Hype Cycle for Wireless Technologies, 2023

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By Analyst(s): Nick Jones

Initiatives: Digital Future

> Organizations will use many wireless technologies at optical and radio frequencies delivering bandwidths from a few Kbps to 10s of Gbps. The leading wireless systems are evolving from networking tools into platforms providing positioning, sensing and application-specific features.

Analysis

What You Need to Know

Wireless is the foundation for a wide range of business activities providing services such as communication and sensing, and its importance will grow through 2030. The great majority of all data connections will be wireless, driven by the cost and inflexibility of fixed links that will be relegated to more niche cases where wireless isn't fast enough or special factors make it inappropriate.

Wireless is a technically very fragmented space. There are over 50 wireless protocols in mainstream commercial use operating on a wide range of frequencies. Over the last decade, several powerful leaders have emerged, primarily Bluetooth, Wi-Fi, 4G and 5G cellular, LoRa, and NFC. These have widespread usage and strong ecosystems that will drive continued growth. However, selecting a wireless technology inevitably involves trade-offs between conflicting requirements, so we expect new wireless technologies and standards to emerge through 2030 to fill unserved niches or exploit underutilized frequency bands.

The Hype Cycle

Wireless technologies in this Hype Cycle are characterized by seven trends.

Performance improvement. The majority of established technologies such as cellular, Wi-Fi, Bluetooth and others continue to evolve, providing improved performance and features in their core areas of connectivity. In the long term, new high-performance wireless technologies such as Terahertz will become a part of future standards.

The growth of short-range ultra-low-power wireless. Technologies such as RF energy harvesting and backscatter transmission have enabled highly power-efficient systems that, in some cases, need no battery at all. This will enable a range of innovative low-cost tagging and ambient sensing applications.

Satellite wireless becomes mainstream. Three application areas will dominate this technology: The first is broadband communications; the second is “direct to satellite” Internet of Things (IoT) as an alternative to terrestrial cellular connections; the third is Supplemental Coverage from Space (SCS) — satellites that can connect to unmodified terrestrial handsets.

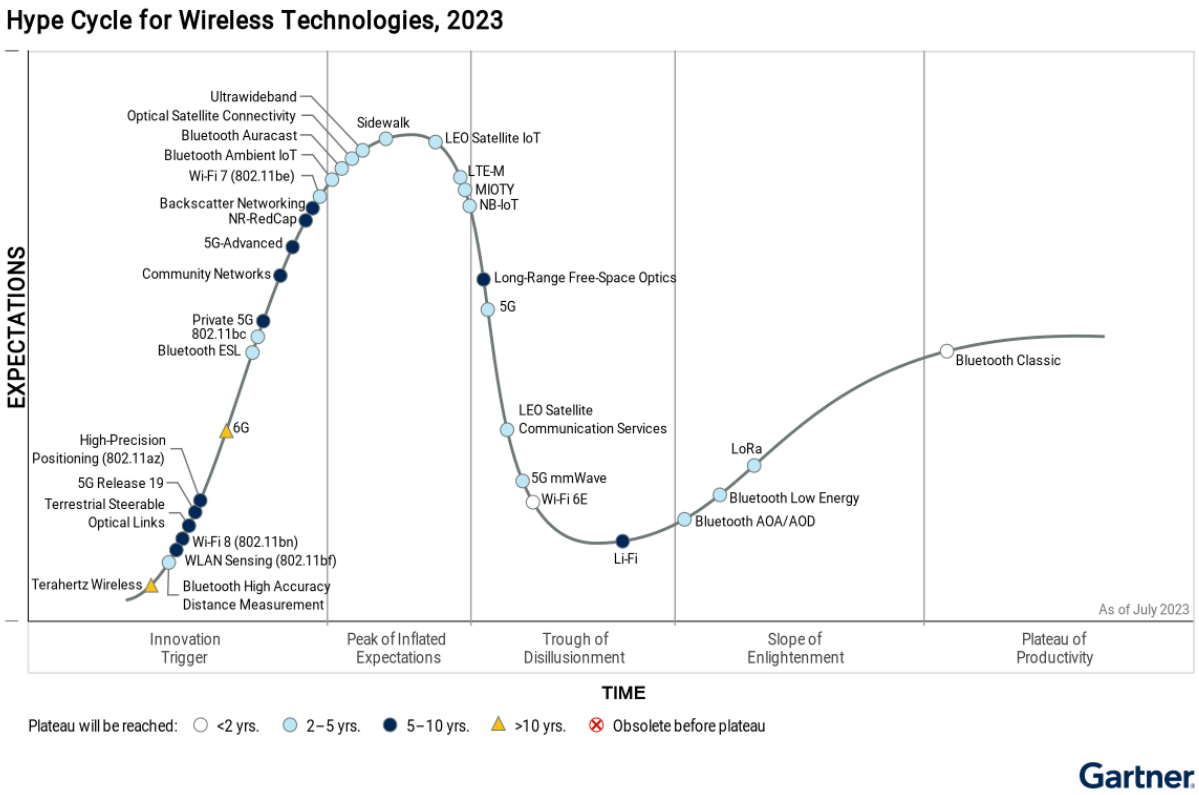
A growing need for optical communications. Optical communications are unregulated, have low observability, and often have higher performance than radio frequency systems. Laser optical systems will address key communications bottlenecks, for example, in links from satellites to ground stations and between satellites. Optical performance is improving; for example, point-to-point terrestrial optical data links can extend to 10 km.

Wireless networks become sensors. Many wireless networks operate at radar frequencies and are capable of sensing as well as communications. In 2023, Wi-Fi, 5G and Bluetooth already support positioning, and new capabilities such as distance measurement and sensing are being incorporated. Academics and startups have also demonstrated advances such as using Wi-Fi to detect fires, measure human respiration, or identify the precise location and activity of people.

Wireless becomes an application platform. Wireless standards such as Wi-Fi, Bluetooth and 5G are gaining application-specific features and becoming platforms on which business solutions can be built. Examples include adding capabilities for edge processing, media streaming, virtual reality, retail smart labeling, vehicular communications and railway applications.

Unlicensed spectrum dominates innovation. The most widely deployed wireless technologies typically use unlicensed or lightly licensed spectrum bands. It’s no coincidence that the two wireless technologies showing the most dynamic innovation roadmaps (Wi-Fi and Bluetooth) operate in unlicensed spectrum, prompting regulators around the world to make more spectrum available in this way.

Figure 1: Hype Cycle for Wireless Technologies, 2023



The Priority Matrix

Only a few wireless technologies are transformational. In this Hype Cycle, we have rated two as such. First, Bluetooth ambient IoT, which has the potential to tag and track huge numbers of items in real time at very low cost. The second is 802.11az, the new high-precision location standard for Wi-Fi. This will enable many innovations when all Wi-Fi endpoints become precisely trackable.

The majority of the technologies on this Hype Cycle will deliver either high or moderate value. Value, however, is contextual, depending on the application, situation and even region when dealing with technologies using licensed spectrum. Therefore, organizations should task their innovation teams to look at all the technologies in the “high” and “moderate” categories of the Priority Matrix to identify opportunities.

Most technologies on this Hype Cycle will mature in the two-to-10-year time frame; only two are rated as maturing in more than 10 years: 6G and Terahertz wireless. Both of these are very long-term bets with a high level of uncertainty. The 6G wireless standard probably won’t emerge until around 2030. Terahertz wireless requires major scientific breakthroughs before it can become commercially viable.

Finally, one wireless technology that has been rated as having low potential benefit in the Li-Fi, which has struggled to make any impact outside a few specialized niches.

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Table 1: Priority Matrix for Wireless Technologies, 2023

(Enlarged table in Appendix)

Benefit	Years to Mainstream Adoption			
↓	Less Than 2 Years ↓	2 - 5 Years ↓	5 - 10 Years ↓	More Than 10 Years ↓
Transformational		Bluetooth Ambient IoT	High-Precision Positioning (802.11az)	
High		5G Bluetooth AOA/AOD Bluetooth ESL Bluetooth Low Energy LoRa LTE-M NB-IoT Optical Satellite Connectivity	5G-Advanced 5G Release 19 Backscatter Networking Community Networks NR-RedCap Private 5G Terrestrial Steerable Optical Links	6G
Moderate	Bluetooth Classic Wi-Fi 6E	5G mmWave 802.11bc Bluetooth Auracast Bluetooth High Accuracy Distance Measurement LEO Satellite Communication Services LEO Satellite IoT MIOTY Sidewalk Ultrawideband Wi-Fi 7 (802.11be)	Long-Range Free-Space Optics Wi-Fi 8 (802.11bn) WLAN Sensing (802.11bf)	Terahertz Wireless
Low			Li-Fi	

Source: Gartner (July 2023)

On the Rise

Terahertz Wireless

Analysis By: Nick Jones

Benefit Rating: Moderate

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Definition:

Terahertz wireless refers to radio frequencies operating in the range between 300 GHz and 10 THz. In 2023, many aspects of terahertz wireless are technically extremely challenging and are still the subject of academic research.

Why This Is Important

Terahertz wireless is expected to be a key technology in future 6G cellular standards, which could be published around 2030. If technical challenges can be overcome, terahertz has the potential to deliver extremely high bandwidth and very low latency, while offering new sensing features and support for extremely small wireless devices.

Business Impact

Terahertz technology may become a significant innovation enabler. Terahertz could enable an order-of-magnitude performance improvement in wireless networking, and may enable major innovations in sensing. Terahertz equipment can measure distances with submillimetre accuracy, and the way in which Terahertz is absorbed and reflected can provide information about the material out of which an object is made. Terahertz wireless may also enable physically very small nanoscale devices with wireless interfaces.

Drivers

- There is potential for extremely high-bandwidth and low-latency communications.
- There is potential for submillimetre positioning accuracy, and new types of sensing and imaging combined with networking.
- The terahertz spectrum is virtually unused so it is uncongested.
- Terahertz wireless is less subject to certain forms of atmospheric disruption relative to laser point-to-point links.

- The very short wavelengths used by Terahertz systems may enable wireless devices that are physically very small (for example, the size of a biological cell).

Obstacles

- Viable commercial terahertz devices will require many fundamental breakthroughs in areas such as electronics, antennae and beam control. There is a possibility that terahertz may never become a viable technology for mass market deployment.
- Terahertz will be especially challenging in the case of moving endpoints.
- Very short range communications like terahertz frequencies are easily absorbed by physical objects. In 2023, the longest free-space terahertz link that has been demonstrated is only 2 kilometers.
- Most terahertz band technology that has been demonstrated is operating at sub 1 THz frequencies. Scaling up to higher frequencies may be challenging.
- Terahertz sensing can “see” through certain types of materials, including clothing, which could raise privacy concerns.

User Recommendations

- Task innovation and technology tracking staff with monitoring terahertz technology and 6G standardization efforts to identify innovation opportunities in areas such as sensing.
- Evaluate terahertz point-to-point links as an alternative to optical communications when (and if) terahertz matures sufficiently.

Gartner Recommended Reading

Top Strategic Technology Trends for 2023: Wireless Value Realization

Emerging Tech Impact Radar: Semiconductor and Electronics Technologies

Bluetooth High Accuracy Distance Measurement

Analysis By: Nick Jones

Benefit Rating: Moderate

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Definition:

Bluetooth high accuracy distance measurement (likely to be known as HADM) is a proposed extension to the Bluetooth standard enabling precise peer to peer distance measurement. The capability is likely to be incorporated in a release of the standard by 2024. Precise details aren't yet available but we expect rangefinding accuracy of better than 1M to be feasible.

Why This Is Important

In 1H23 Bluetooth peer-to-peer systems typically estimate the distance between two devices using signal strength measurement which is very approximate and easily disrupted by local conditions. Therefore current Bluetooth devices aren't ideal for applications such as smart locks where precise distance measurement is essential because poor accuracy provides opportunities for hackers. HADM will provide reliable high precision measurement for such applications.

Business Impact

When it becomes available, HADM will make Bluetooth more suitable for applications such as automotive and domestic locks. It will also enable new position sensing approaches based on measuring range combined with Bluetooth's existing signal angle of arrival (AOA) and angle of departure (AOD) technologies. This could reduce the cost of some position sensing systems which could operate with less infrastructure. It may also enable new types of proximity security systems, e.g., for PCs.

Drivers

- Makes Bluetooth more appropriate for peer to peer applications such as smart locks where high accuracy ranging is essential.
- Enables a new position sensing approach based on combining range and AOA/AOD.
- Provides differentiation for Bluetooth semiconductor and equipment vendors looking to increase functionality of commoditized products.

Obstacles

- Likely to need new silicon chips and may not interoperate with older Bluetooth devices, so some equipment may need to be replaced.
- Very simple ultralow cost Bluetooth devices may not support this capability.
- HADM will likely not be integrated into a wide range of products until 2024.

User Recommendations

- Monitor Bluetooth standards to determine when HADM will be officially released.
- Wait until HADM equipment is available before purchasing Bluetooth technology for applications where precise distance measurement is critical for security or operational performance.
- Consider replacing equipment relying on older Bluetooth distance measurement technologies with new HADM equivalents in cases where exploits might be possible, and would be damaging.
- Consider alternative technologies such as ultrawideband for applications that require precise distance measurement before Bluetooth HADM is widely supported.

Sample Vendors

Broadcom

5G Release 19

Analysis By: Nick Jones

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Definition:

5G release 19 (R19) is a future release of the 3GPP 5G standard. Some study items are already being researched; development of the official standard is expected to start in 2023 to be completed in late 2025 or early 2026, with the first deployments likely to begin in 2027.

Why This Is Important

5G is the global cellular communications standard which will be used by virtually every organization. The features of 5G have a major impact on how organizations communicate, and the products and services they can deliver. New 5G features can enable innovation and support new business models. The 3GPP standards development process for 5G is very open, providing good information for technology monitoring and innovation teams.

Business Impact

In addition to improved communications, one of the themes underlying the development of 5G is a growing focus on applications and specific use cases. Although the precise contents of 5G R19 have not yet been defined, the list of study items 3GPP is investigating provides clues to areas of interest. These include satellite communications, robots and drones, sensing, ambient Internet of Things technology, media, railway systems, ultraprecise positioning and the metaverse. Many of these areas will enable business innovation.

Drivers

- 5G R19 is likely to add new features that may provide operators with new applications for which customers will pay. Existing 5G standards are proving difficult for network operators to monetize.
- Future 5G releases will enable new business offerings and capabilities, as well as new network operator services.
- 5G features are evolving to provide greater support for specific applications and use cases.
- 5G standards development is a fairly open process, so organizations have good visibility into the likely content of future standards releases before they are finalized.

