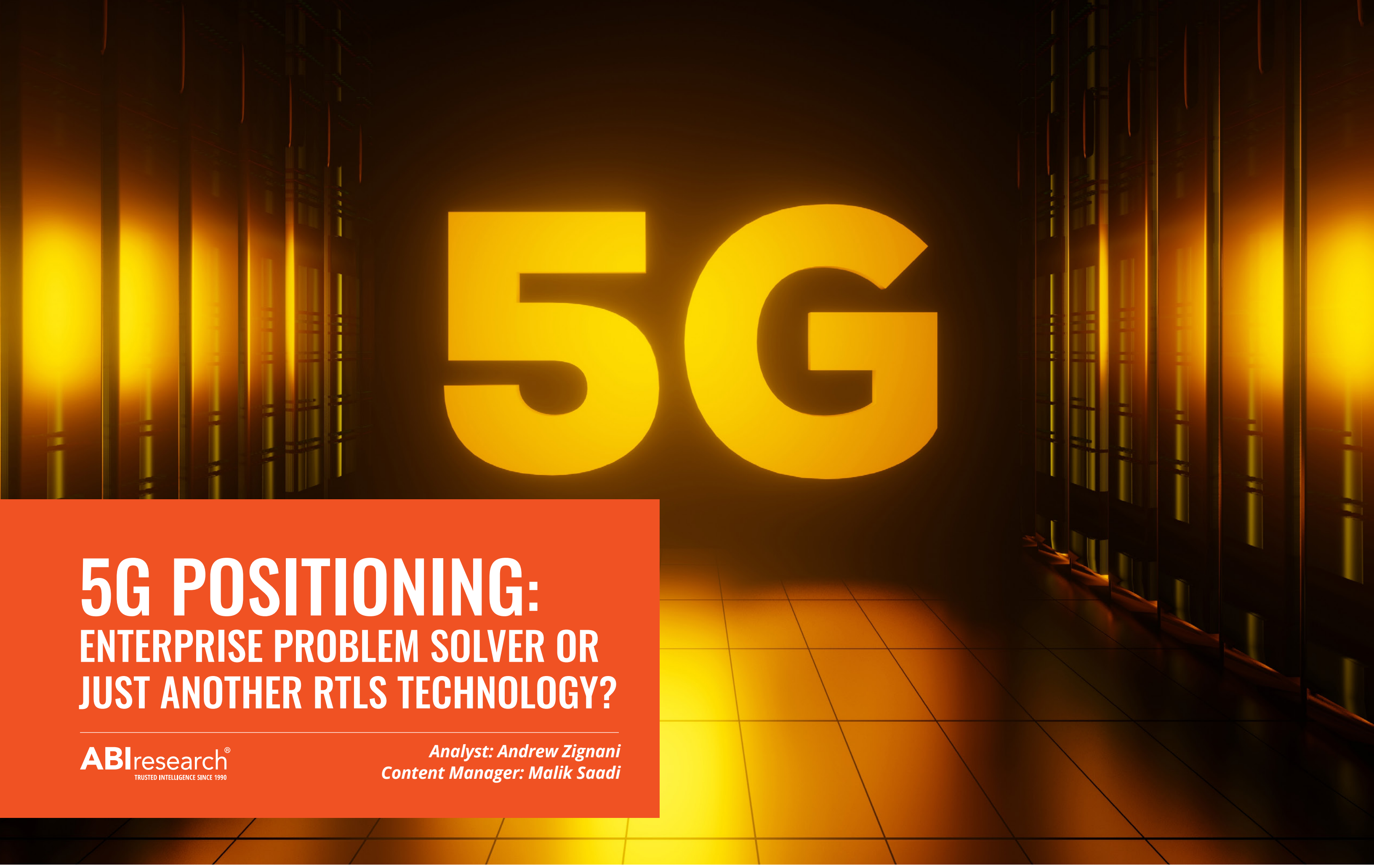

5G POSITIONING:
ENTERPRISE PROBLEM SOLVER OR JUST ANOTHER RTLS TECHNOLOGY?

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INTRODUCTION

Over the last 2 decades, the indoor and outdoor positioning landscape has evolved significantly. Real-time location systems (RTLS), enabled by a number of different technologies including Wi-Fi, Bluetooth, Ultra-wideband (UWB), Active RFID, Visual Light Communication (VLC), Ultrasound, and Geomagnetic sensing, among others, have dominated the indoor positioning landscape. These technologies, each with their own strengths and limitations, have been able to support a wide range of use cases, including asset and material tracking, staff and visitor tracking, tool and equipment tracking, indoor navigation, and proximity services. This indoor positioning landscape has been supplied by an active ecosystem of RTLS hardware and software solution providers, system integrators, and infrastructure vendors, with deployments spanning a number of market verticals including manufacturing sites, warehouses, hospitals, airports, oil & gas, smart buildings, public venues, retail spaces, and mining. Many of these industries have been able to take advantage of RTLS in order to help streamline operations, improve worker safety, optimize production environments, prevent losses, improve compliance, or increase customer engagement and satisfaction. As a result of these benefits and growing demand for accurate and reliable positioning services within many enterprises, ABI Research forecasts that by 2025, the market for RTLS infrastructure is set to reach almost US$13 billion in revenue.

While the aforementioned technologies are able to service indoor environments effectively, outdoor localization and positioning has been dominated by Global Navigation Satellite System (GNSS) receivers. GNSS is well entrenched within smartphones, wearables, and the automotive industry, while future growth is projected within a number of public and private asset tracking use cases, including devices such as shared bicycle and scooter tracking, personal trackers, and goods and livestock tracking. GNSS technology also continues to evolve, with many smartphones now capable of supporting dual-frequency GNSS, enabling more accurate and reliable positioning within urban environments. RTK solutions can also achieve centimeter level precision, vastly improving the typical GNSS accuracy to support a number of high-precision and professional applications, while recent innovations in low-power GNSS solutions make it more suitable than ever before in supporting a number of battery sensitive tracking applications. By 2025, ABI Research forecasts there will be over 2.2 billion annual GNSS chipset shipments across these varied market segments.

However, there are several challenges facing RTLS and GNSS positioning implementations today. GNSS, being a satellite-based technology, is inherently incapable of supporting indoor or indoor-like environments and use cases. Meanwhile, though RTLS infrastructure based on short-range wireless technologies are beginning to be made available at acceptable price points, there has been no silver bullet technology that has been able to adequately address all major use cases and meet key performance metrics while being deployed in a simple, cost effective, futureproof, and scalable manner. **According to ABI Research's recently conducted survey of end vertical decision makers and OT professionals, 87% of respondents have not yet deployed RTLS technology within their enterprise**.[1] This is due to a number of factors, including the following:

Firstly, RTLS applications and use cases can be extremely varied, with each facility having their own unique and well defined use case requirements and priorities. Typically, this has required a combination of different RTLS technologies, each with their own specific strengths and weaknesses around accuracy, robustness, power consumption, coverage area, and cost (at both the tag and infrastructure level). However, this fragmentation of enabling technologies has restricted growth, and it is clear that end users of RTLS do not want to deploy different and separate infrastructures for each RTLS use case. In addition, with many enterprises who leverage positioning technologies likely to require a combination of indoor and outdoor tracking, this currently requires the use of different technologies, such as UWB, Wi-Fi, or BLE for indoors, and GNSS or LPWA for outdoors. This brings additional challenges and complexities from both an infrastructure and management perspective, with the two realms having remained relatively independent to date.

In addition, RTLS equipment is often very complex to implement and deploy, requiring site measurements, surveys, extensive configuration, testing phases, and further tweaking. Often, one of the biggest reported challenges is that the cost of deployment and installation can often be a bigger barrier than the cost of the infrastructure itself, particularly if centimeter level accuracy is required.

1 *ABI Research recently surveyed professionals and decision makers within medium to large enterprises (250 and above employees) on their attitudes to RTLS and 5G positioning across manufacturing, healthcare, warehousing and supply chain, transportation, and oil, gas and mining verticals.*

There are also cost challenges—while higher cost can be justified for certain applications requiring ultra-high precision, for wider applications with higher node counts, expensive tags and infrastructure will limit deployments. At the same time, there are also operating expense challenges with maintenance staff, battery replacement, and complexity of infrastructure installation and maintenance.

The power consumption of RTLS tags and end devices is also a key priority that has not been properly addressed for many existing technologies so far. It is increasingly desired that these energy-constrained terminals can sustain battery life for several months or years, not just days or weeks.

Finally, interoperability with IT/OT is still a paramount barrier. One of the main challenges for RTLS vendors is being able to connect all these different assets and subsystems together in a way that can allow for flexible and future-proof integration into an IoT platform as more and more devices are connected. The presence of multiple technologies can further complicate this process.

