Science for Scale

Charting India's scientific and impact leadership in the next phase of the evolution of Computing

Research India 25

IBM

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Preface

Computing in India has gone through transformative cycles of adoption and scale with the rise of the IT services industry, Digital India programs and the technology start-up boom of recent years. The country is poised at an exciting juncture where we now have the opportunity to bring deep scientific innovation together with the technology scale that India is already capable of. This opportunity is especially timely given the rise of exponential technologies that will power the future of computing such as Quantum, AI, 5G and at the same time the challenges posed to our nation and the world in ensuring a sustainable future.

IBM Research has had the privilege to be a key contributor in the research and industry ecosystem in India over the last 25 years as a driver for advancements in the state of the art, and as an engaged supporter of the research ecosystem in India. On this occasion of our 25-year anniversary, we at IBM Research India (IRL) were privileged to facilitate an ecosystem dialogue on this opportunity, in the form of a Science for Scale summit on April 13, 2023.

The world of research and scientific pursuit is where the next major breakthroughs can happen — we represent this with the term “Science”. The world of digital transformation and socio-economic impact is where nation-scale value is created — we represent this with the term “Scale”. In India, we can create a virtuous cycle between these two worlds, leveraging the formidable technology and intellectual capacity available in the country. One major enabler for closing this cycle will be Computing and the technology vectors shaping the future of Computing. Science for Scale brought leaders, experts, and imaginative thinkers together for a dialogue to explore the linkage between the world of research and the world of scale, through the lens of computing, and what is needed to realise this virtuous cycle alongside an evolving policy landscape. Leaders from academia, industry and government shared their vision of opportunities, priorities, and requirements along key technology vectors such as Artificial Intelligence, Quantum computing, 5G and Distributed cloud, Cybersecurity and Sustainability.

— **Amith Singhee**
Director, IBM Research India
CTO, IBM India/South Asia

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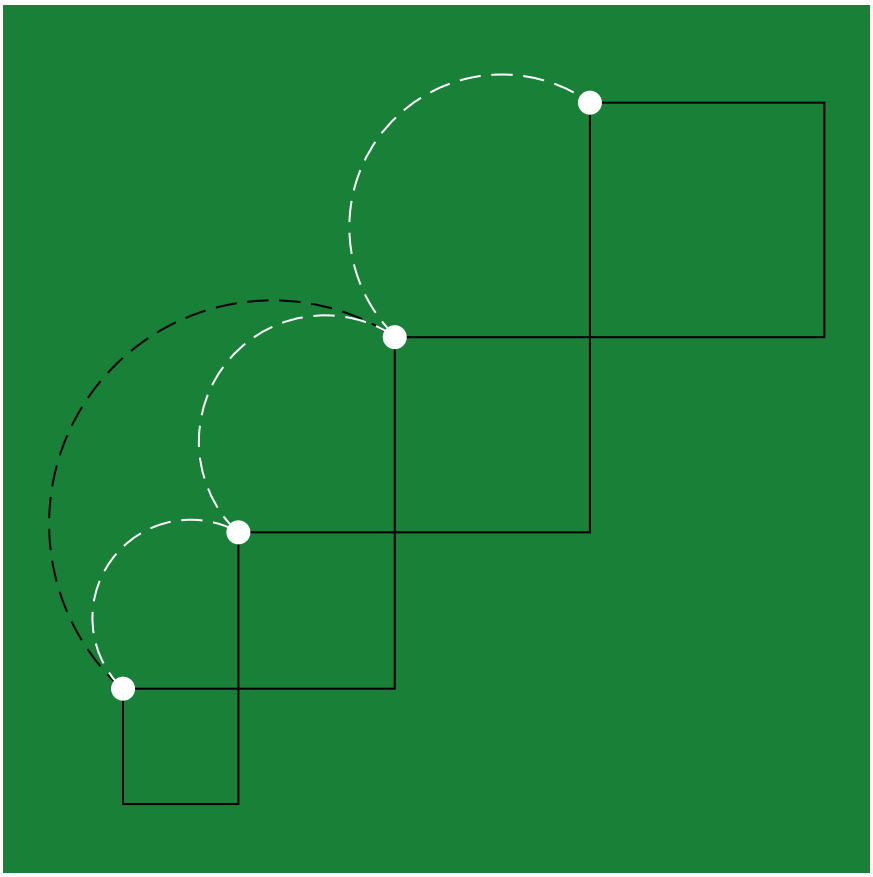


The ingredients for Science for Scale

The Science for Scale summit brought together the following distinguished set of speakers for the plenary session, who shared broad-ranging perspectives that provided a foundation for the deeper discussions in the topical workshops:

— **Ajay Kumar Sood**
Principal Scientific Adviser, Government of India

— **Kris Gopalakrishnan**
Chairman, Axilor Ventures

— **Debjani Ghosh**
President, NASSCOM

— **Dario Gil**
Senior Vice President and Director of IBM Research

We summarize these foundational perspectives in this chapter, recognizing that they provide many of the key ingredients for driving Science for Scale in India.

India's technology and scientific foundations are ready to scale

Equity investment into deep-tech start-ups in 2022 was about 2.8 times that in 2019 [1]. This is an indicator of increasing interest and viability of industry investment and scaled value from deep technology innovations built in India. On the scientific side, over the period from 2007 to 2020, India's global rank in scientific and technical publication output has gone up [2] from 11th to 4th. If we dig a bit deeper, we find that the discipline which enjoyed the largest share of these publications from India, is Computer Sciences [3]. While there are many indicators that could tell a similar story, this sampling of indicators shows the tremendous progress the country has made in developing capacity in deep technology and scientific research, and raise the promise of translating this capacity to large scale impact.

There are several areas of strength that India can leverage to advance on this promise. The country is home to world class and large-scale technology talent that is global in its exposure, outlook and expertise, while at the same time enjoying the advantage of a lower cost economy and very competitive people costs. The information technology (IT) services sector has fostered a population of sophisticated technologists, who have experience working in many developed economies and multinational organizations and managing large programs across geographies. With about 1,500 global capability centres located in India, many providing research and development support to the parent multinational organizations, there is also a growing ecosystem of technology innovation across industry sectors, with access to some world class technology and tools. The indigenously developed India Stack [4] provides a world-leading operational architecture at nation scale to engage the citizenry digitally and inclusively. Combining this, with a strong government support for

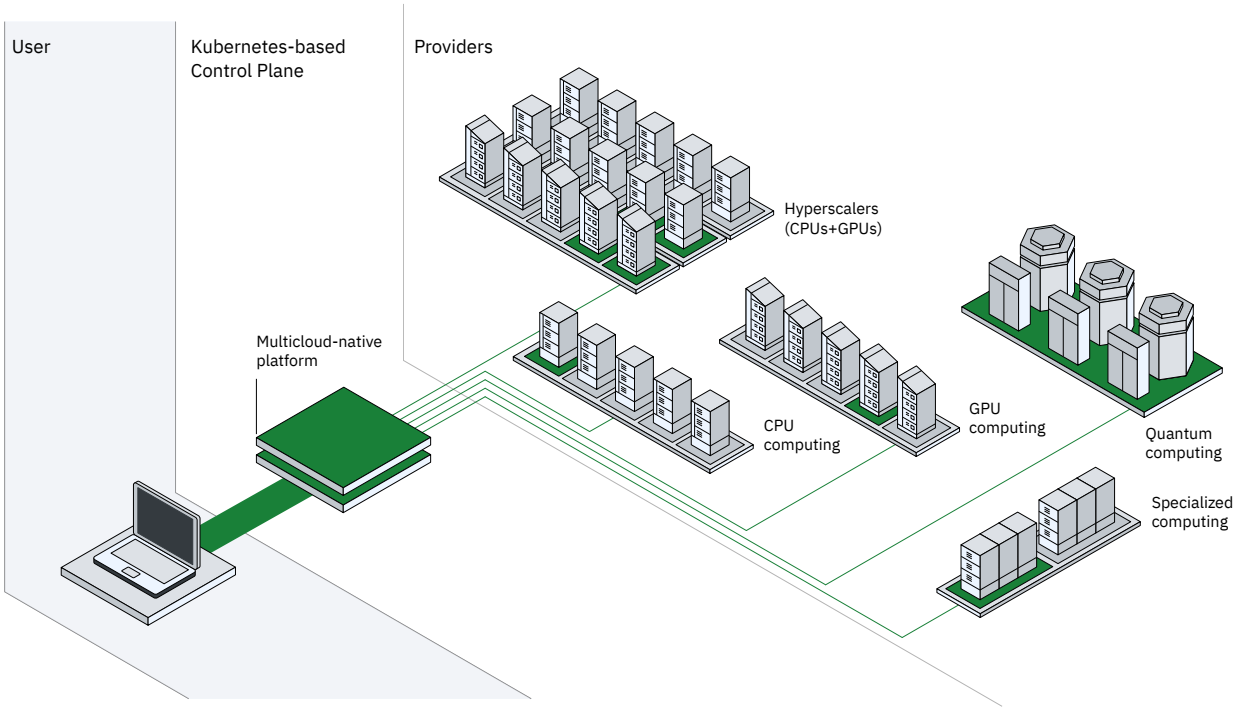
in-country technology development and employment sets up a formidable foundation in India for evolving and growing deep technology leadership.

Computing technology is moving into an exponential phase

We are at an inflection point in the evolution in computing, that offers opportunity on two fronts for India to develop Science for Scale. The first is the inherent potential the emerging technologies of AI, Cloud and Quantum offer. They are all advancing exponentially but will also converge together for a new kind of hybrid quantum-centric computing that will be able to address some of the most challenging, and as yet unsolved, computational challenges underlying the urgent and critical business and societal problems across finance, climate, sustainability, health care and other domains. The second opportunity for India is the fact that with Quantum computing and AI, there remains a tremendous amount of foundational technology innovation to be done. Given the formidable foundation the country has at this time in history, India can develop scientific leadership in a way with these emerging technologies that was not feasible with past technology disruptions. The convergence of AI, Quantum and high-performance computing will be enabled by a hybrid cloud fabric that enables easy interoperability across these technologies and a unified experience for composition and consumption. With such a composable architecture, shown in Figure 1, we will be able to leverage multiple choices of computing technology, with substantially reduced computational time and costs, and a much more sustainable energy and carbon footprint.

Figure 1:

The emerging hybrid computing architecture that will allow optimal composition of workloads across different computing technologies. Courtesy: IBM Quantum and StoryTK



As these technologies come together, there are five innovation vectors that will shape the future of Computing and its impact at a nation scale:

1 Artificial intelligence (AI)
2 Quantum computing
3 5G and distributed cloud
4 Sustainability
5 Cybersecurity

In subsequent chapters, we will elaborate further on each of these vectors, covering the opportunities, challenges, and recommendations for each that were identified at the Science for Scale summit.

India's Science for Scale ambitions

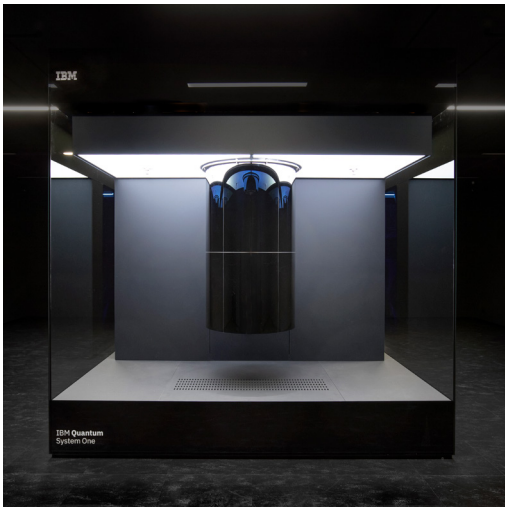
Along each of these five vectors, there are several science and technology missions and initiatives by the Government of India that can provide strong drivers for developing scientific breakthroughs and scaling their impact. In AI, for instance the National Translation project called BHASHINI [5] is developing a platform for translation between different Indian languages, and the AIRAWAT [6] program is looking to develop AI-centric cloud computing for use by the national ecosystem. In the area of Quantum, the government recently launched the National Quantum Mission with deliverables across Quantum computing, sensing, communications, and materials. Quantum computing holds the promise to help us apply computing to address some of the critical computing challenges across a large variety of socio-economic use cases across sectors such as sustainable energy, financial risk, life science and drug design, agriculture, chemistry, and logistics.

The planned National One Health Mission that aims for pandemic preparedness and integrated disease control across human, wildlife and livestock, can provide significant opportunities for scaling the impact of these technologies, including 5G and distributed cloud, bring health services to the large expanse of the nation. India has made meaningful sustainability commitments in the form of the Nationally Determined Contributions (NDCs) to the United Nations Framework Convention on Climate Change (UNFCCC). These goals need progress on multiple fronts across policy, citizen engagement, investments and technology. Computing technology with big data, AI, quantum computing and digital engagement can play a significant role in advancing on these NDCs, and also related national missions such as the National Mission on Sustainable Habitat and the National Mission on Sustainable Agriculture. The National Cybersecurity Policy, the Cyber Swachhta Kendra and the Digital India program all provide foundational requirements and impetus for cybersecurity innovations. Additionally, as critical infrastructure gets increasing networked digitally, and with the evolution of disruptive technologies such as broad and general AI, and Quantum computing, new disruptive for cybersecurity are emerging.

Bridging the industry and research divide

It is estimated the private sector invests only 0.1 – 0.3% of India's GDP into research. Also, a large proportion of research proposals in academia tend to be funded at a relatively modest level of under INR 1 crore (10 million). To truly realize the virtuous cycle of Science for Scale in India, these numbers have to dramatically grow such that we see the Industry investing in medium to long-term research at much higher levels and many more multi-year, mission-mode and multi-disciplinary research programs in academia. A much bigger focus on disruptive technologies is needed, while connecting to India's societal and development needs. This has traditionally been lower priority in India given more urgent developmental and business needs in the ecosystem. However, there are some green shoots that can be grown.

We see some areas of sustained research investment from industry and philanthropic sources such as in the areas of brain research by the Pratiksha trust, or the launch of the private-funded TCG Centres for Research and Education in Science and Technology (TCG CREST). There is a slowly but steadily increasing number of industrial research centres by multi-national and national companies, which engage with the academic ecosystem to drive joint research. These models for longer-term research funding and collaborations across industry and academia can be scaled up as the ecosystem gears up for bigger ambitions around science and impact mentioned earlier. Today there are about 3,000 deep tech start-ups out of which close to 500 are truly inventing new patentable and ground breaking inventions. We as an ecosystem could help repeat and scale the model of these start-ups, with perhaps a goal of reaching 10 times the number by 2030. This will need new investment models that allow for patient funding at a much larger scale and enabling start-ups to more easily access and attract top talent.



India's rich population diversity across social, economic, and geographic dimensions offers a unique opportunity to develop frameworks for responsible innovation that is inclusive and scales across all these dimensions of diversity. For a Science for Scale effort to truly succeed, it needs to engage and empower all of India, and not just serve the benefit of a few at the top of the pyramid. In fact, it can leverage this diversity as a strength to understand the requirements for such inclusive and responsible impact and develop scalable breakthroughs that can show the way for the rest of the world. As was noted at the Summit, when India solves a problem, it solves it for the 8 billion people of the world.

