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BLE-101

Next-Gen Bluetooth Applications: Driving Innovation and Transforming Connectivity

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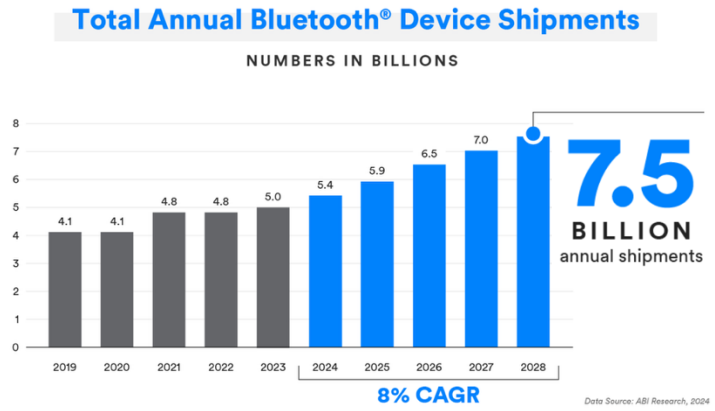
Product Marketing Manager

Contents

- Trends driving innovation in Bluetooth
- Channel Sounding
- PAwR
- Bluetooth Mesh
- Ambient IoT
- Bluetooth LE Audio
- Misc. (Trends to look forward to) - HDT
- SiLabs Offerings/Portfolio
- Resources
- Q&A

Bluetooth is:

Ubiquitous



177 MILLION

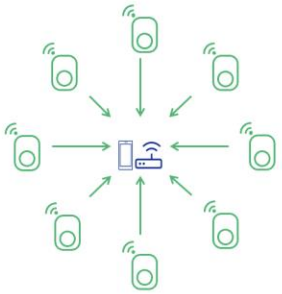
Bluetooth® smartwatches will ship in 2024

35 MILLION

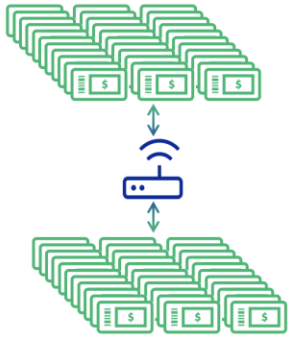
Bluetooth® sports, fitness, and wellness trackers will ship in 2024

Bluetooth is included in all of our roadmap products

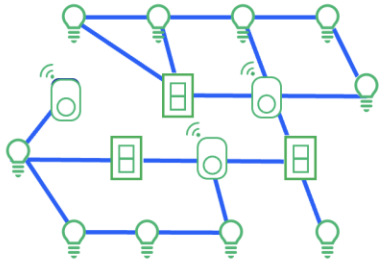
More than point to point



Star
Connection-oriented
32 devices



PAwR
Connectionless
32K devices



Mesh
Multi-hop communication

Always evolving

2024

Auracast
Broadcast audio over Bluetooth Low Energy

Bluetooth 6.0
Channel Sounding for distance estimation

2025*

Ultra-low latency (HID)
Gaming controllers, mice, keyboards over Bluetooth

2026*

Bluetooth 7.0
High Data Throughput for faster data transfer

2028*

Bluetooth 8.0
Bluetooth at 5GHz and 6GHzCS enhancements

** dates subject to change*

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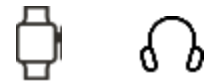
Trends in Bluetooth



Audio Streaming

Data Transfer

Location Services

Device Networks

Past

- Bluetooth Low Energy standard and initial goals
- Definition of the four quadrants (audio, data, location, network)
- Pre 5.0 Bluetooth Low Energy Feature overview

Present

- Bluetooth 5 - big changes, major rev
- 5.x key features: Mesh, Audio, PaWR
- Bluetooth 6 – Channel Sounding
- Ambient IoT

Future

- High Data Throughput
- High Frequency Bands

Bluetooth® Channel Sounding

THE CHALLENGE:

IOT applications need 'spatial' awareness to be more secure, reliable, and responsive

