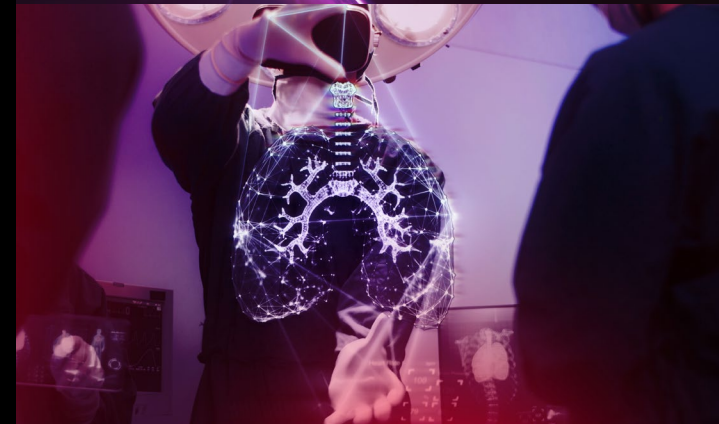# Emerging Technologies 2024 Vision Report

Report

Introduction

Keysight partners with researchers, companies, and standards bodies at the forefront of new technology.

We see how co-innovation and collaboration across industries and disciplines are vital to bridging the gap between research and the real world — so innovators like you can keep pushing boundaries and solving complex engineering problems to bring world-changing technologies to market faster.

At Keysight World: Innovate, industry leaders and researchers with diverse expertise and perspectives share their insights on how innovative capabilities such as artificial intelligence, machine learning, and digital twins will propel disruptive technologies forward.

This report highlights our most recent event, which explored trends and opportunities in wireless communications, automotive, aerospace and defense, and digital healthcare.

Key topics included:

The **metaverse's** foundation is connectivity. Multiple layers of 5G and, eventually, 6G connections must seamlessly bridge and coexist for the metaverse to connect everything.

Software-defined vehicles are the next milestone in the automotive industry's journey toward full autonomy. Sensor modeling and fusion are necessary to deliver this evolution, so software can make sense of all the vehicle data without the need to build a data center on wheels.

Moving to **non-terrestrial networks** to augment terrestrial 5G communication creates many possibilities. As more

companies and countries make the shift, we must address multi-network coexistence, frequency optimization, and latency minimization.

AI-driven digital healthcare will improve disease prediction, diagnosis, treatment, and patient outcomes. As healthcare moves from simple medical wearables to integrated diagnostic tools, what are the industry's design limitations and roadblocks? Technical hurdles must be overcome to deliver personalized healthcare.

As an enduring business that's been around

for over eight decades, Keysight anticipates disruptive technologies and the unexpected challenges that will arise during their development. Sharing insight and expertise is how we become partners in innovation.

Our experts will be there at each step of your research and development journey — with design, emulation, and validation solutions to help your most ambitious dreams become reality.

Jeff Harris
Keysight Vice President
Corporate and Portfolio Marketing

Keysight World: Innovate host Jeff Harris

The Metaverse

Interest in the metaverse has been steadily growing, with [Google](#) recording an average of 1.9 million searches for the term in January 2023 alone.

The metaverse means different things to different people. It has myriad consumer and enterprise use cases — from augmented reality (AR) glasses that provide navigation assistance to three-dimensional (3D) teleconferences enabling globally distributed teams to interact in real time.

At its core, the metaverse is a window that enables people to share an immersive experience, whether it's for pleasure, business, or innovation.

Powered by progress in 5G and 6G, along with ongoing innovations in extended reality and computer-generated imagery, the metaverse will enable a new era of digital experiences that seamlessly blend technology with reality. This has countless enterprise implications, including digital twin innovations that will redefine hardware and software testing. Realizing these possibilities

47%

of Keysight World: Innovate attendees say their companies are currently or planning to invest in the 5G capabilities needed for the metaverse

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requires overcoming the critical latency, speed, and bandwidth challenges.

Defining the metaverse

The metaverse represents a new frontier in mixed reality (MR). The technology brings an understanding of depth and people's movement within a 3D space — enabling them to interact in physical and virtual environments. Such capabilities could enable innovations like performing surgery remotely using MR devices that overlay important anatomical or surgery-specific information.

This blurring of boundaries between the virtual and the real worlds promises exciting new possibilities for use cases across sectors. First, we must define a shared vision to focus our industry-wide expertise on advancing the standards and capabilities needed to make the metaverse a reality.

"We need to define this new future together. As engineers, we're not looking for a solution yet. We're still working to define the problem," says Jonathon Wright, chief evangelist of software testing at Keysight. "At this point, it's easiest to think of the metaverse as a three-dimensional internet experience." Operating under this definition, as the internet changes, so too will the metaverse.

Web 3.0 innovations will decentralize the internet and make it user-driven rather than platform-driven. This shift will enable individuals and their data to shape their experiences, creating new opportunities for services and products.

Expect immersive experiences that revolve around the user — from the latter's physical movements and environments to their connections and data. This will require incredibly fast speeds as well as extremely high latencies. Think about a game of virtual ping-pong with a colleague on the other side of the world and the connection speed required to support real-time play.

Testing challenges

The metaverse will open up new opportunities for testing, but paradoxically, the possibilities can only come to fruition once the industry overcomes numerous testing challenges.

The metaverse will require complex software, hardware, and systems to interact with each other seamlessly and at previously unachieved rates of speed.

Applications must sense the position of objects in a virtual space and the users' physical space, to tracking where the users are looking,

Three critical test requirements for the metaverse

Using the example of remote surgery, let's examine the three primary test cases for metaverse applications.

1

Positioning

The application needs to know the patient's positioning along with the movement of the robotic arm and how they change in relation to each other.

2

Eye tracking

Information must be rendered in the area where the physician is looking and relayed over the internet as quickly as possible.

3

Latency

With motion to photon inputs of less than 20 milliseconds, the metaverse must relay data in real-time within a 3D space — even between two surgeons on opposite ends of the world.

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and instantly rendering their field of vision. The bandwidth needed to deliver a seamless experience will require more data throughput than 5G will ever offer. That's why all eyes are on 6G to overcome these issues and usher in the next phase of metaverse possibilities — a topic we'll explore further in this report.
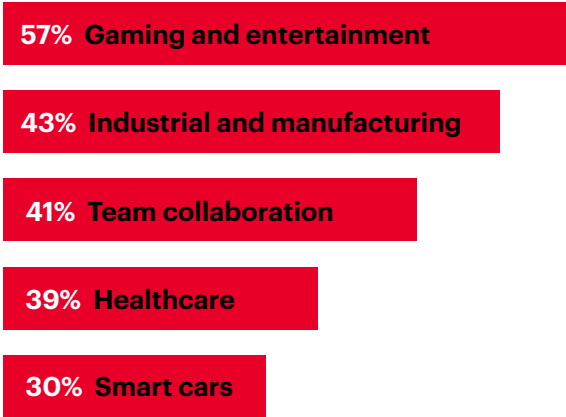
New opportunities for testing

The metaverse is poised to transform hardware and software testing. Digital twins are dynamic virtual copies of a physical system that enable you to evaluate technologies and applications. Digital twin simulations help engineers analyze the safety, performance, and functionality of their designs to determine how they will behave in the real world, enabling them to arrive at the best design faster. By simulating millions of test permutations, engineers can more rapidly identify and address potential issues without time-intensive "test/iterate/retest" cycles.

However, these testing benefits are in their relative infancy when you think about what a metaverse-powered digital twin could do. Consider preparing a spacecraft using a simulation where hundreds of people worldwide can contribute their expertise, simulating and testing complex scenarios before launch. Or developing more natural, prosthetics by using the metaverse to model and understand joint movement as it relates to specific actions — gripping a pen, kicking a ball, or climbing stairs.

Tune in to the metaverse episode on Source De[Code]

Join Ben as he figures out what all the metaverse hype is about. Hear from several experts, including Dr. Alan Bovik, who specializes in making the metaverse experience a reality.

→ **Listen now**

Top areas Keysight World: Innovate attendees expect revolutionary metaverse use cases:

57% Gaming and entertainment

43% Industrial and manufacturing

41% Team collaboration

39% Healthcare

30% Smart cars

Testing in the metaverse will become critical when more devices move into MR, as companies must account for technology performance across elements like hand gestures, eye movements, and body tracking. Enabling product stakeholders to interact and work together — both with each other and the ultimate end users — throughout the design phase will result in better, faster-to-market products and open up new opportunities for innovation.

We're only beginning to realize what the metaverse can do. These technologies may take years to become standard, but work is underway, and together, we can accelerate what's next for the metaverse.

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Left to right: Devaki Chandramouli, Sarah LaSelva, and Muriel Médard share their perspectives during Keysight World: Innovate

Advancing the Metaverse: Experts Weigh In

The possibility of a fully immersive internet is inching closer to reality — but we're not there yet. The vision hinges on new data-compression techniques, intelligent transmission approaches, and advances, in interactive sharing, along with the development of high-speed, low-latency 5G and 6G networks.

To understand more about these enabling technologies and the work ahead, we spoke with some of the leading voices in this space: Muriel Médard, the NEC professor of software science and engineering at MIT; Devaki Chandramouli, Bell Labs fellow and head of North American standardization at Nokia; and Sarah LaSelva, director of 6G marketing at Keysight. Below is an edited recap of the discussion:

Q: What are the metaverse's potential applications, and what are some of the most exciting use cases on the horizon?

Devaki: With the industrial and enterprise metaverses, we have the potential to improve productivity, reduce costs, and save energy. Reducing system downtime can have far reaching effects in getting the services in real time that we can only do manually today. The consumer enterprise is the opposite and focuses on improving the user experience.

Sarah: I'm most excited about the industrial metaverse. It has the potential to revolutionize how we work together. We've all been stuck at home for the last few years, and while some of us are getting back into the office, I know I still have a lot of video calls. I love

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the idea of having those calls feel more like an in-person experience — for example, more body language and expression.

I also love the idea of some of the tech support opportunities, like the concept of having a technician on the floor being able to talk to an engineer at a different location. Let's say they're troubleshooting a car issue. Having the ability to project things onto a screen with AR can help you identify and remedy the problem better.

Leveraging the faster, better, more immersive internet of the metaverse will bring us closer together and facilitate more real-time communication.

Muriel: I take more of an academic view, which is that the metaverse will open up new possibilities in both education and research. We will be utilizing different modes of research and collaboration and also different themes of research — something which, at this point, we've only just begun to consider.

Q: What are some of the key technology enablers in the near term, and what role will 5G play?

> ## It's not just about boosting the bandwidth to get more data — it's also about getting the right data at the right time, and in the right location.

Muriel Médard
NEC professor of software science and engineering
Massachusetts Institute of Technology

Devaki: For a truly immersive experience, users will expect 90 t0 100 frames per second and up to 8K resolution. Delivering on these expectations requires an extremely high data rate. It's also challenging from a device perspective. For example, heat dissipation poses user experience issues, and you also need split rendering, edge computing, seamless mobility, and service continuity.

5G is expected to provide the capacity, high bandwidth, and throughput. 5G also

brings in the coverage — which is the mobility and service continuity we need.

Muriel: One of the biggest things that stands out to me is the issue of latency. It's not just about boosting the bandwidth to get more data. It's also about getting the right data at the right time and in the right location. We need to do this for everybody in all places, without people noticing. Users won't want to be constantly aware of switching from Wi-Fi to 5G to 6G and back again, so it's a question of getting everything involved to peacefully coexist with minimal user awareness.

Sarah: 5G non-terrestrial networks are another connection point to consider. I see these as critical to providing the seamless, gap-free coverage required for the metaverse. But we need 6G to complete the coverage vision that 5G has started.

Q: Speaking of 6G, what advances are necessary to support metaverse experiences?

