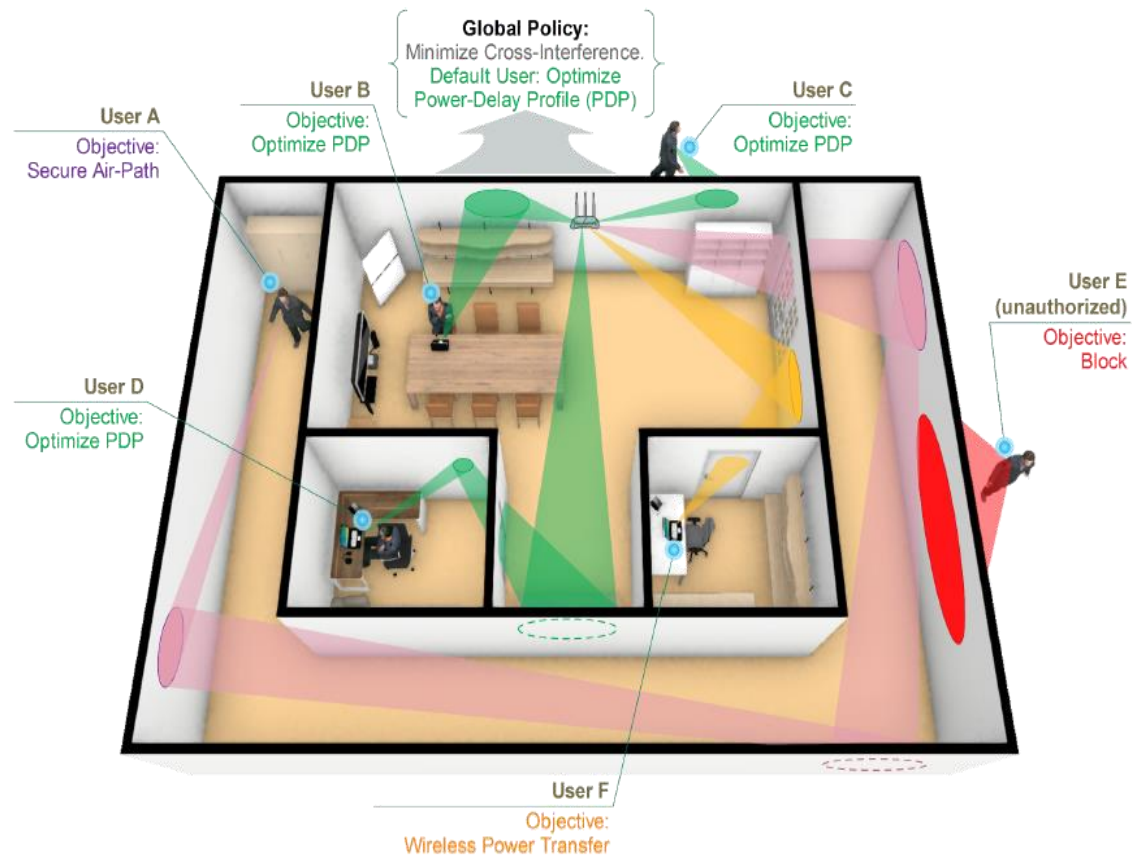


Figure 22: Illustration of programmable wireless environment concept.

To quote as mentioned on a reference below, “In the novel, programmable environments, HyperSurface coated walls and objects become connected to the Internet of Things. As such, they can receive software commands and change their interaction with electromagnetic waves, serving the user needs in unprecedented ways.”

The target controlled environments where SREs can be potentially deployed include Smart cities, Smart Buildings, Smart Homes, Smart Factories, Smart Hospitals, University Campuses, Train Stations, Airports, Billboards, Smart Glasses, Smart Clothing, Smart Cars, Airplanes, Trains. Please refer to a below mentioned reference for detailed description of these use-cases and the challenges involved in implementing each of these.

Within each use-case scenario, few system configurations exist where the use of RIS to achieve SRE becomes important. We consider a generic scenario depicted below.

9.3.1 Technologies for the problems to be addressed:

This section should elaborate the problems and technology to be addressed through the project/scheme at the local/regional/national level evidence regarding the nature and

magnitude of the problems should be presented, supported by baseline data/survey/reports etc.

Many use-cases have been identified in the literature that can benefit from the use of SREs. Each use-case comes with its own unique set of challenges and benefits. In this project we will be interested in use-cases with stringent performance requirements. One possible candidate is the Industrial IoT scenario with performance requirements that are more stringent compared to that of the prevailing uRLLC requirements. We will be performing an in-depth study of the requirements of several use-cases that could be promising in near future in terms of potential of multiple start-ups of Indian origin, and the ones which are expected to be realized using beyond-5G/6G technologies. Our first-year study will document such comparison and possible SRE-based approach for these use-cases and would be expected to serve as a guideline. We will then select one use-case for an elaborate real-world demonstration.

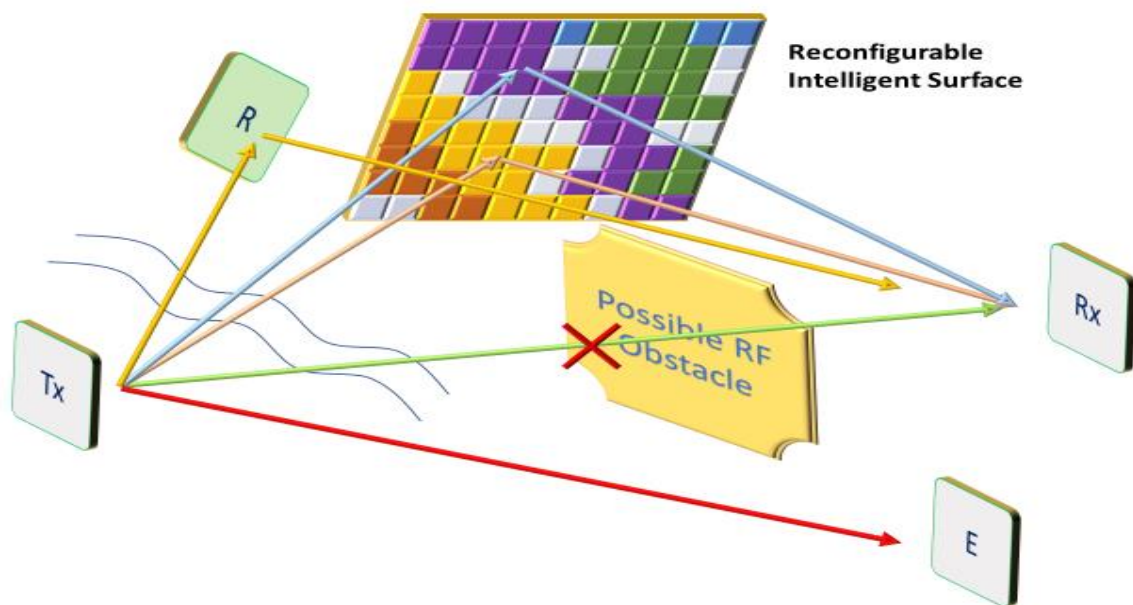


Figure 23: Components in the system considered in this proposal.

Figure 23: depicts the following components that we will be repeatedly considering in the proposal:

- A transmitter equipped with at least one transmit antenna.
- A receiver equipped with at least one receive antenna

- A possible RF block on the direct line-of-sight path between the transmitter and receiver
- At least one environmental RF reflector (R) that would lead to multi-path
- At least one software-controlled RIS element (many RIS elements are shown in the figure)
- A possible eavesdropper (E) which can capture the RF signals over-the-air

Based on this configuration, we have identified several sub-activities in the project.

- I. Fabricating the RIS elements (we will first fabricate passive RIS elements, then active RIS elements and then combine them into meta-surfaces. Details are provided in Section 0
- II. Being able to demodulate the signal in presence of software controlled RIS elements. This includes being able to control the RIS elements' transfer function for an optimized modulation performance. Details are provided in Section 0. This is done in presence of environmental reflectors and considering presence/absence of direct line-of-sight path.
- III. Being able to use active RIS to ensure that the Eavesdropper (E) is not able to retrieve bit-level information from the captured RF signals. This is addressed in Section 0.
- IV. Detailed ability to solve the optimization problem leading to determination of software control signals to the RIS. We propose using Machine Learning-based approach for this objective as several researchers in this field have reported advantages of doing so. However, during the execution of the project, depending on our experiences and more literature study, we may use other methods as well. A high-level view of use of ML in training RIS control signals is provided in Section 0.
- V. We also feel that, given the nascent nature of this field, we should actively identify standardization aspects of this field and bring them to the Indian Standardization platform. This is addressed in Section 0.