As the challenges with existing positioning solutions demonstrate, it is clear that there is a growing desire for accurate, robust, flexible, futureproof, scalable, and cost-effective positioning technology solutions and platforms that are capable of seamlessly addressing a variety of indoor and outdoor positioning use cases that can transcend smaller scale pilot use cases to enable widespread location-based services across a number of key market verticals. 5G positioning is one such technology with the potential to achieve this.

This whitepaper will highlight the industry perspective towards the adoption of RTLS and 5G positioning across manufacturing, healthcare, warehousing and supply chain, transportation, and oil, gas, and mining market verticals. The outcomes of the paper will be guided by an industry survey ABI Research has recently conducted with enterprise decision makers and OT professionals to be able to understand end-implementers' requirements and the pain-points they are trying to address.

This whitepaper also seeks to discuss the competitive landscape around RTLS and precise positioning technologies today, highlight the major benefits of deploying 5G positioning, and analyse its market opportunities and challenges as the technology matures. It will provide recommendations on what needs to be addressed in order for 5G positioning to become a disruptive technology within the RTLS and precise positioning landscape.

WHAT PAIN POINTS CAN RTLS SOLVE FOR THE ENTERPRISE AND WHAT ARE THE CHALLENGES IN ADOPTION?

RTLS technologies can address many industry organization pain-points, primarily through the precise tracking of both assets and personnel, which can enable enterprises to save dozens of billions of dollars in terms of enhanced operational efficiencies, increased worker safety and compliance, and loss prevention. In most deployments, enterprises can take advantage of multiple use cases to compound return on investments and other benefits. For example, within healthcare environments, available beds can be tracked to understand and maximise utilization, reducing the need for cancelled operations or treatment delays. Highly accurate solutions within hospitals that are capable of detecting when medical staff enter or exit a room, whether they use a hand sanitizer dispenser, as well as their proximity to patients, can enable increased hand hygiene compliance. According to the WHO, healthcare associated infections (HAI) still causes complications in 5-10% of admissions to acute-care hospitals in developed countries, while in the US alone, there are at least 80,000 fatalities a year, equating to 200 deaths per day, from HAI. In recent times, RTLS has also been deployed for contact tracing applications and cleaning enforcement, minimizing the risk of infection spreading. In addition, according to various sources, several billion dollars' worth of medical equipment is lost each year globally. With RTLS solutions, this equipment could be tracked and traced, and they can be discovered in real-time whenever they are needed.

In manufacturing, palettes in warehouses often move between the warehouse, the manufacturing floor, and the customer facilities. Tracking them often relies on physical tags and requires substantial amount of labor and time to trace and manage them. Here again, RTLS could provide an ample opportunity to automate the tracking of these assets. This automation becomes even more essential and unavoidable with the ever-increasing size, complexity, and amount of assets contained in warehouses. RTLS can also help monitor underutilized assets, prevent the theft or misplacement of valuable tools and equipment, thus improving equipment utilization, reducing work delays, and minimizing costly replacement of assets. According to Deloitte, the US automotive sector alone loses roughly 15 to 20 percent of its pallets and lids annually, while the total container loss within the US is estimated as being as high as US$1.5 billion dollars annually. Precise location capabilities can also help to enable more flexible production environments that rely upon accurate positioning of people, robots, and AGVs, or help to avoid injuries to personnel. It is estimated that there are nearly 35,000 forklift and industrial truck accidents annually in the US alone, according to the Occupational Safety and Health Administration.

Within oil, gas, and mining verticals, workers are sometimes exposed to potentially hazardous environments and emergency situations. The US oil and gas industry, for example, has a seven times higher fatality rate than other US industries. RTLS can help ensure that personnel do not enter hazardous or forbidden zones, that emergency services can accurately locate lone or remote workers in emergency situations, and digitize mustering processes to enable faster decision making in critical situations. Incorporating RTLS technologies can therefore help to reduce the potential for accidents and enable potentially life-saving responses for when incidents do occur.

RTLS VERTICALS, USE CASES, AND TECHNOLOGY REQUIREMENTS

RTLS technology can apply to virtually any market vertical to enable a number of valuable location based services, drive operational benefits, improve safety and compliance, enable collaborative and mobile robotics, and eventually lead to self-organizing production environments enabled by AGVs and other vehicles to help revolutionize the factory of the future. While today 5G is used primarily for communications, as 5G small cell deployments grow and densify, it will enable number of market verticals to add positioning capabilities without the need to deploy separate RTLS hardware. A huge number of use cases can therefore be readily enabled by 5G's unique combination of communications and positioning infrastructure.

Table 1 maps key use cases by vertical and technology requirements. Of course, each enterprise is likely to have its own unique requirements, and some may be more stringent than others. The idea here is to demonstrate the breadth of RTLS use cases and some of the key requirements that need to be met in order to achieve success. Some verticals such as manufacturing and oil, gas, and mining are likely to require greater precision and lower latency than healthcare or transportation.

Table 1: RTLS Use Cases by Vertical, Accuracy, Latency, Power, and Coverage Requirements

MARKET VERTICAL	USE CASE	ACCURACY REQUIREMENT	LATENCY REQUIREMENT	MINIMUM BATTERY REQUIREMENT	COVERAGE AREA
Healthcare	Patient Tracking	3-5 meters	Medium (10 - 60s)	30 days plus	Indoor and Outdoor
	Equipment Tracking	3-5 meters	Medium (10 - 60s)	90 days plus	Indoor
	Hygiene Compliance	1-2 meters	Low (<1 - <10 seconds)	90 days plus	Indoor
	Personnel Tracking	3-5 meters	Medium (10 - 60s)	30 days plus	Indoor and Outdoor
	Access Control	1-2 meters	Low (<1 - <10 seconds)	30 days plus	Indoor and Outdoor
	Indoor Navigation	3-5 meters	Medium (10 - 60s)	30 days plus	Indoor
	Contact Tracing	1-2 meters	Medium (10 - 60s)	30 days plus	Indoor
Manufacturing	AGVs	sub-20 cm	Very Low (10ms - 100ms)	30 days plus	Indoor and Outdoor
	Collaborative Robotics	sub-20 cm	Very Low (10ms - 100ms)	30 days plus	Indoor
	Worker Safety	sub-meter	Very Low (10ms - 100ms)	30 days plus	Indoor and Outdoor
	Asset Tracking	3-5 meters	High (Minutes to Hours)	1 year plus	Indoor and Outdoor
	Access Control	1-2 meters	Low (<1 - 10 seconds)	30 days plus	Indoor and Outdoor
	Augmented Reality	sub-meter	Very Low (10ms - 100ms)	30 days plus	Indoor and Outdoor
	Tool and Equipment Tracking	1-2 meters	Medium (10 - 60s)	90 days plus	Indoor and Outdoor
	Visitor Tracking	3-5 meters	Low (<1 - 10 seconds)	30 days plus	Indoor and Outdoor
	Emergency Navigation	1-2 meters	Low (<1 - 10 seconds)	30 days plus	Indoor and Outdoor
Warehousing and Supply Chain	Forklift Collision Prevention	1-2 meters	Very Low (10ms - 100ms)	30 days plus	Indoor and Outdoor
	Asset Tracking	3-5 meters	High (Minutes to Hours)	1 year plus	Indoor and Outdoor
	Access Control	1-2 meters	Low (<1 - 10 seconds)	30 days plus	Indoor and Outdoor
	AGVs	sub-20 cm	Very Low (10ms - 100ms)	30 days plus	Indoor and Outdoor
	Inbound and Outbound Logistics	1-2 meters	Low (<1 - 10 seconds)	30 days plus	Indoor and Outdoor
	Personnel Tracking	1-2 meters	Low (<1 - 10 seconds)	30 days plus	Indoor and Outdoor
	Pallet and Vehicle Tracking	1-2 meters	Low (<1 - 10 seconds)	90 days plus	Indoor and Outdoor
	Visitor Tracking	3-5 meters	Low (<1 - 10 seconds)	30 days plus	Indoor and Outdoor
	UAVs	sub-meter	Very Low (10ms - 100ms)	30 days plus	Indoor and Outdoor
Oil, Gas and Mining	Lone worker safety	1-2 meters	Medium (10 - 60s)	30 days plus	Indoor and Outdoor
	Access Control	1-2 meters	Low (<1 - 10 seconds)	30 days plus	Indoor and Outdoor
	Personnel Tracking	1-2 meters	Low (<1 - 10 seconds)	30 days plus	Indoor and Outdoor
	Vehicle Collision Avoidance	1-2 meters	Very Low (10ms - 100ms)	30 days plus	Indoor and Outdoor
	Emergency Notification	1-2 meters	Very Low (10ms - 100ms)	30 days plus	Indoor and Outdoor
	Emergency Navigation	1-2 meters	Low (<1 - 10 seconds)	30 days plus	Indoor and Outdoor
	Asset Tracking	3-5 meters	High (Minutes to Hours)	1 year plus	Indoor and Outdoor
	Tool and Equipment Tracking	1-2 meters	Medium (10 - 60s)	90 days plus	Indoor and Outdoor
Transportation	Indoor Navigation	1-2 meters	Low (<1 - 10 seconds)	30 days plus	Indoor
	Personnel Tracking	1-2 meters	Low (<1 - 10 seconds)	30 days plus	Indoor and Outdoor
	Access Control	1-2 meters	Low (<1 - 10 seconds)	30 days plus	Indoor and Outdoor
	Cargo Tracking	3-5 meters	High (Minutes to Hours)	1 year plus	Indoor and Outdoor
	Vehicle Tracking	1-2 meters	Low (<1 - 10 seconds)	30 days plus	Indoor and Outdoor
	Tool and Equipment Tracking	1-2 meters	Medium (10 - 60s)	90 days plus	Indoor and Outdoor