Devaki: Right now, there are numerous technology enablers and solutions aimed at improving the 5G quality-of-service framework, including radio resource management, power savings from the device standpoint, and closer integration

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23% say power consumption is the biggest challenge

38% say coverage and network architecture are the biggest challenges

Keysight World: Innovate attendees say coverage, network architecture, and power consumption will be the **biggest challenges** to 5G / 6G performance

between the network and application to enable support for low-latency services. It's imperative that 6G get this right from day one. 6G will also need a spectrum in the *golden band* — 7 to 15 GHz — which will offer 400 MHz bandwidth, improving capacity by 20%. We need to utilize the spectrum effectively with proper antenna design, and it's important that when designing 6G network architecture, it's designed so that it's already application-aware and caters to the adaptive high-bandwidth applications.

Sarah: One of the most critical focus areas is uplink. 5G really struggles with this if you think about uploading a video in a crowded

stadium, for example. This is something 6G must be prepared to address, as we'll need major improvements in both downlink and uplink if we want things like 3D telepresence.

Muriel: The metaverse will necessitate that we're able to switch between Wi-Fi, 5G, and 6G simultaneously. We'll see numerous new devices with different requirements — for example, needing a raw channel or short code. I hope this will introduce a more prescriptive philosophy with standards focused less on interoperability and more on collaboration. Whereas the legacy approach has dictated what devices should say to each other, the prescriptive framework

the metaverse needs should focus on how they talk to each other.

Q: Do you think the metaverse will pull 6G development or is it vice versa, in that 5G and 6G will push it forward?

Muriel: The idea of pull and push is always there with any technology. You have a device pushing the technology, but it's also pulling because now there is a demand. Different metaverse applications are obviously going to a pull. Once you see that you can do things faster and at a higher quality, you can't go back. On the flip side, it's important that things don't just conk out, so the technology needs to be there to support it.

Getting low latency is going to be a key enabler, as well as having it without excessive cost. There are a lot of issues around how much work the devices need to do to get what they need done. I'm hoping that revisiting the view of standards will enable the bespoke types of services we need. The industry has a lot of research — we just need a mechanism for getting that into the network.

Devaki: I agree; it's both a push and a pull. We need 5G and 6G to make the metaverse happen, but we also need the metaverse to

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improve adoption. The metaverse's success rests on an entire ecosystem — from the devices, networking structure, the services, the content, to the tools, and more. And finally, the service innovation; we need the business case to make it all happen.

Ultimately, it will be the market forces that decide which use cases take off. And eventually, when we see millions of users adopting the metaverse, these applications and the cost of devices and services will drop. That's why 5G, 6G, and the metaverse need one another in order to be successful — it's a win-win situation.

Sarah: It's always a bit of give and take. When we pushed LTE out, no one imagined the things that would happen with a device with high-speed connectivity and GPS location. We have things like Uber. Who could have predicted that a ride-hailing app would be so widely adopted? When we deliver the low latency and highly deterministic, low-data throughput needed for the metaverse, we're going to see lots of new use cases come to market. It's definitely a push and pull and, hopefully, a symbiotic relationship.

Q: Where should we focus efforts the most, and where does security fall?

> ## We need 5G and 6G to make the metaverse happen, but we also need the metaverse to improve adoption.
>
> **Devaki Chandramouli**
> Bell Labs fellow and head of North American standardization
> Nokia

Sarah: When I envision a successful metaverse, Wi-Fi-to-cellular handoff plays a big role. If your Zoom call drops when you leave your office, that's a minor annoyance. But it's a much bigger issue when you think about immersive experiences. A drop in service could be a real deal breaker for metaverse adoption, and the industry needs to address this accordingly.

From a security perspective, we need to think about data protection and engendering users' trust in our ability to safeguard that information. We're already seeing stories of utilities being hacked, and this threat will increase with industrial metaverse use cases unless security is prioritized from the get-go.

Muriel: To expand on this, if the metaverse becomes part of the daily necessary fabric of our professional, civic, and family lives, what happens if there is a denial of service? I can foresee jamming becoming a huge problem in industrial scenarios, for example. There's also the question of IP exposure in industrial applications when companies start building new technologies in the metaverse. Security is clearly a multidimensional problem, and I'm hoping that 6G will look at all of these aspects from the start.

Devaki: The use of plain data is another concern. We need to ensure that it's encrypted, either end to end or within the network itself, and we also must confirm that the devices are capable of this encryption.

It's clear that 5G has started us on the path to metaverse innovation, but much hinges on next-generation 6G to make these possibilities a reality.

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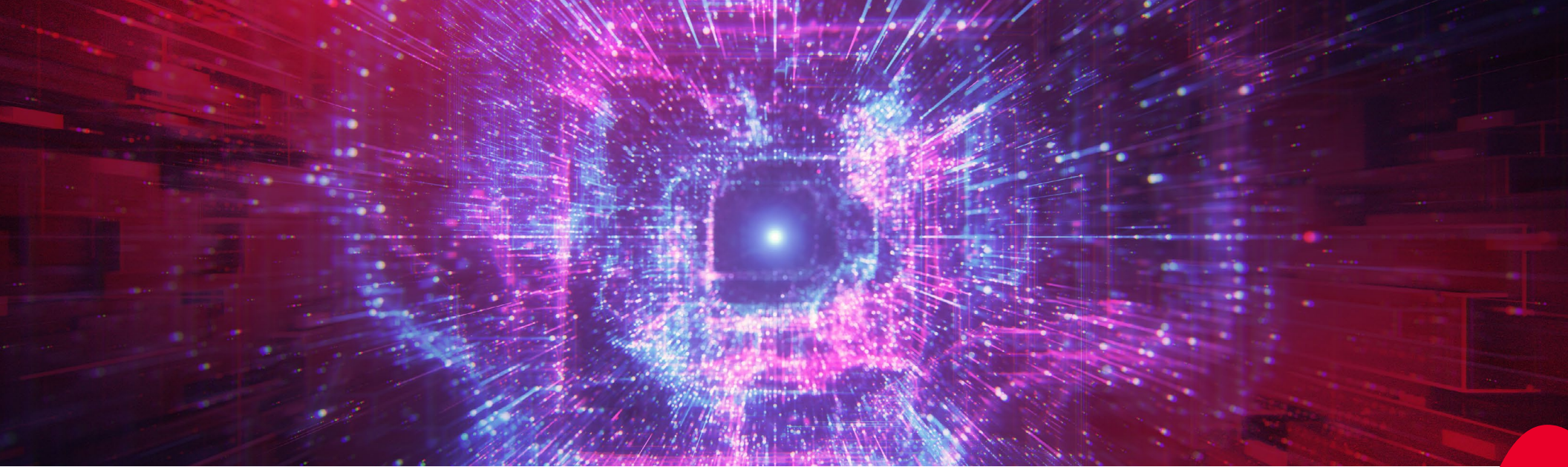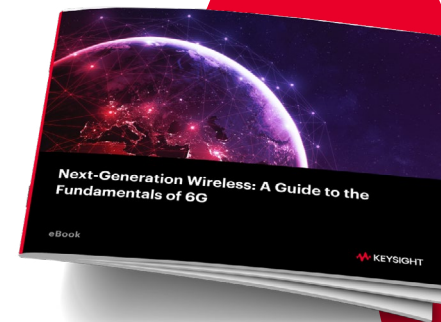
Hacking the Wireless Metaverse with 6G and AI

The metaverse requires a unique combination of resilience, reliability, and robustness, along with support for AR, MR, cognitive reasoning, and other critical technologies and applications.

Enabling this necessitates extremely high data rates, which require lots of terabits per second. Near-zero end-to-end latency and high reliability are also critical, along with synchronization — meaning actions must align between the physical and virtual worlds. For example, when an autonomous vehicle makes

a turn, its twin must sense the movement and turn. This combination of high data requirements and synchronization represents a new challenge for wireless.

The role of 6G

6G THz bands can support the data needs, but something as simple as a hand movement can block the signal. When you extend this into a typical metaverse environment, it's clear significant blockage would create more delays and affect reliability. The latter requires a continuous line of sight, making sensing a critical component of the metaverse. We spoke with Virginia Tech professor Dr. Walid Saad to understand more about this and other wireless requirements for metaverse success.

Next-Generation Wireless: A Guide to the Fundamentals of 6G

eBook

KEYSIGHT

→ **Download our guide to 6G fundamentals**

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Saad believes that THz can help with sensing, stating, "Every communication signal blockage is actually a sensing opportunity," he says. The wireless system can extract the sensing and identify the blockers and draw on AI to predict the past and future — thereby becoming more resilient and reliable.

Getting in sync

The question then comes down to synchronization, a topic Saad believes contains more questions than answers at this point. He suggests thinking of the metaverse not as a single system, but rather as a distributed set of "sub-metaverses"—perhaps geographical or logical pieces.

Each piece has a different integration requirement, and a single cloud cannot address all of these needs. Not only would that prevent synchronization, it's also not sustainable or energy efficient, meaning it's not a viable approach as the metaverse scales.
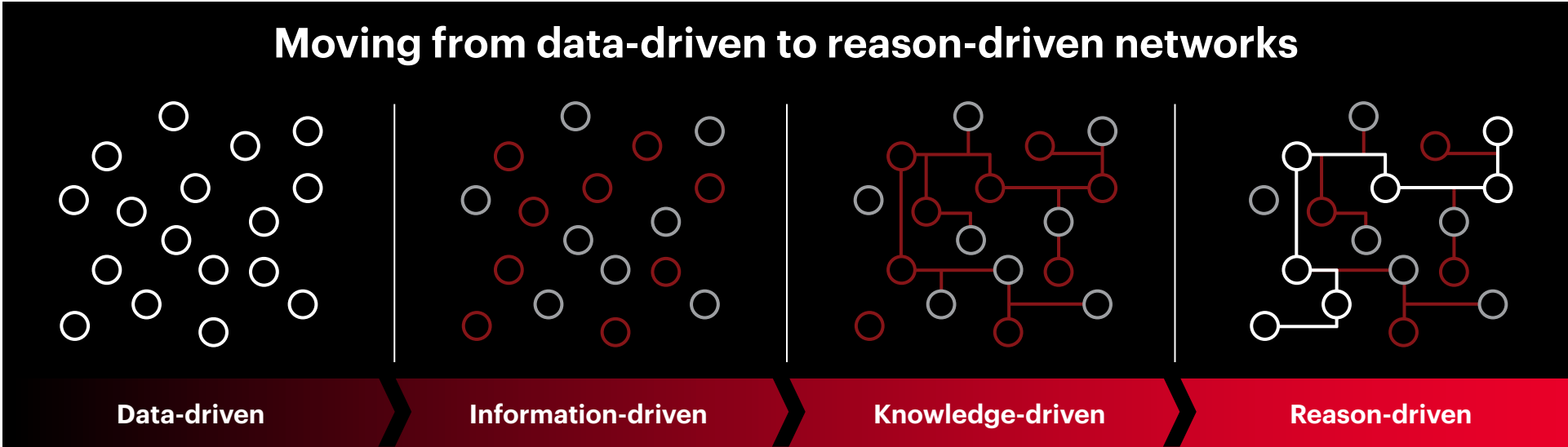
Much work remains to address these concerns, as current 6G work focuses on latency requirements with less attention paid to resilience and synchronization. 6G research must expand to encapsulate these areas and also tackle their respective testing challenges.

Beyond 6G

6G is critical to realizing metaverse possibilities, but the industry also must

rethink how communication, computing, and AI come together. To achieve such coordination, wireless networks must boost their cognitive capabilities — for example, hone the ability to learn from data, reason, and build a knowledge base. As Saad puts it, "We need to move away from data-driven wireless networks to reason-driven networks."

He envisions a future of semantic communications in which the transmitter becomes a teacher, extrapolating meaning from the data and teaching its apprentice, the receiver. Just as human instructors rely on students' reasoning faculties to fill in certain areas of a lesson, AI-powered receivers will contain the requisite cognitive function to draw correlations from their

Moving from data-driven to reason-driven networks

Data-driven ⟩ **Information-driven** ⟩ **Knowledge-driven** ⟩ **Reason-driven**

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We need to move away from data-driven wireless networks to reason-driven networks.

