Exploring

Bluetooth 5

Teledyne LeCroy Frontline Overview

Frontline Joins Teledyne Technologies

Charlottesville, Virginia, USA – April 7, 2016 – Frontline Test Equipment, Inc. the worldwide leader in Bluetooth® protocol analyzers and testing services is excited to announce that they have been acquired by Teledyne LeCroy, Inc., the worldwide leader in protocol test solutions, expanding their family of protocol analysis solutions to include the best *Bluetooth* protocol analysis on the market, as well as a host of analysis tools for other wireless and wired "Internet of Things" (IoT) technologies…

http://teledynelecroy.com/pressreleases/document.aspx?news_id=1956&capid=107&mid=554

Teledyne LeCroy Frontline - The *Bluetooth* Experts

- 30+ years of protocol analysis experience
- Involved with *Bluetooth* wireless technology initiatives from the beginning (~13 years)
- Work closely with the *Bluetooth* SIG – specifications, working groups, technology committees
- Frontline products support every *Bluetooth* specification, profile and protocol

"…accelerate our partners' time to market, increase their product quality and ensure a superior end user experience for their customers, through our products, services, and consulting."

Your competition probably uses Frontline products and services…

FORTUNE® 100

- 10 out of the top 10 of the Fortune 100 are Frontline customers.
- 21 of the 25 biggest tech firms on the Fortune 100 are Frontline customers.
- 9 of the top 10 Auto Manufacturers worldwide are Frontline customers.

Teledyne LeCroy Frontline – Products and Services

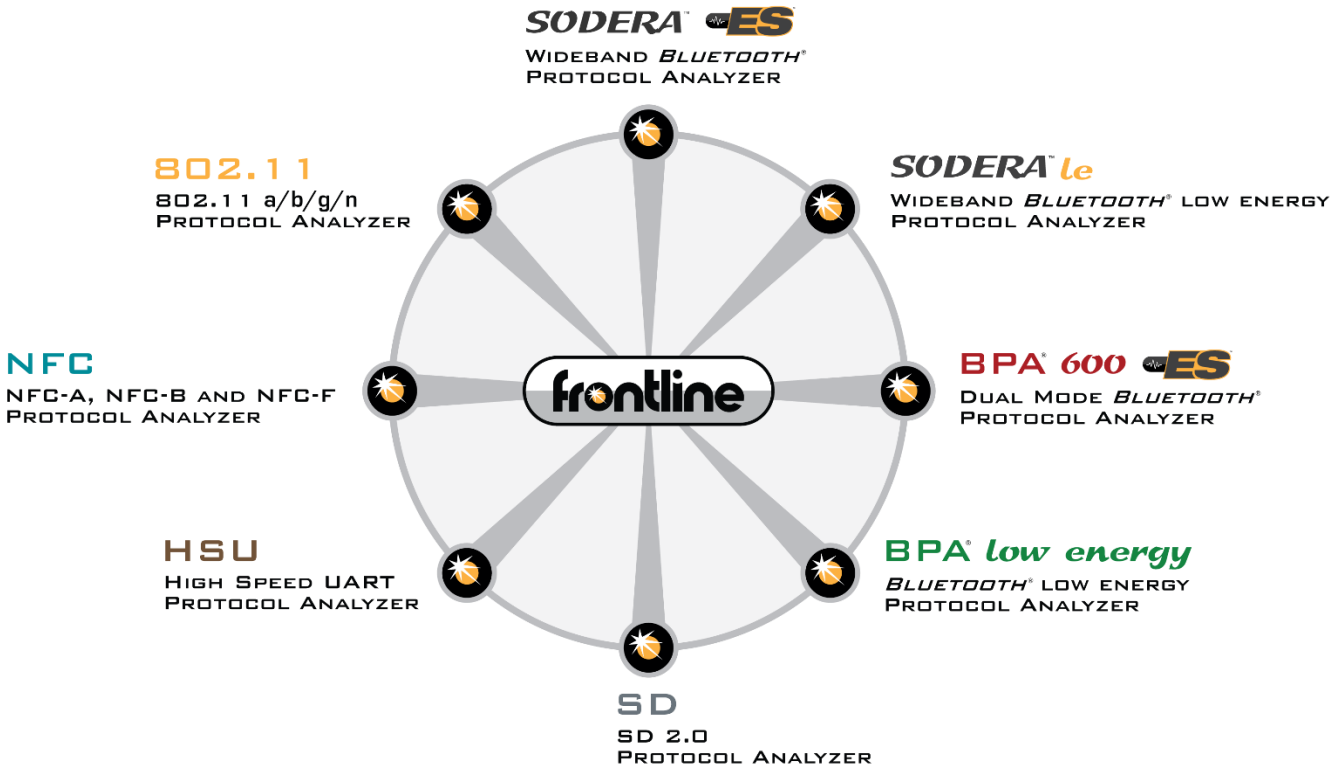
Services

- Interoperability
  - Bluetooth
  - WiFi
  - NFC
- Validation
- Benchmark testing

Products

- *Bluetooth*
- NFC
- 802.11
- SDIO
- HSU
- Industrial Protocols

Frontline Developer Products



One-Click Sniffing

- Capture all *Bluetooth* wireless channels concurrently:
  - Bluetooth Classic (BR/EDR)
  - low energy traffic
  - Bluetooth 5

Excursion Mode

- capture *Bluetooth* traffic with *no PC attached*

Coexistence View with Sodera

2.4 GHz Spectrum Analysis

See RF spectrum data shown within the "Coexistence View" – all RF energy resulting from *Bluetooth*, Wi-Fi, or other technologies as detected by the Frontline Sodera Wideband *Bluetooth* Protocol Analyzer!

802.11 Coexistence

Capture *Bluetooth* and Wi-Fi data together – including decryption, decoding, synchronization, and analysis of packets. Combine the Frontline Sodera analyzer with Frontline 802.11 analyzer together for full protocol synchronization.

Bluetooth Wireless Technology

Introduction and Overview

Bluetooth Short History

Bluetooth Classic:

Also know as Basic Rate/Enhanced Data rate (BR/EDR)

It is possible to have a Classic Only Bluetooth chip
(V2.0/EDR, V2.1, V4.0,V4.1)

Bluetooth low energy:

Sometimes also referred to as Bluetooth V4.0

It is possible to have a low energy Only Bluetooth chip
(V4.0,V4.1)

It is also possible to have a Dual mode Chip
(supports Classic + low energy)

Bluetooth 5:

This includes above specifications (Classic and low energy) Plus new specification features.

Bluetooth Specification Roadmap 2003 - 2017

Rev	Date	Comments
3.0 + HS	April 21 2009	• New features added in 3.0 + HS: -AMP Manager Protocol (A2MP) -Enhancements to L2CAP for AMP -Enhancements to HCI for AMP -Enhancements to Security for AMP -802.11 Protocol Adaptation Layer • Enhanced Power Control -Unicast Connectionless Data -HCI Read Encryption Key Size command -Generic Test Methodology for AMP -Enhanced USB and SDIO HCI Transports • Errata for v 2.0 + EDR and v2.1 + EDR
v2.1 + EDR	July 26 2007	• New features added in 2.1 + EDR: -Encryption Pause and Resume -Erroneous Data Reporting -Extended Inquiry Response -Link Supervision Timeout Changed Event -Non-Flushable Packet Boundary Flag -Secure Simple Pairing -Sniff Subrating -Security Mode 4 • Updates to IEEE language in Volume 2, Part H, Security • Errata for v2.0 + EDR
v2.0 + EDR	Aug 01 2004	This version of the specification is intended to be a separate Bluetooth Specification. This specification was created by adding EDR and the errata.
v1.2	Nov 05 2003	New features added in v1.2: - Architectural overview - Faster connection - Adaptive frequency hopping - Extended SCO links - Enhanced error detection and flow control - Enhanced synchronization capability - Enhanced flow specification The Core System Package now comprises two volumes and the text has gone through a radical change both in terms of structure and nomenclature. The language is also more precise and is adapted to meet the IEEE standard. The following parts are moved from the Core System Package to other volumes or were deprecated: RFCOMM [vol 7], Object Exchange (IrDA Interoperability) [vol 8], TCS [vol 9], Interoperability Requirements for Bluetooth as a WAP Bearer [vol 6], HCI USB Transport Layer [vol4], HCI RS232 Transport Layer [vol 4], HCI UART Transport Layer [vol 4], Bluetooth Compliance Requirements [vol 0], Optional Paging Schemes [deprecated]

Rev	Date	Comments
5.0	Dec 06 2016	• New features added in 5.0: - CSA 5 features (Higher Output Power) - Slot Availability Mask (SAM) - 2 Msym/s PHY for LE - LE Long Range - High Duty Cycle Non-Connectable Advertising - LE Advertising Extensions - LE Channel Selection Algorithm #2 • Park State was deprecated and removed • Errata for v2.0 + EDR, v2.1 + EDR, v3.0 + HS + 4.0 + 4.1 + 4.2 (ESR09, ESR10 and ESR11). See also [Vol 1] Part C, Section 9.4.
4.2	Dec 02 2014	• New features added in 4.2: - LE Data Packet Length Extension - LE Secure Connections - Link Layer Privacy - Link Layer Extended Scanner Filter Policies • Errata for v2.0 + EDR, v2.1 + EDR, v3.0 + HS + 4.0 + 4.1 (ESR08). See also [Vol 1] Part C, Section 8.2.
4.1	Dec 03 2013	• New features added and changes made in 4.1: - CSA 2 features - CSA 3 features - CSA 4 features - Secure Connections - Train Nudging & Generalized Interlaced Scan - Low Duty Cycle Directed Advertising - 32-bit UUID Support in LE - LE Dual Mode Topology - Piconet Clock Adjustment - Removal of At Least One New Feature - LE L2CAP Connection Oriented Channel Support - LE Privacy v1.1 - LE Link Layer Topology - LE Ping • Errata for v2.0 + EDR, v2.1 + EDR, v3.0 + HS + 4.0 (ESR05, ESR06 and ESR07)
4.0	June 30 2010	• New features added in 4.0: -Low Energy • Errata for v2.0 + EDR, v2.1 + EDR, v3.0 + HS

Core System Architecture

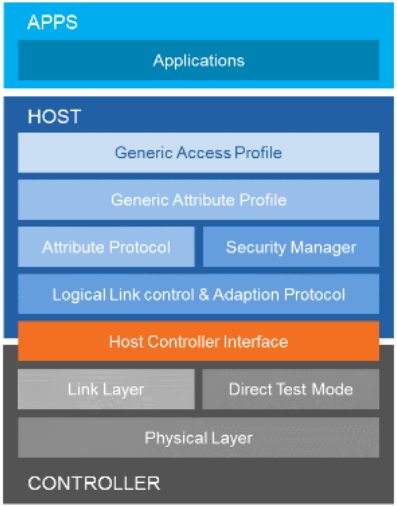
Physical (PHY) Layer
Controls transmission/receiving of the 2.4Ghz radio with Bluetooth communication channels. BR/EDR provides more channels with narrower bandwidth, while LE uses fewer channels but broader bandwidth.

Link Layer
Defines packet structure/channels, discovery/connection procedure and sends/receives data.

Direct Test Mode
Allows testers to instruct the PHY layer to transmit or receive a given sequence of packets, submitting commands to it either via the HCI or via a 2-wire UART interface.

Host to Controller Interface (HCI)
Optional standard interface between the Bluetooth controller subsystem (bottom three layers) and the Bluetooth host.

Logical Link Control and Adaptation Protocol (L2CAP) Layer
A packet-based protocol that transmits packets to the HCI or directly to the Link Manager in a hostless system. Supports higher-level protocol multiplexing, packet segmentation and reassembly, and the conveying of quality of service information to higher layers.



Core System Architecture

Attribute Protocol (ATT)

Defines the client/server protocol for data exchange once a connection is established. Attributes are grouped together into meaningful services using the Generic Attribute Profile (GATT). ATT is used in LE implementations and occasionally in BR/EDR implementations.

Security Manager

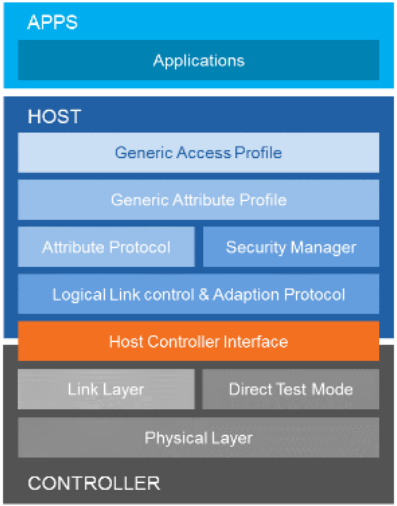
Defines the protocol and behavior that manages pairing integrity, authentication and encryption between Bluetooth devices, and provides a toolbox of security functions that other components use to support almost any level of security needed by diverse applications.

Generic Attribute Profile (GATT)

Using the Attribute Protocol, GATT groups services that encapsulate the behavior of part of a device and describes a use case, roles and general behaviors based on the GATT functionality. Its service framework defines procedures and formats of services and their characteristics, including discovering, reading, writing, notifying and indicating characteristics, as well as configuring the broadcast of characteristics. GATT is used only in Bluetooth LE implementations.

Generic Access Profile (GAP)

Works in conjunction with GATT in Bluetooth LE implementations to define the procedures and roles related to the discovery of Bluetooth devices and sharing information, and link management aspects of connecting to Bluetooth devices.



Transmitter Characteristics: Bluetooth 5 specification.

Bluetooth Devices may be Classified into Power Classes
(see below) based on the Max Power O/P the LE PHY supports.

Power Class	Maximum Output Power (P_{max})	Minimum Output Power[1]
1	100 mW (+20 dBm)	10 mW (+10 dBm) NEW
1.5	10 mW (+10 dBm)	0.01 mW (-20 dBm)
2	2.5 mW (+4 dBm)	0.01 mW (-20 dBm)
3	1 mW (0 dBm)	0.01 mW (-20 dBm)

Minimum Output Power	Maximum Output Power
0.01 mW (-20 dBm)	100 mW (+20 dBm)

Note: the Max O/P Power for LE V4.0, 4.1, 4.2 is 10mW (+10dBm)

- Using High Tx power within close proximity between devices can result in Rx saturation and connection link loss.
- Using 2 or more Power levels can ensure low Tx Power for short range use cases and avoid Rx saturation and possibly link loss.

LE Physical layer (PHYs)

PHY	Modulation scheme	Coding scheme		Data rate
		Access Header	Payload	
LE 1M	1 Msym/s modulation	Uncoded	Uncoded	1 Mb/s
LE 2M	2 Msym/s modulation	Uncoded	Uncoded	2 Mb/s
LE Coded	1 Msym/s modulation	S=8	S=8	125 kb/s
			S=2	500 kb/s

Table 3.1: Summary of PHYs, modulation schemes, and coding schemes

- 1 Msym/s* Modulation is mandatory and supports Two PHYs.

(1) LE 1M Un-coded data rate of: 1 Mb/s

(2) LE Coded (Optional, supports Error Correction coding)

S2 Coding = 2 Msyms / sec = 500Kb/s

S8 Coding = 8 Msyms/ sec = 125Kb/s

- 2 Msym/s* Modulation supports One PHY

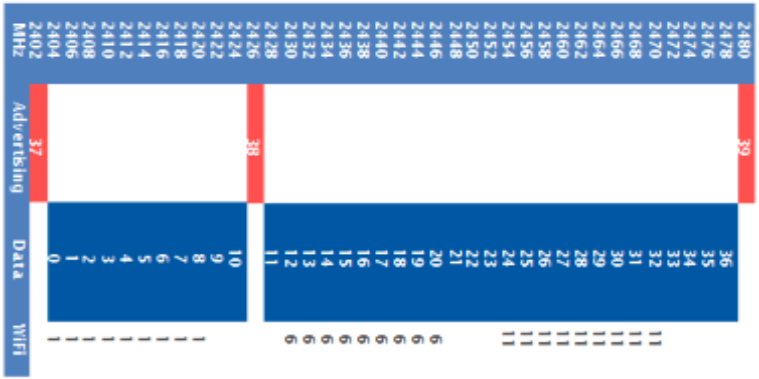
  LE 2M with Un-coded data rate of : 2 Mb/s

- LE 1M and LE 2M are collectively referred to as the LE Uncoded PHYs

*(1 Msym/s = 1 Mega symbol / second = 1 bit/sec = 1 Megabit.)

Bluetooth low energy, Advertising Channels

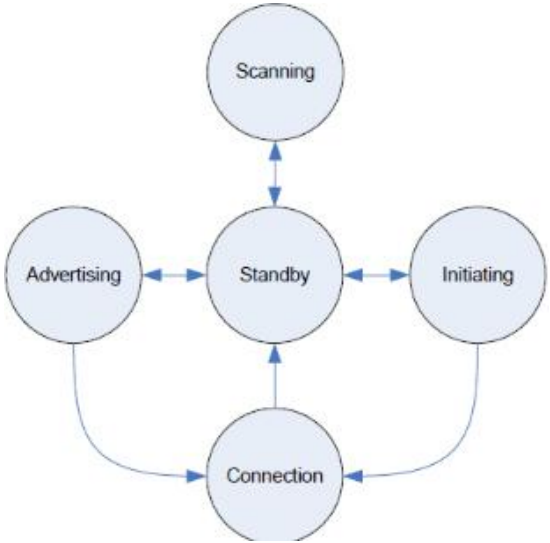
- LE Advertising Channels are used to set up connection or to Broadcast information between Unconnected devices
- LE system uses 40 RF Channels, 2MHz per channel, 0…..39 Channels
- 3 Advertising Channels (ch. 37,38,39) These are the Primary Advertising Channels.
- The payload of Primary Advertising Packets can vary between 2 to 37 Octets.
- There are Secondary Advertising Channels. (Auxiliary packets). There are 37 Channels
- These Secondary channels are the same channels as the Data Channels used in connection. Secondary Channel Payload varies 0 to 255 Octets
- The secondary Advertising Channel is used to Offload Data from the Primary Adv Ch.



Lower guard band of 2MHz, upper guard band of 3.5MHz

Channels and Connection Events

- Two types of Channels.
- Advertising Channels (37,38,39)
- Data Channels (0….36).
- Devices can be in different states.



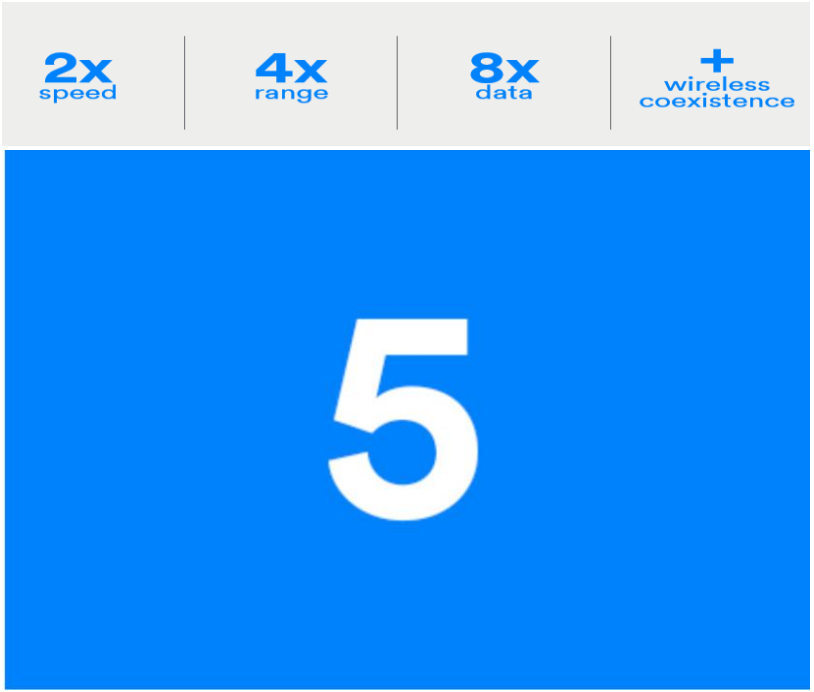
Connection state:

The LL shall send Data Channel PDUs in Connection Events. A Channel Index is used for each Connection Event. The same Channel Index will be used for that event.

The connection Event is open as long as M&S send packets.

Bluetooth 5

Bluetooth® 5, Doubles Speed, Quadruples Range, Increases Data Broadcasting Capacity by 800%



IT'S ALL ABOUT…… Bluetooth 5

- **Internet of Things (IoT)**
  - Creating a new opportunity on how to utilize the IoT
  - Delivering reliable IoT connections (longer Range less Tx time, same low Power characteristics)
  - Enhancing the adoption of beacons
  - Decreasing connection barriers to experience seamless IoT
  - Long Range feature will enhance IoT connectivity for Industrial-Home use cases.

IT'S ALL ABOUT…… Bluetooth 5

Ubiquitous

- Bluetooth 5 has a hereditary install base of over 10 billion devices.
- Bluetooth 5 includes features to enhance Coexistence with other technologies
- Bluetooth 5 new features still ensures low-energy functionality and better more flexible performance.

Coexistence

- Bluetooth 5 also includes updates that enhance Coexistence with other technologies in an increasingly complex IoT world.