- Earlier Bluetooth LE versions lack native support for precise ranging
- RSSI-based ranging is noisy and unreliable in real-world use
- Direction Finding needs complex antennas, adding cost & complexity
- UWB is accurate but often too costly, and bulky for IoT

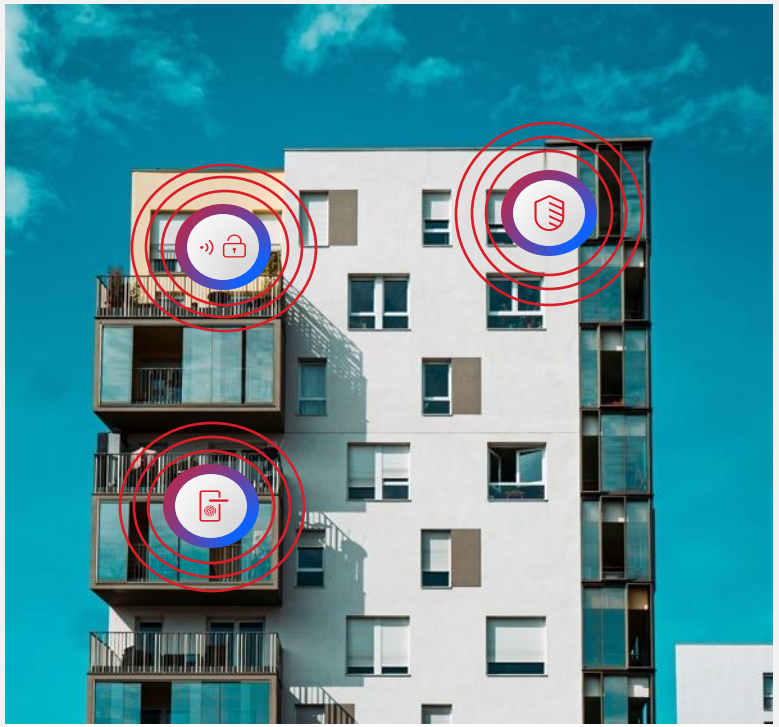
THE OPPORTUNITY:

Channel Sounding for Bluetooth

- Standardized approach for accurate, secure ranging in Bluetooth 6.0
- Enables sub-meter accuracy with robust performance, even in NLOS
- Works with single or dual antenna setups - flexible for different form factors
- More cost efficient than UWB; requires minimal external components

Built on existing Bluetooth infrastructure, simplifying adoption and ecosystem integration