Dr. Walid Saad
Professor of electrical and computer engineering
Virginia Tech

instruction. Saad underscores that with semantic communications, rather than sending "dumb bits," we need to send an interpretation of that data to wireless networks.

AI algorithms must become more predictable, reasoning-based, able to adapt based on their learning, able to aggregate collective brainpower, use significantly less energy, and continually learn.

If and when we address these considerations, semantic communications will support a reason-based network with contextual awareness at the transmitter level. For example, the wireless system will be able to identify that this is a metaverse experience about software testing and can predict what is going to happen and correct errors more effectively.
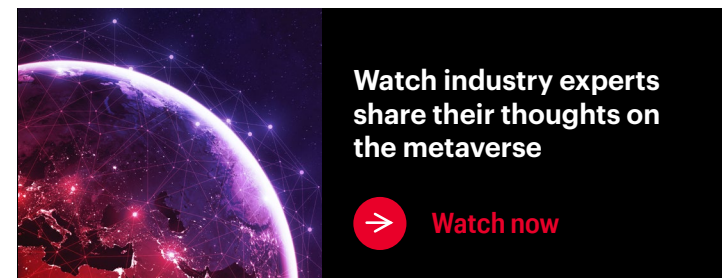
Theoretically, this system would transmit less data compared with current state-of-the-art networks but achieve greater semantic reliability. And the latter means that we can better support immersive metaverse experiences over real-world 6G and beyond in areas such as digital twin technology, quantum computing, and autonomous vehicles, to name a few.

Innovating smarter to capitalize on metaverse opportunities

Technology is transforming all aspects of how we work and live. At Keysight, we believe that the metaverse is one of the most exciting examples of this change. To deliver on its potential, the metaverse must provide a continuous experience without interruptions — a feat at which current MR use cases fall woefully short.

Many elements must come together to realize the metaverse's possibilities. From a wireless perspective, things like robustness, resilience, and synchronization are critical. The concept of reason-driven networks that convert dumb bits into meaningful communication, has the potential to address many current limitations. As we overcome these hurdles, our understanding of what the metaverse can do will deepen.

With new capabilities, however, comes further complexity. Here at Keysight, we work with innovators across industries to provide a deeper understanding of how this evolution affects applications at the technology, system, and business process levels. We empower organizations to overhaul their testing strategies so that they can simultaneously account for and capitalize on these emerging technologies.

Watch industry experts share their thoughts on the metaverse

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Software-Defined Vehicles

The automotive industry is undergoing a revolution with the shift to electric and increasingly autonomous vehicles (AVs). Today, vehicles are a complex web of software, sensors, and systems with the goal of making driving safer through more automation. Cars now have an array of embedded software and systems, such as advanced driver-assistance systems (ADAS), forward collision alerts, and blind-spot monitoring. Across the globe, numerous pilots are underway to test and evaluate these capabilities in order to advance autonomous driving.

AVs and robotaxis are becoming more commonplace in some US cities, including San Francisco, Austin, and Phoenix. Progress is more measured in Europe, with the different countries at various stages. In Asia, multiple pilots are underway as the region strives for a leadership role in the AV market. These initiatives have highlighted the differences the auto industry must consider.

The industry needs to account for numerous variables before level 4 and 5 autonomy can become a reality. They include the role of weather, the impact of other pedestrians and cyclists, and the challenge of navigating a narrow road versus a wide freeway.

Autonomous driving is extremely complex. Achieving Level 5 autonomy, where the vehicle makes all of the decisions, is a huge undertaking as there are so many variables to account for. AVs need a lot of sophisticated technology in order to function safely, including a mix of sensors, such as cameras, lidar, and radar, to perceive their surroundings. All of this generates a lot of data for the vehicle to process in real time, requiring advanced hardware and software coupled with sophisticated and reliable algorithms.

Overcoming technical issues such as interoperability and compute power is necessary to increase autonomy. This creates

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38%

of Keysight World: Innovate attendees say AI-based systems enable quick and effective decisions on the road
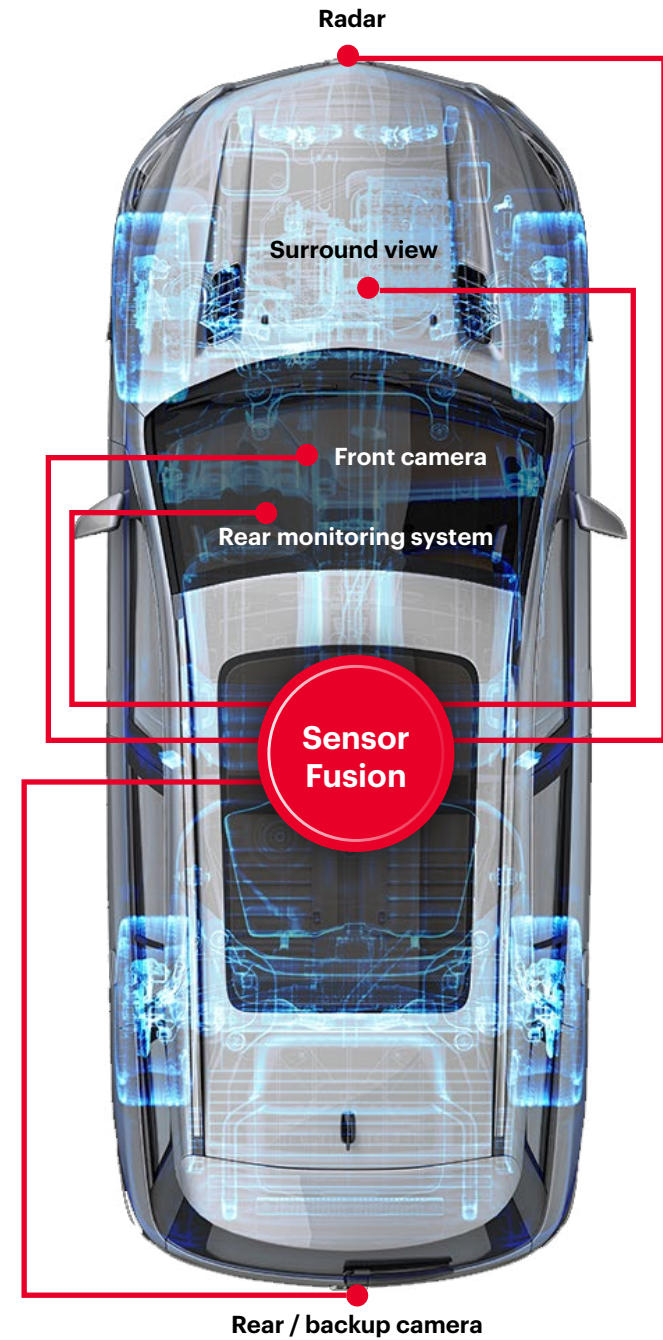
Programming a car with just traffic laws is not sufficient and fails to account for the wider environment, which can include cyclists, pedestrians, and other vehicles that are very unpredictable and often fail to obey traffic laws.

When AVs run into problems, they either slow to a crawl or stop to avoid any issues while they figure out how to respond. A self-driving vehicle needs to be able to balance driving comfort and time efficiency. Achieving this requires an AV to understand the intentions of the people and other machines it will encounter while driving.

Delivering fully autonomous driving requires building on the mix of technology already embedded, such as sensors, radar, and lidar, to help vehicles see and anticipate problems.

Software-defined vehicles

Software-defined vehicles (SDVs), which need sensor modeling and fusion, are the next critical milestone in the automotive industry's journey toward more autonomous driving. With sensor fusion, a processing system uses the combined abilities of all sensors in a vehicle to provide the best possible safety system. For example, weather impacting road conditions results in the sensors feeding that

a vast testing burden to ensure the AV handles safely and effectively. As a result, delivering a safe, fully autonomous driving experience under every eventuality is a seismic challenge requiring collaboration across the ecosystem.

Having clear rules is crucial for algorithms to make safe real-time decisions and achieve full autonomy. This requires replicating the human brain with the technology and sensors in a vehicle to make it predictable.

Radar

Surround view

Front camera

Rear monitoring system

Sensor Fusion

Rear / backup camera

information to processors and algorithms that enable the processing system to make decisions about how the vehicle should respond.

How the SDV interprets all of the data to make accurate real-time decisions is a significant challenge. A mix of AI and machine learning is necessary for autonomous driving to work reliably without a network connection. And all the components need thorough testing and evaluation before the rubber meets the road. How vehicles learn to perceive and predict is crucial in order to accelerate autonomous driving.

Training a vehicle to anticipate

The technology race in vehicles is creating vast data streams that can aid development by improving deterministic decision-making. The critical next step for self-driving vehicles is the ability to predict how a traffic situation will develop. The vehicles must understand, for example, how other users, like pedestrians or cyclists, will react and then determine a response, such as slowing down when approaching a dangerous scenario and accelerating when the potential problem is in the rearview mirror. The ability to sense and react to context comes naturally to humans; however, vehicles require training to do this.

> **An important human sensory modality has been neglected by self-driving vehicles so far: hearing... we can sometimes hear other road users before seeing them.**
>
> **Dariu Gavrila**
> Professor and head of the Intelligent Vehicles Group
> Delft University of Technology

Just think about the volume of scenarios, weather, speed, other vehicles, e-bikes, and pedestrians on a journey from Florida to Maine.

We spoke with Dariu Gavrila, professor and head of the Intelligent Vehicles Group at Delft University of Technology, to understand more about the drive to fully autonomous vehicles. Highway driving can be considered relatively easy because of the structured environment," he explains. "Urban driving is relatively hard

as lanes might not be well marked. There's cross traffic or pedestrian cyclists and traffic lights to care about."

Humans rely heavily on contextual clues to anticipate how a traffic situation will evolve. Training a vehicle to do this requires a predictive model that can assess multiple inputs and potential outcomes (or scenarios) to determine if a collision might occur and the required response to avoid it or minimize the impact.

Anticipation is a key hurdle for self-driving vehicles to overcome, and the industry is evaluating which motion cues to incorporate. More context is vital to improve decision-making. However, this requires reliably extracting context, and these sophisticated models require enough data to thoroughly train them.

The ability to predict the unpredictable is the biggest challenge on the road to fully autonomous driving. Moving forward, a mix of expert and data-driven models will likely be the answer. As part of this, we need to agree on whether to use one model globally for road user behavior or if there should be various options based on the type of road, country, or the size of a city or town. As Gavrila summarizes, "One thing becomes clear:

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AI training models for autonomous vehicles

1. Dynamic Bayesian network

A dynamic Bayesian network (DBN) evaluates variables that change over time. It focuses on discrete time, which considers data at separate periods.

With AVs, the predictive model considers factors such as whether the pedestrian is looking at a cell phone, where the person might step off the sidewalk, and if so, whether the car and human will collide.

The DBN consists of various nodes, which are either measurements or latent variable quantities that incorporate conditional dependencies between nodes.

These expert-driven models extrapolate the underlying basic motion as the prediction. The decision is learned from training data by observing actual pedestrian crossing and stopping behaviors. This approach supports quicker decision-making than previous models without context as it enables a car to take action, such as braking sharply, to avoid a crash.

Another advantage is that the motion prediction is generic and can apply to other road users. It also requires a comparatively low number of parameters to make its prediction.

2. Predictive motion models

These data-driven models involve neural networks, including recurrent and, more recently, transformers. This approach requires a lot of data, and it's harder to interpret. But with sufficient data to train the model, they outperform expert-driven models like the DBN.

Motion prediction has focused on line-of-sight sensing. As Delft University of Technology professor Dariu Gavrila points out, "An important human sensory modality has been neglected so far: hearing. In traffic, we can sometimes hear other road users before seeing them."

