Delivering on the Promise of Massive IoT Tracking and Location Services

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INTRODUCTION

Until recently, the IoT has relied on technologies and services built for the smartphone. Technologies from radio modules and connectivity protocols to batteries and GNSS receivers were brought to the mainstream to create and connect handheld consumer devices. As the IoT has grown, these technologies have found a place either by being repurposed without modification into new use-cases or, increasingly, through refinements as these use-cases become more specialized. LPWA networks, battery and antenna components, data analytics, and edge computing are among key advancements extending innovation into the IoT ecosystem.

Location is another area that has received particular interest. Legacy technologies, from standard GNSS to network-based positioning (e.g. Cell-ID or enhanced Cell-ID) are increasingly proving unfit in satisfying the requirements of asset tracking use-cases needing low-cost, low-power, and low-form factor devices. Beyond asset tracking, location is increasingly seen as a valuable piece of data even in applications where positioning is not the primary focus. Creating a fit-for-purpose location technology is a key boundary that needs to be crossed to power the next generation of IoT devices and deliver the tracking and location capabilities which will enable massive IoT.

The supplier market is increasingly responding to this market need through new IoT-centered location products and services, ranging from low-power and low-footprint GNSS technologies to novel ways of establishing location using a radio communication module. These technologies have been built in response to the growing opportunity in massive IoT, in which WAN-based technologies will play a critical role in serving markets for asset tracking, metering, and condition-based monitoring among others. LTE/5G cellular connections are forecast to reach 4.1 billion by 2025 but could grow to even more given cellular's wide area coverage and the massive investments into these networks. As a result, there has been considerable investment in new cellular location technologies to create new opportunities for cost-effective and power-efficient location on smaller devices. This can both address the needs of current use-cases more effectively than legacy technologies, as well as open opportunities for yet-unknown use-cases.

This white paper introduces a new approach to positioning over low-power LTE/5G technologies, namely device-based positioning as developed by PHY Wireless. The paper begins by examining the specific technology conditions that will drive the next generation of IoT devices. It then analyses how the market for location services is evolving to meet these requirements, and looks at how cellular positioning technologies are aiming to capitalize on this market. The paper then introduces PHY Wireless' new approach with device-based positioning, outlining its benefits and limitations relative to other technologies on the market, and explaining how this approach addresses changing market conditions.

IOT MARKET EVOLUTION

The IoT's growing market and technological maturity means that innovation needs to happen at an ever-faster rate. OEMs are under increasing pressure to understand the specific needs of a customer's use-case and to deliver new iterations of devices with greater functionality within a smaller package. The following are key trends emerging as a result of these pressures.

Location-Enabled Sensors – IoT devices have two primary operational functions: sensing and location. These functions overlap and converge very frequently. Location clearly plays a critical role for moving or portable assets (e.g. asset tracking, aftermarket telematics, people/pet tracking), with potential outcomes of loss/theft prevention, movement and in-transit condition pattern detection, or utilization optimization. Increasingly, location is also considered a valuable additional data point for less mobile or even stationary assets (e.g. street-lights, metering devices, industrial condition-based monitoring sensors), whether for added context or to create new actionable insights.

Miniaturized Form Factors – Smaller devices result in less cost as well as the ability to connect items at an increasingly granular level. To achieve miniaturization, OEMs need to make more efficient use of internal device space, whether through smaller batteries, more integrated module/modem components, or removing excess components for single-purpose devices. From a geolocation angle, two principal approaches are of interest: first, increasing power efficiency of the currently-used location technologies to decrease battery size; and second, to limit the number of location technologies used within a device, thereby diminishing the number of components drawing power.

Battery-Powered Devices – Battery-powered devices need to be autonomous and long-lived. In particular as devices get smaller and the battery claims a higher proportion of total available space, effort and innovation is going into device power efficiency and total power consumption. This means not only adapting physical components, but also software and firmware to minimize total device 'on'-time. More power-efficient location technologies to complement or replace GNSS standards are one area where significant savings can be gained, in particular in asset tracking – where geolocation is responsible for the vast majority of a device's 'on'-time power consumption.