It is understood from the discussion so far that design and development of an SRE system requires detailed understanding and expertise in the field of application development, reconfigurable intelligent surface design and fabrication, ability to control the RIS to achieve

a desired SRE performance, and importantly, being able to design and control the SRE to ensure that an eavesdropper is not able to make sense of the wireless signal.

9.3.2 Fabrication Aspects

The design and development of reconfigurable intelligent surfaces (RISs) for future communication networks is a highly interdisciplinary research area and involves concepts from communication engineering, electromagnetics, physics, mathematics, and computer science. The RISs need to possess some special features so that they can be effectively used in wireless communication. They should be almost passive, and ideally, should not require any dedicated power supply. Due to the absence of active elements, they do not introduce any noise while reflecting the incident electromagnetic waves. The RISs should be easily deployable in different use environments like urban areas, homes, vehicles, large buildings, and even clothing. These special characteristics make RIS assisted wireless communication a challenging, but unique and promising future communication technology.

The wireless communication technologies utilize electromagnetic (EM) waves of different frequencies which get scattered, reflected, or diffracted by various objects in the environment. These processes make the wireless channel inherently probabilistic in nature. The main aim of RISs is to alter the propagation of EM waves in a controlled manner. Thus, we can have a better control over the radio environment. In general, RISs are large area two-dimensional surfaces which reflect the incident signal waves and modify them suitably in terms of phase.

The RISs can be made using passive reflectarrays (RARs) or using dynamic meta-surfaces (METS) which can be manipulated to achieve a desired control over the properties of the reflected EM waves.

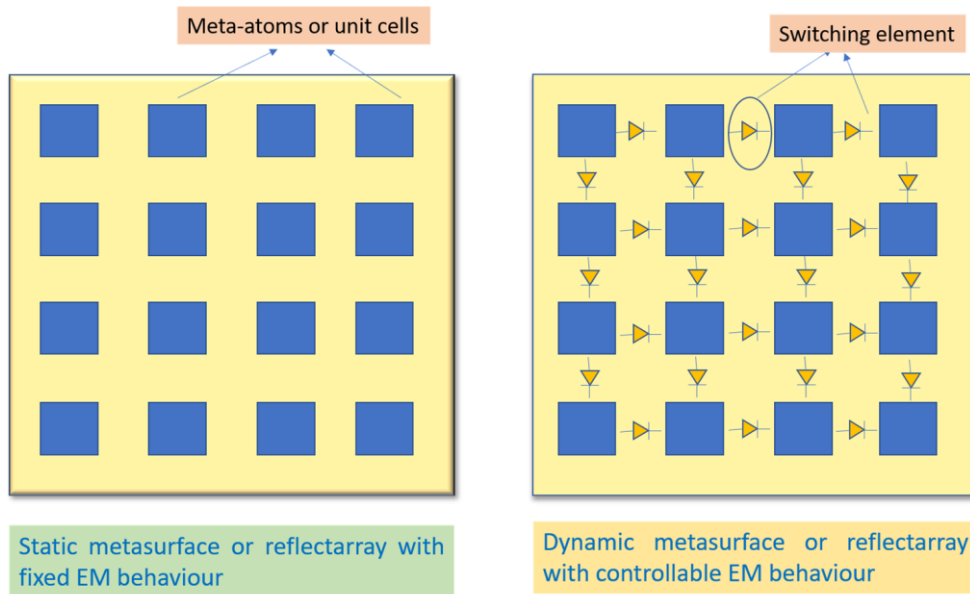


Figure 24: Static metasurface design with limited or fixed EM behaviour and dynamic metasurface with switch elements (p-i-n diodes, MEMS or others) with tunable EM behaviour.

The researchers across the globe are involved in the design and development of novel metasurface structures for use in wireless communication technologies. Achouri et al. have shown that an RAR or METS should be of size $10\lambda \times 10\lambda$ (λ is the wavelength of the incident EM wave) so that it can properly alter the phase and angle of the reflected signal. Such a size would allow the RAR to be modelled as a specular reflector. Considering the gigahertz (Hz) range of frequencies used for modern wireless communication technologies, and also considering the future technologies where the operating frequency is expected to be still higher, the size of the RAR/METS is of the order of a few square meters. Meta-surfaces of this size range can be easily deployed in homes, classrooms, buildings, vehicles, and other environments.

Indian researchers at CSIR-NAL demonstrated swastika-shaped metasurfaces with frequency selectivity properties. Another group of researchers made frequency selective surfaces with p-i-n diodes and demonstrated an intelligent wall. Kaina et al. showed that binary-only phase state tunable meta-surfaces allow one to obtain a good control of the waves, owing to the random nature of the EM fields in complex media. A novel concept of HyperSurfaces has been demonstrated by researchers wherein the metasurfaces are software-controlled. These HypeSurfaces can be used as coatings on furniture and walls, and are used to control the wireless behaviour of a wireless environment via software.

The project will focus on the design and development of static and dynamic metasurfaces or reflectarrays for use as RISs in a smart radio environment. The working principle of a dynamic or controllable metasurface is shown in the figure below.

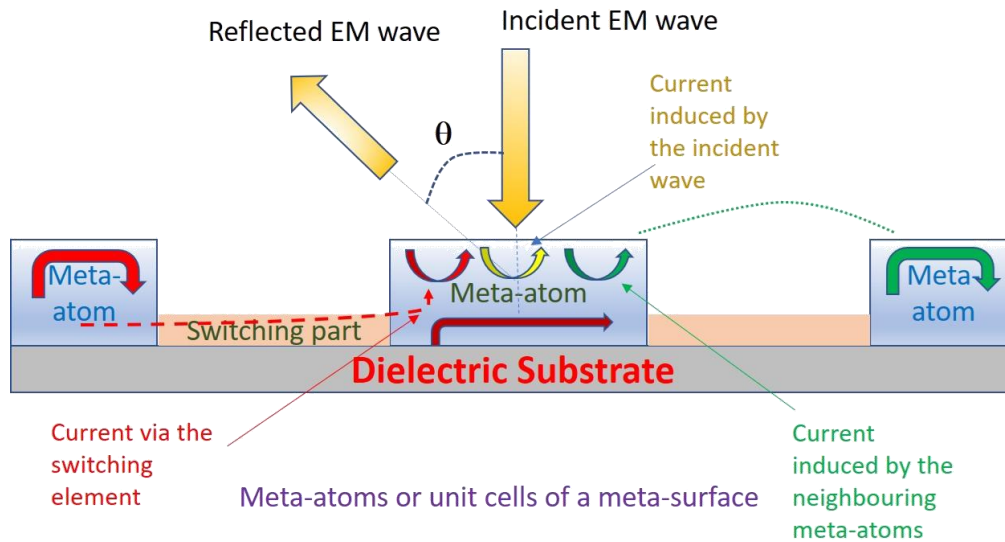


Figure 25: The working principle of a metasurface. The incident EM wave can be reflected towards a predetermined angle θ in a controlled manner. The metasurface functionality, in this case the fixed angle θ , is obtained all over the surface.

It is proposed to build the following structures:

1. A passive reflect array (or static metasurface) using commercially available double-sided printed circuit board (PCB) substrate. The design of the reflect array will be optimized using 3-D electromagnetic simulation software (HFSS Ansys) to obtain the desired functionality for a given frequency range (e.g. Wi-Fi band)
2. Large area electronics (LAE) concepts will be utilized to print conductive patches on low-cost substrates like glass and plastic. These custom printed plastic/glass substrates can be coated or placed on top of other common objects like furniture, doors, walls and ceilings.
3. In the later part of the project, efforts will be made to fabricate a dynamic/controllable meta surface using the materials mentioned in points 1 and 2 above. Electronic switch elements like p-i-n diodes will be used, along with suitable low-cost controllers like Arduino, R-pi and FPGA boards, to realize a 'smart' dynamic meta surface or reflectarray.

A workflow diagram is shown below. The design and fabrication are envisaged to be continuously evolving steps. Lessons learned at each stage will be used to optimize the design and fabrication aspects at the subsequent stages.