Obstacles

- 5G R19 will not be finalized until 2025-2026, and features will only be deployed to networks in 2026-2027. Therefore, it is currently relevant only to organizations with long-term technology strategies.
- The study items and potential R19 features discussed by 3GPP in 2023 are only indications, not commitments, so they are subject to change.
- Likewise, the 5G standards timetable is also subject to change.

User Recommendations

- Task technology monitoring and innovation teams with tracking the progress of 5G R19 to identify when proposals or firm commitments to features will create opportunities.
- Communicate information about future 5G releases to business peers, both to educate them about opportunities and to manage hype and unrealistic expectations.

Sample Vendors

Ericsson; Huawei; Nokia; Samsung Electronics; ZTE

Gartner Recommended Reading

A CTO's Guide to 5G-Advanced and 6G

Terrestrial Steerable Optical Links

Analysis By: Bill Ray

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Definition:

Optical communication with an aircraft, drone or robot offers high bandwidth and high security, but requires steerable transceivers that are capable of tracking the target in real time and aiming the laser used. Tracking is often done visually, while aiming can be done with microelectromechanical mirrors or spatial light modulation. However, both techniques require significant onboard processing and can be vulnerable to vibration or shock damage.

Why This Is Important

Communications with aerial assets is limited by the radio frequencies and network coverage available, with drones often unable to stream high-quality video or provide remote operations due to limited bandwidth. Aircrafts are often reliant on satellite communications, which can only offer limited bandwidth at a significant cost. Military applications are particularly important, as laser communications are difficult to detect and disrupt.

Business Impact

High-speed communications with and between aircraft will enable new use cases, such as real-time asset inspection and high-definition aerial observation. A high-resolution camera flying (or floating) at 2 km can easily track individuals or vehicles on the ground, and laser communications can provide an effective way to get that data back. Remote operation of an aircraft, including cargo-carrying drones, also requires the kind of bandwidth and long range which lasers can deliver.

Drivers

- Being able to stream live, high-quality video from a drone in flight permits real-time analysis of data collected during asset inspection or security patrolling.
- AI analysis can be moved from the drone into the cloud, reducing onboard power consumption and increasing flight time.
- Remote operation of multiple drones becomes viable, thanks to the high bandwidth available and the limited interference generated.
- The demand for intraconstellation satellite communications, particularly within LEO (low earth orbit) networks, is driving technical development of steerable lasers and tracking techniques.
- The difficulties in detecting or disrupting laser communications are particularly attractive to military users, who see steerable laser links as a key enabling technology for air-to-air and air-to-ground communications.

Obstacles

- The technical challenges in tracking the target and aiming the laser are both at the experimental stage, and investment is limited by the forecast market size.
- Laser range is quite limited — existing systems operate over a kilometer or so, though the range is rapidly increasing.
- Aiming systems are currently quite fragile and unsuited to fitting in high-vibration environments.
- Bright sunlight can still generate interference with some laser systems.

User Recommendations

- Create a benefit analysis on the value of high-bandwidth communications with mobile endpoints for existing and planned products, which can be matched against the falling cost of the technology.
- Identify new use cases that could be enabled by high-capacity wireless communications, and create a cost analysis for the price of laser communications needed to make such a use case viable.
- Track development of spatial light modulation, which could substantially reduce the cost and complexity of steerable optical communications.

Sample Vendors

AAC Hyperion; Aalyria Technologies; Mynaric; QinetiQ

Wi-Fi 8 (802.11bn)

Analysis By: Mike Leibovitz, Tim Zimmerman

Benefit Rating: Moderate

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Definition:

Wi-Fi 8 is a proposed standard to follow Wi-Fi 6 and Wi-Fi 7. Wi-Fi 8 IEEE 802.11bn (Ultra-High Reliability) is the next proposed amendment to IEEE 802.11 WLAN beyond Wi-Fi 7 (802.11be). Its working group is expected to be established in late 2023, and its release cycle is anticipated to last until 2028.

Why This Is Important

Wi-Fi 8 is a future wireless standard aimed to enhance the reliability of the Wi-Fi protocol with deterministic latency. It prioritizes service availability and delay guarantees by improving connectivity, spectrum availability and performance consistency. These enhancements will be critical for industries like healthcare, public safety and industrial automation, where reliable wireless communication is essential. Wi-Fi 8 is expected to become available by 2028.

Business Impact

Wi-Fi 8 promises to deliver more dependable wireless communications capable of better supporting the mobility of robots, machines, vehicles and drones. The improved reliability will enable greater support for employees, customers, Internet of Things (IoT) and operational technology (OT). This could create new use cases, including immersive communications, digital twins and cooperative robots that demand stringent levels of uptime, which are not currently enabled by existing Wi-Fi protocols.

Drivers

- Improved roaming experiences for people, devices, robots and IoT, ensuring that endpoints stay connected at all times. This is made possible through the new roaming capability of Wi-Fi 8, which includes distributed multilink operation (MLO) technology.
- Deterministic wireless communication is required to meet emerging demands across multiple industries related to automation and robotics. Wi-Fi 8 will be designed to ensure these applications perform not only in terms of data delivery, but also in terms of maximum latency.
- Full-spectrum utilization enables high-performance wireless connectivity for enterprise and industrial endpoints. By supporting multiple devices operating simultaneously across radio bands with less interference, Wi-Fi 8 will deliver consistent performance and offload opportunities for a range of use cases.

Obstacles

- There are currently no Wi-Fi 8 devices or infrastructure available on the market.
- There is no ratified Wi-Fi 8 standard yet, as it has yet to be drafted. The working group responsible for its development is set to begin its work in late 2023.
- The process of developing and ratifying a Wi-Fi standard typically takes around five years, which means we can expect Wi-Fi 8 products to become generally available around 2028.

User Recommendations

- There is no action required, as no Wi-Fi 8 commercial offerings are currently available in the market.

WLAN Sensing (802.11bf)

Analysis By: Tim Zimmerman, Bill Ray

Benefit Rating: Moderate

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Definition:

IEEE 802.11bf is a new task group developing wireless LAN (WLAN) sensing within the IEEE 802.11 working group. WLAN sensing — also referred to as WLAN Radar — exploits the prevalent wireless signals and collects data about how the signals bounce or penetrate within the environment to sense and measure changes, such as motion, presence, and gestures exhibited by objects, people, and animals.

Why This Is Important

WLAN sensing will allow wireless signals to detect range, velocity, angular information, motion, and presence or proximity of objects, people or animals in rooms, cars or enterprise environments. WLAN sensing has various applications, including tracking, fall detection, gesture control and activity recognition.

Business Impact

In addition to providing location information, WLAN sensing will potentially reduce costs in remote monitoring applications — where sensors or cameras were historically needed — using the existing WLAN infrastructure. At higher frequencies, WLAN tracking and the ability to obtain a higher resolution in the environment will enable enhanced remote health monitoring or real-time gesture recognition. It can also be used for asset management or geofencing.

Drivers

- The foundational IEEE communication standards are widely available. 802.11bf is an amendment, and the functionality can capitalize on existing Wi-Fi infrastructure.
- In the existing Wi-Fi environment, it supports real-time tracking and sensing of people or objects with higher resolution and accuracy (within 2 meters).
- Synergy with sensing and active objects. It provides two-factor authentication for tracked items when motion is detected.
- Existing infrastructure can be harnessed, thus reducing the cost of deployment with software updates available to many existing Wi-Fi access points.

Obstacles

- Tracking infrastructure for large areas requires Wi-Fi infrastructure.
- Interpretation of the signals can be complex. Not all Wi-Fi access points can support the additional processing required.
- Limited market traction due to existing technical solutions. Infrared Data Association (IrDA), SONAR and passive RFID can also provide similar outcomes with the same system-level cost profiles.

User Recommendations

- Include 802.11bf when specifying applications that need low-cost sensing where IrDA, SONAR or other inexpensive technologies, such as passive RFID, cannot be used.
- Identify applications that can gain from additional data beyond physical location.
- Look for innovation opportunities involving multiple technologies — for example, two-factor authentication or hybrid sensing.

Sample Vendors

Cognitive Systems; Origin Wireless

Gartner Recommended Reading

Magic Quadrant for Indoor Location Services

High-Precision Positioning (802.11az)

Analysis By: Ankita Khilare, Nick Jones

Benefit Rating: Transformational

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Definition:

802.11az is an IEEE standard that addresses high-precision positioning using Wi-Fi (2.4 gigahertz [GHz] or 5GHz wireless technology) to locate a device within 1-meter accuracy. Thus it enables absolute and relative position tracking of Wi-Fi devices with high accuracy improving the efficiency of Wi-Fi networks with reduced wireless medium utilization.

Why This Is Important

Wi-Fi is one of the world's most important networking technologies and a standardized high-precision and low-latency positioning capability will enable a wide range of applications tracking connected devices. It will also reduce costs by standardizing features that in the past relied on proprietary technologies.

Business Impact

With 802.11az, organizations will be able to track and trace Wi-Fi devices with greater accuracy. It opens up new business opportunities in high-precision tracking areas which may not have been possible before with Wi-Fi. For example, anti-collision applications for health and safety, tracking things in warehouses and factories, preventing accidents, social distancing applications and autofollow drones. It also has potential in augmented reality applications.

Drivers

- High-precision, low-latency positioning is beneficial in a wide range of business situations and it supports both absolute and relative positioning.
- It will allow tracking of a large range of standard Wi-Fi-equipped devices such as PCs and smartphones.
- A precise ranging capability is desirable in high-security applications, for example, to prevent man-in-the-middle attacks.
- The standard can support a large number of connected devices.
- It leverages multiple input multiple output (MIMO) technology providing better resilience to multipath effects in complex environments.
- It may reduce costs in some situations by using Wi-Fi infrastructure rather than proprietary systems needing additional technologies.

Obstacles

- Since it is likely to require new infrastructure and chipsets, making changes to large-scale Wi-Fi installations is not simple.
- It will take several years to become mainstream and be adopted in endpoint equipment.
- Accuracy and precision will vary depending on the chipsets and network design.
- Precise location tracking would enable physical tracking of a person through personal devices raising personal security and privacy concerns.

User Recommendations

- Identify new business opportunities enabled by knowing the precise location of Wi-Fi-connected devices.
- Seek high-value location tracking opportunities to justify infrastructure upgrades.
- Contact your vendors to determine their plans to support 802.11az in Wi-Fi infrastructure and the upgrade path for existing infrastructure.
- Specify 802.11az as a requirement for new Wi-Fi devices when products are commercially available.

Gartner Recommended Reading

Market Guide for Indoor Location Application Platforms

Architecting for Location

6G

Analysis By: Kosei Takiishi

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Definition:

6G is the generic name for the next-generation cellular wireless, also called Beyond 5G. In 2023, the features and timetable for 6G are not clearly defined, although it's expected to be commercialized in 2028 by some communications service provider (CSP) pioneers. 6G will enhance 5G capabilities and is intended to provide higher peak data rate (e.g., 100 Gbps to 1 Tbps), lower latency (e.g., 0.1 ms) and much more connection density and energy efficiency (e.g., 10 times more efficient).

Why This Is Important

The U.N.'s 2030 Agenda for Sustainable Development, including 17 goals, is heavily impacted by the mobile industry. Many of these social issues and ambitious goals will result in technologies that will become a part of 5G or future 6G cellular deployments. Design and research for 6G is already underway by many industrial associations and academic and commercial organizations. 5G can solve some of these challenges; however, 6G is indispensable for continuous growth and problem solving in the 2030s.

Business Impact

6G will enable end users, including consumers and enterprises, to transfer and process large volumes of data in real time, which enables true immersive experiences as well as more mission-critical human machine communications. Much richer and advanced connectivity of the physical world with the digital world — digital-physical fusion — is expected. There is no clear 6G definition, but 6G is aiming to improve 5G capabilities by adding one generation every 10 years (same as before).

Drivers

- Different from 4G and current 5G, 6G will become a sort of national network supported or impacted by countries and national policies. Some leading countries have started their initiatives, which will drive further research and discussions. In February 2023, the South Korean Minister for Science and ICT unveiled the K-Network 2030 plan, calling for South Korean tech firms to lead the way in developing world-class 6G technologies and software-based networks. The Chinese government has nominated 6G as one of its priority projects for 2023. In March 2023, the Beyond 5G Promotion Consortium in Japan published its B5G White Paper 2.0.
- Academics and commercial organizations want to be part of the 6G process, and active research has already begun. Working group one6G in Europe hosted a summit and held related open webinars in 2022. In February 2023, NTT DOCOMO hosted Open House'23, where 6G was one of the main topics. In November 2022, NTT DOCOMO published the 6G White Paper 5.0.
- Many commercial organizations and academic institutions have started their 6G research to be a part of the future 6G patent pool.

Obstacles

- The 5G journey is still in its early years, and its best practices and monetization are not clear. Success or failure of 5G to drive revenue and new business opportunities will have a major impact on 6G commercialization and business.
- The telecommunications industry has formulated its own specifications and standardization (such as 2G, 3G, 4G and 5G). It is unclear whether 6G will be able to incorporate external opinions, extending the start provided by some other industries' participation in developing 5G standards.
- Some 6G technologies, such as THz wireless, may not prove to be technically viable or cost-effective for most cellular users' needs.

User Recommendations

- Monitor discussion of the currently emerging 6G carefully.
- Prepare early trials and proofs of concept (POCs) in the late 2020s with vendors to learn more about the capabilities of 6G and early use cases, and begin building skill sets.
- Support your regulators and government to create their new national policy for 5G-Advanced and 6G. Technology innovation and strategy leaders should look at evolving 6G standards to get an early idea of future networking technologies.

Sample Vendors

Ericsson; Huawei; Nokia; NTT DOCOMO; Qualcomm; Samsung Electronics; SK Telecom

Gartner Recommended Reading

Emerging Tech Impact Radar: Communications

802.11bc

Analysis By: Nick Jones

Benefit Rating: Moderate

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Definition:

802.11bc is an enhanced broadcast mode extension to the 802.11 wireless networking standard. It allows Wi-Fi networks to broadcast information to devices which are not associated with a specific 802.11 network. It will also allow 802.11 networks to support new Internet of Things (IoT) use cases by permitting endpoints to broadcast messages which can be forwarded to a home server with no network-specific setup requirements.

Why This Is Important

Broadcast mode has the potential to enable a range of new 802.11 use cases such as emergency announcements, new forms of media streaming and broadcasting, distributing information such as slide decks in lectures. It will also make Wi-Fi more suitable for some IoT applications. Broadcast mode could also enable vendors to create new simple special-purpose Wi-Fi enabled devices that operate with minimal setup.

