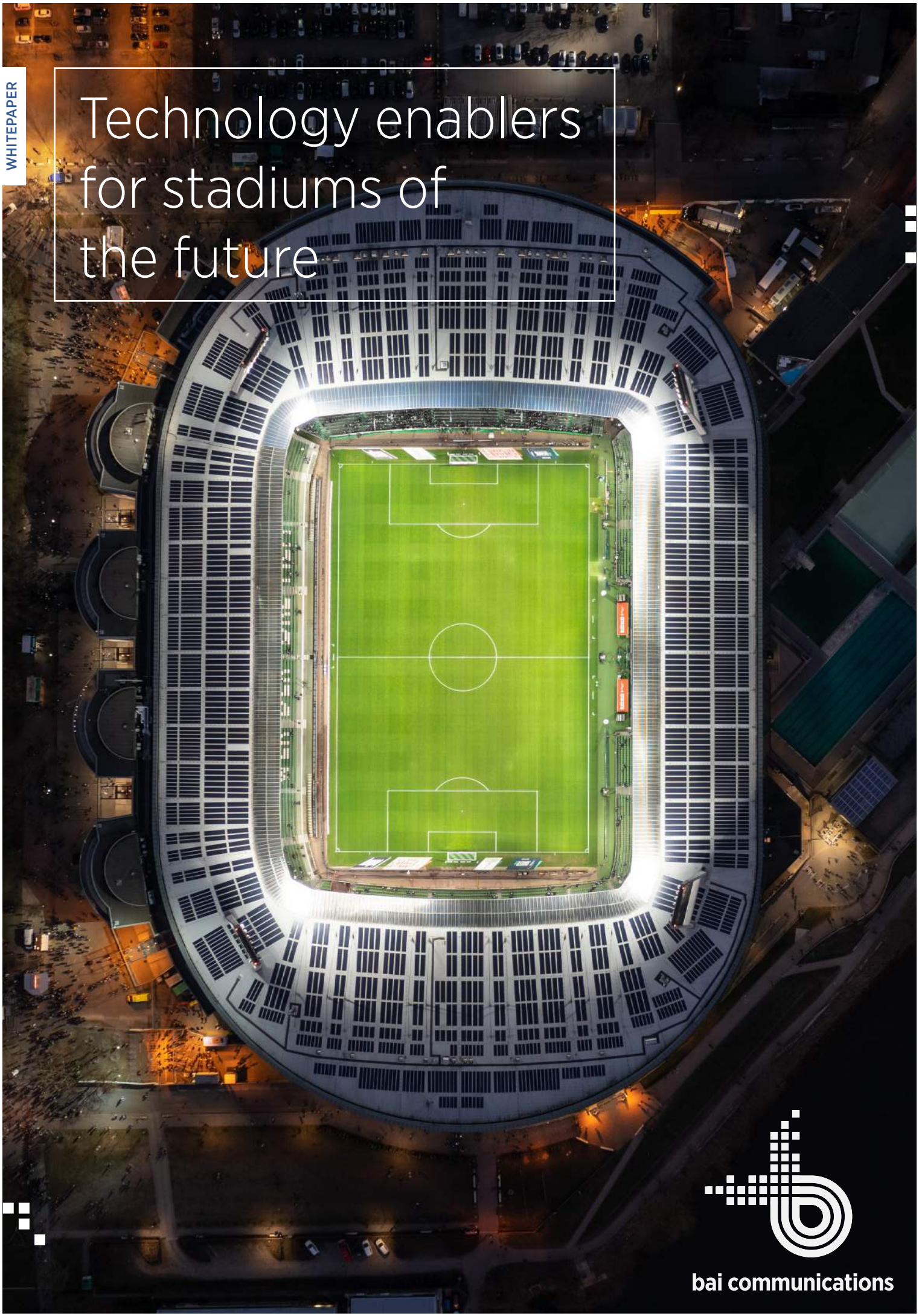
WHITEPAPER

Technology enablers for stadiums of the future



bai communications

Contents

At a glance

How stadiums are evolving

We'll critically examine the fan experience in stadiums and explore the ways venue owners can leverage the modern living room experience to transform their events. We also consider the needs of other stakeholders including sports teams, broadcasters and streamers onsite, sponsors, advertisers, retailers/concessions, Mobile Network Operators (MNOs), public transportation authorities, rideshare services, the community around the stadium, and stadium operators.

Identifying and discussing core technologies central to the evolution of stadiums.

These include fixed communications and power, wireless technologies (Wi-Fi, neutral host, public and private 5G), Internet of Things (IoT), machine learning (ML) and artificial intelligence (AI), edge and cloud computing, and data analytics.

Technology applications for stadiums

Including eExperience for fans, video screens, wayfinding, virtual assistants, second screens, advanced cameras, augmented and virtual reality (AR/VR), eSports, crowd control and safety.

How BAI Communications (BAI) is making stadiums of the future a reality today.

We'll share a selection of our global projects including our partnerships with Crypto.com Arena, L.A LIVE and Arrowhead Stadium. BAI has deployed more wireless infrastructure in sports and entertainment venues globally than any other provider over the last ten years, with more than 250 major venues across our portfolio. As a world leader in shared communications infrastructure, we're pioneering solutions that empower our customers to advance their services, accelerate their networks and amplify their reach in the most efficient and cost-effective ways possible.

1. Stadiums of the Future

1.1 Stadiums are here to stay

From the birth of the Olympic games in Greece and the Colosseum gladiator games in ancient Rome, to the globally broadcast sports and entertainment events of today. Stadiums have always aimed to deliver immersive fan experiences and investments in the area continue to this day, as can be seen from the table[1] below:

The top 10 most expensive stadiums in the world

Stadium	Location	Year of launch	Investment in USD	Capacity
SoFi Stadium	Los Angeles, USA	2020	5.5 billion	70,240
Yankee Stadium	New York City, USA	2009	2.3 billion	50,000
Allegiant Stadium	Las Vegas, USA	2020	1.9 billion	65,000
MetLife Stadium	New York City, USA	2010	1.7 billion	82,500
Mercedes Benz Stadium	Atlanta, USA	2017	1.5 billion	81,000
Wembley Stadium	London, UK	2007	1.5 billion	90,000
Tottenham Hotspur Stadium	London, UK	2019	1.33 billion	62,850
Singapore National Stadium	Singapore	2014	1.31 billion	55,000
AT&T Stadium	Dallas, USA	2009	1.15 billion	80,000
Optus Stadium	Perth, Australia	2018	1 billion	61,000

Tottenham Hotspur Stadium, UK

1.2 Fan experience in stadiums versus the modern living room

Fans expect to consume content and experience events in new and engaging ways.

For live events – sports, concerts and other performances – stadiums have always provided, and continue to provide, unique experiences that rely on fans' physical presence. Entertainment providers must carefully consider the complete event atmosphere, from the ambiance to the amenities offered, in order to capture fans' attention and shape the in-person spectating experience.

The modern living room – with large ultra-high-definition TVs and surround sound systems – can provide a direct event experience that allows fans to feel close to the action from the comfort of their homes. Some may even think it superior. Video adjuncts, such as multiple camera angles and close-ups, replays and commentaries, provide fans with a clear view of an event's key moments. Second screens (phones and tablets) on hand allow fans to do their own background research and participate in messaging and social media.

This is why forward-looking stadiums are increasingly providing at-home comforts in their venues, such as huge screens and communications infrastructure for second screens.

Stadiums must also address the expectations of the 'connected generation' who want to transact online for all their needs. In parallel, stadiums need to keep their audience safe and instill confidence that adequate safety measures are in place.

The sense of community and being part of something bigger that a physical event in a stadium provides is something that a modern living room will never be able to compete with. However, it is something that fans may be willing to trade for other comforts. Forward-looking stadiums will remain competitive by filling those gaps.

1.3 Stadium stakeholders beyond fans

As well as the fans themselves, stadiums serve other stakeholders.

A stadium's most important customers are often the live acts or sports teams who use the stadium as their home. These teams expect full support, both physical and digital, for pre-event practice and preparation, for optimising event performance and conducting post-event analysis.

Closely following is the TV/Internet production company that has media rights to broadcast/stream events from the stadium. Covering cameras, production facilities and communications.

Sponsors and advertisers want to ensure maximum exposure to fans – in-stadium and at home.

Retailers, restaurants and concessions in the stadium want to maximise their business.

The stadium and inter-dependent businesses such as MNOs need to co-operate to maximise services and revenues and minimise costs.