Hearing can't be ignored as we hear cars and cyclists before seeing them — influencing our behaviors. For example, we are aware of the sound of a vehicle about 1 second before it becomes visible. Acoustic reflection patterns reveal the presence and location of hidden traffic, and earlier detection provides more time for the vehicle to react.

The adoption of EVs will not affect acoustic patterns as they still create sound despite being quieter than combustion engines. Once a vehicle travels faster than 20 mph, the noise from tires dominates any engine-related sound.

prediction is very difficult, especially about the future."

Cars today have an array of sensors and in-vehicle networks, and all of the data collected is helping make them more predictable. Digital twin solutions enable simulations to evaluate the performance in realistic scenarios, fostering an environment where AVs can make accurate, predictable, and safe real-time decisions.

SDVs provide a dynamic platform that can accommodate the rapid advancements in AV technology. With software-defined architectures, automakers and developers can continually improve autonomous capabilities, paving the way to an autonomous future.

Keysight is working with market leaders to integrate advanced simulation, emulation, and testing platforms into their development workflows to give engineers a 360-degree view of their mission-critical vehicle systems with more insights into how they will operate in the real world.

To summarize: predictive motion models must evaluate everything and everyone in the vicinity, judge the probability of behaviors, and make adjustments as needed.

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Left to right: Sam Abuelsamid, Vijitha Chekuri, and Aaron Newman share their perspectives during Keysight World: Innovate

Advancing Autonomous Driving: Experts Weigh In

To understand more about SDVs and the challenges ahead in the pursuit of fully autonomous driving, we spoke to some of the leading voices in the industry: Sam Abuelsamid, principal analyst for mobility research at Guidehouse Insights; Vijitha Chekuri, automotive data expert for cloud computing at Amazon Web Services; and Aaron Newman, business development manager for autonomous vehicle technologies at Keysight. Below is an edited recap of the discussion:

Q: What is the state of technology today for software-defined vehicles as we transition to the vehicle of the future?

Sam: Many people thought we'd be riding in automated vehicles by now. However, the problem has turned out to be a lot more difficult than anybody anticipated to prove that these systems are safer than human drivers. A lot of work is underway on highly automated vehicles that don't need a human to supervise or intervene, and this technology is migrating down into driver-assistance systems. This is making these systems better so that those vehicles are safer, and we can hopefully start to reduce road crashes and fatalities in the coming years.

Vijitha: It's the decade of accelerating ADAS. All the technology developed to support AVs is shifting to consumer vehicles. Automated features like lane keeping, highway pilots, and traffic jam assistants are now widely available, but it will take a long time to perfect these systems.

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Q: How will partnerships and collaborations play into advancing AVs, and how will they deal with all of the data?

Vijitha: Partnerships are key. If you look at what it takes to develop highly automated vehicles, there are many elements, and collaboration is critical. Data needs to be organized and cataloged because storing data is expensive in the development phase. Engineers need tools that can quickly get data from the various systems, visualize it, and then run the particular data set through the system again to ensure the algorithm is performing well. This is a complex operation requiring complex tools.

Regarding sensor fusion, the two key things are perception and prediction models. Currently, there is no collaboration between companies, and there are differing views on relying on cameras and radars. It's a highly variable and complex topic.

Q: How will the industry manage all of the data, and how will that impact the strategy of vehicle software development?

Vijitha: When it comes to autonomous driving, it's a big data and a big compute problem. Depending on the sensor stack in the vehicle, you're collecting anywhere from

> ## Partnerships are key. If you look at what it takes to develop highly automated vehicles, there are many elements and collaboration is critical.
>
> **Vijitha Chekuri**
> Global head of automotive compute services GTM and business development
> Amazon Web Services

3TB of data for really low-end vehicles that have a couple of features. If you are going for Level 5 autonomy, you have upward of 40 sensors per vehicle generating approximately 80 TB of data per day. Therefore, a fleet of 100 cars creates a petabyte of data every day. This is a significant data management and maintenance issue as the information must be uniformly available to engineers and machine learning scientists around the world at scale.

Q: How do developers test all of their sensor fusion and algorithms, especially with regard to testing the vehicle?

Vijitha: Software development is a muscle that the industry is still mastering. You need to have a perfect DevOps environment for engineers and be able to control the software versioning and keep the data provenance model in place. The other big concept with SDVs is that you're trying to separate hardware development from software. If you test everything in hardware, it's expensive and time-consuming. With SDVs, you're testing early in the cycle and more often and making the emulators as closely developed to represent hardware as possible.

Aaron: The technology industry philosophy has long been to move fast, break things, and ship a minimum viable product. With vehicles, that's not viable, as the consequences of making a mistake can be life-threatening. That's why testing an incredibly broad range of scenarios is essential, as the driving environment has so many variables to account for. The testing burden is both significant and necessary.

Q: Does a vehicle decide what sensor data is most important when it comes to making instantaneous decisions on the road, or are

all those decisions preprogrammed?

Sam: It's a combination. With AI-based software, it's a probabilistic approach to deciding what's going to happen. In contrast, traditional software algorithms are much more deterministic. And because software doesn't work the same way the human brain does, it's really important to put some preprogrammed deterministic guardrails in place. This limits what it can do in order to make it as safe as you possibly can.

Q: How will the regulatory landscape evolve, and how will this impact the development and adoption of new self-driving car features?

Sam: This is one of the biggest challenges today — how do you decide these systems are good enough? Because the consequences are so significant when you get it wrong, this requires setting some pretty high standards. We've got regulations in some regions, but we still need a full regulatory regime that defines what is good enough. And that will probably take some years before we get to that stage.

It's going to be a slow, painful process. This is one of the reasons why today there are no self-driving vehicles that you can buy — because we haven't yet determined what is good enough to put in consumers' hands. There needs to be a lot more discussion and collaboration between regulators and

59%

of Keysight World: Innovate attendees say regulations are lagging in the automotive industry

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the industry. We want to avoid a scenario where the companies developing this are self-regulating. Rather than trusting they will do the right thing, we have to have some baseline thresholds for what's good enough before deployment.

Another important step is the Insurance Institute for Highway Safety (IHS) is updating its testing so that ADS systems will now be evaluated to verify that the features work. When the next round of safety picks come out based on these tests, automakers will push to ensure their systems comply.

Q: What does the future hold for the automotive industry, and how will the industry overcome the challenges on the road to fully autonomous vehicles?

Sam: The big challenges are around data transparency. We've got to be willing to share more data with each other about how these systems are performing in order to help develop best practices across the industry and to assist regulators as they develop their rules. Then manufacturers need to work on developing public trust in the technology. People must trust that the technology is actually doing what it promises. Part of this is showing people how it works, and organizations like the New

> ## We've got to be willing to share more data with each other about how these systems are performing in order to develop best practices across the industry.
>
> **Sam Abuelsamid**
> Principal analyst for mobility research services
> Guidehouse Insights

Car Assessment Program (NCAP) and IHS validate that these features are performing how we expect them to.

Q: What do we need to do to get to Level 5 fully autonomous vehicles? And when do you see that vision being delivered? What gaps do developers need to fill to get there?

Aaron: The sensors we have today don't really enable us to operate in cold climates.

Radar can help, but the net is that when the weather gets bad, autonomous vehicles will have to pull over to the side of the road until we improve our ability to sense the environment. We will need a lot of data from Level 4 to understand where the limitations are and a lot of learning for a car to drive as well as a human on icy roads.

Sam: With Levels 4 and 5, both are capable of driving without human intervention. The difference is that Level 4 can do it within a limited, defined operating domain. Level 5 means the vehicle can drive anywhere, anytime. I think what we're going to see is a gradual progression of Level 4 capabilities. Over the next few years, we'll see some vehicles capable of driving fully automated on highways, such as long-haul trucks. Over time the domain will gradually expand as trust grows with developers and the public.

Vijitha: Technology needs to ensure that the functions work in all weather conditions, all road conditions, and all possible environmental conditions.

It's clear we have a better understanding of what it will take to achieve full vehicle autonomy and more tools to make it a reality.
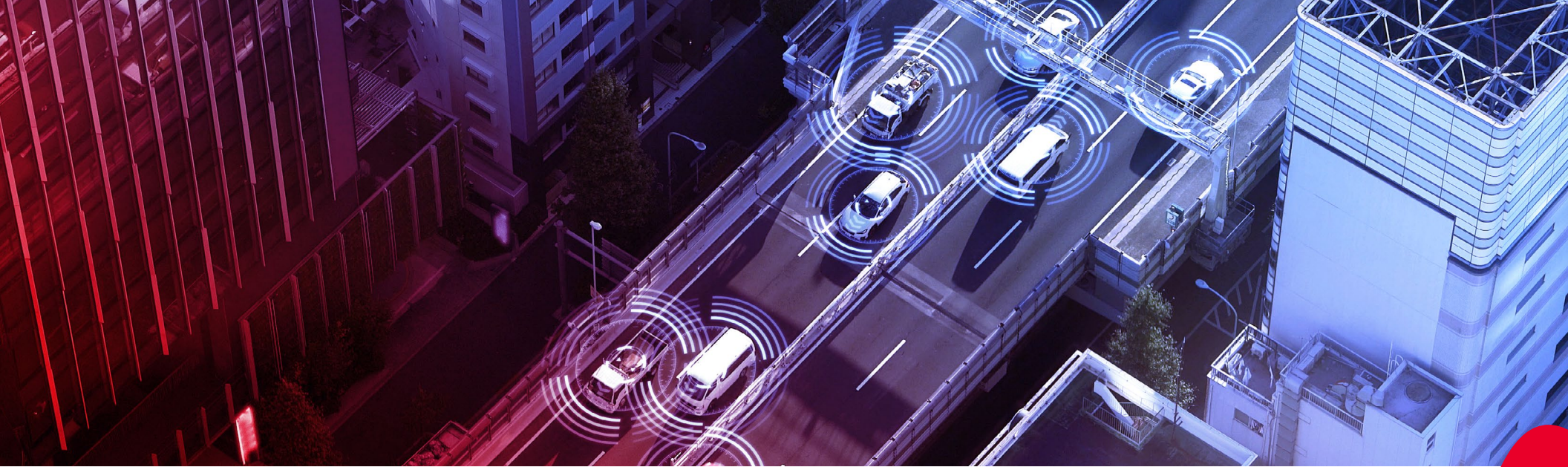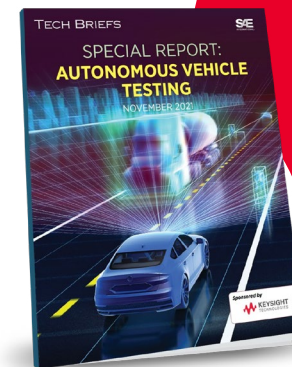
The Road Ahead Is Paved with AI

As we look forward, vehicles will undoubtedly become increasingly electric, connected, and autonomous. With the complexity and safety challenges involved in realizing full autonomy, intelligent technologies, including AI, machine learning, and deep learning, will be vital to supercharging these shifts. Let's explore how AI will help smooth the road toward more autonomous driving.

The drive to safety

AVs promise a safer driving experience.

Currently, 94% of crashes result from a human error around recognition, decision-making, or performance. As a result, many assume that by automating driving, the issue disappears. However, in reality, it simply shifts from a people problem to a programming problem.

This is still favorable, as avoiding a crash through programming until an optimized outcome is available is preferable to trying to do it live in the middle of an emergency. This sheds light on the fundamental challenge facing developers: the need to build and scale a vehicle able to recognize, decide, and perform as well or better than the best human drivers. And this is why it will take time before Level 5 fully autonomous vehicles become a reality.

→ **Download the SAE report on AV testing**

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As the industry develops SDVs with the goal of ultimately delivering fully autonomous driving, these cars must be capable of performing at the highest levels. Ensuring they operate as needed requires analyzing every aspect of the car through the lens of physics to understand and evaluate the vehicle dynamics to optimize performance.