Applications



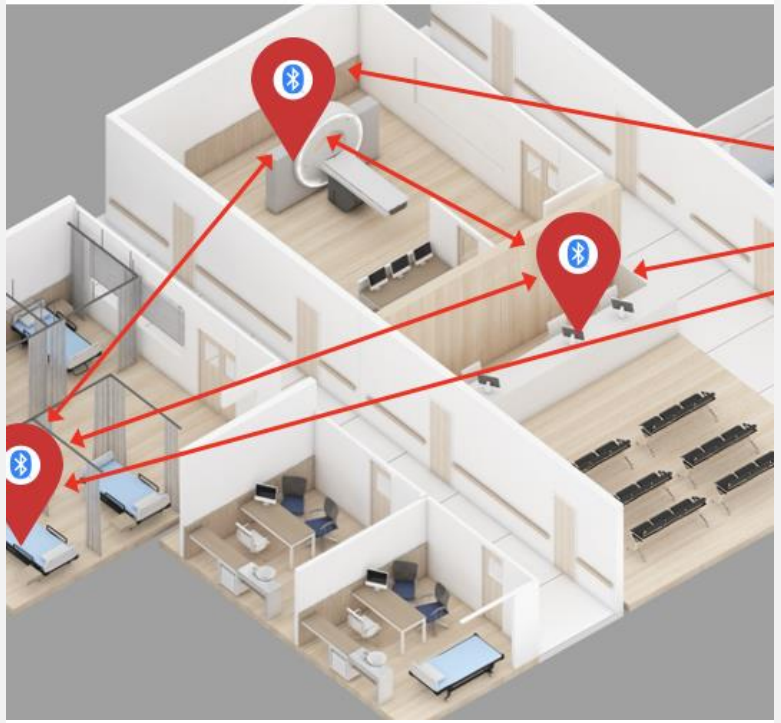
RANGING

Keyless entry

Geofencing - security alerts

Indoor asset management

Item finding - wallet, keys



AUTOMAPPING

Solar Trackers

Luminaires

