

Leveraging Tracking Technology for Live Sports Events: The High-Accuracy RTK GNSS Advantage

A deep dive into how emerging tracking technologies can augment audience engagement (TV & Mobile), arbitration and safety in live sport, with high-level strategic considerations.

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Introduction

Live sports events, by nature, are a messy proposition. The rotating door of venues, conditions, competitors and formats makes technology deployment a challenge. Yet that variability is central to their appeal: in a world of algorithms and systems, the new and unexpected keeps these events more relevant than ever.

This paper explores how tracking technology, and high-accuracy RTK GNSS, can augment audience engagement, improve officiating and safety, and unlock new commercial opportunities in live sport, and importantly, how it can be done. Through six key pillars, we provide actionable recommendations for deploying tracking technology successfully, drawing on real-world experience across some of the most demanding event environments.

At a high level, we will discuss the challenges faced by event organizers, broadcasters and rights holders across sports such as golf, horse racing, endurance events and offshore racing. From there, we cover individual technologies and how they can assist with specific challenges, providing a primary recommendation where multiple technologies are available. Where relevant, we detail how Lightbug products can be used, along with recommendations for configuration parameters. We also discuss performance evaluation and key outcomes to help existing Lightbug customers get the most out of their deployment. Finally, we will look at upcoming technology and opportunities, with the hope of inspiring forward-looking technical leaders to drive development and adoption of what could be a set of game-changing technologies.

Why Use Tracking Technology in Live Sports Events?

High-accuracy GPS tracking, particularly RTK (Real-Time Kinematic), offers transformative benefits for live sports events that go far beyond simple location pin-pointing. It provides the foundational data necessary for creating dynamic, highly engaging audience experiences: real-time 3D visualizations, precise performance metrics (speed, distance covered, acceleration), and accurate 'virtual leaderboards'. In 2026, it is also worth noting that AI systems are only as good as the data they are fed, and high-accuracy tracking is one of the richest real-world data sources available.

Fans now expect high-quality engagement and immersive experiences as standard. This is no longer a premium add-on. According to IBM's 2025 global study of over 20,000 sports fans, 82% use apps during live events, with 91% actively engaging with real-time stats, positions and performance data.[1] That data has to come from somewhere, and high-accuracy tracking is the engine behind it.

Beyond engagement, it also serves a critical function in event operations: enabling reliable real-time arbitration decisions, enhancing safety through location monitoring, real-time communication with participants, and reducing reliance on manual, error-prone data collection methods. The result is lower operational overhead and new commercial data streams.

Challenges in Deploying Tracking Technology in Live Sports Events

Many event organizers have long recognized the value in tracking, but there are many barriers to deploying solutions successfully at scale in live events: below are the most common and high-cost issues that we have encountered.

Lack of adequate cellular infrastructure

Events often take place in vast, challenging, or remote environments such as golf courses, open water for offshore racing, or large natural parks for cross-country events. Traditional cellular infrastructure in these areas, often straddling national borders, is non-existent or minimal. Sprawling locations, chosen for their scale and suitability for the event, are frequently far removed from established urban mobile coverage areas. This inherent remoteness means that the cellular network required for real-time data transmission, critical for safety monitoring, live data broadcasting and arbitration, is simply unavailable.

Even when events are located within areas that typically have standard mobile coverage, the sudden and massive influx of thousands of spectators and participants can severely overload local cell towers. The infrastructure, designed for typical population densities, cannot handle the sheer volume of simultaneous connection requests, resulting in network congestion, drastically reduced speeds, and frequent signal dropouts. For real-time tracking systems, this unreliability is a critical barrier: data transmission cannot be guaranteed when the network is overwhelmed.

Events that cross or run close to national borders present their own distinct challenge. As devices roam between networks in different countries, SIM conflicts and forced network switching can significantly reduce connection reliability.

Interference

Live events hosted in stadiums and arenas are inherently dense with technology, meaning interference is rarely avoidable. The sheer volume of existing broadcast equipment, wireless cameras and uplinks creates a complex electromagnetic environment that degrades the quality and reliability of comparatively very weak GNSS signals received by trackers. This can lead to intermittent lock-loss and reduced accuracy (or “jumping”).

In cities or mountainous areas, large physical structures can introduce GNSS canyon issues. The height and proximity of these structures obstruct the line of sight to the satellites, causing multi-path issues and signal shadowing. This has historically made achieving high precision difficult, even with RTK.

Managing battery-powered devices

Dealing with rechargeable devices is a pain. Unlike fixed infrastructure, every tracker deployed must be actively managed, often requiring a remarkably patient support team to maintain optimal equipment charge levels and keep on top of routine maintenance. Workarounds for issues including daily rotation of devices, identifying and setting aside non-operational units can all be a huge resource drain.

Cold climate events need special consideration, as battery capacity can be reduced by up to 30%, or in some cases prevent devices from operating entirely. Even in “nominal” conditions, devices used for live events have a hard life: frequent charge-discharge cycles and continual physical knocks are just the baseline abuse. Batteries need replacing, potentially more than once, to ensure device costs can be amortised over a meaningful period.

Complexity has historically been compounded by the high-power consumption of high-accuracy systems. RTK GNSS trackers, until recently, could not sustain a full day of usage at the required update rates. Thankfully as technology marches on, meaningful battery life can now be achieved with centimeter-level accuracy.

Assignment and handout

Giving trackers to competitors, or attaching to their associated equipment, marks the final preparation stage before an event begins, and is a common point of friction, if not outright failure.