Note:

- *To update a previous qualified product to Bluetooth 5, you need to requalify.*
- *Previous qualified products do not require new qualification.*

Frontline Sodera Support for Bluetooth 5 Features

Feature	Supported
2 Mbps LE	Yes
LE Advertising Extensions	Yes
Slot Availability Masks	Yes
LE Long Range	Yes
Channel Selection #2	Yes
High Duty Cycle Non-Connectable Advertising	Yes

Bluetooth wideband Sniffer

Bluetooth 5: **2Mbps LE**

Increased bandwidth for *Bluetooth*® technology with low energy

Key Feature:
Up to 2x bandwidth of Bluetooth 4.2 with low energy.

Bluetooth 5.0 introduces a new capability to increase the bandwidth to 2 Mbps. By doubling the amount of data that devices can transfer, Bluetooth 5.0 reduces the time required for transmitting and receiving data, facilitating rapid and reliable over-the-air firmware updates for mobile devices and fast upload of days' worth of collected data from a sensor when a mobile device is turned on.

Bluetooth 5: **2Mbps LE**

Includes the following:

- additions to the Physical (PHY) layer to allow 2Ms/s (megasymbol per second) packets to be transmitted and received by the radio;
- a new control procedure in the Link Layer to allow transition (switching) between 1 Ms/s and 2 Ms/s;
- additional HCI commands and events to transition the LL between 1 Ms/s and 2 Ms/s;
- an update to DTM mode for PHY testing.

Bluetooth 5 – Faster (Double) Speed

- Doubles the speed of low energy communications
- Will support faster data transfers and software updates for devices. (e.g. Firmware update OTA)
- Increase Bandwidth to 2Mbs.
- Applications benefiting from faster Bluetooth include:
  - more responsive apps
  - more responsive human interface devices
  - Faster update of Sensor information
  - better audio over Bluetooth
  - more responsive beacons
  - ALL applications benefit from faster speed

Frontline Sodera Support for Bluetooth 5 Features

Feature	Supported
2 Mbps LE	Yes
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Slot Availability Masks	Yes
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Channel Selection #2	Yes
High Duty Cycle Non-Connectable Advertising	Yes

Bluetooth wideband Sniffer

Bluetooth 5: **LE Advertising Extension**

- Primary Advertising Packet (Ch 37,38,39) 2 to 37 Octets
- Secondary Advertising Packet (Ch 0 to 36) 0 to 255 Octets
- Advertising Payload is Offset to Secondary Advertising Channels,
- Free up congested Primary Advertising Channels. and…
- Increase Advertising Channel capacity to 255 Octets.
- With Data Packet payload now between 31 – 255, means fewer Transmissions and less Broadcast time.
- Efficient method to Broadcast “connectionless” IoT
- Adaptable for Beacon applications.

Bluetooth 5 delivers “connectionless” IoT…

…advancing beacon and location-based capabilities in home, enterprise and industrial applications.

- More than 371 million Bluetooth enabled beacons are projected to ship by 2020, according to ABI Research. With eight times the broadcast messaging capacity, Bluetooth 5 will further propel the adoption and deployment of beacons and location-based services in the home automation, enterprise, and industrial markets.

- In scenarios where contextual awareness like navigation and pin-point location are crucial – such as hassle-free airport navigation experiences, asset tracking of warehouse inventory, emergency response, even smart city infrastructure that helps the visually impaired be more mobile – Bluetooth 5 will send information without connection barriers.

Frontline Sodera Support for Bluetooth 5 Features

Feature	Supported
2 Mbps LE	Yes
LE Advertising Extensions	Yes
Slot Availability Masks	Yes
LE Long Range	Yes
Channel Selection #2	Yes
High Duty Cycle Non-Connectable Advertising	Yes

Bluetooth wideband Sniffer

Slot Availability Mask. (Negate LTE Interference)

Slot availability masks detect and prevent interference on neighboring bands

Key Feature:

Detect and prevent interference at the edges of the 2.4 GHz ISM band and the neighboring LTE band.

For mobile phone developers creating the next generation of devices, slot availability masks can be used to detect interference on neighboring bands and automatically prevent the interference. A Bluetooth 5.0 device can indicate transmission and reception availability of its slots when working with Mobile Wireless Standard (MWS) systems.

Bluetooth 5 : Slot Available Mask (SAM)

8.6.11 Slot Availability Mask (SAM)

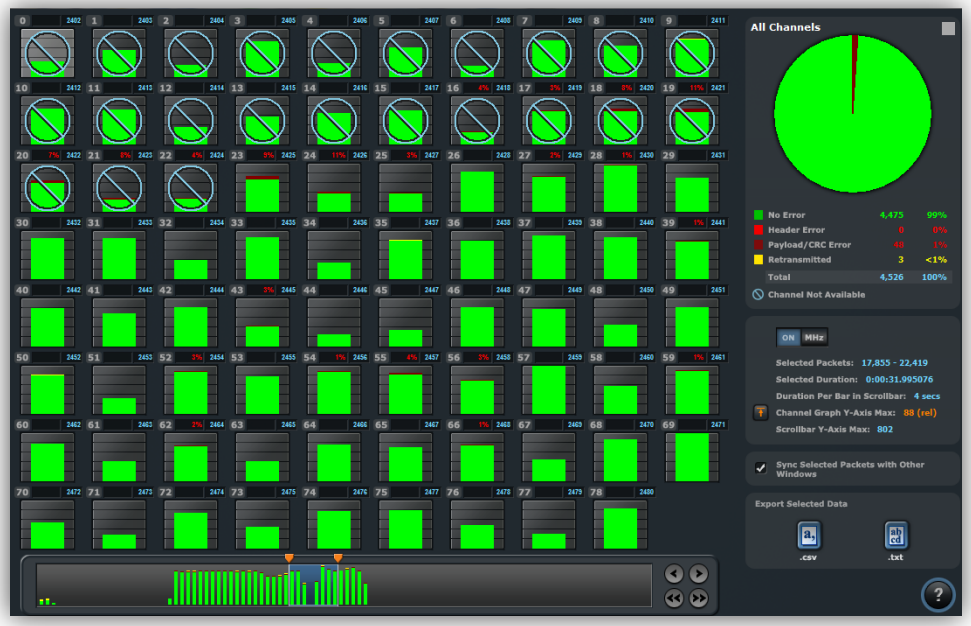
Slot Availability Mask (SAM) allows two Bluetooth devices to indicate to each other the availability of their time slots for transmission and reception. From the baseband point of view, SAM provides a map - the SAM slot map - which marks the availability of Bluetooth slots. The availability arises from either external conditions (e.g., MWS coexistence) or internal conditions (e.g., topology management for scatternets). The SAM slot map marks each slot using one of four type codes defined in [Vol 2] Part C, Section 5.2 and repeated for convenience in Table 8.7.

Slot type code	Meaning
0	The slot is not available for either transmission or reception
1	The slot is available for transmission but not reception
2	The slot is available for reception but not transmission
3	The slot is available for both transmission and reception

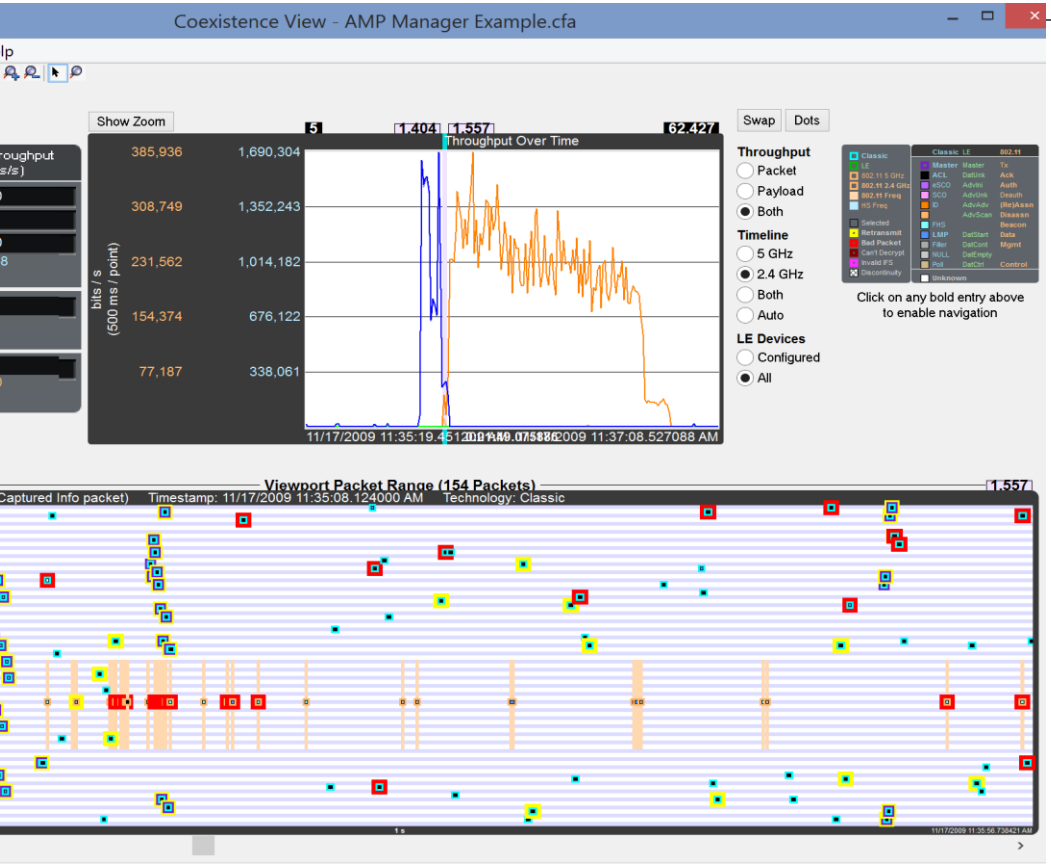
Table 8.7: SAM Slot Types

Bluetooth Coexistence

- Existing Coexistence support is Adaptive Frequency Hopping (AFH, introduced V1.2 Specification). Where Bluetooth Channel Map can avoid hopping on channels that have “interference” AFH is Dynamic.



AFH Coexistence (Bluetooth avoids Wi-Fi Channel space)



Bluetooth Coexistence

- Now with SAM Slot-Map, availability of Bluetooth Slots is shared. This enables control of when Data is sent or received on Bluetooth slots.
- Information for SAM slot map is available and used through MWS Coexistence support or Topology Management. (MWS, Mobile Wireless Standard)
- Bluetooth spec provides a way for a MWS device to interface with Bluetooth Controller in real time.
- The object of the interface logic data is to exchange information and enhance Coexistence.

Frontline Sodera Support for Bluetooth 5 Features

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Bluetooth wideband Sniffer

Bluetooth 5: **LE Long Range** (Up to 1000 Meters)

Increased range for low energy enables whole-home, building, or location coverage

Key Feature:
Up to 4x range of Bluetooth 4.2 with low energy.

Bandwidth can be decreased to achieve up to 4x longer range while maintaining similar power requirements. With quadruple the range over which their devices can transmit and receive data, product designers creating home automation and security solutions can provide coverage of an entire home, building, or locality.

The range can be tuned for a variety of environments. Not every application requires the same range, speed or broadcasting capability. Bluetooth 5.0 provides the flexibility for a developer to make the best choice for their implementation.

Bluetooth 5 – Longer (Quadruple) Range

- Quadruples the range while maintaining Power requirements.
- Will enable connections to IoT devices that extend far beyond the walls of a typical home
- Applications benefiting from long range Bluetooth include:
  - medical devices
  - ePOS terminals
  - automotive diagnostic equipment
  - barcode scanners
  - industrial cable replacement
  - truck weighing scales
  - pipeline leak detection devices
  - anything over water (which rapidly attenuates RF signal)

Range V Bandwidth

- Range V Bandwidths is a compromise
- Increased Range is achieved by Coding changes.
  - 1Mb/s for the LE 1M PHY 2Mb/s for the LE 2 M PHY
  - 125 Kb/s for the LE Coded PHY (using S=8 Coding)
  - 500 Kb/s for the LE Coded PHY (using S=2 Coding)

- In order to achieve Bluetooth 5 capabilities, both sides must support what is referred to as “Stable Modulation Index” capability as opposed to “Standard Modulation Index”
- Modulation = GFSK. Modulation Index =0.5
- Longer Range is achieved by using stronger FEC coding but at a cost of Bandwidth.
- This versatility (Range V Bandwidth) allows for many different use cases.
- increased range will deliver reliable IoT connections that make full-home, building, and outdoor use cases a reality.
- increased speed of Bluetooth 5 lays the groundwork for the next generation of Bluetooth audio,
- Bluetooth 5 offers the flexibility to build IoT solutions based on feature need- range, speed and security can be adjusted for a variety of environments and end products.

Range V Bandwidth.

- **Increased Range**
- Increased Bandwidth V increased range. How is this accomplished? Coding.
- There is a rate ½ code and a rate 1/8th code.
- The rate ½ code(S2) gets us approximately 4-5dB of sensitivity and about 2x the range at 500kbps,
- and the rate 1/8th code (S8) gives up to 12dB of sensitivity plus the 4x range at 125kbps.

Caveat

Okay, so here is the caveat. You don't get BOTH longer range and higher bandwidth in the same low power envelope.

Remember, one is a new coding scheme, and one is a new modulation scheme.

Think of this as a dial, or a lever, where you can tune the performance based on your application.

Some applications, like firmware updates perhaps, would benefit from increased bandwidth (and distance isn't a big detractor).

Other applications, like an in-home thermostat, would benefit from the increased range (and the data that it transmits doesn't need high bandwidth as it's not very much data).

Bluetooth low energy at 125kpbs will be ~3 dB better than the 802.15.4 tech out there today.
And at 500 kbps, provides a 15% lower duty cycle than 802.15.4 (ZigBee) with twice the throughput.

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Bluetooth wideband Sniffer

Channel Selection Algorithm #2

- Channel Selection Algorithm #1 supports Channel selection for connection events (Spec V4.0 – V4.2)

- Channel Selection Algorithm #2 supports Channel selection for connection events and Periodic Advertising packets

- At the start of a Connection Event or Periodic Advertising Packet, the Algorithm generates an event Channel Index. This can be Data or Secondary Advertising Channel Index

- This is how we “Hand Off” Advertising data from Advertising Channels, 37,38,39, to Secondary Channels, 0…36.

Frontline Sodera Support for Bluetooth 5 Features

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2 Mbps LE	Yes
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Bluetooth wideband Sniffer

Increase Broadcast Capacity by 800%

Broadcasting channel improvements power the beacon revolution

Key Features:

Up to 8x the broadcasting message capacity over Bluetooth 4.2, with support for larger data packets: 31-octet to 255-octet packages.

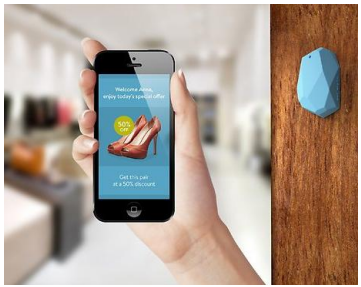
Ability to offload advertising date from the 3 advertising channels to up to 37 broadcasting channels.

High Duty Cycle Non-Connectable Advertising

- The Broadcast Mode provides a method for a Device to send connectionless Data in Advertising Events.
- A Device in Broadcast Mode may send Data using Non-Connectable Advertising Events.
- High Duty Cycle makes provision for reducing the Time interval between Broadcast Advertising packets.
- It is recommended for Advertising intervals less than 100ms, consideration to interference to other devices should be taken. For example cease Advertising for a few minutes after several seconds Transmissions.

Bluetooth 5 – Greater (800% Increase) Messaging Capacity

- Increases the capacity of connectionless data broadcasts by 800 percent. 31-octet to 255 octet packets.
- Ability to offload Adv. Data from 3 channels to 37 Channels.
- Applications benefiting from greater advertising packet capacity include:
  - Less Broadcasting time to complete the tasks.
  - More efficient utilization of 2.4Ghz Band
  - Larger Data packets
  - More channels to Broadcast on (37)
  - New Application to avail of more efficient
  - ecosystem.
  - Creating a friendlier RF environment



Wrap Up / Questions

Bluetooth 5: Facts and Information (Review)

- Extends the functionality of Bluetooth v4.0 - v4.2
- Backward compatible in relation to LE v4.0 - v4.2
- Backward compatible with BR/EDR v1.1 - forward.
- Features designed for Bluetooth LE enhancements
- Adds performance and interoperability improvements

Note:

- *To update a previous qualified product to Bluetooth 5, you need to requalify.*
- *Previous qualified products do not require new qualification.*

Thank You!

Bluetooth® Protocol Expert System

Makes the novice an expert and makes the expert's job easier.

ES™

Resources

- Bluetooth SIG – Bluetooth 5 landing page - https://www.bluetooth.com/specifications/bluetooth-core-specification/bluetooth5
- Teledyne LeCroy Frontline website – http://www.fte.com
- Frontline Sodera Wideband Bluetooth Protocol Analyzer landing page – http://www.fte.com/products/sodera.aspx
- Bluetooth Protocol Expert System landing page – http://www.fte.com/protocolexpert
- Coexistence View and Spectrum landing page – http://www.fte.com/products/sodera-spectrum.aspx
- Sales – Frontline_OnlineSales@teledyne.com
- Technical Support – Frontline_TechSupport@Teledyne.com

Happy 20th Birthday, Harald

TELEDYNE LECROY
Everywhereyoulook™

Tomas O'Raghallaigh
October 2018

Bluetooth Market projection to 2022

Bluetooth SIG is supporting new markets with new specifications.

Real products meet new and real markets Faster than ever before.

Bluetooth is Ubiquitous!

Bluetooth Market sectors:

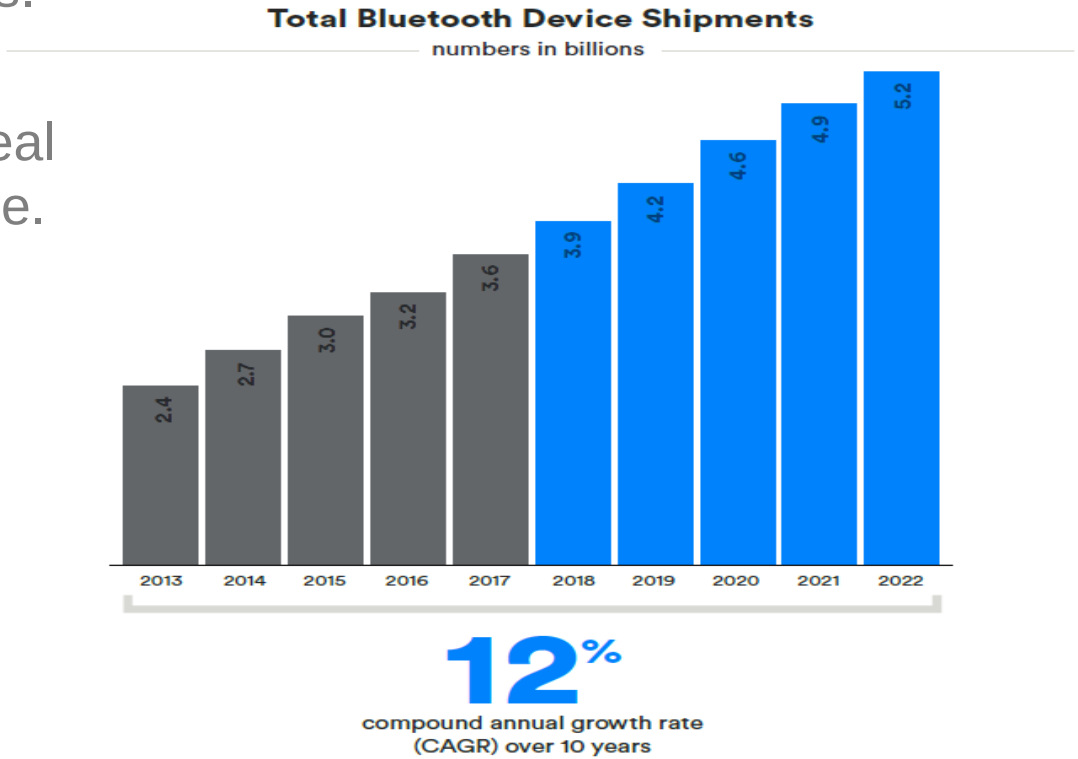
Phone Tablets & PC.

Audio & Entertainment.

Automotive.

Connected Devices.

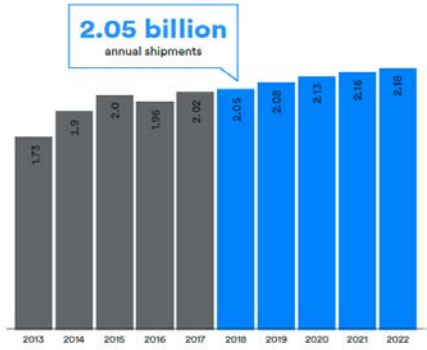
Smart Buildings, Industry, City, Home.



Bluetooth Market growth and expansion

Phone Tablets & PC.