The role of vehicle dynamics

Vehicle dynamics analyzes how a vehicle moves and changes in response to various in-motion situations. Once engineers understand these dynamics, they can optimize performance. For example, it is important to model how friction impacts a tire in response to forces caused by weather, accelerating, braking, and turning. An engineer can understand exactly how a car will respond through a mix of friction forces and vector math.

Engineers can then use these models to simulate and scenario plan for how vehicles will react under different circumstances. The data can help develop control systems to determine the optimal reaction. Vehicles already generate vast amounts of data daily, and as SDVs progress, we need a way to tap into this information to help build models to support more autonomous and safe driving.

> ## We can develop systems for the road that leverage the advances in AI and provide us the safety that we want to see.
>
> **Chris Gerdes**
> Professor and founding director
> Center for Automotive Research at Stanford (CARS)

AI to the rescue

AI can help process and learn from these data streams. For example, if you replace a math model with a neural network that mirrors human thinking, it uses deep learning to analyze the data sets from the real car. Its understanding of physics determines how the vehicle should drive safely based on the current variables. The intelligence learns how to determine when and how to brake, steer,

or accelerate. It's clear that AI is a powerful accelerant in the push for safer and more autonomous driving. However, these intelligent networks must undergo rigorous testing and evaluation to ensure confidence before a car hits the open road.

Building confidence in AI

We spoke to Chris Gerdes, director of the Center for Automotive Research at Stanford University, to understand more about building confidence in AI systems.

Gerdes believes there are three fundamental steps to follow:

1. **Build AI safely:** For example, when replacing an existing physics model with a set input-output, you should add a feedback control to increase the measure of safety.

2. **Simulate:** Use a digital twin and simulation to try and subject the system to every possible scenario and variation.

3. **Test in the real world:** Once the system has passed the lab testing creating a controlled real-life test is the final step in validating the system.

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Top technologies Keysight World: Innovate attendees believe instill confidence in AI:

- **26% Road testing**
- **23% Sensor fusion**
- **20% AI**
- **17% Digital twin**
- **16% LIDAR test**

The data from these steps feeds back into the digital twin to train it further and refine the responses, helping improve the safety of AVs.
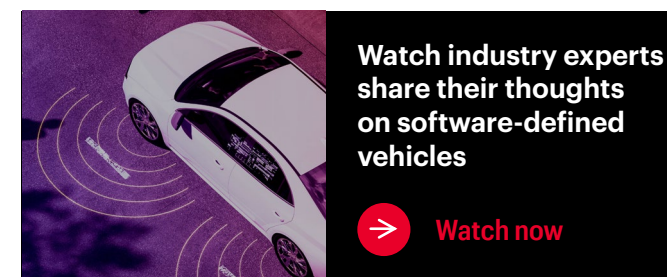
Gerdes' view is this "We can build competence and safety-critical systems with the new techniques of artificial intelligence. We can develop systems for the road that leverage the advances in AI and provide us with the safety that we want to see. With that, we can envision a future where the only limits to avoiding crashes are the very laws of physics themselves."

At Keysight, we share this vision that AI is opening a world of possibilities that will transform how we design and build innovations safely and securely, including the pursuit of more autonomous driving. Developing trust in these systems is critical, but delivering on this is complex, with little to no room for error. Identifying and addressing every potential loophole is critical to delivering a safe autonomous driving experience. And it's not enough to test until the car hits the road. Each software or system update must be subject to the same rigorous evaluation to avoid introducing performance issues.

More intelligent technology is necessary to test that the AV performs exactly as expected, meeting the necessary safety standards under every scenario. This is shining a spotlight on AI and digital twins that are blending physical and virtual worlds, ushering in a new era of designing, emulating, and validating complex innovations. In the coming years, cars will become increasingly autonomous and, with that, safer.

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Exploring the Possibilities of Space 3.0

Non-terrestrial networks (NTNs) are another exciting example of how advances in technology open the door for innovation.

Previous cellular network technologies used terrestrial network infrastructure exclusively. In contrast, the 3rd Generation Partnership Project (3GPP) plans to leverage 5G to incorporate low-Earth-orbit (LEO) satellites and high-altitude platforms such as balloons, airships, and pilotless aerial systems. With NTNs, mobile network operators (MNOs) can deliver 5G services to areas lacking terrestrial infrastructure and in situations where terrestrial networks become unavailable, such as a natural disaster. Satellite communications will also bolster coverage stability for passengers on planes, trains, and other moving platforms; augment service continuity for machine-to-machine and IoT devices; and bolster the reliability of mission-critical communications.

NTNs bring real-world benefits

5G NTNs will fill gaps in terrestrial cellular coverage, enabling operators to augment the latter without driving up costs. They can dynamically enhance coverage in response to changing conditions. Consider a packed stadium hosting the Super Bowl. Under typical terrestrial network conditions, Wi-Fi and connectivity suffer with the sheer volume of fans posting and streaming from such a densely populated area. NTNs will eliminate this issue, as drones serve as flying base stations around the stadium to temporarily boost connectivity.

NTNs will also eliminate the coverage challenges typically associated with sailing, hiking, and other activities in isolated areas. Think about the lives that could be saved if an injured hiker on a remote trail could summon help from a smartphone.

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New use cases on the horizon

3GPP has outlined numerous 5G NTN use cases, including:

Multi-connectivity

This enables customers to connect through both terrestrial and satellite links, with the former handling low-latency traffic and satellites reserved for high-latency traffic.

Fixed-cell connectivity

This allows users in remote areas or industries such as offshore oil platforms to access 5G services.

Mobile-cell connectivity

Passengers would be able to maintain 5G connectivity even on aircraft and high-speed rail by switching to satellite links when terrestrial networks are unavailable.

With speeds of up to 20 Gbps, 5G NTN's high-speed data transfer capabilities offer tremendous opportunities for applications that rely on real-time data processing like AV. This means that offshore oil platforms, mining companies, and other enterprises operating in isolated regions without terrestrial infrastructure will be able to monitor operations and equipment more closely.

Organizations clamoring to capitalize on NTN's potential

While NTNs are in an early stage of development, numerous companies are hard at work to pioneer the technology. For example, SpaceX Starlink has over 3,600 satellites and plans for many thousands more. "To understand why LEO broadband is so promising, it's important to recognize a key market dynamic," says Dr. Todd Humphreys, a professor at the Cockrell School of Engineering at the University of Texas at Austin. "As high-performance user terminals come down in both size and cost, and as you launch more satellites, the broadband service you provide becomes more compelling, which attracts more customers, which allows you to finance the development and launch of even more satellites and the development of better terminals — it's a positive feedback loop."

Testing the next frontier in space communications

In order for these development efforts to be successful, however, satellite communication systems require rigorous testing prior to deployment. Errors discovered in operational systems can cost as much as 1,000 times more than finding the same problem in the design and development phase. That's why testing strategies must account not only for performance, but for how the latter may change under the various extreme conditions posed by space.

1,000x

Errors discovered in operational systems can cost as much as 1,000 times more than finding the same problem in the design and development phase.

One of the best ways to achieve this is by replicating space on Earth and testing non-terrestrial performance in the lab. Keysight is working with companies to leverage digital twin technology and create simulated versions of satellite systems and subsystems to ensure they can weather any condition in space.

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Left to right: Dr. Mohsen Hosseinian, Dr. Alison Brooks, and Phil Lorch share their perspectives during Keysight World

Advancing 5G NTN: Experts Weigh In

Rigorously testing satellite systems and subsystems is undoubtedly a prime consideration for NTN's success, but it's far from the only challenge the industry faces.

As more organizations move networks to space, issues with frequency optimization, latency, and multi-network coexistence arise. There are also questions about how MNOs optimize their networks and what opportunities exist for network handoffs in space.

To explore these and other topics related to 5G NTNs, we spoke with Dr. Alison Brooks, research vice president at IDC Worldwide Public Safety Practice; Dr. Mohsen Hosseinian, wireless systems, 5G and NTN expert from Samsung Systems LSI; and Phil Lorch, director of satellite and space mission assurance at Keysight. Below is an edited recap of the discussion:

Q: Where did the term 5G NTN come from, and what does it mean?

Mohsen: 5G NTN started with Release 15 of 3GPP. Up until that point, 4G had been all terrestrial, meaning that base stations and towers were on the ground. Now we have new possibilities with satellite communications in multiple altitudes and orbits — GEO, MEO, and LEO.

Phil: NTNs aren't new; we've been using satellite communications for decades. With 5G and 3GPP bringing commercial standards that have the promise of interoperability across different networks, we're at a really exciting time for the technology. What we're going to see in the next few years

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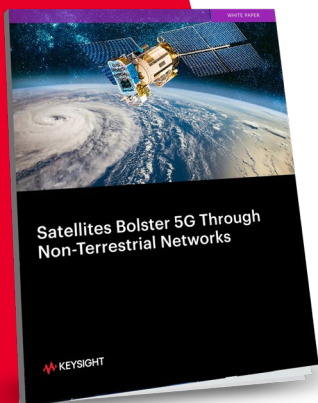
Download our guide for bolstering 5G through NTNs

is the networks of the past, which were bound to one operator's system and their hardware, changing with the potential for interoperability and universal service. I think that's really exciting and is what's driving market interest.

Q: We hear a lot about NTNs as something far off on the horizon. Let's talk about some of the most important things happening right now in NTN.

Alison: I have an example of something that's taking place right now. The war in Ukraine is being mediated from an open-source intelligence capacity, by using satellite-driven imagery to bolster situational awareness about what's happening. We all saw that jarring Maxar-driven image that showed the military column perched outside Kyiv, for example. There have also been niche developments from other satellite and commercial players to detect where things are happening on the ground in cloudy conditions or at night. I think this open-source recalibration of imaging represents a big shift with NTNs and will also be used to track global warming and other macro events.

Mohsen: To expand on this, I wouldn't say NTN is a far-off innovation — it's happening now. I look at this from two different angles. One, there are companies with their own proprietary networks. We've all heard about the Starlink project; they already have 1 million customers and are providing low-latency broadband internet services to remote areas around the world. Amazon Kuiper is another initiative, with two prototype satellites recently launched. Starlink and T-Mobile have announced plans to bring NTN to cell phones, and I think we'll see more companies making similar announcements within the next year.

The second angle is standardization. Release 17 of 3GPP is meant to be functioning, meaning that if a manufacturer implements based on the standard, the technology should work. I believe we're not very far off.

Phil: In terms of what's happening now, just recently, a small Spanish company launched the first NB-IoT, Release 17-based satellite. It's not turned on yet, but it will support narrowband messaging to your phone — as long as you have a Release 17-compatible phone. This is the first democratization of satellite connectivity with open standards.

I think Release 18 will be the next phase of that evolution on the path to 5G-Advanced. I'd urge those in the industry to get involved if you're not aware and find out who in your organization is attending these sessions. There is an opportunity for everyone to make important contributions as the standard evolves in the next couple of releases.

Alison: It's important to clarify something. Think about the traffic. It's going to be quite the logistical hurdle in space when you think about the challenges.

Q: Are there any technical trade-offs in the design process that would impact what services an operator could offer, and what

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are those trade-offs?

Phil: In satellite technology, solar and RF power is everything. NTNs' link budgets are terrible compared to terrestrial networks. Imagine cell towers moving at 17,000 miles an hour through space. How do you plan for that?

The answer largely depends upon what kind of service you want to offer. If it's narrowband mobile messaging, it might have a lower data rate, so you could use a simpler satellite that doesn't use much power. A broadband service to a fixed or mobile user, on the other hand, requires more power and bandwidth. With an eye to future flexibility, satellite designs are incorporating more software-defined payloads so that the satellite has the ability to change its mission. For example, doing narrowband first but eventually supporting broadband.