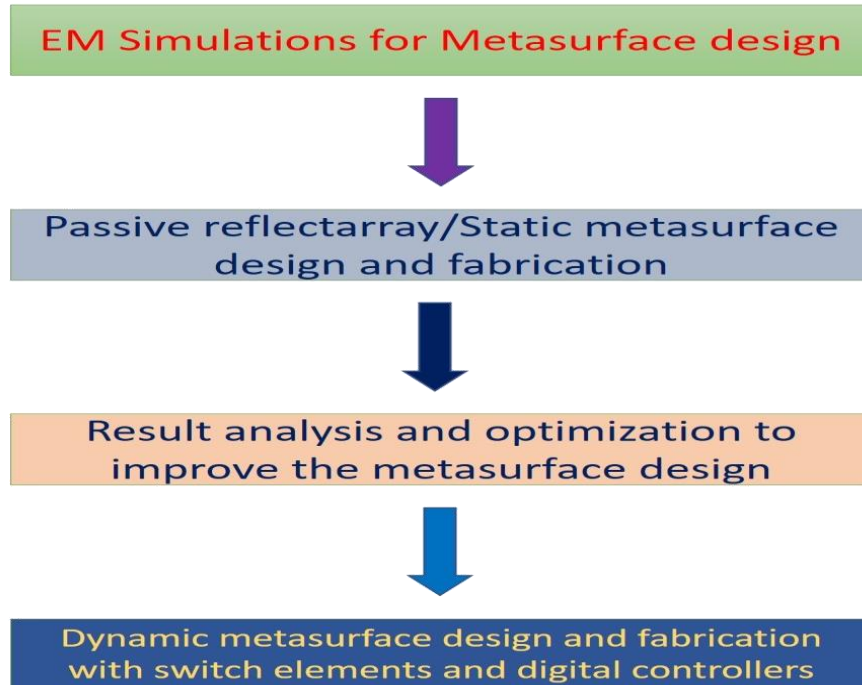


Figure 26: Workflow diagram for the design and fabrication of static and dynamic metasurfaces.

9.3.3 Channel Control Aspects

Due to the constructive and destructive interference of the multiple signal paths between the transmitter and receiver, received signal strength and other parameters of radio signal may vary over time, space and frequency. This is known as fading, which is the main bottleneck of wireless communication systems. Current wireless network designs are focusing on compensating these distortions by designing sophisticated transmission and reception schemes. However, the SRE researches focusing on technologies which can control the propagation environment in order to boost the signal quality at the receiver, i.e., turning the wireless environment to an optimization variable, jointly with the transmitters and receivers, instead of trying to adapt to the wireless channel.

A communication-theoretic view of the SREs is provided in the Figure 27 from a reference mentioned below. In a conventional communication theoretic viewpoint, the channel is modelled as random variables which cannot be controlled and hence cannot be an

optimization variable. Under the SRE based systems, the programmability of RIS makes the wireless environment a controllable random variable. The SREs can be with and without joint encoding and modulation at the transmitter and at the RIS as shown in figure below. Theoretical performances of these schemes are analysed in the references mentioned below.

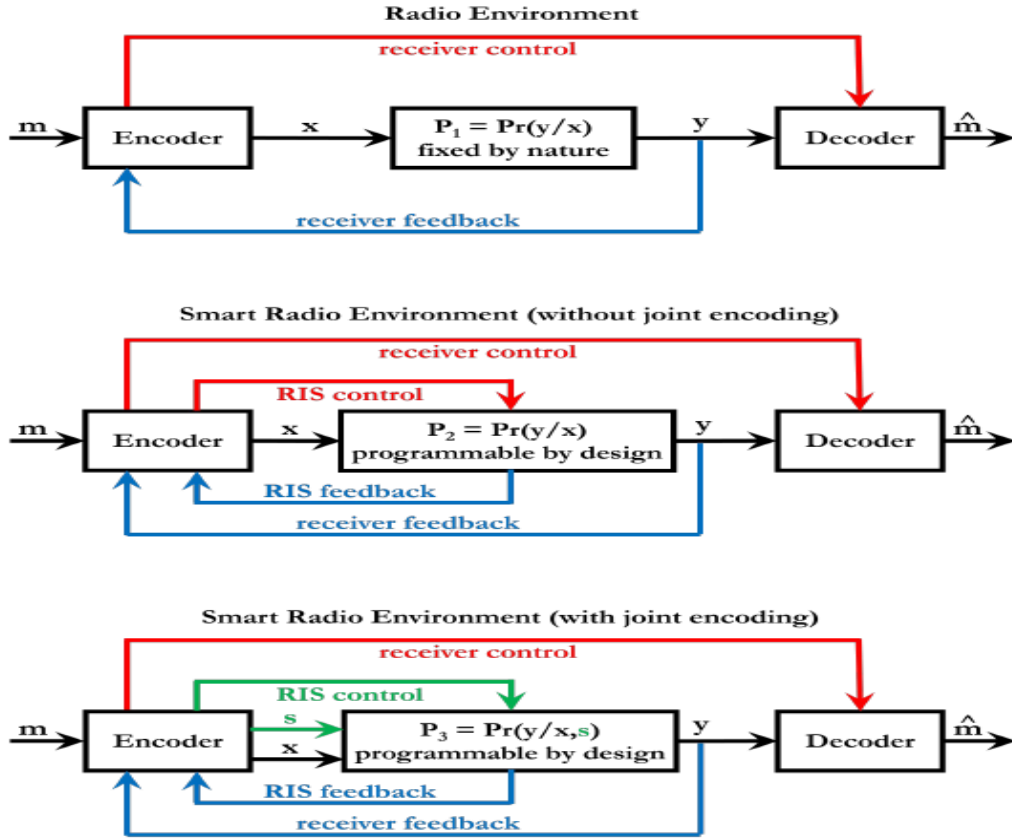


Figure 27: A high-level view of changes in conventional thinking.

The above high-level block diagram shows the difference in the conventional communication systems and the one provided by RIS. MIT's RFocus presents one such solution. We can imagine that the individual elements in the RIS system are the weights in a Neural Network-like setup and can provide an optimized algorithm for quickly learning the correct weights for exciting the individual RIS elements to achieve the best performance between the sender and the receiver. LAIA is another such solution.

The approach of a citation mentioned is worth discussing here as it provides an easy-to-understand model for the developing an intuition about the way the standard received signal equations get modified. This also paves way for understanding the use of Machine

Learning/AI as an optimization tool. We reproduce the basic propagation scenario considered in a reference as shown in the below figure:

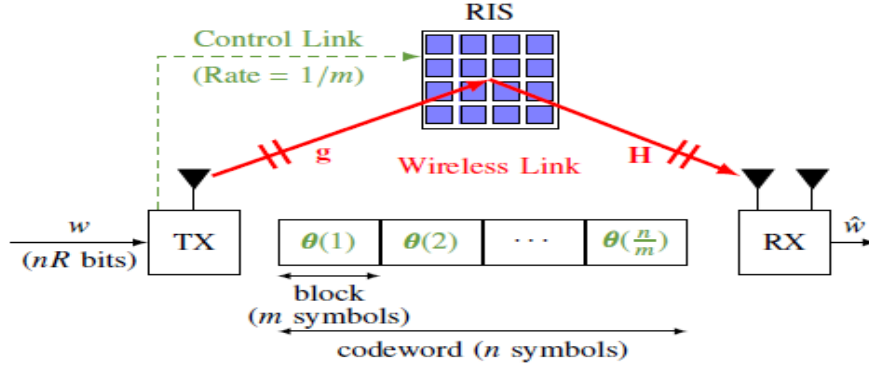


Figure 28: A simple channel model for RIS-based communications.

Without getting into the details of each notation that appears in the figure above, we note that the standard received signal equation now becomes (we can think of t as discrete time code blocks)

$$\mathbf{Y}(t) = \mathbf{H}\mathbf{S}(t)\mathbf{g}\mathbf{x}(t) + \mathbf{Z}(t),$$

where $\mathbf{x}(t)$ is the vector of symbols transmitted in the t^{th} interval, \mathbf{g} denotes the channel from the transmitter to the RIS, and $\mathbf{S}(t)$ can be considered as the effect on wireless channel of applied control on the RIS, and \mathbf{H} is the channel matrix from RIS to the receiver. $\mathbf{Z}(t)$ is the noise component. In indoor environments, one can assume that \mathbf{g} and \mathbf{H} are quasi-static flat-fading, hence their slow dependence on t is dropped. One of the strong assumptions is that \mathbf{g} and \mathbf{H} are also independent across the RIS elements. Looking at the above equation, one is reminded of the standard precoding approach for a given channel. Basic Information theoretic view can be applied and one can define the capacity of such channel as the supremum over all the achievable rates (defined for long code lengths) for a given \mathbf{g} and \mathbf{H} . It is a natural next step for someone trained in this field to view the above equation as yet another joint coding and optimization problem where now another control variable is available to the controller.