Business Impact

There are two potential applications of 802.11bc. Firstly, broadcasting media and information, it could be used in sports stadiums, museums, airports, schools and stations to transmit media or alerts to computers or consumer devices such as smartphones that know where to look for the signal. The second opportunity is in making Wi-Fi more suitable for IoT, allowing sensors or complex IoT equipment such as defibrillators to access connectivity without the need for setup and association with an access point.

Drivers

- Extends Wi-Fi connectivity to new use cases and optimizes it for some existing use cases.
- Potentially simpler to configure in IoT devices than cellular networks or Wi-Fi that does not support 802.11bc.
- Simplicity and usability; information can be received without joining a specific network.
- Broadcast technology improves performance and makes efficient use of spectrum and infrastructure than multiple separate unicast streams.
- Could enable new types of Wi-Fi devices, operating without the need for complex configuration, e.g., audio guides in museums.

Obstacles

- Vendor commitment is very weak, in 2H23 few vendors support 802.11bc and there seems little interest in providing such support rapidly.
- User demand is limited and awareness of 802.11bc features is very poor.
- Existing devices will need firmware or driver updates to support 802.11bc.
- 802.11bc is not ideal for some forms of IoT (such as battery powered devices) because of the power consumption of Wi-Fi compared to other networking technologies.
- Cellular V2X may be a superior solution for some automotive use cases such as alerting drivers of accidents ahead on the road or changes in weather conditions.
- Users are not yet familiar with Wi-Fi broadcasts.
- Broadcast technology may create new security concerns and enable new attack paths into devices.

User Recommendations

- Request your innovation teams to monitor 802.11bc to determine when it's sufficiently widely available to consider pilots.
- Pilot 802.11bc as a simple way to deliver media in organizations, hosting large numbers of individuals such as stations, stadiums, airports, hotels and exhibition space.
- Consider 802.11bc as an additional communication mechanism in IoT devices which need Wi-Fi connectivity and where network-specific configuration is required today.
- Pilot 802.11bc for use by public broadcast content owners such as radio, TV or streaming companies looking for new delivery channels.
- Check with vendors when 802.11bc support will be available in new consumer devices such as smartphones, tablets and PCs.

Sample Vendors

7SIGNAL

Bluetooth ESL

Analysis By: Nick Jones

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Definition:

Bluetooth electronic shelf labeling (ESL) is a new standard for communication with electronic shelf labels. It standardizes the protocol for common functions such as sending images to labels, monitoring label status, querying sensors (for example, for temperature), and controlling alert and notification LEDs. The protocol is extensible to support vendor-specific label features and sensors, and labels can support other Bluetooth capabilities such as beacons and geolocation.

Why This Is Important

Physical retailing continues to undergo rapid transformation. Electronic shelf labels and other in-store Internet of Things (IoT) solutions are critical components in the digitalization of the physical store. However until 2023, there have been few ESL standards and most systems are proprietary. Bluetooth ESL standardizes the communications between labels and control servers (known as access points), and will enable wider use of ESL at a lower cost.

Business Impact

ESL benefits retailers in areas such as:

- Reducing the labor cost of tasks such as updating price tags.
- Enabling new capabilities such as automated dynamic pricing and new types of promotions.
- Supporting tasks such as in-store picking and replenishment.
- Integrating sensing with labels, for example, to monitor product temperature.

Bluetooth ESL will reduce the cost of ESL infrastructure and projects and enable retailers to leverage Bluetooth store infrastructure for new purposes.

Drivers

- A standard communications infrastructure for ESL should reduce label and infrastructure costs.
- Scalable to thousands of devices per access point.
- Bluetooth in-store infrastructure can be used for other purposes such as tagging and tracking, consumer marketing, and geolocation.
- A standard will improve flexibility for retail buyers of ESL technology through better interoperability between ESL vendors.
- Future Bluetooth features such as new frequency bands and higher data rates will benefit future ESL installations.

Obstacles

- Bluetooth ESL standardizes only the basic communications functions of a label; there will likely be many vendor-specific proprietary features on different models of labels.
- It may be necessary to update the existing store Bluetooth infrastructure to support the new communications protocols and the need for better connectivity coverage.
- Replacing old nonstandard labeling technology could be expensive and disruptive.
- It will take some time for label vendors to adopt Bluetooth ESL as it typically involves hardware reengineering.

User Recommendations

- Favor vendors with plans to adopt Bluetooth ESL communications when selecting new ESL technologies.

Sample Vendors

SES-imagotag

Gartner Recommended Reading

Top Unified Retail Commerce Execution Trends for CIOs 2023

Private 5G

Analysis By: Sylvain Fabre

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Adolescent

Definition:

A private 5G network is based on 3rd Generation Partnership Project (3GPP) standard R15 or above to provide unified connectivity, optimized services and security for enterprises. A 5G private mobile network (PMN) is specific to the enterprise and used to interconnect people and things. Deployments can be entirely on-premises, with local breakout, or linked to a public cloud or local telco.

Why This Is Important

Multiple verticals will require 5G PMN deployments to realize the full effect of their digital transformation initiatives. Adopting new 5G standards earlier than communications service providers (CSPs) can offer on their public infrastructure can provide access to additional functionality. Distinct from the public network, private 5G supports voice, video, messaging, data and Internet of Things (IoT) with higher performance requirements. It can optimize cost or connectivity (for example, less expensive than Wi-Fi for large area coverage).

Business Impact

Private 5G enables transformational digital use cases for industry, especially in conjunction with other technologies, such as factory digital twin or edge AI for computer vision. 5G PMN can offer enterprises improved security, independence and enable efficiency gains; for example, complete 5G coverage in factories, with speeds over 1 Gbps, and support for edge and AI use cases with guaranteed performance levels.

Drivers

- Applicability and vertical specific integration are increasing. Beyond 3GPP, other bodies are now contributing, such as 5G Alliance for Connected Industries and Automation (5G-ACIA) or 5G Automotive Association (5GAA).
- Liberalization of the radio spectrum has opened up standard radio bands, often around 3.5 GHz, for use by private 5G networks.
- Requirement for full, reliable network coverage for machines, sensors and equipment, including indoor, outdoor, office and large industrial areas at lower cost than Wi-Fi.
- Performance profile for demanding industrial use cases, in particular when low-latency, high-bandwidth (especially uplink), and reliability are required and exceed the capabilities of the shared public infrastructure.
- Private 5G has another class of use cases, not focused on mobility initially, but requiring a high-performance backbone where wiring is complex and costly — such as in a factory deployment.
- Interest from telecommunications service providers (TSPs) that can offer 5G PMN to various verticals, such as I4.0 factory automation, mining, oil, utility and railroad companies. IoT providers, universities, stadiums and so on are thereby expanding into industries and generating new revenue.
- Alternative provider types beyond the CSPs, such as integrators, infrastructure vendors and hyperscalers, are driving new deployments and proofs of concept.
- Some enterprises deploy private networks because they want to run their network more independently, as their own infrastructure, with limited outside dependency. One example is long-term commitment from public network operators; also, data privacy can be a key concern, with data loss prevention security controls in place to ensure sensitive information does not leave the enterprise perimeter.
- Some defense and government clients have indicated a wish to have more control and visibility into the vendors involved in the mobile services provision, which can be an issue over a shared public network built and managed by a CSP.
- Low-latency applications using processing embedded in network infrastructure are logistically easier if the application, and infrastructure are owned by the same entity.

Obstacles

- Unclear business models and value justification vs. alternatives (e.g., 4G PMN).
- Perception that real value begins from 3GPP R16, and that maturity and availability of R16 solutions are still a work in progress; for example, with network slicing.
- Complex deployment and operation.
- Limited availability and cost of equipment designed to use the radio bands available for private network use.
- Module availability and pricing for R16 and up.
- Lack of outcome-based pricing models.
- Spectrum availability and/or cost in some countries.
- Perception of risk regarding timing and relevance of private 5G.
- Feedback from some industrial clients mentioned that the majority of their use cases could be serviced by a 4G private network, and/or NarrowBand-Internet of Things (NB-IoT) and other low-power wide-area networks (LPWA networks), such as LoRaWAN.

User Recommendations

- Differentiate from other providers, like large equipment vendors, systems integrators (SIs), resellers, smaller specialist network vendors and hyperscalers, by integrating PMN with other functions like supplier information management (SIM), IoT platforms, edge computing, design and managed services, and national roaming.
- Co-create networks by partnering with SIs and consultancies that have the required industry skills for design, deployment, and managed services engineering headcount and evaluation test bed environments. For example, build manufacturing 5G PMN with connectivity, security and AI capabilities.
- Design licensed and unlicensed/shared spectrum options where available.
- Supplement your engineering teams by working with IT service providers. Do not expect or plan on public 5G replacing WLAN in large portions of your environment. Instead, IT leaders should select private 5G for specialized use cases with large coverage areas and known application performance requirements.
- Identify use cases and their requirements to establish where 5G can be implemented — for example, in applications using HD wireless cameras.

Sample Vendors

AT&T; Celona; China Mobile; Ericsson; HPE (Athonet); Huawei; Nokia; T-Mobile; Verizon; Vodafone

Gartner Recommended Reading

Infographic: 5 Steps for Vendors to Scope and Run Successful POCs for Enterprise 5G PMNs

Market Guide for 4G and 5G Private Mobile Networks

3 Go-to-Market Strategies for Product Leaders in Private Mobile Networks

Research Roundup: How to Build Winning Propositions in 5G Private Mobile Networks

Quick Answer: What Metrics Can TSPs Consider for Their Private Mobile Network Solution Development?

Community Networks

Analysis By: Bill Ray

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Definition:

Community networks use an installed base of devices as crowdsourced network infrastructure. The infrastructure is not owned (or deployed) by the organization running the network. Devices comprising the infrastructure may act solely as access points, maintained in exchange for access to the community resources. The products can also be purchased for other reasons, such as a consumer doorbell, speaker or smartphone, which is co-opted into becoming part of the network infrastructure.

Why This Is Important

The provision of wide-area networking has traditionally been an oligopoly, based around a small number of large companies which have ownership of radio spectrum within a specific region and have invested in national infrastructure. A community network allows new competitors to provide regional/national connectivity services in competition with existing cellular operators, without the enormous capital expenditure normally associated with such deployments.

Business Impact

Companies such as Apple and Amazon have started providing national/international services based on communication networks which cost them almost nothing to build. This presents a threat to existing cellular network operators who are hoping that consumer, and enterprise, IoT will generate significant revenue. Within broadband services the balance is more complicated, as the sustainability of broadband community networks is still logistically, and financially, unproven.

Drivers

- Cellular operators have been slow to capitalize on their low power, wide-area connectivity, being more interested in broadband and smartphone connections.
- By avoiding the cost of deployment community networks can provide service at very low rates, even bundling connectivity with other IoT capabilities or providing a free service to community volunteers.
- As large companies like Amazon and Apple can avoid being beholden to cellular network operators for their connectivity, by building global community networks.
- The value of narrowband services, such as text messaging, has increased with the availability of battery powered sensors and low-cost radio transmitters.
- Some communities are trying to monetize community efforts with blockchain currencies or other rewards.

Obstacles

- Coverage is far from guaranteed, with network availability often being dependent on voluntary contributions, which discourages enterprises which might make use of the network.
- Users may opt out, or not opt in, over concerns with privacy or the cost of participation (in data rates and power consumption).
- Internet service providers may forbid the sharing of backhaul connectivity in their terms and conditions. This is unlikely to be a factor in narrowband community networks, but will become more important if broadband networks grow in popularity.
- Users may be concerned about the security of their data when passing over privately-owned networks.
- Incumbent network operators may lobby against community networks, encouraging the public to opt out while promoting their licensed alternatives.

User Recommendations

- Prepare for the availability of community networks by building support as a low-cost alternative to cellular wide-area network connections for IoT electronics and use cases including asset tracking.
- Evaluate both the Apple Find My accessory program and the Amazon Sidewalk Developer Service as a differentiator to provide wide-area network connectivity, given that these two community networks already have significant scale, especially within the U.S. (Sidewalk is, at the time of publication, U.S. only.)
- Create a platform framework for IoT products by using community network connectivity that can be optimized by region, because support for community networks will vary depending on the installed base of products acting as infrastructure.

Sample Vendors

Amazon; Apple; Fon; The Things Network

Gartner Recommended Reading

Emerging Technologies: Apple and Amazon Take Community Networks to the Masses

5G-Advanced

Analysis By: Kosei Takiishi

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Definition:

5G has been commercialized in many countries based on 3rd Generation Partnership Project (3GPP) Release 15 and later specifications. 3GPP decided to call the 5G successor technology 5G-Advanced as 3GPP Releases 18 and beyond will bridge the gap between current 5G and future 6G.

Why This Is Important

The completion of 5G-Advanced's first release, 3GPP Release 18, is scheduled for March 2024. This aims to expand the market reach of 5G by adding new big features such as XR and AI/ML and addressing additional requirements from CSPs and verticals. These requirements could include various enhancements of eMBB and URLLC, public-safety/mission-critical, satellite and IIoT/mMTC. This improvement will aid CSPs in more efficient use of the limited radio spectrum and provide new business opportunities.

Business Impact

5G-Advanced has two priorities, both of which can improve network and service capability for consumers and enterprise clients:

- Enhance the existing capability or cost reduction, such as multiple input/multiple output (MIMO), dynamic spectrum sharing, AI/ML and energy saving.
- Create new business, including extending terrestrial networks and vertical use cases supported by Sidelink NR positioning, nonterrestrial networks, AI/ML, AR/VR and IIoT/URLLC enhancement.

Drivers

- CSPs' interest in developing additional 5G monetization opportunities that require capabilities beyond 3GPP Release 17 is driving this technology.
- Standardization bodies and related consortia — such as 3GPP, ETSI, 5G-ACIA and 5GAA — have been promoting new features that can solve the challenges facing stakeholders.
- Developing new technologies and standards takes time, therefore this stepwise approach to adding more features and capabilities to 5G standards allows commercial equipment and deployment before the full vision of 5G is enabled. Iterative learning can then be incorporated into the standard process to address any gaps or further needs.

Obstacles

- Uncertain 5G ROI based on 5G monetization opportunities, coupled with heavy investments in initial 5G deployments and coverage expansion, could hamper willingness to invest significantly in 5G-Advanced.
- COVID-19 and other uncertainties related to standardization of work are concerns.
- There is increased complexity of coordination work due to the proliferation of technology-related standards organizations and industrial consortia, as well as increased dependency on other technical domains such as edge and cloud.