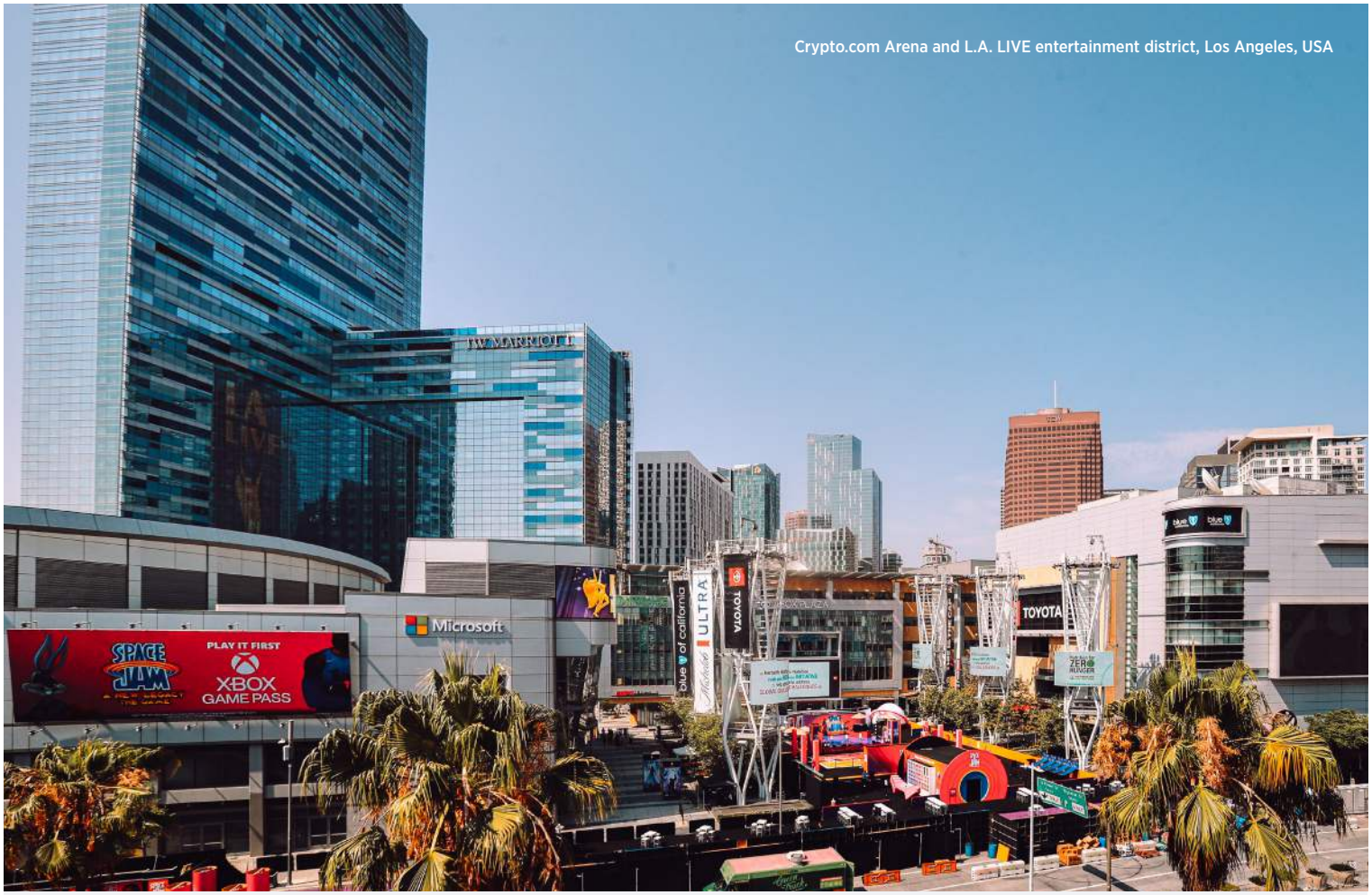
The stadium needs to be efficiently integrated into surrounding public transport, pedestrian walkways, and road/parking systems.

A stadium needs to be an asset for the city/town/community in which it is located.

Finally, the stadium itself wants to run its business as efficiently as possible.

1.4 So how will stadiums evolve?

Unique live experiences for fans	Stadiums need to offer experiences that the fan cannot receive at home, for example: – The ambience of live events and the crowds supporting them. – Great game-related interactive screenshots of yourself. – Sweepstakes and live betting. – Holographic experiences with your favourite artists and players. – Skywalks. – Special stadium 'membership' privileges and commercial offers.
Digital complements to live experience	Stadiums must provide complements now common in the modern living room: – Immersive video, streamed and rendered to multiple huge screens around the stadium, fed by multiple fixed and moving cameras capturing events from multiple points of view and with detailed close-ups. – 'Game within the game' second-screen experiences, where smartphones and in-seat screens (and augmented reality devices in the future) are used to complement the in-stadium experience with digital content, instant replays and close-ups, statistics, and add-on info on the game or a player.
Social meeting places	Stadiums must provide the social experience for enjoying and relaxing with family, friends and fellow fans. This experience is enriched by: – Special/block seating, concession services, and social gathering areas. – Social gatherings and hospitality before and after events. – In-stadium exclusive social networking opportunities.
Total fan convenience	Stadiums must make every step of the fan journey easier, from the moment they decide to purchase a ticket through to when they head back home after the event: – Smarter (face ID) and personalised ticketing solutions. – Ticket bundles that include stadium access, food/drink deals and other exclusive perks. – Automation and navigational aids to get to and from the stadium, whether by public transport or car – including upgrades for equitable accessibility. – No queuing on arrival at the stadium through the use of automated crowd controls and entry using smartphone/smartwatch/facial-recognition (in place of physical tickets). – Navigational aids to get to your seat. – Smart parking solutions. – Connectivity with local public transport services.
In-seat personalised eCommerce	Stadiums must provide personalised experiences for individual fans through in-seat eCommerce solutions: – Food, beverages and merchandise ordered and paid for by fans sitting in their seats using their smartphones or smartwatches. – Prompt direct delivery to the fan in their seat. – Personalised offers and services based on fan profiles, preferences, time and location, and past purchasing habits. – 'Grab & go' checkout-less transaction experiences.
Remote events seen live	Through the use of in-stadium screens and augmented reality applications, live stadium experiences will extend to: – Fans visiting their home stadium to watch away games or remote concerts/performances. – Nearby stadiums providing overflow capacity for visiting fans (a second stadium was used in this way for the May 2022 Europa League soccer final in Seville, Spain).



Crypto.com Arena and L.A. LIVE entertainment district, Los Angeles, USA

Retailers, restaurants and concessions	Stadiums must provide more than just a seat. Fans want to be able to move around and enjoy different experiences. This provides huge opportunity for retailers, restaurants and other concessions.
Safety & security	Stadiums must ensure the safety of their fans from threats, pollution and accidents. If they feel safe they will stay longer and enjoy more amenities. – Secure ticketing and entry controls. – Facial recognition (with privacy protections). – Crowd control. – Car safety barriers. – Air quality monitoring and purification.
Sports teams	Stadiums must leverage advanced connectivity to enable a litany of smart applications in sports and health technology to enhance athlete performance. Including biometrics collection during training and games.
Broadcasting and streaming	Stadium camera, production and communications infrastructure needs to support TV and internet production companies with the media rights to broadcast or stream events from the stadium and create great at-home fan experiences.
Multipurpose stadium use	Stadiums and their precincts will become increasingly multipurpose. As well as hosting games, concerts and other live events, future stadiums will, for example: – Become small entertainment cities where people gather and have a good time. – Allow parking lots to be re-purposed for city commuters during the day. – Allow businesses and residents to rent stadium spaces for meetings, celebrations and other gatherings. – Host exhibitions and fairs on the stadium grounds between live events.

New business models for monetisation	Using network data, stadiums will deliver personalised content to fans, driving added revenue through gamified viewership. This includes live payments for digital products, new camera angles, volumetric video highlights or statistical analysis and betting. Data-driven stadiums are better equipped to offer in-depth information and added-value services to sponsors and partners. A multi-sided approach would allow data to be shared for the benefit of all participants (B2B, B2B2C and B2C), boosting business growth, and with it, the local economy.
Out-of-stadium monetisation	Future stadiums operators will be able to provide on-line services to bring the stadium to the sofa for home subscribers and pay-as-you-go users. Potentially also linking in eSports (professional video gaming) alongside traditional sport. For example, the Washington Capitals ice hockey team has partnered with NBC to launch 'Virtual Gameday', a second screen experience that offers fans an in-venue experience from home[2]. In the future, this will extend to virtual reality (VR) - based 'digital twins' in the metaverse[3].
Smart operations	By leveraging smart operations, stadiums will be able to reduce operational costs and enable efficiencies. For example, outages can be reduced by predicting whether a device is on course to break down, or waste can be reduced by determining how much food needs to be prepared.

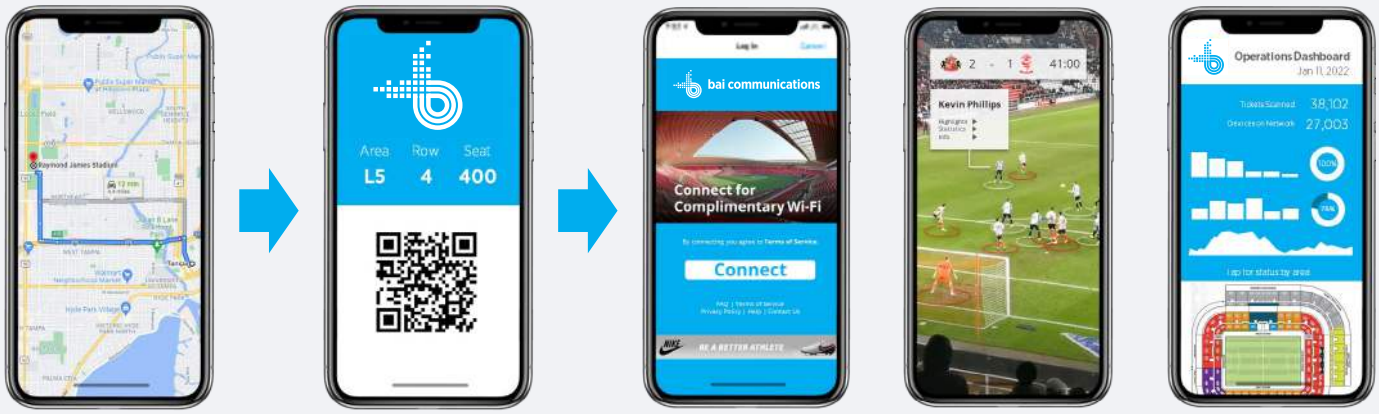
Multipurpose stadium use

Examples include:

- The Miami Grand Prix which repurposes the Hard Rock National Football League stadium (home of the Miami Dolphins) to stage Formula One car racing extravaganzas.
- ocV!be[4], an entertainment complex under development in Orange County, California in the United States will provide the best of sports, entertainment, food, hospitality, hybrid and collaborative office, residential, and inclusive spaces. All connected with an emphasis on walkability and wellness.