In these problems, we would aim to

1. Understand the implications and generalizations of the above basic modified equation better using analytical approach

2. Would aim at achieving the best configuration of the developed dynamic RIS to get the desirable $\mathbf{S}(t)$ coefficients
3. We would undertake a study on practical limitations/constraints imposed on the achievable region in the \mathbf{S} space, and more importantly, the way \mathbf{g} and \mathbf{H} matrices impact this achievable region
4. In Previous Section, we introduce an extension of the above equation where the direct channel between the transmitter and receiver is also considered. The intuition gained from this section will help us understand the extension better, and also the related ML/AI techniques can be better worked upon

At an abstract-representation level, we are concerned about the relation between \mathbf{g} , \mathbf{H} and \mathbf{S} . This interplay is depicted at an abstract (and, currently, very crude level) in the discussion below. Here we deviate from the approach of a reference and do not consider the joint coding where the parameters of code and RIS components are jointly considered. We only consider 2 elements in the RIS, one transmit antenna and one receive antenna. Under this scenario, $\mathbf{x}(t)$ is a single symbol, \mathbf{g} is a 2×1 matrix, \mathbf{H} is a 1×2 matrix and \mathbf{S} is a 2×2 matrix. Note that the view of \mathbf{S} as per a reference is overly simplistic and is only a phase shifter. We will, for now, continue with this view and assume that the two paths have the phase change in the \mathbf{h} component of θ_{h1} and θ_{h2} while those in the \mathbf{g} component are θ_{g1} and θ_{g2} . This indicates that the total phase change on the two paths are $\theta_{h1} + \theta_{s1} + \theta_{g1}$ and $\theta_{h2} + \theta_{s2} + \theta_{g2}$. The optimization problem is now, intuitively, of selecting θ_{s1} and θ_{s2} in such a manner that

$$\theta_{h1} + \theta_{s1} + \theta_{g1} = \theta_{h2} + \theta_{s2} + \theta_{g2}$$

Clearly, this may lead to infeasible solutions as there may be no solution in the region $[0, \pi]$. Further, we expect practical constraints limiting the achievable values of θ_{s1} and θ_{s2} .

Considering a two-dimensional symmetric arrangement of the elements of RIS surface and assuming a fluid regime, where a high number, $K \times K$, of RIS elements are arranged in small area, we can model the dependency between θ_{hij} , $i, j = 1, \dots, K$ by assuming that these come from a spatial field with a given Jacobian flow over the RIS surface, with some random variation across the plane. A similar model can be used for θ_{gij} , $i, j = 1, \dots, K$. This then indicates that the RIS elements are not necessarily individually controlled, but are controlled in an

incremental manner, relative to the control applied to the nearest elements. This leads to the possibility of using differential controls for the RIS elements.

9.3.4 Dynamic Encryption

Eavesdropping and traffic analysis attacks on wireless systems are caused by broadcast nature wireless medium, making it difficult to shield transmitted signals from unintended recipients. Having obtained these wireless signal samples, an eavesdropper can analyze and utilize wireless broadcast signals. Eavesdropping can be made hard by using one of the several techniques that require a tight transmitter-receiver coordination. These techniques include using beamforming, spreading the transmitted signal with a known sequence, etc.

Though the treatment of SREs so far in the literature has been around the fabrication of RIS, use-cases at application layer, communication-theoretic aspects, we feel that SREs enable very intuitive but strong encryption mechanisms. We provide an example now.

In traditional communication systems, since the channel varies across multiple transmissions, and since these variations are not controllable, each transmission is appended with reference signals for channel estimation. These reference signals are generally known to all the users in the system. Further, each such transmission is required to have a reference signal. If we have SRE available to us, we can set a channel. This has implications in terms of ciphering of transmitted signals. For example, if we send a reference signal before a transmission, and then make a transmission to a target receiver, but do not include reference signals in this transmission. However, we change the channel (SRE) in such a way that it is related to the previous channel estimate of the target receiver in a private manner, i.e., only the transmitter and receiver can derive the new channel matrix based on the previous estimate. Then, it is clear that an eavesdropper will not be even able to get enough information to be able to decode the signal at the physical layer. This mechanism can increase the system throughput significantly as the communication overhead required for securing the system in such a manner is significantly lower than, say, appending digital signatures, etc. The proposal is described using the figures below:

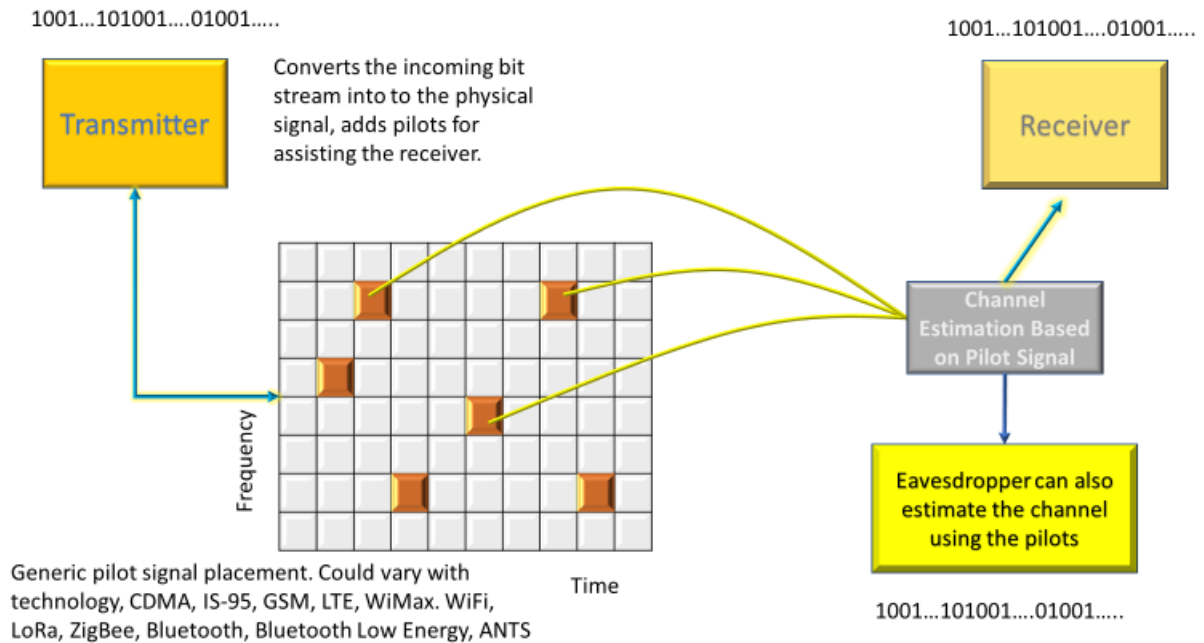


Figure 29: Traditional pilot-with-transmission-based channel estimation system.

This figure shows the contemporary approach to inserting some kind of channel estimation assistance in form of pilot signal (the term used may vary with technology). Emphasis is given to the point that an eavesdropper is also aware of these pilot signals and can estimate the channel and get the bits that formed the input to the physical layer processing. Such requirements on including the pilot signal in every transmission is dictated also possibly due to fast *uncontrolled* variation in the channel that renders the previous channel estimates worthless. Compare this arrangement with the proposed approach shown in the following figure.

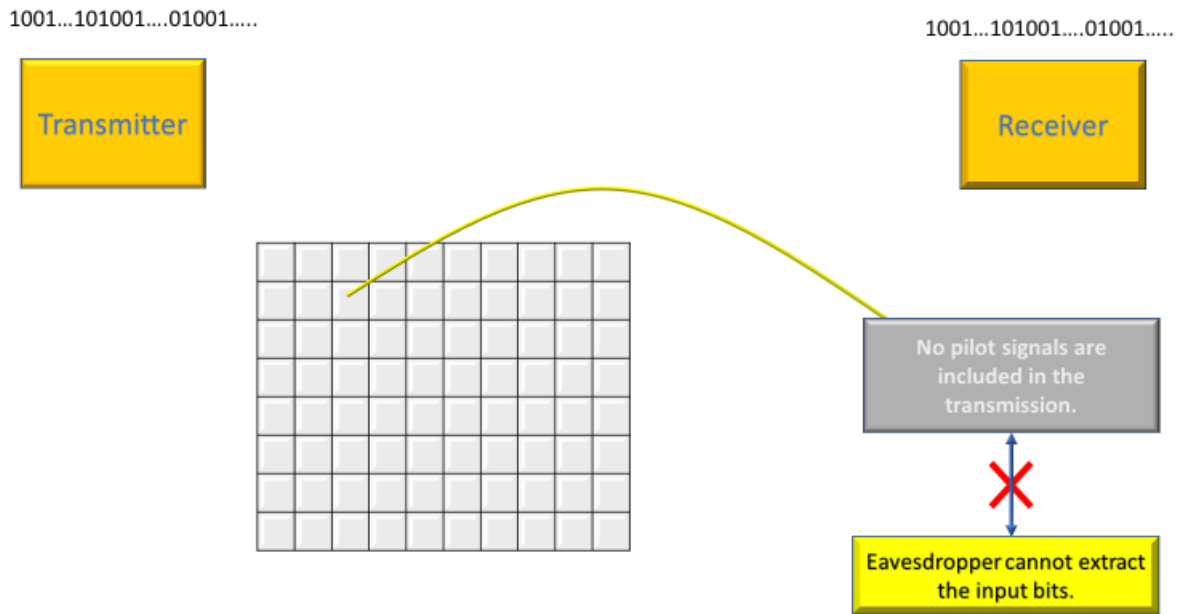


Figure 10: Pilot-less transmissions with controlled RIS elements.