Critically, each physical object, whether an athlete, boat, or horse needs to be linked to its “digital twin” within the event management system. This step is highly prone to human error, and often painstakingly slow, especially considering the high-pressure, time-constrained conditions at the start of a live event.

Efficiently giving the right devices to the right people is often challenging enough, but becomes a nightmare when a swap is needed minutes before a race begins: data is frequently lost or misattributed, requiring human intervention which can be a major barrier to scale.

Handout issues are the most common cause of downstream problems with broadcast graphics, arbitration feeds, and safety monitoring: at best they lead to audience confusion, and at worst, a safety incident.

Reliability & availability

For any system operating in the context of live events to be effective, it must be reliable. Physical tracking devices, the networks that underpin them and the cloud applications that communicate with them must be highly available, fault tolerant and self-healing. Building and maintaining such a system is no small feat.

The high-performance, high-availability issue is exacerbated by the typical scheduling of major events. Major events are typically run on weekends and public holidays when technical support from key suppliers, cloud providers, and network operators is reduced or entirely unavailable. In practice, this places the full burden of system stability squarely on the event's internal technical team.

Six Key Pillars for Deploying Tracking Technology in Live Sports Events

Pillar 1: Versatile Connectivity

Live events' variable and demanding conditions (poor cellular coverage, high density, remote venues) make relying on a single connectivity solution risky. A mission-critical tracking system needs a multi-bearer connectivity strategy, using a layered infrastructure. This ensures data continuity via automatic failover when any one channel (cellular, LoRa, Wi-Fi, Bluetooth) fails or congests. The result is a resilient system capable of performing reliably across any event environment.

Cellular

High Level Overview

Purpose	Key Limitations
High Bandwidth Data Link: Ideal for transmitting rich, high-frequency (up to 10Hz) RTK GNSS position data and receiving large correction files (RTCM) where infrastructure allows	**Network Congestion:** Highly susceptible to spectator overload, leading to dropouts and high latency in dense areas
Wide Area Coverage: The best solution for tracking assets across large, established areas, essentially most of the populated world	**Infrastructure Gap:** Non-existent or minimal coverage in remote or vast natural venues (e.g., cross-country, open water racing)
Primary Real-Time Link: When available, often offers the lowest latency for immediate broadcast graphic updates and arbitration decisions	**High Power Consumption:** Constantly searching for and maintaining a cellular connection is a major drain on battery life, limiting device runtime

Technology Overview & Maturity:

Cellular technologies (4G/LTE, and increasingly 5G) are mature, standardized, wide-area wireless communication systems operated by mobile network providers. They offer high bandwidth and low latency for transferring large amounts of data over vast geographical areas, relying on established public infrastructure. 2G, whilst an important backup in 2026 for maximum coverage, is losing relevance as more networks get turned off.

Future Outlook

For those trying to stay a step ahead, our strong recommendation is for 4G LTE Cat 1 bis if deploying devices in 2026. We know 5G is a nice buzzword, but it really hasn't gotten round to IoT yet and the solutions available are currently far inferior to what 4G can do. Technically, LTE-M is a part of 5G, but that's cheating, and we don't recommend the use of LTE-M for commercial reasons, after five years operating tens of thousands of devices using it.
Late 2027 will be the time to start considering using eRedCap devices, and there may be some justification for RedCap devices before then in certain territories, but we will be waiting for the networks to start showing up before integrating the technology.

Private 5G is a slightly different matter: whilst we still need the device hardware (modules, antennas) to catch up and serve the needs of IoT, private networks are gaining popularity and offer a great way to connect devices in a live event setting with confidence, even if expensive and complex.

LoRa/LoRaWAN

High Level Overview

Purpose	Key Limitations
Long-Range, Low Power: Provides low-bandwidth communication over several kilometers, making it ideal for large, remote venues with minimal power usage	**Low Data Rate:** Limited to sending small data packets and hampered by duty cycle limits (essentially data usage is capped at a low number)
Private Network Resilience: Can be deployed using strategically placed private gateways (hotspots/base stations)	**Infrastructure Deployment:** Requires the installation and maintenance of LoRa gateways across the event site, adding to setup complexity and overhead
Backup / Active Standby Link: Excellent for sending lower frequency backup data in parallel to the primary. For example 5Hz data on Cellular is sent at 0.5Hz on LoRa to guarantee minimum data rate	**Varying Regulations:** International events potentially introduce regulatory challenges if not automatically managed

Technology Overview & Maturity:

LoRa (Long Range) is a proprietary, low-power wide-area network (LPWAN) modulation technique, achieving exceptional range (1-20km). LoRaWAN is the open protocol

specification built on top of it. It is moderately mature, designed to send small amounts of data over very long distances with minimal power, making it excellent for private, dedicated networks where data rate is secondary to range and battery life.

Future Outlook

2.4Ghz LoRa solves a lot of the problems around duty cycle limits and is becoming increasingly popular. Whilst Lightbug devices don't currently support this standard, we are actively looking to include it in future products.
LoRaWAN public networks are maturing, but they are not good candidates for live events. Private LoRaWan will remain a good option for many sports use cases.