User Recommendations

- Develop a roadmap for what features to add to your 5G infrastructure while observing the progress of standardization activities.
- Collaborate with 5G-Advanced vendors to trial new capabilities to assess performance as well as potential business opportunities with leading enterprise and vertical market customers.
- Do not anticipate deploying 5G-Advanced commercially until 2024.

Sample Vendors

Ericsson; Huawei; Nokia; Samsung Electronics; ZTE

Gartner Recommended Reading

Magic Quadrant for 5G Network Infrastructure for Communications Service Providers

NR-RedCap

Analysis By: Kosei Takiishi

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Definition:

NR-RedCap, also known as reduced capability new radio and NR-light before, is a 5G specification focusing on the IoT part of 3GPP Release 17 that was frozen in 2022. Release 16 for 3GPP covers high-performance (e.g., industrial) and low-complexity (i.e., LTE-M/NB-IoT) IoT, but with a gap between them. NR-RedCap aims to reduce power consumption, which is indispensable for IoT applications, with communication speeds of several Mbps to 100 Mbps and latency delays of tens to hundreds of ms.

Why This Is Important

While NB-IoT and LTE-M enhancements have been folded into the 5G specifications in 3GPP Releases 15 and 16, they are not very new and are just relatively minor improvements compared to other new functions. In contrast, NR-RedCap will enable a new class of devices that is more capable than LTE-M/NB-IoT but supports different features and smaller bandwidth than 5G NR eMBB/URLLC. NR-RedCap can be a suitable technology for use cases such as high-end wearables or industrial IoT cameras and sensors.

Business Impact

NR-RedCap is designed to bridge the capability and complexity gap in 5G, catering to midtier use cases. This optimized design addresses various applications such as wearables and industrial wireless sensors. This can satisfy communication service providers (CSPs) and enterprise clients that are trying to find devices with a balance of functionality and cost.

Drivers

- NR-RedCap can support new use cases and capabilities that have not been supported effectively by incumbent technologies, including reduced power consumption, affordable device pricing with communication speeds of several Mbps to 100 Mbps and latency delays of tens to hundreds of ms.
- The telecom industry is promoting 5G as a platform for vertical industries such as automotive and healthcare, and NR-RedCap capability will become a key component for the platform.
- Vertical industries, including the automotive industry (5G Automotive Association) and the manufacturing industry (5G Alliance for Connected Industries and Automation), are demanding NR-RedCap for their digital transformation.

Obstacles

- One or two years of preparation will be needed before NR-RedCap is ready for mass commercialization. This preparation includes vendor implementation, CSP deployment and device vendors' adoption.
- Unclear monetization models for use cases of NR-RedCap could delay its commercialization. Currently, most IoT-related use cases could be satisfied by either LTE-M/NB-IoT or 5G eMBB, while LTE (4G) networks provide a lower-cost alternative for applications requiring the kind of speeds that NR-RedCap is designed to deliver.
- Introducing another alternative for IoT communications risks confusing the market that needs to believe in the longevity of NB-IoT and LTE-M before investing in them.

User Recommendations

CSP CTIOs should:

- Estimate suitable use cases of NR-RedCap by observing and participating in related 3GPP standardization.
- Develop monetization strategy of NR-RedCap device and services by engaging with potential vertical industry customers.
- Adopt multi-IoT access technologies, including LTE-M, NB-IoT and NR-RedCap, to satisfy multiple demands from clients.

Sample Vendors

Ericsson; Huawei; Nokia; Qualcomm

Gartner Recommended Reading

Magic Quadrant for 5G Network Infrastructure for Communications Service Providers

Wi-Fi 7 (802.11be)

Analysis By: Tim Zimmerman, Mike Leibovitz

Benefit Rating: Moderate

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Definition:

Wi-Fi 7 (802.11be) is a proposed wireless LAN (WLAN) standard. IEEE 802.11be (very high throughput) is the next amendment proposal to IEEE 802.11 for advances in WLAN and is expected to be ratified in early 2024. The amendment is expected to provide more efficient usage of noncontiguous spectrum, support up to 40 Gbps performance and increase the number of spatial streams from eight to 16. Moreover, it will introduce TSN capabilities for low-latency traffic as well as standardize 6 GHz support.

Why This Is Important

New high performance applications like 8K video streams, as well as augmented reality/virtual reality, are driving user performance requirements. The introduction of Wi-Fi 7 (802.11be) provides new unused spectrum in many geographies for additional performance and allows time-sensitive networking (TSN) capabilities that will address low-latency and real-time traffic requirements.

Business Impact

For IT leaders, the introduction of low-latency real-time capabilities will help with the integration of operational technology (OT) applications onto the IT infrastructure. This is needed for industry 4.0 initiatives as well as for closed-loop applications, including the deployment of robots and drones, while providing over 40 Gbps performance for wireless connectivity in a single coverage area.

Drivers

- **Higher performance for video and lower latency:** This will boost theoretical performance with higher speeds upward of 40 Gbps, offer increased WLAN capacities and the integration of TSN for wireless applications addresses. Address low-latency requirements (potentially less than 2 ms for critical traffic) and eliminate congestion.
- **Increases number of radio streams to 16 and introduces coordinated multiuser multiple in, multiple out (CMU-MIMO):** Enabling support for more discrete endpoints within a coverage area, coordinated with allocated capacity based on endpoint type and application. This functionality will also increase the efficiency and resilience of mesh networks with allocated bandwidth.
- **Expand to 6 GHz increasing available spectrum:** The new amendment will use the unlicensed spectrum newly allocated at 6 GHz to create more efficient use of noncontiguous spectrum and allow 320 MHz bandwidth and 16 spatial streams. Additionally, since 6 GHz is a new spectrum, it will not cover legacy devices that could slow the overall performance.

Obstacles

- **Surplus performance for many enterprises:** Wi-Fi 7 (IEEE 802.11be) will theoretically provide performance of up to 40 Gbps in a single coverage area, which is more than three times greater than 802.11ax. The applications needing this much performance are in the future.
- **Required wired infrastructure upgrade:** The uplink ports of intermediate distribution frame (IDF) switches will need to be upgraded beyond the 1 Gbps ports that are currently available, since the radio performance of one or more access points will exceed the wired connection.
- **Price:** The list price for Wi-Fi (802.11be) access points is expected to be more expensive than earlier generations and enterprises will need to justify the value.

User Recommendations

- Do not pay a premium for any prestandards adoption of Wi-Fi 7 (802.11be) unless existing wireless solutions are unable to provide the performance and functionality needed to meet defined end-user requirements.
- Be aware of access points' product end-of-life status as we do not expect Wi-Fi 7 before 2024, since silicon vendors will limit the production of previous versions of radio chips. These will cause vendors to shorten the availability of some models and only offer newer access point versions.
- Review the 6 GHz coverage area since it may differ from 2.4 GHz or 5GHz and result in coverage holes.
- Be prepared to update LAN switching to address higher power over Ethernet (PoE) requirements for access point as well as accommodate the higher performance wireless connectivity.

Sample Vendors

Cisco; Extreme Networks; Hewlett Packard Enterprise (Aruba); Huawei; Juniper Networks

Gartner Recommended Reading

Magic Quadrant for Enterprise Wired and Wireless LAN Infrastructure

Critical Capabilities for Enterprise Wired and Wireless LAN Infrastructure

Next-Gen Campus Connectivity Must Start by Defining the End-User Experience

I&O Platforms Primer for 2023

At the Peak

Backscatter Networking

Analysis By: Nick Jones

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Definition:

Backscatter networking operates by remodulating or reflecting ambient, RF-enabling equipment to transmit information with low power consumption — typically less than 10% of that required for conventional direct transmission.

Why This Is Important

Backscatter techniques can be used in sensors or tracking tags that require extremely low power consumption. This makes backscatter a potentially important technology for applications such as low-power or low-cost Internet of Things (IoT). Backscatter systems using high-frequency, radar-like scanning by the ambient power source will also provide precise location tracking in the future.

Business Impact

Backscatter networking will enable sensors and tracking tags with low power consumption suitable for use with energy-harvesting sources, such as thermal, ambient RF or optical. Some backscatter systems use relatively simple electronics that have the potential to provide very-low-cost devices manufactured using novel technologies, such as printed electronics. Low power consumption makes battery-free devices more feasible, providing the potential to reduce long-term e-waste.

Drivers

- Very low power consumption provides extreme battery life for IoT devices or enables the use of novel battery-free power sources, such as energy harvesting.
- Researchers have demonstrated millimeter-wave backscatter systems that support high sensor density, combined with precise location tracking.
- Future potential for low-cost devices using technologies, such as printed electronics.

- Can reuse existing radio infrastructure, such as Wi-Fi, as a power source.

Obstacles

- Very low transmitted power results in limited range (e.g., a few tens of meters maximum).
- Some implementations support only low data rates on the order of kbps.
- Backscatter systems may not be able to support all wireless protocols; remodulation or reflection constrains the types of signals and protocols that can be implemented.
- Requires ambient wireless as a power source, either from an existing system or a dedicated power transmitter.
- Some variants of the technology are still immature and are the subject of academic research.
- Limited range of vendors, most of which operate in the silicon technology space, so there are few off-the-shelf business solutions available in 2023.

User Recommendations

- Task your technology innovation teams to monitor academic research into backscatter developments, which could prove transformational for some future applications.
- Consider working with innovative backscatter vendors to develop new products or solutions that can't be created with existing wireless technologies, because of power supply constraints.

Sample Vendors

HaiLa Technologies; Jeeva Wireless

Gartner Recommended Reading

Top Trends in Building a Digital Future: Next-Gen Computing

TechWatch October 2022: Innovations in Wi-Fi Sensing, Robotics, Massive IoT and Edge AI

Bluetooth Ambient IoT

Analysis By: Nick Jones

Benefit Rating: Transformational

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Definition:

Bluetooth ambient Internet of Things (IoT) combines energy harvesting with Bluetooth low energy (BLE) technology to create low-cost battery-free Bluetooth tags and sensors. Ambient devices typically communicate with nearby gateways that forward location and sensor information.

Why This Is Important

Bluetooth ambient IoT enables tagging, tracking and sensing without the complexity or cost of battery-powered devices. The smallest energy harvesting tags are flexible, the size of a postage stamp and cost around 40 cents, although some vendors charge to access the cloud services that track the tag location. Tags can include sensors, e.g., for temperature or acceleration providing additional business data. In the long term (five years) we expect this technology will create new ecosystems.

Business Impact

Low-cost tagging and tracking have many applications such as real-time inventory in warehouses or retailers, reducing item losses (such as reusable transport containers), or sensing key business events (such as customers taking garments to fitting rooms). Longer-term ecosystems will involve multiple stakeholders, e.g., clothes labels that manage inventory in a store and communicate with a washer in the home.

Drivers

- Real-time tagging, tracking and sensing can provide value in a wide range of business processes.
- Bluetooth ambient tags can be tracked with some existing indoor location sensing systems.
- Low tag costs are likely to fall further as volumes increase.
- Physically small tags that are compatible with a wide range of items.
- In 1Q23 products using these principles are proprietary but we expect that by 2024 some elements of ambient IoT may be covered by Bluetooth standards which will aid interoperability.
- Potential to create new multivendor ecosystems with tags accessed by multiple stakeholders.

Obstacles

- Current systems are predominantly proprietary, and even after standards emerge we expect proprietary elements will remain.
- Nontrivial infrastructure requirements. Energy harvesting tags have a small power budget and hence a short transmission range (about 10M) which implies a need for significant numbers of Bluetooth gateways to receive and forward the messages.
- The “as a service” pricing model of some vendors may be an inhibitor.
- Some brands of tags need a separate RF system to supply energy.
- If active sensing tags remain in consumer products (for example, sewn into purchased clothes) after purchase some buyers will have privacy concerns.
- Current proprietary tags may not be able to roam across multiple organizations in a supply chain.

User Recommendations

- Pilot Bluetooth ambient IoT for applications where large numbers of items must be tracked in real time in either a single organization or a tightly coupled supply chain.
- Look for opportunities where sensing adds value to location tracking.
- Monitor the evolution of Bluetooth standards to identify opportunities where standardization might reduce costs or enable greater interoperability.

Sample Vendors

Nexite; SMK Electronics; Wiliot

Gartner Recommended Reading

Market Guide for Indoor Location Application Platforms

Architecting for Location

Bluetooth Auracast

Analysis By: Bill Ray

Benefit Rating: Moderate

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Definition:

Bluetooth Auracast adds several significant features to the Bluetooth low energy (BLE) standard, notably support for streaming audio which was hitherto restricted to Bluetooth Classic. Bluetooth Auracast extends audio support to include broadcasting to multiple speakers or listeners, it also mandates high-quality audio codecs, and provides audio for medical devices, such as hearing enhancement products.

Why This Is Important

Bluetooth Auracast reduces the power consumption of Bluetooth audio products considerably, with early products already offering a 28-hour battery life, enabling all-day use suited to wearable and hearing enhancement products. Directional amplification and AI noise filtering are creating a new category of product aimed at an aging population, while broadcast enables new usage models like streaming different languages in cinemas or tourist attractions, and selective audio in public spaces.

Business Impact

In addition to enabling new use cases with broadcast audio and extending battery life, Bluetooth Auracast will create a new class of “hearing enhancement” products targeted at an aging population for all-day wear. These fit between Bluetooth earbuds and medical hearing aids (initial pricing is $1,000 to $2,000) and will create a new market for audio products. No longer needed for audio, Bluetooth Classic will rapidly become redundant, supported only for compatibility with legacy devices.

Drivers

- Battery life is a key point of differentiation in existing Bluetooth earbuds, and Bluetooth Auracast will significantly extend that.
- Auracast requires support for advanced codecs, increasing the minimum quality of audio available through a Bluetooth stream.
- The ability to share audio, locally, with friends will provide a point of differentiation in smartphones sold during 2023-2024 (where Bluetooth 5.2 is supported).
- The ability to subscribe to local audio broadcasts in public places can reduce the noise pollution in such areas (like providing airline announcements, or television audio, in an airport).
- An aging population is suffering from hearing loss, while the stigma of wearing earbuds has been reduced by the popularity of portable music services, creating a ready market for hearing enhancement products.
- National regulators, such as the U.S. Food & Drug Administration (FDA), are creating legislation permitting over-the-counter sales of hearing enhancement products. The initial products in this category are all using Bluetooth Auracast, and the standard will dominate this market.
- By replicating the audio streaming function Bluetooth Auracast makes Bluetooth Classic redundant (as Bluetooth Auracast works over BLE). While support for legacy equipment will persist in smartphones and computers, audio-only products, such as speakers and headphones, can reduce the cost of parts by supporting only BLE.