Absence of pilot signals in the transmitted signal ensures that the eavesdropper is not able to translate the physical signal into a bit-stream. We do acknowledge that the bit-stream that is given to the physical signal generator could itself be an encrypted data, however, we contend that such encryption can be done away with in special cases of RIS availability. A desirable positive effect of this is that the end-devices would not have to use hardware accelerators for digital encryption operations, thus reducing the device cost significantly. Another advantage of not having to perform digital encryption is that the timing requirements in the (usually real time OS-driven end devices') tasking architecture would be significantly relaxed, thus enabling a faster turn-around time between scheduling and transmission.

Deliverable from this part of the activity will be a clear use-case demonstration where the above scheme is designed in detail (requires basic building blocks from the previous sections) and implemented using the RIS developed/identified as part of this activity. We would use a smart campus scenario for demonstration of this capability.

Recall the model introduced in previous section where we had introduced the path variables $\theta_{h1} + \theta_{s1} + \theta_{g1}$ and $\theta_{h2} + \theta_{s2} + \theta_{g2}$, with the control variable being θ_{s1} and θ_{s2} . In the present setup, we will see a scenario where, in absence of pilot signals in the transmissions,

and since we are assuming that θ_{h1} , θ_{g1} , θ_{h2} , θ_{g2} are flat, so that the previous estimates made at the receiver continue to be valid, the transmitter and the RIS control system can use a scheme that varies θ_{s1} , θ_{s2} using a sequence known at the transmitter and receiver, but not known to the eavesdropper.

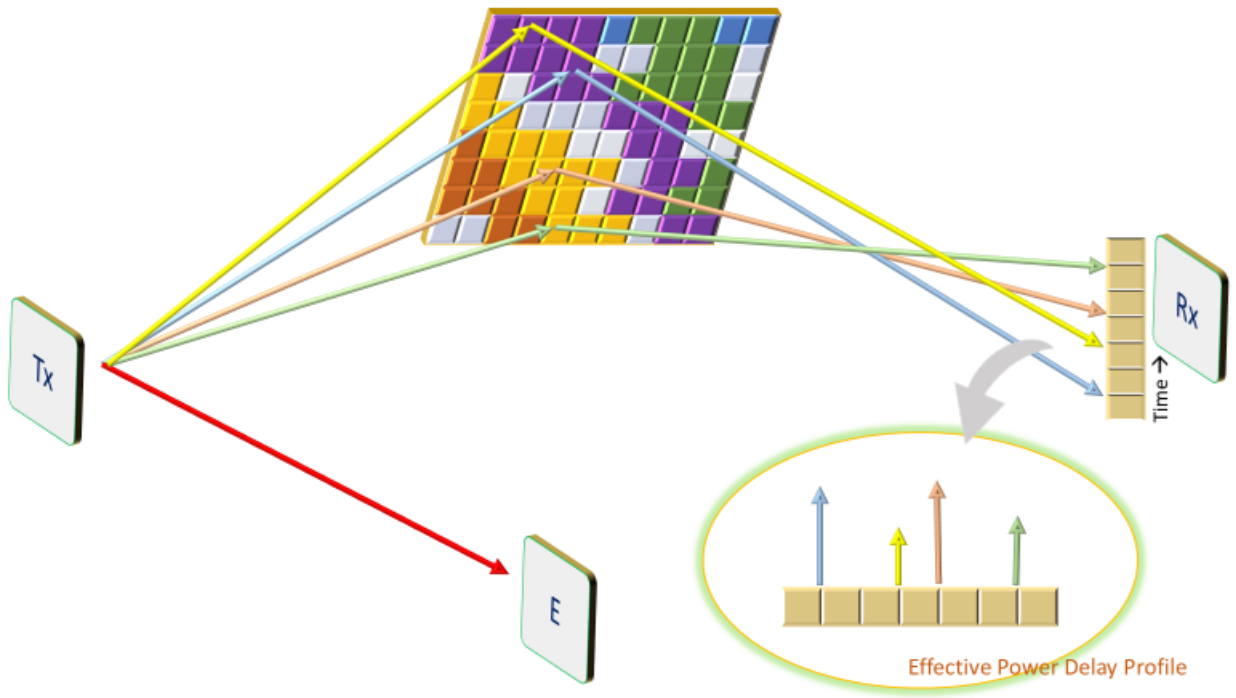


Figure 11: Control of effective Power Delay Profile seen by the intended receiver.

Figure 11 depicts another approach where the different RIS elements are configured in such a manner that the receiver sees a particular power delay profile. This, along with the assumption of flat fading, ensures that a pilot-less transmission would benefit from availability of RIS. The approach followed is to artificially introduce possibly high number of power delay profile taps (in IEEE 802.11ac channel models, we can have up to 30 taps, however in the RIS system, we could have many more). Further, the power delay profile can be spatially scrambled using a pre-fixed sequence as shown in Figure 32 that emphasizes use of a known seeded function $F(s, \cdot)$ and a seed (s) used to get the new power delay profile based on the previous one. The seed and the function can be negotiated infrequently.

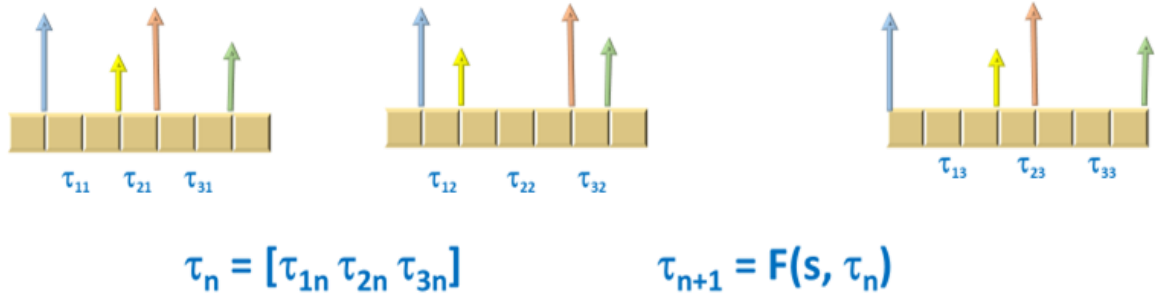


Figure 32: Linking the power delay profiles in time.

One of the advantages of such a scheme is that we can get huge search space for the eavesdropper by using the large number of RIS elements' transfer angles and the fact that the range of these angles is in the region $[0, \pi]$.

9.3.5 Standardization

At this point in time, SREs are expected to bring in a paradigm change in wireless local communications. We would prefer to be among the first movers in this field from the point of view of standardization efforts. With this effort, India will be the first country to have standardized the use of SREs with or without the use of RIS. It is well known that the cellular standards spend huge effort in channel modelling for a good spectral efficiency performance. The current activity will be around being able to *design* a channel, hence would be of significant implications for the disparate communications systems.

9.3.6 Use of AI/ML in Control Loop

The previous section introduced the problem of being able to control the wireless channel by appropriately applying control signals to the dynamic RIS developed in this project. In this section we emphasize on the use of machine learning techniques to achieve this task. This is an emerging and promising field and some of the initial pointers in this regard are given in the list below. Also given in the list below are the key takeaways from these references and how we think these will shape our work.

A reference uses the term Software Defined Metasurfaces (SDM) to refer to an equivalent of RIS. They formulate a neural network problem to find optimal configuration of the metasurface tiles. The input layer units are configured by the propagation environments including the numbers and locations of transmitters (TXs) and receivers (RXs), densities and dimensions of metasurface tiles, operating frequencies, noise levels, among others. The

corresponding output links can be activated at certain levels. The objective of the neural network is to find the best tilt (SDM tile steering) required for maximum power transfer between a target transmitter/receiver pair for a given environment.

The basic system model of a citation is among the easiest to appreciate the approach and is reproduced in the figure below.