Low Cost Sensors for Everything – Lowering the cost of devices is key to achieving the promise of massive IoT. Elements noted above, such as smaller form factors, more efficient power consumption, fewer or more highly integrated components, as well as higher volume projects, will help drive down costs. Lowering power consumption of geolocation elements, as well as strictly limiting the number of location technology components on a device, is key to achieving this. One example where more power-efficient components, design, and services have enabled lower-cost devices is with recently-commercialized smart labels for asset tracking: these simple devices are prime examples of how to drive massive deployments from the traditional high-value markets to lower-value markets.

Configurable Features – On many devices with long field lives, the ability to make changes to software and firmware over-the-air (OTA) will be crucial for application Return on Investment (ROI). This includes the ability to activate or de-activate hardware features or to change a device's reporting patterns with the value not only for device power efficiency but also for security and use in evolving use cases. Within the geolocation space, a significant value-add is the ability to configure a device to choose different location technologies and location sampling frequencies based on context: for instance, infrequent cellular network positioning in the majority of cases, switching to GNSS or Wi-Fi in specific scenarios when a higher accuracy is required (e.g. retrieval of a stolen item). This more broadly reflects a trend towards greater device autonomy with greater edge intelligence.

Secure Data – Maintaining the security and integrity of data is increasingly a requirement for IoT customers. Both device edge and cloud components are getting significant attention to prevent spoofing and device-based attacks on the one hand, and broader server hacks on the other hand. The security imperative is a growing area of attention for geolocation as well, with some of the 3GPP's studies on positioning noting that security is expected to become a key element of the service alongside more traditional considerations of accuracy and availability.

One-Stop-Shopping – On the non-technological front, IoT customers value simplicity. Part of this is the ability to have a single point of integration for software and services – either bundled with devices or with devices acquired separately from a third-party. For non-GNSS location (e.g. cellular, Wi-Fi), this means that IoT customers want a solution ready to go and offered within a bundle alongside a broader services package.

LOCATION SERVICES

As discussed above, location is a critical element to delivering on the promise of massive IoT. The geolocation landscape however is far from straightforward, and numerous considerations must be accounted for when assessing technologies – with requirements and considerations varying further on a use-case by use-case basis. These considerations center around position accuracy, power efficiency, security, indoors and outdoors coverage, network infrastructure and on-device hardware requirements, implementation ease and flexibility, and frequency of location sampling and transmission.

A CHANGING LANDSCAPE: WHERE IS LOCATION HEADING?

While GNSS has been the traditional go-to for location (often complemented by other technologies such as Wi-Fi, Bluetooth, Cell-ID and enhanced Cell-ID) , the IoT market is assessing new options to address the use-case challenges that occur when adding location to small, low-powered, and low-cost devices.

Accuracy Trade-Offs – IoT customers typically approach an IoT tracking project searching for devices with 3-5 meter level accuracy, the standard provided by GNSS. However, after Proof-of-Concept (PoC) trials, many asset tracking customers realize that GNSS location accuracy may not be needed for their specific use-case. The adoption of alternative location technologies that have lower accuracy (typically in the range of 50-500m) but more benefits in power efficiency, device component reduction, lower cost, and higher location yield from a single radio interface is accelerating as IoT customers become more educated on the specific requirements of their use-case. ABI Research expects that GNSS, when used, will become a secondary back-up location technology for occasional times when the highest accuracy is required; while in many cases, it will be removed entirely.

Power Efficiency – This criteria is key for IoT customers, in particular for battery-powered devices. There are multiple ways of improving the power efficiency of geolocation, including optimizing the frequency of location sampling and transmission and using alternatives to many existing GNSS technologies. For instance, location technology providers for LTE/5G networks boast device battery life anywhere between 10 and 100 times longer than devices using GNSS. As devices seek to decrease in size and cost to serve a broader range of IoT use cases, improving geolocation power efficiency will accelerate and will drive adoption of alternative location technologies, either to complement or replace GNSS.

Component Reduction for Seamless Indoor/Outdoor Use Cases – Location services for devices traveling between indoor and outdoor locations will typically currently use multiple technologies such as GNSS for high accuracy outdoors, Short-Range Wireless (SRW) technologies for high accuracy indoors, and CID/eCID for low accuracy outdoors. Much attention is now being paid reducing the number of technologies drawing power to carry out a location fix while offering a higher location 'yield': relatively accurate location, indoors and outdoors, in urban or rural settings, all from a single cellular communication module. This approach reduces the cost of building a device, limits the number of components drawing power, helps limit the size of the device, and provides good-enough location for many use-cases. While some devices will retain hybrid location capabilities for specific use-cases, many new device types will remove SRW and GNSS capabilities to lower BOM cost, reduce device size, and lower power consumption – all conditions necessary for massive IoT to become a reality.