There are lots of trade-offs like size and weight that factor into it. Given that, I think companies should start by determining what the business mission of their service is and using that to drive design.

Mohsen: To add to this, we have GEO satellites that are basically stationary in the sky, LEO satellites that fly at 7.4 km a second,

Most companies have been focusing only on GEO or LEO, but moving forward the industry must expand and focus on the hybrid model.

Dr. Mohsen Hosseinian
Wireless systems, 5G and NTN expert
Samsung Systems LSI

and MEO satellites as well. Each of these is geared for a different type of service. It could be either a future hurdle or an opportunity to offer multi-orbit strategies, where you engage all different orbits with different data rates and quality of service. I expect that covering multi-orbit will become a big topic. Most companies have been focusing only on GEO or LEO, but moving forward, the industry must expand and focus on the hybrid model.

Phil: From a technology perspective, you're obviously dealing with longer delays and

higher Doppler shifts, so you have to rethink some of the current processes. Terrestrial networks were designed for things going a couple of kilometers per hour — like high-speed trains. Now with NTN there are higher velocities, Doppler shifts, and distances, so there needs to be more flexibility, and this is something 3GPP is working on.

Radio frequency (RF) power is also critical. For example, bringing phased-array antennas into the mix to point the RF energy exactly where it needs to go, as opposed to the legacy approach with lots of inefficiencies. All of this needs to be modeled and planned for. There is a lot of work going on in the RF chain specifically that will determine what kind of service you can offer.

Alison: The goal is moving to a more reconfigurable, sustainable ecosystem in which we can use multiple payloads for different customers without returning to Earth to do it. We want to get to a point where you do it in space to minimize the launch costs and risk.

Q: What kind of applications are ideal for NTNs, and are NTNs used for standard home and business internet and streaming or are there other applications that are better suited for NTNs?

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25%

say local regulations will be the biggest challenge

27%

say global regulations will be the biggest challenge for NTN

Keysight World: Innovate attendees say global and local regulations will be the biggest challenge for 5G NTN

Alison: There is certainly a consumer angle in terms of augmenting 5G, but I think the sweet spot is going to be anything that is really data-dependent and data-intensive. For example, what I mentioned previously about military image intelligence coming from satellites, this can also be used for global warming tracking. These are examples of the real-time, data-generated insights that can be developed from NTNs.

There are also really niche areas in things like medical pharmaceutical production — there is a lot of allure in zero gravity and

the temperature of outer space. There are numerous possibilities for use cases that we haven't been able to take advantage of before, and this is something that a lot of people are talking about.

Phil: We think a lot about service to the phone. There are all the commercials from terrestrial carriers talking about 5G and cellular connectivity. But the main goal of 5G, even before NTNs came along, was IoT and ultra-low latency to enable massive communications and machine-to-machine transmissions. Satellite networks can bring

capacity for those use cases as well.

Think about remote pipeline monitoring. No cell tower is going to relay a signal, so that will be NTN. If you look at companies today, there is a business model around narrowband IoT traffic from all over to a central operating center, so we will see an opportunity for 5G narrowband IoT services in the near future.

Mohsen: IoT is very important. There will be billions of IoT devices across the world and mostly in remote areas. There is no way you could have that coverage with existing

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terrestrial networks. With NTN, we will have full coverage across the world for every single IoT device — for example, IoT agricultural sensors, ocean sensors, et cetera. Only NTN is able to support the full global coverage required.

Q: How do you model a network as complex as NTN and how do you make sure you deliver the data?

Alison: There is a ton of innovation coming from the private sector in traffic management in outer space. For example, leveraging digital twins to model out who is where. This will become critical as the whole realm is more congested and the risk of a horrible accident increases. It will be so important to have situational awareness that is leveraging NTN communication but being validated on the ground, and back and forth in that manor.

Phil: I'm so glad you mentioned digital twins. If you think about the complexity of these networks, you have to have high-fidelity network simulation well in advance of starting to build hardware. In model-based systems engineering, the concept development phase was historically done with DIY tools like Excel. Now there are commercial off-the-shelf solutions companies can use to build out networks on

The technology is there, the innovation is there, but now it comes down to policy.

Dr. Alison Brooks
Research vice president
IDC Worldwide Public Safety Practice

the computer and simulate traffic patterns, cyberthreats, et cetera.

We've all heard the phrase, "If you're going to fail, fail fast, fail early." It's better to do that in simulation than with the real network that you spent billions of dollars deploying. You can build very sophisticated models now to exercise and try different things. There are companies now like test labs that can test satellites in early development. They can put all the electronics and subsystems into an

anechoic chamber and simulate all of the conditions of space, as well as subjecting them to the same cyberattacks or traffic patterns they will see in orbit. Doing this during the design and development phase is going to be crucial going forward.

There is also AI and bringing in ML techniques on the fly to manage network dynamics. That's something that Release 18 is going to look at, not just for terrestrial networks but for NTN as well.

Q: Are AI and ML used in 5G NTN development and, if so, where and how?

Mohsen: AI and ML are a big topic of Release 18. A typical satellite focused on imaging will collect about 10 Tbits of image data per day. This data has to be refined and processed, as not all of it is useful. The question is, should we process this data on the satellite or send it to the ground for processing? If you do it on the satellite, it's called edge computing, and if you do it on the ground, it's called cloud computing.

Each has its own pros and cons. On the satellite, you need huge processing power, and with the cloud, you need huge bandwidth, which is very expensive.

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Companies need to decide which option is best, and AI and ML can help by determining which amount of data should be processed via edge and how much should be by the cloud.

Allison: I think the ability to leverage AI and ML in space is critical, in conjunction with edge computing, to manage the overall sustainability of the ecosystem — how and where you are storing. Space seems unlimited, but there are cost and logistical realities associated with that question. You need parsing of the data, where you hold on to just what is useful to you and don't process the rest.

Phil: A lot of it comes down to, what is the mission? Defense companies only care about

what has changed from one pass to the next. They are looking for small changes, and that kind of thing could be done on the satellite via edge computing.

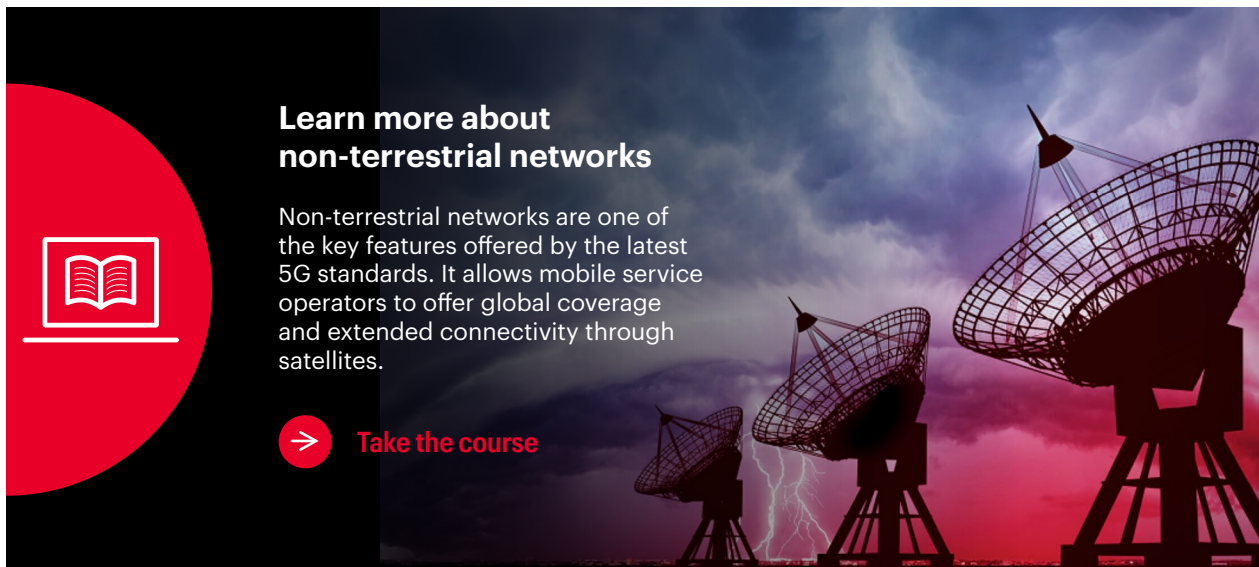## Q: What are some of the business and technical challenges to overcome?

Phil: We have standards and technology that works well, but the problem is it's proprietary. If you are using a specific satellite, you're probably using a modem that only works with that satellite. The big question is, will it be attractive to that installed-base ecosystem to migrate to 5G NTN to take advantage of that standardization? I think it will take time. If I were an incumbent, I would pay close attention

to the new players. Governments want interoperability and want to take advantage of the economies of scale that global standards will bring to the industry.

Mohsen: Standardization is a critical issue. Some companies may not choose to go that way out of concern that it prevents innovation, so we'll have to see how things go.

One more thing in terms of hurdles — we talked about satellites flying overhead. There are 5,500 satellites orbiting around the Earth, and it's predicted that by 2030, we'll see 10 times more. They won't fly themselves; you have to launch them. Launch capacity is a big hurdle, and all launching capacity until 2027 is already booked. So if you're a satellite startup, you have to wait until at least 2028. This is a big hurdle we should take into account.

Phil: We have to give a lot of credit to SpaceX for what they have done for the industry. The idea of reusable rockets goes back to the company's founding and the notion that we have to reduce the cost to get a payload to space. The cost to launch a kilogram used to be on the order of $10,000 or $100,000 in the space shuttle era. That's now down to under $2,000 a kilo, and with Starship, it's going to be under $1,000 or maybe even pushing in to the hundreds of dollars. As this launch

Learn more about non-terrestrial networks

Non-terrestrial networks are one of the key features offered by the latest 5G standards. It allows mobile service operators to offer global coverage and extended connectivity through satellites.

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cost decreases, expect to see more rocket companies emerge, along with additional launch capability.

Allison: The technology is there, the innovation is there, but now it comes down to policy. It's no longer a government-to-government entity; it's a business-to-business undertaking, and that means that there's a far greater coordination required from the policy level on things like traffic management.

Q: What should we be thinking about in terms of space management, and what is regulators' role?

Phil: Frequency overlap is probably the biggest issue, not just with each other but with terrestrial networks. Organizations like ITU, FCC, and their country-specific equivalents are going to be critical going forward to both legislate and also exert punishment when people violate these rules. There hasn't been much of this to date, but it will become a bigger issue. We want to encourage companies in the ecosystem to work together; otherwise, it could be the Wild West as the industry has gotten ahead of regulations' ability to keep up. Space debris is another thing. What happens when satellites collide?

Mohsen: There are multiple topics on regulatory issues like public safety, rescue and emergency services, and tariffs. Satellite coverage is different from terrestrial; NTNs could cross borders and countries. You need to know what country your user is in because operators want to charge them accordingly. For that reason, standardization must dictate how to find out where users are; otherwise, there will be challenges with charging and tariffs, as well as public safety.

Q: Any other positives that you are looking forward to with NTNs?
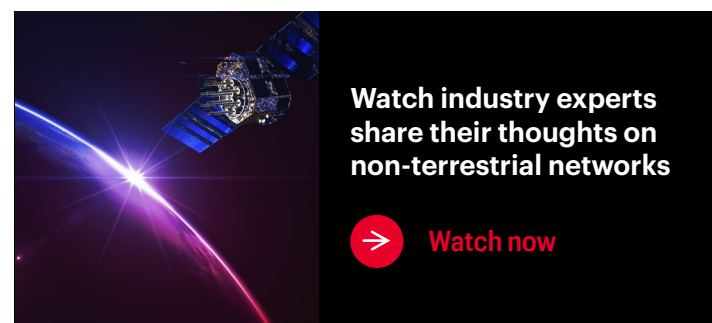
Mohsen: One of the most exciting potentials of NTN is coverage provided to cell phones. We know we have coverage like Starlink or rooftop antennas, but the most exciting part would be when NTNs can offer cell coverage everywhere you go. For example, having the capability to send a text or SOS in a remote area. This global coverage is the most exciting part of NTNs, and I think it could happen within two years.