- 100% of Smartphone, Tablets and Laptops shipped in 2018 will support Bluetooth.
- Rapid adoption of Bluetooth 5 specification in smartphones.
- Trend to replace Audio Jack with Bluetooth continues.
- Smartphone UI Apps become standard for industrial and commercial applications.
- Device Pairing and connectivity becomes more seamless (easier).



Bluetooth Market growth and expansion

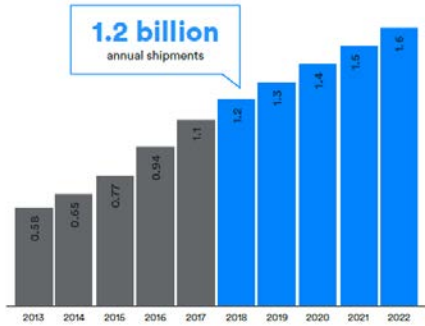
Audio & Entertainment

- By 2022, 80% of all speakers shipped will support Bluetooth.

- Headsets, Ear Buds continue to lead the Audio Market.
- Bluetooth is now dominant in Game controllers and now TV remotes.

- Smart Speakers growth, predicted to 3X by end 2022.

- Hearing Aids continue to lead with Bluetooth technology (Audio over LE)



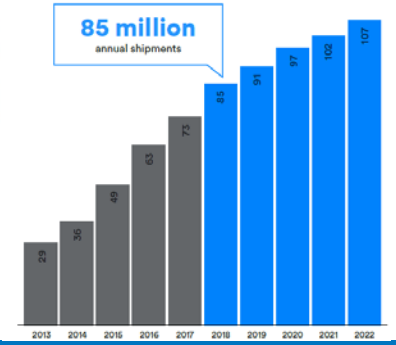
Bluetooth Market growth and expansion

Automotive. (85 Million shipment in 2018)

- Bluetooth is established technology for the Car industry.
- Wearables are encroaching into the Automotive market.
- Smartphones are becoming new Key Fob.
- Bluetooth facilitating service history and vehicle data.

86%
of new cars, trucks, and SUVs shipped worldwide in 2018 will come standard with Bluetooth

85%
of Bluetooth automotive device shipments will be in-car infotainment systems in 2018



Bluetooth Market growth and expansion

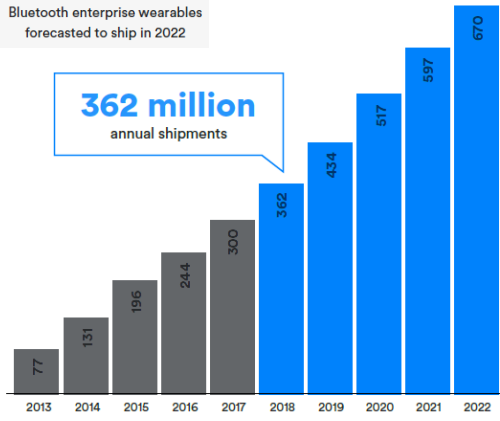
Connected Devices

4x
growth in annual smartwatch shipments over the next 5 years

- Consumer wearables are becoming more sophisticated.
- Medical devices are availing of Bluetooth technology.
- Enterprise wearables and equipment market growth.
- Home Bluetooth robotics continue to grow.

102m
Bluetooth enterprise wearables forecasted to ship in 2022

80m
Bluetooth consumer robots forecasted to ship in 2022

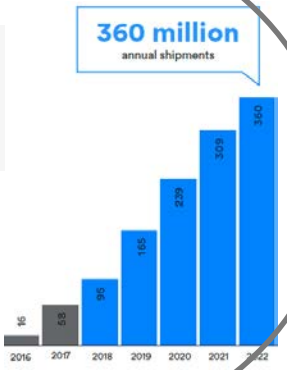


Bluetooth Market growth and expansion

Smart Building,

10x

growth in annual volume of Bluetooth location services devices by 2022



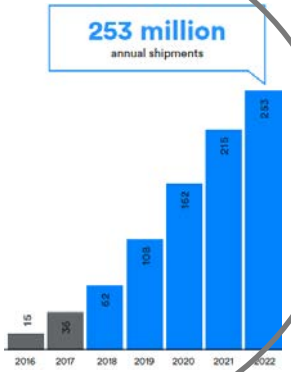
Industry,

7x

increase in annual shipments of Bluetooth smart industry devices from 2017-2022

12x

increase in annual volume of asset tracking and management solutions by 2022



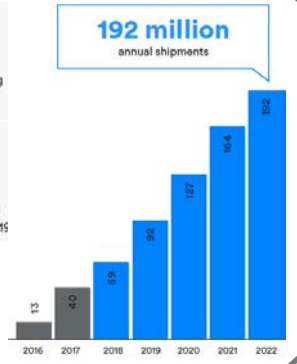
City,

84%

of global airports will be using location services by 2019*

93%

of US baseball stadiums will deploy location services by 2019



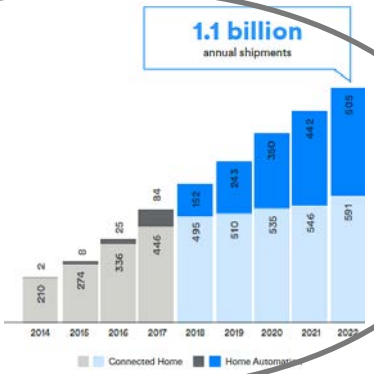
Home

650m

Bluetooth smart home devices will ship in 2018

6x

growth in annual shipments of Bluetooth home automation devices by 2022



Home Automation

Location services

Wireless Sensor Networks

Asset Management

Smart Phone provides Ubiquitous UI

Bluetooth Special Interest Group (SIG)

- What is Bluetooth SIG?

(Special Interest Group)

- Bluetooth SIG has Three functions.

1. Bluetooth Specification. Members create new specifications and use cases (Profiles)
2. Bluetooth Qualification (Bluetooth Logo) Qualification of Bluetooth specification Conformance and Interoperability
3. Promotion of Bluetooth Technology . Invite new membership and educate Bluetooth specification understanding and Adoption.

Bluetooth Organisation and support

- Bluetooth Membership:
- Membership in 2017 = 33,900 (Adopter, Associate, Promotor)
- 90% membership growth in 5 years.
- 35% Americas, 36%APAC, 29% EMEA

- Bluetooth Specification:
- 15 Working Groups, 70 Active Spec Projects, 11 new Updated Specifications.

- Bluetooth Promotions:
- UnPlugFests, Conferences, free test Tool for profile (PTS), Webinars.

Bluetooth Evolution - Specification Roadmap 2003 - 2017

Rev	Date	Comments
3.0 + HS	April 21 2009	• New features added in 3.0 + HS: -AMP Manager Protocol (A2MP) -Enhancements to L2CAP for AMP -Enhancements to HCI for AMP -Enhancements to Security for AMP -802.11 Protocol Adaptation Layer • Enhanced Power Control -Unicast Connectionless Data -HCI Read Encryption Key Size command -Generic Test Methodology for AMP -Enhanced USB and SDIO HCI Transports • Errata for v 2.0 + EDR and v2.1 + EDR
v2.1 + EDR	July 26 2007	• New features added in 2.1 + EDR: -Encryption Pause and Resume -Erroneous Data Reporting -Extended Inquiry Response -Link Supervision Timeout Changed Event -Non-Flushable Packet Boundary Flag -Secure Simple Pairing -Sniff Subrating -Security Mode 4 • Updates to IEEE language in Volume 2, Part H, Security • Errata for v2.0 + EDR
v2.0 + EDR	Aug 01 2004	This version of the specification is intended to be a separate Bluetooth Specification. This specification was created by adding EDR and the errata.
v1.2	Nov 05 2003	New features added in v1.2: - Architectural overview - Faster connection - Adaptive frequency hopping - Extended SCO links - Enhanced error detection and flow control - Enhanced synchronization capability - Enhanced flow specification The Core System Package now comprises two volumes and the text has gone through a radical change both in terms of structure and nomenclature. The language is also more precise and is adapted to meet the IEEE standard. The following parts are moved from the Core System Package to other volumes or were deprecated: RFCOMM [vol 7], Object Exchange (IrDA Interoperability) [vol 8], TCS [vol 9], Interoperability Requirements for Bluetooth as a WAP Bearer [vol 6], HCI USB Transport Layer [vol4], HCI RS232 Transport Layer [vol 4], HCI UART Transport Layer [vol 4], Bluetooth Compliance Requirements [vol 0], Optional Paging Schemes [deprecated]

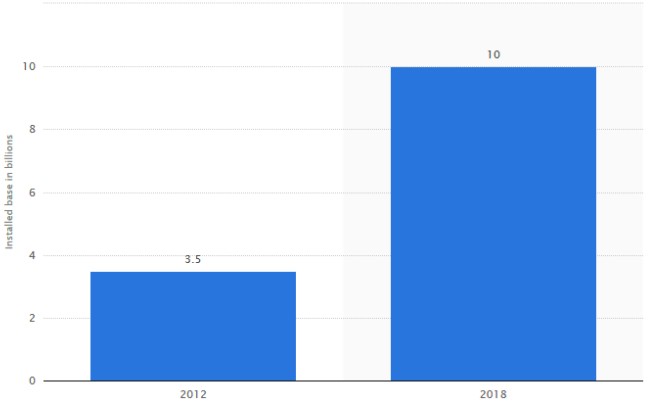
Rev	Date	Comments
5.0	Dec 06 2016	• New features added in 5.0: - CSA 5 features (Higher Output Power) - Slot Availability Mask (SAM) - 2 Msym/s PHY for LE - LE Long Range - High Duty Cycle Non-Connectable Advertising - LE Advertising Extensions - LE Channel Selection Algorithm #2 • Park State was deprecated and removed • Errata for v2.0 + EDR, v2.1 + EDR, v3.0 + HS + 4.0 + 4.1 + 4.2 (ESR09, ESR10 and ESR11). See also [Vol 1] Part C, Section 9.4.
4.2	Dec 02 2014	• New features added in 4.2: - LE Data Packet Length Extension - LE Secure Connections - Link Layer Privacy - Link Layer Extended Scanner Filter Policies • Errata for v2.0 + EDR, v2.1 + EDR, v3.0 + HS + 4.0 + 4.1 (ESR08). See also [Vol 1] Part C, Section 8.2.
4.1	Dec 03 2013	• New features added and changes made in 4.1: - CSA 2 features - CSA 3 features - CSA 4 features - Secure Connections - Train Nudging & Generalized Interlaced Scan - Low Duty Cycle Directed Advertising - 32-bit UUID Support in LE - LE Dual Mode Topology - Piconet Clock Adjustment - Removal of At Least One New Feature - LE L2CAP Connection Oriented Channel Support - LE Privacy v1.1 - LE Link Layer Topology - LE Ping • Errata for v2.0 + EDR, v2.1 + EDR, v3.0 + HS + 4.0 (ESR05, ESR06 and ESR07)
4.0	June 30 2010	• New features added in 4.0: -Low Energy • Errata for v2.0 + EDR, v2.1 + EDR, v3.0 + HS

Bluetooth 5

- This includes Classic (BR/EDR) and low energy (LE) specifications, plus new specification features:
- Doubles Speed,
- Quadruples Range,
- Increases Data Broadcasting Capacity by 800%

Bluetooth 5 Market

- Sports and Fitness – pedometers / watches / heart rate
- Assisted Living – fall alarms / monitoring health
- Consumer Medical – weighing scales
- Entertainment – remote controls
- Security – proximity
- Home / Industrial Automation – sensors / actuators
- Advertising – malls / museums / tourists / transport hubs



10 billion units worldwide by 2018 - *Key IoT market growth areas will include the smart home and smart lighting, beacons, and wearables, among others*

Bluetooth 5 Market – Why?

- **Ubiquitous** - found everywhere
  - Hereditary install base heading towards 10 billion devices
  - Includes features to enhance Coexistence with other technologies
  - New features ensure low-energy functionality and better more flexible performance
- **Coexistence (ISM band)**
  - Includes updates that enhance Coexistence with other technologies in an increasingly complex IoT world

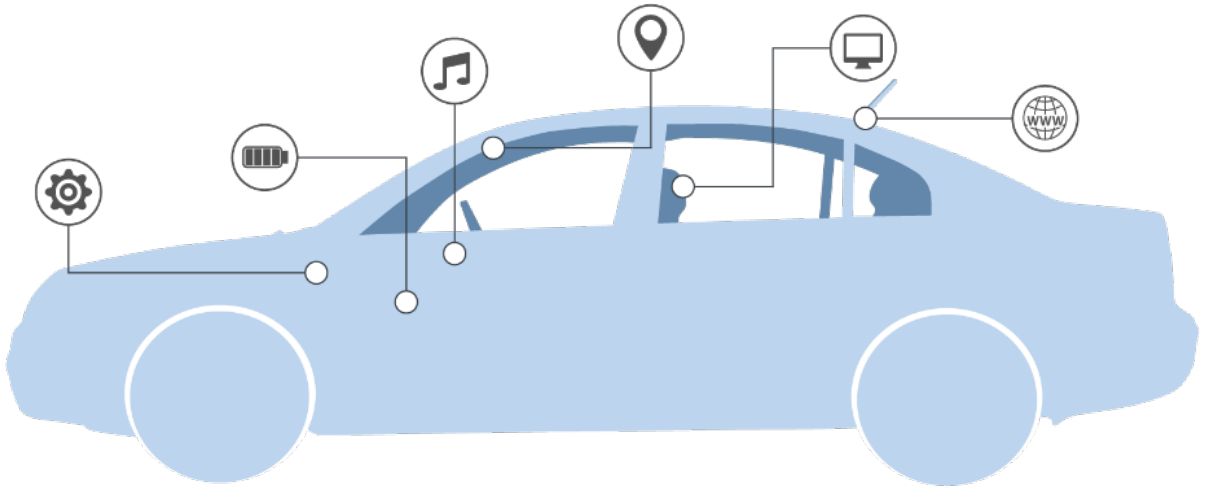
Note: To update a previous qualified product to Bluetooth 5, you need to requalify.

Bluetooth 5 Market – Why?

- **Internet of Things (IoT)**
  - Creating a new opportunity on how to utilize the IoT
  - Delivering reliable IoT connections
    - longer Range less Tx time, same low Power characteristics
  - Enhancing the adoption of beacons
  - Decreasing connection barriers to experience seamless IoT
  - Long Range feature will enhance IoT connectivity for Industrial and Home use cases

Bluetooth 5 Market – The Connected Car

- Vehicle Safety features
- Data gathering/analysis
- Driver Awareness
- Infrastructure planning
- User Experience



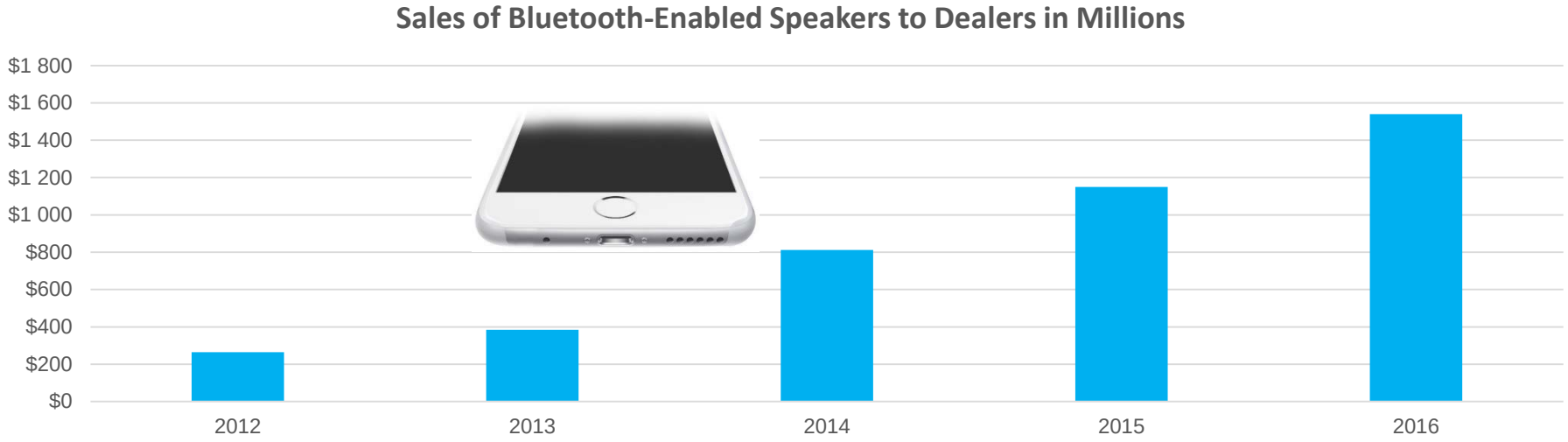
Connected car market is expected to reach 37.7 Million units by 2022, at a CAGR of 35.54% between 2016 and 2022.

Bluetooth 5 Market - Beacons

- Personal tracking tags, retail, and advertising, etc…
  - Aided by the increased range and broadcast messaging capacity of Bluetooth 5, Bluetooth beacons in these markets will achieve a CAGR of 133% between 2016 and 2021.

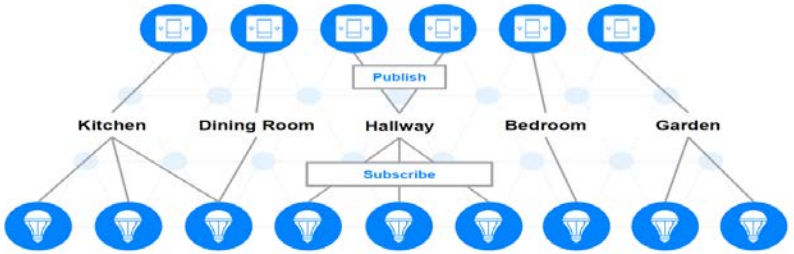
Bluetooth 5 Market – Bluetooth Audio in LE (Future)

- Growth for Bluetooth in speakers and the automotive segments highlights the continued importance of audio in the marketplace.
- Different codecs recently led to improvements in the quality of Bluetooth audio.
- Today this is a BT Classic only market but provides a huge opportunity for Bluetooth 5 when Audio over LE is available.

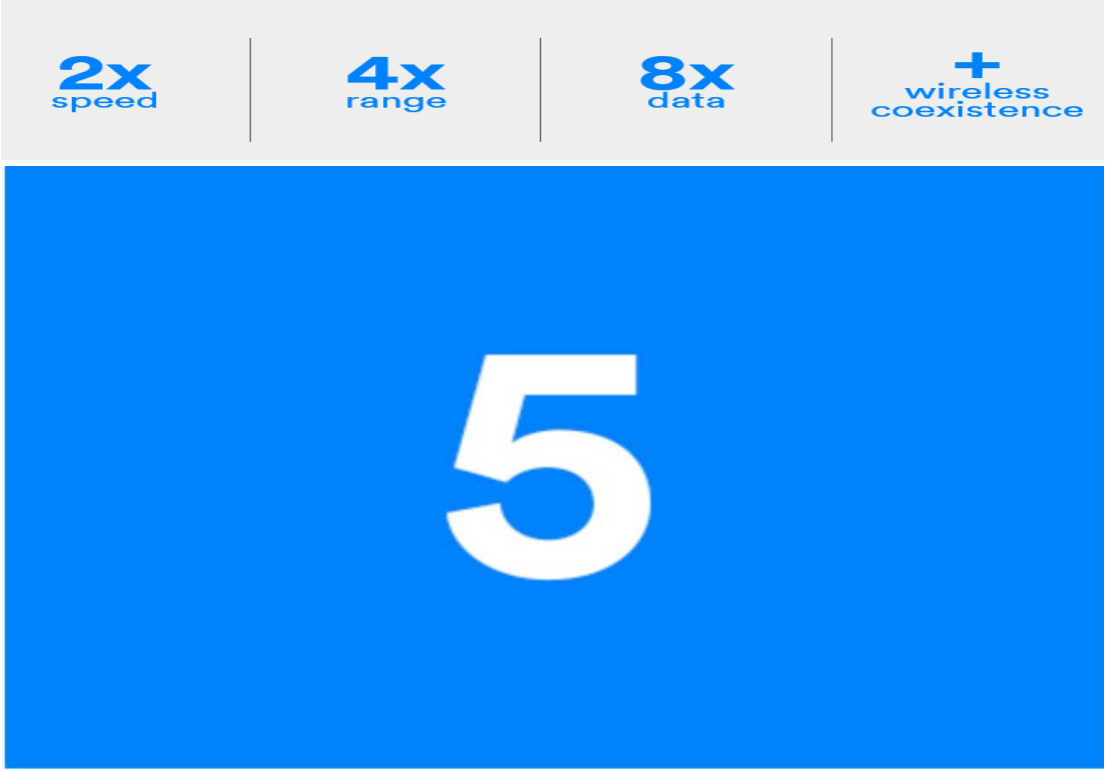


Bluetooth 5 Market – Mesh Capabilities (outside core BT 5 spec)

- New IOT markets
- Low latency
- Scalability
- Minimum power consumption
- Security
- Used with BT 4.0 or >



Measurements in BLE 5



Bluetooth 5 Enhancements – Foundation for Growth

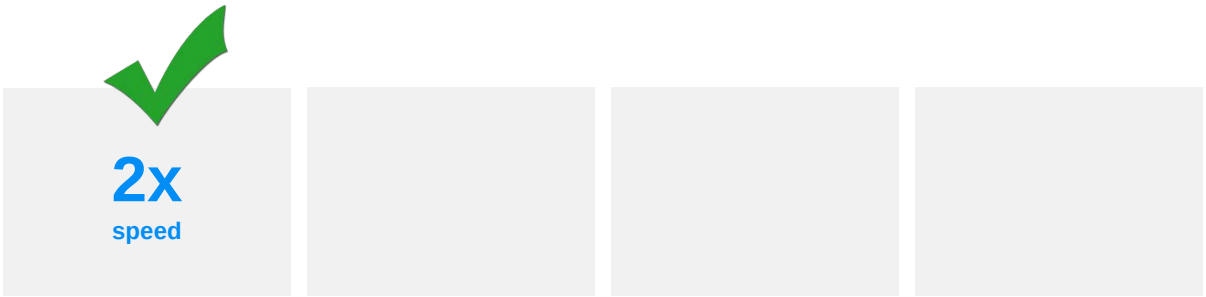
- Faster speeds (2X)
  - 2M data rate (2M PHY)
- Longer range (4X) (coded PHY)
- Greater (800% Increase) Messaging Capa
  - LE advertising extension
- Improved interoperability/coexistence

Bluetooth 5 Enhancements – Foundation for Growth

- **Faster (2X) Speed**
  - Doubles the speed of low energy communications
  - Will support faster data transfers and software updates for devices. (e.g. Firmware update OTA)
  - Increase Bandwidth to 2Mbs (2M PHY)

- more responsive apps
- more responsive human interface devices
- faster update of sensor information

- better audio over Bluetooth
- more responsive beacons
- ALL applications benefit from faster speed



RF Physical Layer (PHY)

- Delivers data at 2X speed, gets the job done faster!
- Less time Transmitting On the Air and less time receiver On
- Better Co-existence.