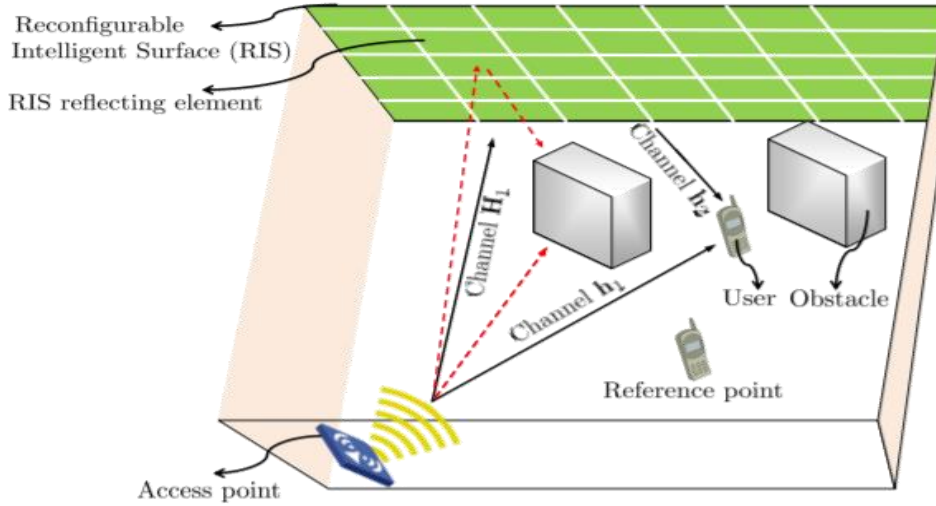


Figure 13: Basic system model for ML-based control signal.

The complex-valued baseband (discrete time) received signal at the intended user can be mathematically expressed as

$$z = \mathbf{h}_2 \mathbf{\Phi} \mathbf{H}_1 s + \mathbf{h}_1 s + n$$

where $\mathbf{h}_{2,k}$ denotes the channel vector between RIS and the user, \mathbf{H}_1 represents the channel matrix between AP and RIS, \mathbf{h}_1 is the direct channel matrix between AP and the user (the AP transmits the signal s), and $\mathbf{\Phi}$ denotes a diagonal matrix including the phase shifts that are effectively applied by the RIS reflecting elements. The authors use DNN to compute the mapping between the measured coordinate information of the targeted user and the optimal phase matrix $\mathbf{\Phi}$ that maximizes this user's received signal strength. Compare this system with that introduced in previous Section where the direct path (channel \mathbf{h}_1 here) is not accounted for.

In one of the references mentioned below, the authors put forth the connection between RISs and machine learning, arguing that both are needed to realize the vision of SREs. The authors discuss how the use of machine learning is essential to reduce the complexity related

to the design of RIS-based wireless networks, which is anticipated to be higher than in conventional wireless networks. The same set of authors also have looked at reinforcement learning approaches for the RIS configuration. The reference and the companion paper argue that it is incorrect to assume that the spectral efficiency of RIS increases as N^2 whereas that in similar sized MIMO beamforming systems increase as N , hence RIS-based SREs perform significantly better. In fact, the authors claim that RIS systems, due to near-field effects, have worse SNR performance compared to the comparable massive MIMO system, with the gap not completely vanishing asymptotically.

10. Management

(Responsibilities of different agencies for project management or scheme implementation should be elaborated. The Organization structure at various levels, human resource/requirements as well as monitoring arrangements should be clearly spelt out.)

10.1 Management plan

The project will follow hub and spoke/spike model with IIITB being the HUB, responsible for coordinating the project. The governance will follow the structure laid down by HGB and NM-ICPS DST. In this project, majorly two sets of manpower needed: (A) Operation and Management of the project, and (B) Technical manpower. In this section we are presenting mainly on the project operation management and manpower in (A). Point (B) technical manpower and operation manpower have been incorporated in finance section. Modification of manpower requirement and expenditure will be in the purview of HGB as suggested by NM-ICPS scheme. For management of project and manpower for it the point (A), the Hub comprises of the following roles:

- i. The Hub Governing Body (HGB) is the highest authority of HUB's policy and for giving broad guidelines.
- ii. The Professor, who is the Project Director (PD)/CEO/PI of the HUB will be the Head of the operation for the HUB. As mentioned below, there will be HUB staffs to help and coordinate all the operations of the HUB.
- iii. PD/HUB will have 5 major activities: (i) Administration and operation of the HUB; (ii) R&D progress of the project (iii) Finance; (iv) IPR and Entrepreneurship Related, and

(v) Workshops/Conference and other related activities. Each of the above activities will have supporting manpower as described below. If the activities of HUB increases and difficult to manage with following given number of staffs, then the staff may be increased with discussion with HGB to grow further.

- a. **Chief-Executive-Officer/Chief-operation officer (CEO/COO):** 1 person; CEO/COO will report to PD/PI of the project, will be appointed. He will coordinate between all the staffs of above 5 verticals. For each the above verticals number of staff required mentioned. Preferably, he will be from technical background with multiple years of management and technical experiences. He will be coordinating and following up for all the works given to above five divisions,
- b. **Administration and operation staff of the HUB:** 2 persons – one senior person and other one assistant; Job description: Coordination of meeting between all the collaborators, spokes/spikes, industry, academia, maintaining all files, emails, follow up, taking notes for draft preparation for the minutes of the meeting of the meetings, logistic planning for any event and travel, coordination, etc.;
- c. **R&D Progress of the project:** 2 persons; preferably technical persons; They will follow up with all the collaborators for technical progress, make presentation slides and documentation, writing technical parts of the reports, IPR filing and follow up, IPR protection, will do given technical works, etc.
- d. **Finance management:** 2 persons; One finance officer and one assistants to him/her; good in tally or equivalent tool to manage, one out of above three preferably knows PFMS, make the purchase process; understanding the tax system of the country, UC and other document preparation for DST, helping collaborating institutes to prepare the financial reports, helping the HUB financial report, working with auditors for annual reports, preparing financial reports for board meetings, know and advise the rules of DST and GoI and Company laws related to finance/purchase/expenditure, etc.;
- e. **IPR and Entrepreneurship Related:** 2 persons: One of the major focus of the HUB is to run the incubation centre. It has to host start-ups, manage meetings with start-ups, MoU with start-ups and other entities interested to work the HUB, IPR management,

one of the person preferably know/read IPR law of India and International, can write IPR/patent filing documents, follow up with patent office and HUB as well as collaborators/spoke, etc., arranging the entrepreneurship workshops and training etc., proactive to see that Indian companies and academia get benefited in right way to be self-sufficient, presentation of slides, initiatives for CSR, industry, any foundation, government fund for the HUB. Will do other activities as advised by PD, COO, for the benefit of HUB.

Services for the following functions will be shared and coordinated with the IIITB Innovation centre so that there is no duplication of effort with in IIITB. If required, we will take help of other incubation/Innovation centres in collaborators/spokes place.

- Promotion and Acceleration of Young and Aspiring technology entrepreneurs (PRAYAS)
 - Cell for Entrepreneur in Residence (EIR)
 - Cell for Start-ups & Spin-off companies
 - Cell for Technology Business Incubator (TBI)
 - Dedicated Innovation Accelerator (DIAL)
 - Seed Support System (SSS)
- f. **Standard body, Workshops/Conference and other related activities:** 2 persons; Technically sound; represents HUB and Collaborators works in Standard body (TSDSI, 3GPP and other), works for India centric and international standards, writing and presentation of standard document, helping IPR team for patent, attend conference/workshop on behalf of HUB and promote HUB activities for collaboration and funding for HUB. Also do marketing strategy for HUB, etc.

10.2 Roles and responsibilities of faculty members in management in addition to R&D and Collaborations

(TIH Team Expertise Area of expertise of team members, their role and contribution to demonstrate that the team has the capability to accomplish the objectives);

The faculty from IIITB in TIH are mainly from core Networking and Communication background in their R&D experiences, which is of more than 65 man years. Each one of them relevant expertise given in respective attached bio-data.

S. No	Name of Team Member	Area of Expertise	Roles/ Responsibilities
1	Dr. Debabrata Das	Wireless and Optical Network Protocols	Chairman of HGB ; He will also coordinate with the all the members of TIH and Collaborators; He is also responsible of Coordination of Finance and manage the staffs.
2	Dr. Jyotsna Bapat	Wireless Communication and IoT	PI of the TIH team; Work packages related to Scheduling; Coordination of operations of TIH. Also responsible for two WPs deliverables.
3	Dr. Amrita Mishra	Wireless Network Protocol and MIMO Communication	She is also responsible for R&D in 5G base station performance.
4	Dr. Vinod Reddy	Signal Processing, Antenna, Radar Communication	Coordinate among TIH Collaborators and Industry, help to set the test bed, IPR follow up. He is also responsible for one WP.
5	Dr. Priyanka Das	Physical layer communication and Security	Coordinate workshop, training programs, manage PhD, M. Tech/ MS and interns working in the project. She is also responsible for one WP
6	Dr. Prem Singh	Physical Layer and MAC layer performance and MIMO	PHY layer R&D, Hardware design, Coordinate and organize Entrepreneurship related events for this project along with proposed Company 8.