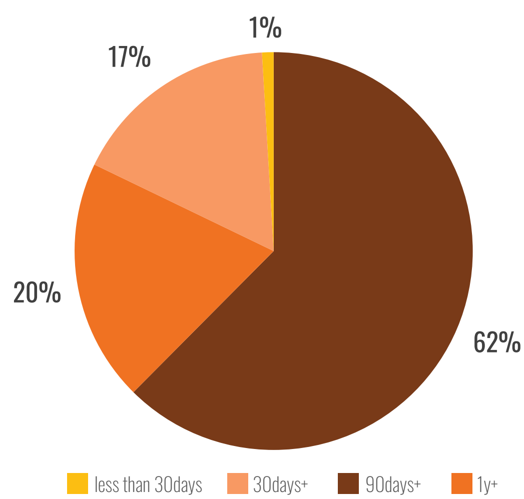
As Table 1 demonstrates, many of these use cases have requirements that go beyond the current 3GPP Releases in terms of accuracy, latency, and power consumption. This demonstrates a clear need for continued evolution within the 5G positioning landscape in order to be able to target many of these current and future use cases. This includes key metrics such as improved accuracy up to submeter level, reduced latency, improved scalability to support simultaneous tracking of assets, and improved power consumption.

Feedback from decision makers across numerous verticals appear to back this up. For example, according to ABI Research's survey, **46% of respondents believe that the typical positioning accuracy required across the majority of use cases they are planning to support is 1-2 meters or below, while over 1/5 of respondents reported that they require sub-meter and below accuracy**. This re-affirms the need for 5G positioning to go beyond 3GPP Release 16 capabilities and to provide much greater accuracy.

In addition, many of these use cases will require the precise localization of large amounts of assets. Therefore, 5G positioning infrastructure needs to be capable of providing accurate, power sensitive positioning, for potentially thousands of assets. **According to ABI Research's recent survey, over two-thirds of respondents reported that their organization requires precision (sub-10 meter to cm level tracking) of at least 500 assets, with 37% requiring between 1000-5000 or more**. This will require low-cost tags in order to scale effectively.

It is also clear that 5G positioning will need to bring improvements to the power efficiency of 5G enabled RTLS tags. Many of these use cases require several months or more of battery life, with other use cases potentially requiring years of battery life in order to reduce OPEX costs. As Chart 1 shows, **99% of survey respondents believe that the optimal tag/terminal battery life required across the majority of use cases needs to be at least 30 days or more, with 62% reporting 90 days and above, and 20% one year and above.**

Chart 1: What do you think is the optimal tag/terminal battery life required across the majority of use cases you are planning to support?



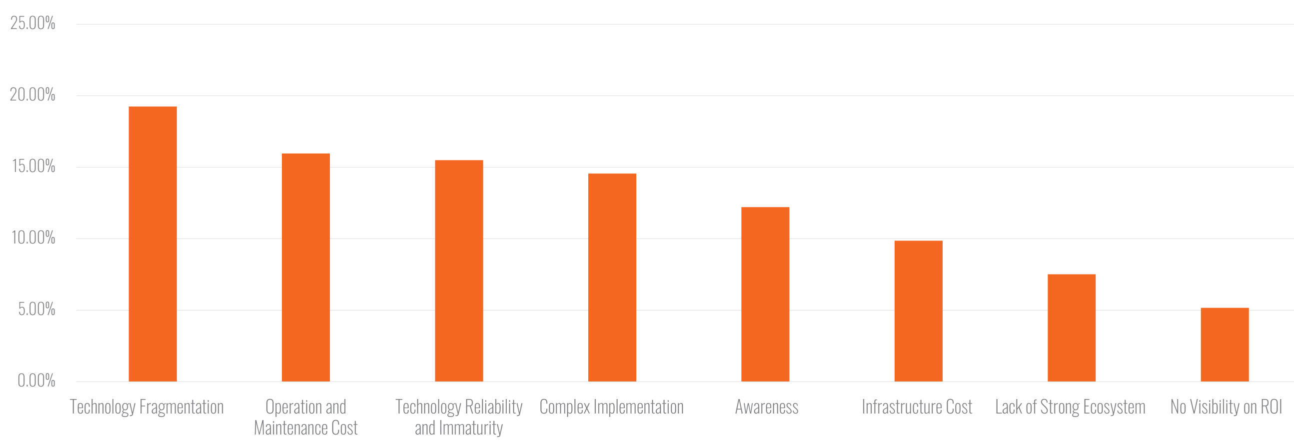
Primary use cases are also likely to evolve over time as 5G deployments become more widespread and new industry 4.0 use cases are able to emerge. **Whereas the survey identified asset tracking and tool and equipment tracking as the top two use cases driving RTLS adoption today, respondents reported that in 5 years-time, AGVs and robotics control, as well as staff management, safety, and access control will drive adoption**. This will also represent a shift in the accuracy requirements that ranges from several meters to meter and sub-meter level accuracy.

CHALLENGES ENTERPRISES ARE FACING WHEN IMPLEMENTING RTLS

Interestingly, most of the barriers to deployment of RTLS mentioned in ABI Research's recently conducted survey point to the implications of deploying multiple existing technologies in terms of total cost of ownership, the ability and the ease to operate these solutions within the legacy IT/OT equipment, their reliability, their seamlessness, and the lack of accuracy alignment across all supported use-cases.

Chart 2 shows the top ranked barriers facing the deployment RTLS to date, according to ABI Research's recently conducted survey among industry professionals.

Chart 2: What is the number one barrier facing the deployment of precise positioning so far?



DEMAND FOR RTLS IS HERE, BUT SUPPLY IS NOT

According to ABI Research's survey results, the demand for RTLS is strong as most respondents showed interest in deploying the technology. The varied use cases highlighted above demonstrate the enormous benefits that RTLS can bring to a wide range of enterprises. However, existing RTLS technologies are failing to grasp the market potential. While numerous existing RTLS technologies, including Bluetooth, Wi-Fi, and UWB, have been servicing the market for few years now, each with own strengths, maturity cycle, and targeted use-cases, most of them have failed to capture the market potential so far, with the most successful having hardly reached 10%-15% penetration of the potential addressable market (PAM). This has been confirmed by the recent survey showing that that **87% of enterprises have not yet deployed RTLS technology within their business**, largely because of the major barriers to adoption facing existing RTLS, as explained in the previous section. The enterprise is clearly waiting for these challenges to be addressed by any alternative technology with the potential to simplify the complexity of implementation, irradicate fragmentation, improve reliability, and lower the cost of operations and maintenance. Could 5G positioning be this technology?

INTRODUCING THE 5G POSITIONING VALUE PROPOSITION

The arrival of 5G has the potential to open an entirely new era for cellular based positioning. 5G technology, thanks to its numerous benefits, seeks to address a number of new use cases that will transcend enhanced mobile broadband and accelerate digital transformation across a number of market verticals, enabling massive machine type communication and ultra-reliable low latency communication across a variety of environments including healthcare, manufacturing, transportation, warehouses, and other smart spaces. Many of these new use cases enabled by 5G connectivity will benefit significantly from the ability to precisely locate the same equipment via 5G positioning techniques. For example, the ability to precisely track AGVs and mobile robots alongside personnel tracking will enable workers to work closely alongside moving equipment safely, while the location of valuable industrial tools and equipment will help reduce losses and ensure the right tool is being used in the right process for compliance purposes.