Access Points

Accurate Mapping for Battery Storage

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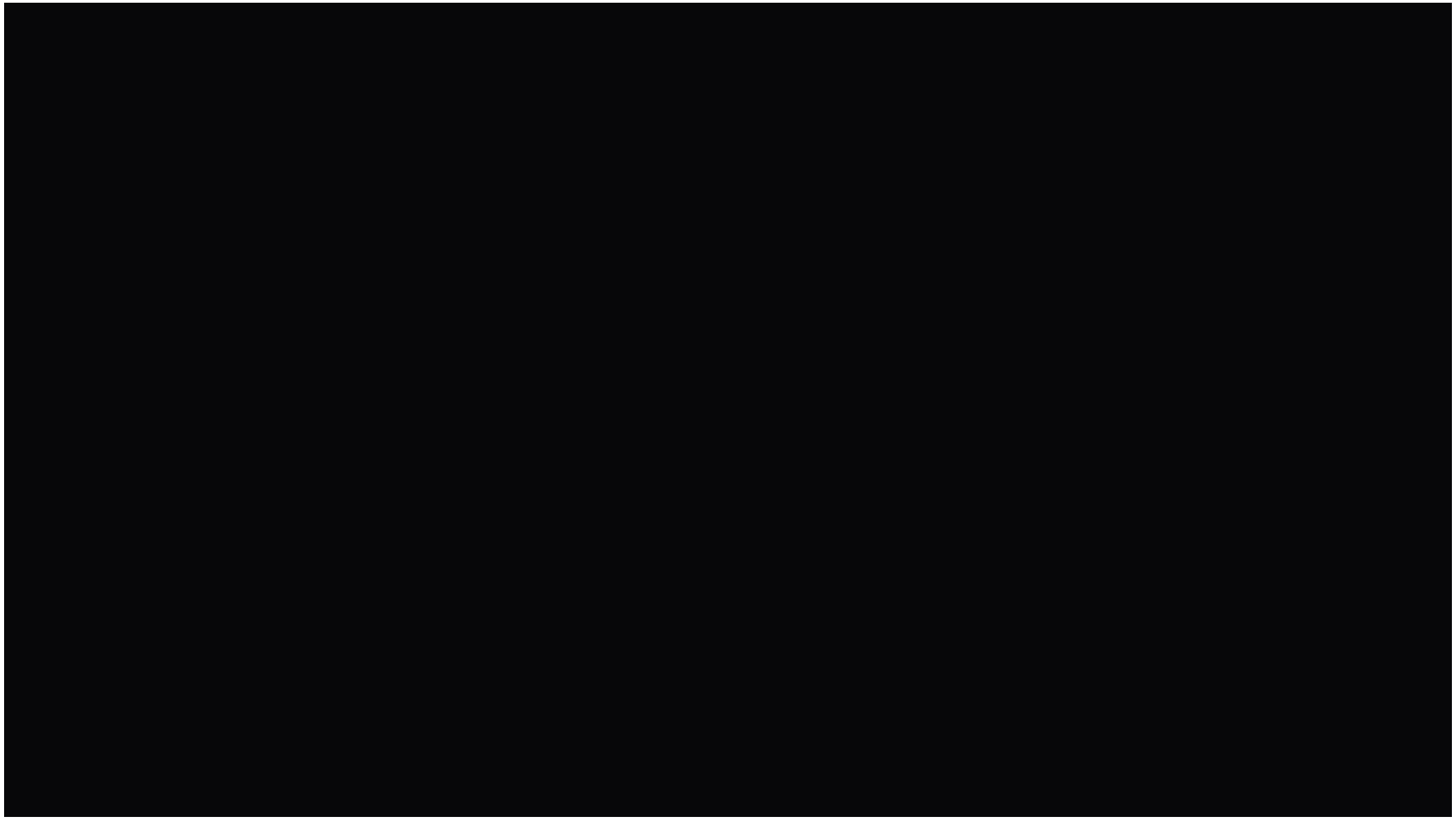
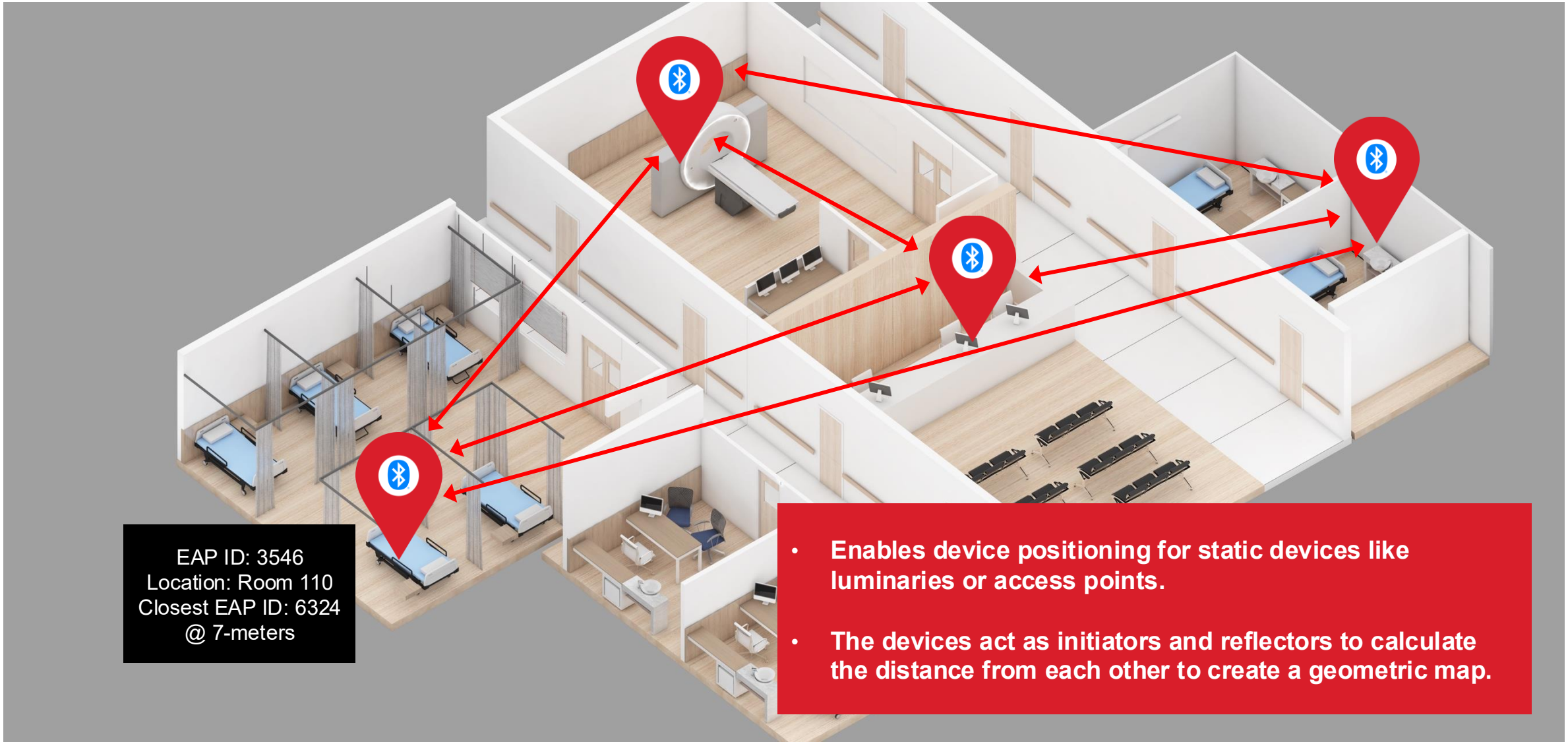
Tracking/Item Finding