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Chapter

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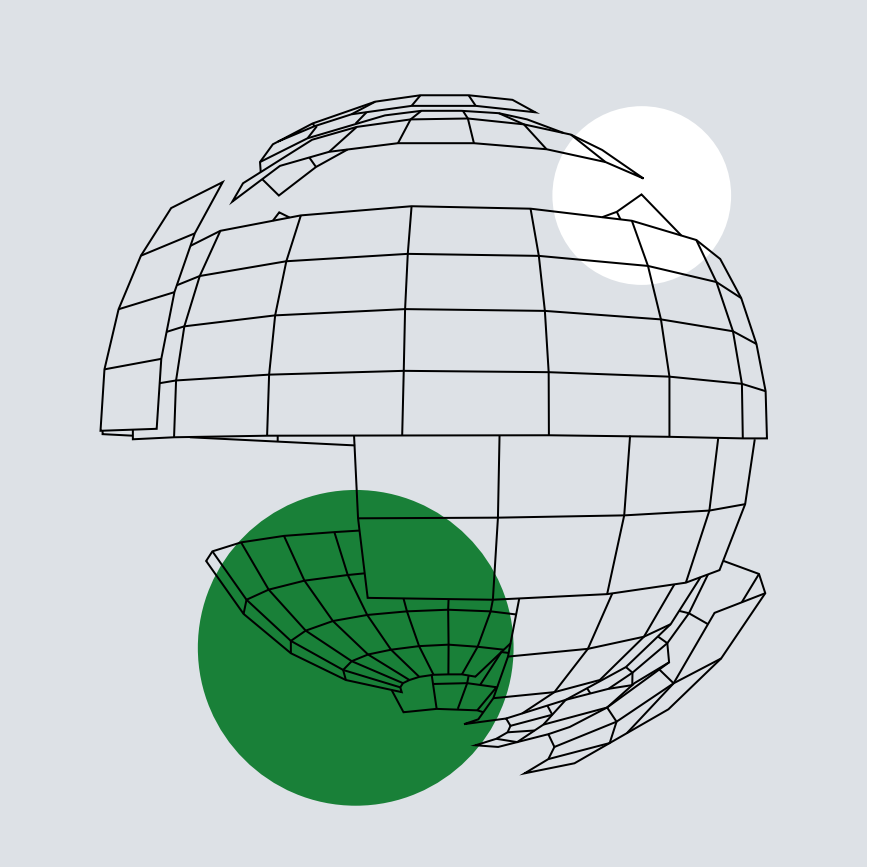

Climate change and sustainability for India: Can computing technology help India accomplish its sustainability goals in the coming decade?

Abstract

Sustainability means many things to many people but India has made very specific Nationally Determined Contributions (NDCs) under the Paris Agreement to be achieved by 2030. These include a climate friendlier path to economic development, reducing its emissions by 45%, domestic and other funds to implement actions, and build capacities with a framework for technology diffusion and joint collaborative R&D. With its presidency of G20 in 2023, this topic is under the spotlight for awareness, investment, and action. In keeping with the theme of the "Science for Scale" Summit organised by IBM Research India, we brought together thought leaders from government, academia, and industry to discuss and debate one key question:

"What additional goals and enabling mechanisms are needed to support our NDCs keeping our country's scale in mind supported by computing technology?".

Introduction

A broad range of experts spanning policy, academia, industry, investment, and the startup ecosystem came together in this session to debate several aspects toward answering the posed question of what the state on the ground was in their respective fields, and looking forward whether technology could help India achieve its sustainability goals in the coming decade. This position paper highlights the collective thinking of this group and focuses on four major areas of debate. The first topical section is on Climate Change and its impact on India as the changing pattern of weather and extremes is something everyone has faced in the last decade or so. The next topic of discussion was the important Energy Systems Transition and what it takes to really move away from fossil fuels towards renewable energy at national scale. Next, we discuss the interesting triangle of Policy, Investments, and Markets which examines what policy and funding mechanisms are needed to provide scale and market access to sustainability solution providers in the Indian context. In keeping with the theme of Science for Scale, a final important section examines the role of Science and Computing for scaling environmental, social, and corporate governance (ESG) and broader Sustainability solutions for India. We conclude by outlining the interplay and inter-connectedness between all these aspects and point to how multiple system changes need to work in concert for us to succeed.

Figure 2:

Achieving India's NDCs by 2030 — the role of technology and other areas. NDCs are Nationally Determined Contributions as per the Paris Agreement.

2030 NDCs

— Climate friendly economic development

— 50% power from non-fossil fuel sources

— GDP's emission reduction by 45%

— Domestic and new funds for actions

— Capacity building for technology diffusion

— Joint collaborative R&D

Action vectors

— Climate resilient development and citizenry

— Energy systems transition

— Policy, investment, markets

— Scaling ESG solutions with technology

Needs of the decade

— India specific Earth Systems model applications

— Power plant and reactor systems optimization

— Technology financing with patient longer time horizons

— Technology to scale mitigation and adaptation solutions

— Multi-system and behavioural change

Climate change and its impact on India

The Earth system is a single, interlinked, and self-regulating system comprising solar input, atmospheric activities, the hydrological cycle, land and ocean surfaces, and human influences among other components. Energy and material transport within and across components of the Earth system occur continuously over local and global scales and across timespans. Human activities affect the Earth system and vice-versa and this has only very clearly come to light since the Industrial Revolution where the release of greenhouse gases (GHGs) from human activity has already led to the 2010's decade being 1.1°C warmer than 1850 – 1900. Countries of the world have been coming together under the United Nations umbrella to recognize and act upon these changes and have signed various treaties, namely the Kyoto Protocol in 1997 and the well-known Paris Agreement in 2015. The Conference of Parties (COP) annual gatherings are where countries update their Nationally Determined Contributions (NDCs) and demonstrate their progress toward reducing their GHG emissions and achieving Net Zero emissions by certain dates.

India's own NDCs under the present government have been updated to state a few key commitments namely; Achieve the target of Net Zero by 2070 balancing growth, development, and global climate responsibility; Take its non-fossil energy (Renewable + Hydro + Nuclear) capacity to 500 GW by 2030; Meet 50% of its energy requirements from renewable energy by 2030; Reduce the total projected carbon emissions by one billion tonnes from now till 2030; Reduce the carbon intensity of its economy to less than 45% of 2005 levels.

Under the aegis of the UN, the Intergovernmental Panel on Climate Change (IPCC) has released its 6th Assessment Report (AR6) which will be last such report to come out till 2030. It contains many scenarios that affect the whole world. AR6 and other research that has been done in India specifically calls out the impact on the country and what mitigation and adaptation actions need to be taken urgently in the next few years.

Countries like India are already facing, and will continue to face, adverse effects from climate change in the coming decades based on the established Representative Concentration Pathways (RCPs) of the amount of global warming that will happen. For example equatorial countries including India will face severe Heat Stress (in the form of heat waves and urban heat islands) in the coming years requiring new ideas around urban development. Precipitation extremes are also increasingly being felt with South Asia having borne the brunt in the last two years and these are expected to increase along the various pathways. In terms of food scarcity, India is poised to face food shortages and major drop in fishery yields along with much of the tropical world. Perhaps an often overlooked fact is the loss of bio-diversity and sometimes extreme species loss which stand at very high levels of risk causing unknown damage to ecosystems. The IPCC AR6 Synthesis Report [7] (SYR) very clearly establishes these risks globally and can be found in detail at ipcc.ch/report/ar6/syr. The climate resilient development of India specific earth system models is motivated by these risks and we explicitly call this need out along with various associated warning systems and guides for the public and policy makers at large.

We discuss next some of the important vectors of the Energy Systems Transition; Policy, Investments, and Markets; and Science and Computing to scale solutions that span a

multitude of changes needed from industry action, to societal, to behavioural. While this discussion is India focused, it is broadly applicable to the rest of the developing world.

Energy systems transition

One of the major system transitions that affects countries and their emission reduction commitments is the transition of their energy system(s). While it is well understood that there is a desire to move away from carbon emitting fossil fuels to renewable sources of energy including wind and solar, the practicalities on the ground place a practical bound on this transition and the path forward. Significant effort and investment are known to be needed to make this transition to 'greener' energy happen, with assumptions on big strides on the technology and innovation aspects of renewable energy prediction, amassing, storage, and distribution.

India faces a 70% emissions challenge from the 4 main sectors of Industry, Agriculture, Transport and Buildings [8]. To encourage mitigation in this space, the government of India has recently drafted the Business Responsibility and Sustainability Reporting in India (BSRS) guidelines that specifically call for environmental emissions and energy reporting requirements for the top enterprises — this requirement was voluntary in 2022 – 23 but is mandatory in 2023 – 24. The requirements call for reporting of resource usage and intensity metrics, air pollutant metrics, Scope 1,2 and 3 GHG emissions, waste related metrics, impact on bio-diversity. These are well in line with the IPCC report findings and the expectation is that businesses should respect and make efforts to protect and restore the environment.

The distribution grid of a region being purely powered by renewable energy is only feasible under appropriate weather and time-of-day conditions. Battery energy storage systems are emerging as an area of focus but these only meet about 25% of daily energy requirements. Further the acquisition costs of critical minerals like Lithium, but more importantly Cobalt and Nickel, are rising and the supply is restricted to very few countries creating a crunch.

A few ideas have recently been gaining ground to support this transition and reuse infrastructure that has now aged. Thermal power plants supply 78 % of our energy needs today. Shutting down inefficient (~200) thermal power plants which are more than 25 years old or using them only as peaking plants in summer is one mitigation method. Utilising High Efficiency Low Emission (HELE) plants to meet baseload electricity demands while ensuring efficient use of coal and water and affordable power tariffs is another desirable policy change in the works. It is also proposed to support the setup Small & Modular Reactors (SMRs) at the site of closed thermal plants or other suitable sites to supplement Zero-carbon power generated by conventional nuclear power plants that have specific siting requirements. In particular, the MSME sector, which is considered the engine of economies around the world

(and in India too) is an especially vulnerable sector with respect to climate change and the energy transition due to their current lack of access to funding.

Policy, investment, and markets

There are two broad classes of actions that countries, industries, and society take to combat climate change, namely 1) Mitigation, that is, to try and limit damage caused so far by reducing GHG emissions, and 2) Adaptation, that is, accepting that change is happening and hence adopt policies and actions that help countries survive and thrive with the effects of climate change.

No country has developed economically without increasing access and use of energy resources. The broad class of Mitigation actions recommended and being enacted in India include phasing down of all fossil fuels as per our NDCs. The long term impact of this move away from fossil fuels is opposition from oil producing countries. The government has been implementing various development schemes and measures ranging from environmental to developmental to societal — which though not directly related to climate change mitigation, support the overall broader components of the SDG goals and the broader notion of sustainability. Some of these schemes are the National Agricultural Insurance Scheme, Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), Coastal Regulation Zone Notification, and Participatory Forest Management — the details of all of these are well known in the public sphere and accessible from government sources.

Adaptation measures on the other hand are more complex to understand and community and regional levels. The interplay between environmental, political, social, and economic aspects is more complex. A global or national goal

is hard to set up as benefits of adaptation only accrue locally. In the technology section below, we articulate the need for a climate information and early warning system at local scales.

The role of the developed world is key for the success of the above laid out mitigation and adaptation strategies in the developing and under-developed world. UNFCCC in 1994 laid down principles of global efforts to combat climate change which articulated the concept of differentiated responsibility. Five big economies — US, China, Russia, Germany, and Japan — have accounted for 55% of total emissions since 1750 while India has accounted for less than 3% since that time. These countries have not owned up to their historical responsibilities though the evidence is clear. They have further refused to make deep cuts to their own emissions but expect the developing world to do the same and are not delivering on their promise of providing finance and technologies to developing countries. However there is hope, as at COP 27 the Loss and Damage Fund talks went further than in the last 9 years for compensating vulnerable countries which are primarily in Asia and Africa. However, such a fund is difficult to set up and manage owing to the complexity of calculating the amount of damage done as well as the appropriation of responsibility. Developed countries had promised to provide $100 billion per year from 2020 but are likely to finally start doing so from 2023. $4 trillion need to be invested in the renewable energy sector every year till 2030 if Net Zero targets are to be achieved by 2050. International financial organizations should also simplify procedures to provide funding to developing countries for mitigation and adaptation actions.

The topic of finance and markets, when it draws down to a more local level apart from the above international scales, presents its own sets of challenges. Funding organizations and startups alike are very keen to be involved in problems that matter with respect to mitigation and adaptation with an eye on real local impact in, say, areas like food security and sustainable agriculture. While India has its fair share of climate action and agriculture startups, very few of them have been able to succeed at scale. For an agriculture dependent country like India several factors play out on the ground. While topics like emissions, sequestration, over fertilization, risks due to extreme weather events are well understood among the intellectual community, information systems that disseminate this information to the grass root farmer are for example missing or rare. Further, the startups working in this space face a lack of funding action because the typical venture investment timescales (3 – 5 year exits) and financial metrics (like IRR and cash flow) are not amenable to this space. There are startups making solid impact and innovation in this space but they have a clear ask for ‘patient’ finance which has a long-term developmental outlook rather than being short-term focused.

To realize the benefits of sustainability, it should not be considered as social liability. It should help to grow the business by improving the efficiency. We need to factor carbon intelligence in each and every decision making. For example, each project proposal should have a measurable sustainability goal and every employee should consider

the individual sustainability checkpoints. Considering the example of IT companies, the demand shaping, dynamic workload management across geography, workload dispatching based on carbon intensity and container-based application migration should have measurable sustainability goals.

Science and computing for scaling ESG and broader sustainability solutions

There is substantial high-quality scientific research happening in Indian academia around remote sensing, climate change research, materials discovery, and other aspects of sustainability and a concerted effort to bring this research from the lab to the market. Several premier academic institutions are working with industrial research partners and forming centers of excellence where jointly funded research happens and allows new scientific discovery to trickle into market reality. This is a model that can be significantly scaled up with easier well-governed sources of the funding promised in the NDCs, but the mechanisms are yet to be worked out. The deep-tech startup ecosystem in India has also grown by leaps and bounds in recent years around data, AI and cloud technologies. These startups, in concert with the technology majors, are building novel solutions around sustainability including sustainable agriculture, market access, infrastructure management, supply chains, and IT infrastructure. The startups face similar funding access and market access challenges for scale as in other sectors, but specific to sustainability the idea of 'patient' financing is a need that has been pointed out above. Thankfully there are some funding organizations that understand this and are successfully working on this with novel startups in this space but the broader investment community still needs to adapt to these needed longer impact timescales.

We now present some case studies that are indicative of the efforts that the private sector is taking in supporting SDGs and India's NDC and these efforts span Indian companies from the IT services and Retail sectors as well as the large presence of MNCs in India reflecting their global and local goals. While computing technology plays a large part in several of these efforts, they do go beyond the computing paradigm and typify sustainability actions across broader goals. This case study list is not exhaustive but rather indicative.

1 **One of India's largest business houses and their Consumer Retail division is making great strides across all ESG metrics**

This business house represents many of the clothing retail brands that urban Indians associate with. As a group company and as part of its own existence, they have been taking sustainability to heart within their industry and making huge strides toward all aspects of environmental, social, and governance metrics that companies usually report on. A few significant highlights of their efforts are outlined next. With 3.4k+ retail stores, 6.5k points of sale, and 28k multi-brand retail outlets, 49% of their employee population is less than 30 years of age. Their first sustainability mission established in 2013 titled ReEarth committed to give

back more than what they consume from the ecosystem. They have saved Rs. 6 Cr. by reducing packaging materials, and reduced energy consumption by 30% with a 50% move to renewable energy. They have a 2030 Net Zero ambition and aim to create sustainable value by 2025 as part of their second sustainability movement since 2020.

2 **A marquee homegrown name in the Indian IT sector has already achieved their NetZero goal by 2020**

As one of the most respected companies in the country, they stayed away from greenwashing and focused on the energy efficiency of their built infrastructure as their primary business was IT services and not manufacturing. From a corporate perspective they invested in social development for renewable energy and realized that in the long run it was cheaper and more efficient to be sustainable. Their large campus in Bangalore has received a township status from the government of Karnataka. They have invested significantly around bio-diversity in this 300-acre campus and planted tens of thousands of trees that are working to mitigate the heat island effects of built infrastructure. As a testimony of this initiative, they received the Climate action award from UN.

3 **Very Large MNC IT companies and their Indian arms are committed to Net Zero by 2030**

With business spread across digitization and IT infrastructure, software products and services in most countries across the global, these MNCs and their significant Indian operations are very much in sync with their global commitments to regulators and investors. They have ambitious targets to power their datacenters purely by renewable energy in the coming years. They believe digitization could help their large enterprise clients across the world to decarbonize their supply chains and infrastructure and asset management. The pace in which the digital innovation happening is eye opening. For example, the cost of processing satellite data changed dramatically, usage of virtual battery to support flexible computing resource and the compute work which used to take few months can be done in few days. The open sourcing of code will accelerate innovation in the sustainability space. Calculation of carbon footprint with tools and software products from such well trusted names will significantly give the large cross-center enterprises of the world these capabilities at their disposal in keeping with the adage — 'what you can't measure, you can't reduce'.