Obstacles

- Supporting the software and user experience (UX) for Bluetooth Auracast will take some integration, so the cost saving of supporting only BLE will only deliver over time as product shipments scale.
- The UX for subscribing, and unsubscribing, to audio broadcasts is still being standardized, particularly where screenless support is demanded.
- Directional amplification and AI noise cancellation, are both at the development stage, with few products providing a demonstrably positive UX.
- While the industry (particularly Apple) has gone a long way in reducing the stigma of wearing earbuds all day, development is still needed to ensure the comfort of such a use case.

User Recommendations

- Ensure that newly deployed products support Bluetooth Auracast for future compatibility.
- Create use case scenarios where broadcast audio might enhance existing product offerings, including instances where headphones or speakers could be issued to workers or visitors (like museums, entertainment venues and other public spaces).
- Plan for wide scale adoption of hearing enhancement products, in the five to 10 years time scale, and create a list of use cases applicable to your organization with a view to early development.

Sample Vendors

Nuheara; Sony Group

Optical Satellite Connectivity

Analysis By: Nick Jones

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Definition:

Optical satellite connectivity uses lasers to provide high-speed data links between satellites and from satellites to the Earth — and vice versa. It provides higher bandwidth and better immunity to interception than radio frequency (RF) systems.

Why This Is Important

Low Earth orbit (LEO) satellite applications, such as broadband communications or Earth observation, involve transmitting very large amounts of data. Optical links are attractive because they are unregulated and provide higher bandwidth than RF communications. Optical links will be used between satellites and from satellites to Earth, providing improved performance and greater operational flexibility.

Business Impact

Most organizations will use optical satellite connectivity as a side effect of buying other services, such as satellite broadband and Earth observation. Optical satellite connectivity can improve the performance of such services and, in some cases, reduce response times — for example, in situations where large amounts of data must be downlinked from a satellite. In the future, organizations launching private satellites may need to specify optical links to complement wireless communications.

Drivers

- Better performance than RF communications: In 2023, speeds exceeding 200 Gbps have been demonstrated and terabit links are now expected.
- More difficult to observe or intercept than radio communications.
- Optical links to and from the Earth are typically unregulated and not constrained by radio spectrum allocations or frequency congestion.
- Optical links between satellites of the same constellation improve resilience and operational flexibility by providing more communication paths that allow satellites to access a wider range of ground stations.
- Optical links are faster than terrestrial fiber links. Therefore, routing via an orbital mesh to a ground station close to the end user could significantly reduce latency in some situations.

Obstacles

- Optical links may be impacted by weather conditions.
- Optical satellite connectivity is immature and still the subject of academic and industry research.
- Lack of standards and interoperability.
- Ground station equipment is complex, physically large and expensive. It’s unsuitable for individual users or small organizations.

User Recommendations

- Favor satellite service providers with optical capabilities when buying services, such as Earth observation or satellite broadband. They are likely to be able to provide services with better performance or resiliency.
- Organizations that own high-capacity conventional ground stations in 2023 should monitor optical technologies to determine when to augment them with optical capabilities.

Gartner Recommended Reading

LEO Satellites Will Be an Essential Part of Your Future Networking Strategy

Ultrawideband

Analysis By: Bill Ray

Benefit Rating: Moderate

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Definition:

Ultrawideband (UWB) radio transmission harnesses a wide frequency band to provide communications at low power. Originally proposed for high-speed data applications, the primary application now uses the angle of a received signal, along with its time of flight, to determine relative location. UWB is capable of determining location and distance within a few centimeters, and it is used for tracking and innovative interface design.

Why This Is Important

UWB compares favorably to competing wireless technologies in determining precise direction and distance. Advantages of UWB include greater accuracy, reliability and security. Support from Apple and Samsung Electronics is making the technology a premium smartphone feature, while transmission over a wide frequency range improves its reliability, and eliminates indirect signal paths to enable highly accurate location and orientation detection.

Business Impact

UWB will expand beyond applications in smartphones and home automation to include use cases in automotive, enterprise, smart city, and retail. The precise information about location and direction it can provide will enable new use cases in asset tracking and management. The ability to identify the direction in which a phone, or any other device, is pointing will create new interfacing paradigms for smart home and industrial applications.

Drivers

- Accurate indoor location is enabling a range of applications in supply chain and logistics management, and UWB can offer unparalleled accuracy and reliability.
- Asset tracking is becoming an important consumer offering, as electronics (such as earbuds) become smaller and can get easily lost.
- Smartphone vendors are looking to differentiate their products with additional features that can be enabled with UWB.
- Smart home applications are looking for better interfacing technologies, including point-to-interact capabilities.
- The additional security provided by accurate location tracking can provide a point of differentiation in car door locking and immobilizers.

Obstacles

- UWB is more expensive than competing technologies, such as Bluetooth or RFID.
- Power consumption remains a challenge, particularly for small, battery-powered products.
- Many vendors (notably Apple and Samsung Electronics) are locking their products within their proprietary ecosystem, despite the existence of appropriate standards.
- The first-generation UWB semiconductors are relatively large, which limits their use in small products, such as earbuds.

User Recommendations

- Identify use cases that would benefit from the spatial awareness and precise location capabilities of UWB.
- Consider UWB as an alternative to Bluetooth location technologies, with the expectation that costs will decline with economies of scale and its accuracy may enable additional use cases.
- Implement UWB technology in the enterprise for access, indoor navigation and automation as adoption matures in personal devices.

Sample Vendors

Apple; NXP Semiconductors; Samsung Electronics

Gartner Recommended Reading

Emerging Technologies: Critical Insights on Ultrawideband

Sidewalk

Analysis By: Bill Ray

Benefit Rating: Moderate

Market Penetration: 1% to 5% of target audience

Maturity: Adolescent

Definition:

Sidewalk is an IoT connectivity service, which uses Wi-Fi, Bluetooth and LoRa connectivity hosted by Amazon hardware, such as the Ring doorbell and Alexa smart speakers. Owners of the hardware provide the service by default. The collected data is transport independent and is available via Amazon's IoT Core API. Amazon also sells "professional" access points for enterprise customers who want to guarantee Sidewalk coverage.

Why This Is Important

With Sidewalk, Amazon managed to build an IoT network covering most of the U.S., including 90% of the population, without spending any money on infrastructure or radio spectrum. Sidewalk is a community network, one which automatically enrolls the community (though owners of Amazon products may choose to opt out). This represents a new way of building a communication network, enabling Amazon to compete in a market which has, hitherto, been largely an oligopoly.

Business Impact

While the Sidewalk network won't compete with broadband cellular services, it will allow Amazon to compete directly with telcos in delivering IoT for consumers and enterprise customers, potentially undermining CSP revenue models from such services. The network is currently limited to the U.S., but is likely to expand internationally over the next few years, as the use of LoRa, Wi-Fi and Bluetooth will permit deployment in almost every country.

Drivers

- Reduced cost and power consumption of electronics has resulted in a proliferation of small-end electronic devices, which can gain significant functionality through connectivity even if the bandwidth is limited.
- Cellular operators are considered uncompetitive in pricing of low-volume data, such as that required by IoT applications.
- Cellular operators have largely targeted the bigger enterprise customers for their IoT network offerings, leaving smaller companies looking for an alternative.
- Amazon has integrated Sidewalk very closely with its IoT Core and other Amazon Web Services (AWS) products, while cellular operators struggle to provide standard platforms for IoT data delivery.
- Enterprises using IoT data collection prefer to avoid technology-specific solutions, so the standard data access offered by Sidewalk is attractive.

Obstacles

- Sidewalk is limited to the U.S. for the moment, and the LoRa protocol being used is not compatible with the European limits on the use of the 900MHz band. Changes to the protocol will be needed before European expansion is possible.
- Given the complete dependence on the installation of Amazon products, coverage cannot be guaranteed and is largely lacking in the rural areas.
- Customer backlash may encourage more users of Amazon hardware to opt out of hosting Sidewalk access points, over concerns with privacy and bandwidth sharing.
- The variant of LoRa being used by Sidewalk to provide wide area coverage is not compatible with the LoRaWAN standard, which risks customer confusion over interoperability issues.

User Recommendations

- Consider Sidewalk a viable option for wide area IoT projects where coverage is only needed in urban areas within the mainland U.S.
- Establish the cost of adding Sidewalk support to existing IoT products, particularly where LoRa (or LoRaWAN) is currently being used as the cost may be incremental.
- Ensure that Amazon's IoT Core is a supported platform for IoT products and services, given it will increase in importance with the growth of Sidewalk.

Sample Vendors

Nordic Semiconductor; Amazon; Semtech

LEO Satellite IoT

Analysis By: Bill Ray

Benefit Rating: Moderate

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Definition:

Low Earth orbit (LEO) satellites offer low-power communications with a global footprint, being able to collect short data bursts from Internet of Things (IoT) endpoints for tracking locations or environmental monitoring. Data is generally in the form of short messages made available through a cloud service, but battery life may be five years or more and data costs are comparable with terrestrial low-power wide-area (LPWA) networks.

Why This Is Important

International IoT projects have been hampered by terrestrial IoT networks operating on different frequencies, and require negotiated roaming agreements between different carriers. Coverage is also limited, while asset tracking and environmental monitoring are often required across very rural areas. Satellite services can provide global tracking, and the 3rd Generation Partnership Project (3GPP) is working toward integrating satellite connectivity into its IoT connectivity standards.

Business Impact

Being able to track anything, anywhere, has immediate implications on supply chain management and visibility. Fleet operators can improve efficiency, while remotely monitoring temperature and other shipping conditions. Remote monitoring of wide-scale projects, such as construction and mining projects, water seepage in dams or pipeline conditions, is made possible (and economically viable) through low-power satellite communications.

Drivers

- Enterprises are seeking greater visibility of supply chains and operations, which isn't available from terrestrial networks.
- The growth of digital twins, and the value of preventative maintenance, is increasing demand for real-time (or near-real-time) monitoring of remote assets.
- Technical innovations (largely from the smartphone industry) have reduced the cost of satellite development and deployment.
- The development of successful services has proved the technical viability, encouraging new entrants and business models.
- Wide-area monitoring of environmental change, particularly in remote regions, is increasingly important as governments are prioritizing environmental spending.

Obstacles

- Satellite services often require line of sight, or near line of sight, which can limit applications to outdoor use cases.
- The quantity of new entrants anticipates a period of disruption, and consolidation, which could leave some customers disconnected as vendors restructure or collapse.
- Competitive pressure is driving down the cost of terrestrial IoT connectivity, making satellite service comparatively more expensive (if still comparable).
- Few services are truly global, with regulator licensing and radio spectrum access still proving barriers to ubiquitous service.

User Recommendations

- Complement IoT connectivity services by including satellite communication as a global network option in IoT deployments, particularly in supply chain management and industries such as agriculture, energy and maritime, where terrestrial coverage is limited.
- Consider how hybrid solutions may be applicable in mobile applications, where standards such as LoRa and/or NB-IoT may enable roaming between satellite and terrestrial services.
- Identify projects where gateway solutions may provide an additional option, using a satellite to backhaul local endpoints equipped with LPWA network technologies via a hub.

Sample Vendors

Iridium Communications; Myriota; Swarm

LTE-M

Analysis By: Ankita Khilare

Benefit Rating: High

Market Penetration: 20% to 50% of target audience

Maturity: Adolescent

Definition:

LTE-M is a low-power wide-area (LPWA) network technology and cellular communications standard to interconnect objects and sensors offering higher data rate and greater mobility than NB-IoT and voice capability over the network.

Why This Is Important

The cellular standard LTE-M offers efficient and nationwide connectivity for IoT devices that is less expensive than other high speed data connections. LTE-M networks are supported by major vendors and designed to rely on existing LTE or 5G infrastructure. Thus, they reduce the compatibility issues for machine/machine communication, and benefit from all the security and privacy features of mobile networks. Voice channels can be used for security system applications.

Business Impact

LTE-M supports a wide range of IoT applications while providing greater bandwidth and better support for objects in motion — e.g., asset tracking in logistics, monitoring industrial processes in remote or dangerous conditions — than the other cellular alternative NB-IoT. It will be more cost-efficient in terms of hardware than a fully capable cellular communications module. Availability of a voice channel is useful for security systems like burglar alarms which may need occasional voice communication.

Drivers

- LTE-M is widely available in many countries as a part of cellular networks.
- Long battery life of up to 10 years.
- LTE-M uses cost-efficient IoT devices and is easy to scale up.
- Reduced complexity of communication modules.
- LTE-M devices use radio spectrum exclusively licensed to cellular carriers. Thereby, they are reducing the risk of network interference or congestion.
- Roaming agreements between carriers provide international coverage.

Obstacles

- Hardware costs are higher than some of the other noncellular LPWA technologies like LoRA.
- LTE-M is not yet supported by all networks across the globe.
- Although it offers a higher data rate, it's not sufficient for demanding applications that require transmission of large amounts of data in the form of audio or video files.

User Recommendations

- Look out for business needs and opportunities where LTE-M can support in terms of greater mobility and voice capability features over the network.
- Evaluate cellular IoT technologies and consider LTE-M when you require nationwide connectivity.
- Validate operators or vendors with multinational products for specific business requirements.
- Select LPWA or cellular technologies that align with your business needs related to network coverage, operational cost and security requirements.

Sample Vendors

Aeris Communications; Deutsche Telekom; NTT; Verizon Communications

Gartner Recommended Reading

2022 Strategic Roadmap for Edge (IoT) Networking

Critical Capabilities for Managed IoT Connectivity Services, Worldwide

Magic Quadrant for Managed IoT Connectivity Services, Worldwide

MIOTY

Analysis By: Nick Jones

Benefit Rating: Moderate

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Definition:

MIOTY is a narrowband IoT wireless protocol operating in unlicensed subgigahertz spectrum and intended for private low-bandwidth IoT applications. It features long-range, low-power consumption and excellent resistance to electrical interference. MIOTY has a range of several kms (depending on conditions) which is comparable to other narrowband IoT networks such as LoRa. MIOTY was launched in 2020 so is a relative newcomer in the crowded IoT wireless space.