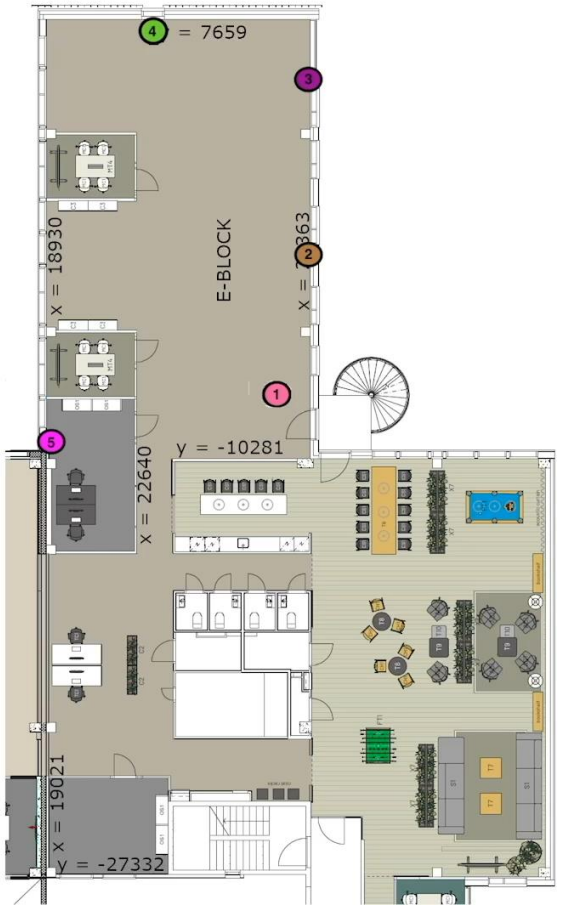


Channel Sounding for Static Device Positioning



- **Enables device positioning for static devices like luminaries or access points.**
- **The devices act as initiators and reflectors to calculate the distance from each other to create a geometric map.**

Automapping



Silicon Labs Channel Sounding Algorithm

- **Algorithm Features**
  - Supports Multiple Channel Sounding Ranging Modes
    - PBR, RTT, PBR with RTT as sub mode
  - Antenna Switching
    - Built-in support for antenna diversity
    - Supports 1, 2 and 4 antenna paths
  - Supported Algorithm modes
    - Static mode – Delivers the highest accuracy with high measurement latency; optimized for ranging between stationary devices
    - Real Time Basic – Provides high accuracy with increased computational and measurement latency; supports tracking at speeds up to 1 m/s
    - Real Time Fast – Balances moderate accuracy and range with low latency; supports tracking at speeds up to 2.1 m/s, additionally produces velocity metric
  - Configurable Channel Selection (72, 37, or 20 Channels)
    - Selectable based on accuracy needs and power constraints

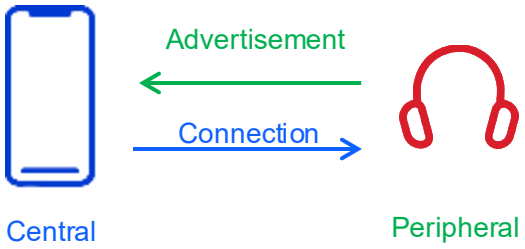
- **Key Benefits**
  - Licensing cost free
    - Eliminates third-party royalties, simplifying BOM cost structure
  - Optimized HW-SW Co-Design
    - Tight coupling between silicon & firmware ensures seamless performance & efficiency
  - Single-Vendor Lifecycle Support
    - Unified hardware & software ownership streamlines debugging, validation, and updates

Performance in Indoor Office Environment

- **Ceiling rail infrastructure**
  - Internal test environment
  - Multiple stationary EFR32 devices placed at different locations
  - Mobile EFR32 device for controlled measurements (repeatability)
- **Challenges - heavy multi-path in an indoor office setting**
- **Statistical analysis**
  - Static measurements at multiple distances up to 33 meters
  - Hundreds of measurements per distance to determine min/max, mean, median, std, absolute error