Connected Venues

Connected venues enhance visitor experiences and operations through custom branded experiences



Smart wayfinding

Smart ticketing

Wi-Fi portal

Augmented reality experience

Operations application

Smart stadium

Visitor experience

- Location-based services and maps
- AR/VR
- Live event info, wait times, replay
- Pre-game/ tailgating experiences
- Social media integration
- Suite control
- Public transport integration

Commercialisation

- Sponsorships, merch promotions
- User accounts
- Mobile ordering
- Seat upgrades
- Next-game tickets sales
- Gambling, mobile games
- Third-party ticketing integration

Operations/safety

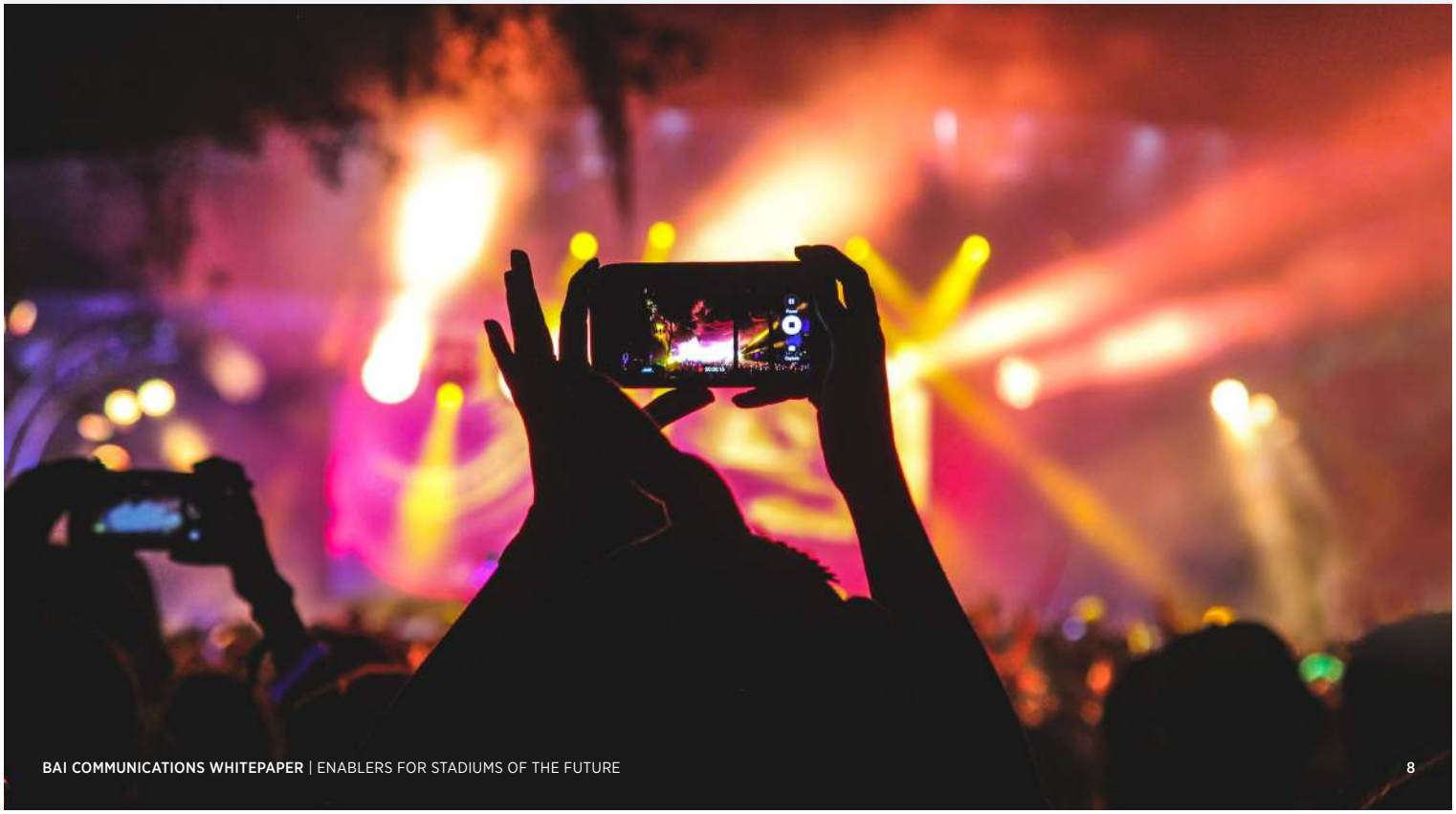
- Comms, media devices, security cameras
- Digital ticketing
- COVID status checking
- League operational requirements
- Training device/support
- Asset tracking
- Crowd control measures

Data/analytics

- CRM and loyalty program management
- First time vs. recurring visitors
- Season ticket holders
- Ad & page performance

Media/marketing/PR

- Improved connectivity for media
- Social media from visitors
- Event/game promotion



2. Core technologies for stadiums

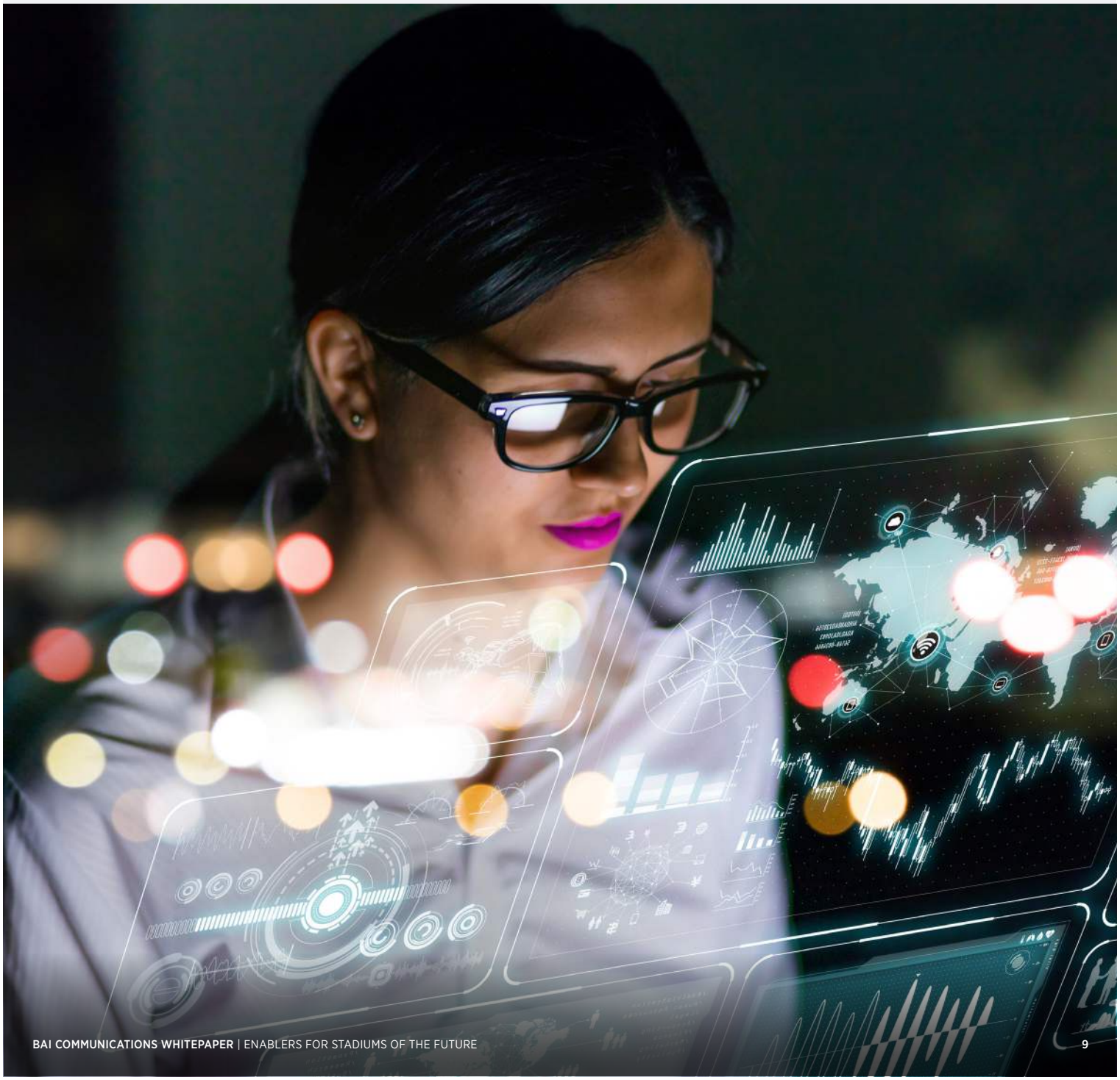
2.1 Fixed communications & power

At first glance, fixed networks may appear outdated but base stations and access points for wireless networks cannot operate without fixed communications backhaul and power. The latest 5G and Wi-Fi wireless technologies require higher densities of base stations and access points to provide ubiquitous coverage and high throughput. Fixed networks need to extend across all indoor and outdoor locations throughout the stadium. Including hospitality suites, restaurants, bars, toilets and showers (for emergency purposes), and areas surrounding the stadium such as waiting areas, car parks, metro stations and public walkways.