Wi-Fi (802.11)

High Level Overview

Purpose	Key Limitations
High-Speed, Localized Data Transfer: Can work in smaller stadiums for live data, but typically would be used in bursts, for example downloading stored data when returning to base	**Extremely Limited Range:** Only effective within a short range (<300m, usually <100m) from a hotspot or access point
Configuration and Setup: Enables quick, reliable configuration updates and diagnostic checks on devices prior to deployment	**Frequency Congestion:** Highly susceptible to interference in dense media/broadcast environments, as many media networks also rely on the 2.4/5GHz Wi-Fi spectrum
Local Correction Data: Can be used to broadcast RTK correction streams (RTCM) from a local base station directly to trackers within a small, defined area	**Power Consumption:** High power use compared to LoRa, roughly equivalent to cellular power usage

Technology Overview & Maturity:

Wi-Fi (IEEE 802.11 standards) is a highly mature and ubiquitous technology providing high-speed, high-bandwidth local area network access. It is best suited for scenarios requiring rapid data transfer within a limited physical space, often relying on established access points (routers).

Future Outlook

Wi-Fi 6,7... the standards keep moving and there are some very interesting low power and long range developments happening in the space. For indoor events, especially if positioning standards become widely adopted (range finding, multiple bases,

connectionless), a single Wi-Fi chip plus a battery could be all that is needed for live tracking.

Bluetooth (BLE)

High Level Overview

Purpose	Key Limitations
Device Handout and Assignment: Enables pairing of a physical tracker to a competitor or connected biometric devices such as heart rate monitors. A local link can be set up with competitor and staff mobile devices	**Ultra-Short Range:** Only useful for very close-proximity operations, typically person-to-device interaction (less than 10 meters, can be extended but reliability may suffer)
Local Diagnostics and Setup: Provides a low-power, direct link for technical staff to check device status, battery level, and perform minor configuration changes in the field without using the main network	**No Uplink Capability:** Not suitable for sending live position data to the cloud or broadcast center, unless streaming data to a smartphone
Proximity Awareness: Can potentially be used in conjunction with other BLE beacons for highly localized indoor tracking or micro-location data (approximate timing gates)	**Interference:** Performance can degrade in areas with high density of other Bluetooth or Wi-Fi devices

Technology Overview & Maturity:

Bluetooth Low Energy (BLE) is a mature, personal area network technology designed for very short-range, low-power communication. It is not intended for wide-area data transmission but serves as an essential link between the tracking device and local user interfaces or other proximity-based systems (such as timing gates).

Future Outlook

As with Wi-Fi, the standards march on. Effectively, you'll get the same things (sub-meter positioning, low power connectivity), but with less cost, less power, less bandwidth, and usually, more range.

Comparison & Summary

Technology	Primary Use Case	Data Speed (Approx.)	Range (Typical)	Latency (Approx.)	Power Consumption	Resilience /Dependence
Cellular (4G/5G)	The default. Outdoor, Low and high-frequency live data, firmware updates, RTK corrections	High (up to 10 Mbps)	“Infinite” across the populated world Technically km per cell	Low (50 ms - 200 ms)	High	Dependent on public mobile network infrastructure
LoRa / LoRaWAN	Low-rate backup position, device health monitoring, remote areas. (2.4ghz - higher rate)	Very Low (0.3 kbps - 50 kbps)	Long Range (Kilometers)	Moderate/ High (1 s - 10 s)	Low	Private network possible; independent of public cellular
Wi-Fi (802.11)	High-speed local data dumps, configuration, local RTK correction broadcast	Very High (10 Mbps - 1 Gbps+)	Short Range (Tens of Meters)	Very Low (< 50 ms)	High	Dependent on local access point deployment
Bluetooth Low Energy (BLE)	Device assignment, local diagnostics, proximity awareness	Very Low (0.01 Mbps - 1 Mbps)	Ultra-Short Range (< 10 Meters)	Very Low	Very Low	Local, device-to-device connection; no network required

Fallback when nothing will work: Local Data Buffering

A common solution is to save data during an event and download it later, either manually or automatically. It’s an almost foolproof way of ensuring no data is lost when

communication fails. Trackers use non-volatile memory to continuously log all high-frequency data, and a retransmission scheme then manages this buffered data.

An example buffering scheme:

1. **Continuous Local Logging:** All positional and sensor data is saved locally, regardless of network status.
2. **Smart Buffer Management:** A modified FIFO strategy prioritizes the newest, highest-resolution data, discarding the oldest, least critical data if storage is full.
3. **Prioritized Uplink:** When the network returns, the device immediately transmits the backlog, sending the newest data first for immediate live updates.
4. **Data Integrity Check:** A check ensures the entire backlog is transferred correctly.

This approach guarantees data recovery and prioritizes the most recent, critical information upon network restoration, minimizing service impact, but can lead to unacceptable data loss. A workaround could be to downsample data whilst overwriting, such as overwriting every other stored position which would effectively create a log of points every 2s (if the original data was recorded every 1s), doubling the storage time available.

The Lightbug Approach

In terms of connectivity, our approach is to integrate all available bearers into a single device. Rather than pre-selecting a communication method, the on-device software decides dynamically, based on conditions and user-configured preferences via a scripting interface.

In terms of data storage, Lightbug firmware, historically, would take the circular buffer approach: oldest data would be overwritten when space ran out for new data. This has served us well and the simplicity of the solution means we would still recommend it for all but the most complex use cases.

Unfortunately (or fortunately, depending on the point of view), we have needed to deal with the most complex use cases and have evolved our firmware to provide many more “knobs to turn”.