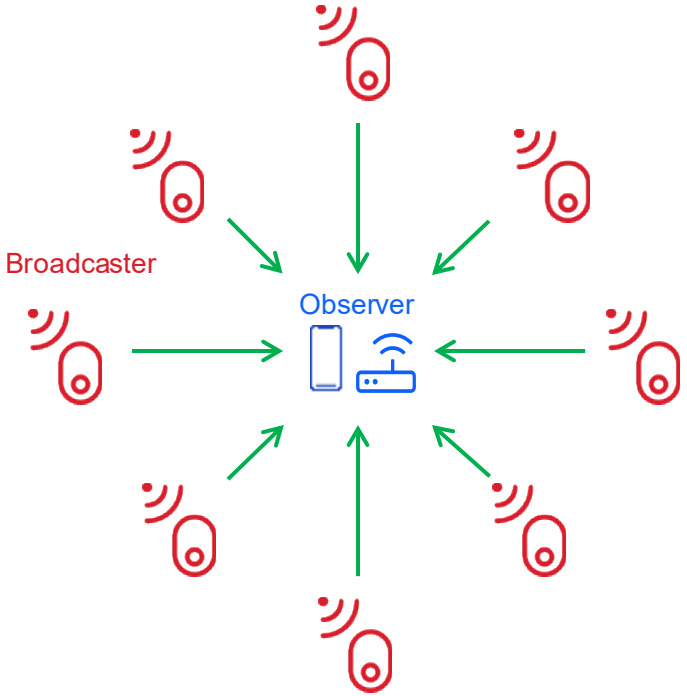
Why PAwR?

Advertising for Connection
(irregular, unidirectional)



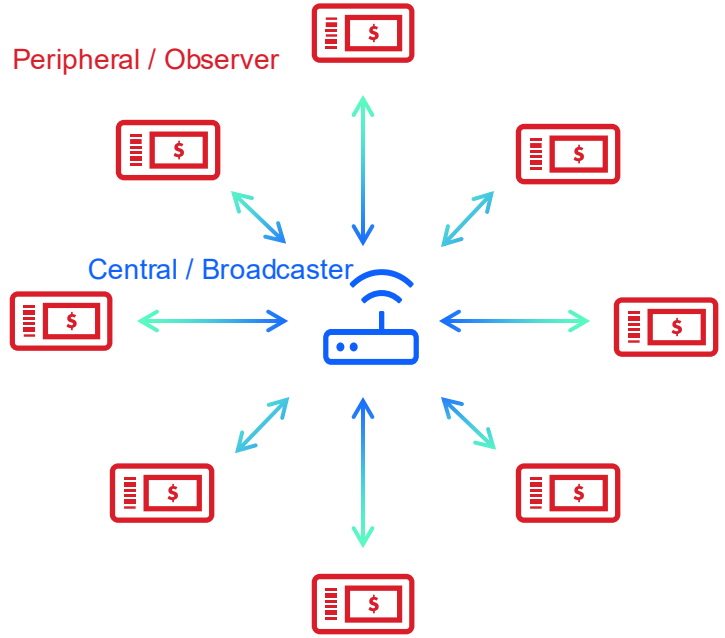
Max number of connections: **32**

One-way “Beaconing”
(regular, unidirectional)



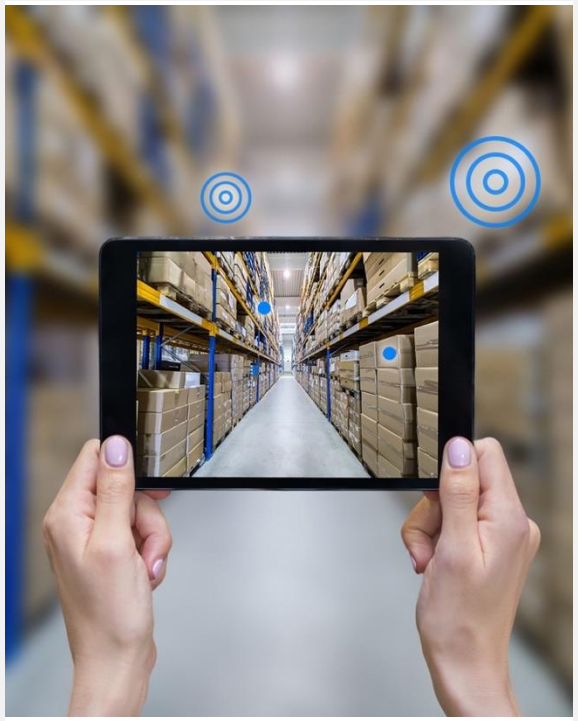
Max number of beacons:
limited by channel capacity to a **few 1000s**
(unsynchronized nature causes collisions)