LE Physical layer (PHYs)

PHY	Modulation scheme	Coding scheme		Data rate
		Access Header	Payload	
LE 1M	1 Msym/s modulation	Uncoded	Uncoded	1 Mb/s
LE 2M	2 Msym/s modulation	Uncoded	Uncoded	2 Mb/s
LE Coded	1 Msym/s modulation	S=8	S=8	125 kb/s
			S=2	500 kb/s

Table 3.1: Summary of PHYs, modulation schemes, and coding schemes

Bluetooth 5 Enhancements – Foundation for Growth

- **Longer (4X) Range (Coded PHY)**
  - Quadruples the range while maintaining Power requirements.
  - Will enable connections to IoT devices that extend far beyond the walls of a typical home

- industrial cable replacement
- truck weighing scales
- pipeline leak detection devices
- anything over water (which rapidly attenuates RF signal)

- medical devices
- ePOS terminals
- automotive diagnostic equipment
- barcode scanners

Bluetooth 5 – Longer (Quadruple) Range

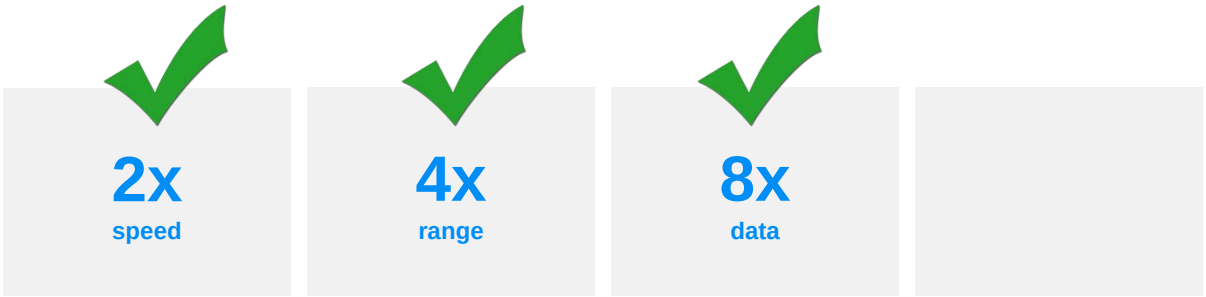
- Quadruples the range while maintaining Power requirements.
- Will enable connections to IoT devices that extend far beyond the walls of a typical home
- Applications benefiting from long range Bluetooth include:
  - medical devices
  - ePOS terminals
  - automotive diagnostic equipment
  - barcode scanners
  - industrial cable replacement
  - truck weighing scales
  - pipeline leak detection devices
  - anything over water (which rapidly attenuates RF signal)

Bluetooth 5 Enhancements – Foundation for Growth

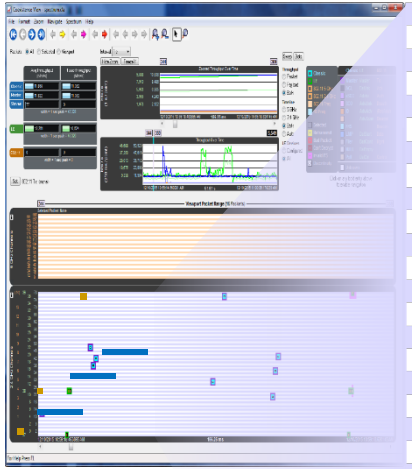
- **Greater (800% Increase) Messaging Capacity**
  - Increases the capacity of connectionless data broadcasts by 800 percent
    - 37-octet to 255 octet packets
  - Ability to offload Adv. Data from 3 channels to 37 Channels
    - LE advertising extensions - Secondary advertisements

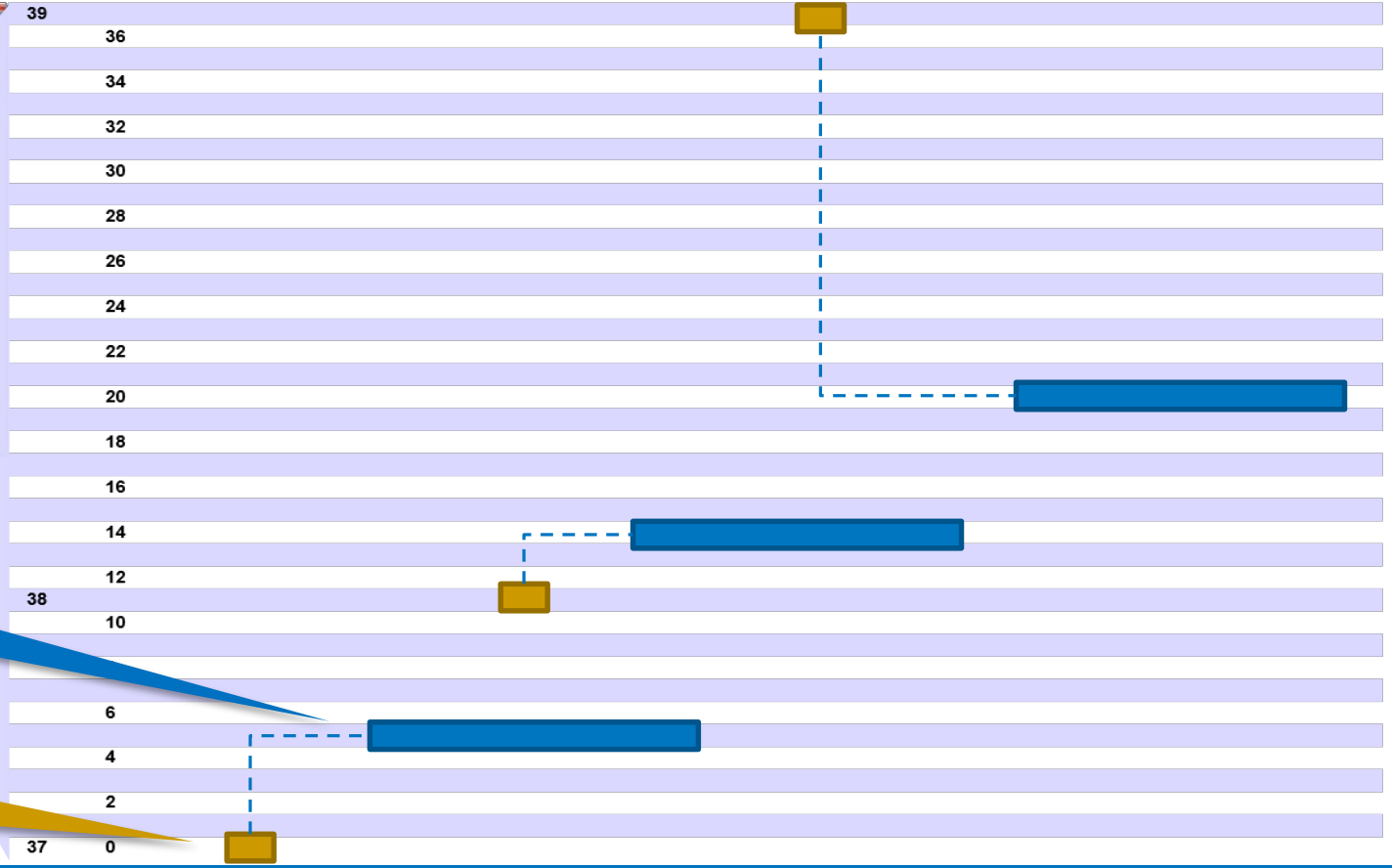
- less Broadcasting time to complete the tasks
- more efficient utilization of 2.4Ghz Band
- larger data packets

- more channels to Broadcast on (37)
- new Application to avail of more efficient ecosystem
- creating a friendlier RF environment



Bluetooth 5 Enhancement – Extended Advertising



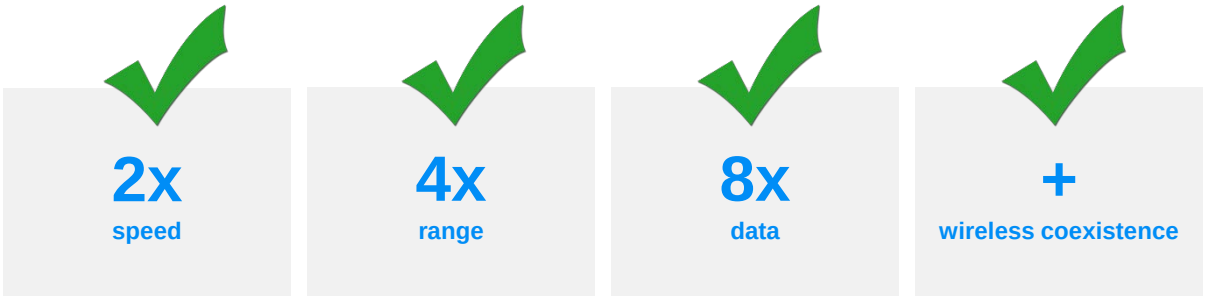


Advertising Extension

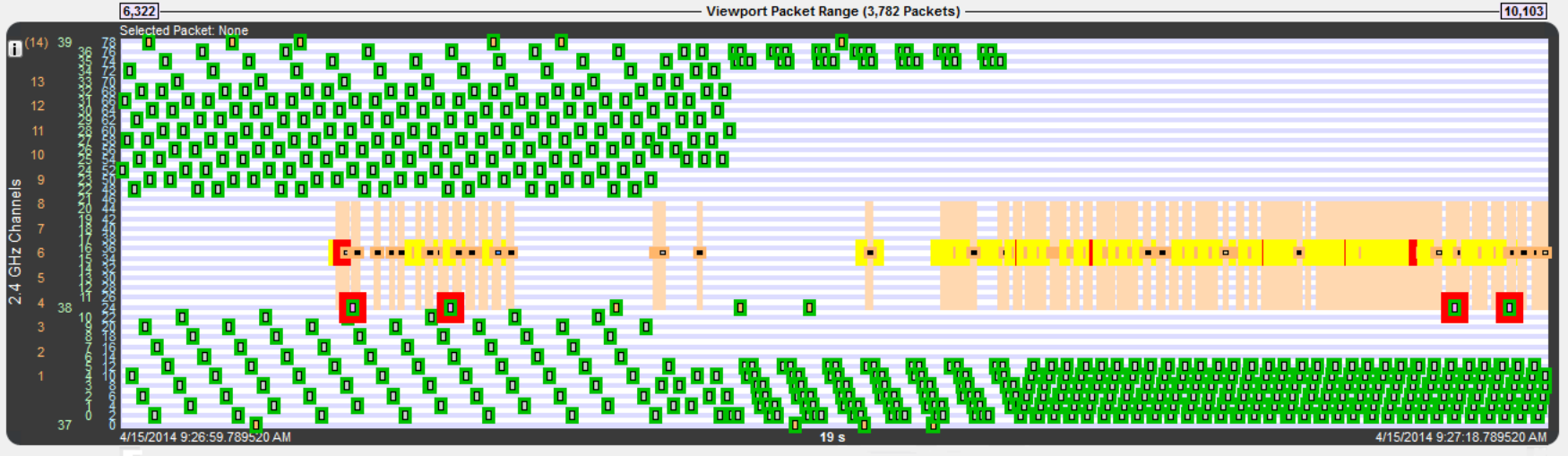
Advertising Packet

Bluetooth 5 Enhancements – Foundation for Growth

- **Improved Interoperability/Coexistence**
  - SAM Slot-Map enables control of when data is sent or received on Bluetooth slots.
    - Slot availability masks detect and prevent interference on neighboring bands
  - Provides a way for a MWS device to interface with Bluetooth Controller in real time.
  - The object of the interface logic data is to exchange information and enhance Coexistence.



Measurements in BLE 5 - Coexistence



Is your product able to coexist with multiple wireless technologies?

Bluetooth 5 Facts and review.

- Extends the functionality of Bluetooth v4.0 - v4.2
- Backward compatible in relation to LE v4.0 - v4.2
- Backward compatible with BR/EDR v1.1 - forward.
- Features designed for Bluetooth LE enhancements
- Adds performance and interoperability improvements

Useful information…….Thank You!

- http://www.fte.com/ Teledyne LeCroy Frontline web site
- www.Bluetooth.com
- **Bluetooth TV and Bluetooth Magazine Bluetooth ... – Incisor**
- **Inside Bluetooth Low Energy 2nd Edition Pdf Download | e-Books**
- https://www.bookdepository.com/Bluetooth-Low-Energy-Robin-Heydon/

Bluetooth® mesh networking

TELEDYNE LECROY
Everywhereyoulook™

Tomas O'Raghallaigh
October 2018

What is Bluetooth mesh?

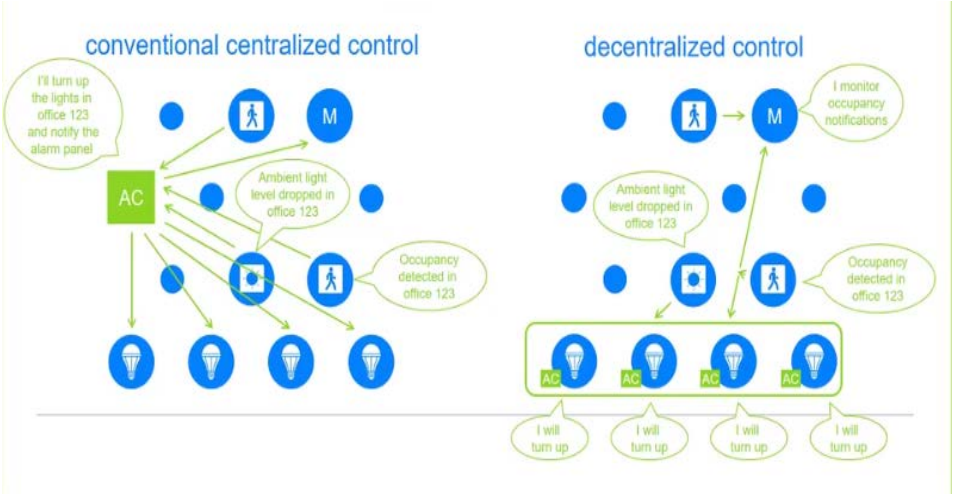
- Bluetooth® mesh networking enables many-to-many (m:m) device communications.
- Bluetooth® mesh networking is ideally suited for creating IoT solutions.
- IoT (Internet of Things) enables tens, hundreds, or thousands of devices need to reliably and securely communicate with one another.
- Bluetooth® mesh was born from the failings of existing wireless specifications.
- Bluetooth® mesh utilises Bluetooth spec. but adds a network Topology

What were the Goals in driving Bluetooth mesh specification

- Multi Node Topology (Thousands of nodes).
- Multi-cast messaging.
- Reliable multi-hop messaging.
- Low latency application.
- Support for battery powered devices (IoT)
- Protection from security threats, hackers.
- Utilise the Bluetooth specification (Bluetooth low energy v4.0 +).
- Using existing smartphone customer base. (Bluetooth is Ubiquitous)

Bluetooth mesh compared to other wireless networks

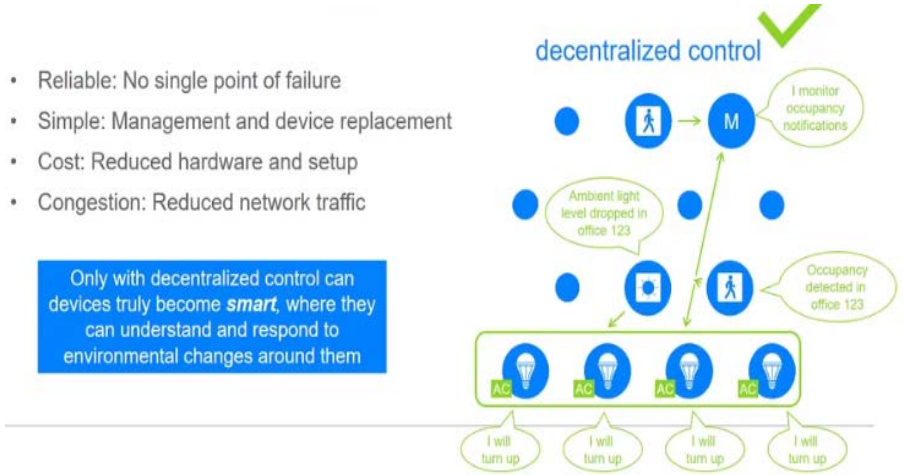
- Bluetooth mesh adopts a Decentralised approach.
- Conventional wireless networks generally use a Centralised control topology.
- Bluetooth Mesh uses a Publish/Subscribe messaging system.
- Sensors publish messages, the lights subscribe and receive messages. The light can respond to the message (reduce light)
- Sensors don't drive anything, they just Publish messages.



Bluetooth mesh compared to other wireless networks

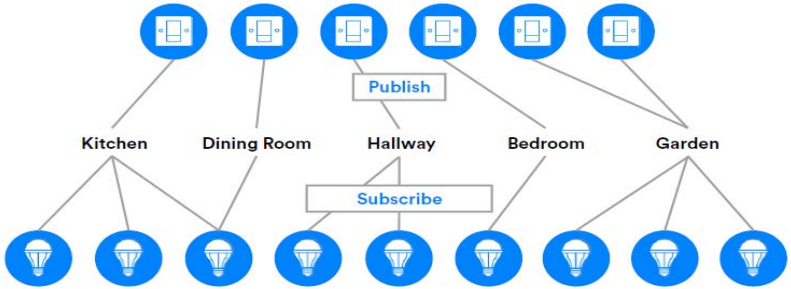
- Huge cost reduction- Control Hardware is gone.
- Les complicated to setup new Nodes.
- No single point of Failure (no controller) mean more reliable
- Easy to replace or scale network with new devices.
- Less Traffic on the network so good for interoperability.

You could say works similar to witter today. The publications are #Tags (switch) and the (light) subscribers receive those #Tag messages flow between them



where is Bluetooth mesh networking being used?

- Control Systems.
  - Lighting control for the Smart Building



- Monitoring systems.
  - networks are monitoring lighting, temperature, humidity.
  - Improve conditions, lower cost, increase efficiency.

- Automation systems.
  - Automatic control of environmental conditions within buildings
  - Lowering costs and saving resources and energy.

Mesh Network Summary.

Traditionally a network using a Router will pass All messages through the Router. If the Router fails then the Network fails.
Bluetooth Mesh Network deploys Managed Flooding to deliver messages.
Messages are Broadcast as opposed to being routed to specific devices.
All Nodes receive messages from within range, if configured to do so, the Node will relay received message.
Relaying is rebroadcasting the message so that more Nodes will receive the message and are further from the original Broadcasted message.

Flooding ensures messages are received from many Nodes, hence it is reliable (Multi delivery)
Managed Flooding ensures efficient operation of received messages (what are they??)

Heartbeats:
Heartbeat messages are sent periodically. These messages have information on how far away and how many hops needed to reach the Rx node. Something called Time To Live (TTL) is used along with the Heartbeat information.
Heartbeats also indicate that a Node is still alive.

Time To Live (TTL):
TTL is used to control how many times a message is Relayed. This conserves energy. When TTL is 0 value, the message will not be rebroadcasted.
Heartbeat messages can help determine what the optimum TTL value should be set to.