In Lightbug devices, all sensors emit streams of data, annotated with metadata such as “Valid” and “Changed”. There is a data subscription system with three levels of storage that manages those streams. This effectively allows users to configure a near-infinite combination of data storage permutations. One example request that could be satisfied by this system:

1. Send ALL position information 5 times per second, do not retry sending if upload fails
2. Send VALID position information once per second, use a circular RAM buffer to resend failed uploads
3. Send VALID position information once every 2 seconds, use a persistent (NVM) buffer to keep all failed uploads
4. Send ONLY CHANGES for Battery status, Temperature, Network Status, Current Cell tower, and store in persistent buffer if not transmitted.

This effectively enables “graceful degradation”, without compromising top performance when conditions allow. In the example above, under normal conditions, the server would receive 5Hz position data, ideal for live streaming and AR graphics when upsampled to 25fps. If network conditions degrade partially, the server would start seeing bursts of positions, sometimes at 5Hz, sometimes lower, but the chances of receiving a position every one second are greatly increased as the device will retry sending only one of those 5 positions every second (rule 2). If network connectivity disappears completely, the device would fill up and continuously overwrite its RAM buffers, but would periodically write the historical 2Hz data into a file, for later upload (rule 3). In this scenario, once connectivity resumed, the server would receive, roughly, the last 5 seconds of data at 5Hz, the last 30 seconds of data at 1Hz, and then very shortly thereafter, the full log of all missing data at 0.5Hz. Approximately 300,000 points can be stored on our devices in this way, or 7 full days of continuous 0.5Hz data (the same data storage used at 5Hz would be just 16h).

Pillar 2: Robust High Precision Positioning

Achieving the required sub-meter, and ideally centimeter or decimeter-level, accuracy often required for live event tracking necessitates a strategy that focuses on maximizing the reliability of Global Navigation Satellite Systems (GNSS), while integrating localized augmentation for precision, context and failover.

Standard GPS accuracy of 3-5 meters is sufficient for navigation, but falls well short of what live sport demands. For broadcast graphics, centimeter-level accuracy means players precisely placed within a pitch, competitor gaps measured in real-time, and 3D visualisations that hold up on a 4K broadcast. For officiating, marginal calls such as a photo finish, a boundary crossing, an offside decision can be separated by centimeters and need to be made definitively, in real-time. For safety, knowing an athlete or vessel is "somewhere in a 5 meter radius" is simply not good enough in high-speed or high-risk environments.

At the scale required for large-area sports, such as golf, motorsports, or offshore racing, GNSS (GPS, GLONASS, Galileo, BeiDou) remains the only truly viable and economical technology for wide-area, continuous positional tracking. GNSS is not perfect, performance suffers when there is no clear line of sight to the sky. However, it can be augmented, and often is, with local infrastructure:

- **BLE Beacons:** Placing Bluetooth Low Energy (BLE) beacons at critical locations (e.g., pits, transition areas, start/finish lines) allows a tracker to confirm its presence at a precise point using ultra-short-range communication. While BLE cannot track continuous movement, it provides highly reliable, meter-level accuracy for defining key moments or micro-locations, complementing the wide-area GNSS data.

- **UWB Gateways:** Ultra-Wideband (UWB) gateways can deliver sub-meter, sometimes 10cm accuracy via Time-of-Flight (ToF) measurement, making them ideal for indoor micro-location. However, installation is often cost prohibitive.

- **Timing Gates/RFID:** Traditional timing gates or localized RFID systems provide instantaneous, high-confidence timestamps and positional confirmation as an asset passes a defined point. This data serves as an excellent cross-validation reference for the continuous GNSS track log, helping to correct any cumulative drift or brief signal interruptions.

Maximizing GNSS Reliability: Multi-Frequency and Augmentation

The primary focus for mission-critical tracking must be on making the core GNSS data as robust as possible. This is achieved through two key technological approaches:

1. **Multi-Frequency Receivers (L1+L5):** Modern high-accuracy receivers utilize signals from multiple frequency bands (e.g., L1 and the newer L5 band). Using multiple frequencies allows the receiver to effectively mitigate ionospheric error, a major source of inaccuracy, leading to faster fixes, fewer dropouts, and better overall reliability, especially in challenging environments.

2. **Accuracy Augmentation:** To move from meter-level standard GNSS accuracy to the centimeter-level precision required for broadcast graphics and arbitration, an augmentation service is essential. The two main solutions are Real-Time Kinematic (RTK) and Precise Point Positioning (PPP-RTK).

For most remote or high-density live event scenarios, **RTK**, using a dedicated, locally deployed base station, is the preferred solution. It offers the highest level of control and

minimizes reliance on congested or non-existent public cellular infrastructure for the critical correction data.
When local deployment is not practical, it is almost always preferable to run RTK or PPP-RTK correction data over the cellular data link using a commercially hosted source of correction data such as Swift Navigation Skylark Precise Positioning service to minimize errors and setup overhead.

PPP-RTK is a good solution when all that is required is sub-meter accuracy. The data requirements are lower (lower SIM card costs), buying commercial subscriptions is cheaper and usually is more readily available across large geographies. Simplistically, it works by correcting global errors only, whereas **RTK** corrects both global and local errors. There are drawbacks in terms of resiliency to obstacles and convergence time (time to get a good accuracy) but in clear sky conditions, PPP-RTK is able to reach sub 10cm accuracy quite easily.

It is worth noting that the ongoing deployment of Galileo E6 HAS will effectively provide free global PPP-RTK data with no requirements for sending data over the internet. This service has been shown to achieve 20cm accuracy, given good conditions and enough time to converge.