Allison: Speaking as somebody who had a family member stranded overnight on a ski hill, this potential is huge. It's a life-or-death opportunity to bridge that gap in terrestrial coverage.
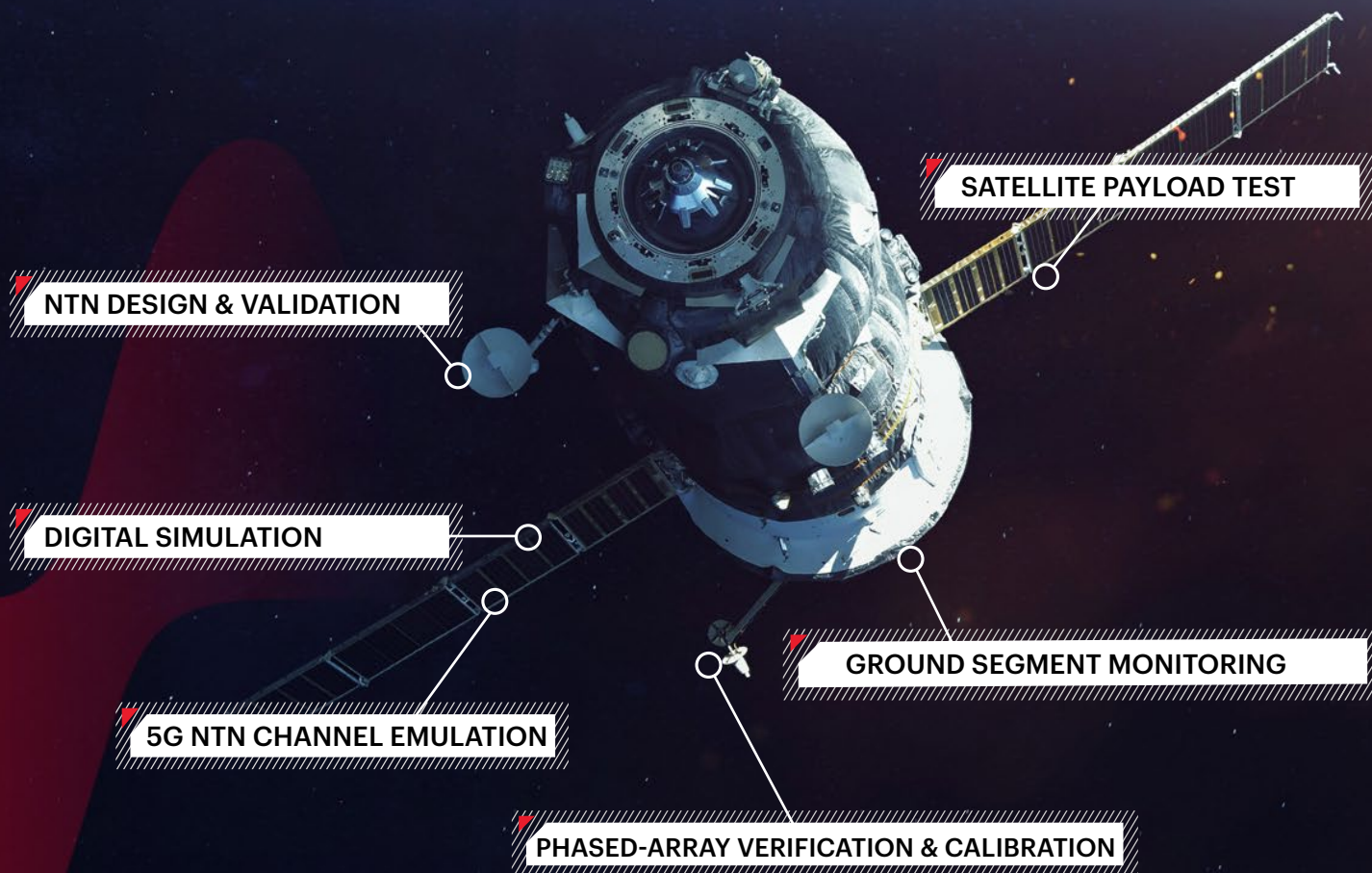
Phil: There are two things I'm excited about, with the first being the preservation of human life. If you go back and listen to the Starlink / T-Mobile announcement, it's about avoiding tragedies where hikers were lost, had no water or no cell tower, and couldn't get help. And also doing it at a low cost. You don't need to buy an expensive monthly plan to have that connectivity, whether you're hiking, skiing, et cetera.

And the other one is, I want better Wi-Fi on my flight! It sounds humorous, but I think we've all experienced poor connectivity or no service at all on a transcontinental flight. Satellite-enabled in-flight connectivity is a big market, and doing that is a promise I think the industry will fulfill in the next few years.

There's no doubt that with continued development and investment, 5G NTN has the potential to revolutionize the way we communicate and connect to the internet.

Watch industry experts share their thoughts on non-terrestrial networks

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Intelligent Digital Healthcare

The healthcare industry has experienced tremendous disruption and challenges during the past few years. As the sector strives to enhance outcomes, digital healthcare continues to gather momentum to improve efficiency and shift from hospital-centric to more personalized and precise medicine.

Innovations, including AI, digital therapeutics, and continuous sensors, have the potential to revolutionize disease prediction, diagnostics, and treatment, leading to better healthcare. From ambient signatures to implants and consumer wearables, there is an array of data to harness, and sharing this information is vital. This is fueling a technology race as the industry strives to usher in a new era of preventive health.

Predictions are that the global mobile health and fitness sensor market size will be worth US $8.95 billion by 2028. And we can expect connected medical and consumer devices to continue to grow more complex.

As the industry pivots from reactive healthcare to a more proactive and personalized approach, advances in consumer technology are changing where relevant health data can come from. A sophisticated web of devices and software captures health-related data, including smartwatches, pulse oximeters, fall detectors, and sleep apnea monitors.

Healthcare: Personalized, predictive, and preventive

The revolution in sensors is creating data streams with the potential to transform health and wellness, allowing us to move beyond one-size-fits-all solutions in healthcare. These smaller sensors are changing the role consumer devices play in providing data and biomarker insights that inform personal health decisions.

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32%

of Keysight World: Innovate attendees say digital healthcare is ready for widespread adoption

As Poppy Crum, a neuroscientist and technologist at Stanford University, noted, "The consumer ecosystem is not just the window to our subconscious user experience, but effectively it's the biggest opportunity to become a personal health advocate and help with our cognitive optimization. Devices in our ears can measure our brain state; they can measure heart rates; they can detect whether we potentially have had a stroke or might have an epileptic seizure.

"Devices on our eyes can leverage information about how our pupils dilate. We have devices on our hands. All of this becomes a very powerful part of building the human digital twin."

Testing patients virtually with digital twins

Building digital twins with data from various sensors and using AI and ML to analyze the information will improve the ability to forecast and prevent disease. Enhanced sensing gives better data sets; this situational intelligence will transform individual agency over wellness and quality of life. For example, our digital exhaust — deterministic signatures that we give off constantly as humans — is a key data source that will enable bespoke healthcare once we continuously capture and analyze the information.

Building on this, Crum noted that "multiple sclerosis and bipolar disorder both have linguistic cues that show up in dynamics of speech that are measurable with AI algorithms 10 years before a typical clinical diagnosis can be made."

Digital twins in healthcare are already

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optimizing drug delivery and efficacy, helping support the shift to more personalized care. As the technology becomes more sophisticated, you can fine-tune it to be more effective and intelligent and, ultimately, personalize it at the therapeutic level.

However, delivering personalized care depends on how effectively we enable the interoperability of datasets and keep the information secure. Improved technology enhances the ability to predict and increases the accuracy of decisions.

Building confidence in AI

Recent research has validated the forensic insights AI can provide. For example, a study showed that using AI to detect breast cancer outperformed the standard clinical risk model for predicting the disease's five-year risk. The AI algorithms identified missed cancers and breast tissue features that help predict future cancer development. In Sweden, another trial found that AI accurately detects 20% more breast cancers from mammograms than screening by radiologists.

Intelligent healthcare

Personal data is transforming how we forecast and prevent disease, redefining health

> ## Ambient signatures like our breath and voice will be the most powerful phenotypes for mental and physical wellness.
>
> **Poppy Crum**
> Neuroscientist and technologist
> Stanford University

management, and enabling new opportunities. Once we start correlating and analyzing this data, it will be invaluable in predicting our future health state, from aging in place safely to social support to improved chronic disease management. Intelligence gathered from our own data streams and monitoring the dynamics of our bodies will enable bespoke care.

Delivering holistic healthcare requires intelligent technologies to tap into the data streams from

all the connected devices and sensors. Fusing AI and ML with digital twin solutions will provide a way to model, scenario plan, and predict outcomes.

However, personalized care requires intelligent digital twins with interoperable real-time data to model, assess, gain insight, and take effective action. The future of healthcare will include tapping into information streams and biomarkers and, ultimately, creating digital individuals to test and evaluate treatment plans. And as Crum succinctly stated, "Technology will know more about us than we know ourselves."

At Keysight, we empower our healthcare customers to deliver what's next with a portfolio of test, visibility, and security solutions. Our innovative technology helps solve design and test challenges across the entire connected medical device product life cycle. Artificial intelligence-driven digital healthcare and sensor devices promise to drastically improve disease prediction, diagnosis, treatment, and patient outcomes. However, some underlying issues exist before personalized healthcare at scale can be realized.

Read on for more on these key concerns and how they can be overcome.

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Left to right: Dr. Joel Selanikio, Poppy Crum, and Erik Johnson share their perspectives during Keysight World: Innovate

Advancing Digital Healthcare: Experts Weigh In

AI has the potential to revolutionize disease prediction, diagnostics, and treatment, leading to better patient outcomes. And the same is true with AI-driven digital healthcare devices.

We're moving from simple medical wearables to integrated diagnostic tools with the hope that AI and other cutting-edge technologies

like ML, robotics, natural language processing, and predictive analytics will improve the delivery and quality of healthcare.

We spoke to some of the leading voices in the healthcare sector to understand how AI is transforming healthcare and the challenges that lie ahead. They are Poppy Crum, neuroscientist and technologist at Stanford University; Dr. Joel Selanikio, physician, health and technology activist, and CEO of Magpi; and Erik Johnson, digital healthcare business development manager at Keysight.

Below is an edited recap of the discussion:

Q. What's the industry perspective on emerging healthcare services using real-time sensing and unmonitored field data for diagnosis?

Joel: First, you must recognize that the healthcare industry is never at the forefront of technology, including AI. Most hospital systems still communicate information about patient records via a fax machine. The technology industry has

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phenomenal products that they want to bring to healthcare, and currently, it's about introducing the healthcare sector to the potential of these.

Poppy: Companies developing continuous sensing solutions can now extract relevant biomarkers you could only previously sample in your clinician's office. However, now I can develop a dynamic time series that provides insights into how that patient interacts with their environment and its impact. It's an entirely new way of thinking about where the data comes from. If I look at something like a digital stethoscope, very few doctors today use one; instead, they put on tubes and listen. We know there are new, better ways, but it's about changing the system and the data that we use to rely on and make decisions, and it takes a while to move us there.

Erik: With all the technology that's becoming available, when you peel back the hood, there are a lot of testing requirements around this. As wearables and implantables become smaller, the device circuitry becomes more critical in the design phase.

Factors like the temperature requirements of devices and how that impacts the body and, conversely, how the body affects 5G signals from an implanted device need evaluating.

For example, you need to test radio-frequency coexistence technologies to ensure that your cell phone doesn't affect a patient's monitoring capabilities in a hospital. These are all aspects that testing needs to take into account as we bring new technologies to market.