Bluetooth Mesh terminology

Scenes. This is a stored collection of states. Imagine a room with lamps at different levels and a temp setting. Save the desired levels and set the Scene by sending a scene-related Mesh Message.

Provisioning. (5 steps)

1. Unprovisioned Device Beacon. (includes Device UUID)
2. Invite New Device
3. Agree on Authentication
4. Share Public Keys
5. Configure Models.

Now Device is a Node in the Network.
The Node can be Blacklisted and reset.

1. Mesh Provisioning Bearers.

a) PB ADV. Uses LE ADV packets, Mandatory to support
b) PB-GATT. Uses GATT Services , optional to support. To provide Mesh capability on legacy devices.

Mesh Topology

Nodes that support the various features described above can be formed into a mesh network. An illustration of a mesh network is shown in Figure 2.8 below.

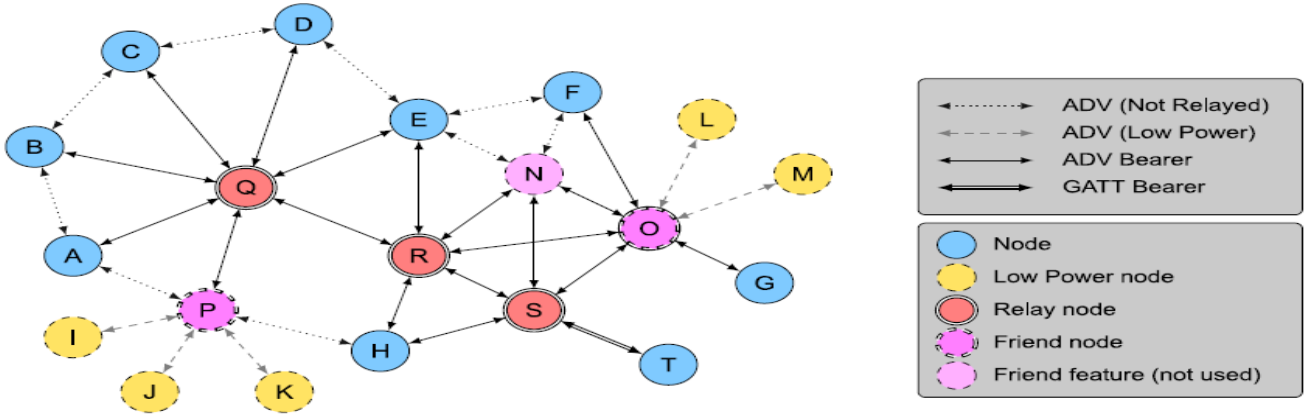


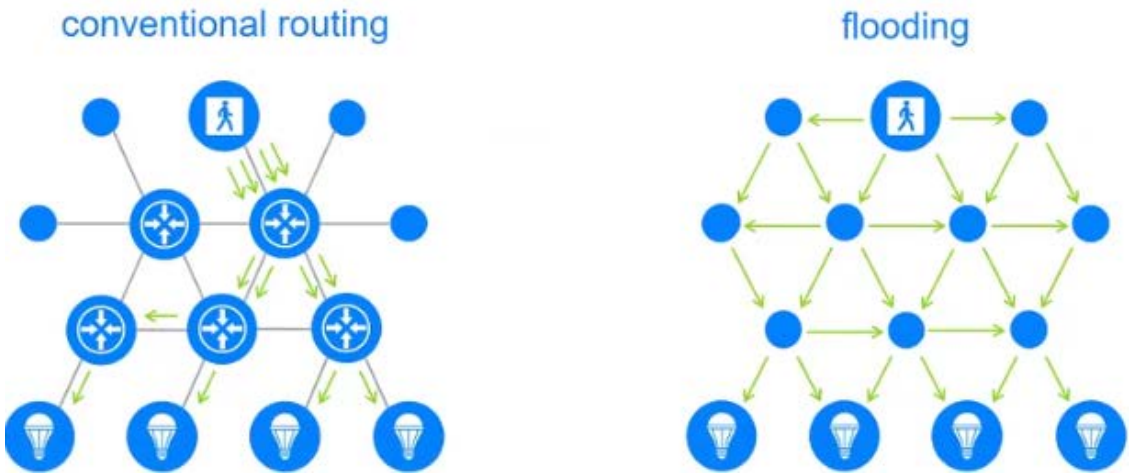
Figure 2.8: Example Topology of a mesh network

Figure 2.8 shows three Relay nodes: Q, R, and S. The three nodes that support the Friend feature are N, O, and P, however N does not have any friendships; therefore only O and P are Friend nodes. There are five Low Power nodes: I, J, K, L, and M. Nodes I, J, and K have P as their friend, while L and M have O as their friend. Node T is only connected to the mesh network using a GATT bearer; therefore S must relay all messages to and from T.

For example, if a message is to be sent from T to L, then T will send the message to node S using the GATT bearer. Node S will retransmit this message using the advertising bearer. Nodes H, R, N, and O are within radio range of node S; therefore they will receive this message. Node O, being the friend of node L will store the message, and if the message was a segmented message, node O will respond with an acknowledgment at the lower transport layer. Sometime later, L will poll node O to check for new messages, such that O will forward the message originally sent by T to L.

Message Routing V Message Flooding

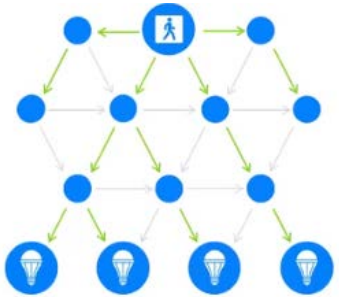
- Conventional Message Routing is a standard method in todays networks.
- Routing developed for wired networks, wireless brings other challenges.
- Wireless networks are not good at routing.
- Mesh Goals not a good fit for routing (multicast messaging, Group communication, publish/subscribe…)
- Message Flooding brings Congestion to the network !
- Managed Flooding developed to manage this issue of congestion brought by Broadcasting messages.



Managed Flooding

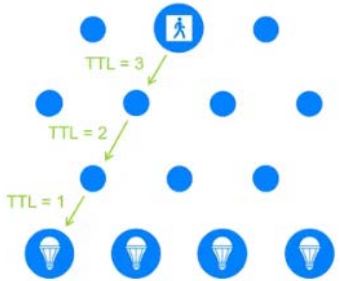
- Managed Flooding is designed to reduce the number of messages on the network.

Message Caching



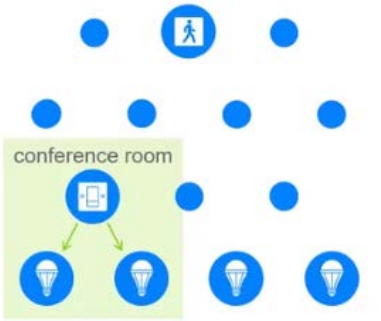
Nodes do not relay messages already seen

Time-to-Live counter



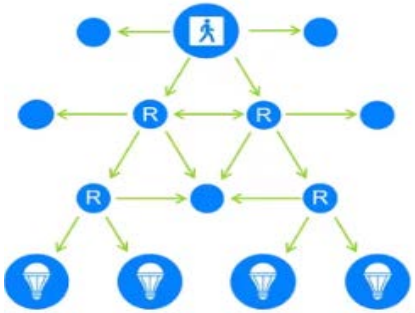
Nodes only relay messages with TTL >=1

Subnets



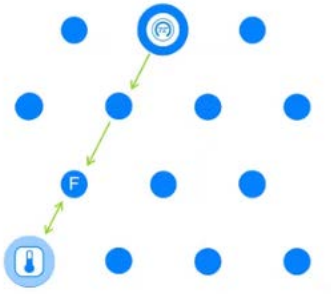
Messages can be confined within a subnet

Message relay



Only nodes with the *Relay* function provisioned retransmit messages

Low Power and friend nodes



Low Power nodes find nodes with *Friend* function provisioned to cache messages for them

Mesh Security.

Mesh Security is Mandatory:

Bluetooth low energy allows the designer to apply a range of security levels from Pairing to implementing own security level.
It is possible to have a low energy device with No security (open device)

However, with Mesh implementation, security is Mandatory. The Network, Application and Devices are all secure and Cannot be disabled.

Fundamentals:

- All Mesh messages are encrypted.
- Network, Application and Device security works independently of one another.
- Security Keys can be changed during the life of a Mesh.
- Message Obfuscation makes it difficult to track Nodes

  Obfuscation:
  The network security model utilizes a privacy mechanism called obfuscation that utilizes AES to encrypt the source address, sequence numbers, and other header information using a privacy key. The intent for obfuscation is to make tracking nodes more difficult.

- Mesh Security protects against “Replay Attack”.
- The Provisioning process is itself a security measure.
- Nodes can be removed securely in a way that prevents Trashcan attacks.

Mesh Security. (“Separation of Concerns”)

There are 3 types of security keys in a Mesh Network (Network, Application and Device keys)
These keys are independent of one another.
A device such as a light bulb could also relay a message to a Door for example. The Light Node can Relay the message without knowing or being able to access its content (no need to know) . Hence the separation of concerns.
Different Keys are used at the Network level as opposed to keys used to secure Data at application level.

Network Keys: (NetKey)
Nodes possess Network Keys. A network encryption key and a Privacy Key are derived from NetKey.
Now it is possible to decrypt up to Network layer.
Networks can have subnetworks which have their own NetKeys (like rooms in a Hotel)
(Privacy Key derived from NetKey and used to Obfuscate Network PDU Hearer values)

Application Key: (AppKey)
Application Data for specific Apps can only be decrypted if Node has right AppKey.
Across a Mesh there can be many AppKeys. Example Light switches and bulbs would possess the AppKey for Lighting but not the AppKey for heating system.
AppKey is used to decrypt application message before going to Access Layer.
AppKey is accociated with only one NetKey, this is called Key Binding

Device Key: (DevKey)
The DevKey is used for Provisioning and only knowen by the Provisioner. This makes Provisioning a secure procedure.

Why Bluetooth mesh is a “Disruptive Technology”

- Scalable
- Reliable
- Security
- Smartphone utilization
- Global Interoperability
- Open standard.
- Maturity due to learning from other wireless limitations.
- Bluetooth proven technology that just works!

> We feel like we are changing the world. We feel very strongly that we've just delivered a third Bluetooth revolution... I think we've taken a significant part of the world by surprise because Bluetooth has always been considered a small personal system. And suddenly we are coming out with something that's so complete, so well-performing, and addressing completely new territories.
>
> *Szymon Slupik*
> *Silvair CTO and Bluetooth SIG Mesh Working Group Chair*

Conclusion.

Bluetooth mesh networking brings multi-vendor interoperability.

Employing, Low power and low latency features of Bluetooth LE , will allow the creation of reliable, responsive, secure and scalable wireless Network systems.

These systems can evolve to act as a platform for distributed wireless building services that will deliver business benefits by helping establish efficient building environments.

The Mesh specification is scalable, in that you could start with Lighting control then add other functionalities in your building such as sensors for occupancy, heating, environmental control, etc.

this can lead to more efficiency and manageable structure support and control

Bluetooth®

Bluetooth market update

2018

table of contents

a letter from the executive director

In 2018, nearly 4 billion devices will ship with *Bluetooth*® technology. Thanks to Bluetooth mesh networking and the momentum of Bluetooth 5, Bluetooth is now poised as an industrial-grade connectivity solution that will be the wireless constant in the Internet of Things (IoT) for decades to come.

Since its inception 20 years ago, Bluetooth has continuously evolved, expanding the universe of innovative ways for things to connect — driving innovation and creating new markets. Whether it is a connection for wireless audio, wearable devices, tracking assets, or automating buildings, Bluetooth is the innovative force creating new consumer, commercial, and industrial markets.

It's an honor to be part of such an incredible community.

Mark Powell | *Executive Director* | *Bluetooth SIG, Inc.*

20 years
of **blue.**
(thanks to you)

what is Bluetooth SIG, Inc.?

Formed in 1998, the Bluetooth Special Interest Group (SIG), Inc. is the organization at the heart of Bluetooth technology, serving industry-leading member companies across the globe.

Based in Kirkland, Washington, USA, we operate as a nonprofit trade association that works with its member companies to perfect and advance a flexible, reliable, and secure wireless communication solution that solves market challenges and helps realize a better future.

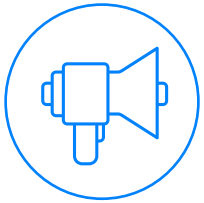
The Bluetooth SIG manages three charter programs:

Specification

We expand the capabilities of Bluetooth technology by facilitating the collaboration of our member companies to create new and enhanced Bluetooth specifications.

Qualification

We drive Bluetooth interoperability through a world-class member product qualification program that includes access to the Bluetooth technology and trademark license agreements.



Promotion

We grow the Bluetooth brand by increasing the awareness, understanding, and adoption of Bluetooth technology.

what is the Bluetooth Market Update?

The Bluetooth community continually expands the technology to solve new connectivity challenges and address new market opportunities.

Supported by updated forecasts from ABI Research*, the Bluetooth Market Update examines:

- The growth and health of the Bluetooth SIG member **community**
- The trajectory of Bluetooth **technology**, including trends and forecasts for each radio version and the key Bluetooth solution areas
- New trends in traditional Bluetooth **markets** as well as forecasts in emerging markets in which Bluetooth is taking on an expanded role

The Bluetooth Market Update is intended to help global IoT decision makers stay up-to-date on the role Bluetooth technology can play in their technical roadmaps and markets.

The trends identified in the Bluetooth Market Update highlight the direction of the Bluetooth member community and technology as Bluetooth continues its expansion from a personal communication solution to an industrial-grade connectivity engine.

*Unless otherwise indicated, numbers are derived from ABI Research. Data files include: Wireless Connectivity Technology Segmentation - Addressable Markets, Indoor Positioning RTLS Technology Infrastructure Applications. Forecasts do not constitute a promise to ship.

Over the last 20 years, Bluetooth has been pivotal in enabling compelling customer experiences. It has been one of the key technologies underpinning the consumer wireless revolution. The Bluetooth community continues to grow and extend as the technology enhances its specification in order to retain its prominent position in future markets.

Stuart Carlaw
Chief Research Officer,
ABI Research

Bluetooth is more than a technology. It's also a community.

An incredible community of more than 33,000 member companies driven to continually advance wireless connectivity to create a better world.

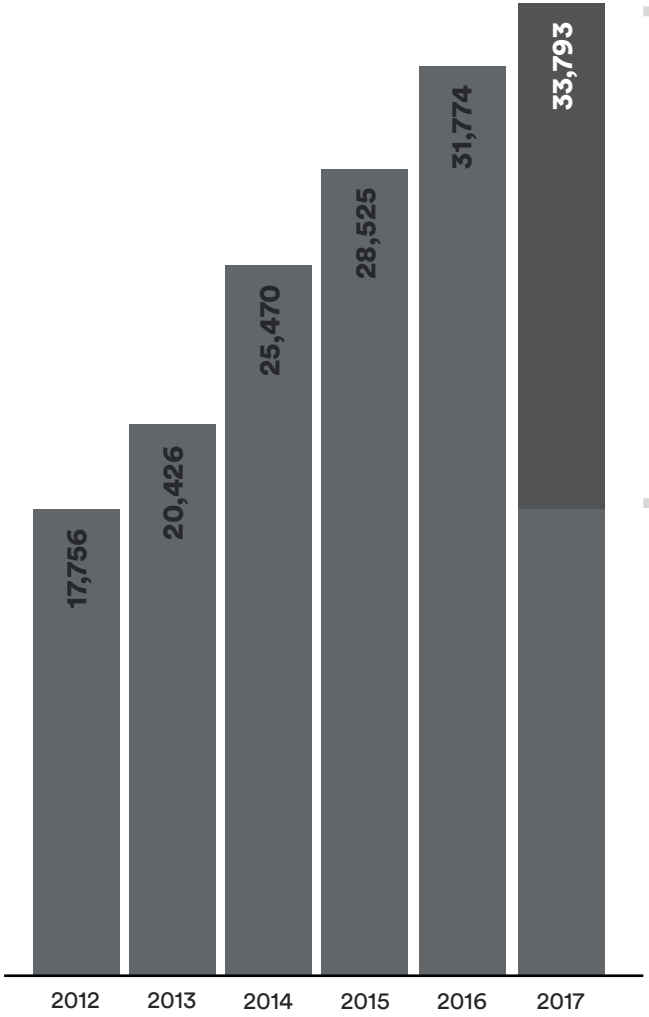
community

membership

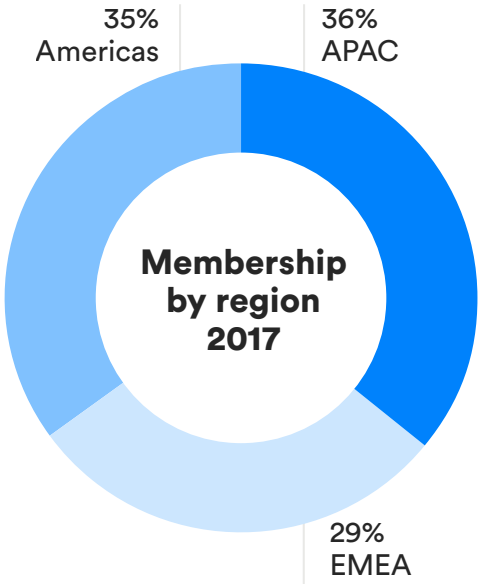
Membership at the Bluetooth SIG continues to experience strong growth. By the end of 2017, the community grew to over 33,000 companies spread evenly across all regions of the world, highlighting the true global footprint of Bluetooth technology.

Learn more about membership

Total Membership



90% growth in membership over 5 years



Source: Bluetooth SIG, as of 31 Dec 2017

specifications

The hard work and commitment of our working groups and committees deliver continuous innovation. With the help of 2,004 new group and committee participants in 2017, the Bluetooth SIG working groups delivered nearly one new or updated specification each month.

These groups and committees are the reason Bluetooth technology is the global wireless standard powering the Internet of Things.

Learn more about working groups

Working Groups are the backbone of the Bluetooth SIG, bringing specifications to life.

15
Working Groups

70
Active Specification Projects

11
New/Updated Specifications in 2017

2,004
New group and committee members in 2017

Bluetooth 5

Only nine months after the release of the latest version of the Bluetooth core specification, many of its new features became commercially available in products from the world's leading smartphone vendors. This sets the stage for the widespread adoption of those features in peripherals, beacons, and other key IoT enabling devices.

Learn more about Bluetooth 5

2x speed
more performant devices

4x range
whole building coverage

8x data
richer location services

Bluetooth 5 found its way into high-volume consumer products faster than any of our previous technology releases. Now, less than a year after its initial release, Bluetooth 5 is available from all the leading smartphone vendors on the planet.

Mark Powell
Executive Director | Bluetooth SIG

Bluetooth 5 adoption: 7 Dec 2016

Bluetooth mesh

In 2017, the Bluetooth SIG added mesh networking capability to Bluetooth.

The mesh topology, now available on Bluetooth Low Energy, enables the creation of large-scale device networks and is ideally suited for control, monitoring, and automation systems where tens, hundreds, or thousands of devices need to reliably and securely communicate with one another.

Learn more about Bluetooth mesh

industrial-grade solution

proven, global interoperability

mature, trusted technology

We feel like we are changing the world. We feel very strongly that we've just delivered a third Bluetooth revolution... I think we've taken a significant part of the world by surprise because Bluetooth has always been considered a small personal system. And suddenly we are coming out with something that's so complete, so well-performing, and addressing completely new territories.

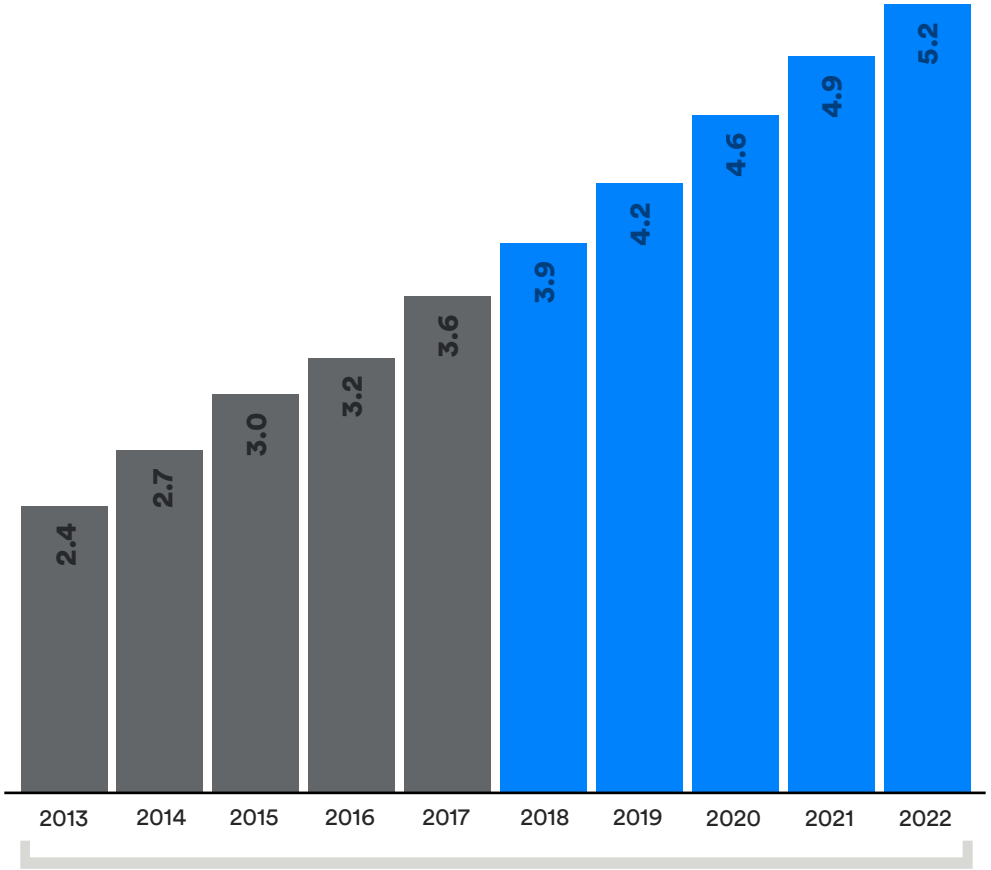
Szymon Slupik
Silvair CTO and Bluetooth SIG Mesh Working Group Chair

shipments

Thanks to a membership community driven to expand the technology's capabilities to address new markets, Bluetooth shipments have maintained uncommonly consistent growth, and show no signs of slowing down.