On the topic of climate resilient development for a country like India, we articulated in the climate change section above the increasing risks that India will face in the coming years. Science and Computation technology need to come together across our R&D ecosystem to make this adaptation technology a reality. Earth System Models today have resolutions that are 100 km X 100 km or 25 km X 25 km. To really build Climate Resilient Development strategies we

need modeling down to 1 km X 1 km. We don't have good understanding of critical infrastructure for India specific needs and a computational goal like this is going to be a big undertaking requiring all round participation, funding, policy support. Due to the deep uncertainties in the global models available today, planning will only succeed with hyper-local solutions that make climate services available to all like early warning systems for public, and planning and analysis tools for policy makers (specifically with a medium-long term multi-year outlook).

A few other solutions that are being attempted in various countries sit at the intersection of finance and technology. Carbon markets have typically not worked in countries that have experimented with it. A few in the developed world are contemplating carbon border taxes etc. but these are very early days to determine success of these measures. Unless the carbon price goes up very significantly, it is not anticipated that a big impact will be made. There are some interesting technology underpinnings in these experiments but the fundamental change will have to come from the finance side starting mainly with a broader adoption of reporting requirements.

Conclusion

Climate resilient development revolves around 5 simultaneous system transitions. These are, 1) new approaches to governance and regulation driven by NDCs, 2) access to finance for climate and sustainability solutions with the fair share coming as per globally decided constructs, 3) capacity building to imbibe knowledge about mitigation and adaptation down to the common man, 4) technological innovation to support the scaling up of experiments to real market solutions involving the academic and startup ecosystem, and 5) lifestyle and behavioral change that stems from capacity building but really allows adaptation in the coming years to new urban lifestyles while recognizing that climate change is probably here to stay and drastic action will affect daily lives in the coming decades.

Science and Computing technology will clearly play an important role in these system transitions but will not in itself be enough as can clearly be seen above based on the scope of change, education, and collaboration across sectors needed. However computing technology will play a key role in sectors like mitigation and adaptation solutions, building hyper-local earth system models, supporting the energy transitions, and helping enterprises and governments measure and ultimately reduce their footprints (along not only carbon emissions but also the broader ambit of the S and G in ESG and the UN SDGs).

Chapter 2
key takeaways

1 Countries like India are already facing, and will continue to face, adverse effects from climate change in the coming decades.

2 The multiple systems transitions, including energy, require innovations in policy, market and financial access for effecting sustainable change.

3 Science and computing are poised to play a critical role in meeting NDCs by providing finer grained quantifiable data for each stage of an enterprise's operations.

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Chapter

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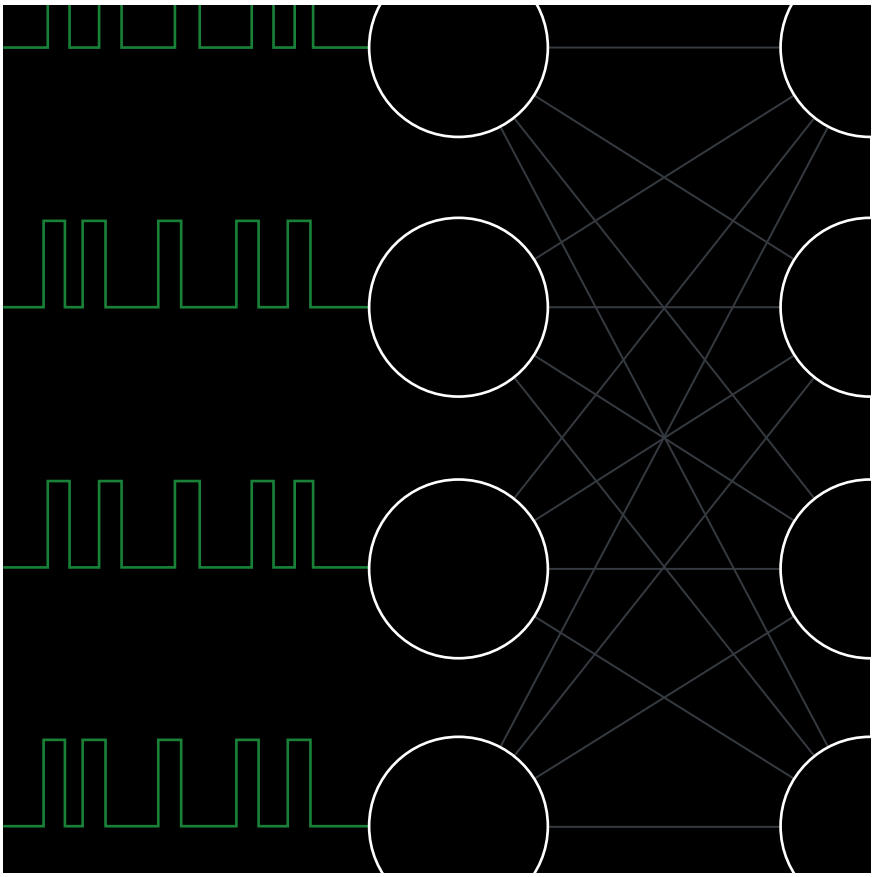

The next AI iteration: How can India lead ?

The emergence of generative AI and large language models has revolutionized the approach to solving AI problems, leading to continuous advancements in the field. Each day brings exciting new developments in this transformative technology. The key question is how we can effectively leverage these advancements to address complex real-world challenges. When considering the wide-scale adoption of AI in India, numerous opportunities and challenges come to light. On one hand, embracing AI on a large scale presents immense opportunities for various sectors such as healthcare, agriculture, education, and governance. At the same time, several challenges must be addressed for successful wide adoption. These challenges include establishing robust infrastructure to support the computational demands, building datasets that can facilitate research where opportunity lies, investing in research and skill development to equip individuals with the necessary expertise to navigate this AI-driven landscape effectively, and ensuring developing ethical guidelines for AI usage.

India has undoubtedly showcased its potential in developing practical and user-friendly technology, positioning itself as a leader in driving the economy towards digital transactions. However, this accomplishment is merely the tip of the iceberg. The opportunities to leverage technology,

particularly AI, are vast and hold the potential to significantly enhance our standard of living. While strides have been made in addressing challenges related to language diversity, healthcare, agriculture, and mobility, there is still a long road ahead. Continued efforts are required to fully unlock the potential of AI in these areas and explore new avenues for progress.

Current AI adoption and use cases

AI solutions have been embraced across multiple domains, significantly transforming industries such as finance, healthcare, education, accessibility, and mobility. These intelligent systems have brought about substantial changes, reshaping processes, services, and experiences within these sectors. We will explore a few notable use cases where AI has made a noteworthy impact, showcasing its transformative potential and illustrating the positive shifts it has brought about.

Finance

India Stack is a collection of open application programming interfaces with the objective of enabling identity, data, and payments at scale. It provides a secure digital identity infrastructure, simplifies digital payments, and enables data digitization and sharing. India Stack promotes efficiency, financial inclusion, personalized services, transparency, and innovation in India's digital ecosystem.

Aadhaar is a significant component of the India Stack, serving as the identity layer of the ecosystem. As of June 2023, approximately 1.3 billion Indians have enrolled in Aadhaar [9]. Each Aadhaar ID is associated with essential demographic details and biometric information, including a photograph, fingerprints, and iris scans, all of which are securely stored in a centralized database. The vast scale of biometric data available through Aadhaar has opened new possibilities for extensive research in areas of AI, such as fingerprint liveness and matching, face liveness and matching, iris liveness and matching, document validation, and biometric deduplication. With such a vast amount of data, there is immense potential to develop state-of-the-art systems and solutions in these domains.

Unified Payments Interface (UPI) plays a crucial role as the payments layer within the India Stack. In May 2023, UPI witnessed an impressive milestone with 9 billion transactions [10], making it accessible to every common person. The massive scale of these transactions necessitates the utilization of AI to address challenges like fraud modeling. Utilizing AI techniques is essential for fortifying security measures and upholding the integrity of the payment system.

Assistive technology for languages

India, a country with rich language pluralism, boasts 22 official languages along with a multitude of dialects. Recognizing the significance of bridging linguistic barriers, the *National Language Translation Mission* was established with the aim of leveraging technology to facilitate seamless

communication among Indian languages. This mission seeks to unlock a large reserve of governance and policy-related knowledge present on the internet and make it accessible to individuals in their native languages. To turn this vision into reality, the Bhashini project [11] was initiated. It focuses on developing robust models for machine translation, automatic speech recognition, text-to-speech conversion, optical character recognition, and natural language understanding. Once these models are learnt, they are made accessible to developers and creators through the Bhashini APIs. This strategic approach ensures that the power of these advanced language technologies can be harnessed to build innovative and impactful end-applications. By enabling easy access to these APIs, the Bhashini project paves the way for the seamless integration of language-based functionalities into various solutions, further driving the mission of breaking down language barriers and promoting inclusive communication.

The Bhashini APIs have facilitated the development of remarkable applications that leverage their language capabilities. One such application is Jugalbandi [12], which offers a multilingual chat interface for accessing information about Government Schemes. This application built on top of ChatGPT enables seamless communication and interaction across different languages, ensuring that individuals can easily access and understand relevant information. Additionally, the Bhashini APIs have played a pivotal role in the creation of tools like AI-assisted Judgement Explorer and Judges Intelligent Virtual Assistant (JIVA). By utilizing the power of Bhashini APIs, these applications are revolutionizing the accessibility of government schemes and legal information.

Smart mobility

India boasts one of the largest road networks globally, and it is rapidly expanding. However, this impressive infrastructure comes with a downside, as road accidents are alarmingly prevalent. To tackle this issue head-on, the innovative project iRASTE [13] has been launched. iRASTE harnesses the power of AI to identify accident blackspots and implements advanced driver assistance systems (ADAS) on public transport buses, with the ultimate goal of reducing road accidents. The project has been diligently pursued in two prominent regions: the city roads of Nagpur and the highways of Telangana.

India faces a unique set of challenges when it comes to using AI models for smarter mobility, distinguishing it from the issues encountered in developed countries. Unlike the well-structured driving conditions found in developed nations, India's driving conditions are often unstructured and demanding. Furthermore, problems such as triple rider detection, no helmet detection, and pothole detection are quite specific to India. To tackle these challenges head-on, a dedicated dataset called the India Driving Dataset [14] has been meticulously created. This dataset focuses on unstructured driving environments and serves as a valuable resource for addressing the specific issues faced on Indian roads. Additionally, a data collection platform named Bodhyaan [15] has been introduced. This platform comprises a car equipped with cameras, radars, and sensors, which all researchers, academics and start-ups can utilize to collect data in unstructured driving environments. Through the amalgamation of the India Driving Dataset and the Bodhyaan platform, efforts are being made to gather crucial information and develop effective solutions for smart mobility.

Healthcare

Early screening and detection of cancer face significant challenges due to the sporadic availability of highly skilled medical professionals. This scarcity often hinders timely diagnosis and intervention, potentially impacting patient outcomes. However, AI presents a promising solution to bridge this gap in healthcare. By leveraging AI technology, cases of cancer can be identified in their early stages, allowing for proactive measures to be taken before it is too late. To facilitate this, initiatives such as the Early Oral Cancer Screening Tool [16] and the collection of Indian Pathology Dataset [17] have been launched. By combining the power of AI with the expertise of medical practitioners, the goal is to improve the efficiency and effectiveness of healthcare, leading to better outcomes for patients in India.

National strategies and policies for AI

Recognizing the significance and the growing potential of AI, the government of India has developed strategies and initiatives for AI. The national strategy for AI [18] aims to define a strategy to harnesses the power of AI for driving economic growth, promoting social development, and strives to position India as a leading AI solution provider for emerging and developing economies. To ensure ethical use of data and AI, NASSCOM in collaboration with industry partners such as IBM has developed a Responsible AI Resource Kit [19]. This kit includes self-regulation guidance and a set of tools designed to empower businesses in adopting AI while maintaining user trust and ensuring safety.

Strategies to prepare India for the AI revolution

In recent years, a groundbreaking technological revolution has emerged, captivating the world with its potential to redefine the way we live, work, and interact. Artificial Intelligence (AI), once a mere concept confined to science fiction novels and movies, has now become a powerful and influential presence that affects every part of our lives. At the heart of this revolution lies the advent of large language models, pushing the boundaries of AI capabilities and propelling us into a new era of innovation.

Large language models have revolutionized the field of AI with their ability to understand and generate human-like text. These models, trained on vast amounts of data, have unlocked the potential for machines to comprehend and generate language in a manner never seen before. These models have become the backbone of language translation tools, content generation systems, and even chatbots that simulate human-like conversations. Their ability to process and generate human language at scale has sparked a wave of innovation, driving the AI revolution forward.

In order to prepare India for the AI revolution, it is crucial to envision the country's role and set clear objectives. If India aims to be at the forefront of this revolution, several key factors must be considered. Firstly, fostering a pool of readily available AI talent is essential, nurturing a skilled workforce capable of driving innovation. Additionally, the Indian IT industry should strive to be at the forefront of AI advancements, ensuring that it remains competitive on a global scale. Encouraging the growth of AI unicorns in India will further establish the country as a hub of technological excellence. Simultaneously, it is imperative to focus on improving the quality of life globally through AI innovation, leveraging the power of technology to address societal challenges. Implementing AI-ready policies within the Indian government will facilitate a supportive environment for AI adoption and development. Finally, establishing thought leadership in AI research will position India as a respected and influential contributor to the field. By aligning these strategic goals, India can pave the way for a thriving AI ecosystem that benefits both its citizens and the global community.

India's current position in the field of AI presents both challenges and opportunities. Researchers play a pivotal role in the AI ecosystem: Firstly, in AI startups, where they contribute by developing innovative solutions that go beyond the limitations of existing AI techniques. Their expertise helps identify and address the challenges that hinder progress. Secondly, to create substantial impact on a larger scale, India needs an innovation engine that shapes the state-of-the-art for foundational AI technology. To achieve these, a strong pool of researchers is essential. According to the Global AI Talent Report of 2018, India falls behind in terms of the number of PhD-educated researchers, ranking 10th globally with only 386 researchers out of a total of 22,000 worldwide [20]. Similarly, in terms of influential experts presenting at leading AI conferences, India ranks 13th globally with just 44 top-notch presenters. Furthermore, the AI Readiness Index of 2022 positions India at 32nd among 181 nations [21]. These statistics highlight the urgent need for capacity building in both industry and research within the country.

Need for capacity building

The cornerstones of an AI innovation ecosystem encompass crucial elements such as *compute, data availability, and human resources.* While compute power and data are significant factors, the human resource aspect presents a key challenge that requires careful attention. The presence of highly skilled professors, researchers, engineers, venture capitalists, and other professionals is vital for driving AI innovation. Increasing the number of professors in the field would contribute to a larger pool of trained engineers and researchers, accelerating progress in deep tech projects. Essentially, more professors equate to increased innovation within India's AI landscape. However, addressing this shortage of skilled human is not a simple task and requires concerted efforts in building a robust talent pipeline.

Need for compute

As AI models become increasingly complex and data-intensive, the need for immense computational power grows exponentially. This insufficiency in compute resources poses a substantial challenge, hindering progress and innovation in AI research. To overcome this hurdle, it is necessary to address the issue of compute scarcity and explore solutions that can provide researchers with the computational horsepower they need.

Need for data

To drive AI innovation in India and address the specific challenges faced by the country, it is crucial to have access to data that is specific to India's context. AI algorithms thrive on data, and the availability of diverse and comprehensive datasets is essential for training accurate and effective models. Furthermore, establishing benchmarks and standards for evaluating AI performance within the Indian context is equally important. This will foster healthy competition, encourage innovation, and drive the development of AI systems that are optimized for Indian conditions. By leveraging India-specific data, AI technologies can be developed to improve healthcare, enhance transportation systems, enable efficient governance, and address a myriad of other societal challenges.