7.	Dr. Nikhil Krishnan N	Information Theory	NM-CIPS lab in-charge. Research in PHY sub-layers.
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The TIH team will work closely with collaborating and spoke/spike/collaborators.

10.3 Present Facilities in HUB and Collaborators

- It has 30,000 sq. ft. available.
- IIITB has access to a network emulator, IoT test bed, spectrum analyser, and a private good virtual computational facility for simulation.
- IIITB has its private cloud to support the initial requirements for the project.
- HUB has incubation cell for start-ups, which will help the TIH to start its entrepreneurship programs.

11. Finance:

(This section should focus on the cost estimates, budget for the scheme/project, means of financing and phasing of expenditure. Options, for cost sharing and cost recovery (user charges) should be explored. Infrastructure projects may be assessed on the basis of the cost and tenor of the debt. Issues relating to project sustainability, including stakeholder commitment, operation maintenance of assets after project completion and other related issues should also be addressed in this section.)

The finance given below in sub-section 11.1 is for Technology Innovation Hub (TIH) in IIITB. IIITB has R&D contribution along with TIH responsibility. In 11.1 the fund has been allocated for TIH/spokes, spikes, collaboration and entrepreneurship, etc. As a process of TIH, these collaborators, spokes, spikes and entrepreneurship funds will be allotted according to their presentation to a sub-committee according to the guidelines of Hub Governing Body (HGB). The process will start to take them on board immediately after TIH starts operation. Sub-section 11.2 presents sustainability of the project after 5 years.

11.1 Budget

Table 11.1: Guidelines of fund given by DST over 5 years for Recurring and Non-recurring fund:

Budget Head	Budget in Rs Crores					
	1 st Year	2 nd Year	3 rd Year	4 th Year	5 th Year	Total
Recurring	7.25	17.5	29.75	20.5	14.70	89.75
Non-Recurring	0.00	17.5	20.25	17.5	5	60.25
Total	7.25	35.00	50.00	38.00	19.70	149.95

Table 11.2: Year and Head Wise Non-Recurring Budget

Year and Head wise INR in Lakhs						
Non-Recurring Budget						
Heads	Year 1	Year 2	Year 3	Year 4	Year 5	Total of Heads
Equipment	₹ 0.00	₹ 1,710.00	₹ 1,825.00	₹ 1,150.00	₹ 157.33	₹ 4,842.33
Entrepreneurship & Start-ups	₹ 0.00	₹ 20.00	₹ 100.00	₹ 300.00	₹ 210.67	₹ 630.67
Spokes/Spikes Institutes	₹ 0.00	₹ 20.00	₹ 100.00	₹ 300.00	₹ 132.00	₹ 552.00
Total	₹ 0.00	₹ 1,750.00	₹ 2,025.00	₹ 1,750.00	₹ 500.00	₹ 6,025.00

Table 11.3: Year and Head Wise Non-Recurring Budget

Recurring Budget						
Heads	Year 1	Year 2	Year 3	Year 4	Year 5	Total of Heads
Manpower	₹ 290.00	₹ 860.00	₹ 1,400.17	₹ 1,537.12	₹ 1,221.87	₹ 5,309.16
Consumables	₹ 71.00	₹ 129.42	₹ 444.52	₹ 108.18	₹ 0.00	₹ 753.12
Contingency	₹ 71.00	₹ 107.85	₹ 251.78	₹ 79.96	₹ 52.84	₹ 563.43

Travel	₹ 35.40	₹ 56.10	₹ 138.91	₹ 36.06	₹ 28.14	₹ 294.61
IPR and Publications	₹ 62.50	₹ 86.28	₹ 217.05	₹ 129.80	₹ 64.65	₹ 560.28
International Collaborations	₹ 16.10	₹ 17.26	₹ 36.46	₹ 15.86	₹ 0.00	₹ 85.68
Hosting of Workshop/Standard Meeting	₹ 4.22	₹ 8.62	₹ 23.88	₹ 0.00	₹ 0.00	₹ 36.72
Entrepreneurship & Start-ups	₹ 0.00	₹ 163.93	₹ 186.95	₹ 0.00	₹ 0.00	₹ 350.88
HUB Office infrastructure and furniture establishment	₹ 80.00	₹ 8.63	₹ 0.00	₹ 0.00	₹ 0.00	₹ 88.63
Spokes/Spikes Institutes	₹ 44.20	₹ 189.82	₹ 67.72	₹ 0.00	₹ 0.00	₹ 301.74
Sub-Total	₹ 674.42	₹ 1,627.91	₹ 2,767.44	₹ 1,906.98	₹ 1,367.50	₹ 8,344.25
TIH/ Institutes Overhead (7.5%)	₹ 50.58	₹ 122.09	₹ 207.56	₹ 143.02	₹ 102.56	₹ 625.82
Total	₹ 725.00	₹ 1,750.00	₹ 2,975.00	₹ 2,050.00	₹ 1,470.06	₹ 8,970.07

11.2 Sustainability Planning

Plan for revenue generation and sustainability,

1. Incubate 25 companies over 5 years that develops 5G and Beyond related technologies and applications. HUB will also encourage collaborators, spoke and spikes to encourage incubation of startups in the areas of Communication Systems.
2. Start-ups will be incubated by the HUB by seed money. The % of stake will be decided by HGB with an agreement. We have assumed certain % stake and royalty for revenue projection below.
3. Projected revenues of incubated companies 4 years after their inception;
4. Equity/Royalty sharing with incubated companies and TIH. Royalty generated by IP sharing;
5. Sustainability based on the revenues: Project the expenses for the Hub after 5 years.

Below is Table-11.4 showing number of companies to be incubated per year and expected revenue details:

Table 11.4

	Year-1	Year-2	Year-3	Year-4	Year-5	<ul style="list-style-type: none"> • 10 crore/ year revenue after the 4-year of incubation • Assume average valuation of company after 4-years at 50 crores • Assume equity from at least one company is sold per year at 10% ownership • Assume one company becomes a 250 crores valuation per year after year-9 and Hub offloads the equity starting year-9 at 5% 	
Number of companies incubated	5	6	6	5	3		35% percent revenue growth/year given in below table 11.5.

Details of expected expenses for the Hub and sustainability are in the below Table-11.5, assuming equity in one company is offloaded each year after year-5;

Table 11.5: The total income in last row of the table is in Rs in Crores

	Year-6	Year-7	Year-8	Year-9	Year-10
Revenue of Year-1 incubated companies in crores	40	54	72.9	98.415	132.86025
Year-2 companies		50	67.5	91.125	123.01875
Year-3 companies			50	67.5	91.125
Year-4				20	27
Year-5				0	20
Total revenues	40	104	190.4	277.04	394.004
Royalty: 0.3 percent of sales	0.12	0.312	0.5712	0.83112	1.182012

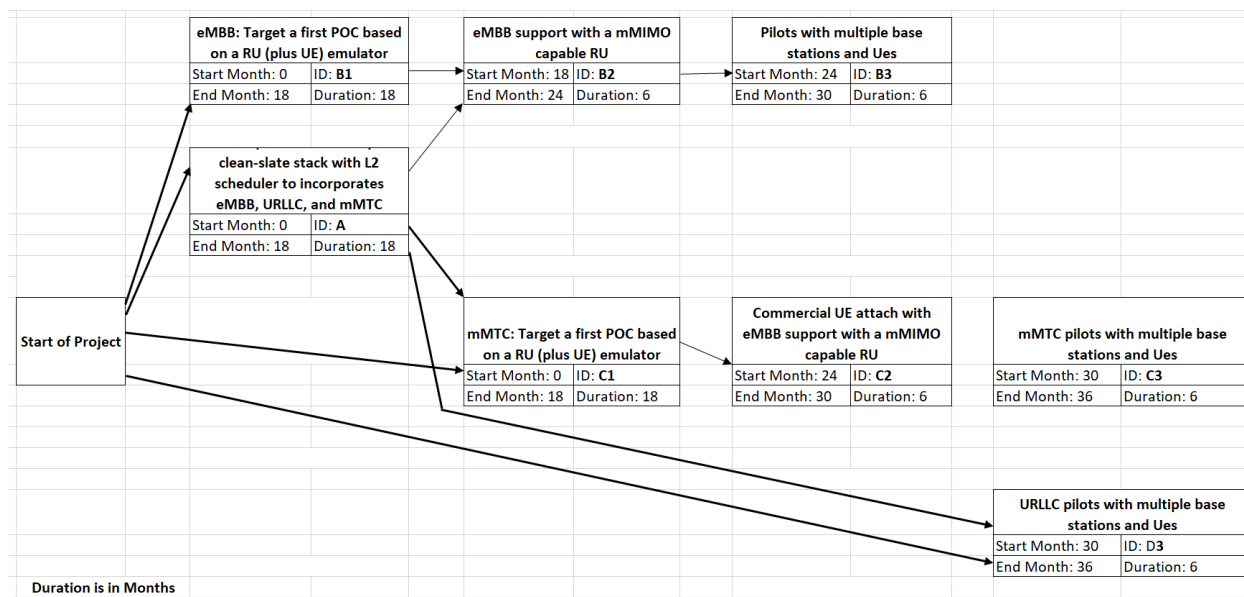
Income from sale of the equity in the company	5	5	5	5	5
Income from sale of the equity in the company				25	25
Total income	5.12	5.312	5.5712	30.83112	31.182012

12. Timeframe

(This section should indicate the proposed zero date for commencement and also provide a PERT/CPM chart, wherever relevant.)