Total Bluetooth Device Shipments

numbers in billions



12%

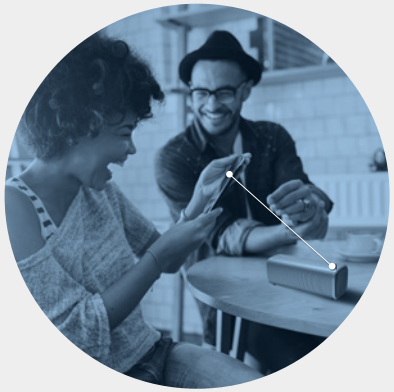
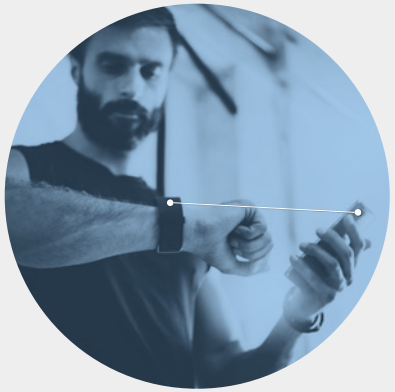
compound annual growth rate (CAGR) over 10 years

More than just a radio technology, Bluetooth provides full stack, fit-for-purpose solutions aimed at addressing specific connectivity needs.

technology

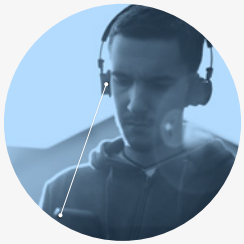
expanding to meet the needs of the IoT

As the demands of the IoT continue to grow, so does Bluetooth. After first addressing point-to-point connectivity, Bluetooth expanded into broadcast communications to enable indoor positioning and location services. Now, Bluetooth mesh networking has propelled Bluetooth into emerging markets in need of a reliable wireless solution to establish large-scale device networks.

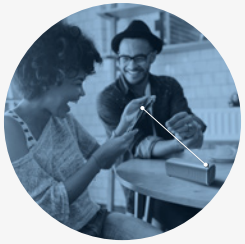
	audio streaming	data transfer	location services	device networks
solution				
	wireless headsets wireless speakers in-car infotainment	sports & fitness devices health & wellness devices peripherals & accessories	point of interest information navigation & way finding item & asset tracking	control systems monitoring systems automation systems
topology	point-to-point	point-to-point	broadcast	mesh
radio	Bluetooth Basic Rate/ Enhanced Data Rate (BR/EDR)	Bluetooth Low Energy		

audio streaming

The point-to-point topology available on Bluetooth BR/EDR is optimized for audio streaming, making it the standard-bearer in wireless audio.



Wireless headsets - The original device of the wireless audio market, Bluetooth headsets are now a must-have accessory for mobile phones.

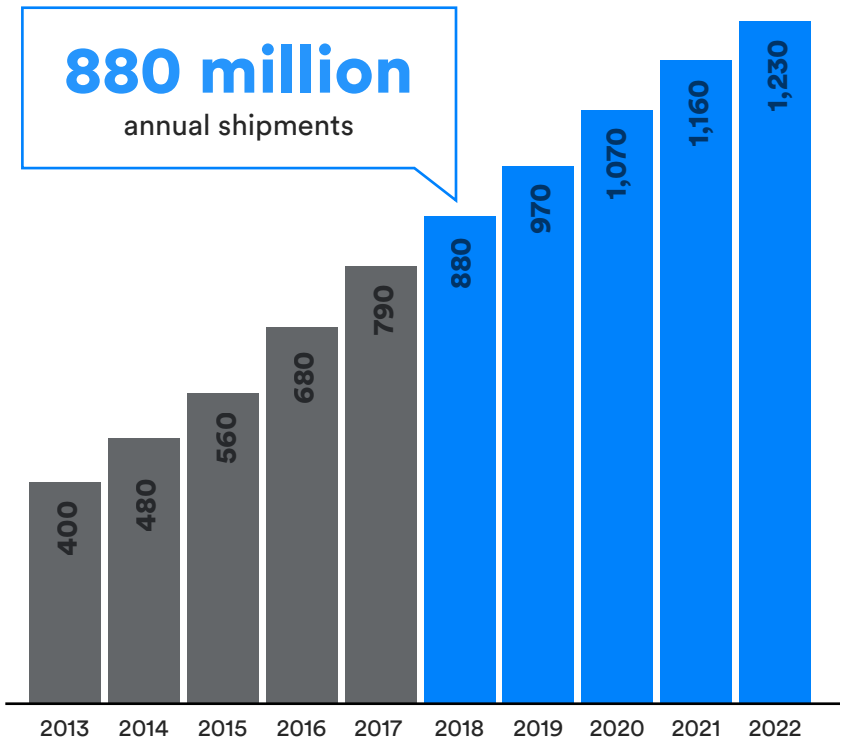


Wireless speakers - Whether it's a high-fidelity entertainment system in the home or a portable option for the beach or park, there's a speaker for any occasion in every imaginable shape and size.

In-car systems - Bluetooth in-car infotainment systems pair with driver smartphones to enable hands-free audio streaming and calling, allowing drivers to keep their focus on what matters most.

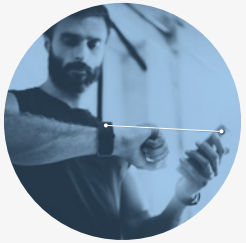
Bluetooth Device Shipments

numbers in millions



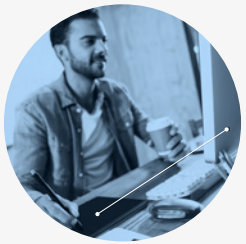
data transfer

The Bluetooth Low Energy point-to-point topology is optimized for very low-power data transfer, making it ideal for connected device products.



Sports & fitness - Bluetooth powers wearables like fitness trackers and smart watches that are showing up on wrists everywhere to monitor steps, exercise, activity, and sleep.

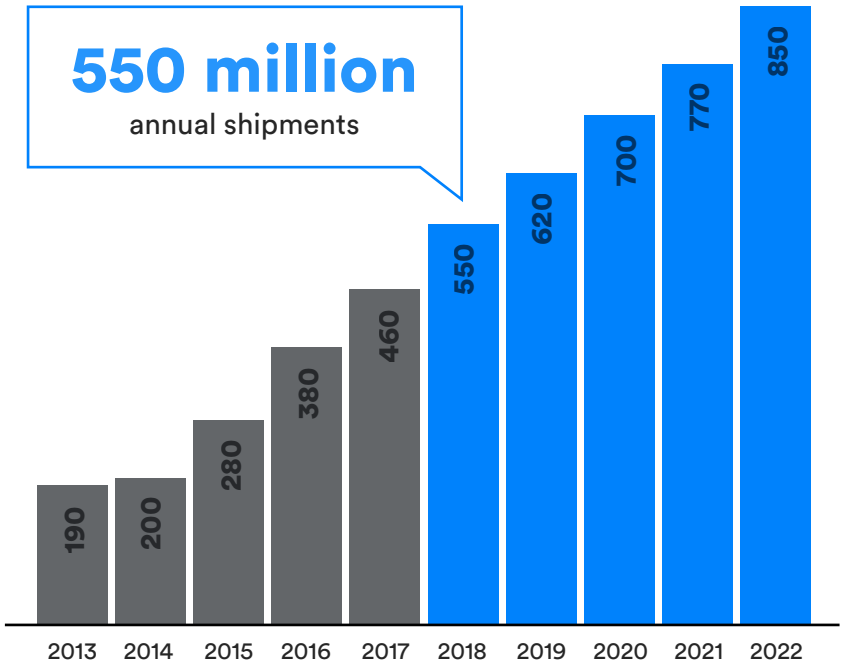
Health & wellness - From blood pressure monitors to portable ultrasound and x-ray imaging systems, Bluetooth technology helps people track and improve their overall wellbeing, while making it easier for healthcare professionals to provide quality care.



PC peripherals & accessories - A driving force behind Bluetooth is freedom from wires. Whether it's a keyboard, trackpad, or mouse, consumers no longer need wires to stay connected.

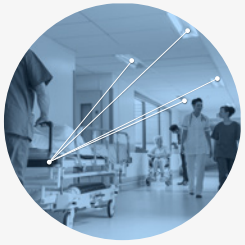
Bluetooth Device Shipments

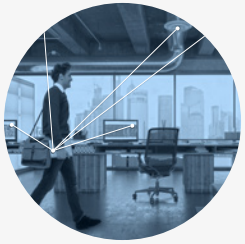
numbers in millions



location services

The broadcast topology available on Bluetooth Low Energy is ideally suited for enabling indoor positioning and location services.





Point-of-interest information - Retailers were among the first to adopt point-of-interest (PoI) beacons. Smart cities are now discovering how PoI beacons can improve the quality of life for citizens and enhance the visitor experience.

Indoor navigation - Bluetooth beacon-based indoor navigation and way-finding solutions have quickly become the standard way to overcome indoor coverage challenges that GPS can't address.

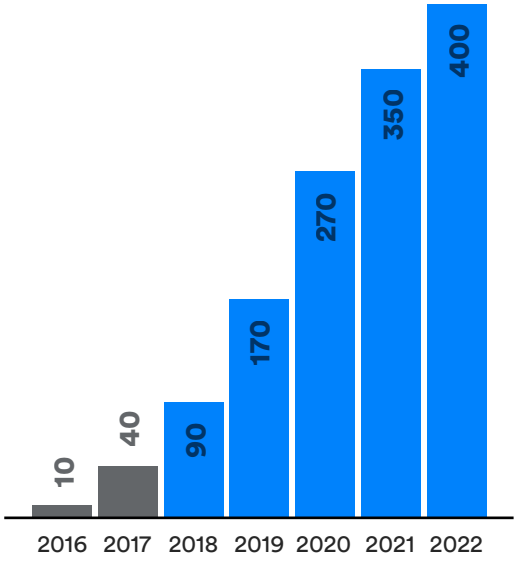
Asset and item tracking - Bluetooth beacons power the rapidly growing asset tracking and item finding markets, from inexpensive personal item tracking solutions to large-scale asset tracking solutions found in hospitals and factory floors.

Space utilization - Bluetooth beacon solutions are being deployed within office buildings, airports, exhibition centers, and even on city streets around the world to enable building owners and city planners to better understand how space is being used.

Bluetooth Device Shipments

numbers in millions

400 million
annual shipments



device networks

The mesh topology on Bluetooth Low Energy is optimized for creating large-scale device networks.

Control systems - Bluetooth mesh is quickly being adopted as the wireless communications platform of choice in a number of control systems, including lighting control solutions for the smart building and smart industry markets.

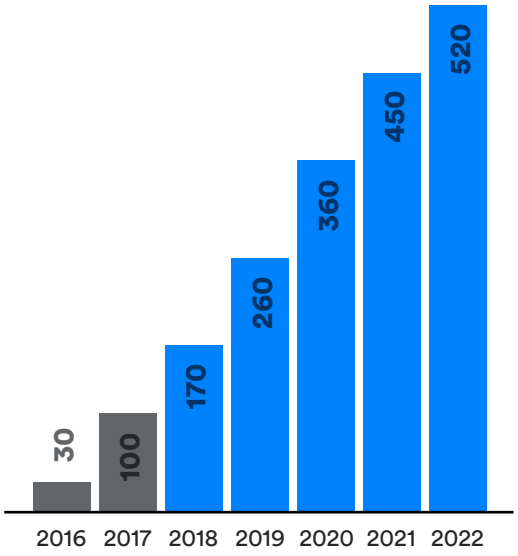
Monitoring systems - Bluetooth wireless sensor networks (WSN) are monitoring light, temperature, humidity, and occupancy to improve employee productivity, lower building operating costs, or better meet condition and maintenance requirements of production equipment to reduce unplanned downtime.

Automation systems - Bluetooth enables the automatic, centralized control of a building's essential systems, including heating, ventilation and air conditioning (HVAC), lighting, and security to harness energy savings, lower operating costs, and improve the life span of a building's core systems.

Bluetooth Device Shipments

numbers in millions

520 million
annual shipments



shipments by solution area

2x

growth in annual volume of audio streaming and data transfer solutions by 2022

Point-to-point is still on the rise

Despite Bluetooth technology's expansion to support a wider range of topologies and emerging use cases, the use of Bluetooth for audio streaming and data transfer continues to grow, with annual shipments expected to double in the next five years.

10x

growth in annual volume of Bluetooth location services devices by 2022

Location services have the steepest 5-year growth forecast

Bluetooth indoor positioning and location services are poised to be the fastest growing solution area. Bluetooth based location solutions are increasingly deployed by smart buildings and venues around the world to enable point-of-interest solutions, way finding, asset tracking, and space utilization.

5x

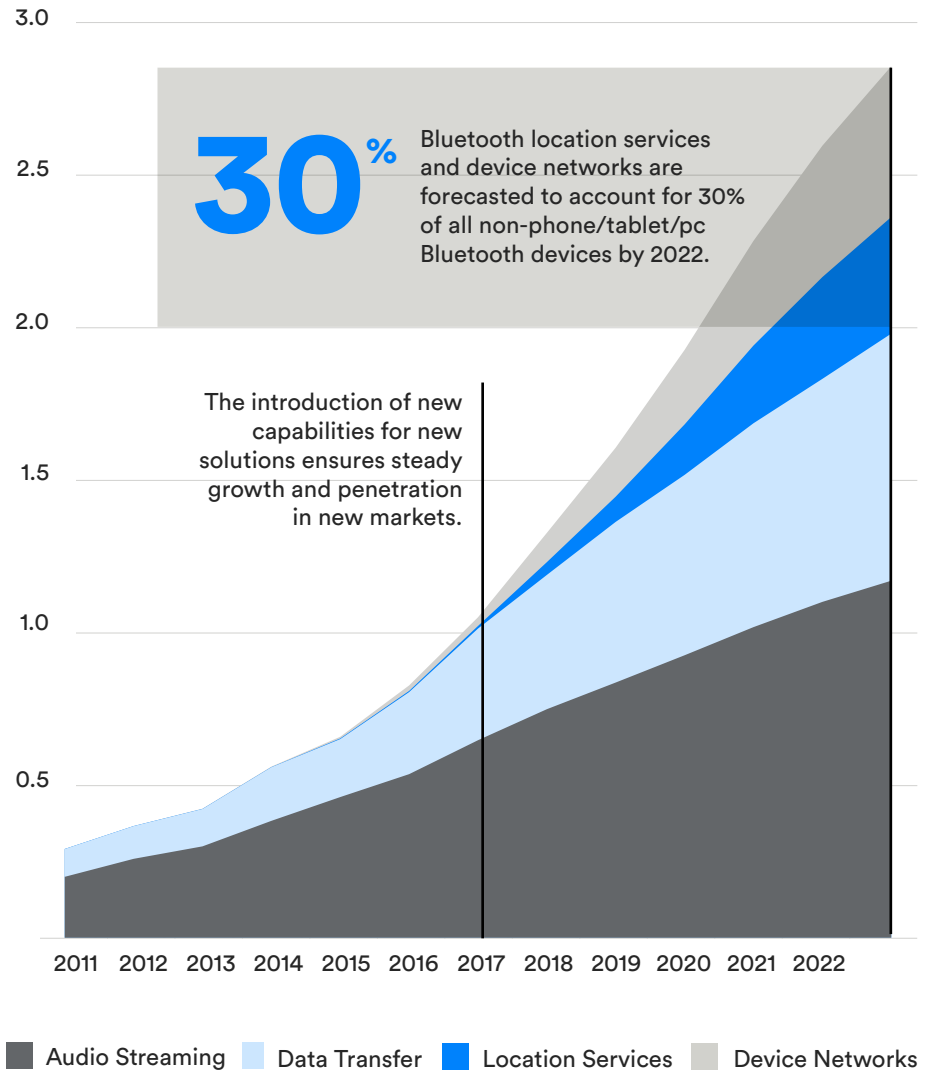
growth in annual volume of Bluetooth device network products by 2022

Device network solutions are predicted to grow rapidly

The launch of Bluetooth mesh has accelerated the growth of device network solutions. Lighting control systems and wireless sensor networks are two use cases driving the increase in device network implementations.

Bluetooth Device Shipments

numbers in billions



*Phone, tablet, and PC devices not included

shipments by radio version

1/3

Bluetooth Low Energy (LE) single-mode chips are forecasted to account for more than 1/3 of all shipments by

Demand for low energy spurs rapid growth in Low Energy single-mode chips

The rapid adoption of connected device solutions across multiple markets and the accelerated deployment of location services are driving swift momentum in Bluetooth Low Energy single-mode chip solutions.

97%

of all Bluetooth chips shipped in 2022 will contain Low Energy technology

65%

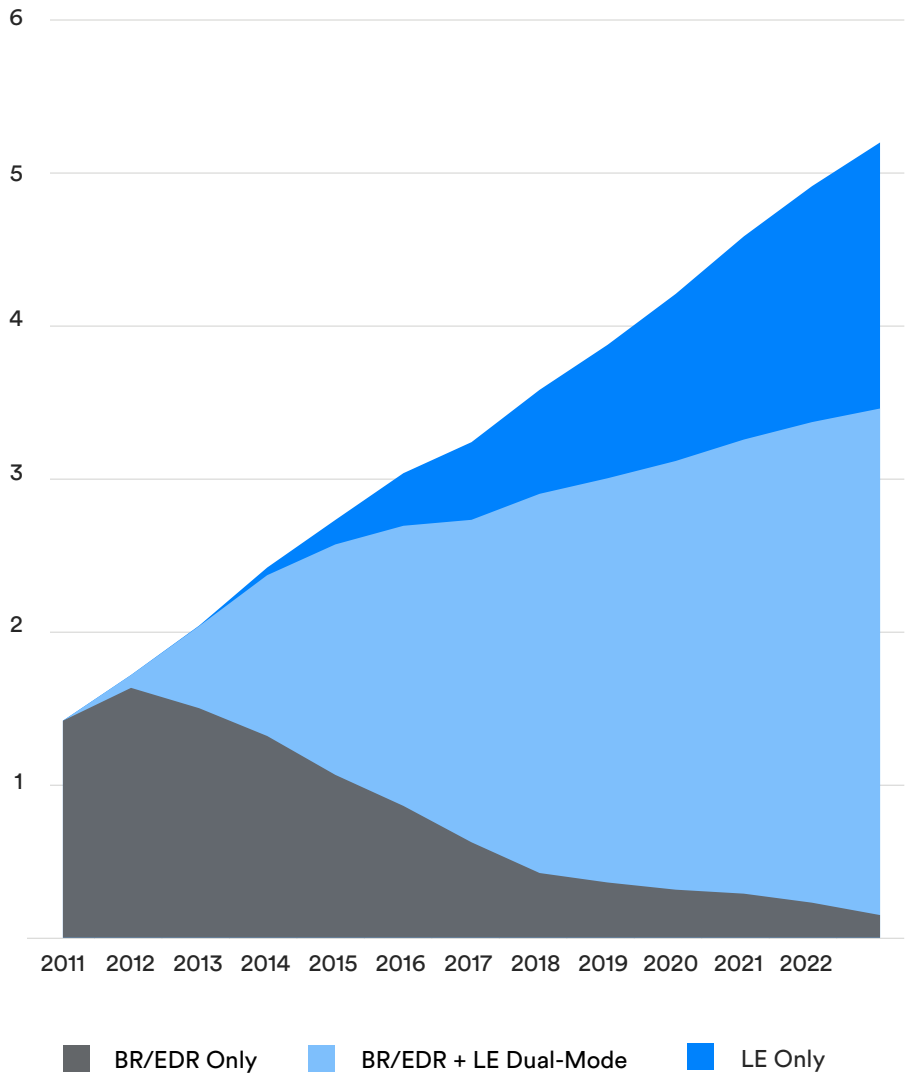
of all Bluetooth chips shipped in 2022 will contain BR/EDR technology

Multi-purpose functionality is driving sharp growth in dual-mode chips

Since the 2010 release of Bluetooth Low Energy, shipments of dual-mode Bluetooth chips have followed a steep growth trajectory. By 2022, 97% of all Bluetooth chips are expected to contain Low Energy technology.