Fixed networks also have their own merits in stadiums. They provide the data backbone for gathering high-definition TV camera feeds from multiple vantage points around the stadium, they feed multiple high-definition video walls, TV screens and speakers around the stadium, and they interconnect multiple IoT sensors around the stadium.

As well as data connectivity, fixed networks also need to provide power to all active devices around the stadium, including USB charge points at seats.

To give some perspective, 1,200 kilometres of fixed cabling has been installed in the newly built 62,850 seat Tottenham Hotspur stadium in London[5]. This is five metres of cabling per seat! Feeding 305 square meters of screens, 1,640 under-seat Wi-Fi hotspots and 4,500 speakers.



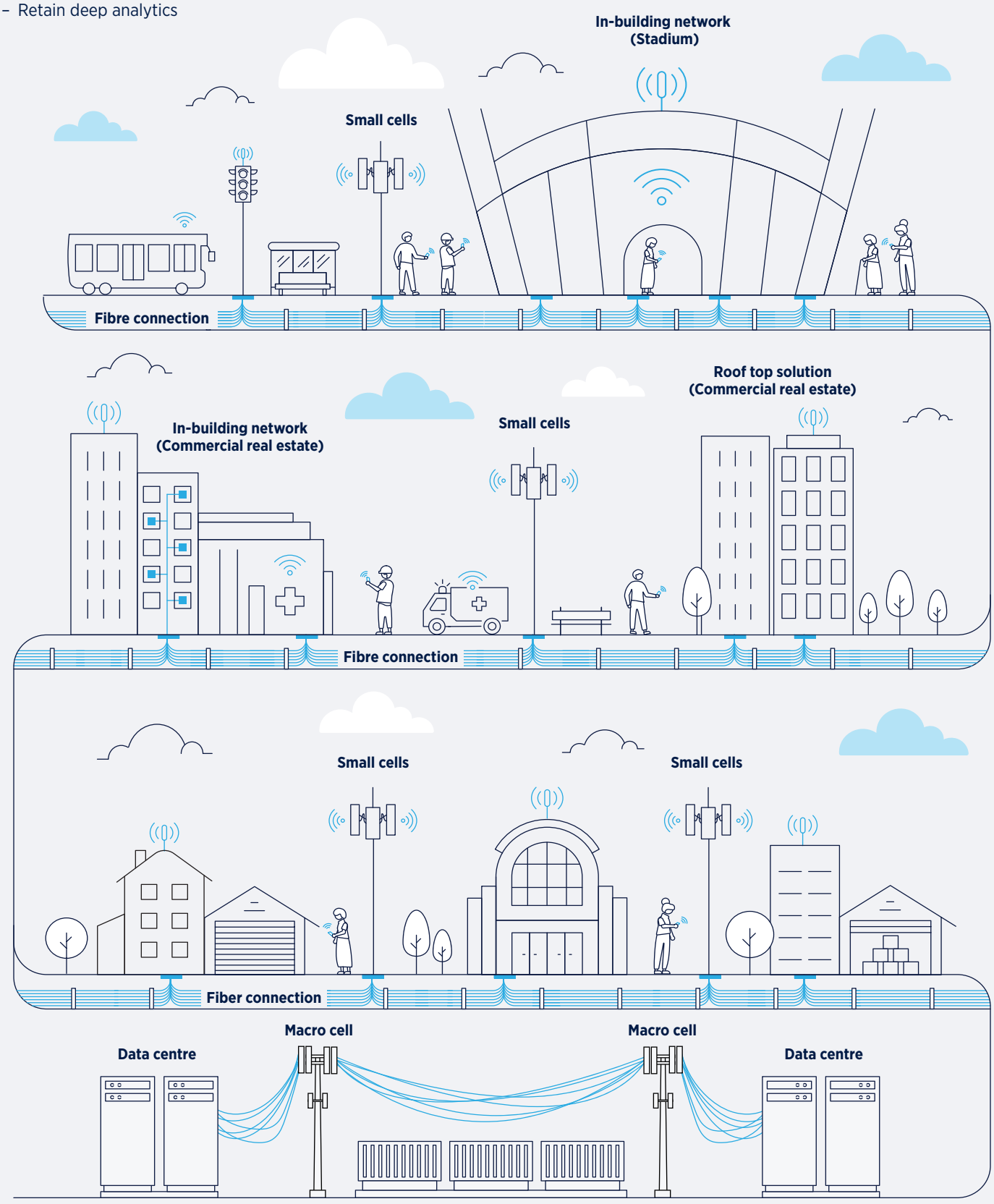
Core technology infrastructure

Comprehensive Wi-Fi 6

- Fastest, most robust Wi-Fi protocol
- Highest access point (AP) capacity
- Backwards compatible
- Facilitates MNO off-load
- Seamless authentication
- Facilitates ad-based revenue
- Retain deep analytics

Neutral-host DAS

- Distributed Antenna System (DAS)
- Providing connection for each of the MNOs
- Facilitates seamless connection for visitors and operations



2.2 Wireless communications

2.2.1 Technology options: public mobile, Wi-Fi and private mobile

Stadiums typically have three technology choices for deploying wireless communications:

1. **Public mobile:** used by MNOs to provide public networks. The MNO has control over user authentication (logon), services offered and quality of service. Operation is in Licensed[6] radio spectrum. 5G[7] is the latest technology evolution providing increased capacity, throughput and performance. 5G Ultra Wideband[8] offers the highest speeds and is best suited for outdoor deployments; Verizon[9] is aggressively deploying 5G Ultra Wideband in stadiums.
2. **Wi-Fi:** Wireless connectivity operated by stadiums to have control over user authentication (i.e. logon), services offered and quality of service. Whist Wi-Fi operates in unlicensed[6] radio spectrum, the stadium can apply controls to avoid interference problems within the Stadium. The latest Wi-Fi technology evolutions[10] are Wi-Fi 6 and Wi-Fi 7.
3. **Private mobile:** Leverages the same 4G/5G technology as public networks operated by MNOs but privately operated by stadiums. Like Wi-Fi, the stadium has control over user authentication, services offered and quality of service. Operation is in Shared[6] spectrum which is locally dedicated to, and controlled by, the Stadium.

2.2.2 Stadium neutral host DAS for public mobile networks

Instead of each MNO independently deploying antennas across the stadium, there is strong technical logic for the stadium to provide a single DAS to ensure that robust wireless coverage extends to all parts of the stadium (indoors and outdoors), and to ensure that the capacity needs for each public MNO are met not just for today, but well into the future.

The stadium then offers access to all mobile networks on a 'neutral host' basis, meaning that each MNO receives equal service and contributes to costs on an equitable basis. Each MNO's radio signals would be aggregated and fed into the neutral host DAS at the central headend, then transmitted throughout the stadium on the shared infrastructure without any co-interference.

However, depending on the local motivations of MNOs, it may not be possible to get a sufficient proportion of them to agree to make a neutral host approach commercially viable.

The Crypto.com Arena in Los Angeles is a great example of a large-scale neutral host deployment. The arena has deployed a DAS providing venue wide coverage across all commercial cellular spectrum bands covering low band – 700-850MHz, mid band – 1900-3700MHz, and high band – 28-39GHz, including 5G operating in C-band spectrum. It's comprised of 331 antenna and 434 remote units. A fibre backbone provides redundancy up to 30 Gbps capacity to the campus core. Each MNO interconnects at this core.

2.2.3 Most stadiums deploy Wi-Fi to enable fan connectivity

Irrespective of mobile networks and neutral hosts, most stadiums deploy Wi-Fi to provide connectivity to devices, such as smartphones, smartwatches and tablets, within the venue or its proximity. These networks provide generic connectivity to stadium administrative systems (such as ticketing, maps/directions, concessions and merchandising) and to the public for services such as email, messaging, photo/video sharing and social media.

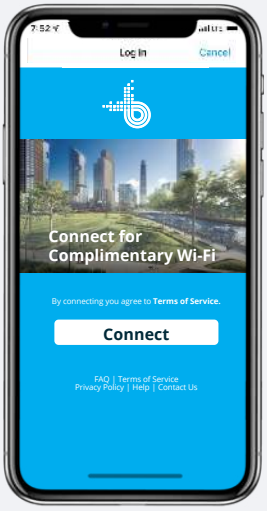
There are several reasons why a stadium provides its own Wi-Fi service as opposed to relying on mobile networks:

- The stadium operator is in complete control of the service provided to fans, from the time of fan arrival to departure.
- The stadium operator can design and manage its Wi-Fi networks to ensure continuous fan coverage and capacity (bandwidth) across the stadium and its proximity (outdoors and indoors).
- The stadium operator, with appropriate anonymisation to ensure privacy, can use Wi-Fi to track devices and monitor the flow of people around the stadium as a key input to crowd control and to ensure safety of fans.
- There are no complications of revenue sharing with third parties such as MNOs.