Note on transmitting Correction Data via LoRa

Where cellular connectivity is unreliable or unavailable, LoRa/LoRaWAN can be configured to serve as a resilient, long-range transport layer for RTK correction messages, with some effort.

- **Mechanism:** The fixed RTK base station calculates the localized correction data (RTCM) and feeds it into a dedicated LoRa gateway. Trackers within the network range receive these small, essential data packets via the LoRa network.

- **Benefit:** LoRa's long-range capability (several kilometers) allows a single gateway to cover a vast event area such as a golf course or open water bay. Its low-bandwidth design is perfect for the small size of RTCM messages and its independence from public networks ensures the critical accuracy link remains stable even when spectator cellular traffic peaks.

- **Limitation:** Regulatory constraints mean correction data must be cut down and/or frequency hopping must be employed for long-range transmission. The correction broadcast must also avoid interfering with the uplink (tracking data). Note: this can be circumvented with LoRa 2.4G.

Future Outlook

Galileo E6 with HAS (high-accuracy service) is slowly becoming available and promises 20cm accuracy (currently after a long convergence time). As it becomes more widespread, it will likely become the obvious choice for most sports events: free correction data from space, no secondary link, subscriptions or base stations needed.

Pillar 3: Software Defined Deployments

The key concept here is to have hardware that can adapt to any event setup, and change only settings and scripts based on the specifics of the current event.

The idea is that if all the technology is available on a single device, features can be enabled or disabled on demand to optimize reliability and power consumption.

For example, it's often known before an event begins if cellular coverage will be unavailable. When this happens, it should be easy to change the primary communication method. In an ideal world, this optimization would happen automatically.

Including all the required hardware may seem counterintuitive from a cost perspective, but these days the foundational technologies are relatively inexpensive. When you buy hardware, up to 90% of the cost has nothing to do with the components themselves, especially when buying or building specialised equipment: it's the firmware and all the overheads involved in getting a physical device in your hands that end up being the largest cost drivers. In our experience, adding $20 to the cost in exchange for a single, versatile device is a decision that pays for itself.

The primary downside of this approach is size. Whilst the components can be disabled and won't consume battery power, they still need to be physically present. For applications requiring a small form factor - typically anything smaller than a credit card footprint - this approach is not viable.

“All in One” Hardware

Pros	Cons
Adaptive Hardware: Suitable for any event setup. Example: A single device type can be used for ultra high-accuracy tracking in populated areas using cellular, and then seamlessly transition to local LoRa comms when out at sea	**Size:** Not viable for very small devices (smaller than a credit card footprint) due to the physical presence of disabled components
Optimization: Features can be enabled/disabled on demand to optimize reliability and power consumption (e.g., changing communication method)	**Additional Complexity:** If tools are not available to make switching easy, this becomes a burden for the event team, particularly under the pressure of a live event
Cost-Effective: While seemingly counterintuitive, the low cost of foundational technologies means adding $20 for a single, adaptable device type is cost-effective, as hardware cost is a small percentage (up to 10%) compared to firmware and overheads	**Initial Cost:** The BOM (Bill of Materials) cost of the single, fully-featured device is inherently higher than a non-adaptive, minimum-feature device

Keep Things Modular with Accessories:

Ensuring hardware is as modular as possible goes hand in hand with software configurability.
The more the core technology can be made general purpose, the better - it’s using the same tool with different attachments. Allowing for extension is key to futureproofing (requirements always change), ROI (more uses for the same price), and minimizing overhead (just one user manual).

The issue with being a jack of all trades is, of course, that you aren’t particularly good at any one thing: this is where an ecosystem of accessories becomes important.

Below are some examples of common accessories which Lightbug offers:

- **Bespoke Mounts:** The main one. The attachment of devices is usually the first thing that needs changing when switching event types. Mounts should fit securely, look professional and maintain optimal antenna orientation, whilst protecting the device from the physical demands of the environment.

- **External Power Integration:** For long or multi-day events, swappable battery packs are an essential consideration. Charge cables for connecting to a vehicle might also be useful to remove the need for charging.

- **Charge & Carry Cases:** Whilst most remain a one-size-fits-all solution, cases that are “ready-to-go” deployments in a box for a specific event can be a huge help in reducing event overhead. For example, the case could double as a LoRa RTK base station.

- **Bluetooth Extendability:** The most common use case is connecting to standard heart rate monitors, but this extends to any external sensor. If Bluetooth is available and configurable, any number of external sensors can be observed and have their data relayed via the primary device link.

Keep Things Flexible with Data Pipelines

On the software side, focus should eventually shift from data acquisition to **data distribution**. The raw location fix is merely the input; the true value is unlocked when this data is reliably and flexibly delivered to multiple downstream consumers. Those consumers could each independently feed into:

- Arbitration and Scoring
- Live Television Graphics (Augmented Reality)
- Audience Engagement Apps
- Forensic and Post-Event Analysis

A future-proof, scalable solution requires decoupling the data producer (the tracker) from the data consumers via a robust message-brokering and format standardisation infrastructure.

Future Outlook

It is worth returning to AI here. Clean, real-time data streams that can be split, augmented, aggregated and distributed to multiple downstream systems are the prerequisite for any meaningful AI layer. It makes sense and there are likely people already selling such AI systems, but the heavy lifting will still need to be done when it comes to connecting the real world into those systems.