The wireless audio community continues to leverage the streaming capabilities of Bluetooth BR/EDR, and increasingly turns to dual-mode chips to accommodate multiple use cases within audio devices.

Bluetooth Device Shipments



Connection drives innovation.
Innovation creates markets.

For two decades, Bluetooth technology has been creating connections that power innovation, establish new markets, and push the limits of wireless communication worldwide.

markets

phone, tablet & PC

Phones, tablets, and PCs have become portals through which people experience every thing and every place. And Bluetooth technology is native in all of them.

With over 2 billion of these Bluetooth devices expected to ship in 2018, industry leaders are increasingly turning to Bluetooth to power their IoT solutions.

phone, tablet & PC

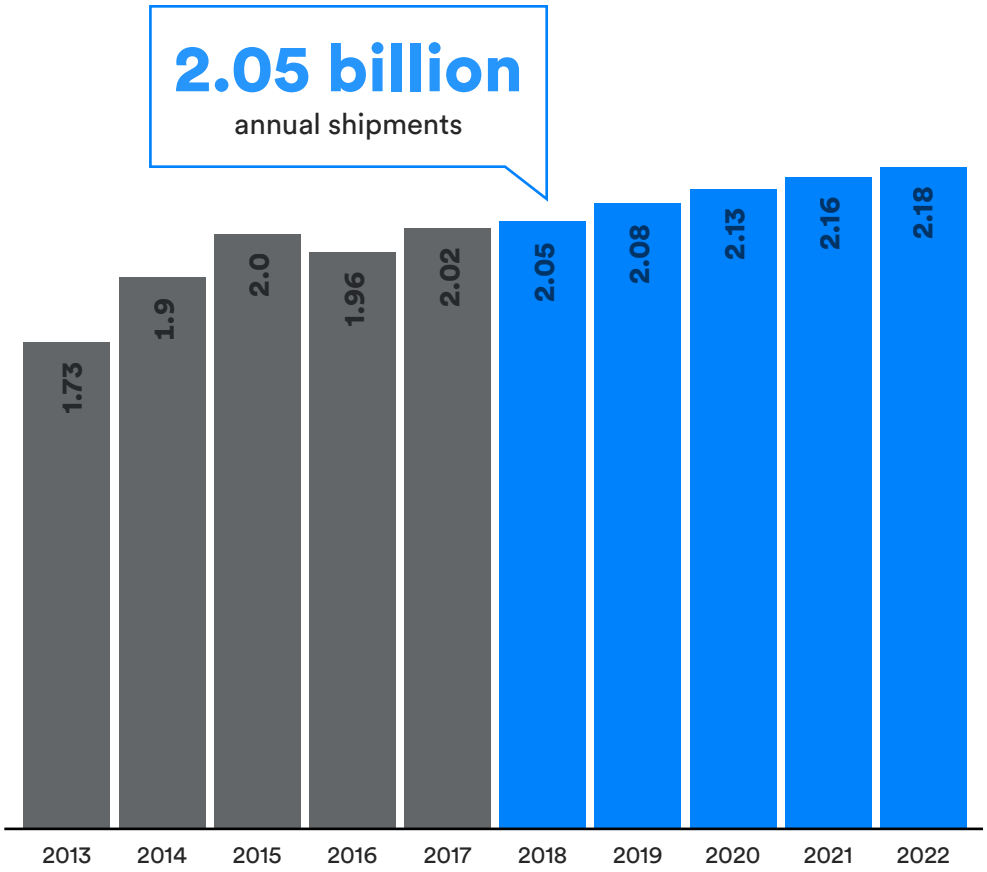
market numbers

100%

of smartphones, tablets, and laptops shipped in 2018 will include Bluetooth

Bluetooth Device Shipments

numbers in billions



phone, tablet & PC

market insights

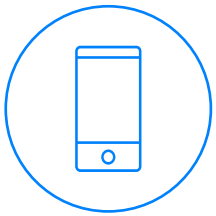
Rapid adoption of Bluetooth 5 in smartphones

The latest version of the Bluetooth core specification found its way into its first smartphone faster than any previous release, further accelerating the widespread deployment of connected devices, beacons, and key IoT enabling solutions.

The trend to design out the audio jack continues

The proven reliability of Bluetooth audio has inspired smartphone manufacturers to design the audio jack out of the phone.

This trend signals increased confidence in Bluetooth as a complete wire replacement and positions Bluetooth as the default way to listen to audio.



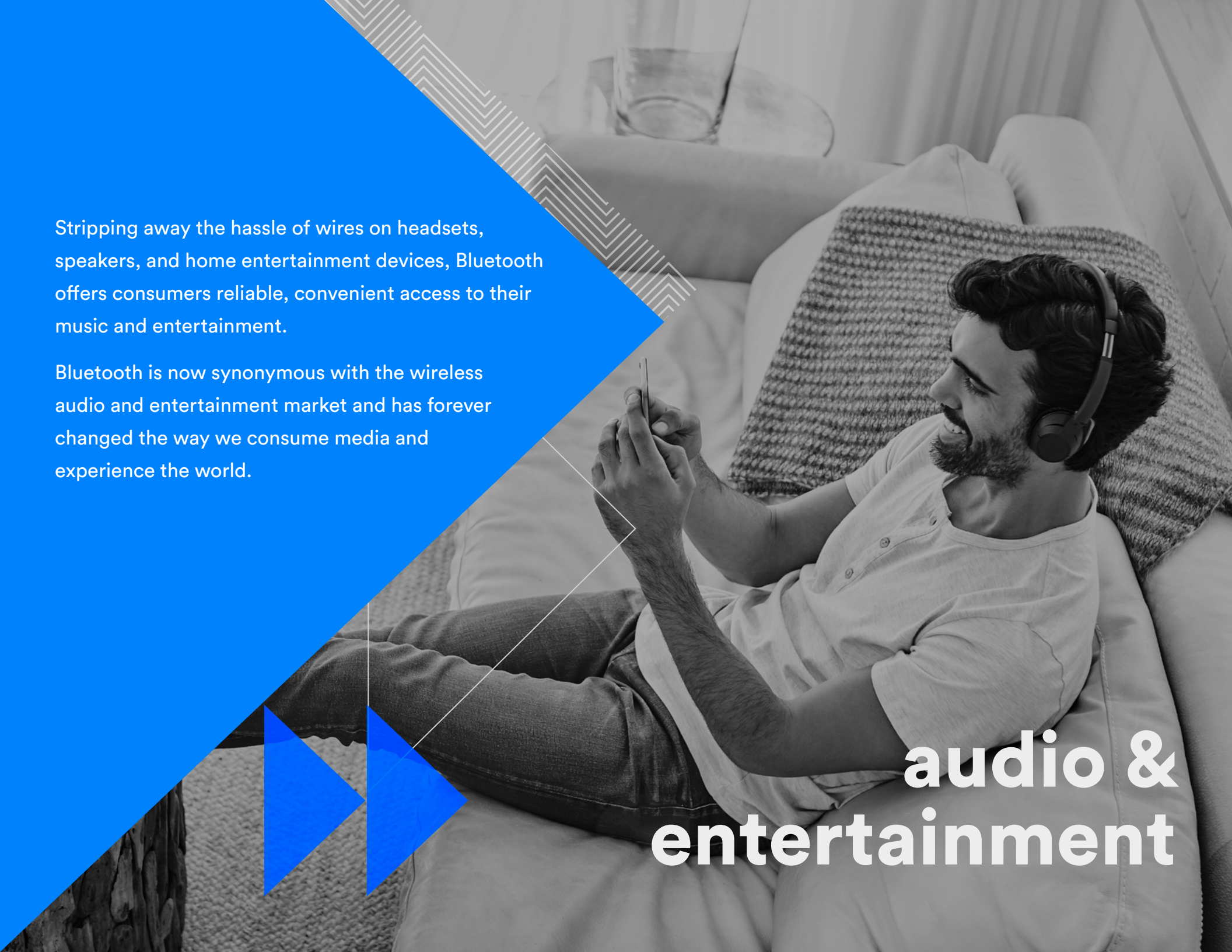
Smartphones become central in industrial and commercial use cases

The phone is emerging as a provisioner and central tool for new commercial and industrial use cases such as location services and building automation, making Bluetooth even more essential in mobile devices.

Device pairing becomes even easier

Major device vendors are enhancing the discovery and pairing experience and making a simple process even easier.

Learn more about the phone, tablet & PC market



Stripping away the hassle of wires on headsets, speakers, and home entertainment devices, Bluetooth offers consumers reliable, convenient access to their music and entertainment.

Bluetooth is now synonymous with the wireless audio and entertainment market and has forever changed the way we consume media and experience the world.

audio & entertainment

audio & entertainment

market numbers

8 out of 10

speakers will include Bluetooth by the end of 2022

100%

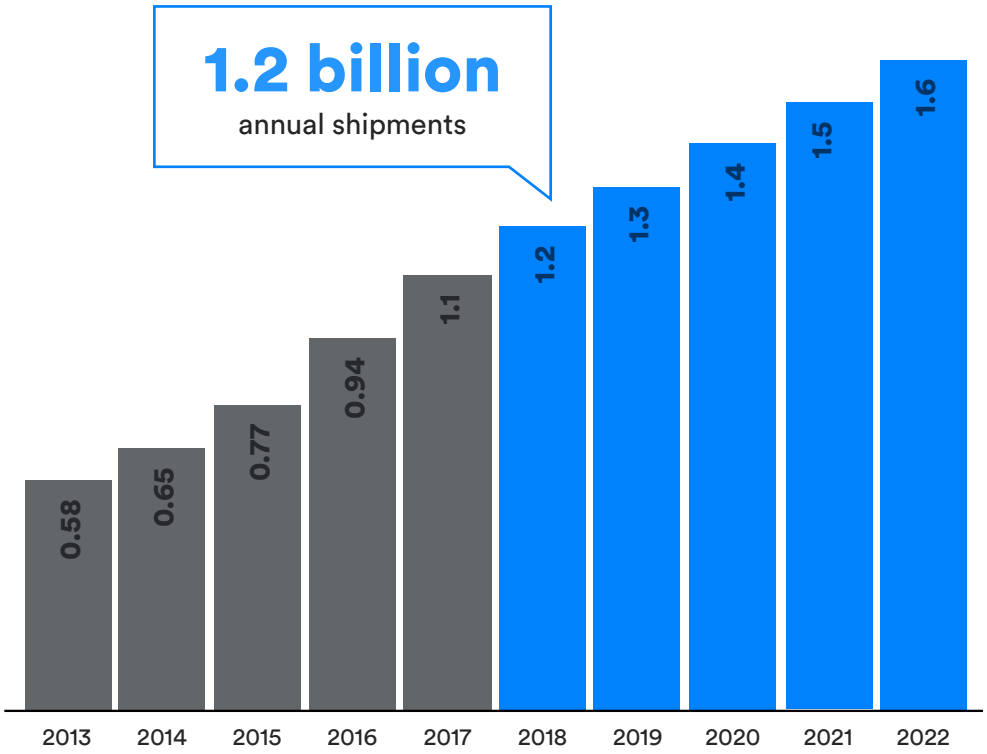
of wireless game controllers shipped in 2018 will include Bluetooth

3x

growth in annual volume in the smart speaker market by the end of 2022

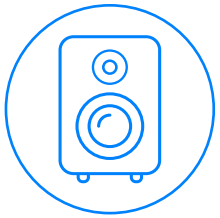
Bluetooth Device Shipments

numbers in billions



audio & entertainment

market insights



The transition to wireless speakers is almost complete

Steady growth in portable speakers, soundbars, and home theaters signal confidence in Bluetooth quality and reliability. By 2022, 80% of all speakers will include Bluetooth technology.

Headsets, headphones, and earbuds lead market growth

Wireless headsets, headphones, and earbuds account for over 80% of the overall audio market. Notably, earbuds are starting to assert their dominance in the market.

Bluetooth is now dominant in game controllers, with TV remotes following the trend

The transition away from proprietary solutions to Bluetooth is underway in remote controls. Bluetooth is now the dominant wireless technology within game controllers, with TV remotes on a similar trajectory.

Smart speakers emerge in the connected home

A new category of speaker has emerged. The smart speaker market will double in annual volume by the end of 2018 and is forecasted to grow 3x by the end of 2022.

Hearing aids begin the transition to Bluetooth

2017 saw a steady stream of announcements from hearing aid manufacturers, trusting Bluetooth to provide medical-grade audio quality to the hearing-impaired community.

Learn more about the audio & entertainment market

A mainstay in the automotive market, Bluetooth technology has created connections between car and driver that have brought new levels of safety to our roads and more convenience to the in-car experience.

Bluetooth is the leading technology behind in-car infotainment systems that enable hands-free calling and audio streaming, and is now powering emerging use cases for keyless entry, in-vehicle wearables, and connected maintenance.

automotive

automotive

market numbers

86%

of new cars, trucks, and SUVs shipped worldwide in 2018 will come standard with Bluetooth

4.5x

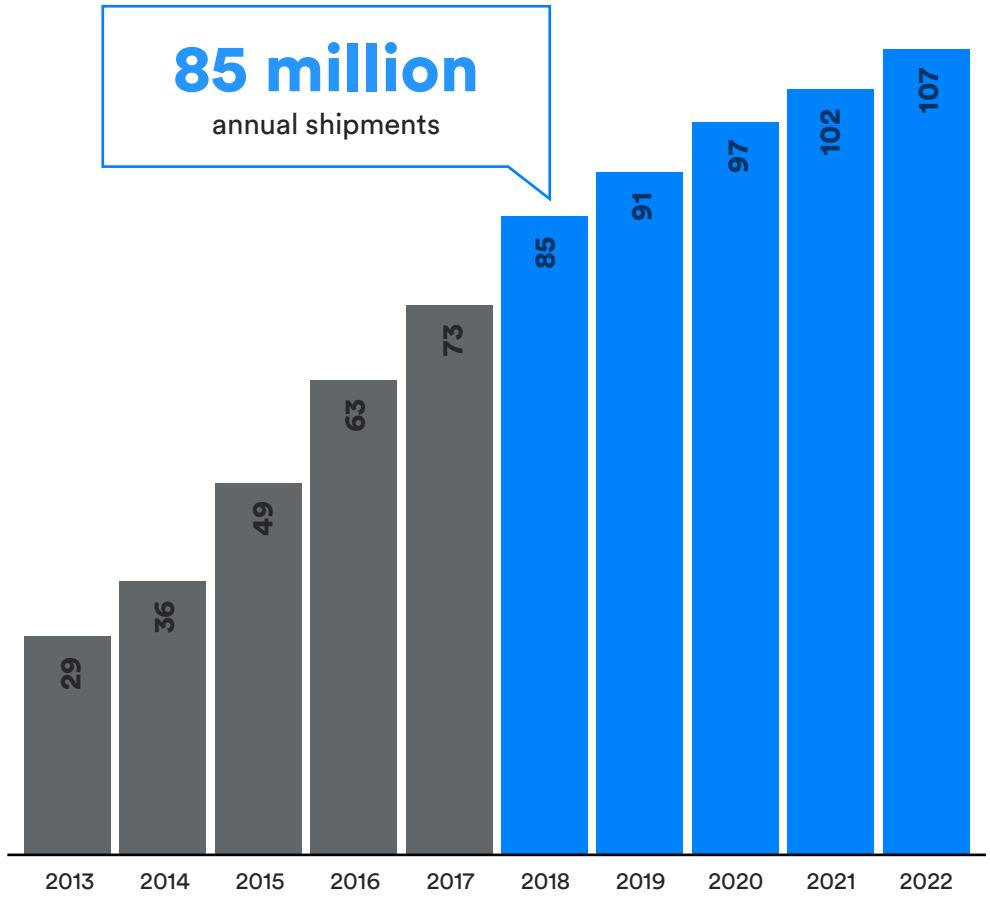
growth in annual volume of under-the-hood Bluetooth devices shipped by 2022

85%

of Bluetooth automotive device shipments will be in-car infotainment systems in 2018

Bluetooth Device Shipments

numbers in millions



automotive

market insights

Bluetooth is now standard equipment in most new cars

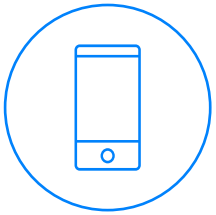
In 2018, 86% of all new vehicles will include Bluetooth connectivity.

In-car infotainment systems will account for 85% of Bluetooth automotive device shipments in 2018.

Wearables are becoming part of the automotive market

Bluetooth is powering in-vehicle wearables that monitor blood pressure, heart rate, and activity levels, triggering driver alerts when detecting signs of sleep or fatigue.

In-vehicle wearables will show strong growth in volume over the forecast period.



Smartphones are becoming the new key fob and more

The key fob migrating into the smartphone will enable a wider variety of convenience features, including proximity detection for automatic locking and unlocking, custom seat positioning, and the transfer of virtual keys to additional drivers.

Bluetooth is being adopted for under-the-hood solutions

Bluetooth wireless sensor systems simplify maintenance in both commercial fleets and consumer vehicles by transferring diagnostic information and alerts to service management solutions.

The volume of under-the-hood devices shipped each year is forecasted to grow 4.5x by 2022.

Learn more about the automotive market

From everyday household items to health and wellness devices that are changing the face of healthcare, Bluetooth is the common thread across the connected device market.

By connecting billions of everyday devices and enabling the invention of countless more, Bluetooth technology is helping transform the IoT vision into reality.

connected device

connected device

market numbers

4x

growth in annual smartwatch shipments over the next 5 years

102m

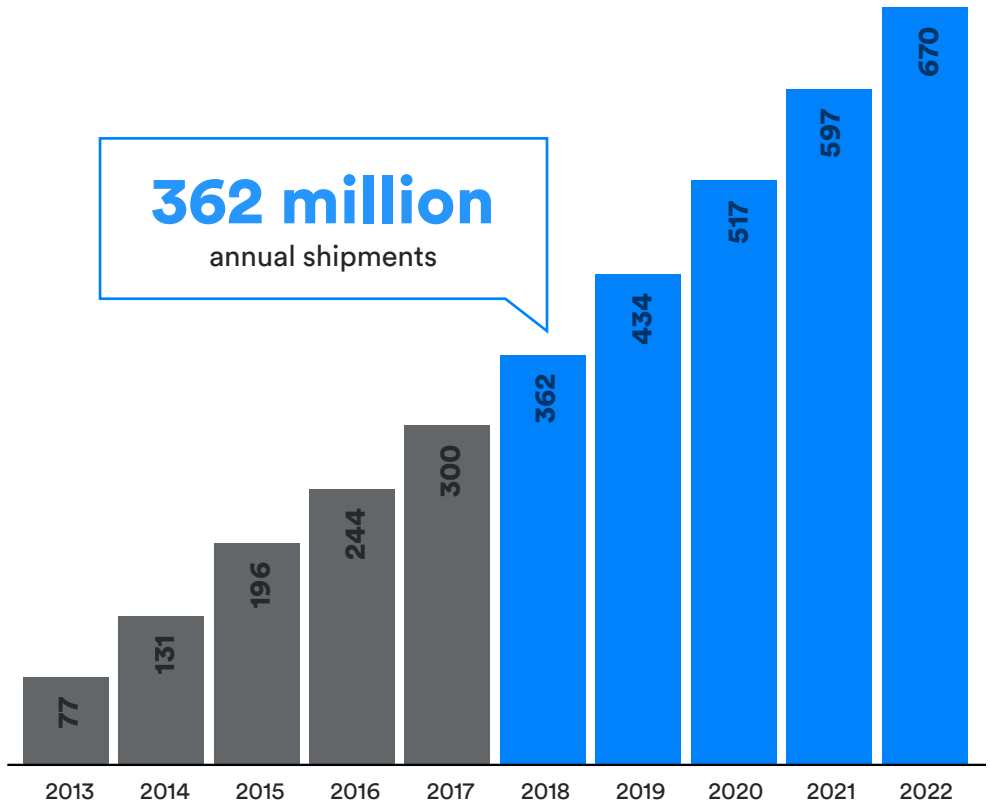
Bluetooth enterprise wearables forecasted to ship in 2022

80m

Bluetooth consumer robots forecasted to ship in 2022

Bluetooth Device Shipments

numbers in millions



connected device

market insights

Consumer wearables are getting more sophisticated

A new breed of fitness devices that offer more specialized, multi-purpose functionality have emerged and will continue to experience consistent growth.

The smartwatch market has also become more diverse and will maintain its steady growth trajectory.

Medical grade devices are on a steady climb

Demand for healthcare providers to better administer medication, diagnose injuries, and receive critical updates on their patients' conditions is driving a 28% CAGR in Bluetooth healthcare wearables over the next 5 years.