LOCATION SERVICES OPTIONS FOR WIDE-AREA NETWORKS

SHORT-RANGE WIRELESS (SRW)

Technologies such as Bluetooth and Wi-Fi are often used as a complement to wide-area location technologies, often hybridized alongside GNSS to provide higher location yield and accuracy in urban or indoors environments. Their capabilities are briefly highlighted here:

Wi-Fi's high availability in urban or built-up environments enables it to provide an accuracy level between 10-50 meters in these settings. Power consumption from positioning over Wi-Fi can be low, due to a radio's ability to passively scan for MAC addresses. However, adding a Wi-Fi radio for positioning only comes with a significant additional cost, greater device complexity, and a limited yield when outside of urban environments. Wi-Fi positioning also requires crowd-sourcing to identify Access Point (AP) locations, with repercussions on database consistency and on Wi-Fi user privacy.

Bluetooth is often used for accurate indoor positioning use-cases, with greater range and accuracy of positioning coming from latest specification releases of BLE. Chips are very low-cost and can also be used for transfer of data to a gateway, which has made this an attractive proposition for many use-cases with a beacon to WAN tracker architecture. However, Bluetooth's short range limits its potential applications for WAN tracking applications, both as a hybrid technology as well as for beacons.

GPS/GNSS

The capabilities of GPS are well-documented, offering the highest accuracy of all wide-area location technologies and the greatest outdoor coverage – at the cost of power efficiency and on-device hardware space, and with low to no yield for indoor location. Assisted GPS (aGPS) goes some way to addressing power issues, but still require significant GPS and cellular receiver 'on'-time. Some new technologies use only a GNSS antenna (rather than a receiver/antenna combination) and forward received GNSS coordinates to the cloud, where the position determination is carried out. By making greater use of the cloud, these technologies help to reduce device footprint and power consumption while maintaining a very high level of accuracy .

LTE/5G POSITIONING

Some of the most interesting developments in the IoT location market come from companies offering location services based on low-power LTE/5G networks – such as LTE-M, NB-IoT, and higher cellular categories. These require no further hardware to be built into the device, leveraging the embedded cellular communication module to provide a location estimate based on signals received from surrounding cell towers within the device's range. The nature of cellular signals furthermore means that location fixes can be obtained whether the device is indoors or outdoors – enabling a high location yield from a single radio interface. Three principal types of LTE/5G location technology are worth noting.

NETWORK-BASED

Two types of network-based techniques exist: uplink-based and device-assisted. Uplink-based refers to a device transmitting known reference signals to a base-station enabling a position estimation to be made from the uplink; this technique is still promoted for 5G, though primarily for E911 use-cases rather than for IoT. Device-assisted methods, namely CID/eCID and Observed Time Difference of Arrival (OTDOA) , are the established methods for positioning using cellular signals in IoT use-cases. Device-assisted techniques require a device to go through three steps :

1) Establish a connection to surrounding base stations. To do this, a cellular module needs to be in Radio Resource Control (RRC)-connected mode, during which time it is drawing the most power;

2) Receive the unique cell tower identifier (Cell-ID) and any metadata , such as Timing Advance (TA) information;

3) Transmit this data to a server where the cell tower data is matched against an existing database, and sometimes augmented further calculations, such as Time of Arrival (ToA)/Time Difference of Arrival (TDoA).

BENEFITS	LIMITATIONS
Quite Power Efficient CID/eCID is considerably more power efficient compared to traditional GNSS technologies. **Low Footprint** As with all three cellular positioning technologies laid out here, no additional on-device footprint is necessary beyond the existing cellular module. A software-based agent (API or SDK) is all that is required to get a location fix. **Low-Cost** The technology is usually included as part of an MNO's service. Third party vendors with larger databases and frequently with higher accuracy offer this additional service at a low cost. **Availability** CID/eCID is offered by MNOs as part of their network services.	**Power Efficiency** Cell tower information is obtained through connecting to the network, requiring the device to be in RRC-connected mode every time a location fix is required – extending device 'on'-time and drawing more power. Data gathered from the cell tower needs to be transmitted back to a server for processing, requiring more power draw to transmit data. **Accuracy** CID/eCID is mostly used as a fallback option due to its high accuracy variability depending on cell-site density. Average accuracy is usually measured in the multiple hundreds of meters, while for low-power networks such as LTE-M or NB-IoT, the accuracy drops significantly. **Availability** While CID/eCID is offered by MNOs, it should be noted that the service is siloed between these different service providers such that performance is not consistent or guaranteed.