How can we address these challenges?

1 To bolster AI research and development in India, it is vital for industries to establish strong partnerships with top professors, mirroring the model seen in the West where professors split their time between universities and collaborating companies. However, widespread implementation of such partnerships has been limited by concerns surrounding data and IP sharing. To overcome these hurdles, it is important to work towards creating norms for non-disclosure agreements (NDA) that facilitate data sharing, and clearly negotiate IP sharing policies. By addressing these concerns and fostering robust collaborations, India can leverage the expertise of esteemed professors and industry professionals to drive innovation and advance AI capabilities.

2 Compute infrastructure has emerged as a significant bottleneck in advancing AI research and innovation. To overcome this challenge, it is imperative to pool our resources and establish a research cloud. By consolidating computing power and creating a shared infrastructure, we can effectively tackle complex problems that are currently beyond our reach. One possible direction can be to expand existing AI specific infrastructure such as AIRAWAT [22]. Collaboration and collective efforts are key to unlocking the potential of compute-intensive tasks and accelerating progress in AI.

3 To effectively address the myriad of large-scale societal problems in India, it is essential to foster collaborations between researchers, policy makers, and local communities to collect *data* directly from the field. This collaborative approach ensures that data collection efforts capture the nuanced realities and diverse perspectives of the challenges at hand. Furthermore, creating India-relevant benchmarks is key to driving progress in AI. By establishing benchmarks that reflect the unique socio-cultural context of India, researchers and developers can push the boundaries of innovation, striving to outperform existing standards and deliver impactful solutions.

What will the next iteration of AI look like?

Generative AI has revolutionized the way we consume artificial intelligence. With its ability to create realistic and creative content, such as images, text, and even music, generative AI has opened up new possibilities and applications. As we move forward, there are several exciting developments on the horizon. Here are a few potential directions for the future of AI:

AI for healthcare

India, with its significant rural population, faces challenges in providing adequate healthcare services due to a shortage of healthcare experts. However, the integration of AI technologies holds great potential to address this issue by assisting healthcare professionals and optimizing their time effectively. AI can play a crucial role in healthcare by automating routine tasks, analyzing vast amounts of medical data, and providing valuable insights to healthcare experts. With AI-powered tools, healthcare professionals can streamline administrative tasks, such as patient scheduling and record-keeping, allowing them to dedicate more time to direct patient care. AI-powered chatbots can be used to provide basic medical advice, answer common queries, and triage patients, enabling timely access to healthcare information and resources in remote areas.

Responsible AI

With the increasing complexity of AI systems, it is paramount to prioritize ethical and responsible operations. A significant challenge associated with generative AI is the generation of plausible yet factually incorrect images or text,

commonly known as “hallucinations.” While such capabilities can be advantageous for creating fictional content, they can become harmful when misused to generate misleading or false information. For instance, the creation of deepfake images or the generation of financial articles with inaccurate facts can have severe consequences. To address this issue, future AI models should possess the ability to attribute their generation and explicitly indicate any uncertainties regarding factual correctness. This approach ensures that users are aware of the nature of the generated content and can exercise caution when interpreting it. By explicitly conveying when a generated output may be unreliable, AI models can help users make informed decisions and better understand the limitations of the technology.

Inclusive AI

As we embrace the advancements in AI, it is crucial to be mindful of the potential consequences that may lead to an increase in the digital divide. Many of the celebrated AI technologies are primarily focused on English, which only represents a fraction of the world’s languages. This English-centric approach inadvertently excludes a significant portion of the global population, affecting around 90% of people who do not speak English as their first language. This linguistic bias has the potential to widen the gap between those who have access to AI-driven benefits and those who do not. To prevent this, it is essential to actively work towards ensuring that the benefits of AI are extended to Indian language users. This includes (1) collecting a large datasets of various Indian languages, (2) using the collected data to train a large language model that is inclusive, and (3) establishing benchmarks that quantify the performance of language models in Indian languages. By prioritizing linguistic diversity, we can strive for a more inclusive and balanced AI landscape that uplifts and empowers all individuals, regardless of the language they speak.

Conclusion

In conclusion, we highlight the transformative potential of large language models and the need to effectively leverage these advancements to address real-world challenges in India. While opportunities abound in various sectors, the adoption of AI at a large scale requires addressing challenges such as infrastructure, data availability, and skill development. The workshop brought together stakeholders from diverse backgrounds to discuss these challenges and explore strategies for building a robust AI ecosystem in India. By addressing these challenges and fostering collaboration, India can position itself as a global leader in AI, unlocking the full potential of this transformative technology and reaping the benefits it offers to society. Embracing the AI revolution and embracing it with a responsible and inclusive approach will pave the way for a brighter future powered by artificial intelligence.

Chapter 3
key takeaways

1 AI applications such as generative AI are poised to have a great impact on a country like India, given its size and diversity, and enable better interaction/service delivery between the citizenry and government services.

2 India has a formidable tech stack in the form of India stack that can provide the railings on top of which AI applications can be built and delivered at scale.

3 To benefit from the emerging AI landscape, India needs to invest in capacity building along multiple dimensions including skilling people, building robust infrastructure for collecting datasets and large scale compute infrastructure at a national level.

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Chapter

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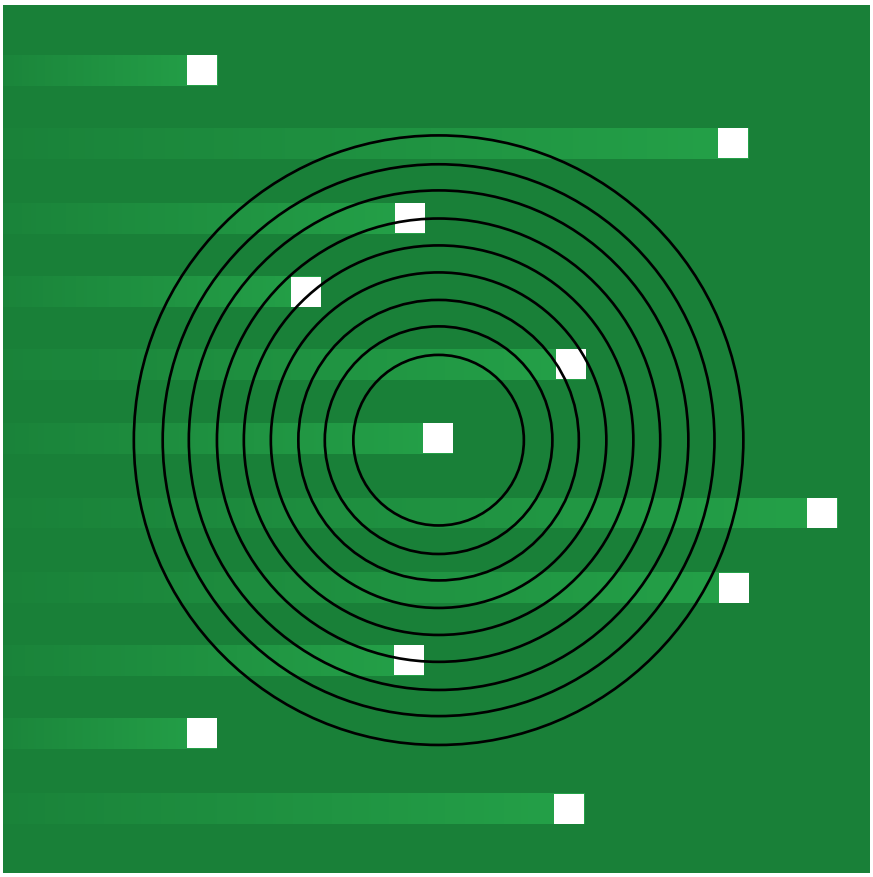


Securing and scaling digital India

Abstract

The Digital India initiative has established India as a leader in digitalising governance, citizen services, and financial services. The “India Stack” is intended to provide scalable and secure layer for identity, transactions, and data. At the same time, India is also in the process of establishing critical infrastructure in several areas like communication, healthcare, transportation, and power infrastructure. India’s user base is very different from that of advanced economies in terms of numbers, affordability, and digital literacy. Therefore, it poses unique challenges (and opportunities thereof) in terms of scale, lower levels of user awareness, risks of fraud and disenfranchisement, and skepticism of adoption. These aspects require the scientists, technologists, and policy makers to advance their respective state of the art in novel, scalable, and cost-effective ways. There is a need to borrow the global best practices in an appropriate manner and combining them with innovations needed to handle unique local challenges. A parallel development on a global scale is the widespread adoption of cloud computing, e-commerce, and digitalisation of services like transportation, communication, and energy. Therefore, there is a massive explosion of the privacy and security threats to all the economies — in terms of scale, vulnerable system components exposed to the adversaries, and attack methods. This has resulted in a massive demand for skills relevant

to assure security, privacy, risk and fraud management. Given the scale of India's own requirements in this regard, it provides an excellent opportunity for India's technology ecosystem to emerge as a global leader. A core group of industry and academic experts on the topics of cryptography, security, privacy, policy, and industry practice came together to discuss the above-mentioned aspects of securing and scaling India's digital infrastructure. This position paper is an attempt to capture and present an overview of the collective insights shared by the experts.

Introduction

This position paper provides a brief overview of the workshop on Securing and Scaling Digital India was held as part of the Science for Scale event organized by IBM Research on April 13th, 2023. The workshop — consisting of four keynote talks and two panel discussions — covered certain key topics in the context of digitalization in India. They included unique challenges posed by India, technological innovations required to address the challenges, gaps in industry response and the resulting skilling requirements, and opportunities to emerge as a leader in cybersecurity. In this position paper, we provide a brief overview of the insights that the participants provided on these themes.

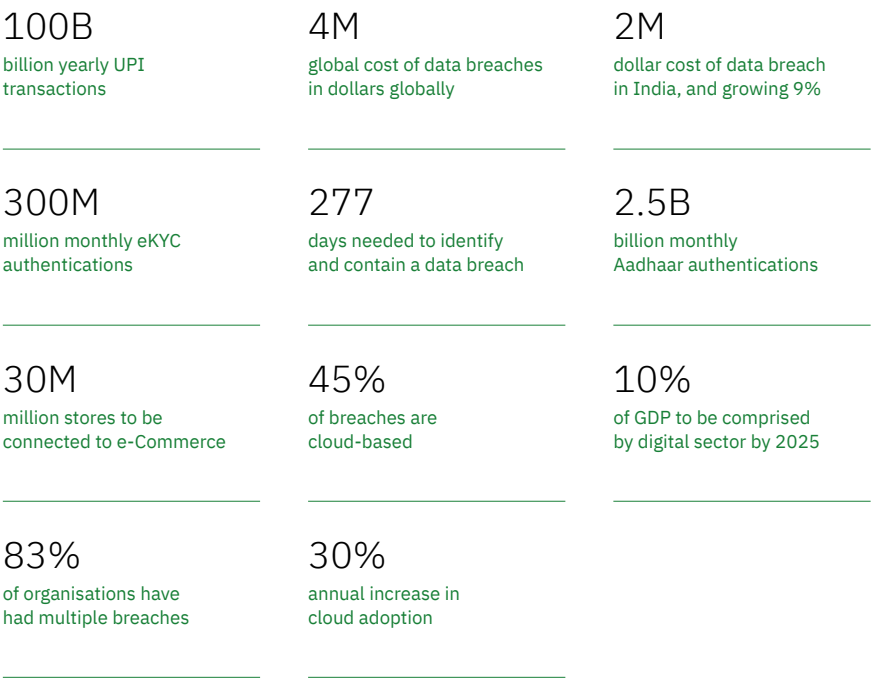
Context and challenges

India is fast emerging as a leader in digitalization. The Digital India mission launched few years back has already transformed several sectors in India like financial services, citizen services, and transportation. The table below captures the essence of the growth and the challenges faced. The quoted numbers are based on research conducted by Data Security Council of India (DSCI), IBM Institute of Business Value, and articles published by leading media houses [23–29, 38, 39]. They tell a very clear story: while India's digital growth has been phenomenal, its durability depends critically on robustly securing the underlying infrastructure.

This position paper is structured as follows. We first review a uniquely Indian approach to the creation of digital public infrastructure. This is followed by sections that touch upon recent progresses in cryptography, privacy, and hardware security that the technology ecosystem needs to be aware of and adopt suitably. We then review the recent progress in quantum safe cryptography and highlight the urgency of the Indian ecosystem to develop a framework for its adoption. We end with a discussion on the skilling requirements of the industry and the opportunity for India to emerge as a global cybersecurity leader.

Figure 3:

The infographic captures the essence of the growth and the challenges faced. The quoted numbers are based on research conducted by Data Security Council of India (DSCI), IBM Institute of Business Value, and articles published by leading media houses [23–29, 38, 39]. They tell a very clear story: while India's digital growth has been phenomenal, its durability depends critically on robustly securing the underlying infrastructure.



Digital public infrastructure: Indian approach

At 5.3 billion, 66% of the global population was online in 2022 accessing a wide range of services like commerce, payments, communication, health, and citizen services. The significant raise in quality of life that digitization has brought about cannot be overstated and was one of the key reasons that the global economy could minimize the overall economic impact of the COVID pandemic. Globally, many of these services are provided by platforms operated by private corporates. While there is no denying the value of these services, it also gives rise to several concerns [23]. They are:

- Privacy and security issues arising out of entrusting personal data with private enterprises.
- Monopolistic repercussions of network effects
- Protection of consumers from vertically integrated commerce at scale
- Possibilities of creating data silos because of unwillingness of data collectors to cooperate and collaborate.

Regulators all over the world are grappling with these issues. Two broad approaches have emerged over the years. The first approach is to let private enterprises freely build platforms and services with minimal regulatory oversight, for example, the almost laissez faire framework that powers U.S. innovation. The second approach provides a strong regulatory framework for protecting the rights of individuals by putting the onus of regulatory compliance on the data collectors and enterprises, for example, the General Data Protection Regulation (GDPR). The first approach enables free market innovation and adoption, it ends up entrusting private corporates with benevolent behavior and requiring individuals exercise judgement on what they choose to do on platforms. The second approach puts heavy burden of compliance on the enterprises and thus, increasing the cost of doing business. The Indian market has two key

characteristics, namely, scale and the low levels of user awareness of security and privacy issues. These make it difficult to adopt one or a combination of these approaches. India has developed a new approach called Digital Public Infrastructure (DPI) [23] which is motivated by viewing some of the core aspects of digitization as public goods and therefore, acknowledging the government and public sector as key stakeholders.

India's DPI is a techno-legal architecture that establishes a population scale (i.e., billion plus end users) technological infrastructure into which legal principles can be encoded in such a way that the data governance can be regulated, not by passing the obligations of compliance to the innovators, but, by the very operation of the infrastructure itself. India's DPI retains the regulatory control of the infrastructure with the government to ensure data governance in accordance with law and national interests. At the same time, it leverages the innovations and enterprising nature of the private companies to foster market adoption. DPI is collaborative and multi-stakeholder in its basic approach and offers a global alternative.

The so-called "India Stack" is one of the most visible examples of India's DPI approach. It consists of a foundational layer of population scale digital identity provided by the Aadhaar system. The second layer of the India stack is the uniform payments interface (UPI) implemented and maintained by the national payments commission of India (NPCI). NPCI regulates the payments industry and provides the infrastructure for routing payments. However, there are several private players who build value-added payment solutions on top of UPI (e.g.: Paytm, Google, PhonePe, etc.). The third layer is the data exchange layer that provides individuals with greater control over how their data is used. The Data Empowerment and Protection Architecture (DEPA) establishes players called "consent managers". The consent managers disaggregate the consent management from the actual data flow. We have witnessed a thriving industry innovation that has resulted in highly scaled and layered applications like credential management (e.g., DigiLocker) that leverage different aspects of the India Stack. Other examples of the DPIs that India is building are, Open Network for Digital Commerce (ONDC) and Bhashini — a digital infrastructure for Indian languages that uses AI and Natural Language Processing. With the number of digital transactions projected to reach 167 billion annually by 2024 – 25, a threefold increase in just three years, India's DPI will play a key role in enabling that growth [24].