Pillar 4: Know Your Event Site

The first year at any new venue is a testing year, regardless of preparation. Every event site, from a specific golf course to a particular stretch of coastline, has its own unique challenges when it comes to tracking technology. Those challenges are rarely identifiable ahead of time, at least not all of them. Successful deployment at one venue does not guarantee success at another.

Event Tech Bible

We suggest the creation of an “Event Tech Bible” to institutionalise the memory of known issues and fixes for any event site. This type of document is common practice across other operational activities, and technology deployments should be no different. The creation and maintenance of this “Bible” is essential for minimizing overhead and ensuring subsequent deployments work as expected.

A well-maintained “Event Tech Bible” typically covers four core components. The table below outlines what each should capture and why it matters:

Tech Bible Component	Essential Information to Log	Technical Impact & Mitigation
Connectivity Map	GNSS-logged data of cellular signal strength (all major carriers), LoRa gateway optimal placement, Wi-Fi hotspots	Identifies crucial cellular "dead zones" where a fallback (LoRa or Local Data Buffering) must be actively managed. Informs the required quantity and placement of private LoRa infrastructure
GNSS Health Map	Areas with known multi-pathing or signal shadowing (e.g., near grandstands, tall trees, deep valleys). Logging of observed horizontal position error (HPE)	Smooth or discard data from known low-accuracy zones
Physical and RF Notes	Specific mounting requirements for different asset types, known sources of radio-frequency (RF) interference (e.g., proximity to media trucks, timing equipment)	Ensures the right Bespoke Mounts are prepared and utilized. Informs decisions on enabling/disabling specific comms bearers (e.g., switching off Wi-Fi in a known congested media area)

Tech Bible Component	Essential Information to Log	Technical Impact & Mitigation
Handout / Retrieval	Known entry, registration and exit points	Enables installation of local, short range infrastructure if needed (e.g. on a registration desk) and ensures dedicated device recovery at key exit points

Inferred Changes to Strategy Based on Learning

The “Event Tech Bible” directly feeds back into the "Software Defined" strategy by informing the dynamic configuration of the flexible hardware:

- **Connectivity Switching:** The technical team can push configuration updates via the working network (Cellular, LoRa, Wi-Fi, or even cable when docked) to adjust the primary communication bearer based on known dead zones or congestion (e.g., forcing a switch from Cellular to LoRa/Local Buffering in a known RF-congested valley).

- **Accuracy Normalization:** The post-processing services in the data pipeline can be pre-configured to smooth, filter, or discard positional data that falls outside of the expected accuracy observed in known "GNSS canyon" areas, ensuring that graphics and arbitration systems do not display unreliable "jumping" data.

- **LoRa Infrastructure Placement:** The “Connectivity Map” informs the strategic positioning of LoRa gateways and RTK base stations to maximize coverage in areas identified as cellular dead zones or complex terrain, guaranteeing a resilient correction data link and a low-rate backup uplink.

One Step Further: Course Survey and Digital Twin Creation

Prior to the event, a dedicated surveying team, equipped with the same high-accuracy trackers (potentially vehicle-mounted), could map the entire course. This could include 3D point cloud mapping. The data generated is invaluable for:

- **Visualization Calibration:** Creating the high-fidelity 3D digital twin of the course required for accurate TV broadcast graphics and augmented reality overlays.

- **Point of Interest (POI) Mapping:** Augmenting the base map with zones, pins for landmarks and services maximises data value.

- **Platform Foundation:** Once the environment is fully digitized, building new applications, products and revenue streams becomes significantly more accessible and scalable.

Future Outlook

With all of the rules and knowledge about an event codified in a way that can be fed into a computer system, we are likely to see increasing automations in more events. Consider the VAR system in football but for every live event, no matter the size: what if organizers were able to make near instant arbitration decisions and replay the events leading up to an incident or point score? Or even simply locate all competitors when a thunderstorm rolls in and instantly instruct all of them to return to base?

This level of automation, if made accessible, has the potential to transform not just professional but also amateur sports.

Pillar 5: Easy Management & Handout

Even if all the technology works as intended, the need for battery management remains. Keeping them “charged, but not too charged” if they won’t be used for a while, can be painful. Swapping devices or charging mid-event is usually a deal-breaker.

The target should be a device capable of lasting a full 24 hours, with at least a few hours of active time (when the device is moving and actively transmitting). This provides a sufficient buffer for charging the night before, disconnecting the charger at 6am, handing out at 10am, and racing from 11am to 8pm. It also leaves room for error and accounts for low temperature environments, where battery capacity can drop by up to 30%. It also allows for capping maximum charge at 85%, which can effectively double the operational life of a device.

Sleep mode on a timer (e.g. 6pm-6am) or when stationary is a practical way of achieving multi-day battery life without manual intervention.

Reliable, scalable charging solutions are also key to successful long-term use of tracking devices. Ideally, those chargers should be smart and perform some form of configuration control to connected devices. A setup of 10-50 devices per charger, with rugged transport cases carrying 2-4 chargers, is the most common and practical configuration.

Ensuring event teams have sufficient battery life across all deployed devices, painless charging, and an effectively self-service handout process significantly reduces their overhead.

Notes on Handout Automation

Errors at the handout stage propagate throughout the entire data pipeline, making accurate assignment critical for data integrity. Deployment assistance should focus on minimizing human error and providing immediate cross-validation.