The ability of 5G to combine connectivity with high precision positioning has the potential to significantly enhance the value proposition of 5G rollout and enable new location-based services within a variety of enterprises. As will be discussed throughout this whitepaper, 5G positioning will bring a number of new enhancements to cellular based positioning technologies, making it more accurate, reliable, seamless, scalable, and valuable than ever before. By leveraging a standards-based approach that will be a key component of 5G network infrastructure, 5G positioning will benefit from the global rollout and large-scale adoption of 5G across numerous market sectors, providing a unique value proposition that does not require the need of a costly independent RTLS and US-case specific infrastructure. In addition, in contrast to other short-range RTLS technologies and GNSS with limited coverage, 5G positioning offers the ability to provide high precision positioning seamlessly across both indoor and outdoor environments, addressing use cases on- and off-campus. This provides unique advantages in terms of deployment rollout and complexity, infrastructure costs, management capabilities, and security, among other benefits. In addition, 5G positioning will continue to evolve over time via upcoming 3GPP releases to improve key metrics such as accuracy, reliability, scalability, and power consumption, further improving performance and addressable use cases.

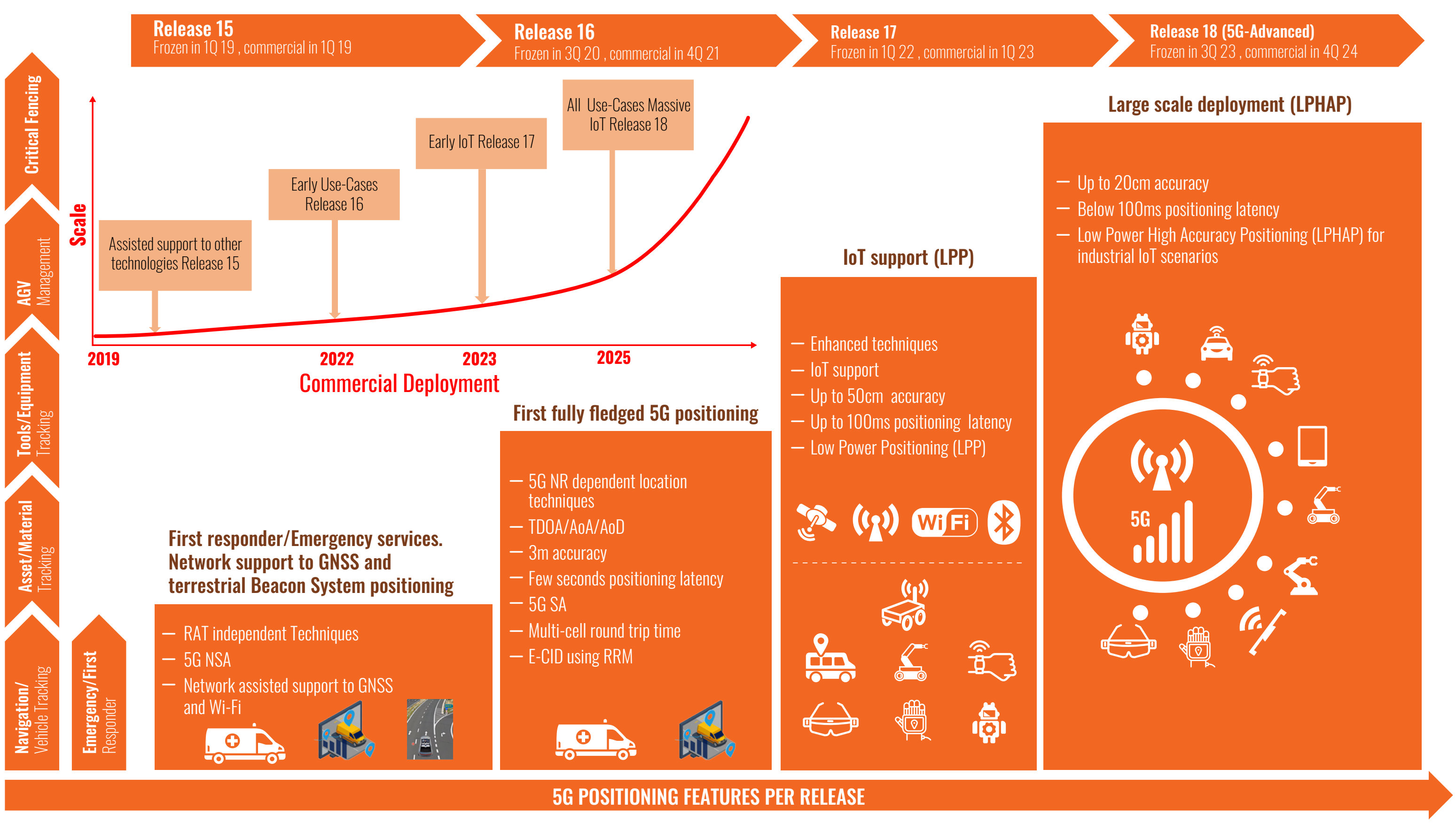
CONTEXTUALISING 5G POSITIONING WITHIN 3GPP STANDARD EVOLUTION

Existing cellular-based positioning solutions anchored on 4G infrastructure are capable of 20-50 meters of accuracy, which can be combined with GNSS for further improvements. However, as 5G network infrastructure becomes increasingly entrenched within new environments, such as manufacturing, warehouses, healthcare, oil, gas, and mining, many of the use cases it will enable also require much more precise positioning which can be quickly obtained in order to drive value and enable new location services. Many of these use cases will require low latency positioning capabilities that can meet stringent horizontal and vertical positioning requirements, sometimes down to few centimeters' accuracy, and that can seamlessly operate within both indoor and outdoor environments. While 3GPP Release 15 incorporated LTE based positioning techniques, it is clear there was a necessity to improve the quality and accuracy of 5G positioning in order to support these new positioning use cases. Fortunately, 5G technology brings a number of inherent advantages that make it much better suited than ever before to higher positioning accuracy, including the following:

- Large cell site density to enable better positioning accuracy through rich and diversified anchor points available for generating and processing positioning.
- The deployment of massive Multiple Input, Multiple Output (MIMO) and beamforming, which can enhance the direction accuracy for algorithms like Angle of Arrival (AoA) and Direction of Arrival (DoA).
- The use of high-frequency channels by 5G networks, which can contribute to better accuracy through reduced channel sparsity due to better array gains.
- Large bandwidth provided by a 5G network can offer better multipath resolution and, therefore, high accuracy for measuring distances, which again can contribute to improving the accuracy of positioning measurements.
- Single infrastructure handling positioning and telecommunication functions, which will not only help in lowering the overall infrastructure cost, but can open the doors to a plethora of new geo-information applications.

As a result, new radio access technology (RAT)-dependent techniques for 5G positioning were introduced within 3GPP Release 16, which was frozen in mid-2020, while a roadmap to even greater positioning performance and accuracy has been developed for upcoming 3GPP Releases 17 and 18 (5G-Advanced), in which a new technology known as low power high accuracy positioning (LPHAP), is defined as a new work item, highlighted in Figure 1.

Figure 1: 5G Positioning Evolution – Technology Enhancements and Addressable Markets



3GPP RELEASE 16

Release 16 seeks to meet requirements of 3 meters indoor positioning and 10 meters outdoor positioning 80% of the time. To achieve this, a number of techniques have been leveraged from LTE, including Enhanced-Cell ID (E-CID), Observed Time Difference of Arrival (OTDOA), and Uplink Time Difference of Arrival (UTDOA). In addition, taking advantage of 5G's inherent benefits, Downlink Angle of Departure (DL-AoD), Uplink Angle of Arrival (UL-AoA), and Multi-cell Round Trip Time (multi-RTT) have been introduced to meet these requirements. However, while these offer significant improvements to cellular positioning, the capabilities are still not adequate for a number of precision use cases demanded by the industry.

3GPP RELEASE 17

3GPP Release 17 seeks to build upon the existing 5G positioning capabilities through improving key metrics such as accuracy, latency, and power consumption. This will enable 5G positioning to better address a number of indoor end market use cases such as commercial and industrial IoT. Targeted positioning accuracy for commercial use cases is less than 1 meter, while targeted latency is under 100ms. For industrial IoT applications, targeted accuracy is less than 50cm with less than 100ms of latency, both of which require 90% reliability. Other enhancements, such as improving scalability of the positioning network to support simultaneous positioning for larger size IoT deployments, are desired, as is improving the reliability and integrity of the positioning capabilities. However, these upcoming enhancements also rely upon the widespread deployment of Ultra-Reliable Low-Latency Communication (uRLLC) and Massive Machine-Type Communications (mMTC), with local private 5G networks for machine automation, Internet of Things (IoT) sensor monitoring, and digital factory cloud services rollout becoming key milestones in the wider deployment of 5G positioning. However, Release 17 is not expected to be frozen until Q1 2022, with real world deployments expected from 2023 at the earliest.