The core architecture principles of the DPI are, (i) Open Protocols, (ii) Modularity and Interoperability, and (iii) Unbundling of the processes. The unbundling concepts is very powerful. Instead of simply digitizing existing processes, it unbundles the processes into their constituent elements and digital implementations of the same. This allows the implementation of the existing processes in a manner that is more suited for the digital world. Figure 4 shows how this approach allows for stakeholders like government, enterprises, citizens, OEMs, system integrators, start-ups

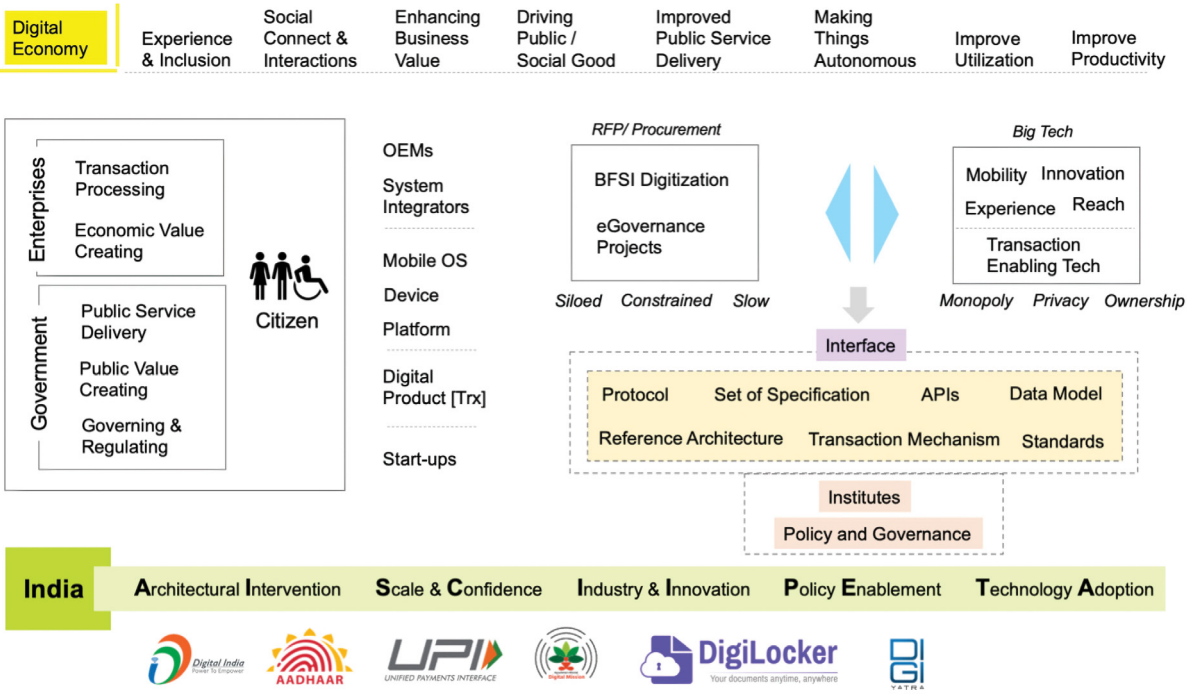


Figure 4:

Digital Economy driven by India's DPI. Source: DSCI

to build a digital economy with scale and confidence. The Indian technology ecosystem needs to act as the ambassadors of the DPI approach so that India can influence the evolution of global infrastructure in sync with our approach.

Privacy technologies and practical considerations

India's existing DPI infrastructure has been built with the privacy of user data as a core requirement. Currently, privacy is assured through the operations of the DPI infrastructure and the data exchange is managed by the individuals through consent managers. However, whenever data is shared after the user provides consent, the data is shared in plaintext. However, there are many use-cases in which the user may be willing to share only a derived attribute of their data without revealing the actual data. A simple example of this could be an individual proving to an application that she is an adult without revealing the age.

There is a wide spectrum of privacy technologies that are available to enable use-cases in which the data of end users can be used in applications in a privacy preserving manner. At a high level, there three types of technology:

1 technologies in which privacy is provided at the cost of introducing gaps or errors in the data, for example, Masking and Differential Privacy,

2 technologies which provide cryptographic guarantees on the privacy, for example, Zero Knowledge Proof (ZKP) and Secure Multi-party computation (SMPC), and fully homomorphic encryption (FHE), and

3 hardware-based solutions, for example, Trusted Execution Environments (TEE).

Masking and differential privacy have the limitation that the data either becomes unusable, like in the case of masking, or unreliable, due to noise addition in case of differential privacy. Therefore, techniques like ZKP, SMPC, and FHE provide cryptographic guarantees on privacy and do so while keeping the data, and its derivatives, completely usable for insights. However, traditionally, they have not been adopted widely as, until some recent promising advances, they tend to impose heavy performance overheads and are hard to use. Often, they impose multiple orders of magnitude performance overheads. Further, they require teams with advanced cryptography skills to implement them.

The limitations of the solutions with cryptographic guarantees have resulted in the practitioners looking for other solutions. One of the examples is to consider output privacy and achieve it using masking and differential privacy. Technology start-ups have also focused on developing notions of privacy dashboards and policy driven management. However, there are many applications where input privacy is a critical requirement. For these applications, use of TEEs is an option as well. For example, confidential clean rooms leveraging TEEs have been introduced under the DEPA framework for applications like Account Aggregation [30].

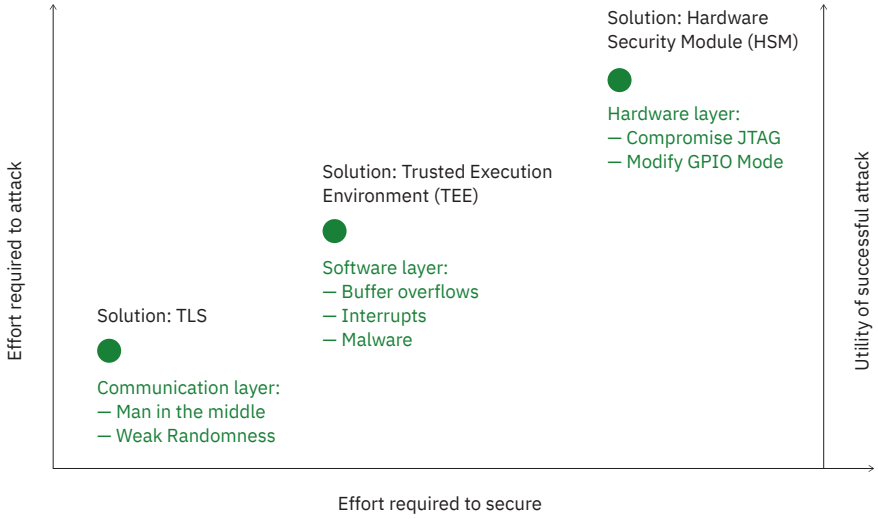
Multi-layered approach to cybersecurity

However, it is to be noted that there have been noteworthy improvements in the state of the art of ZKP and SMPC protocols — especially in the context of them using them in a performant manner insider decentralized networks. The improvements have been on two fronts. Firstly, algorithmic and engineering improvements have resulted in significantly reducing the performance overheads to the point of bringing them to the realm of possibilities. For example, there have been applications of advanced privacy-preserving techniques in the context of validating the properties of data and models in AI pipelines [33, 34]. Secondly, there have been notable efforts by security researchers to make them easy to use. EzPC [32] and Zokrates [37] are two classic examples of tools that have lowered the barrier for using advanced privacy techniques in applications. So, this is a good time for India's ecosystem to review their past experiences with these technologies and investigate their use in new class of privacy applications, especially in the DPI context. An example could be, setting up an infrastructure for organizations to share real threat data in a privacy preserving manner using ZKPs and SMPC.

Modern approaches to cybersecurity consider a multi-layered model of system security, where each layer has its own attack surface and corresponding costs of protection (Refer to Figure 5). These layers can be broadly categorized as: (i) the communication layer, which is typically vulnerable to low-cost communication attacks such as man-in-the-middle attacks) (ii) the software layer, which is vulnerable to software attacks such as buffer overflows, interrupts and malware) and (iii) the hardware layer, which is vulnerable to hardware-oriented attacks that often require physical access to the device. While it has been widely observed that the relative costs of attacking each layer increase from (i) to (iii), the corresponding costs of protection also scale in a similar

Figure 5:

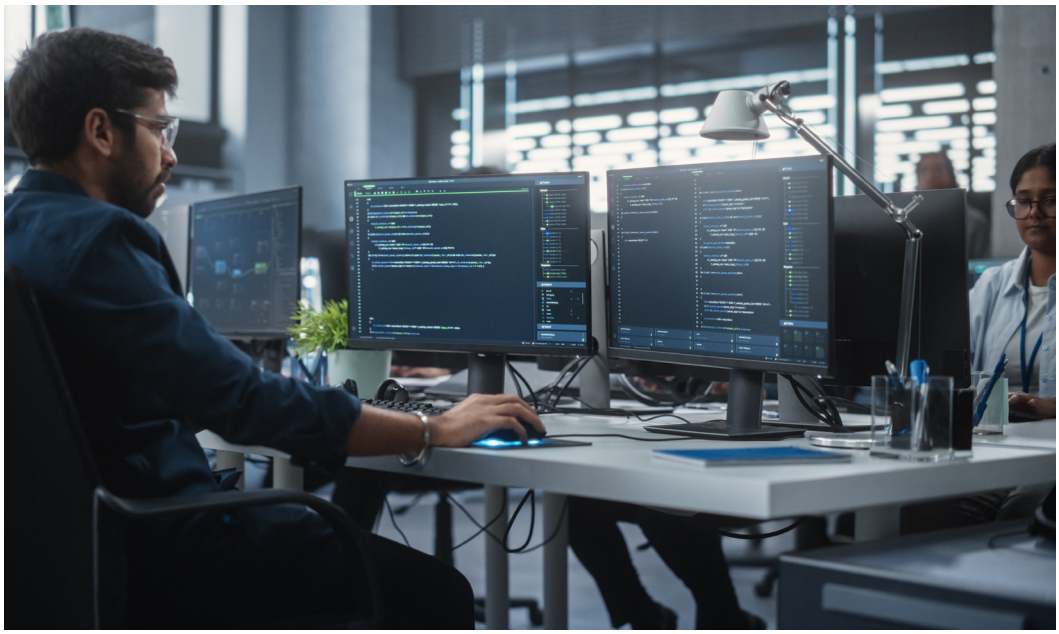
Multi-layered view of system security.



manner. While layer (i) can be protected using well-established and relatively low-cost mechanisms like Transport Layer Security (TLS), layers (ii) and (iii) are typically costlier to protect. Trusted execution environments (TEEs) offer a solution to prevent attacks on layer (ii), while layer (iii) is often protected using Hardware Security Modules (HSMs) and similar secure elements. When viewed in the context of the cybersecurity landscape in India, each of these layers offers unique challenges — from the perspectives of technological advancements, legal and regulatory concerns, and finally building capabilities and training manpower to effectively counter cyber threats.

The cyber threat landscape in India has evolved rapidly in the past decade, especially due to the extensive digitalization enabled by the universal ID system, digital payment and fintech explosion, rapid proliferation of mobile devices and the commensurate increase in Internet usage, as well as the advent of smart critical infrastructure, such as smart grids, smart cities, smart transportation, and smart civil infrastructure. There remains significant work to be done to achieve the level of pan-India education and awareness in cybersecurity that is required to tackle such rapid digitalization and ever-growing threat of cyber-attacks in the Indian ecosystem. Over the last few years, India's cybersecurity capabilities have been bolstered due to efforts by Ministry of Electronic and Information Technology (MeitY) sponsored centers of excellence established in leading academic institutions and other activities sponsored by Niti Aayog and DSCI. There is a need to take stock of these initiatives and channelize them towards pan-India collaborations focused on strategic directions like cybersecurity of IoT devices in India-centric applications like environmental monitoring, e-governance, and modern pharmaceuticals.

From a technological standpoint, a core approach to cybersecurity that needs to be explored is "design for security", wherein security is considered a primary goal alongside performance and efficiency, as opposed to an afterthought. For example, Intel suffered a major drop in its stock price after the exposure of hardware and software security vulnerabilities such as Meltdown and Spectre in Intel processors. Similarly, the vast majority of commercial IoT devices and



embedded systems today often lack security measures against hardware-oriented attacks, include ng side-channel and fault injection attacks. Research in hardware security aims to address such vulnerabilities, and it is crucial that such research is also translated into the design of deployable cyber-physical systems. This calls for a systematic and collaborative effort by academia, government, and industry to develop and expand the hardware security research community in India.

Notably, securing layer (iii), the hardware layer, appears especially relevant in the Indian context given the recent "Indian electronics wave", which includes the imminent announcement of first large-scale commercial Indian chip fabrication facilities under the National Semiconductor Mission. It is important to note that secure systems cannot be built without hardware security modules. For example, while cryptographic algorithms provide strong security guarantees in theory, implementations of such algorithms can be potentially subverted by hardware-oriented attacks such as side-channel attacks, as well as by threats at different stages of silicon design and manufacturing flow (e.g., Trojan intrusions). These threats are omnipresent in any cyber-physical ecosystem, but are especially important in the context of the Indian ecosystem, which has, for a very long time, relied on imported hardware. In fact, India's software exports success has been offset in the past by rising hardware imports. If India wishes to reverse this trend and establish independent and indigenous capabilities in securing the hardware layer of its cyber-physical ecosystem, then it is the need of the hour to recognize hardware security as the "root of trust" in the chain of cybersecurity measures. Hardware security research needs to provide the necessary impetus for developing state-of-the-art equipped laboratories. At the same time, academia-Industry-government interaction should enable joint development of security solutions, while also making chip designing a more lucrative and integral part of the academic curriculum in Indian institutions.

Quantum-safe cryptography

Although models of quantum computation and quantum algorithms have been studied extensively in the computer science literature for close to four decades, the last few years have witnessed significant advances in building real quantum computers with non-trivial quantum computing power. There is a spectrum of technology majors (e.g. IBM, Google, and Microsoft) and niche quantum computing companies (e.g. DWave Systems, IoNQ, and Rigetti Computing) have built quantum computers with tens of qubits to a few thousand qubits. The roadmap announced by these organizations aim to achieve orders of magnitude increase in the number of qubits, thereby bringing quantum computing to the realm of possibilities. While quantum computing will help us solve hitherto unsolved problems, they will also pose significant dangers to the security of today's digital infrastructure. Specifically, scalable implementations of Shor's algorithms can help solve large-scale integer factoring problem — thus, breaking the fundamental security assumption underlying almost the entire public-key infrastructure and digital signature infrastructure.

This gives rise to the possibility of adversarial actors launching "store now and decrypt later" attacks — thus implying that the systems we are building today are at risk and that the data that we are assuming to be protected are vulnerable to future breaches. This also puts the integrity of

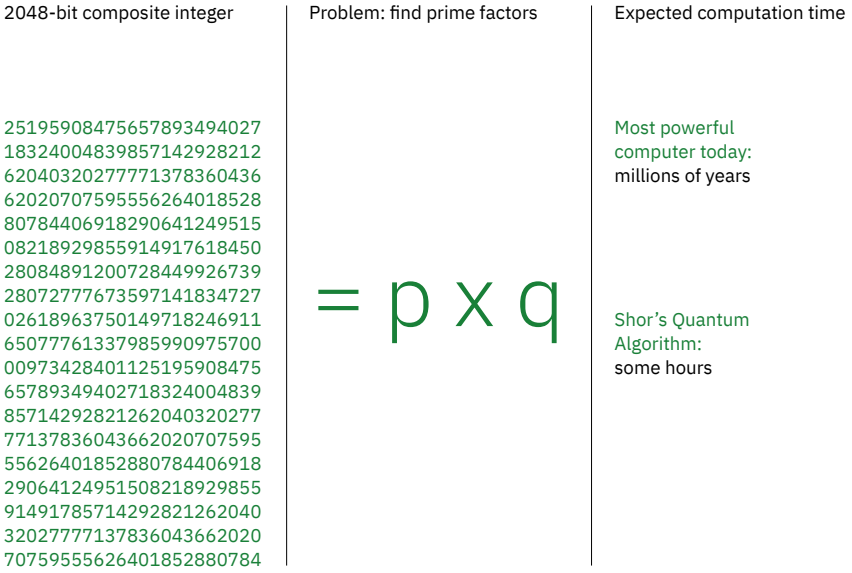


Figure 6:

Risk posed by quantum computation.