Why This Is Important

MIOTY's main differentiation from other wide-area networks is the use of an European Telecommunications Standards Institute (ETSI) standard which fragments messages into smaller packets that are transmitted at different times and frequencies and reassembled by the receiving gateway. This allows MIOTY to recreate messages even if half the packets are lost, so provides exceptional resistance to interference. MIOTY networks are very scalable with a gateway able to support thousands of nodes.

Business Impact

In 2023, MIOTY is a somewhat niche technology in terms of its ecosystem of vendors, equipment and consulting skills. It's therefore more likely to be valuable in situations where it provides a significant technical advantage over other IoT networking technologies. MIOTY can also support endpoints moving at relatively fast speeds, up to 120 kph, although this is a somewhat uncommon requirement for small IoT devices. In many situations MIOTY's main competitor is likely to be LoRa.

Drivers

- Excellent resistance to interference and operates well under poor propagation conditions.
- Low-power consumption, delivering long battery life.
- Partially standardized technology (the telegram splitting approach is standardized by ETSI, but other aspects of the protocol are not).
- Scalable to large IoT networks.
- Operates in unlicensed private spectrum, so there are no data-related fees.
- Long range, multiple kilometers (depending on conditions).

Obstacles

- Small ecosystem of products and technology vendors.
- Very limited bandwidth (512 bits/sec), so it is best suited to simple sensing applications.
- No broadcast or relay capabilities, in contrast to the most significant competitor: LoRa.
- Not an IP network beyond the MIOTY gateway so not suitable for endpoints needing IP connectivity.
- No integrated positioning and ranging features in the standard although some implementations may provide proprietary options for positioning.
- MIOTY devices need a license for some underlying technologies which attract royalty payments. The licensing process involves a third-party provider which may complicate some use cases.
- There is little clarity about the technology roadmap and evolution path compared to other more comprehensively standardized networking technologies such as Wi-Fi or 5G.

User Recommendations

- Consider MIOTY for applications needing high interference resistance, where the necessary sensors and gateways are available off-the-shelf so its technical advantages outweigh the risks of a relatively small ecosystem. Examples include mines, complex industrial facilities, or smart agriculture, applications where sensors need very long battery life.
- Favor applications with simple endpoints sending small messages that do not need high bandwidth, precise positioning, or IP connectivity.

Sample Vendors

Behr Technologies; Texas Instruments; Wittra

Gartner Recommended Reading

Important and Compelling Innovations for Commercial IoT Use Cases

2022 Strategic Roadmap for Edge (IoT) Networking

NB-IoT

Analysis By: Ankita Khilare

Benefit Rating: High

Market Penetration: 20% to 50% of target audience

Maturity: Adolescent

Definition:

Narrowband Internet of Things (NB-IoT) is a low-power wide-area network technology standard for cellular wireless communication to enable a wide range of IoT devices and services while improving system capacity, network efficiency and minimizing power consumption.

Why This Is Important

NB-IoT offers efficient low-power wireless performance for IoT applications. Extended long range and deep penetration make it ideal to use for indoor and underground connectivity, for example, underground building floors, tunnels, sewage or rural areas. It is easily deployed and integrated into cellular systems and thus it gets benefits from all the security and privacy features of mobile networks.

Business Impact

NB-IoT has many advantages and the potential to improve the efficiency of companies by offering new use cases and services. Considering the scalability and penetration capability of NB-IoT, it is effectively used in various applications such as smart metering, smart parking, precision agriculture and industrial IoT solutions. It supports applications with low data rates where radio conditions might be challenging.

Drivers

- NB-IoT being a cellular technology offers broader coverage, for example, nationwide in many places.
- It offers excellent penetration for indoor IoT and smart meters applications.
- It can support narrow bandwidth and works well with low data rates applications.
- Long battery life of up to 10 years due to low power consumption.
- Supports a massive number of device connections.
- Cost-efficient in terms of lower charges than other cellular data connections like long-term evolution (LTE).

Obstacles

- NB-IoT is not yet supported by all networks across the globe.
- Currently, NB-IoT does not have support for SMS that is used for embedded SIM (eSIM) provisioning.
- NB-IoT has fewer roaming agreements than LTE-M.
- Limitations for moving devices connectivity; best suited for stationary devices.
- It only supports messaging, with no support for voice or continuous data connections.
- Inconsistent frequencies, used by different network operators, require endpoints to support a range of bands or the use of region-specific equipment.

User Recommendations

- Identify business requirements that can match NB-IoT capabilities and supported use cases.
- Deploy NB-IoT for suitable applications such as smart meters and utilities and industrial IoT solutions, which are managed by large-scale service providers.

Sample Vendors

AT&T; Deutsche Telekom; Qualcomm Technologies; Verizon

Gartner Recommended Reading

2022 Strategic Roadmap for Edge (IoT) Networking

Critical Capabilities for Managed IoT Connectivity Services, Worldwide

Magic Quadrant for Managed IoT Connectivity Services, Worldwide

Sliding into the Trough

Long-Range Free-Space Optics

Analysis By: Nick Jones

Benefit Rating: Moderate

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Definition:

Long-range free-space optics (FSO) uses optical communications to provide very high speed, point-to-point terrestrial data links over distances up to 20 kilometers.

Why This Is Important

High-speed terrestrial wireless data links are essential for many situations that need multigigabit connectivity, when it's not practical or economic to lay fiber and when radio frequency (RF) communications aren't fast enough or require licenses. Modern free-space optics (FSO) systems have demonstrated ranges of 10 kilometers and speeds exceeding 10 Gbps — and further advances are expected. This has increased the set of FSO use cases. FSO principles can also be used over short ranges underwater.

Business Impact

FSO systems can provide very high speed, point-to-point links for varied purposes, such as campus networking and 5G backhaul. FSO can also be installed rapidly and may be less expensive than complex infrastructure works, such as laying fiber. Unlike mmWave, FSO systems do not require a license. New generations of FSO systems have longer ranges, superior resistance to disruption by weather conditions, and are physically smaller and easier to maintain and operate than their predecessors.

Drivers

- High bandwidth, which exceeds 10 Gbps in 2022, with further improvements likely to happen by 2025.
- High security and low observability compared to RF systems.
- Rapid installation.
- Optical spectrum is unlicensed, so no permits are required.

- Efficient and relatively low power consumption
- New technologies, such as dynamic tracking, allow longer range than older forms of FSO. Current systems support a few kilometers. Ranges up to 20 km are expected by 2025.

Obstacles

- Need a clear line of sight between endpoints.
- Certain weather conditions, such as thick fog or heavy rain, may disrupt links.
- Systems are proprietary, thus implying lock-in to a single vendor.
- Range is relatively short compared to alternatives, such as microwave or fiber.
- In 2023, the most innovative and best-performing systems may come from small or startup vendors.

User Recommendations

- Consider long-range FSO for point-to-point links to extend network connectivity in large-area sites, such as academic campuses, industrial locations, ports or airports.
- Use FSO links to provide connectivity across physical obstructions, such as rivers or when the geographic situation makes laying fiber difficult — for example, mountainous regions.
- Consider FSO when point-to-point links are required urgently and fiber installation would take too long.
- Consider special cases of FSO for situations when wireless is not an option — for example, underwater communications or where low observability is required.

Sample Vendors

ADVA; Aircision; Taara; Transcelestial

Gartner Recommended Reading

Emerging Tech Impact Radar: Communications

5G

Analysis By: Sylvain Fabre

Benefit Rating: High

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Definition:

5G is the fifth generation cellular technology standard by the 3rd Generation Partnership Project (3GPP). The standard targets maximum downlink and uplink throughputs of 20 Gbps and 10 Gbps, respectively. Latency is as low as 4 milliseconds in a mobile scenario and can be as low as 1 millisecond in ultra reliable low-latency communication scenarios, down to centimeter-level location accuracy indoors, and massive IoT scalability. New system architecture includes core slicing and wireless edge.

Why This Is Important

5G supports the 4th industrial revolution and IoT. Its fast and reliable real-time data transfer will benefit many industries. 5G supports eMBB, URLLC and MIoT — vital for enterprise transformation. 3GPP 5G standards releases deliver incremental functionality in: R15, extreme mobile broadband; R16, industrial IoT (massive IoT, slicing and security) — latest commercially available release; R17, MIMO enhancements, sidelink, DSS, IIoT/URLLC, bands up to 71GHz, nonterrestrial networks; and RedCap R18 is under definition with a planned freeze date in 1Q24.

Business Impact

- 5G enables three main technology deployments; each supports distinct new services for multiple industries and use cases of digital transformation, and possibly new business models (such as latency as a service). These are enhanced mobile broadband (eMBB) for HD video, mMTC for large IoT deployments, and URLLC for high-availability and very low-latency use cases, such as remote vehicle operations.
- Promising applications for 5G use include fixed wireless access, IoT support and private mobile networks.

Drivers

- Over 249 operators have rolled out 5G (see GSA), 30% of public mobile networks, and some form of 5G capability is penetrating lower cost smartphones in vendors' portfolios (with over nine versions of the technology depending on the band and the 3GPP release).
- Gartner estimates that 5G-capable handset penetration in 2025 will reach 54% worldwide, and 78% in Western Europe, with 5G-capable handset share of sales reaching 80% in 2023 in Western Europe from 51% in 2021. North America share will rise to close to 87%.
- 5G capability is starting to deliver value in emerging always-on wearables use cases.
- Increased data usage per user and device requires a more efficient infrastructure.
- Requirements from industrial users value 5G lower latency from ultra reliable and low-latency communications (URLLC) and expect 5G to outperform rivals in this area.
- Demand continues for massive machine-type communications (mMTC) to support scenarios of very dense deployments up to the 5G target of one million connected sensors per square kilometer. While diverse networks can offer adequate and cost-effective alternatives to 5G for many use cases (e.g., LPWA, NB-IoT, LoRa, Wi-SUN), overall total cost of ownership (TCO) and future proofness may not be as good.
- Availability has increased for industry-specific spectrum options (e.g., CBRS).
- Competitive pressures continue, for example, if one CSP launches 5G in the market others usually have to follow or risk losing market share — this includes both public as well as private 5G offerings.

Obstacles

- Issues with availability and cost of spectrum, in particular for industrial private networks, occur in some countries.
- Security concerns arise when using 5G in critical industrial scenarios.
- Availability and pricing of networks and modules for R16 and beyond solutions.
- Upgrade to 5G SA (stand-alone) core is needed for more advanced R16 releases (such as slicing), and commit to the continuous evolution of 5G releases over R17, R18 and beyond.
- Cost of radio network upgrades for 5G coverage and availability may require additional sites.
- Use of higher frequencies and massive capacity requires denser deployments with higher frequency reuse, which could raise network costs.
- Uncertainty exists about use cases and business models that may drive 5G for many CSPs, enterprises, and technology and service providers (TSPs).
- Feedback from some industrial clients mentioned that the majority of their use cases could be serviced by a 4G private network, Wi-Fi and/or NB-IoT, and other LPWA such as LoRa.

User Recommendations

- Enable R16 and above 5G for enterprise connectivity for mobile, nomadic and FWA secondary/tertiary use cases for branch location redundancy, as long as 5G is not the primary link for high-volume or mission-critical sites and unless there are no other options.
- Provide clear SLAs for network performance by testing installation quality for sufficient and consistent signal strength, signal-to-noise ratio, video experience, throughput and coverage for branch locations.
- Ensure backward compatibility to 4G devices and networks, so 5G devices can fall back to 4G infrastructure.
- Focus on architecture readiness — such as SDN, NFV, CSP edge computing and distributed cloud architectures, and end-to-end security — in preparation for 5G.
- Build an ecosystem of partners to target industry verticals more effectively with 5G before your competition.

Sample Vendors

Ericsson; Huawei; Mavenir; Nokia; Qualcomm; Rakuten Symphony; Samsung Electronics; ZTE

Gartner Recommended Reading

Emerging Tech: 5G mmWave at a Crossroads

Infographic: 5 Steps for Vendors to Scope and Run Successful POCs for Enterprise 5G PMNs

Invest Implications: Magic Quadrant for 5G Network Infrastructure for Communications Service Providers

Market Guide for 4G and 5G Private Mobile Networks

Quick Answer: What Vendor Product Leaders Need to Know About MWC Barcelona 2023

LEO Satellite Communication Services

Analysis By: Bill Ray

Benefit Rating: Moderate

Market Penetration: 5% to 20% of target audience

Maturity: Emerging

Definition:

Low earth orbit (LEO) satellites operate at an altitude of less than 4% of the distance compared to a traditional communication satellite. Connecting to satellites in LEO uses significantly less power, supporting low latency and faster data. However, coverage requires a large number of satellites, most of which will have a limited life span. Several companies have launched LEO services for broadband internet access, while others are focused on low-speed (and low-power) IoT connectivity.

Why This Is Important

Innovations from the smartphone industry, along with lower launch costs, make LEO constellations economically viable. The orbit makes power consumption and latency comparable to terrestrial services. As of 2Q23, Starlink is providing internet access to a million customers and OneWeb is providing global connectivity to enterprises. Other operators (including Amazon) are still working toward commercial services.

Business Impact

LEO services make broadband internet and IoT data globally available. Companies and employees can assume that internet access and IoT sensing will always be available, which would remove network access as a limit on locations to work or live. Geography will cease to be a factor in recruiting the best staff and supporting the most profitable customers. This connectivity is extending to include airplanes, ships and sea platforms, creating a ubiquitous internet (and corporate intranet).

Drivers

- LEO satellite constellations are being launched to address two distinct markets: broadband internet access and low-power IoT connectivity. These markets are being addressed by different companies using different constellations, as the requirements are quite distinct. Other customers include airlines, ships and the military.
- Satellite broadband is relatively expensive (SpaceX's Starlink charges $99 per month, plus $499 for installation) and won't compete with already installed fiber to the cabinet or home. However, we have calculated that there are enough homes without connectivity to sustain the Starlink service with reasonable penetration.
- LEO satellites can also provide backhaul for cellular services — a single satellite uplink can provide connectivity to a cell tower providing 5G, 4G, Wi-Fi or any other local access technologies. This reduces the cost of network deployment for cellular operators, extending coverage into areas that have previously been economically impossible.
- As of 2Q23, Starlink and OneWeb are both offering commercial services. But these will need to compete with offerings from Amazon's Project Kuiper network, as well as competing projects such as E-Space, SATNet and Telesat.
- The 3rd Generation Partnership Project (3GPP) is creating standards for integrating LEO services with terrestrial networks, initially for narrowband (IoT and messaging), but in recognition that supplementary coverage from space (SCS) will become an increasingly important factor in providing global connectivity.
- IoT connectivity is a different market, focusing on low cost and low power to provide global asset monitoring and tracking. While asset tracking remains the primary application, condition and environmental monitoring will also be an important use case.