We recommend looking for the following features:

- Self-identification: The ability for a device to identify itself via LED or audio cue.
- Display: Devices with screens can show competitor name or number, reducing misassignment.
- NFC assignment: Devices that can be “programmed” like ski-passes or hotel room keys, enabling fast, reliable pairing.

If none of the above are available, we’ve seen the old fashioned pen & paper approach work best: a simple table of competitor names where the person handing out writes down a serial number against each name beats or at least matches any automated system that isn’t 100% reliable.

Watch the Lightbug Control Center in action, using our extensive hardware APIs to show competitor names on screen and light up on command.

Pillar 6: Self-Sufficiency

Even with the most meticulously planned and robust systems — versatile connectivity, multi-frequency corrected GNSS, extensive pre-event planning and intelligent power management — the unpredictable nature of live events dictates that things *will* inevitably go wrong.

For high-stakes live events, the primary measure of a successful technology deployment is not its theoretical reliability, but actual (or rather perceived…) reliability. If it doesn’t “always” work, it’s not deployable. Having an SLA and maybe a refund doesn’t really cut it.

In our experience, every successful deployment has had one thing in common: an internal tech team. Expecting iPhone-level usability from tracking devices is unrealistic, at least for now. It is currently best to acknowledge that complexity and resource appropriately to build internal expertise.

These expert deployment teams should be assisted, not hindered, by the products they use. When selecting hardware to purchase and deploy, observability ("troubleshoot-ability") should be top of mind. The ability to self-manage both connectivity and cloud-based resources are close followers.

We won't dive into the details of creating a High Availability (HA), high reliability cloud systems, as this is a cross industry, cross use case problem that has been solved many times. Instead, we will look at the two main paths for achieving this in practice.

Open communication standards

There is usually a need to build a "translator" for trackers which communicates with devices in a data efficient way and then emits JSON data that can be used by downstream software services.

The format and protocol for both of these data packets should be available to the integrator (as mentioned, typically the event organizer tech team) to allow for direct communication with devices, ensuring maximum flexibility.

At Lightbug, we've ended up creating our own binary protocol (now on version 3) https://docs.lightbug.io/devices/api/protocol/ and are slowly making more and more tools available to make integration and customisations a breeze.

Mature software tools that can be run on premise

Stable, regularly updated for security, horizontally scalable: the server software has its own set of requirements. Ultimately though, for live events, there will generally always be a need to host the system internally: it is important to be able to control the roll out of updates. 4am on a Sunday might generally be a good time for updates, except when there is day 2 of an event starting at 6am that day and the devices were working just fine the day before...

At Lightbug, we've historically sold an on-premise or "silo deployment" add-on for these performance and independence conscious users. As things have evolved, we are now pivoting to an Open Source first approach, where users can not just take and run our ingestion and data pipeline services, but they can integrate them fully with confidence. We are actively working on the ability to move devices between servers with ease, with a full open-source transition planned for later this year.

Case Studies

The challenges outlined earlier in this paper are not hypothetical. The following case studies demonstrate how high-accuracy tracking technology is already delivering measurable results across audience engagement, athlete safety and race integrity - in some of the most demanding sporting environments in the world.

Case Study 1: SailGP - High Precision Broadcast AR

Sport: Offshore foiling sailing
Benefit: Audience engagement & commercial growth

When SailGP launched, the core problem was that high-speed sailing is spatially difficult for viewers to understand. The LiveLineFX system was implemented using RTK GNSS and inertial sensors to track boats with 2 cm accuracy, and developed entirely in-house. This data is injected into a specialized graphics engine to overlay virtual boundaries, "ladder lines" (showing who is leading), and real-time speeds onto the live helicopter feed[2].

Outcome:
Tom Peel, Director of LiveLine, is unambiguous about the technology's role: "SailGP wouldn't be the compelling viewing experience it is without LiveLine, and it's now grown to be a huge part of the commercial success."[3] By Season 5 in 2025, SailGP's dedicated broadcast audience had grown to nearly 215 million viewers, averaging 18 million per event, with total social views surpassing 1.65 billion - a 90% increase year on year. In just five seasons, annual audience and revenue grew 12x and 20x respectively from Season 1.[4]

Case Study 2: Marathon des Sables - Athlete Safety

Sport: Ultra-endurance running
Benefit: Life-saving rescue and remote monitoring

Since 2015, the Marathon des Sables has deployed satellite trackers across all competitors in one of the world's most extreme environments, the Sahara Desert. The system transmits each runner's location every five minutes to centralized race control via the LEO satellite network, functioning in an extreme environment where no cellular infrastructure exists.[5]

Outcome:
In the first year of deployment alone in 2015, the system enabled the precise location of 18 competitors in distress and the rapid dispatch of medical rescue teams to each. Across

subsequent years, the system has been responsible for over 45 critical rescues - often involving runners who had wandered miles off-course due to heat-induced disorientation.[6]

Case Study 3: Tour de France - Digital Transformation & Fan Engagement

Sport: Professional Road cycling
Benefit: Real-time data storytelling and digital fan engagement

The Tour de France utilizes GPS transponders on every bicycle to create a "Digital Twin" of the race. High-precision sensors transmit speed, location, and proximity data to relay motorcycles and planes, allowing broadcasters to show metrics like "Catch Probabilities" and live time gaps.[7]

Outcome:
Peter Gray, who leads NTT DATA's Tour de France technology program, notes that the system turns the race into a "connected stadium."[8] The Tour de France's Race Center live tracking platform recorded over 25 million visits during the 2024 race[8], rising to 27.4 million in 2025[9], highlighting the scale of engagement with real-time race data.