FUTURE RELEASES

Further improvements are likely to come within future 3GPP Releases, such as Release 18, which was defined officially by the 3GPP as 5G-Advanced in April 2021. While the roadmap is less clear, potential enhancements could include centimeter-level precision, further reductions in latency and power consumption, enhancements via machine learning and sensor fusion, efficiency improvements, and cooperative localization. This will enable 5G positioning to target even more demanding end markets with the most stringent accuracy and latency requirements, while the longer-term expansion of positioning capabilities both indoors and outdoors will enable the provision of high-value location services across many industries. Furthermore, in order to meet the requirements of scalable deployments and to compete with other technologies, it is crucial for 5G positioning to reduce power consumption of end nodes. In March 2021, a new 3GPP Work Item titled "Low Power High Accuracy Positioning" was approved, seeking to bring about significant enhancements to end-node battery life to months or years, all the while maintaining sub-meter level accuracy 90% of the time. It is important to note that the low power positioning (LPP) discussion has already started in Release 17, with the aim to accommodate early IoT use cases. The combination of high accuracy with low power will be increasingly valuable in order to reduce maintenance and operational costs associated with battery replacement, a key challenge facing industry players today. However, deployments of Release 18 (5G-Advanced) positioning solutions are likely to begin 4-5 years from now at the earliest, and final features are not yet confirmed.

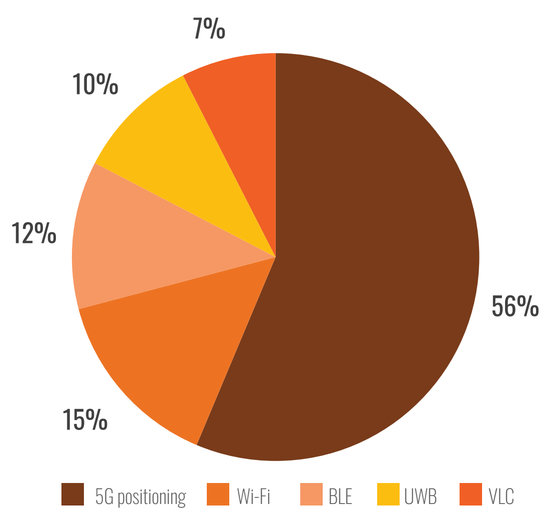
Table 2: Road Map of 5G Positioning Releases

	R16	R17	R18 (5G-ADVANCED)
Accuracy	Outdoor 10m@80% Indoor 3m@80%	Indoor 1m@90% IIoT <0.5m@90%	IIoT 0.2m@90% (under discussion)
Latency	1s	100ms	<100ms (under discussion)
Low Power	NA	Under discussion (~1 month)	Under discussion (~1 year)

INDUSTRY ON STANDBY UNTIL 5G POSITIONING MATURES

Demand for 5G positioning is extremely strong. **Chart 3 shows what technologies are currently being trialled or planned to be trialled for RTLS applications according to ABI Research's decision maker survey. Among those respondents planning to deploy 5G positioning, 20% said they plan to deploy it within the next 1-2 years, 20% within the next 3-5 years, and 36% of respondents 5 years from now or beyond**.

Chart 3: What technology are you trialling or planning to trial for RTLS applications?



5G POSITIONING TECHNOLOGY DEVELOPMENT

While there is clear demand for 5G positioning, as has been discussed, there are still many limitations for the technology within existing releases that need to be overcome in order for the industry to be ready to deploy. While Release 16 is a good foundation, it is clear that the requirements are not quite there in order to meet the KPIs of various end markets. As a result, the industry is taking a wait-and-see approach to 5G positioning and waiting for future releases, such as Release 17 and Release 18 (5G-Advanced), to bring increased accuracy, scalability, reliability, and power efficiency. In the shorter term, this may hinder ecosystem adoption and willingness to invest effort within 5G positioning technology. The industry needs to be encouraged to take a staggered approach to 5G positioning as it will be some time before widespread adoption will occur. Compared to other RTLS technologies, 5G positioning is very much in its early stage of development. However, on a positive note, the end market is clearly encouraged by the 5G positioning roadmap and this may result in a swift rollout as upcoming Releases are frozen and can better meet market demands.

While we have seen some initial proof of concepts for high accuracy deployment of 5G positioning, this pales in comparison to real world deployments of alternative technologies. However, Qualcomm recently demonstrated precise indoor positioning for AGVs using a 5G positioning trial, achieving a targeted 23 centimeter accuracy which will help contribute to upcoming Release 17 studies. Similarly, in March 2021, Huawei and China Mobile Suzhou enabled the world's first 5G indoor positioning deployment within a subway station in Suzhou, China. The deployment was capable of achieving 3-5 meters accuracy in 90% of the platform and hall areas. However, much more needs to be done here to help promote the capabilities of 5G positioning across different market verticals, and the potential services it can enable.

On a related note, the length between 5G releases and the gap between commercialization has widened in recent times. For example, the release of 3GPP Release 16 equipment and devices is taking some time to emerge, and there is currently a lack of commercially available Release 16 RAN and User Equipment, despite being frozen in mid-2020. Any further delays may push back opportunities for initial 5G positioning solutions. Furthermore, if future 3GPP standards also slip in terms of timeline, this could further delay the rollout of high accuracy positioning via 5G positioning infrastructure. This should serve as a wake-up call for the industry to come together and ensure that future releases and commercialization are not delayed so as to ensure 5G positioning can meet future demands as soon as possible.

5G POSITIONING VERSUS ALTERNATIVE RTLS SOLUTIONS

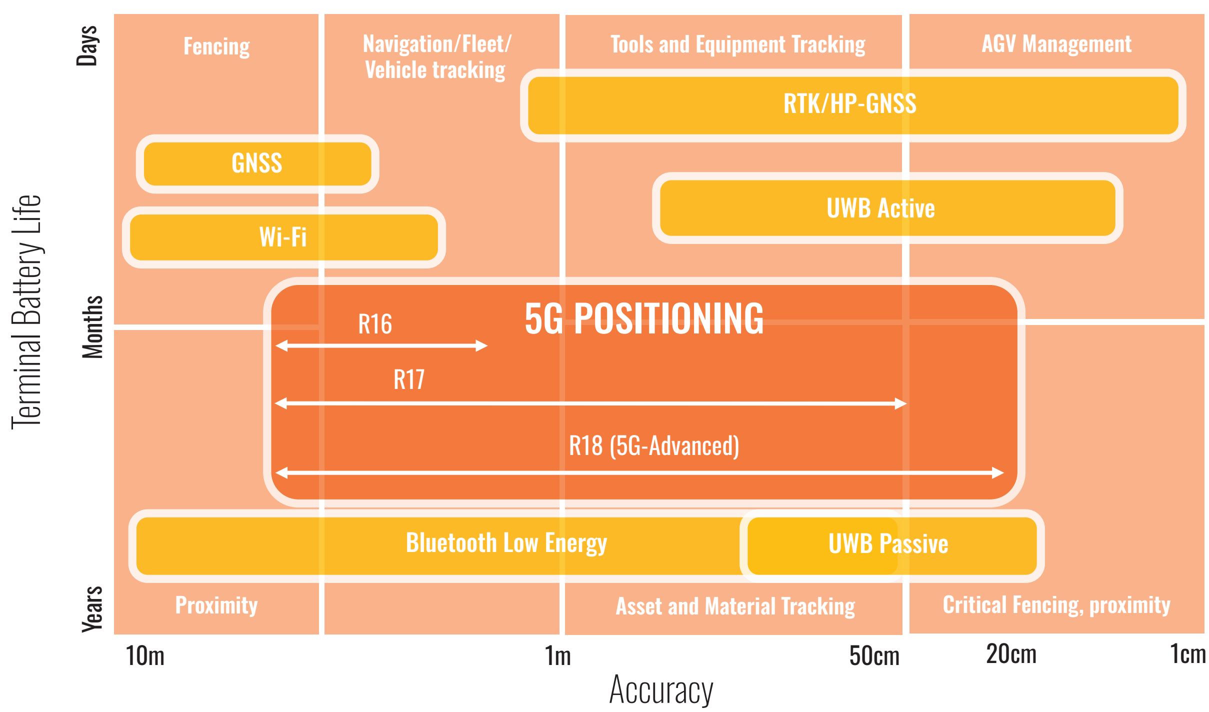
As aforementioned, there are a number of technologies currently being deployed to address a wide variety of RTLS use cases. These include Wi-Fi, Bluetooth, Ultra-wideband (UWB), Active RFID, Visual Light Communication (VLC), Ultrasound, Geomagnetic sensing, camera sensing, and infrared, among others. However, it is important to note that these underlying technologies can often have different approaches to localization techniques, ranging from methods such as less accurate RSSI to higher accuracy AoA or ToF measurements. When comparing the capabilities of different RTLS technologies, both the underlying technology and localization technique must be considered as part of the overall system evaluation. For example, while traditional RSSI based Bluetooth Low Energy RTLS has historically provided zonal level tracking to within several meters, Bluetooth Angle of Arrival (AoA) solutions have been able to support real-time, sub-meter RTLS applications for some time, with AoA capabilities now being standardized in Bluetooth 5.1. However, in many respects, this has also added to the complexity and fragmentation within the RTLS market today. Indeed, according to **ABI Research's recently conducted survey, nearly ¾ of decision makers listed technology fragmentation as one of the top five major barriers to deployment facing precise positioning technology so far, with almost 1/5 of respondents ranking it as the number one** obstacle. The following segment will provide an overview of key enabling RTLS technologies and benchmark their capabilities with 5G positioning across a number of key metrics.