Section 4 has the deliverables year wise for all the work packages for this project. Here we present the PERT chart year wise (as advised to give where relevant above).

- PERT Chart for Development of world-class ORAN – massive MIMO base station



Timelines - ORAN – massive MIMO base station				
Activity	Description	predecessors	Duration in months	
			Start	End
A	Build a team to develop a clean-slate stack with L2 scheduler (and RRC) that incorporates eMBB, URLLC, and mMTC use cases along with massive MIMO PHY	-	0	18

B1	eMBB: Target a first POC based on a RU (plus UE) emulator	-	0	18
B2	eMBB: Commercial UE attach with eMBB support with a mMIMO capable RU	B1	18	24
B3	eMBB: Pilots with multiple base stations and UEs	B2	24	30
C1	mMTC: Target a first POC based on a RU (plus UE) emulator	A	0	24
C2	mMTC: Commercial UE attach with eMBB support with a mMIMO capable RU.	C1	24	30
C3	mMTC: mMTC pilots with multiple base stations and UEs	C2	30	36
D1	URLLC: URLLC pilots with multiple base stations and UEs	A	0	36

13. Cost Benefit Analysis:

(Financial and economic cost benefit analysis of the project should be undertaken wherever such returns are quantifiable. Such an analysis should generally be possible for infrastructure projects but may not always be feasible for public goods and social sector projects. Even in the case of the latter the project should be taken up for appraisal before the PIB and some measurable outcomes/deliverables suitably defined.)

This is not an infrastructure type project. It is more a R&D project envisioned for public good. However, there are significant outcome with financial gain through HUB. The measurable evaluation given in Section 16.

14. Risk Analysis:

(This section should focus on identification and assessment of implementation risks and how these are proposed to be mitigated. Risk analysis should include

legal/contractual risks, environmental risks, revenue risks, project management risks, regulatory risks etc.)

Out of the list of risks mentioned above, this project may face man power management risk due to attrition and market dynamics. However, the project management will take adequate care to overcome the above point, if required.

15. Outcomes:

(Success criteria to assess whether the development objectives have been achieved should be spelt out in measurable terms. Base-line data should be available against which the success of the project will be assessed at the end of the project (impact assessment). Similarly, it is essential that the base-line survey be undertaken in case of large beneficiary oriented schemes. Success criterion for scheme deliverables/outcomes should also be specified in measurable terms to assess achievement against proximate goals.)

The HUB will create following outputs:

15.1 Commercial Level 5G Base Station and Affiliated Technologies/Applications

1. ORAN complaint 5G-advanced base station IPs that will be commercialized;
2. Field trial of 5G base station
3. The hub will create AI/ML wireless optimization technologies that are deployable in 5G-advanced and Beyond networks
4. Smart and Intelligent surface to improve the 5G performance;

15.2 Innovation, Entrepreneurship and Start-up Ecosystem

1. IIITB has highly successful innovation centre (<https://www.iiitb.ac.in/innovation-center>) that has incubated more than 40+ companies over the last 10-years. The project will follow the best practices already established by this IIITB innovation centre for promoting innovation, entrepreneurship and technology translation during the execution of this project.

15.3 HRD and Skill Development

B. Tech, M. Tech and PhD students along with post-docs will be integral part of this effort. The host institute as well as the partner academic institutes will deploy their own research students as well as interns, and project staff. We can expect more than 400 engineers to be trained in this project. The country will benefit significantly due to the creation of man power skilled in these advanced 5G and 6G technologies.

15.4 National/ International Collaboration

- The project plans to include IIITB (Hub), and several other academic institutes, companies that that will join this effort. This will forge strong linkages between the students and faculty of these institutes through collaborative research.
- The project plans to include leading international institutes such as Texas A&M, Rice University and University of Oulu who are actively developing 5G and 6G testbeds.
- There will be periodic technical reviews and workshops/conferences among the national as well international collaborators that will nurture cooperation and joint research, student exchange etc.

15.5 Industry Collaboration/ Partnership

- The project initiated discussions with Tejas Networks Pvt Ltd, and other leading domestic telecom companies towards collaboration in ORAN compliant base station development.
- The project-initiated discussions with ITI Ltd, A public sector telecom manufacturing company. ITI is keen on manufacturing the domestically grown technologies and wireless products for operator deployment.
- The project-initiated discussion with TCS a telecom and IT powerhouse who is involved in the business of 5G radio systems integration. The outcomes of this project can be included in the field trails along with the components sub-systems developed by the industry.
- The technologies developed in the project will be aimed at deployment with operators like BSNL and others.

- Collaboration and partnership will be established with the above mentioned industries and other entities that will join in the due course of the project.

15.6 Tentative Minimum Target for the HUB/TIH

S No	Target Area	Targets					
		1 st Yr	2 nd Yr	3 rd Yr	4 th Yr	5 th Yr	Total
1	Technology Development						
(a)	No of Technologies (IP, Licensing, Patents etc.)	2	4	5	7	9	27
(b)	Technology Products	2	4	5	7	10	28
(c)	Publications, IPR and other Intellectual activities	8	14	18	21	23	84
(d)	Increase in CPS Research Base	8	14	18	25	30	95
2	Entrepreneurship Development						
(a)	Technology Business Incubator (TBI)	0	0	0	1	0	1
(b)	Start-ups & Spin-off companies	2	6	9	12	18	47
(c)	GCC - Grand Challenges & Competitions	0	0	0	1	0	1
(d)	Promotion and Acceleration of Young and Aspiring technology entrepreneurs (PRAYAS)	0	0	0	0	1	1
(e)	CPS-Entrepreneur In Residence (EIR)	2	4	5	8	9	28
(f)	Dedicated Innovation Accelerator (DIAL)	0	0	0	0	1	1
(g)	CPS-Seed Support System (CPS- SSS)	0	0	0	1	0	1
(h)	Job creation	460	1540	2500	3500	3875	11875
3	Human Resource Development						
(a)	Graduate Fellowships	60	60	60	60	60	300
(b)	Post Graduate Fellowships	11	11	11	11	11	55
(c)	Doctoral Fellowships	5	8	8	4	0	25

(d)	Faculty Fellowships	2	2	1	1	0	6
(e)	Chair Professors	1	2	2	1	0	6
(f)	Skill Development	93	103	113	124	137	570
4	International Collaboration						
(a)	International Collaboration	0	0	1	0	0	1

16. Evaluation

(Evaluation arrangements for the schemes/project, whether concurrent, mid-term or post project should be clearly spelt out. It may be noted that continuation of schemes from one period to another will not be permissible without a third party evaluation.)

- i. HUB will go through every six months technical, financial and planning review by HGB;
- ii. PD/CEO of the HUB will take review of all the collaborators, spokes, spikes and other participants at least once in six months.
- iii. HGB also review the collaborators/spoke/spike, as schedule.
- iv. Clear roadmaps for the goals should be mentioned and followed for TIH/HUB, collaborators, spoke and other partners.
- v. If any unseen challenges to project in future, the PD will bring the things to the notice of HGB for discussion and possible solution.
- vi. Start-ups will be incubated by the HUB by seed money. Once a quarter, their progress will be monitored by PD. Each start-up valuation can be evaluated by HGB or a committee formed by HGB.
- vii. Some start-ups may not take seed-money but license/buy IPR of the TIH/HUB. The evaluation of these start-ups stake will be done by HGB or a committee formed by HGB.

- viii. Start-ups/companies giving services to the IPR/product from TIH will give royalty to the TIH, as decided by HGB or a committee formed by HGB.
- ix. HUB will decide when to offload the stake for the benefit and run of the HUB.
- x. HGB will also decide the licensing terms of IPR coming out of HUB for outside companies, for the generation of revenue.

17. References

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Advanced Communication System;

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