Obstacles

- To provide oceanic and remote region coverage (needed by military customers), satellite-to-satellite (intraconstellation) links are required. Starlink is testing such connections, but other constellations are still at the planning stage.
- Customer equipment currently costs more than $1,000, and subscription costs will vary widely between providers.
- Maintaining 30,000 satellites, with a life of five years, requires 500 new satellites per month. Current launch vehicles, such as SpaceX's Falcon 9, can launch 60 satellites at a time. This will not be sufficient, so larger launch vehicles (such as SpaceX's Starship or Blue Origin's New Glenn) will be needed.
- Satellite operators are required to avoid interfering with incumbent deployments, limiting the radio spectrum they can use. We expect that radio spectrum access will become a key point of negotiation, and perhaps litigation, in the next five years.

User Recommendations

- Exploit the rapid development of LEO services by adding satellite connectivity into strategic workforce and business planning.
- Prepare for international availability by liaising with local regulators and resellers. LEO services are inherently global, so these will spread internationally as quickly as regulators will allow.
- Protect investment by validating the technical and financial ability of your provider to launch and maintain its constellation.
- Mitigate against requirements for proprietary equipment by planning for a reinstallation in five years, allowing for updated equipment or a change of satellite service provider.

Sample Vendors

Astrocast; Myriota; OneWeb; SpaceX

Gartner Recommended Reading

Maverick* Research: LEO Satellites Will Trigger the Revolution That 5G Has Failed to Deliver

3 World-Changing Opportunities Emerged While You Were Fighting COVID-19

5G mmWave

Analysis By: Jon Erensen

Benefit Rating: Moderate

Market Penetration: 1% to 5% of target audience

Maturity: Adolescent

Definition:

5G cellular systems in the mmWave spectrum use frequencies between 24GHz and 100GHz. These frequencies offer large swaths of contiguous spectrum, enabling wide channels capable of carrying high volumes of data/high bandwidth, but at the expense of operating distance. Even with these limitations, deployment of 5G in the mmWave spectrum can create efficiencies by offloading traffic from the sub-6GHz spectrum in congested areas, improving the performance of the entire network.

Why This Is Important

5G mmWave will be used as additional capacity to offload sub-6GHz 5G networks. The primary use case is the ability to improve mobile service and performance in high-traffic areas, including areas like stadiums/arenas, performance halls, downtown city centers, train stations/transit hubs, and indoor malls and shopping centers. Initial adoption has been limited and focused on premium smartphones, but over time, we expect use cases in addition to handsets to emerge.

Business Impact

Currently, adoption has focused on premium smartphones in the U.S. Most communications service providers (CSPs) globally are deploying 5G networks on low-band/midband spectrum, and mmWave spectrum auctions and commercial rollouts have been limited. 5G mmWave will see adoption in certain fixed applications in fixed wireless access and industrial use cases where propagation and coverage challenges associated with mmWave can be managed.

Drivers

- Adoption of 5G mmWave spectrum can improve network performance for all users in locations with high data traffic demands by offloading users from 5G sub-6GHz and 4G LTE spectrum.
- 5G mmWave provides large swaths of contiguous spectrum enabling wide channels capable of carrying high volumes of data/high bandwidth that will be needed as demand for data capacity steadily increases.
- Although limited primarily to premium models in the U.S., adoption in smartphones has attracted new entrants, in addition to market leader Qualcomm, for mmWave antenna modules. New entrants, including MediaTek and Samsung, are increasing competition and availability.
- mmWave spectrum has high reflectivity, which permits multiple radio paths for improved multiple input/multiple output (MIMO) performance.
- mmWave spectrum has high data throughput with limited interference, as this spectrum is not as crowded compared to sub-6GHz.
- 5G mmWave support is possible with extremely small individual antenna elements, simplifying the use of phased arrays or multiple points of reception/transmission.
- While propagation limitations can be seen as a challenge, they also allow for clearly defined networks in confined spaces/locations.

Obstacles

- 5G mmWave signals have significant propagation limitations as they do not penetrate walls or other solids, making non-line-of-sight applications challenging.
- Adoption in smartphones has been slower than expected as the technology remains partitioned in premium models in the U.S.
- In the U.S., wireless carriers have shifted focus to sub-6GHz deployments due to the need to improve coverage.
- Outside of the U.S., 5G mmWave spectrum auctions and commercial network rollouts have been limited.
- Costs remain high with significant bill of materials (BOM) additions for needed components and for infrastructure, which requires a dense deployment of access points.
- The radio frequency (RF) front end for 5G mmWave, including antenna arrays, is technically challenging.
- Although 5G mmWave will enable performance improvement to existing applications, it will not significantly change existing products' capabilities.
- Applications that make use of the additional bandwidth available with mmWave have been slow to develop.

User Recommendations

- Prioritize adoption of 5G sub-6 GHz, and limit support for mmWave to premium smartphones in specific regions until CSPs provide incentives or differentiating applications emerge that require 5G mmWave frequencies.
- Adjust product roadmaps with the potential to benefit from this technology by factoring in delays in overall mmWave adoption and preparing for higher sustained mmWave component pricing.
- Consider mmWave when applications or services require high-bandwidth uplink.
- Focus mmWave deployments on improvements from a uniform performance perspective rather than highlighting peak speeds.
- Improve adoption and deployment of 5G mmWave by monetizing the technology through differentiating user experiences, including more immersive content or improved user experiences and consistent, reliable download and upload performance in video and social media.
- Consider 5G mmWave for adoption in certain fixed applications, including fixed wireless access (FWA), where it can be easier to address some of the propagation and coverage challenges.

Sample Vendors

Apple; Huawei; MediaTek; OPPO; Qualcomm; Samsung Electronics; Verizon; vivo; Xiaomi; ZTE

Gartner Recommended Reading

Emerging Tech: 5G mmWave at a Crossroads

Emerging Technologies: Emergence Cycle for mmWave 5G

Market Trends: 5G mmWave Stalls in Smartphones

Emerging Technology Horizon for Semiconductors and Electronics, 2022

Market Trends: Progress in Critical Chip Manufacturing Technologies for mmWave 5G Deployment

Wi-Fi 6E

Analysis By: Tim Zimmerman

Benefit Rating: Moderate

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Definition:

Wi-Fi 6E is a certification extension of the existing Wi-Fi 6 standard to 6GHz. It is not based on IEEE standards, since IEEE 802.11ax is only defined for 2.4GHz and 5GHz. Wi-Fi 6E is a Wi-Fi Alliance certification that standardizes the use of the IEEE 802.11ax in the 6GHz spectrum — that is, from 5.925GHz to 7.125GHz.

Why This Is Important

The additional spectrum will provide more options for devices that need high performance. A single 160MHz channel supports 1.2 Gbps. Further, the 6GHz spectrum supports up to seven 160GHz channels, in addition to operations at 2.4GHz and 5GHz. If enterprises are experiencing congestion issues at 2.4GHz or 5GHz, 6GHz may be an option wherever permitted by regulators.

Business Impact

Wi-Fi 6E represents an opportunity to significantly improve performance. This is especially important for use cases such as dense device deployment for applications that may require three or four times the current performance. The addition of new high bandwidth applications such as virtual reality and media streams will contribute to congestion in the 2.4GHz and 5GHz spectrums and expand the need for the 6GHz spectrum.

Drivers

- **Higher performance and low latency:** Use cases such as dense device deployment require higher speeds than are supported by Wi-Fi 6. Also, new applications such as real-time robotic control and virtual reality create a greater need for low latency.
- **The ability to separate clients into different radio streams within a single frequency:** This enables an access point that can support multiple users and multiple user streams.
- **Frequency congestion:** Limited international availability of frequencies within the 2.4GHz and 5GHz bands means that the additional 6GHz band can provide deployment flexibility.

Obstacles

- **No compliance with IEEE standards:** The biggest issue with Wi-Fi 6E is that it is not standards-based. There is no guarantee of compatibility with IEEE 802.11be (Wi-Fi 7), the standards-based 6GHz solution that is expected to be ratified in 2024.
- **Regional variance:** Some countries are permitting the use of the whole band, while others are limiting the access to half the band. Therefore, the equipment requires regional variation or, at least, configuration. Most regions limit the use to indoors and to low power, so observance is also required.
- **Surplus performance:** Wi-Fi 6 theoretically provides performance up to 10 Gbps in a single coverage area that connects to end users. However, Wi-Fi 6E will provide more than 10 Gbps, far exceeding the needs of applications in a single coverage area. A 4K video stream requires only 10 Mbps to 12 Mbps.
- **Lack of end-user devices:** There are currently limited end-user devices with 6GHz capabilities. The lack of capable devices and differing global regulatory issues will slow down adoption.

User Recommendations

- Do not pay a premium for any implementation of Wi-Fi 6E.
- Require vendors to upgrade or update their offerings to be standards-compliant (Wi-Fi 7) at no cost when purchasing a product that has the Wi-Fi 6E certification.
- Be aware of the end-of-life status of access points. Silicon vendors will limit the production of previous versions of radio chips, which will cause vendors to shorten the availability of some models and offer only newer ones.

Sample Vendors

Arista Networks; Cisco Systems; Extreme Networks; Hewlett Packard Enterprise (HPE); Huawei; Juniper Networks

Gartner Recommended Reading

Magic Quadrant for Enterprise Wired and Wireless LAN Infrastructure

Critical Capabilities for Enterprise Wired and Wireless LAN Infrastructure

Next-Gen Campus Connectivity Must Start by Defining the End-User Experience

Will 5G Replace Wi-Fi?

Li-Fi

Analysis By: Nick Jones

Benefit Rating: Low

Market Penetration: 5% to 20% of target audience

Maturity: Early mainstream

Definition:

Li-Fi is a wireless networking technology that communicates using unfocused light and is typically used for local-area networking as an alternative to Wi-Fi or for short-range point-to-point links. Some Li-Fi systems are integrated with smart lighting units, using the same light source for illumination and communication.

Why This Is Important

Li-Fi is somewhat niche but has value in applications requiring low observability, resistance to jamming or when conventional wireless technologies are not viable (e.g., underwater). Li-Fi is also theoretically capable of delivering data rates as fast as 100GB/sec, although most current products don't approach this performance. A few companies have integrated Li-Fi into LED lighting products.

Business Impact

Organizations needing high security and very low observability may consider Li-Fi because, unlike radio frequencies (RFs), optical signals are blocked by walls or even curtains. For example it has been reported that the U.S. Army is conducting Li-Fi trials for forward operating bases where Wi-Fi emissions could expose the location of soldiers. Li-Fi may also be useful when RF technology is impractical (e.g., for safety reasons, or in environments with very high electromagnetic interference).

Drivers

- Very low observability and very difficult to jam.
- No radio spectrum license requirements or limitations.
- High bandwidth (at least in some implementations).
- Safe in hazardous environments where RF emissions might not be permitted.
- Synergy with smart lighting, as the same LED unit can be used for both data and illumination.
- Partially standardized, the Institute of Electrical and Electronics Engineers 802.11bb standard supports optical bearer technology.
- Optical spectrum is uncongested, compared to the radio spectrum.
- More secure than Wi-Fi, under some conditions.
- Support for special use cases, such as underwater networking.

Obstacles

- Very niche technology with a very small vendor ecosystem.
- Rarely integrated into enterprise or consumer equipment, such as PCs, smartphones or IoT devices, and so requires inconvenient and expensive external “dongles.”
- Expensive endpoint adapters and infrastructure access points compared to commodity networking technologies, such as Wi-Fi.
- Needs an optical path between transmitter and receiver, so it can’t operate when equipment is obscured, for example, in pockets, bags.
- In most practical situations with off-the-shelf equipment, there is little or no performance advantage over more mainstream technologies, such as 5G and Wi-Fi.
- Unclear roadmap compared to technologies such as Wi-Fi, cellular, and Bluetooth, which have a very open standards development process.
- Restricted coverage compared to radio signals that can pass through walls, so adopters incur the cost for access technology in each room to be covered.

User Recommendations

- Do not plan for Li-Fi to significantly replace mainstream radio frequency networking technologies, such as 5G or Wi-Fi, which will be more convenient, more capable and less expensive for most purposes.
- Consider Li-Fi for specific situations in which its special characteristics are valuable (e.g., low observability or situations when RF might cause a safety hazard or be affected by electrical interference).
- If you decide to deploy Li-Fi, investigate integration with smart lighting systems to reduce cost.

Sample Vendors

Oledcomm; pureLiFi; Signify; VLNComm

Gartner Recommended Reading

Magic Quadrant for Enterprise Wired and Wireless LAN Infrastructure

Top Strategic Technology Trends for 2023: Wireless Value Realization

Climbing the Slope

Bluetooth AOA/AOD

Analysis By: Nick Jones

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Early mainstream

Definition:

Bluetooth angle of arrival (AOA) and angle of departure (AOD) is a technology to measure the location of Bluetooth-equipped objects. It senses the direction of the incoming and/or outgoing signals allowing a position to be calculated using triangulation and two or more reference points. AOA/AOD can also be combined with Bluetooth distance measurement technologies to deduce location using only one fixed reference point.

Why This Is Important

Bluetooth AOA/AOD can track objects over large areas such as factories, conference centers, construction sites, sports areas or office buildings. Bluetooth AOA/AOD technology can also be used for micro location, i.e., tracking objects over small areas such as a few square meters to higher levels of precision, e.g., around 1 cm.

Business Impact

Virtually any business process can be enhanced by knowing the location of participating people or objects in real time. For example, supporting goals such as theft reduction, improving equipment utilization, process optimization, asset management, social distancing, and geofencing for health and safety purposes. Bluetooth can track a wide range of people and objects and can often exploit existing infrastructure to reduce cost.

Drivers

- Bluetooth is a well-standardized mainstream technology which is widely available.
- Supports real-time low-latency tracking, e.g., of sports players or moving employees.
- Synergy with technologies such as power harvesting to provide battery-free tags.
- Synergy with future Bluetooth high-precision ranging will allow location tracking using only one fixed reference point.

- Good precision, around 20 cm over large areas (depending on the implementation).
- Small incremental cost on items to be tracked; Bluetooth tags are inexpensive.
- Synergy with sensing and active objects. Bluetooth provides a way for tracked items to report sensor information such as temperature, and for information to be sent to objects such as smart labels.
- Bluetooth is already integrated in many items that might need to be tracked, e.g., smartphones.