Table 3: RTLS Technology Comparison by Key Metrics

KEY RTLS METRICS	BLUETOOTH	WI-FI	UWB	5G POSITIONING
Accuracy	Few meters (RSSI) to submeter (AoA)	5-10 meters, 1-2 meters with 802.11mc, further improvements with 802.11az	Submeter	3 meters R16 to sub-meter level with Release 17 and beyond
Location Techniques	RSSI, AoA, AoD	RSSI, FTM on 802.11mc	TDoA, TWR/ToF	TDoA, AoA, OTDOA, UTDOA, multi-RTT
Infrastructure Complexity	Medium	Low	High	Low
Typical Tag Power Consumption	Low	High	Low / High depending on implementation	High (R16), lower in future releases (R17, R18 (5G-Advanced))
Coverage	Indoor	Indoor	Indoor	Indoor and Outdoor
Use-cases Targeted	Indoor navigation, proximity services, asset tracking	Indoor navigation, room level asset tracking	Asset tracking, vehicle tracking, personnel tracking	Asset tracking, vehicle tracking, personnel tracking
Technology evolution	BLE 4.0 ⟶ BLE 5.1 Direction Finding	802.11mc ⟶ 802.11az	802.15.4a ⟶ 802.15.4z	3GPP Release 16 ⟶ (5G-Advanced)
Advantages	Smartphone compatibility, low cost tags, growing accuracy	Takes advantage of Wi-Fi infrastructure, smartphone compatibility	High accuracy and robustness, low latency	Leverage 5G infrastructure and global ecosystem, seamless indoor and outdoor coverage, will improve over time
Challenges	Interferences in metallic environment and 2.4GHz technologies	Less accuracy, tags more expensive and greater power consumption	More complex to implement, higher cost of infrastructure	Technology immature, high tag cost and power consumption today

Figure 2 contextualizes the evolution of 5G positioning alongside other RTLS technologies and its relative strengths and weaknesses around accuracy and power consumption. Given the many differing technical and implementation techniques to RTLS, this is intended an indicator rather than a strict guide.

Figure 2: RTLS Technology Comparison



COMMERCIAL BENEFITS OF 5G POSITIONING

Moving beyond the technical benefits of 5G positioning, there are a number of commercial benefits that 5G positioning can provide. These include:

Multi-Use Network Infrastructure

One of the major commercial benefits of 5G positioning is its ability to combine the 5G communications infrastructure with the positioning infrastructure. The same 5G network that will be leveraged to connect thousands of assets and user equipment across different market verticals can also be utilized to determine the precise position of the very same assets. This helps to remove one of the biggest obstacles to RTLS deployment today—the need to deploy an independent location infrastructure, which can often be complex and costly to plan, deploy, and maintain. This standard-based approach, inherently anchored in 5G telecom infrastructure, will enable 5G positioning to benefit from the global and large-scale deployments of 5G, making it hard for alternative technologies to compete in terms of cost and performance in the longer term. **According to the ABI Research survey, 25% of respondents ranked the ability of 5G positioning to support both telecoms and positioning use-cases as the top reason for planning to trial 5G positioning in the future. This was first joined with the ability to address use cases otherwise not possible with alternative RTLS technologies**.

Seamless Indoor and Outdoor Coverage

Most RTLS deployments today require the use of multiple technologies if assets are to be tracked across both indoor and outdoor environments. In addition, it adds significant complexity if an asset is needed to be tracked across a large-scale campus or multiple campuses. This could add significant cost to the tag itself, requiring a technology supported by both the indoor network, e.g., Bluetooth, Wi-Fi, UWB, alongside GNSS, cellular, or LPWA technologies for outdoor coverage. This adds design complexity, expense, and has obvious constraints on form factor and power consumption. Instead, 5G positioning has the potential to allow user equipment to be tracked seamlessly whether indoors or outdoors, while remaining flexible on the accuracy required. For example, where there is a great density of base stations indoors, cm level could be provided, whereas when moving outside, meter or tens of meters of accuracy may be sufficient. Large scale industrial and other commercial campuses and other sites can benefit greatly from this capability.

Flexible Accuracy via a Single Infrastructure

Assuming 5G can meet the high precision requirements of other technologies over time, in the longer run there will not be a need to deploy multiple different technologies in order to achieve the required accuracy and performance. For example, an industrial campus could leverage 5G positioning to track devices that require cm level precision, alongside those that require 3-5 meter level precision, on the same infrastructure. In contrast, with short-range solutions, providing cm level accuracy may require the deployment of an alternative high accuracy use-case specific technology and infrastructure such as AoA Bluetooth or UWB that require heterogeneous equipment (tags, anchor points, gateways).

Scalability

Some RTLS technologies require dense infrastructure deployments in order to achieve cm level precision. When tracking assets across large scale campuses or outdoor environments, this would prove far too expensive to deploy. In contrast, 5G positioning's coverage can take advantage of densely deployed infrastructure to provide coverage across a whole campus or multiple campuses. In addition, 5G positioning will be able to support tracking of larger numbers of assets across large environments.

5G Ecosystem Advantages

5G positioning will be able to benefit from the large ecosystem of chipset and module vendors, network operators, telecoms, end user equipment manufacturers, developers, and other industry players invested in the wider 5G ecosystem. This can help lead to improvements in product design and functionality, enhancements to upcoming 3GPP specifications, cost and size reductions, power efficiency enhancements, unique hardware and software-based enhancements, and valuable service creation.

Simplified Backhaul

Many RTLS technologies require the deployment of anchor points with embedded ethernet, cellular, or Wi-Fi connectivity to connect to the cloud for positioning capabilities. This can add additional complexity to deployment. In contrast, 5G positioning combines the communications network with the positioning network, reducing the complexity of backhaul requirements.

Simplified Management

RTLS software and management platforms need to offer end to end visibility and analytics, and should be able to incorporate location and identification information from multiple use cases and device types, whether indoors, outdoors, at a single venue, or multiple venues to maximise ROI and the value of location intelligence. In order to achieve this on a scalable level today, this may currently require the effective management of multiple technologies, whether that be RTLS via UWB and BLE, GNSS for extended outdoor and wide-area coverage, RFID, and barcode for zonal, low cost or high-volume asset tracking, as well as machine vision systems. These may leverage heterogeneous networks and infrastructure that make it difficult to manage from end-to-end, which may limit the overall location intelligence of the deployment, reducing the value proposition. Instead, by unifying RTLS into a single technology and infrastructure, there are also numerous benefits with regards to end device management and provisioning, security, service creation, maintenance, software development, and other commercial benefits. 5G positioning can potentially offer a flexible and futureproof infrastructure and easier integration to various IoT platforms as more devices are connected, allowing easier convergence between IT and OT environments. In addition, 5G'S positioning capabilities will be available once connecting to the 5G network, reducing the need for more complex onboarding and provisioning found in other technologies.

Moving Beyond Location

In the longer term, RTLS platforms must move beyond providing basic location data and be able to generate unique and valuable insights—how long is a good staying in a particular location, has the right tool been used by the right person with the right setting, has the right part been used on the right piece of equipment, have any assets been subjected to any contamination or temperature fluctuations, are all tools accounted for, and what efficiencies can be driven from this, etc.? Combining communications, positioning, and additional features such as sensing and machine vision can enable location platforms to enable new value-added geo information applications. Knowing not just where an asset is, but also its configuration, environment, and condition could open the door to a whole new class of positioning related services within a wide range of environments that has been difficult to achieve with independent communications and positioning networks. This could include enhanced compliance and auditing, environmental sensing, SLAM, and other innovations.

Futureproof Infrastructure

5G infrastructure has the capability of easily adding new devices and capabilities to network over time. There is not a need to build totally new infrastructure or location network to improve accuracy, but the deployed infrastructure will be able to incorporate additional and improved positioning capabilities as 3GPP Releases develop. This may allow end users to deploy a futureproof infrastructure that is capable of enabling all major use cases over the next decade, while enabling new features and performance improvements.