CLOUD-BASED

A more advanced form of LTE/5G positioning modifies the approach of CID/eCID. Rather than connecting to surrounding base stations, a device simply 'listens' to incoming signals and forwards these to the cloud, where they are matched to a cell tower database across multiple cellular network operators and undergo further computation to improve the accuracy estimation. Through this approach, devices can achieve lower power consumption through a shorter cellular receiver 'on'-time and faster Time To Fix (TTF), global availability, and higher accuracy estimation. The steps taken by a device are:

1) Listen to signals from any LTE/5G base station within range, without establishing a connection. The radio module must still be in RRC-connected mode to listen to the signals;

2) Compress signal data on the device and transmit to the cloud, where the filtering, base station database matching, and computation is carried out.

BENEFITS	LIMITATIONS
Power Efficient Device only needs to listen to incoming LTE/5G signals, rather than establishing a full connection to the network. This helps establish a faster TTF and limits total device 'on'-time. Significant battery life improvements over GNSS-only solutions. **Accurate** Cloud-based location improves on CID/eCID by using advanced algorithms and by gathering cell tower information from all operators' cell towers to create a proprietary database. Accuracy on LTE-M networks generally varies between 50-500 meters. **Available Everywhere** By not relying on MNO databases, cloud-based location enables cell tower information to be gathered globally regardless of what network the device is operating on. **Easy to Integrate** Can be deployed as an SDK or API, either retrofitted or built into the chip.	**Power Efficiency** While device 'on'-time is lower than CID/eCID, the radio still needs to enter RRC-connected mode to forward received signals to the cloud to establish a location fix. Transmitting all data back to the cloud rather than selecting what data needs to be sent back increases total device 'on'-time. **Variability** While more accurate than CID/eCID, cloud-based location's accuracy varies significantly depending on the cell-site density. **Availability** Requires interface on the chip to compress and transmit data to the cloud.

DEVICE-BASED

One of the latest techniques to reach the market is device-based LTE/5G positioning, developed by PHY Wireless. The technology, named hellaPHY, relies on similar principles as cloud-based location, but carries out all computation using on-device software: this shifts positioning determination from being User Equipment (UE)-assisted to being UE-based. The distinction is important: the process of gathering signals does not consume much energy, but the process of transmitting these signals forward to the cloud does. While network-based and cloud-based positioning require the signals to be forwarded to the cloud to obtain a location fix, device-based positioning eliminates this step and significantly diminishes how often components draw power from the battery.

The technology reflects the growing trend noted earlier towards increased edge intelligence on the device, allowing the device to be more autonomous and make case-by-case decisions on whether and when a data transmission is necessary. In this technology, a device must:

1) Download a compressed Base Station Almanac (BSA) provided by a Mobile Network Operator (MNO). The number of cells included within this almanac varies depending on the coverage area required, and the choice of what cells are downloaded can be modified depending on predicted movement patterns of the device. The device only needs to download a new set of cells when or if it moves out of the coverage area of the downloaded almanac.

2) Listen to incoming signals, which it can receive while in Power Saving Mode (PSM) or extended Discontinuous Reception (eDRX) mode;

3) Use a small amount of on-device Micro-Controller Unit (MCU) power to match signals against the pre-downloaded almanac and perform TOA, filtering, and positioning algorithms to determine a location.

4) Store the location data internally until the next scheduled transmission or event-based transmission trigger.