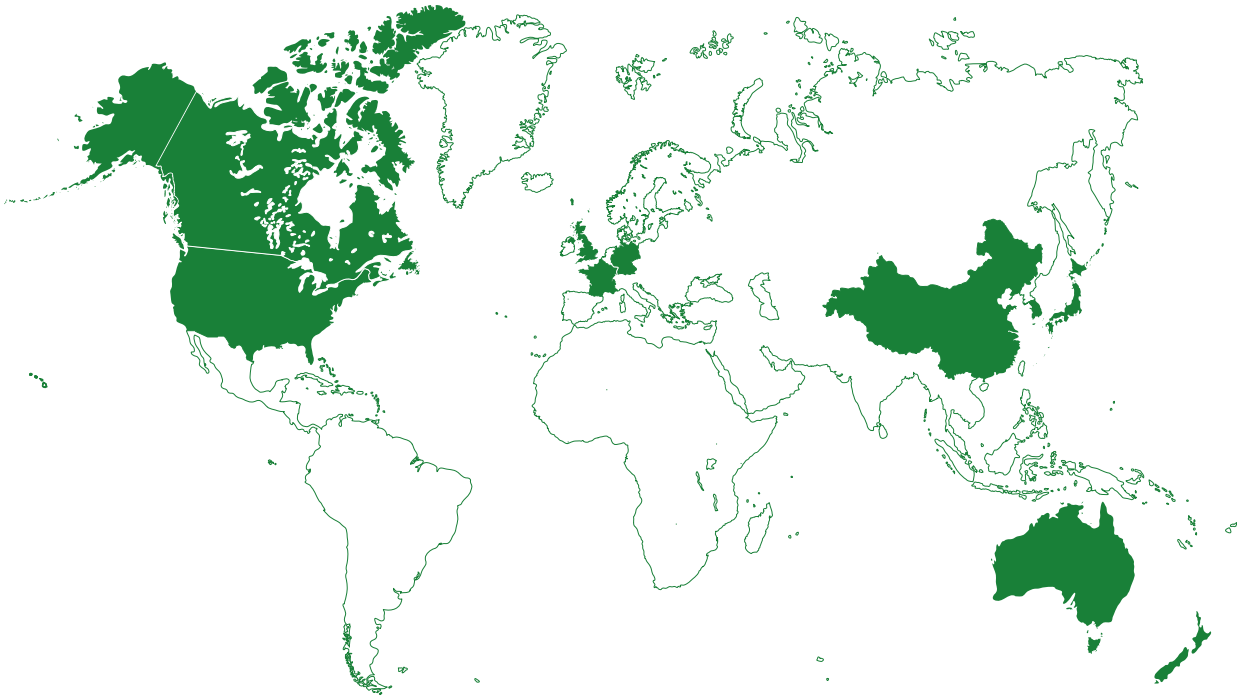
the data and the legal underpinnings behind them under the cloud of future attacks. In response to these dangers, NIST launched a multi-year and multi-round process to standardize cryptographic algorithms that are quantum-resistant, i.e, they are based on hardness assumptions that are not known to be broken even under the availability of powerful quantum computers [36]. The NIST process started in 2016 with roughly 90 entries and concluded in July 2022 after four

rounds with the selection of four quantum safe algorithms. It is to be noted that three of the selected algorithms (ex: CRYSTALS-KYBER and CRYSTALS-DILITHIUM) are based on the lattice-based cryptography.

Several countries have launched initiatives for timely and safe adoption of quantum safe cryptographic algorithms as shown in the picture below. It is surprising that India has not yet launched a visible and sustained initiative on the adoption of quantum-safe cryptography. Since the quantum threat has major implications to national cybersecurity, it is recommended that the academia, industry, policy makers, and the government should work together to evolve a coherent quantum safe strategy as part of national cybersecurity strategy. Such a strategy should focus on methodologies for (a) automatically and comprehensively document an inventory of the use of all cryptography in an organization's information technology (IT) and Cyber-physical infrastructure, (b) assess the vulnerabilities in the documented cryptographic inventory, and (c) repeatable and safe mitigation of identified vulnerabilities to quantum safe variants.

Figure 7:

Global response to quantum-safe cryptology.



USA
NSA (2022)
Implementation
2023–2033

Canada
Cyber Centre (2021)
Start planning:
Implementation
from 2025

UK
NCSC (2020)
Start planning:

Germany
BSI (2022)
Start planning:

France
ANSSI (2022)
Start planning:
Transition from 2025

Singapore
MCI (2022)
Monitoring NIST

China
CACR (2020)
Start planning:

S. Korea
MSIT (2022)
Start competition
1st round
(Nov. 22–Nov. 23)

Japan
CRYPTREC
Start planning:
Initial timeline

Australia
CTPCO (2021)
Start planning:
Early implementation
2025–2026

New Zealand
NZISM (2022)
Start planning:

Skilling

Cybersecurity is not just a matter of technology implementation. It requires a successful synergy between technology, processes, and people. It is an acknowledged fact that the academic curriculum in most universities do not focus on creating awareness of the importance of data and system security among the students. So, the entire discipline of cybersecurity is entirely new to most of the fresh hires into the industry. Therefore, cybersecurity is essentially a lateral skill that needs to be acquired on the job. While there are some well-known certification programs, the industry experience suggests that even the certified people are found wanting when faced with practical, industrial challenges. Two of the key questions that arises in this context are, (a) what the responsibilities of academia are to improve the situation, and (b) what the industry needs to do. The opinions expressed by the academic experts is that the academia has core responsibilities of imparting the foundation of fundamental computer science topics and conducting state of the art research. Therefore, the academia can at best help with the creation of better content for training and certification. The responsibility of taking such content and scaling to the requirements of the industry scale should rest with the industry stakeholders like cybersecurity companies, fintech companies, and the technology consumers like banks and public sector. Another key observation was that the sub-disciplines like AI, IoT, and Blockchain have succeeded in creating entry-level skills by effectively leveraging hackathons. However, it is to be noted that hackathons or threat-hunting kind of challenges are not conducted sufficiently to enthuse the students. So, it is recommended that the industry stakeholders should collaborate to create such avenues. It is to be noted that except for certain localization of the people and process aspects, most of the other skills required to secure India's digital infrastructure is a core requirement of the global digital infrastructure as well. So, the investment by the stakeholders can help create global technology leadership. One of the areas where India is already emerging as a leader is in designing, implementing, and running security operation centers.

The skilling discussion is incomplete without considering the impact of the recent progresses in AI on the nature of jobs in security. Use of AI and data-driven decision making has been underway in the space of security for tasks like threat detection. However, the recent progress in the form of generative pre-trained transformer (GPT) networks and similar foundation models has added new dimensions. There is a possibility that several security "services" roles get heavily automated using these technologies. As an ecosystem, we need to anticipate what these changes would be and play a leadership role in that transformation. While these new age AI tools have transformative potential, they do have challenges in being factual and avoiding hallucination. Domain specific prompt engineering could be a valuable skill in using these technologies gainfully. This is a potential area of growth for the service providers. Adversarial actors with access to these type of AI technologies could also launch new types of attacks that are hitherto unknown. It would be great if the Indian ecosystem could collaborate to identify potential new attacks and develop products, and services

to mitigate such threats. In short, the new age AI provides opportunities to develop new automation services as well as new security mitigation products (or services).

Conclusion

The digital infrastructure has played a significant role in improving the quality of life. The rapid adoption of digital financial technologies, cloud computing, internet of things, decentralization of trust, and the advances in quantum computing have resulted in a wide spectrum of challenges in securing the digital infrastructure. In India, these challenges are further accentuated by the scale. There is a need to adopt advanced cryptographic and security technologies to increase the security and privacy posture of the digital platform. India's technology ecosystem needs to act urgently on the threats created by the advances in quantum computing and adopting quantum-safe cryptography. India's approach to developing a responsible and scalable Digital Public Infrastructure stands out in comparison to some of the alternative approaches and has a good chance to emerge as an influencer. The academia and industry need to work together to create a sustainable model for creating a sizeable and skilled workforce in areas like applied cryptography, security, and privacy. This will not only allow secure the future of Digital India, but also help India's technology ecosystem to emerge as a global leader.

Chapter 4
key takeaways

1 It would be beneficial to India's ecosystem to investigate the possibility of leveraging the advances in the performance and usability of privacy enhancing technologies in the context of collaborations in India's DPI.

2 It would be beneficial to channelize several cybersecurity centers of excellence towards pan-India collaborations focused on making hardware security as the root of trust — especially for security of cybersecurity of India-centric applications.

3 It is essential for India's academia, industry, policy makers, and the government should work together to evolve a coherent quantum safe strategy as part of national cybersecurity strategy.

4 Industry stakeholders like cybersecurity companies, fintech companies, and the technology consumers should — with appropriate help and participation from the academia — take lead in attracting talent and skilling them at the nation scale by mass certification programs, hackathons, and exciting threat hunting challenges.

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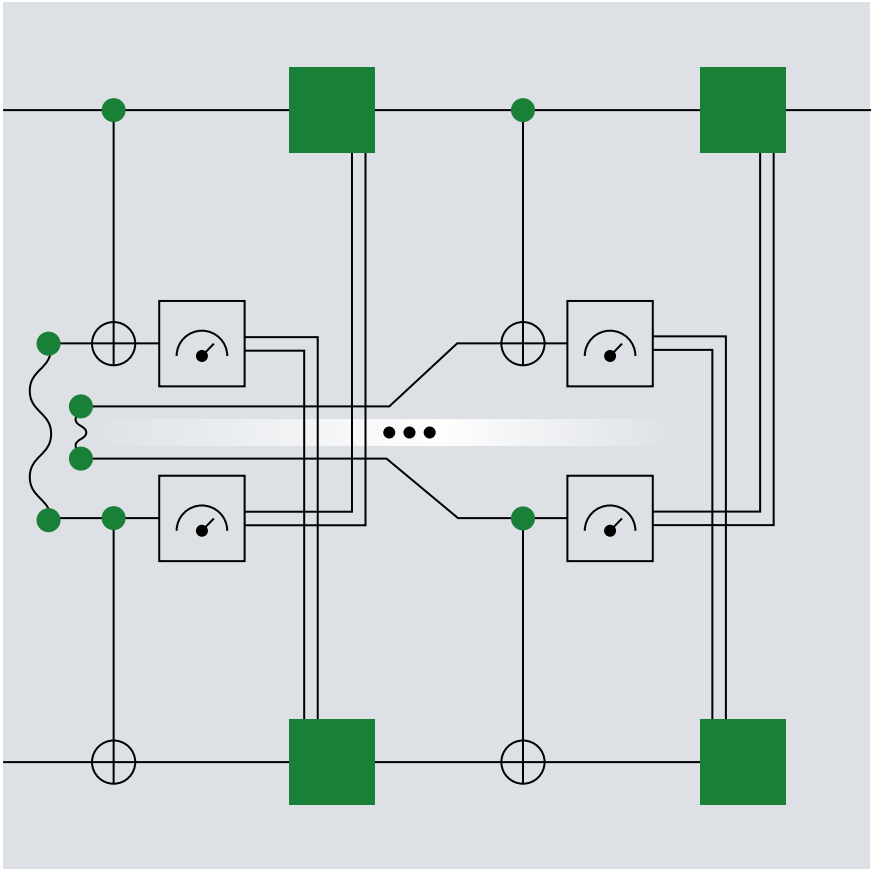
Chapter

5

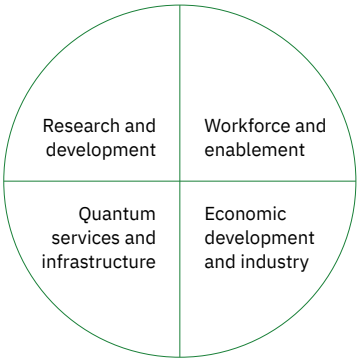


Quantum in India: Navigating forward to scale

India's National Quantum Mission has received cabinet approval with a total budget of Rs. 6003.65 crore. The mission aims to scale up scientific and industrial research and development in quantum technology, fostering accelerated economic growth in this field and positioning India as a leading nation in quantum technology. At the Science for Scale summit leading researchers, academicians and government leaders assembled to discuss the way forward for quantum in India. They provided a framework to guide the national mission along four quadrants shown below.

Figure 8:

The four components comprising a national strategy to build a sustainable quantum ecosystem for quantum computing industry.



The quantum computing ecosystem is characterized by four components: Workforce & Enablement, Economic Development & Industry, Research & Development, Quantum Services & Infrastructure. Each component reinforces the others, so coordination in their development is important to a successful ecosystem. Our goal is to develop the mission of each ecosystem component for a healthy quantum ecosystem to get the whole ecosystem behaving like a flywheel, turning rapidly so that a strategic quantum computing industry can be formed.

The goal of this chapter is to provide inputs to help steer the point of view for India along all 4 quadrants. The workshop held in April brought together the key stakeholders from the Indian quantum ecosystem to discuss and share inputs and these inputs have been collected in this document. The list of participants is provided at the end of this chapter.

Quantum workforce and enablement

Nasscom-Avasant, in their 2022 report [40] on quantum in India, have predicted that India will grow to a roughly $310 B valued industry in quantum technologies by 2030. Such a huge industry requires a strong workforce to drive and be self-sustaining. The report by Nasscom-Avasant predicted 100x or more growth in India's workforce skilled on quantum technologies over the next decades.

Training a workforce skilled in quantum

One important step is to design program specializations in quantum. IISc Bangalore is already offering such a program, but it is, still, unique in India. But to be able to scale it is necessary to develop these courses more broadly in large number of institutes. Quantum computing being an interdisciplinary field, students from different domains such as physics, mathematics, computer science and electrical engineering are expected to opt for these courses. This is, in one sense, an advantage, since such an interdisciplinary band of students can help progress the field more rapidly. However, these students often have very different background and expertise. A sincere interest was observed among the students when an NPTEL course on quantum computing was offered in 2022; however, the similar issue with background diversity was observed there also. Therefore, it is necessary to design courses which has minimal pre-requisite, thus conforming to students from all backgrounds. Furthermore, these courses should involve both the physics and computing aspects of quantum. Currently the courses offered on quantum in different institutes focus mostly on one of these two aspects. This sometimes discourages students from different backgrounds — students from physics feel they are not comfortable with computer science and coding aspects, while those from computer science feel that they don't have adequate physics background.

The rapidly growing ecosystem of quantum demands a large number of highly-skilled researchers in academia and industry of India. Highly trained PhD scholars are an essential aspect of this growth. Having more competitive fellowships in this domain will encourage more PhDs in this area.

Another important aspect is the requirement for cross collaboration amongst institutes within India and abroad. This can help students access hardware and software which are not available in their institutes. There is a need for eco-system development with academia and industry together providing attractive offers for post-doctoral fellows.

Small quantum computers are now available for free or for pay-as-you-go model. IIT Madras is one of the early adopters of the quantum computers which came live in 2016 – 17. Since 2018, they have been using these devices in their classes. Faculties from IIT Madras acknowledge that they found this extremely useful, in particular during the pan-demic period on 2020 – 2021. This cloud-based lab allowed them to have practical sessions even in long distance. The faculties stated that the students make good use of the hardware access to solve problems of interest in their class. For last 6 – 8 months, IIT Madras has also obtained pre-mium access to IBM Quantum computers which has been extremely useful for their PhD and postdoctoral students. The value added by this premium access, as per a faculty from IIT Madras, is twofold. From a learning perspective, it provides a way to visualize the theory that the students learn in the classroom — making quantum mechanics becomes a working principle as opposed to a theoretical abstraction! From a research perspective, it allows to test or benchmark the theoretical schemes that the researchers devise, and the learning from running such experiments opens up newer direction for research that is in tune with the current hardware realities.