Poppy: Building trust in the systems is critical for the clinicians, the patients, and every point.

Joel: A lot of this is happening from the consumer side, so it's not just a question of building trust from the doctors. It's about building trust with the consumers as well.

Q. Are you optimistic or pessimistic about the use of remote monitoring of sensor data?

Joel: I'm tremendously optimistic about all the data we're now producing that has health-related impacts. What matters gets measured, and what gets measured gets managed. We couldn't manage it before because we weren't measuring. And now we're measuring all of this, and it has a tremendous potential to be impactful.

Q. How will ambient signatures help alert healthcare providers to potential risks or emergencies?

Poppy: Ambient signatures like our breath and voice will be the most powerful phenotypes for mental and physical wellness. Our breath's chemical composition gives rise to biomarkers about multiple sclerosis and cancer, but also our emotions, including depression. And it's not what we say; it's how we say it. For example, the biomarkers detected by AI and machine learning applied to my voice can detect early neurodegenerative diseases.

Vital Signs
Key trends and projections for software testing in healthcare
A Keysight study in collaboration with HIMSS

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All of this ultimately gives the consumer more agency, and that's an evolution in the clinical patient and doctor relationship.

There are data privacy issues with ambient signatures, and it involves a shift in how we think about infrastructure. Now, a microphone is a pretty easy and ubiquitous sensor throughout my workplace, coffee shops, and home. I want the analytics of personalized healthcare processed on my ambient signatures in my house, but I don't

Top concerns for developing digital healthcare according to Keysight World: Innovate attendees:

45% Data privacy

43% Security

20% Regulations

18% Real-world device performance

16% Other

12% Compliance

10% Wireless connectivity

want it in my workplace. And so we have to rethink the infrastructure for how we monitor, protect, and capture these signatures. But we want them to support us because the opportunities are phenomenal.

Q. What are some of those roadblocks to digital health?

Poppy: Interoperability is critical for building an effective digital twin and leveraging insights and biomarkers. And that can come from one device digitizing a new part of our body and turning that continuous data into something that can pair with information from a different sensor. And unless we do that effectively, we run the risk of having data that physicians do not trust, and then you have devices that aren't supporting the quality of patient care. Because we want better holistic medicine and diagnostics through an intersection of data across these devices, we need to think about how we build an interoperable ecosystem, a digital twin with data that provides a richer understanding of our patients — leading to a more intuitive, insightful, and greater ability to forecast and make better predictions for the quality of life and quality of care.

Erik: Many of these companies look at things within their own silo, but sharing all

Protecting patient data and critical services

With patient data and safety paramount, how can you be sure your existing security tools are effective against threats?

Read our latest guide on healthcare security to learn more about the following:

- The challenges faced by the healthcare sector, from connected devices to network security.

- How to maintain patient and service security and safety with threat simulation and connected device assessment.

- How to find and fix misconfigurations in a constantly changing healthcare environment.

- How AI and automation can simulate potential attacks before they happen.

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the information across a broader network is better for the patient. And that's ideally what we're trying to get to.

We want to get better testing of the devices; you will get better digital twins that will help generate the next generation of great surgeons. With things like surgical robotics, we'll be able to take out the inherent shakiness of a human hand. We can benefit from these healthcare products. The challenge will be testing everything from the AI to the transmission of data from a surgeon doing robotic surgery and then moving the robot arms. And that time-sensitive network has to be evaluated to ensure we don't have latency issues. Sharing this information is very helpful for patients, but how do you break down the silos between companies and test whether these devices work correctly? This is a big challenge.

Poppy: We've done a lot to digitize the body. All of these different companies are giving us a new dimension of continuous data. That's where we can develop biomarkers, and it becomes very relevant. Analytic interoperability across these datasets is critical to have the insights to make informed decisions.

Q. How will the advances in AI impact

> # What matters gets measured, and what gets measured gets managed. We couldn't manage it before because we weren't measuring.
>
> **Dr. Joel Selanikio**
> Health and technology activist and CEO
> Magpi

unmonitored local decisions, such as administering lifesaving actions based on what the sensors are seeing?

Erik: With AI, we may get to quicker diagnosis, potentially leading to faster treatment of diseases. The challenge will be that AI is a computer program that is self-learning. Humans learn by making mistakes. If we make a mistake, we learn from that, and we integrate that into our future decision-making. How does AI learn what happens when it makes a mistake? We need to trust the decisions so we can slowly start integrating more and more of them into

the decision-making process. Until we get to that point and know how AI learns and makes decisions, we will have to trust the verifying and have a human doctor review and confirm the decision. And over time, we may get to a point where decisions are made in real time.

Joel: It's important to recognize that harm is being done by the way that we live in America. We're the only wealthy country in which the lifespan is decreasing for various reasons, such as opioids and obesity. There's clear potential to use AI to help us live healthier lives. Because right now, our health is in a bad situation in this country, and it's getting worse.

Q. Will AI ever replace doctors?

Joel: AI and other technology are already replacing doctors. For example, the FDA approved a device to diagnose diabetic retinopathy. And with 30 million diabetics in the US who are supposed to have an annual eye exam to see if they have this complication, we don't have enough very expensive ophthalmologists to do this. That machine is making the diagnosis. I think we're going to find that AI is incredibly useful in the future, and doctors will use it to be better doctors; it will help them practice at the top of their range.

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Q. What are the security risks with the transmission of raw sensor data?

Erik: There has always been a heated debate between device manufacturers and regulatory bodies on keeping a patient's information safe. To date, the focus has been on HIPAA: protecting each patient's personal information and preventing it from going beyond where it should go. As we get more wearable and implantable devices, there's going to be concern for the cybersecurity of these devices. If you have an implanted device beneath the skin that sends a signal to a smartphone, then that smartphone transmits information to a doctor somewhere to ensure the patient's doing okay. If a breach occurs, the access is twofold: it can go backward into the device and potentially trigger something unintended that may cause harm, or it can be a pathway into the hospital network.

The attack footprint is relatively small for one handheld device and one implanted device. But if you take that implanted device, and it has to work with four different smartphones and tablets, each running seven different types of operating systems, in that case, the attack footprint becomes much larger. And being able to test for that will be more complicated as we start to roll out these

devices. That's why the FDA has now put out guidelines under 524B of the Food, Drug, and Cosmetics Act that medical devices must have inherent security built into them. I think as we get more and more wearables and implantable devices, the concept of cybersecurity will transcend HIPAA regulations.

Connected continuous healthcare is the new normal

Sensor technology is transforming healthcare. In the coming years, the number of devices and implantables will only increase, allowing us to shift to preventive health. Combining the various data streams and using AI to analyze the information will make it possible to predict and manage health more effectively and efficiently.

The expansion of digital therapeutics has the potential to change how diseases progress and help rebuild neural connections within the brain. Doctors will have data telling them precisely what the patient is doing rather than relying on what they say, which will drive up efficiency and effectiveness. However, as these solutions blur the lines between consumer and health products, they will magnify trust and privacy concerns.

At Keysight, we are helping healthcare providers navigate the complex technology and regulatory landscape. As engineers create new applications for remote monitoring, diagnosis, and treatment, the testing and design burden continues to grow.

Together we can help you design, develop, validate, and manufacture digital healthcare innovations quickly and effectively and guard against cybersecurity threats.
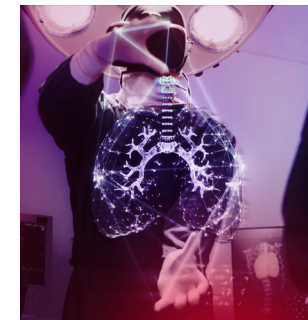
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Accelerating Innovation through Collaboration

Technology transformation will continue at a relentless pace. but advancing the emerging technologies covered in this report will require overcoming significant interoperability, safety, and security challenges.

The complexity involved with these technologies requires collaboration across the ecosystem and adherence to industry standards. It's clear that much work is ahead before these technologies can deliver on their potential. However, organizations should prepare now to capitalize on all of the inherent possibilities they will introduce.

Keysight can help you deliver what's next in evolving and emerging industries. Our portfolio of solutions incorporating digital twins layered with innovative technologies, such as AI and ML, is vital to evaluate and ensure that every component and system, spanning hardware and software, performs exactly as needed under the myriad of environments and situations the product may experience.

Innovation is a journey requiring a trusted partner with solutions that take you from concept to reality. The experience and expertise Keysight provides helps organizations across industries overcome any roadblocks and deploy faster, with less risk.
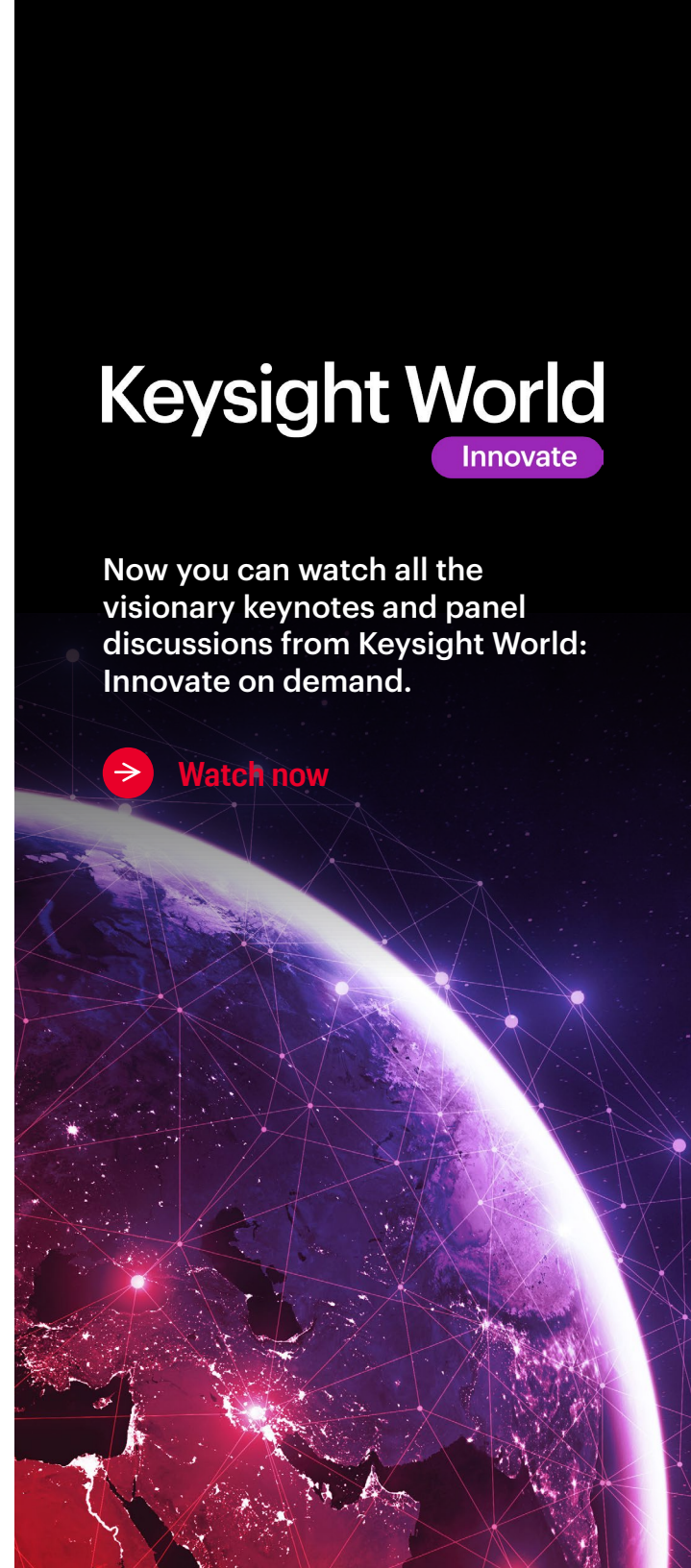
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