Maximises ROI of 5G Deployments

As 5G positioning adds a whole new category of capabilities to those who deploy 5G networking infrastructure, it significantly increases the business cases for 5G rollout overall. Within many RTLS use cases already deployed today, the prevention of a single accident, avoiding the losses of expensive assets, or the increased compliance of hygiene enforcement in hospitals have led to tremendous success stories and significant return on investment. The combination of communications and positioning therefore greatly increases the value proposition of 5G network deployments. **According to the ABI Research survey, 41% of respondents said that 5G positioning would increase the business case for 5G deployment, while an additional 31% believed positioning could become a *primary* reason for investing in 5G infrastructure**.

CHALLENGES FOR 5G POSITIONING WITHIN THE RTLS MARKET

While opportunities lie ahead for 5G positioning, the industry needs to address several challenges to tap into the full potential of the technology, and chief among them are the following:

Competitive Landscape

5G faces strong competition from a number of different RTLS technologies that are continuing to evolve and develop. Technologies such as Wi-Fi are widely deployed and can take advantage of existing infrastructure, while many Wi-Fi APs also now come equipped with Bluetooth Low Energy (BLE) for location capabilities, with new partnerships now being formed with UWB technology vendors for additional accuracy. Continued improvements to these technologies and their ability to provide highly accurate, cost effective, and long battery life RTLS deployments while 5G positioning currently cannot meet the same metrics, may lead others to look elsewhere, particularly in small to medium enterprises where 5G infrastructure may be cost-prohibitive. BLE, Wi-Fi, and UWB also have a strong presence in mobile devices which provides additional incentive to keep those technologies for indoor navigation and wayfinding applications.

Power Consumption

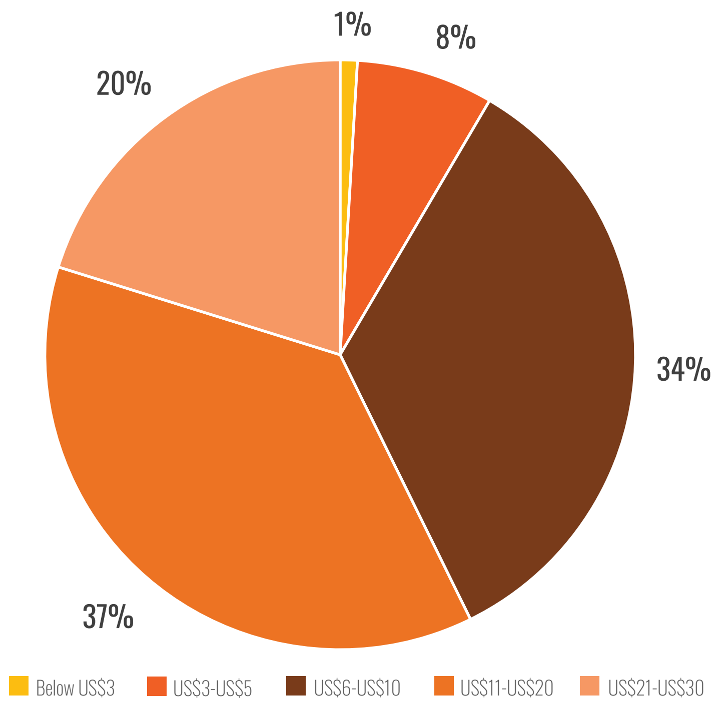
The industry has set a strong foundation for 5G positioning standards through several 3GPP Technical Specifications (TSs) addressing various service-level requirements, including horizontal and vertical accuracy, network availability, User Equipment (UE) velocity, and service latency. However, until recently, 5G positioning has lacked an important framework dedicated to low-power specifications, vital for preserving the terminal battery life without compromising the overall positioning accuracy. Without such specifications, the value proposition of 5G positioning could be eroded and its market opportunities restricted to a very limited number of use cases. Early 5G tags and positioning terminals, anticipated for commercial deployment in 2022, are unlikely to be optimized to meet the stringent low-power requirements of certain RTLS use cases, such as material management or asset tracking. This could make the use of these terminals almost non-practical for these use cases because they are required to offer months, not weeks, of operation without the need for charging or upgrading the device battery. **Indeed, according to the recent ABI Research survey, of those respondents who were not planning to deploy 5G positioning, 27% ranked tag power consumption as the number one reason**.

Fortunately, the 3GPP has acknowledged this and in March 2021 a new work item was approved titled "Low Power High Accuracy Positioning" (LPHAP) for industrial IoT scenarios. This work item acknowledges the mismatch between current releases and the needs of the industry and seeks to ensure that high-accuracy (0.5m at 90%) frequent positioning user equipment can sustain longer lifespans from several months to years, reducing operational costs of battery replacement. Once the terminal power consumption issue is addressed, the value proposition of 5G positioning will be strengthened across a variety of applications; otherwise, business opportunities for the technology could be jeopardized and its market potential could be limited to a handful of use cases and markets. **According to the recent ABI Research's survey, 82% of respondents believe that the optimal tag/terminal battery life across the majority of use cases they plan to support is 90 days or more, of which, 20% believe a minimum battery life of one year or more is optimal**. However, one further challenge is that the full suite of these enhancements will come *via* Release 18 (5G-Advanced), which is not currently scheduled to arrive for some time.

Infrastructure and Tag Cost

5G positioning will present a strong value proposition to large enterprises with strategic plans to transform their businesses and digitize their operation processes. This is in a large part due to being able to rely on a single 5G infrastructure for both communication and positioning needs. However, 5G could be cost-prohibitive for Small and Medium Enterprises (SMEs) that cannot afford to upgrade their infrastructure to wholly-digitized operation processes all at once. These players may instead choose to deploy more cost-efficient radio-in-the box equipment tailored to their specific requirements, such as enabling 5G positioning provided by smaller system integrators that may be lacking expertise in radio systems. Any unspecified protocol stacks under 5G standards, such as low-power positioning, will be a challenge for them to integrate without compromising the terminal battery life, the system accuracy, or both. As the cost and complexity of alternative RTLS technologies falls, these smaller enterprises may also decide to leverage alternative technologies. In addition, competing technologies such as Bluetooth and UWB are likely to offer much lower tag costs than what 5G positioning will be able to achieve when it first arrives. 5G positioning tag costs are not yet optimized for high volume use cases, such as asset tracking. While this may evolve over time as the technology scales, with 37% of respondents requiring between 1000-5000 **assets to be tracked, it a problem that must be addressed. As Chart 4 shows, according to ABI Research's survey of enterprise decision makers, 80% of respondents believe that they will only be able to deploy RTLS at large scale with tag costs of below US$20, with 42% requiring below US$10**.

Chart 4: At what price point for tags and terminal devices you believe you will be able to deploy precision positioning technology at large scale?



Multiple Technologies Proposed

3GPP Release 16 has proposed a number of different techniques to provide precise location. These range from multi-RTT to Angle of Arrival. However, these will often have their own requirements as it relates to infrastructure, with some techniques requiring more dense deployments of base stations to enable higher levels of accuracy. While 5G positioning is reusing the same 5G networking infrastructure, this infrastructure may not be as well suited in providing cm level accuracy for all use cases—and may need additional infrastructure and reception points, fine tuning, tighter time synchronization of base stations, or mmWave deployments to get the required accuracy. In addition, if positioning is a secondary consideration to the communications network, the required effort and planning may result in not reaching the performance required versus a dedicated RTLS system. 5G positioning is currently being positioned as a value add to 5G rollout rather than a primary use case, which may hinder its effectiveness when deploying. Instead, positioning needs to be a central part of the planning process rather than an afterthought in order to address the varied RTLS use cases effectively.

Ecosystem Formation

While the standardization of localization within 3GPP Release 16 and Release 17 opens up the potential for 5G positioning, 5G positioning has not been at the forefront of attention from an ecosystem development perspective. To rollout and commercialize 5G positioning successfully will require the close collaboration between many 5G ecosystem players, including chipset and module vendors, user equipment and device OEMs, network operators, infrastructure vendors, location engine providers, location service providers, system integrators, testing solution providers, RTLS solution providers, and various industry consortia, including the likes of 5G-ACIA to help promote and ensure adoption of the technology. While in the longer term 5G has the potential to scale rapidly, it is likely to take considerable time and effort to build this ecosystem which may hinder adoption in the shorter term. Much work needs to be done on promoting 5G positioning as a key enabler of RTLS.