BENEFITS	LIMITATIONS
Power Efficient Can listen to LTE/5G signals while in PSM/eDRX modes–minimal power draw while carrying out geolocation fix. Devices can carry out hundreds of position fixes without impacting power draw, making near-unlimited positioning possible when using a single almanac. Minimal network interaction, resulting in very low radio 'on'-time. Devices need to be in RRC-connected only on two occasions: to download a cell almanac (infrequent) and during a transmission. Devices do not need to be RRC-connected during a geolocation fix. Transmissions are based on store-and-forward or on event-based triggers. In other words, a transmission is not required to get a geolocation fix as it is with other techniques. Claimed battery life of 100x more than GNSS-only solutions. **Accurate** High accuracy compared to alternative LTE/5G location technologies: having algorithms coupled with the device enables better filtering and cleaning of data. Accuracy on LTE-M networks around 50 meters, and increases with higher cellular categories (Cat-1 and above). **Secure** High security – individual nodes store location, rather than a centralized cloud. **Easy to Integrate** Software-only: can be installed on device OTA. Simple integration and can be retrofitted to existing devices. **Performance Independent of Environment** While some small variations in location accuracy occur as a result of cell site density and geometry, location accuracy remains mostly consistent regardless of indoors/outdoors or rural/built-up environment	**Availability** Relies on operator BSA databases to download cell almanacs onto a device, rather than on proprietary or public databases: solution is siloed to MNOs and MVNOs adopting the solution. In this sense, the technology is similar to CID/eCID. It is worth noting however that operator databases are more accurate and up-to-date than crowd-sourced methods, and contain more metadata than can effectively be used for positioning. Requires operator buy-in to enable PRS transmission on their networks (see below). While software-only, the solution requires an interface that needs to be included in the design of the chip. However, this interface is included in many chips already in the market. **Use-Case Dependent** Power savings are less when doing real-time geolocation on moving assets, where cell almanacs need to be downloaded more frequently

THE 3GPP'S ROADMAP FOR IOT LOCATION

One of the particularities of device-based positioning as developed by PHY Wireless is its reliance on Positioning Reference Signals (PRS) – a location-specific signal standardized in Release 9 of the 3GPP in 2009. Most operators currently do not broadcast PRS, except in some cases for E911 applications. This traditionally has been because PRS relies on cell blanking or muting, turning off certain cell sites momentarily to enable lower interference in the transmission of PRS (a feature which allows PRS to have better accuracy). One of the results of sporadically blanking or muting certain cell sites is that operators are removing network bandwidth needed for data transmission. Traditionally, this has been in the order of 10-25% lower bandwidth because of the 'dense' PRS requirement – i.e. the need to listen to a high number of cell towers to compensate for the narrow bandwidth of the transmitted signal.

Device-based positioning as developed by PHY Wireless addresses these existing network operator concerns with using PRS. Specifically, this approach to positioning addresses:

- **Bandwidth usage –** This approach does not require dense PRS broadcasting. Instead, it is able to receive infrequent PRS transmissions, and only take up 0.625% of a network operator's network overhead – rather than the traditional 10-25%.
- **Operator database security and integrity –** The device-based solution does not require that opera¬tors provide proprietary database information to third-parties: instead, they can deploy a high-accuracy and low-power positioning solution internally on their network, enhancing security and privacy.
- **New commercial opportunities –** By bringing a solution to market that is proprietary to network operators, device-based positioning enables these operators to take advantage of growing opportunities for location using their networks. Instead of simply using PRS for E911 as a mandated requirement, operators can address a very large number of commercial opportunities requiring lowest power and high accuracy – thereby creating a significant new revenue source. This approach also gives operators a more central role in interactions with the rest of the IoT ecosystem by enabling more device features, and by enabling them to push cellular-based location as a primary location technology rather than as a fallback.

Device-based positioning utilizes technology standardized by the 3GPP to provide a realistic and ready-to-deploy positioning solution designed for network operators. By overcoming the challenges traditionally associated with PRS, this approach to positioning opens up new fields of commercial opportunity for these operators.

DEVICE-BASED POSITIONING REVIEW

ADDRESSING CHANGING MARKET CONDITIONS

As shown above, device-based positioning offers a new way of thinking about location in IoT by focusing on power efficiency. The technology relies on the two following precepts, applying initially to asset tracking use-cases but also more generally to the broader IoT market:

1 ***The highest accuracy level provided by GNSS is not frequently required. Trade-offs in favor of battery-life or device cost can better meet specific use-case requirements.***

3-5 meters accuracy from GNSS is nice-to-have, but always comes with trade-offs that can break a business case: higher device cost, shorter device battery life, larger device size, and no indoor coverage (unless hybridized with other location technologies). High-accuracy location is only needed in a small number of scenarios – such as limited use-cases involving lost or stolen goods, and some use-cases in crowded environments or indoors where pinpointing a precise asset (e.g. tools on a worksite, storage room for cold chain product) is valuable.