Case Study 4: Formula One – Race Integrity & Driver Safety

Sport: Motorsports
Benefit: Millimeter-accurate race control and driver safety

Formula One operates one of the most advanced real-time data systems in sport, using a hybrid positioning system combining GPS-based telemetry, track-embedded timing loops, and high-speed data transmission to track every car in real-time. Each car continuously transmits positional and performance data to teams and race control, with telemetry latency as low as 10-15 milliseconds in European races[10]. To ensure accuracy, induction loops are embedded approximately every 150-200 meters (and ~40 meters in pit lanes), recording the exact time each car passes a fixed point and synchronised using GPS timing[11].

Outcome:
The integration of positioning data into FIA race control systems has significantly improved both the speed and scalability of officiating in Formula One. At events such as the Austrian Grand Prix, where over 1,000 potential track limit violations required review, automated systems combining positioning data, timing, and computer vision now handle the vast majority of cases independently, with human involvement needed in only a small fraction (around 5%).[12] This reduces reliance on trackside personnel and enables

incidents to be detected and communicated to teams within seconds, and allows officials to monitor all cars simultaneously and apply rules with greater consistency and accuracy.

Conclusion

Successfully deploying tracking technology in live sport requires a holistic strategy built upon the six key pillars: versatile connectivity, robust high-precision positioning, software-defined hardware, deep event site knowledge, automated management, and technical self-sufficiency. By addressing these core areas, organizers can move past historical barriers to unlock the new commercial and engagement opportunities outlined in this paper's introduction.

The case studies demonstrate that the results, when the approach is right, are significant: audiences of hundreds of millions, life-saving rescues in remote terrain, officiating decisions made in milliseconds, and fan engagement platforms handling tens of millions of visits. These are not edge cases, they are the direction of travel for live sport.

Lightbug devices are specifically engineered for this versatile future, integrating all primary connectivity bearers: Cellular, LoRa, Wi-Fi, and Bluetooth within a single, adaptable platform. The performance of these systems sets a new industry standard, achieving 1cm outdoor accuracy in clear sky view and maintaining a high level of accuracy that rarely drops below 30cm, even in the most challenging environments.

As the line between physical events and digital experiences continues to blur, having a resilient data engine becomes the primary differentiator for forward-looking technical leaders. We invite readers to contact the Lightbug team directly to discuss how our technology can be tailored to meet your specific event goals and fulfill the strategic purpose of this whitepaper.

References

1. IBM Institute for Business Value. "Sports Fans Demand More Dynamic Digital Content, Powered by AI." IBM Newsroom. August 2025. https://newsroom.ibm.com/2025-08-18-ibm-study-sports-fans-demand-more-dynamic-digital-content,-powered-by-ai
2. Sea Screen. "LiveLine Transforms SailGP Real-Time Data Graphics." TMBroadcast. 2024. https://tmbroadcast.com/sea-screen-liveline-transforms-sailgp-real-time-data-graphics/
3. SVG Europe. "Making Waves: How SailGP is Working to Bring LiveLineFX to Other Sports." SVG Europe. 2024. https://www.svgeurope.org/blog/headlines/making-waves-how-sailgp-is-working-to-bring-its-graphics-production-technology-livelinefx-to-other-sports/
4. SailGP. "Record Year for SailGP League Caps Fifth Season on a High." SailGP.com. 2025. https://sailgp.com/news/25/record-year-for-sailgp-league-caps-fifth-season-on-a-high
5. Communications Africa. "Marathon des Sables 2021: Endurance Runners to Benefit from Satellite Tracking and Safety." Communications Africa. 2021. https://communicationsafrica.com/events/event-news/marathon-des-sables-2021-endurance-runners-to-benefit-from-satellite-tracking-and-safety
6. Globalstar, Inc. "Marathon des Sables 2021: Endurance Runners Benefit from Satellite Tracking." Globalstar Investor Relations. 2021. https://investors.globalstar.com/news-releases/news-release-details/marathon-des-sables-2021-endurance-runners-benefit-satellite-0
7. IoT World Today. "Tour de France Digital Twin Gives Fans Real-Time View of the Race." IoT World Today. 2023. https://www.iotworldtoday.com/connectivity/tour-de-france-digital-twin-gives-fans-real-time-view-of-the-race
8. ASO/L'Equipe. "Tour de France 2025 Press Dossier." ASO. 2025. https://storage-aso.lequipe.fr/ASO/cycling_tdf/tdf25-dossier-de-presse-fr-uk.pdf
9. Isère. "Tour de France 2026 Press Dossier." Isère. 2026. https://www.isere.fr/sites/default/files/2025-11/tdf2026-dossier-de-presse.pdf
10. F1 Briefing. "How F1 Teams Use Telemetry for Predictive Maintenance." F1 Briefing. 2024. https://f1briefing.com/how-f1-teams-use-telemetry-for-predictive-maintenance/
11. Wired. "How Formula One Engineers Test Timing Equipment on Race Day." Wired. 2024. https://www.wired.com/story/how-formula-one-engineers-test-timing-equipment-on-race-day/

12. Motorsport.com. "Exclusive: How the FIA Will Use AI to Police One of F1's Most Controversial Subjects in 2026." Motorsport.com. 2025. https://www.motorsport.com/f1/news/exclusive-how-the-fia-will-use-ai-to-police-one-of-f1s-most-controversial-subjects-in-2026/10800288/