Enterprise wearables gain significant traction

New enterprise use cases are driving a rapid growth in wearables in the workforce, including smart glasses and wearable scanners. With 102 million Bluetooth enterprise wearables forecasted to ship in 2022, enterprise wearables represent one of the fastest growing segments in the connected device market.

Consumer robotics are emerging in the home

Home helpers that vacuum, clean gutters, and even mow the lawn are here to stay. Bluetooth consumer robots are forecasted to grow from 29M shipments annually in 2017 to just shy of 80M in 2022.

Learn more about the connected device market

smart building

Bluetooth expanded the definition of the smart building by enabling indoor positioning and location services that focus on enhancing the visitor experience, increasing occupant productivity, and optimizing space utilization.

In addition, the 2017 launch of mesh networking marked the formal entry of Bluetooth into full-building automation.

smart building

market numbers

10x

growth in annual volume of Bluetooth location services devices by 2022

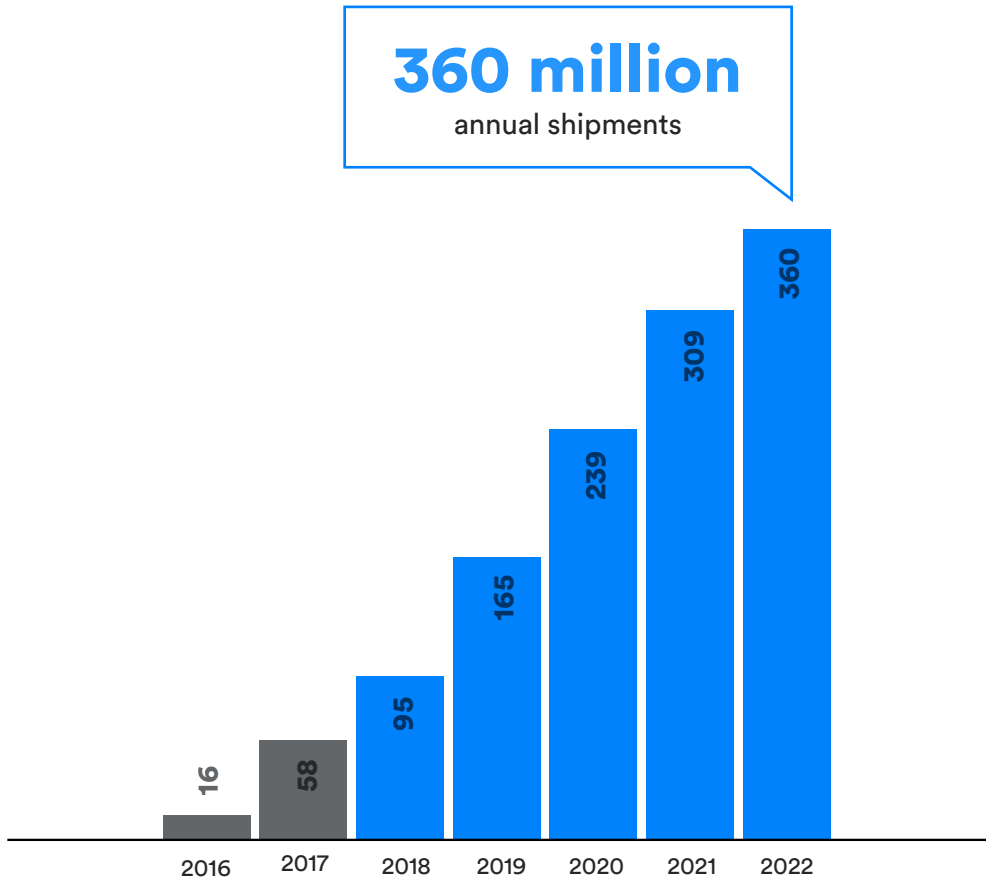
75%

of top 20 retailers have deployed location services*

*Source: Proximity Marketing in Retail, by Unacast

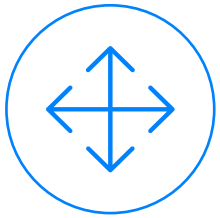
Bluetooth Device Shipments

numbers in millions



smart building

market insights



Location services gain significant traction

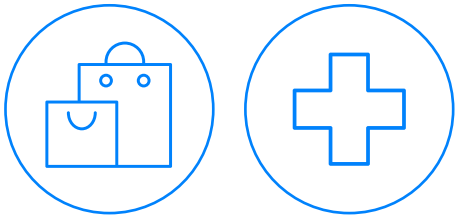
Bluetooth technology is powering building-wide networks of beacons that enable indoor positioning and location services, including point-of-interest information, indoor navigation, and asset tracking.

Space utilization is also gaining momentum, with smart offices using Bluetooth to enable sensor-based occupancy mapping.

Connected lighting emerges as a key use case in automation

The ability to intelligently control lighting has a strong business case on its own. In addition, a wireless lighting solution can also function as a platform to further enable point-of-interest solutions, indoor navigation, asset tracking, and space utilization in the smart building.

The use of lighting as a platform to enable the creation of control, monitoring, and automation systems will continue to increase over the forecast period.

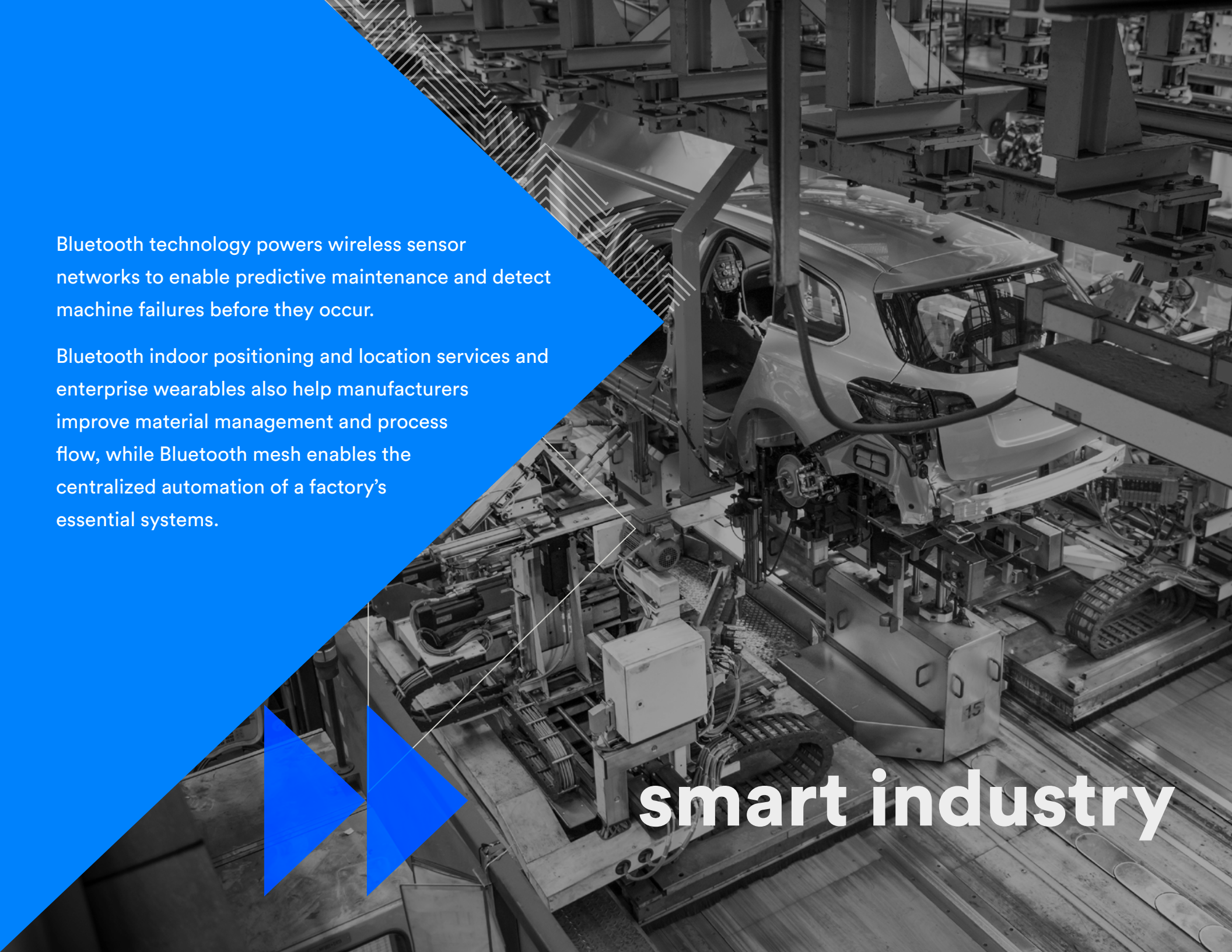


Retail and healthcare continue to be early proving grounds for smart building technologies

Retailers are among the early adopters to leverage Bluetooth to enable personalized promotions and way-finding services that connect shoppers to shelves, increase sales, and reduce operating costs.

In order to combat cost pressures, provide better patient care, and improve operational efficiencies, healthcare facilities are adopting Bluetooth technology to monitor patients, track assets, and advance emergency services. 100 million Bluetooth smart healthcare devices are forecasted to ship per year by 2022.

Learn more about the smart building market



Bluetooth technology powers wireless sensor networks to enable predictive maintenance and detect machine failures before they occur.

Bluetooth indoor positioning and location services and enterprise wearables also help manufacturers improve material management and process flow, while Bluetooth mesh enables the centralized automation of a factory's essential systems.

smart industry

smart industry

market numbers

7x

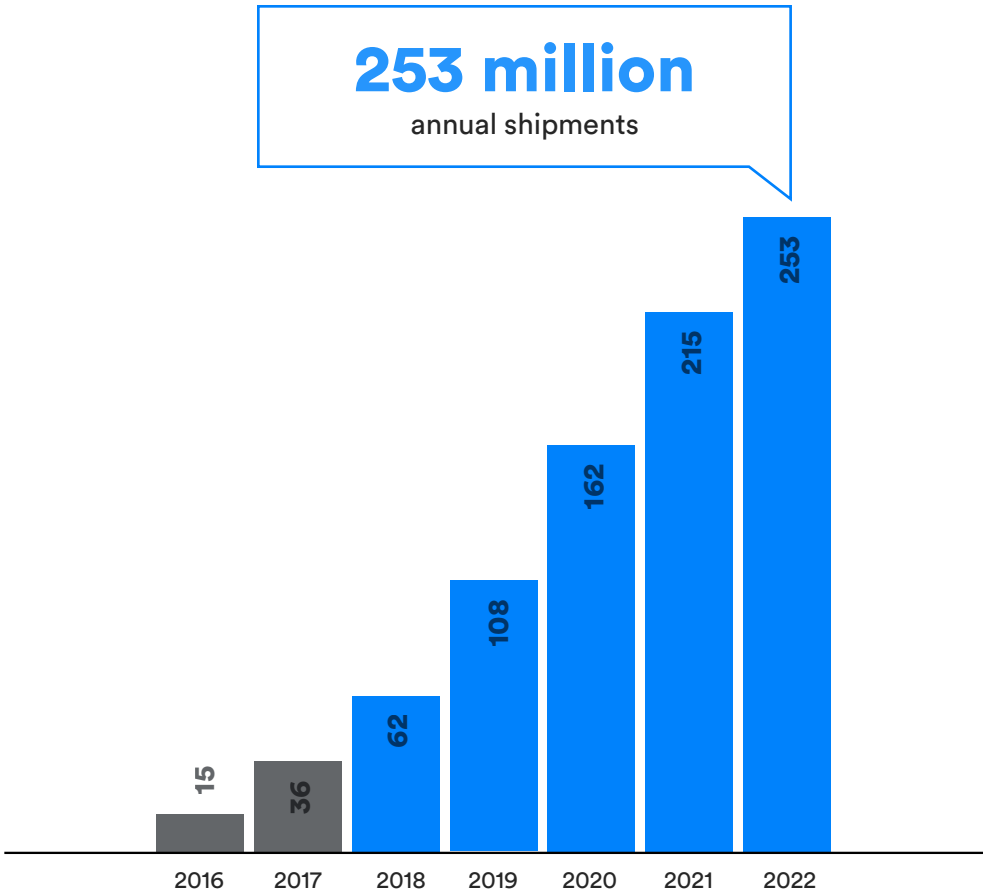
increase in annual shipments of Bluetooth smart industry devices from 2017-2022

12x

increase in annual volume of asset tracking and management solutions by 2022

Bluetooth Device Shipments

numbers in millions

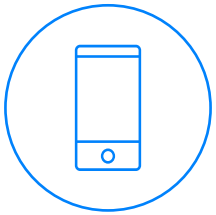


smart industry

market insights

Significant growth expected in industrial wireless sensor networks

In a drive to improve production efficiencies, leading manufacturers are looking to dramatically increase their deployment of sensor networks across the factory floor. These large-scale sensor networks are capable of lowering overall machine downtime and increasing flexibility in the manufacturing line.



Smartphones and tablets are replacing the machine UI

Bluetooth smartphones and tablets are emerging as central control devices within factories and industrial settings, providing a better, safer interface for monitoring and controlling industrial machinery.

Asset management provides transformational improvement to manufacturing

Automated asset tracking and monitoring enables manufacturers to better determine location, availability, and condition of equipment as well as track the overall output across the supply chain.

Industrial deployments of Bluetooth asset tracking and management solutions will continue to increase, allowing factories to achieve new levels of operational efficiency.

Learn more about the smart industry market

smart city

As pressure on resources, utilities, and public funds increases, so too does the need for smarter solutions to effectively manage growing city populations.

Bluetooth technology is connecting smart cities to enhance the visitor experience and improve the quality of life for citizens, businesses, and employees.

smart city

market numbers

5x

growth in annual shipments of smart city enabling devices by 2022

84%

of global airports will be using location services by 2019*

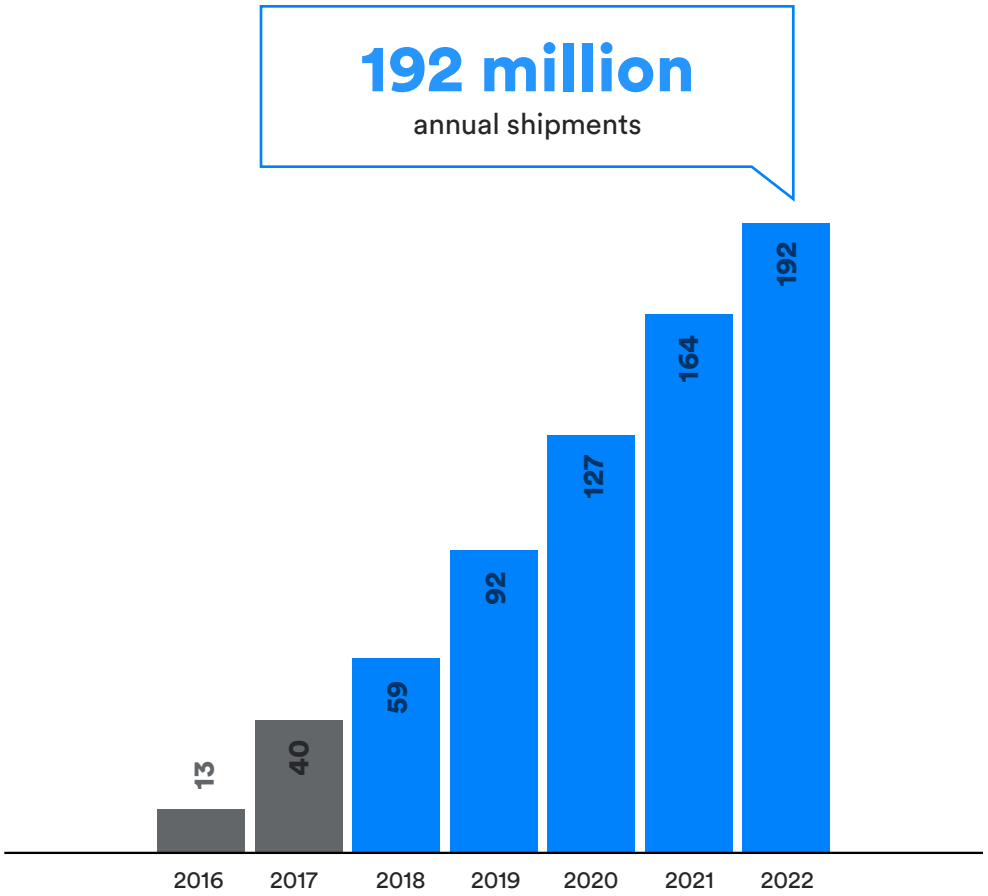
93%

of US baseball stadiums will deploy location services by 2019*

*Source: Unacast Proxbook

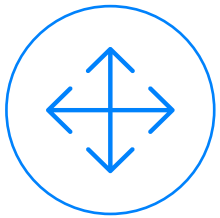
Bluetooth Device Shipments

numbers in millions



smart city

market insights



Cities are adopting location services

Location services driven by Bluetooth beacons are on a rapid growth trajectory across all smart city segments. These smart city services are helping create rich, personalized experiences for concert goers, museum lovers, sports fans, travelers, and tourists.

New technologies are improving the transportation experience within city limits

Government officials and city managers are deploying Bluetooth smart city solutions to improve transportation services, including smart parking lots and meters as well as enhanced bus services.

Bikes help power the sharing economy

Bluetooth is helping bring one of the main drivers of the sharing economy to life. Stationless bike sharing first caught the public's attention in 2016. In 2017, steady rollouts worldwide accelerated its growth, with notable expansion in APAC.

Learn more about the smart city market

smart home

Whether connecting TVs to soundbars or PCs to keyboards, Bluetooth technology has been at the heart of the connected home for years.

Now, Bluetooth mesh is bringing industrial-grade security and dependability to home automation applications.

smart home

market numbers

650m

Bluetooth smart home devices will ship in 2018

6x

growth in annual shipments of Bluetooth home automation devices by 2022

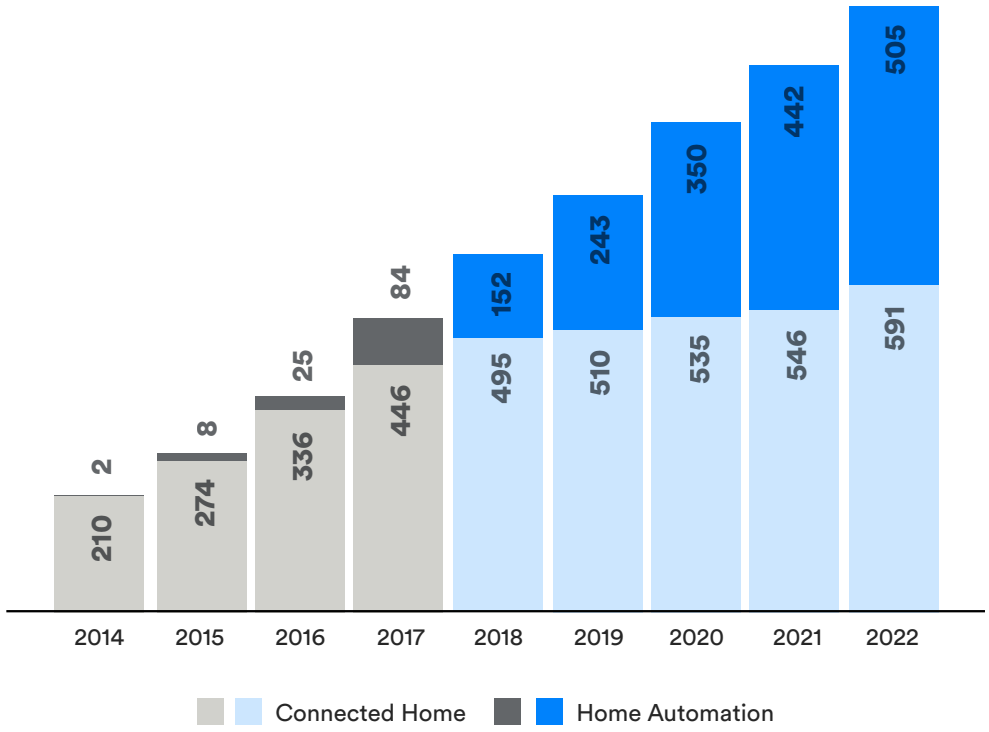
54%

compound annual growth rate of residential smart lighting devices over the next 5 years

Bluetooth Device Shipments

numbers in millions

1.1 billion
annual shipments



smart home

market insights

Bluetooth remains an integral component of the connected home

From TVs to toys to tools, more and more everyday household items are using Bluetooth technology to wirelessly connect.

Steady growth in connected home devices is predicted, with connected home entertainment devices continuing to account for over half the volume.

Home automation is now poised to scale

Two forces will continue to push smart home solutions forward.

2018 has already seen the launch of the first Bluetooth full-home automation systems. Bluetooth mesh will continue to provide a reliable wireless connectivity platform that enables automatic control of lights, thermostats, smoke detectors, cameras, door bells, locks, and more. Among those, lighting is expected to be a leading use case with a 54% CAGR predicted over the next five years.

Meanwhile, the smart speaker has emerged as a potential central control unit for the smart home. Smart speaker volume is forecasted to grow 3x by the end of 2022.

Learn more about the smart home market

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bluetooth.com