As an example of a large stadium Wi-Fi network, the 65,000 seat Camping World Stadium in Orlando, Florida has 665 dual-band (5Ghz and 2.4Ghz) access points deployed under seats and in strategically mounted locations that cover the entire venue's seating area, concourse, suites, press areas, back of house locations, and some field-level areas. Of the 665 access points, 376 are in under-seat enclosures and 41 are mounted in overhang areas pointing toward the bowl seating area. Combined, each access point services roughly 154 bowl area seats.

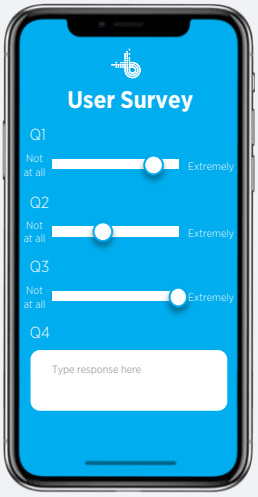
Many opportunities for monetising Wi-Fi

Wi-Fi portals can enhance visitor experience through custom branded interfaces



Wi-Fi portal landing page presents opportunities for sponsorships or paid usage

Interactive map nudges to nearby businesses



User surveys to aid analytics, inform users of businesses / events

Visitor experience

- Location-based services
- Interactive map
- Live event info
- Social media integration
- Public transit integration

Commercialisation

- Freemium service
- Sponsorships / advertisements
- Business partnership promotions
- User data (surveys, verification, existing account connections)

Operations/safety

- Employee / contractor comms
- Media devices
- Security cameras
- COVID status checking

Data/analytics

- Customer relationship management
- First time vs. recurring visitors
- Ad & page performance

Media/marketing/PR

- Improved connectivity for media
- Social media from visitors, residents, workers
- Event promotion

Arrowhead Stadium Kansas City, USA

2.2.4 The role of private 5G in stadiums

5G cellular wireless technology offers unparalleled technical performance backed by a huge commercial ecosystem. By operating a 5G private network, a stadium has complete control including local use of shared[6] spectrum to provide:

- Greatly improved coverage, with no dead zones, wherever needed.
- Huge capacity (numbers of devices, speeds and throughput) wherever and when needed.
- Low latency to ensure fast reaction times.
- Extreme high reliability communications to ensure that connectivity is always available (even in adverse radio conditions) for critical applications, such as safety.
- High security to protect data, device and user identities and locations.
- Support for low-power devices so that battery powered devices (typically IoT) can operate for many years.

For an in-depth analysis of 5G private networks, see BAI's whitepaper on the 'The power of private networks'.[11]

Example use-cases for 5G private networks in stadiums include:

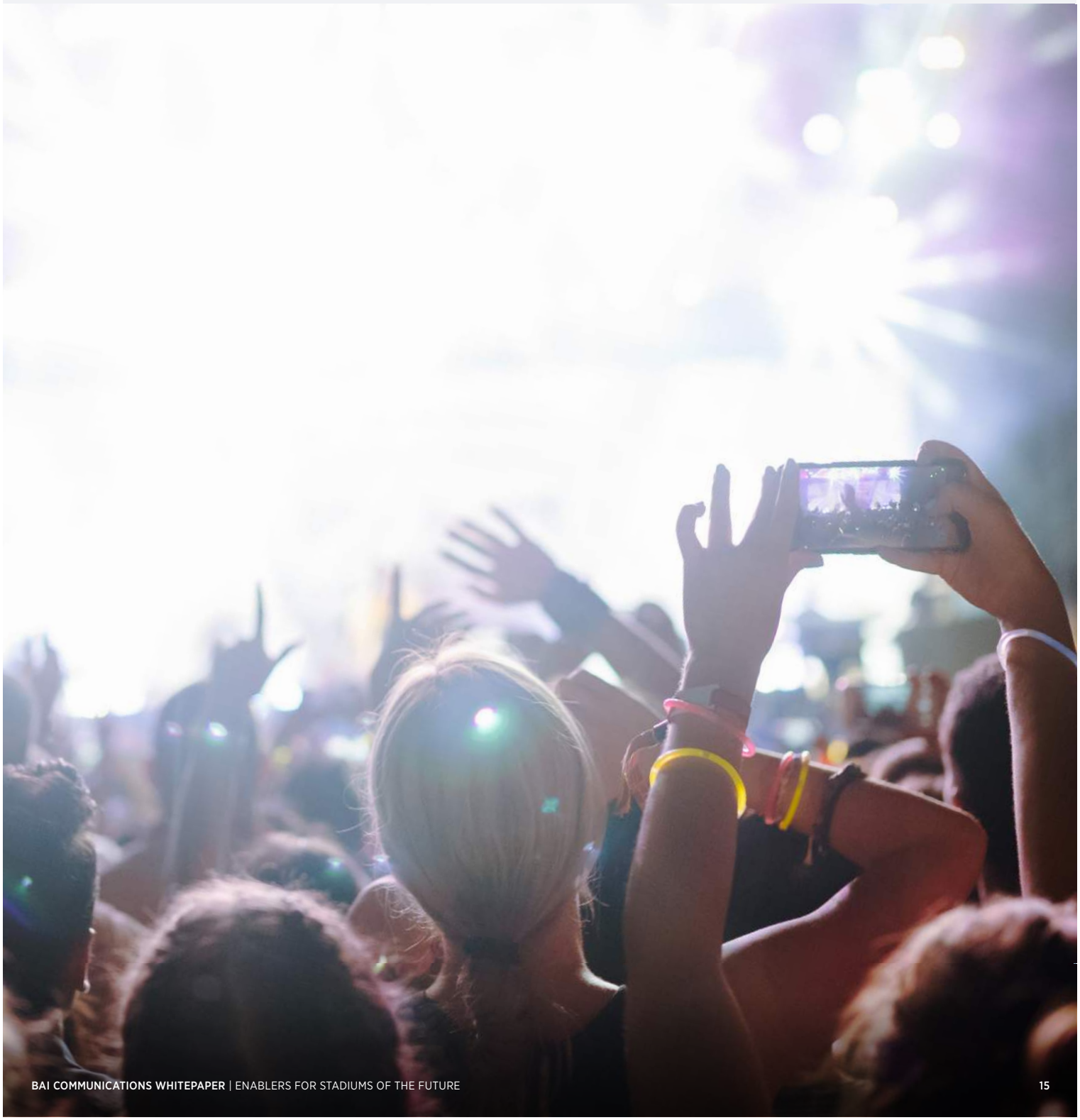
- Connectivity to augmented/virtual reality mobile devices rented to fans (see section 3.8).
- Controlling and receiving high-definition TV streams from drone mounted cameras moving around the stadium (see section 3.6).
- Reliably communicate with IoT sensors and controllers around the stadium (see section 2.3).

2.3 IoT sensors & controllers

Generically, IoT – the 'Internet of Things' – refers to smart devices connected to the internet or private communication networks. In day-to-day life, people use a range of connected devices, from home appliances, smart speakers, wearable and even connected vehicles. For services and utilities, everything from dustbins to parking spaces are becoming networked. Connected machines and objects offer the potential for a step forward in automation, sometimes called the Fourth Industrial Revolution[14]. Huge opportunities exist for healthcare wearable and embedded devices[15]. There are many potential applications in public safety[16] applications such as; autonomous machines, including self-driving cars, are no longer science fiction. The collection and analysis of data from these 'things' – providing personal privacy is protected, offer potential for deep insights into people's behaviour and allow for the optimisation of services provided to them.

There are many applications for IoT to make stadiums smarter and safer, for example:

- Tracking movement of devices around the stadium for crowd control and public safety (see section 3.10).
- Security applications such as detectors for explosives and firearms.
- Optimising the management of stadium venue infrastructure such as lighting, temperature, and airflow control.
- Wearable IoT devices that enables athletes biometrics stats to be shared back with their doctors, trainers or coaches.



2.4 Machine learning and artificial intelligence

Machine learning (ML)[17] allows software applications to better predict outcomes without being explicitly programmed to do so. ML algorithms leverage large volumes of historical data and outcomes to predict inferences from new data. ML learning can be leveraged to provide insights into fan movements, behaviours and preferences, or to spot potential fan overcrowding situations.

Higher levels of AI[18] further leverage rules, decision trees and neural networks to mimic the problem-solving and decision-making capabilities of the human mind.

Together, ML and AI enable enhanced fan experiences and improved stadium operational efficiency. For fans, this includes hyper-personalised experiences (ticketing, in and between games) and sponsorship activations. For stadium operations, ML and AI can optimise seating capacity and improved fan experiences and stadium safety.

ML and AI can also help sports teams boost individual performance, reducing injuries and assist game-day decision making for the coach. For example, Maple Leaf Sports and Entertainment in Canada has partnered with Amazon Web Services to use advanced ML and video analytics during hockey and football games to provide fans with “game within the game” second-screen experiences and to help coaches with training and in-game decision making[19].