With an accuracy of around 50 meters for LTE-M, and improving with higher categories of cellular protocols, device-based positioning improves on the capabilities of other cellular location providers in the market. It gets close to accuracy provided by Wi-Fi geolocation – but makes this capability available everywhere where the service is enabled rather than only in areas of a Wi-Fi network. In indoors spaces using small cells or Distributed Antenna Systems (DAS), this accuracy improves to meter-level – aligning device-based positioning to the 3GPP roadmap for 5G. These accuracy levels are sufficient for most use-cases: whether shipping goods, understanding the distribution of returnable assets, or securing assets within a campus or worksite. Focusing on lowest power consumption and simpler devices, device-based positioning can help to drive the next generation of autonomous and low-cost devices – critical to reaching massive IoT tracking.

2 ***Real-time updates are not frequently required. Store-and-forward and event-based transmissions satisfy the requirements of most use-cases.***

Real-time data transmissions drain asset tracking devices' batteries much faster than intermittent transmissions. Currently, cellular location technologies need to transmit data to the cloud to obtain a location fix – requiring a device to enter RRC-connected mode every time a fix is required. Insights and decisions on what actions need to be taken are made in the cloud. Device-based positioning relies on the principle that avoiding interactions with the network saves power. Autonomy is shifted to the edge, with the device collecting data frequently and deciding what data needs to be transmitted immediately and what data can be stored and forwarded at a later time.

Within asset tracking, real-time updates are used primarily in breadcrumbing applications to gather data on the route of an asset – for instance, following valuable cargo or understanding the route taken by an asset that has left a geofenced area. In the majority of these use-cases, store-and-forward and event-based transmissions enabled by device-based positioning can meet the use-case requirements but facilitated with smaller and lower-cost devices with longer lives: again paving the way toward massive IoT tracking.

APPLICATION REVIEW

This section sets out a few major use-cases that will make up the highest volumes within asset tracking. For each of these, the advantages of device-based positioning are highlighted.

Supply Chain and Logistics – Cargo and goods are frequently tracked to understand their location and condition in transit, which can help generate numerous insights for an IoT customer. Currently, standard re-usable and disposable devices rely on real-time tracking to transmit regular updates at regular intervals – such as every 5 or 15 minutes. Devices largely rely either on GNSS for high-precision location or on network-based cellular positioning, draining the device's battery by requiring significant component 'on'-time and network interaction. Device-based positioning can bring several advantages:

- Devices can still carry out geolocation fixes as frequently, but report them less regularly either at pre-set intervals or based on an unexpected event. An IoT customer only receives data when it is useful while using less costly non-GNSS devices
- Cargo and goods transition between warehouses, trucks, and distribution points where the application only needs to know that a transition or event occurred with an approximate location fix. In the vast majority of use-cases, an accuracy of 50 meters and under can yield all the same insights as obtained through GNSS.
- Minimizing transmission frequency enables smaller batteries, smaller devices (such as smart labels), and a lower cost: making it feasible to track goods at a more granular level while maintaining a suitable battery life.

Returnable Assets – Enterprises and poolers need to track pallets, crates, IBCs, totes, and other types of re-usable and returnable assets used to transport goods. This can help them to prevent loss, theft, and damage of these assets; improve utilization and pool velocity; or provide a higher level of service to customers. Currently, most devices tracking returnable assets use combinations of GNSS, Wi-Fi, and CID/eCID based on the customer's requirements. Device-based positioning can bring the following advantages:

- Understanding the flow of these asset types does not require high precision positioning: an IoT customer needs to understand at what stage of its journey the asset is, and variations in performance (dwell time, trip duration, shock, etc.) between different carriers, customers, and facilities.
- A high location yield from a single positioning technology can diminish device size, battery size, and device cost – enabling devices that can track not only high-value assets (e.g. glass pallets) but also low-cost assets (e.g. wooden pallets).
- Most use-cases with returnable assets heavily use geofencing, requiring a very infrequent data transmission rate.
- Building devices that can match the length of life of the asset it is attached to is a significant challenge, often requiring compromises on device cost, size, and capability. Device-based positioning can help lengthen battery life, and enable more capabilities (e.g. sensors) within the same or a smaller device footprint.