Obstacles

- Tracking infrastructure for large areas can be complex and expensive, typically requiring specialized antennae surrounding the area to be covered and supported by on-premises or cloud services to calculate the location.
- Although the basic electronics is covered by the Bluetooth standard, the tracking infrastructure and services are typically proprietary and require commitment to a single vendor.
- Bluetooth devices are active and so the items to be tracked need a power source which can increase size and cost in some situations. Tags that use batteries incur significant labor costs when they must be replaced.
- Many competing wireless technologies can track items including Wi-Fi and RFID, some may be less expensive or perform better in certain situations.

User Recommendations

- Consider Bluetooth tracking based on AOA/AOD for applications that need high-precision real-time tracking and possibly sensing at relatively low cost per item.
- Consider alternative tracking technologies when the infrastructure cost and complexity is prohibitive or when fine grained high precision coverage is not essential.
- Look for innovation opportunities involving microlocation, e.g., tracking the way tools are used during an assembly process.

Sample Vendors

Airista; Blueiot; Nordic Semiconductor; NXP; Quuppa

Gartner Recommended Reading

Architecting for Location

Magic Quadrant for Indoor Location Services

Bluetooth Low Energy

Analysis By: Nick Jones

Benefit Rating: High

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Definition:

Bluetooth low energy (BLE) is a member of the Bluetooth family of wireless protocols that support point-to-point, broadcast and mesh architectures. BLE is optimized for applications that require long battery life but not high bandwidth. It's used in a wide range of Bluetooth devices, including wearables, sensors, fitness equipment, beacons, smart lighting and IT peripherals such as keyboards.

Why This Is Important

BLE is widely supported in stand-alone equipment and more complex devices, such as PCs and smartphones. Devices featuring BLE alone, which omit the classic Bluetooth protocol, are one of the fastest-growing segments in the Bluetooth market due to the rapid growth in low-cost, battery-powered equipment, such as sensors. BLE standards will be extended by 2024 to support new and less congested frequency bands and high data throughput (HDT).

Business Impact

BLE is a key consumer and enterprise technology used in a wide range of devices and applications. Its low power consumption enables battery-free devices, such as tags and sensors, to use technologies like power harvesting. BLE is a fundamental technology underlying other Bluetooth capabilities, including new shelf-edge labeling standards. New frequency bands and higher bandwidth will deliver improved performance in various situations.

Drivers

- Very widely adopted standard supported by billions of devices.
- BLE-based features provide better performance than classic Bluetooth features — and so will replace them.
- BLE hardware is very low cost — under $1 per chip in some cases.
- Bluetooth equipment is interoperable with a wide range of IT devices, such as smartphones, tablets and PCs.
- Low-power consumption and low cost is driving innovation in areas like tagging and ambient sensing.
- Due to BLE audio protocols improved performance and new features, some classic Bluetooth audio technologies will be replaced.
- Strong ecosystem of products and vendors.
- New use cases, such as slow-speed video and firmware updates, will be enabled by the planned bandwidth enhancements.
- Support for new frequency bands will improve performance by enabling Bluetooth to operate in a less-congested spectrum.

Obstacles

- New frequency bands and HDT will demand new chips and won't be available on legacy devices. Some equipment may have to be replaced.
- Relatively low bandwidth, even the new high-data rate standard, is likely to raise speeds to only around 8 Mbps.
- Relatively short range depends on the equipment and modulation schemes in use. However, most applications don't exceed 100M, and for energy-constrained systems the figure can be much lower — for example, 10M.
- Other wireless technologies, such as backscatter systems, may offer even lower power consumption in special cases.

User Recommendations

- When retiring products using classic Bluetooth, ensure their replacements support BLE to have better performance and battery life.
- Specify BLE on equipment must communicate with mainstream IT devices, such as PCs, tablets and smartphones.
- Favor BLE over less common protocols unless those have significant technical advantages.
- Specify equipment capable of handling the new BLE frequency and bandwidth extensions as soon as they become commercially available. Doing so will maximize performance and interoperability with future device purchases.

Sample Vendors

MediaTek; Nordic Semiconductor; Qorvo; Qualcomm

Gartner Recommended Reading

Forecast: Wireless Semiconductors, Worldwide, 2020-2026, 3Q22 Update

LoRa

Analysis By: Nick Jones, Ankita Khilare

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Early mainstream

Definition:

LoRa is a low-power wide-area (LPWA) network providing long-range Internet of Things (IoT) connectivity. It is intended for applications needing low bandwidth and a long battery life. It comes in two variants — LoRa, which is used for private networks, and LoRaWAN, which adds a layer that supports interoperability and roaming, and is used by operator-run networks.

Why This Is Important

LoRa is the leading noncellular LPWA network technology. It is very power-efficient and in some situations, it can offer a battery life of 10 years. Terrestrial LoRa operates in an unlicensed spectrum at sub-1GHz or 2.4GHz. Some LoRa devices can communicate directly with low Earth orbit (LEO) satellites. LoRa is a very flexible LPWAN which provides three operating modes to offer different trade-offs between performance, latency and battery life.

Business Impact

LoRa provides connectivity for a wide range of low-bandwidth IoT applications in domains like agriculture, energy management, smart cities/buildings, pollution control, logistics and utilities. Private LoRa networks can be set up at low cost without needing spectrum licenses or a telecom operator. LoRa endpoint and gateway hardware is much less expensive than comparable cellular hardware, so better suited to cost-sensitive applications. Satellite LoRaWAN extends coverage to remote areas with no public network operator.

Drivers

- LoRa is a well-established technology that has been proven in a wide range of applications.
- There is a strong ecosystem of vendors supplying equipment and services.
- LoRa uses a license-free public spectrum; license fees are not required.
- The LoRa technology is managed by a nonprofit consortium called the LoRa Alliance, which is responsible for evolving the specification, and for administering certification schemes.
- The needed cost investment is low (compared to cellular systems) for both endpoints and network infrastructure.
- LoRa has been optimized to operate in low-power mode and to provide deep indoor coverage.
- Its transmission range is up to 10 km based on the environment.
- Individual organizations can set up private LoRa networks.
- LoRaWAN supports roaming between operators.
- LoRa has a high capacity in terms of the number of messages supported.
- Many countries have public LoRaWAN networks although coverage may be incomplete.
- LoRa is a key technology used in Amazon's Sidewalk community network which in 1Q23 covered 90% of the U.S. population. Sidewalk has recently been opened up to third-party developers.
- A new relay mode announced in 2022 will provide a low-cost way to improve coverage in challenging situations, such as sensors in metal shipping containers.

Obstacles

- Global availability of public LoRaWAN networks is inferior to cellular IoT coverage. Not all countries have LoRaWAN networks and the networks that exist may not provide nationwide coverage.
- LoRa operates in an unlicensed and unregulated spectrum, leading to interference or congestion issues in some regions.
- LoRa is not a formal international standard like IEEE 802.11 or 5G; although it is managed by an open consortium — the LoRa Alliance.
- International scaling may be difficult in some cases because the unlicensed bands LoRa uses can differ between countries.
- Its low bandwidth may not be suitable for applications with large firmware updates or transmission of large data payloads, such as audio or video.
- LoRa networks have a relatively high latency, it can be seconds in some situations.
- They may require relatively large numbers of base stations to support dense deployments of devices, for example in smart cities.
- Satellite LoRa is an immature and unproven technology.

User Recommendations

- Implement private LoRa networks for low-cost, low-bandwidth IoT applications using battery-powered devices.
- Design in LoRaWAN for low-bandwidth IoT products and services where public networks are available.
- Consider Amazon's LoRa-based Sidewalk network for applications needing low-bandwidth connectivity to be deployed in the USA.

Sample Vendors

Actility; Amazon; Kerlink; Lacuna Space; LoRa Alliance; Microchip Technology; NTT DATA; Telensa; Senet; STMicroelectronics

Gartner Recommended Reading

2022 Strategic Roadmap for Edge (IoT) Networking

Emerging Technologies: Connectivity Technologies for Enabling Smart Home

Top Strategic Technology Trends for 2023: Wireless Value Realization

Entering the Plateau

Bluetooth Classic

Analysis By: Nick Jones

Benefit Rating: Moderate

Market Penetration: 20% to 50% of target audience

Maturity: Mature mainstream

Definition:

Bluetooth Classic is the original Bluetooth protocol designed to support audio streaming and a range of data transfer tasks. Many of its functional profiles have been superseded by more recent elements of the Bluetooth standard, such as Bluetooth low energy (LE) and LE audio. The use of the Classic protocols is declining but most Bluetooth devices will continue to support them for compatibility reasons.

Why This Is Important

Although use of the Bluetooth “classic” protocol is fading, it will be supported by a very large number of devices for compatibility reasons — for example, the Bluetooth SIG estimates that approximately 4 billion devices supporting the classic protocol will be shipped in 2023. Support for the classic protocol will be required on devices such as PCs, smartphones and tablets for some time to come.

Business Impact

Bluetooth Classic will primarily be used for audio and telephony connections, especially involving older audio devices such as headsets and speakers. Newer audio devices are likely to support the more modern LE audio protocols. Other classic profiles that may be required for compatibility with some older devices include phone book access and remote control. Most “large” devices such as PCs, smartphones and tablets will support dual-mode Bluetooth, including both classic and LE protocols.

Drivers

- Needed on devices that may require compatibility with older equipment using the Bluetooth classic audio protocol. For example, audio streaming devices such as headsets and speakers.

- Needed on devices such as smartphones that may have to interoperate with long-lived equipment which supports only the classic Bluetooth profiles, for example older vehicles.

Obstacles

- Bluetooth's innovation focus has shifted to the newer Bluetooth LE protocol, most new features are based on Bluetooth LE rather than Bluetooth classic and many have no equivalents in the classic protocol.
- Bluetooth classic protocols may provide inferior performance and power consumption for some applications.
- Bluetooth classic protocols demand device pairing, which can be inconvenient for users in some situations and is not required for all Bluetooth LE use cases.

User Recommendations

- Ensure that devices, such as PCs, tablets and smartphones that will need to interoperate with a range of Bluetooth equipment of varying ages support the classic Bluetooth protocol.
- When buying long-lived Bluetooth equipment, favor products using LE protocols or dual mode rather than just classic protocols.

Appendixes

Hype Cycle Phases, Benefit Ratings and Maturity Levels

Table 2: Hype Cycle Phases

(Enlarged table in Appendix)

Phase ↓	Definition ↓
Innovation Trigger	A breakthrough, public demonstration, product launch or other event generates significant media and industry interest.
Peak of Inflated Expectations	During this phase of overenthusiasm and unrealistic projections, a flurry of well-publicized activity by technology leaders results in some successes, but more failures, as the innovation is pushed to its limits. The only enterprises making money are conference organizers and content publishers.
Trough of Disillusionment	Because the innovation does not live up to its overinflated expectations, it rapidly becomes unfashionable. Media interest wanes, except for a few cautionary tales.
Slope of Enlightenment	Focused experimentation and solid hard work by an increasingly diverse range of organizations lead to a true understanding of the innovation's applicability, risks and benefits. Commercial off-the-shelf methodologies and tools ease the development process.
Plateau of Productivity	The real-world benefits of the innovation are demonstrated and accepted. Tools and methodologies are increasingly stable as they enter their second and third generations. Growing numbers of organizations feel comfortable with the reduced level of risk; the rapid growth phase of adoption begins. Approximately 20% of the technology's target audience has adopted or is adopting the technology as it enters this phase.
Years to Mainstream Adoption	The time required for the innovation to reach the Plateau of Productivity.

Source: Gartner (July 2023)

Table 3: Benefit Ratings

Benefit Rating ↓	*Definition* ↓
Transformational	Enables new ways of doing business across industries that will result in major shifts in industry dynamics
High	Enables new ways of performing horizontal or vertical processes that will result in significantly increased revenue or cost savings for an enterprise
Moderate	Provides incremental improvements to established processes that will result in increased revenue or cost savings for an enterprise
Low	Slightly improves processes (for example, improved user experience) that will be difficult to translate into increased revenue or cost savings

Source: Gartner (July 2023)

Table 4: Maturity Levels

(Enlarged table in Appendix)

Maturity Levels ↓	*Status* ↓	*Products/Vendors* ↓
Embryonic	In labs	None
Emerging	Commercialization by vendors Pilots and deployments by industry leaders	First generation High price Much customization
Adolescent	Maturing technology capabilities and process understanding Uptake beyond early adopters	Second generation Less customization
Early mainstream	Proven technology Vendors, technology and adoption rapidly evolving	Third generation More out-of-box methodologies
Mature mainstream	Robust technology Not much evolution in vendors or technology	Several dominant vendors
Legacy	Not appropriate for new developments Cost of migration constrains replacement	Maintenance revenue focus
Obsolete	Rarely used	Used/resale market only

Source: Gartner (July 2023)

Recommended by the Author

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Understanding Gartner's Hype Cycles

Tool: Create Your Own Hype Cycle With Gartner's Hype Cycle Builder

LEO Satellites Will Be an Essential Part of Your Future Networking Strategy

A CTO's Guide to 5G-Advanced and 6G

Top Strategic Technology Trends for 2023: Wireless Value Realization

Magic Quadrant for Enterprise Wired and Wireless LAN Infrastructure

Innovation Insight: Free Radio Spectrum Is Changing How Technology Companies Communicate

Table 1: Priority Matrix for Wireless Technologies, 2023

Benefit ↓	*Years to Mainstream Adoption*			
	Less Than 2 Years ↓	***2 - 5 Years*** ↓	***5 - 10 Years*** ↓	***More Than 10 Years*** ↓
Transformational		Bluetooth Ambient IoT	High-Precision Positioning (802.11az)	
High		5G Bluetooth AOA/AOD Bluetooth ESL Bluetooth Low Energy LoRa LTE-M NB-IoT Optical Satellite Connectivity	5G-Advanced 5G Release 19 Backscatter Networking Community Networks NR-RedCap Private 5G Terrestrial Steerable Optical Links	6G

Benefit	*Years to Mainstream Adoption*			
↓	***Less Than 2 Years*** ↓	***2 - 5 Years*** ↓	***5 - 10 Years*** ↓	***More Than 10 Years*** ↓
Moderate	Bluetooth Classic Wi-Fi 6E	5G mmWave 802.11bc Bluetooth Auracast Bluetooth High Accuracy Distance Measurement LEO Satellite Communication Services LEO Satellite IoT MIOTY Sidewalk Ultrawideband Wi-Fi 7 (802.11be)	Long-Range Free-Space Optics Wi-Fi 8 (802.11bn) WLAN Sensing (802.11bf)	Terahertz Wireless
Low			Li-Fi	

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