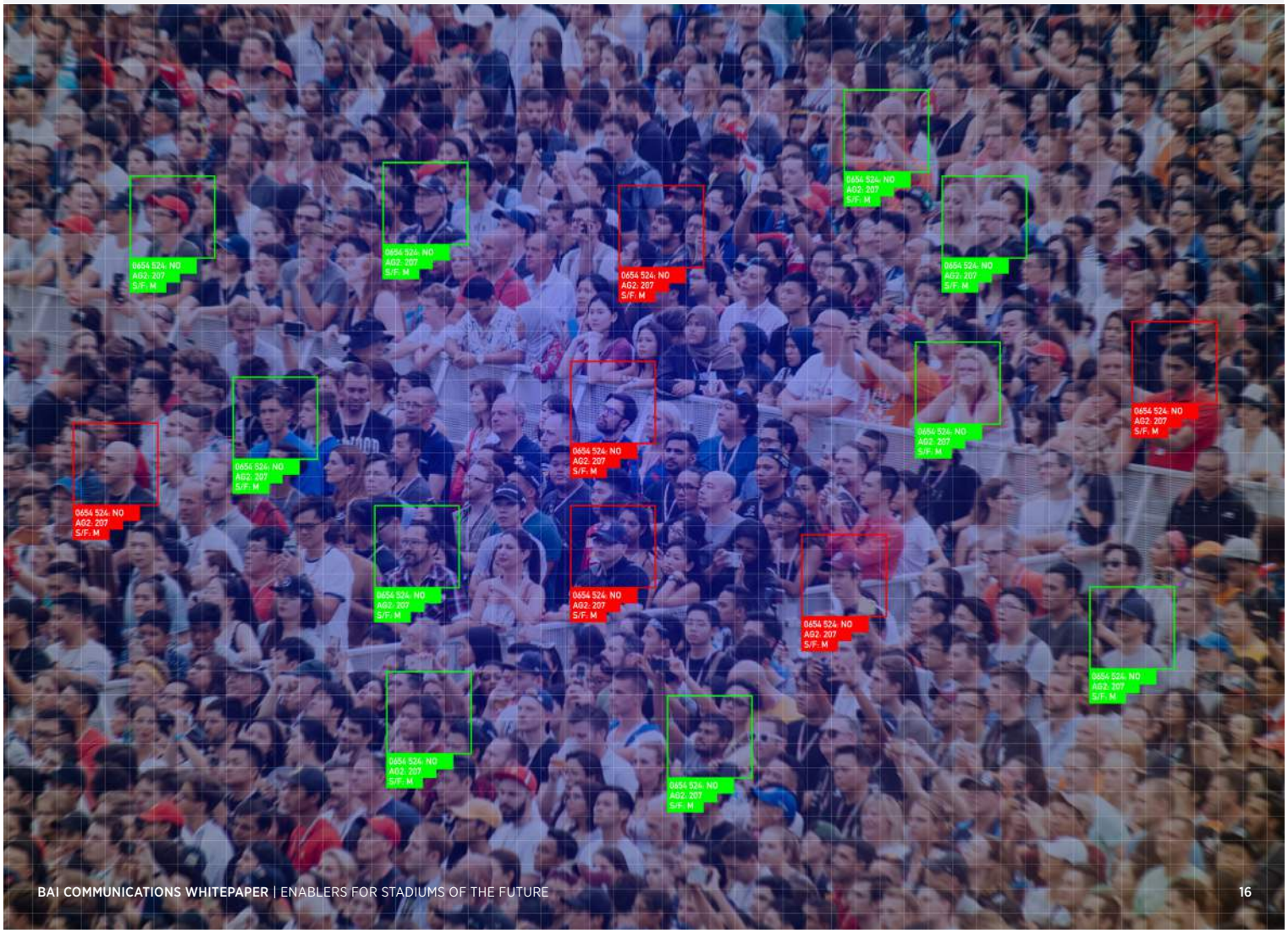
2.5 Edge Computing

The increasing use of Public Cloud[20] and corporate data centre hosting services typically concentrates computing resources in remote data centres which may be many 100s of miles away from the stadium.

However, some aspects of stadium computing are best executed by ‘Edge Computing’ where some computing power – processing and/or data storage – is located within the stadium. This Edge Computing then works in concert with remote Cloud computing allowing you to benefit from the strengths of both worlds.

Instances in which edge computing shows its value include:

- Video content distribution where a single copy of the master content is stored (‘cached’) locally, copied/reformatted locally, and distributed to multiple displays locally. This avoids the huge volumes of data traffic that would be involved if this were to be done in remote data centres.
- Front-end processing within the stadium is typically driven by the need for very fast response times (‘low latency’) and/or the need to extract key information from large volumes of raw data. Examples of this include communications protocol handling for public/private mobile and Wi-Fi, processing of public safety camera video feeds to detect people movements, monitoring IoT sensors to detect key events, web and payment processing for fans, and video gaming.
- Front-end processing for data volume reduction to optimise ML and AI (see section 2.4).
- Video and audio overlays for augmented reality (see section 3.8).



2.6 On-demand Cloud Computing

In addition to Edge Computing, stadiums need access to large-scale back-end computing, data storage and handling, and Internet connectivity resources in the Public Cloud[17] to:

- Provide back-end data and content processing resources to inter-work with Edge Computing in supporting stadium live events. Given that live events happen at specific times, these Public Cloud computing resources are most efficiently provided on-demand to address peaks and troughs in activity.
- Provide websites and mobile apps for fan interactions, including marketing, ticketing, special offers and membership privileges. These applications can offer fans the ability to personalize their profiles, take advantage of membership offers, sign up for stadium experiences and interact on social media.
- Provide business support functions to enable stadium operations, including management of personnel and workforce, stadium assets, suppliers, and finances.
- Support for data analytics; see section 2.7.

Stadiums can use these public Cloud resources on-demand to complement their own computing resources.

2.7 Big data analytics

One of the ways stadiums will be able to earn back some of their investments will be data gathering and analytics[21]. As tens of thousands of fans in stadiums log on to their devices, move around the stadium and make purchases, they generate an enormous amount of data. This can be combined with data from devices around the stadium on fan movements, services utilised, climate and energy usage. The combined 'big data' can be collected and mined to:

- Determine fan preferences and behaviours.
- Support marketing, sales, and fan retention. See section 3.5 on eExperience.
- Focus new products and services.
- Optimise stadium operation, including cost control.
- Improve efficiency on how stadiums select and work with their suppliers.
- Manage risks including support for crowd control and public safety (section 3.10).

The above can benefit stadiums directly and indirectly through sale of data insights to third-party companies.

3. Example technology applications for stadiums

3.1 eExperience to fulfil all needs of fans

The combination of websites, social media, apps for smartphones/smartwatches, and in-stadium wireless, screens and IoT extends well beyond traditional eCommerce into a full eExperience for fans. This enriches fan experience and convenience, driving revenue, fan loyalty, and operational efficiency for stadiums, teams, sponsors and advertisers for delivering public announcements.

eExperience includes:

- In the days leading up to a stadium visit through to the days that follow, fans receive marketing, membership and privilege offers, as well as the access to ticket pre-sales and service bundes. This can include co-marketing and sales with other organisations, e.g. nearby restaurants or car parks.
- To get to the stadium, fans can receive navigational guidance for public transport, car parking, and stadium entrance.
- To ease stadium entrance, smartphone/smartwatch near-field communications and/or biometric facial-recognition[22] can be used in place of physical tickets.
- Once in the stadium, smartphone/smartwatch apps can guide fans to their seats and retailing concessions around the stadium. They can promote individually tailored content and offers as fans move around the stadium based on their location, time, and preferences. Apps can also provide greater accessibility for those with special needs or disabilities.
- At seats, fans can use apps on smartphones/smartwatches, tethered second screens or headsets to buy/receive “game within the game” value-added services for the live event, and order in-seat delivery of drinks, snacks and merchandise.
- After the live event, fans can be encouraged to stay in the stadium to receive value-added follow-up services in their seat, or to visit other in-stadium specialist areas to do so.
- When the time comes to leave the stadium, fans can be guided safely and with minimal hassle.

3.2 Video screens and loudspeakers

Modern stadiums use video screens to supplement the live action and to provide information to fans as they move around stadium entrances, concourses, concession stands and hospitality suites. Multiple speakers around the stadium are important for delivering public announcements and commentary.

Before they hosted the Big Game, SoFi Stadium in Los Angeles, California installed a 70k sq ft 4K Infinity Screen by Samsung[23]. This is a dual-sided display hanging 122 feet above the playing surface and is oval in shape, so no matter where you sit, you have a view of it. One of the fascinating aspects of the display is that each of the panels can be uniquely or concurrently configured with content such as statistics, live video, animations, replays, or other content. Additionally, SoFi has a further 2,000 4K video displays located elsewhere around the stadium, with all the video displays fed content using a Cisco IPTV system[24].

The Tottenham Hotspur stadium in London[25] has installed two large 2,518-square-foot displays mounted to the stadium façade to welcome fans as they arrive, The stadium also features a ribbon display around the venue as well as other displays throughout the property.

The Accor Olympic Stadium in Sydney, Australia has a 120m long and 10m high screen running around an entire side of the stadium and claimed to be the longest high-definition straight-run stadium video display anywhere in the world.

The SoFi and Tottenham Hotspur[5] stadiums each have 4,500 loudspeakers to provide fans with hi-fidelity sound and clear announcements.

3.3 Intelligent wayfinding and digital signage

Intelligent wayfinding provides a digital navigation platform that compliments physical signage to offer real-time updates on the best routes to the event.