Campus- or Worksite-Based Assets – Countless use-cases exist for assets needing to be tracked in certain enclosed or geofenced areas – for instance, rental equipment, construction or industrial tools/ machinery/assets, trolleys and forklifts, among many others. There are many use-cases within worksite, warehouse or other campus settings where asset location and distribution is critical to business operations. Within these scenarios, device-based positioning can bring advantages:

- Devices interact minimally with the network: since devices remain largely on a single campus area, a device does not need to download fresh cell tower almanacs, and can use a single pre-downloaded almanac for the duration of the asset's stay on the campus.
- Devices need to report their location very infrequently, and only in cases where they are behaving in an unexpected way, such as exiting a geofenced area. In theory, a device may not need to report its location at all, significantly extending its battery life.

BENEFITS TO IOT SOLUTION ECOSYSTEM

CHIPSET AND MODULE VENDORS

Chipset and module vendors are looking to provide more integrated hardware solutions as well as to become a one-stop-shop for IoT solutions. They increasingly want to play a pivotal role in IoT device design and services offered on top. Device-based positioning enables these vendors to:

- Enable new services offered by MNOs and broaden relationships with MNOs to offer high-accuracy and low-power location insights;
- Influence IoT community on benefits of cellular-based geolocation and opportunities for low-cost and low-power use-cases;
- Expand capabilities of SoM/SoC hardware through offering capability to support module- or chip-native location without the need for hybridization;
- Take advantage of new IoT use-cases that require very low-cost and low-power, enabling chip and module vendors to assist in the design and services associated with future generations of devices that are paving the way for massive IoT.

DEVICE OEMS

These vendors are increasingly faced with pressures to extend device battery life while offering the same capabilities within the same or smaller device footprint. OEMs also need to be at the forefront of new technology advances for the IoT to design new devices that meet emerging customer needs but cannot be supported by legacy technologies. Device-based positioning enables these vendors to:

- Increase power efficiency of existing devices while offering a better level of accuracy and device security;
- Design new devices that will drive massive IoT, relying on power savings and cost savings made possible through device-based positioning;
- Focus more on specific use-case requirements and change the way customers think about IoT location, with greater flexibility around what type or types of location are built into devices;
- Work more closely with software and service providers to provide fully-integrated ready-to-go IoT solutions.

NETWORK OPERATORS – MNOS AND MVNOS

Network operators are increasingly looking to be one-stop-shop software- and service-providers for the rest of the IoT ecosystem. On the location side, many currently offer basic CID/eCID using the large cell tower databases they own; offering an enhanced service such as device-based positioning can generate more value from these databases while providing a higher level of service to customers. The benefits of device-based positioning for network operators have been examined earlier in the paper.

ENTERPRISES AND CUSTOMERS

The benefits discussed above for the rest of the ecosystem are fundamentally aimed at providing an enhanced level of service to the end customer: higher accuracy, lower power consumption, higher device autonomy, greater security, smaller and lower cost devices, and new use-cases and applications to address emerging enterprise needs – all bundled within a single network operator's service package. Positioning based on cellular technologies can increasingly be pushed towards being a primary or sole location technology, rather than its current status as a fallback location technology.

SUMMARY

Massive IoT across applications requires three principal device-side conditions: low-cost, low-power, and small-form factor devices. Geolocation capabilities enabled through hardware and services is a significant area where savings can be made, both within tracking applications where location technologies are responsible for the majority of the component costs, on-device space, and power consumption, as well as within non-tracking applications where positioning has hitherto not been a viable option. New location technologies and services are looking to redefine what features of location are critical by looking at the specific requirements of IoT and re-focusing the debate from one centered on location accuracy to one centered around use-case and business-case requirements.

Device-based positioning aims to deliver the lowest device power consumption and a high level of device security while simultaneously promising the highest accuracy of all location technologies relying on LTE/5G signals. The technology relies on the principles that IoT in most cases does not require real-time data transmissions or the highest level of accuracy provided by GNSS. Instead, this technology approach holds that trade-offs in favor of simpler devices with a lower cost and superior power efficiency can not only more satisfactorily meet the needs of most current IoT use-cases but also permit new generations of devices and location-enabled applications – and thereby deliver on the promise of massive IoT.

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