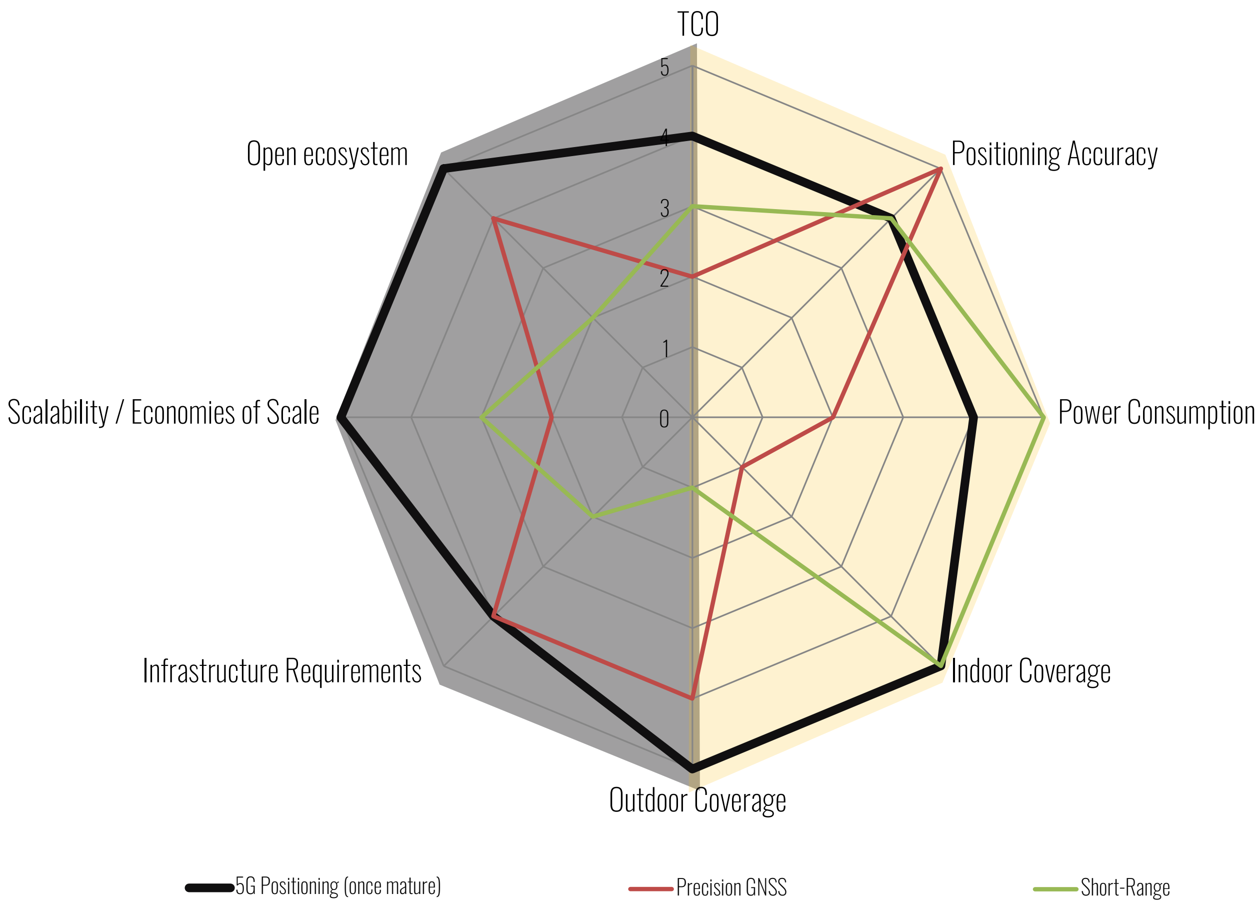
3GPP Evolution vs. Long Term Enterprise Decision Cycles

3GPP traditionally brings upgrades in an incremental manner through various releases, improving existing feature sets and adding new capabilities. While this has worked well in consumer markets, the challenge here is that in certain environments such as industrial manufacturing, end users want to make a purchasing decision and commit to that technology for the next 15-20 years. One key challenge for 5G positioning is to help bridge the gap between these two approaches—incremental upgrades versus complete solutions. While 3GPP relies on contributions from key stakeholders, this makes it difficult to provide a clear roadmap for industries looking to invest in 5G positioning and can be problematic when making purchasing decisions. As a result, close collaboration between end users and the wider 5G ecosystem is required to help speed up adoption and deliver new features as they become available.

RTLS TECHNOLOGY SUMMARY

As has been demonstrated, there is no perfect RTLS technology on the market today. However, if 5G can solve these challenges, once matured it has the potential to offer a very unique value proposition in relation to other RTLS technologies. Chart 5 shows key major RTLS technologies benchmarked against what 5G promises to deliver in future releases across a number of technical and economical critical metrics. Decisions need to be made on tag cost, accuracy, infrastructure complexity, latency, coverage area, reliability, scalability, cost of ownership, and other requirements. While the emphasis has traditionally been on performance metrics such as accuracy, coverage, power consumption—highlighted in red below—the challenge with many RTLS solutions has been their ability to address the business and implementation demands from the industry. These have created a barrier to entry and RTLS scalability, and is a fundamental reason behind the strong demand for 5G positioning from an economic perspective. These economic metrics—highlighted in blue in Chart 5—demonstrate where 5G is particularly strong versus the competition. Alongside this, on paper, 5G will increasingly be able to compete from a technical perspective, as it improves accuracy, latency, coverage, power consumption, integrity, and other metrics. However, much needs to be done in the future to realize this promise and validate the performance. As the chart demonstrates, this will enable 5G positioning to compete and offer a unique value proposition at both a technical and commercial level.

Chart 5: Key RTLS Benchmarks: Mature 5G Positioning versus alternative RTLS technologies



MARKET FORECASTS FOR 5G POSITIONING WITHIN RTLS APPLICATIONS

Providing forecasts for 5G Positioning is a difficult challenge as the technology is yet to mature and many problems must be overcome for it to build success. In addition, there is a clear sentiment from the industry that the technology will only be deployed when it is capable of addressing better accuracy use cases, becomes cost effective, and offers competitive power consumption. Much also depends on the rollout of 5G infrastructure and private networks that support 3GPP Releases 16, 17, 18, and beyond. However, there are many use cases that 5G positioning can begin to address. Not all use cases require cm level accuracy, and the value proposition of combining indoor and outdoor positioning via a single infrastructure is extremely compelling. According to ABI Research, tag revenues for sub-meter level RTLS tracking are expected to account for just 2% of overall RTLS deployments by 2025, in contrast with 37% for 1-2 meter level, and 62% for above 3-5 meters and beyond.

5G positioning faces a difficult competitive landscape made up of other technologies that can currently provide better accuracy, power consumption, and that are solving real enterprise pain points today. However, once 5G infrastructure densifies, the value proposition of 5G positioning will become more compelling. To summarize, the 5G positioning revolution will not happen overnight, and large-scale deployments will come only five years from now at the earliest, starting with less stringent meter level applications, and progressing thereafter to higher precision sub-meter and low power capabilities in safety critical and more autonomous applications. This will depend on timely adoption of upcoming 3GPP releases, the rollout of private 5G networks that support them, and widespread industry collaboration and promotion of upcoming positioning capabilities that 5G can provide.

KEY TAKEAWAYS AND STRATEGIC RECOMMENDATIONS

This whitepaper has highlighted the key barriers facing RTLS adoption today, and discussed how 5G positioning is one emerging technology that can potentially solve many of the issues that have prevented widespread deployment of precise location capabilities across many industry verticals. Within end market verticals such as manufacturing, healthcare, warehousing and supply chain, transportation, and oil, gas, and mining, from the ABI Research survey results, it is clear there is a growing sentiment that 5G positioning is beneficial thanks to its ability to combine telecoms and positioning use cases into a single infrastructure, and that it is capable of addressing use cases that other technologies have struggled to address to date, for a variety of reasons. There is a growing acknowledgement that 5G positioning is emerging to make LBS more accurate, precise, reliable, and seamless across both indoor and outdoor environments. However, it is clear that 5G positioning is very much in the early days of maturity, and there are a number of obstacles that need to overcome.

While it is encouraging that the demand is there, there is much work to be done within the 3GPP to deliver on the positioning promises within Release 16 and upcoming releases. 5G positioning needs to move beyond the concept phase and build out real world deployments, spread awareness across multiple verticals, and deliver on its strong potential. This will require extensive input from a wide range of industry players. In the shorter term, 5G positioning alone is unlikely to be able to address many use cases effectively. Ultimately, 5G positioning is unlikely to replace alternative RTLS technologies. However, for many industry verticals, the unique combination of communications and positioning, as well as seamless indoor and outdoor coverage, backed by the 5G ecosystem, will prove a strong value proposition. That same 5G ecosystem must come together to deliver improvements on accuracy, reliability, scalability, power consumption reductions, cost, ease of deployment, latency, and many other key metrics demanded by the varied RTLS use cases. Only then will 5G positioning reach its full potential as an enterprise problem solver for precise positioning.

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