Periodic Advertising with Responses
(regular, bidirectional)



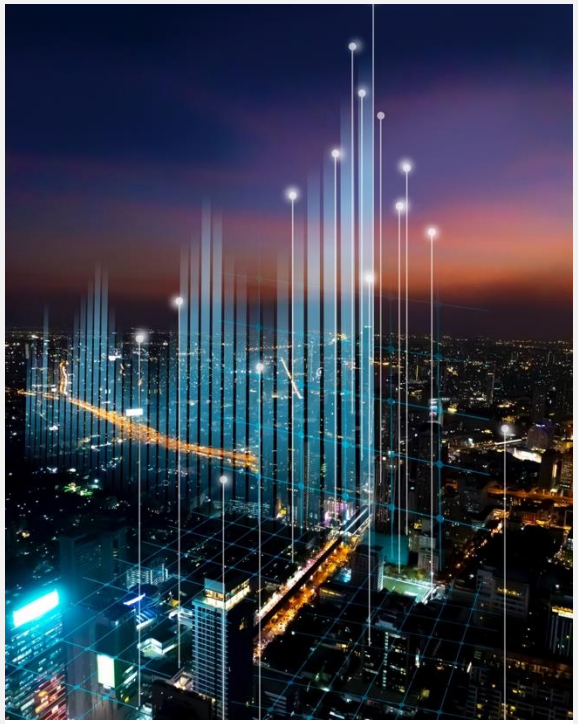
Max number of Peripherals: **32k**
New mode enabling “Synchronized” mode network.