For example, the SoFi Stadium in Los Angeles uses the PAM[26] digital wayfinding systems to control wayfinding, marketing and regulatory messaging across more than 200 digital signs.

3.4 Virtual assistants, bots and conversational user interfaces (UI)

Virtual assistants, web bots[27] and conversational UI will radically change the event experience, with new personalised services based on fan and athlete data, results prediction, and real-time translation for or fans who don't speak the local language(s).

3.5 Personalised second screens for fans

For even greater personalisation, stadiums can leverage and provide second screens for use by individual fans, such as tablets tethered to fan seats. The stadium can then provide applications to further the fan experience, for example:

- To offer a selection of different camera angles with alternate views of the action.
- To give fans the ability to replay any moment of the action on-demand.
- To provide fans with statistics or other background information.
- To enable fan interaction with other fans in real-time, discussing tactics and key moments of the event.
- To allow fans to tune in to another event taking place outside the stadium, making sure they don't miss any of the action.

For example, Verizon[9] is using 5G Ultra Wideband (mmWave) in 25 National Football League (NFL) stadiums in the USA. This connectivity gives fans the ability to watch from multiple angles on their handsets and enjoy augmented reality (AR) games and services, while making it easier to buy food, beverages and merchandise. The network's low latency, paired with mobile edge computing, also enables access to real-time game and player statistics.

3.6 Multiple ultra-high-definition (UHD) / 4D / drone cameras to capture all the action

Future stadiums will include large numbers of UHD cameras to capture action from multiple viewpoints.

In addition to fixed UHD cameras, drone-mounted cameras will give fans a closer look at the action within the stadium as well as cover any additional festivities happening outside the stadium.

In the future, stadiums might also utilise 4D Light Field photography[28]. This provides the ability to refocus images after they taken, including the ability to see through foreground clutter, such as rain.

3.7 Holographic technologies

Holographic technologies[29] will also play an important role in future stadiums. They could allow you for example to enjoy your home's team away games in your home stadium, broadcast in realistic holographic 3D.

3.8 Augmented and virtual reality, digital twins and the metaverse

Augmented reality (AR)[30] provides video and audio overlays on fan's real-world vision and hearing. This augmentation enhances fan experience by combining real-world visuals with digital assets and data to offer additional context during games and other events. For example, adding real-time identification of key players and key moments, as well as background on statistics, historical performance and key achievements. There are huge opportunities for options that individual fan can select on demand.

Virtual reality (VR) – which puts fans in an artificial, but realistic 3D environment – is also a key technology option for future sports games. Since the purpose of visiting a stadium is to see live action, VR is more relevant for use at home, or for training athletes and performers.

These applications provide fans with the chance to enjoy the live experience from any seat in the venue, or even from on the field as a player, coach or referee.

3.9 eSports gamification for loyalty and out-of-stadium monetisation

Future stadium operators will be able to provide online services to bring the stadium to the sofa for home subscribers and pay-as-you-go users. Venue operators and event organizers have an opportunity to layer on VR-based eSports (professional video gaming) with traditional sport. This technology keeps fans engaged wherever they are and generates new opportunities for upselling and cross-selling services and products.

3.10 Crowd control and public safety

Wi-Fi connectivity, IoT sensors and cameras allow stadiums to track the movements of devices around the stadium. ML can then be applied to detect and alert staff of overcrowding and other safety hazards.

Video camera facial recognition can be used to find lost fans (e.g. children) or track trouble makers. Stadiums need to apply controls given the personal privacy implications.

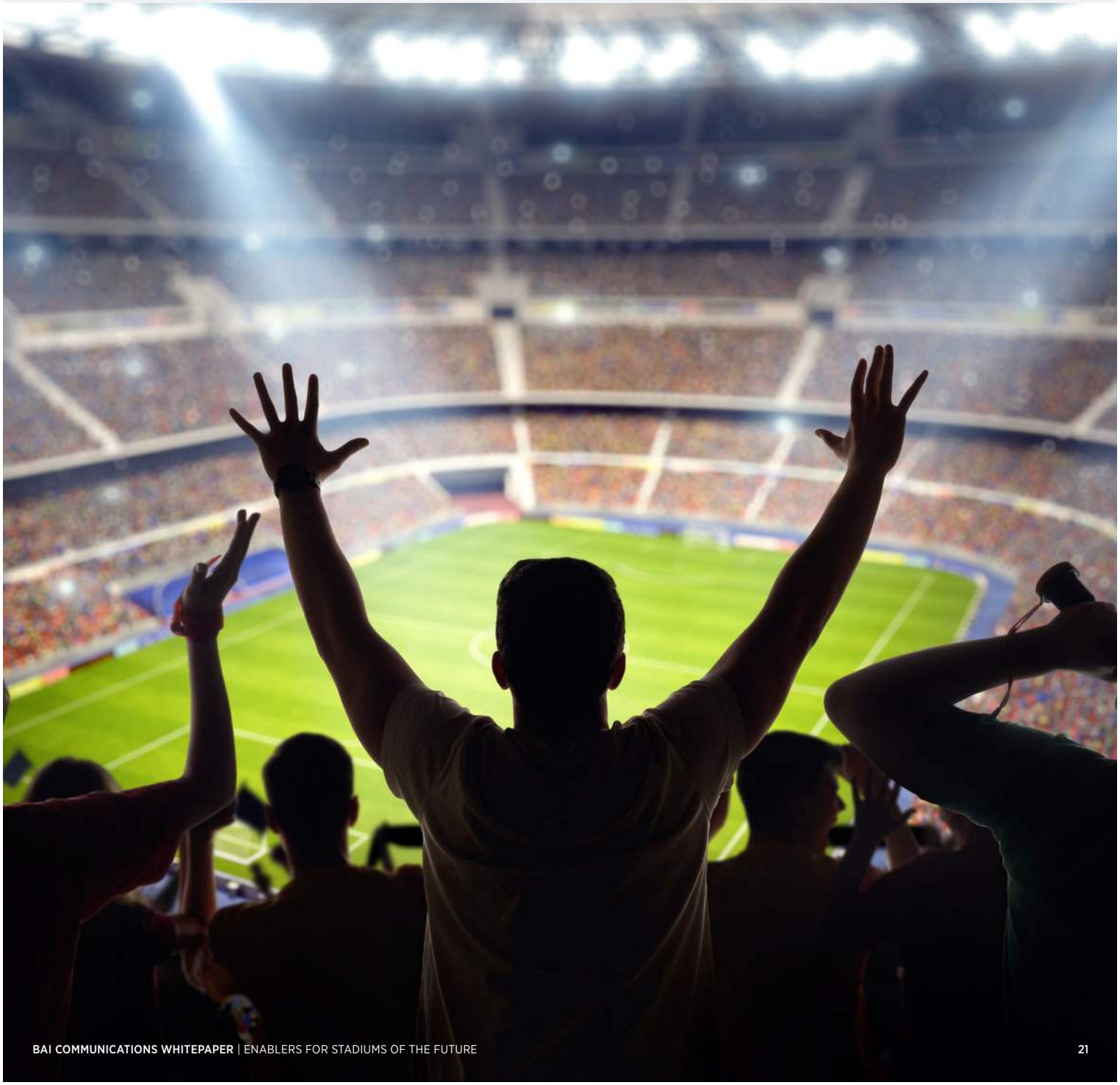
Big data analytics helps understand risks and plan mitigations.

Singapore National Stadium

4. How BAI can support stadiums across the globe

BAI Communications (BAI) has provided the network infrastructure to connect over 250 marquee venues across the globe. As a world leader in shared communications infrastructure, we're pioneering solutions that empower our customers to advance their services, accelerate their networks and amplify their reach in the most efficient and cost-effective ways possible. Having long been at the forefront of network advancement, BAI is harnessing fibre, spearheading the transition from 4G/LTE, accelerating 5G and preparing for 6G - and beyond. We collaborate closely with our customers in telecommunications, government, transport, enterprise, and venues to realise their communications vision, focusing not just on the immediate future, but on the possibilities that exist over long-term partnerships.

Our global operations span the United States, the United Kingdom, Ireland, Italy, Hong Kong, Canada, and Australia. Our BAI Group companies include Mobilitie, Signal Point, Transit Wireless and ZenFi Networks in the United States, and Vilicom in the United Kingdom and Ireland. Together, we're creating smarter communities for all. We bridge the gap between the venue and network operators to provide a harmonious solution that benefits all participants. We understand the capacity issues the industry faces, and we work to deliver solutions that not only solve our customers' problems today but will also satisfy their long-term needs and goals for growth.



BAI has delivered advanced connectivity in 250+ venues worldwide

Case study 1: Redefining the connected 5G experience at Crypto.com Arena and L.A. Live

Located in the heart of Los Angeles, the 20,000 seat Crypto.com Arena and its 4 million square foot sports arena and entertainment district L.A Live, required a major overhaul of its communications network across the entire campus to provide a compelling connected experience for both guests and employees.