Industrial skilling in quantum

Apart from academia, it is also essential to have a workforce with industrial skilling in quantum. India has a large skill base in basic sciences and engineering domains. This demography spreads from young graduates to experienced professionals in different domains like Physics, Mathematics, Computer Science/ Application/ Information Technology, Electronics, Telecom, and allied engineering. The Quantum Computing revolution in the country will benefit by leveraging this STEM professional base. In this regard, in order to build industrial skills, the key areas could be conceived in three pools — theoretical, implementation, and application. Based on the requirement, these pools will build the critical mass required for industry in either help build or find application of the quantum field. For this academic institutions and industry need to work closely. One important aspect of the skilling of industrial participants would require that there are enough opportunities by way of job, internship, and work-based experience. Funding opportunities to start-ups, as well as established industries venturing in Quantum tech-space, and academia would encourage more participants and entrepreneurs to venture in this new domain.

Economic development and industry through quantum computing

Quantum computing has the potential to revolutionize various industries, such as healthcare, finance, logistics, etc. This would require an active participation of Govt, R&D, Academia, Industry and startups in developing a sustained Quantum Computing ecosystem in the country.

Quantum computing development is critical for a country's security and sovereignty. The government is seized with the fact that if it loses the quantum computing race, its technological dependence in this extremely critical cutting-edge area of technology on foreign players will increase, adversely impacting global competitiveness and the economy in the long run. The development of the quantum computing ecosystem requires proactive measures by the government to accelerate the adoption and proliferation of quantum technology. The government needs to focus on long term investment, creation of shared infrastructure with open access to Indian institutions. Along with this the government needs to catalyse development of entrepreneurship along with encouraging close public-private and industry-academia collaborations. Further special provisions need to be put in place to enable and speed up procurement of specialized hardware and peripherals required for setting up as well as the development of quantum facilities. Procurement guidelines need to be suitably modified and adequate waivers on import and customs duties need to be put in place.

Industry should also work towards building a strong quantum computing ecosystem by investing in research and development, partnerships, and human capital. There is a need for Industry to get aggressively involved in delivery-oriented projects funded by the Govt. and implemented by Academia and R&D Institutions. Academia should provide a solid scientific foundation needed to implement the projects. Industry and startup incubators and collaboration

programs need to be carved around the R&D initiatives for quick translation from lab to market.

Problems of national importance can be selected for implementation jointly by industry, academia, startups and government. Enterprises worldwide are already running quantum experiments and collaborating with universities and quantum developers to conduct joint R&D in quantum applications.

It is time for Indian enterprises to identify mission-critical use cases they may want to explore with quantum. One suggested area is logistics where quantum computing can be used to address last mile delivery, constrained optimization, warehouse management & distribution, disruption management, route optimization, preventive maintenance, etc. The national quantum mission can be tied with other important projects like the National Logistics Policy.

According to the data stats in Feb 2022, less than 1% of Indian enterprises are evaluating quantum prospects in their industry and business. This needs to improve multifold.

Startups have an important role to play. India has the 3rd largest entrepreneurial ecosystem in the world, with a growing number of deep-tech start-ups. Start-ups in the quantum computing domain need to be given specific support from the ecosystem in terms of investment, incubation and scale-up.

Scaling quantum computing R & D in India

The industry has to realise that the real important challenges are in design research and development, and not in use of readymade systems. The govt. has already approved the national quantum mission and is funding research in quantum in India.

For the Indian Industry to invest it must see value in investing in quantum computing. This is best done by collaborating and solving a few problem statements, that they can internally champion to their higher management. Each domain of interest (chemistry, machine learning, optimization) must be tackled independently, and POCs developed that demonstrate a route to quantum advantage. With quantum systems still being noisy, it is also important to invest in quantum error correction for specific circuits that are used by specific important algorithms.

Both classical and quantum technologies are evolving rapidly, though in different manners. The focus should be on building a solid foundation by strategically funding research projects in key areas. Dedicated and concentrated efforts (instead of distributing limited resources) in focused areas (instead of trying to cover everything), controlled by scientists who are active in the field supported by industry and government. Successful scientists must be provided with clear and promising outline of their future career trajectory. India needs an open-ended long-term vision that would justify patience and persistence, instead of a search for quick benefits (which may still come as by-products).

Compared to leading research centers worldwide India is still lagging but with concerted and joint efforts from Indian industry, academia and startups, India can take the lead. There needs to be a focus on the translation of research to produce results that would benefit India. Quantum simulations, new materials, machine learning, optimisation are some areas where quantum computing is already being pursued in Indian institutions. By investing in research and development, as well as fostering partnerships between academia, industry and start-ups, India can give a boost to its efforts and position itself at the forefront of this emerging technology.

Often growth of research and development is based on the collaborations between public and private institutions. Funding mechanisms must ensure that startups, industries and academia collaborate with each other to exchange ideas, research findings and for working on complex problems.

We need to create a multiplicative impact on economic and social fronts and to do this R&D must tap into the aspirations of students and software developers, and channel them towards applications with societal value. e.g. a challenge to mitigate climate change, or to identify a new drug molecule, or to improve direct benefit transfers or to improve the efficiencies in the logistics sector. These goals have both societal and economic benefits. When we draw upon the power of quantum computers to solve these problems, we will naturally find a multiplicative effect. We are at the cusp of an inflexion point in the power of quantum computing, and I expect to see the impact very soon.

Industry and academia should also take lead to develop standards in quantum computing which can adopted globally. The development of standards promotes the interoperability of quantum computing systems and facilitates the growth of the industry.

Quantum services and infrastructure

The area of Quantum services and infrastructure can broadly be classified into four different segments.

1 Quantum Hardware Development

2 Cloud ecosystem and middleware

3 Peripherals and components

4 Democratizing access

1 Quantum hardware development in India

Quantum control — and hence quantum computing — typically occurs at sub-nanometer scales like most other quantum phenomena. India is at a very nascent stage in hardware development, with sub-critical infrastructure and trained human resource. The lack of indigenous prowess in nano-fabrication that arose partly because of completely missing the bus on micro (and subsequently nano) electronics revolution during the last quarter of twentieth century is perhaps the biggest impediment to quantum hardware development in the country happening at any substantial scale. It is very much a game of catch-up right now with respect to the already established quantum hardware approaches ranging from superconducting and semi-conducting qubits to trapped atoms, ions or photonic implementations.

The first step to progressively build up India's capabilities will be to create a friendly and lucrative professional environment to increase the human resource in the quantum domain. As much as availability of governmental funding, availability of trained human resources is anticipated to play a key role in determining the success of the ongoing efforts to ramp up development of quantum technologies in India. Development of a quantum eco-system through industry-academia partnerships and governmental assistance can address this problem because there is no shortage of talent pool and what is required is means of training the available talent at scale.

The possibility of a radical breakthrough that establishes a clear new frontrunner when it comes to hardware implementation offers another avenue for hoping that the country can leap-frog to a leadership position in the quantum realm despite a few historical disadvantages.

There is a lack of clarity on the promise held by various hardware approaches to implementing quantum computing. This strongly supports a separate policy for quantum hardware development. There is still room for a radical breakthrough in the hardware front that could change the landscape of quantum hardware drastically. The tremendous scientific and commercial value that such a breakthrough can unlock strongly motives a diversified and intensive push on the hardware front.

In some sense, the phrase “quantum hardware” itself implies programmability. Harnessing the existing, acknowledged base that the country has in the theoretical aspects of quantum information processing through focused collaborative programs with hardware developers is likely to yield rich dividends in terms of novel quantum control, error-correction, data protection and other protocols. It can also lead to defining new quantum programming paradigms and clarifying several gaps in the present understanding of the nature and scope of quantum software.

Software development that is agnostic to the underlying hardware is already an established concept at the dawn of quantum computing. Software development specifically for quantum hardware is therefore naturally tending towards such a hardware-agnostic development path. This of course is driven, in part, by the variety of hardware options available. Qiskit being used across hardware platforms, or the approach taken by Amazon Braket (AWS) to make a variety of quantum hardware available through a unified interface are all cases in point. Remembering the thumb rule that more than 90% of the eventual uses of new technologies

are in use-cases that were not even conceived of at the time of development of the technology, it would be desirable to have a separate software policy that incentivizes not only quantum software development but also active exploration of new realms where the computational possibilities presented by quantum hardware can be put to productive use. This would require nurturing a workforce that can "think quantum-mechanically" about problems in their respective domains of expertise.

2 Cloud ecosystem and middleware

Following the success of global quantum platform providers, India can adopt the cloud model to promote quantum research and innovation. As quantum hardware in India matures for enterprise use, transitioning to cloud access will be a natural progression. Regardless of their presence in the quantum value chain, quantum players in India are eventually moving to the cloud. For instance, BosonQ, a quantum SaaS software start-up, became the first Indian start-up to join IBM's Quantum Network start-up program in March 2023 to develop quantum algorithms for simulations on quantum systems in the cloud. Last year, IIT Madras became the first Indian institution to join IBM's Quantum Network to explore practical applications of quantum in the cloud.

Middleware development, including quantum circuit compilation, error correction and mitigation, hardware calibration and control, interfacing with classical computers, etc., has been a critical focus area for academia, research groups, and the industry, but India has gained limited success here. Government should allocate adequate funds to projects and start-ups focusing on quantum middleware under the National Mission on Quantum Technologies and Applications initiative. This will help India become self-reliant in quantum middleware as these tools and technologies will not be available for import in the distant future for strategic reasons.

3 Peripherals and components

Alongside hardware development, development in peripherals and components is also key. Miniaturizing peripherals is key to densely packing large number of qubits in a chip and communicating over microwaves. This will require tech know-how on semiconductor design and fabrication. Major initiatives are required as far as miniaturization goes. Collaboration between various partners in the value chain from concept to engineered solution requires major uptake. Packaging as well as engineering firms, standards organizations, design houses will all add much needed value to the ecosystem. It is important to focus on few select, perhaps killer applications, with domain experts joining hands will create the impact needed to push the quantum technology to the market in a viable manner.

4 Democratizing access

Quantum software and applications development can progress independently only when we have widespread and affordable access. Widespread access can potentially lead to more innovations, especially in the start-up and services sector. Like we have done with our classical software industry, a lot of economic opportunities may also be created here.

The paradigm of hybrid quantum-classical computing is one possible starting point for pushing the envelope on quantum computing for deep tech start-ups. This involves pairing up of available or new supercomputing facilities with quantum ‘co-processors’ effectively with custom software that make it easy to use such systems.

Chapter 5
key takeaways

1 Quantum in India is expected to grow to a $310 B valued industry by 2030 with 100x or more growth in India's quantum skilled workforce over the next few decades.

2 Policy interventions in terms of funding for mission specific large scale efforts as well as building partnerships amongst government, academia and industry are essential for a vibrant quantum ecosystem in India.

3 India specific quantum applications, specifically in the field of logistics such as last mile delivery warehouse management & distribution etc., can have immediate tangible benefits and attract more start ups in these areas that leverage quantum computing to solve real world problems.

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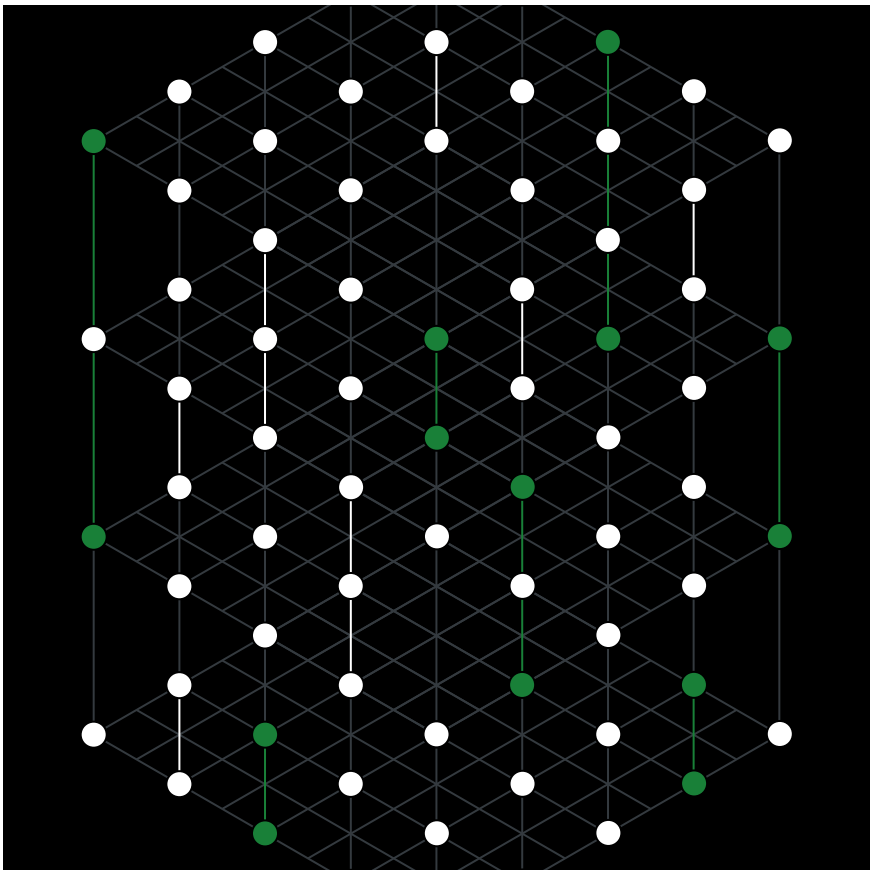
Chapter

6



5G and distributed cloud: Scaling impact for India

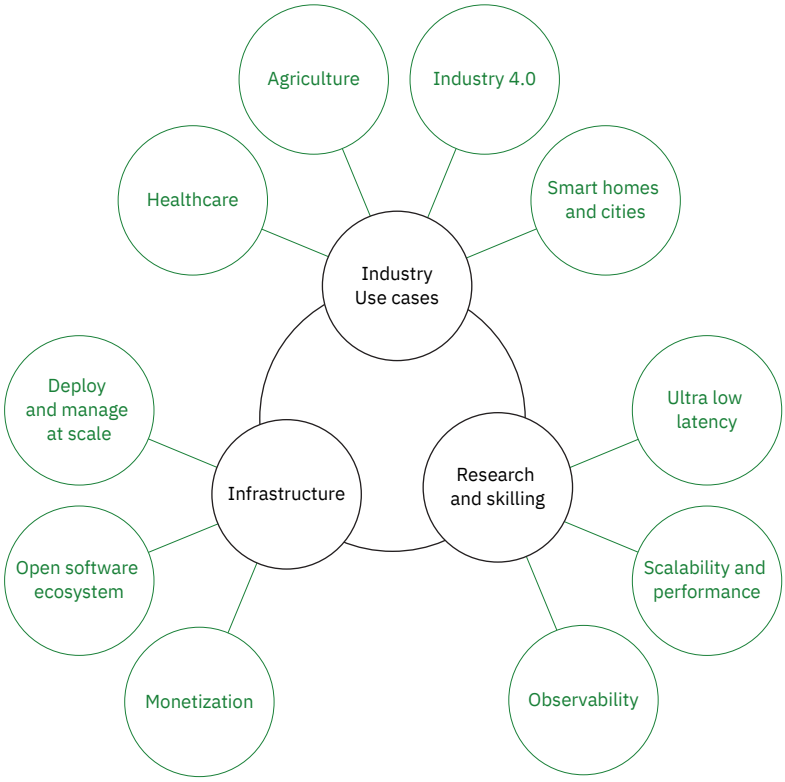
It is estimated that by 2025, 75% of data will be processed outside the traditional data center or Cloud [41]. The proliferation of smart devices in industrial as well as personal spaces together with 5G adoption, is accelerating this transition and the growth of Edge computing. India, with its ubiquitous access to smart phones, cheap cellular communication, and excellent technical talent, is uniquely empowered to innovate as well as stretch the limits of scale of 5G and Edge computing. 5G is expected to deliver $150 billion in additional Gross Domestic Product (GDP) for India by 2040 [42].

5G technology offers an order of magnitude higher bandwidth and ultra-reliable low latency communication compared to 4G. This has enabled a host of new use cases in domains such as healthcare, agriculture, mobility, Industry 4.0 and smart homes and cities. Figure 10 shows the expected value to various industries attributable to 5G. In India, cellular has become cheap and ubiquitous, and is the primary and often only source of network access. Cellular was designed for mobility but in India's context, it is mostly used for fixed and stationary use cases such as broadband Internet access, or for industrial, healthcare and agricultural settings. A primary function of the 5G Core is to handle user mobility, and if the use cases do not require mobility, should we rethink the 5G architecture for India? Perhaps

Figure 9:

Industry use case development, large-scale infrastructure deployment and management, and research, development and skilling need to synergistically work together to scale adoption of 5G and Edge solutions.

5G is expected to deliver $150 billion in additional GDP for India by 2040.



an intelligent Edge or a simplified architecture for the 5G Core can handle necessary aspects, such as authentication, privacy, policy enforcement and billing, and better support Edge computing use cases in an Indian context. This is an example of how India poses unique challenges that require specific solutions and innovation.

However, India has had a very limited contribution to telecommunications standards. The research communities in India have contributed to two IEEE 5G Standards: 1930 on "Software Defined Networking" and 2061 on "Architecture for low mobility energy efficient network for affordable broadband access". A large number of patents are needed for creating impact in these technologies. 90% of Intellectual Property (IP) is owned by US and Europe in the 2G and 3G space. 5G is led more by the APAC region, primarily from China, South Korea and Japan, contributing over 55% of IP ownership [43]. India should target at least 5% of IP in 6G. Most of the technology is software in 5G, and there is no need for specialized hardware. Disaggregation of the software stack helps independently developed innovation to be integrated together in open ecosystems that permit experimentation with the architecture and help evolve standards over time. Therefore, the barrier is now lower and it is definitely possible to develop, test and deploy the innovative new technology locally in India.

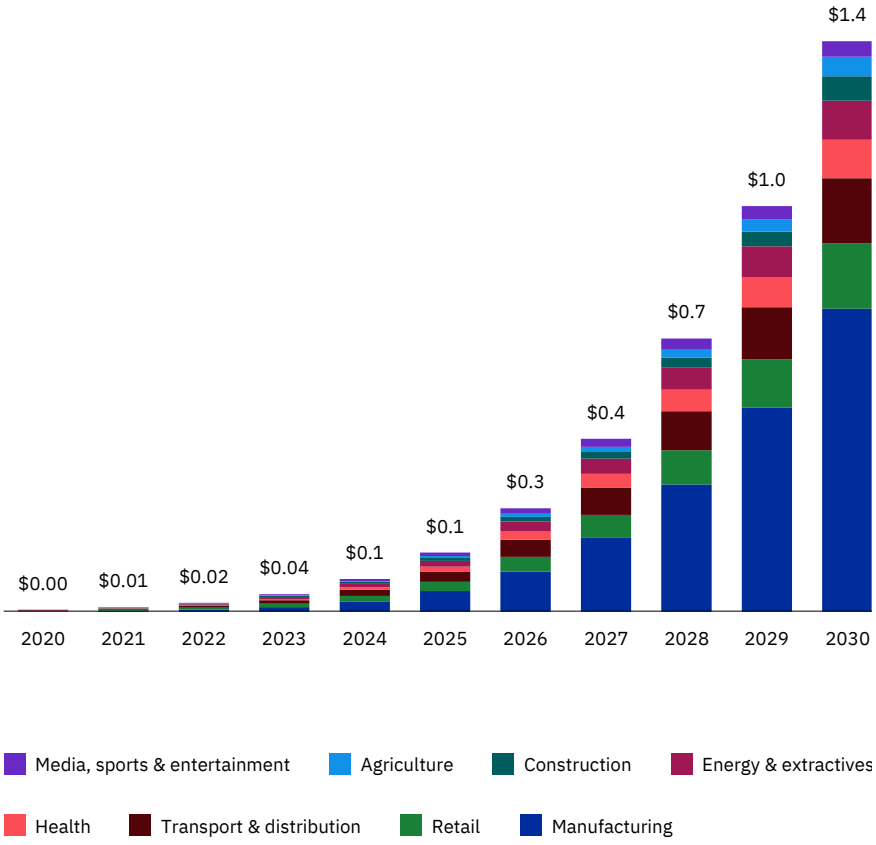
This workshop brought together leading experts in India from academia and industry in a dialogue to unravel the most impactful use cases of the technology, challenges in infrastructure deployment, the important research challenges that need to be addressed, and the ecosystem that is needed to catalyze adoption. In the rest of this article, we summarize the discussions from the workshop.

Industry use cases

In this section, we identify use cases that can reach nation-scale in India, and evaluate the constraints and opportunities they pose. Specifically, we discuss use cases in healthcare, agriculture, industrial and smart homes and cities.

Figure 10:

Benefits to industry attributable to 5G (USD trillions).
Source: stlpartners.com/wp-content/documents/5G_impact_on_industry_webinar_deck.pdf

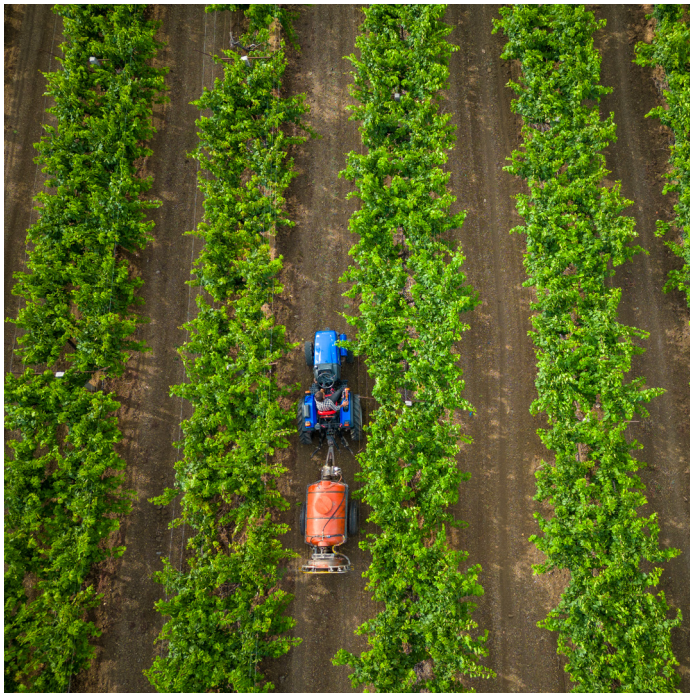


Healthcare

Use cases such as remote surgery becoming technically feasible has brought a lot of excitement and attention to the use of 5G in healthcare. However, healthcare is a very conservative industry when it comes to technology adoption given the regulations and risks involved as lives are at stake. A patient may not consent to be operated by a robot, controlled by a doctor thousands of miles away. Regulations would also require a fully competent doctor to be physically present, who can handle complex situations should they arise, and be responsible and accountable. It is therefore important to study and assess each use case of 5G technology from the perspective of the value it can provide in the health outcomes of patients, and not merely in terms of how much data can be handled or the ultra-low latency that can be achieved. While remote surgery may be several years away, there are many more practical use cases of 5G and Edge computing that can drive business value in the near-term.

Tele-mentoring and tele-education may be the ideal use cases for nation-wide adoption leveraging 5G technology, especially in India. It can help a veteran surgeon remotely and in real-time, monitor and mentor several junior

surgeons who aren't in the same location. It can help surgeons learn not only from their own personal experience, but also by witnessing procedures performed by others. 5G can also help simulate and replay uncommon clinical conditions, accelerating learning and skilling. Simulations can also help drive extreme personalization of surgery by factoring in personal attributes, vital statistics, medical history, etc., of the specific patient. Ambulance services may also immensely benefit from 5G technology, by quickly accessing patient records, connecting to the nearby hospital in advance, and also leveraging artificial intelligence at the Edge.



Technology is fallible and infrastructure is often unreliable in India. It is critical that all systems are built to function robustly even in the absence or failure of technology such as 5G.

Agriculture

Agriculture is not only a large contributor to India's GDP, it also provides employment to a majority of Indians. This is a sector with huge potential for improvement with the use of technologies such as 5G. Autonomous, self-propelled tractors are becoming available. Sensors and drones can help detect diseases quicker or help identify better strategies for improving yield. In agriculture, terrain is tough, areas are remote, and it is impossible to lay fiber. An important challenge to handle here as well as in other use cases that generate large amounts of data is traffic asymmetry. While Internet traffic tends to be downlink heavy, many of these use cases are uplink heavy, which require innovations in network protocols.

Industry 4.0

India is making a strong push to promote manufacturing with the Make in India initiative. With many manufacturing centers located away from urban areas where fiber links aren't yet prevalent, 5G can help provide superior connectivity and compute capability at the Edge. In one use case, Edge computing was shown to improve employee productivity and safety by around 25% in remote oil drilling locations.

Airtel is setting up 120 Edge data centers across India with a large focus on the manufacturing sector. In the automotive sector, testing spare parts for defects in near-real-time leveraging artificial intelligence-based visual analytics is gaining popularity. Images taken in near-real-time can be processed at the Edge, without having to transmit them to a Cloud data center. Detecting the defects sooner can avoid costly and time-consuming reparations and recall later on in the testing cycle. In one case, it helped improve customer satisfaction scores by around 30%.

Smart homes and cities

There are a number of use cases where 5G can help a city or home function better. Street or traffic lights can become Edge hubs that handle surveillance with cameras and other sensors, or power video advertisements. Home devices are all increasingly becoming smart and inter-connected. In most of these use cases, low latency and privacy are the primary drivers for 5G adoption.

5G and Edge infrastructure

In this section, we outline infrastructure requirements for deploying 5G and Edge applications.

With the advent of LTE and 5G, the telecom network stack has transitioned from dedicated and bundled hardware and software combination, to a model where network processing is performed entirely in software running on commodity off-the-shelf (COTS) hardware. This model has proven to be operator friendly along various dimensions such as capex cost, scalability, reliability, and velocity of rolling out new features. It is estimated that about 80% of the work involved in designing a new 5G chipset involves plumbing work such as data movement and protocol adherence, whereas only 20% of the work involves differentiated capabilities. This makes the case for building a common core set of plumbing modules in open source that all vendors and operators can then leverage, instead of each entity building the entire stack ground up. Besides reducing cost, this approach also lowers the barrier for specialized entities to bring in specific differentiators in the form of algorithms for channel estimation, forward error correction, beam forming, etc.

While there have been efforts in the O-RAN community [44] to provide a common software platform for telecom operators for the Radio Access Network (RAN), additional work is needed in this space to reap the benefits of the 5G evolution. For instance, one approach is to enable a marketplace model, where operators provide RAN-as-a-service with Service Level Objectives (SLOs) on key operational metrics

such as spectral efficiency and cost of operation. Enabling such a marketplace model would require well defined interfaces between the various components. Each service could then be implemented as a micro-service that talks to a specific set of dependent services to provide functionality. Such a model natively enables fine-grained telemetry for metering and monitoring SLO violations. The micro-services model is a well adopted model in the information technology world for its numerous benefits such as separation of concerns amongst various services, security, auditing, feature velocity, etc. Bringing this marketplace model to the telecom world is strongly believed to help bring additional innovation and monetization opportunities for all players in the telecom ecosystem. For instance, each device on entering the network, could advertise its capabilities as well as requirements from the network on a per use case basis. Based on this information, the network operator and device could jointly decide on the set of network features such as waveform and FEC parameters that would optimize the application QoS. This is in stark differentiation from the current one size fits all model where all devices are treated equally by the network irrespective of their capabilities and application needs.

Similarly, there is a need on the regulatory side as well to ensure 5G innovations are accelerated. For instance, there is a need to allow active electronics sharing amongst the different operators. Today, operators are allowed to only share passive infra such as base station towers. On the other hand, a marketplace model with appropriate regulatory changes would enable operators to share available spectrum opportunistically to satisfy flash crowds in particular regions or ensure adequate connectivity during critical maintenance

activities. It is imperative that regulatory frameworks designed for 2G are updated for the needs of 5G and beyond.

Closely related to 5G is the deployment of Edge infrastructure for supporting ultra-low latency applications. Typically, Edge deployments are operated on telecom infrastructure to support compute and data processing as close to the source as possible. Having a virtualized infrastructure deployed at the Edge enables deploying applications across both the Edge and the Cloud seamlessly. Depending on application needs and resource availability, such applications can be vertically sliced such that the critical low latency functionalities are deployed at the Edge, while the resource heavy non-latency-critical functionalities reside on the Cloud. A similar marketplace model with well-defined interfaces for Edge applications, would enable rapid innovation in the types of Edge services as well as additional monetization opportunities for both telecom and Cloud operators. Unsurprisingly, all major Cloud operators currently provide Edge services that allow extending Cloud applications to their on-prem or managed Edge locations.

Research challenges and strategies for skilling

To enable wide spread adoption of 5G and Edge computing in India, we need to overcome certain important challenges in networking, storage, observability, operations and management. Research contributions in this space can greatly help evolve our 5G journey. A main challenge that needs to be explored as part of research is: can we enable 5G to be ready for ultra-low latency (< 30 ms) Edge applications? This requires not only evolving the infrastructure but also revisiting the entire 5G architecture. The telecommunication architecture was traditionally built for dedicated hardware boxes and not for the Cloud-based Network Function Virtualization (NFV) paradigm that 5G is being built on. Like most Cloud-based solutions, it is important for 5G and Edge Cloud architectures to consider scalability and fault tolerance as first order requirements and not as an afterthought. But this requires a thorough understanding of the 3GPP standards which is a significant learning curve. Resources and tutorials must be developed to make the learning curve easier to overcome for students and early practitioners.

Efficient systems for monitoring and collecting telemetry information from 5G and Edge components is paramount for efficient operations and management. This problem is extremely challenging given the massively geo-distributed nature of the infrastructure, applications and data. Modern technologies such as programmable networks can be leveraged for efficient telemetry collection and timely diagnosis. This also opens up avenues to use packet headers for monitoring hints and help better root cause identification at Network Interface Card (NIC), kernel and switch layers.

One of the main challenges that academia faces to pursue research in this space is the lack of visibility and access to real telecom deployments. Edge data center deployments like that of Alibaba need to be analyzed to utilize the learnings in other deployments. Industry and academia need to work in tandem for faster and verifiable solutions for the next generation of networks. There needs to be a shared

ecosystem to test solutions for industry grade performance requirements. One such attempt is made as part of the TiHAN project to build an autonomous vehicle environment with an Edge and core Cloud.

Building such an environment not only requires proper infrastructure but also highly skilled and motivated students and developers. Students need to be trained on cutting-edge systems, latest tools and technologies with hands-on courses, workshops and tutorials. They must develop expertise across the software stack, right from the kernel, platform technologies such as containers and Kubernetes, middleware components and in developing the core application logic.

Conclusion

India holds great promise in not only developing innovative solutions leveraging 5G and Edge computing, but also deploying them at a scale not witnessed elsewhere in the world. Realizing this promise requires innovation across the board — in use cases relevant for India, infrastructure roll-out to the most remote villages, and in making the unit economics work for the average Indian consumer. This requires industry, government, and academia to work in synergy to cultivate the ecosystem under which innovation can not only take root, but also thrive. This workshop served as a stepping stone towards this vision.

Chapter 6
key takeaways

1 For a country like India where majority of the population use cell phones as the sole technology touch point, 5G is predicted to have a great impact in terms of improved connectivity and enabling innovative applications across tele health, agriculture, smart manufacturing etc.

2 An important research challenge is around enabling 5G for ultra-low latency (< 30 ms) Edge applications by revisiting the entire 5G architecture, particularly in terms of innovations in the software NFV space that is seeing wide deployment in telcos.

3 There is an ever increasing need for industry-academia collaboration to provide access to large scale deployments and train the next generation of skilled workforce that can understand and solve real world problems.

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