20,000 seat
Crypto.com Arena, 2.5 million square feet

4 million sq. ft.
sports and entertainment district, L.A. LIVE

20 million
guests a year

2.7x increase
in stadium coverage (from 9 to 24 sectors)

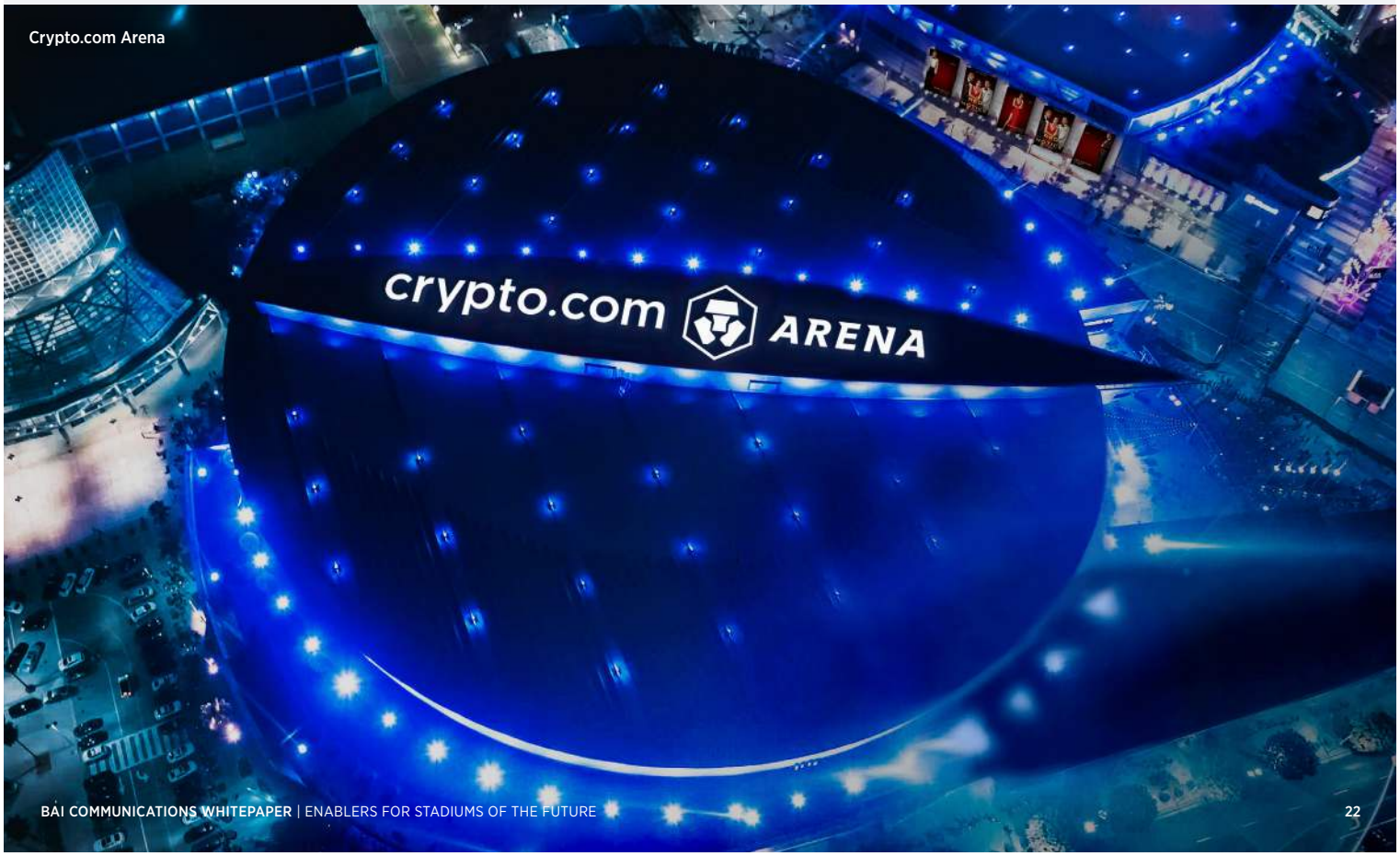
Case study 2: Future forward networks at Camping World Stadium

With a view to the 2026 football world cup, the stadium owners, City of Orlando, have invested approximately US$54 million in the modernisation of the facility. Part of the vision is to deliver an unrivalled connectivity experience across the venue for all fans and visitors and create an unmatched game day experience. Currently, BAI is designing an upgraded 5G mobile DAS network as well as an enhanced Wi-Fi system to accommodate Wi-Fi 6, the latest iteration of Wi-Fi technology.

Seating capacity of
65 thousand

Coverage over an area of
3.2 million sq. ft.

Discrete DAS with
210 antennas



Crypto.com Arena

References

1. Based, in part, on https://sporttomorrow.com/the-top-10-features-of-future-stadiums/.
2. https://www.nhl.com/capitals/news/capitals-and-kiswe-launch-virtual-gameday-second-screen-experience/c-320570074
3. https://www.mlb.com/braves/ballpark/digital-truist-park
4. https://www.ocvibe.com/
5. https://footballstadiumguide.co.uk/tottenhams-new-billion-dollar-field-with-the-most-modern-technology/
6. Licensed spectrum is dedicated to a given organisation typically across a country, a territory, or (in the USA) a large metropolitan 'market' area. Unlicensed spectrum is freely available for public use, subject to limitations on maximum transmitted power, and can suffer from problems other users creating interference. Shared spectrum is used by different organisations across a country or territory but is allocated to a single organisation in a specific local geographic footprint. In the USA, C-band spectrum, also known as CBRS, covering 3.5GHz to 3.7GHz, is being made available as shared spectrum. Other countries are allocating different frequencies as detailed in BAI's white paper on the "The Power of Private Networks", see footnote 13.
7. Compared with earlier evolutions of cellular mobile technology such as 4G, 5G offers increased capacity, throughput and performance. Primarily through of new radio spectrum (most significantly band n77 covering 3.3 – 4.2 GHz), advanced antenna technologies in base stations, and many detailed protocol improvements for latency/concurrency/efficiency.
8. 5G Ultra Wideband uses mmWave spectrum (24/26/28/39 GHz) to provide huge bandwidths and speeds in outdoor scenarios. See https://www.digitaltrends.com/mobile/5g-nationwide-vs-5g-ultra-wideband/
9. https://www.gsma.com/5GHub/stadiums
10. Wi-Fi continues to evolve at a similar pace to, and in similar directions as, cellular mobile. Whilst Wi-Fi can be operated in the 2.4 GHz band this offers limited performance at scale and exists primarily for backwards compatibility. Most smartphones support Wi-Fi operation in the 5 GHz band which provides wide bandwidths for high performance. Recent high-end smartphones support the Wi-Fi 6 (IEEE 802.11ax) standard which provides many detailed protocol improvements to improve performance. The emerging Wi-Fi 7 (IEEE 802.11be) standard further adds to performance including operation in the 6 GHz band.
11. https://www.baicommunications.com/g/whitepaper/the-power-of-private-networks/
12. A Subscriber Identity Module (SIM) securely stores authentication information needed to access a mobile network. Traditional SIMs are small cards slotted into a device. More recently, eSIM ("electronic SIM") technology allows authentication information to be downloaded into a device over the Internet; this is a complex process and not something that can practicably be done anew on each visit to a stadium. Many modern devices support Dual SIMs, either two traditional physical SIMs, or one traditional physical SIM and one eSIM.
13. Authentication of a SIM requires access to cryptographic credentials held by the issuer of the SIM. In roaming, the home network authenticates the SIM of behalf of the visited network.
14. https://www.weforum.org/focus/fourth-industrial-revolution. The Fourth Industrial Revolution is also called "Industry 4.0".
15. https://www.i-scoop.eu/internet-of-things-guide/internet-things-healthcare/
16. https://www.npstc.org/download.p?tableId=37&column=217&id=4195&file=NPSTC_PSIoT_Use_Cases_Report_190616.pdf
17. https://www.techtarget.com/searchenterpriseai/definition/machine-learning-ML
18. https://www.ibm.com/uk-en/cloud/learn/what-is-artificial-intelligence
19. https://www.cloudcomputing-news.net/news/2022/mar/02/maple-leaf-sports-entertainment-and-aws-transform-experiences-for-canadian-sports-fans/
20. Public Cloud offers computing and storage services over the Public Internet. Leaders in Public Cloud are Amazon's Web Services, Microsoft's Azure and Google's Cloud services. See Gartner Magic Quadrant for Public Cloud Infrastructure, obtainable via https://pages.awscloud.com/GLOBAL-multi-DL-gartner-mq-cips-2020-learn.html
21. https://www.forbes.com/sites/forbestechcouncil/2019/11/06/five-benefits-of-big-data-analytics-and-how-companies-can-get-started/
22. See, for example, ASM Global's deployment of PopID facial recognition in California USA https://www.asmglobal.com/p/our-story/news-releases/asm-global-begins-deployment-of-facial-verification-network
23. https://www.installation-international.com/technology/video-and-lighting/samsung-provides-sofi-stadium-with-first-of-its-kind-70000-square-foot-videoboard
24. https://www.zdnet.com/article/how-cisco-runs-its-massive-network-at-las-futuristic-sofi-stadium/
25. https://www.stadia-magazine.com/news/screens-visual-displays/led-video-display-experience-at-tottenham-hotspur-stadium.html
26. https://pam.co/sofi-stadium-wayfinding/
27. Bot is an abbreviation for robot. In the context of computing, a bot is a program that runs on a network and is programmed to automatically do certain actions, such as chatting with users or collecting statistics.
28. https://news.stanford.edu/press-releases/2017/07/21/new-camera-impro-virtual-reality/
29. https://www.respeecher.com/blog/holograms-real-life-technology-works-industry-use-cases
30. https://www.softwaretestinghelp.com/best-augmented-reality-glasses/

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