Applications



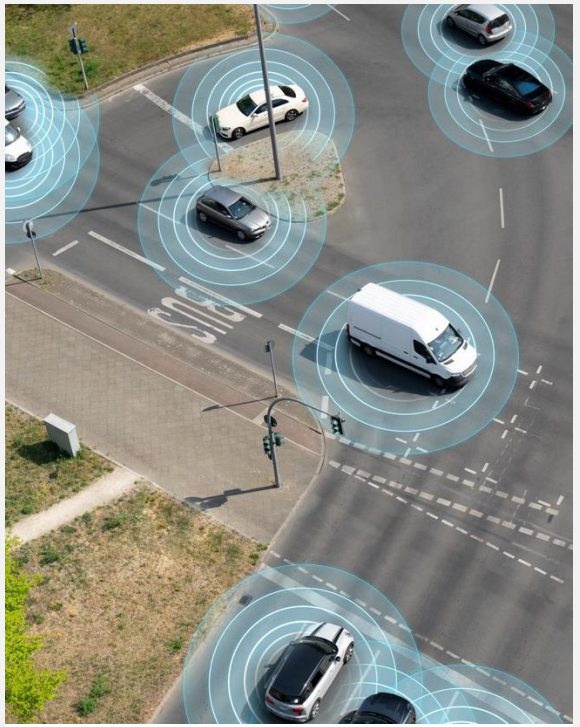
ASSET MANAGEMENT

Status updates from a huge number of items, location finding



SMART CITIES

Access Points to connect to more than 32 Bluetooth devices nearby



AUTOMOTIVE

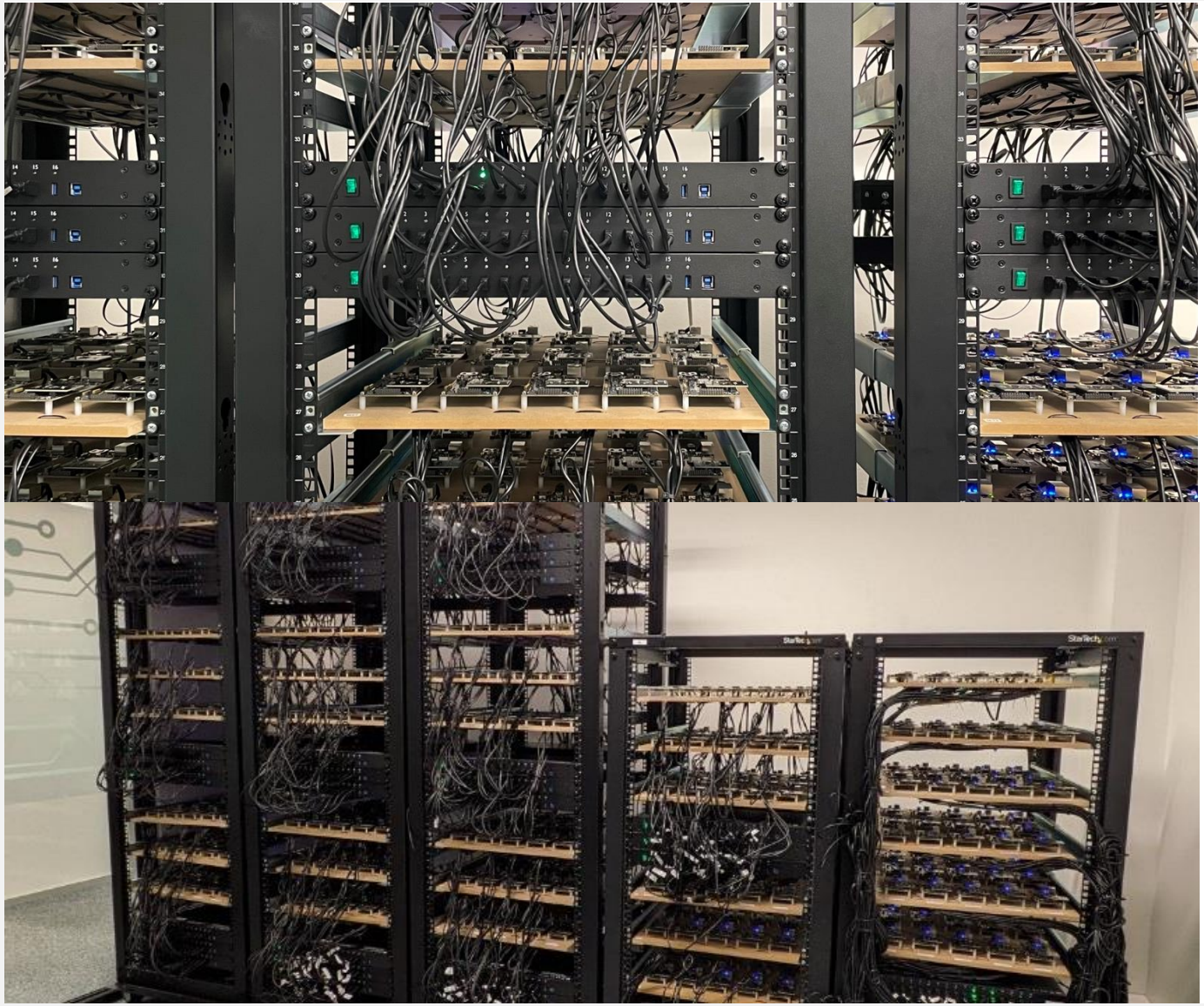
Non safety critical electronics to communicate with the central computer

SOLAR TRACKERS

Large Solar Farms controlled by PAwR in combination with Channel Sounding

Asset Management (PAwR)

Bluetooth ESL using PAwR - Test Lab Network



- **Rack-mounted device farm based on MG24 development kits**
  - Capacity for ~1500 devices
  - Network mimics a large-scale, real-life scenario
- **Controlled test framework**
  - Network deployment, ping with PAwR and network recovery tests conducted on ESL tag groups
  - Results show encouraging signs for a variety of use cases other than ESLs
- **Generating realistic radio environment for PAwR testing**
  - Flexible configurations demonstrated to show low latency and high reliability
  - Bluetooth PAwR viable for ultra-low power, centralized networks for industrial and commercial use

Bluetooth Mesh

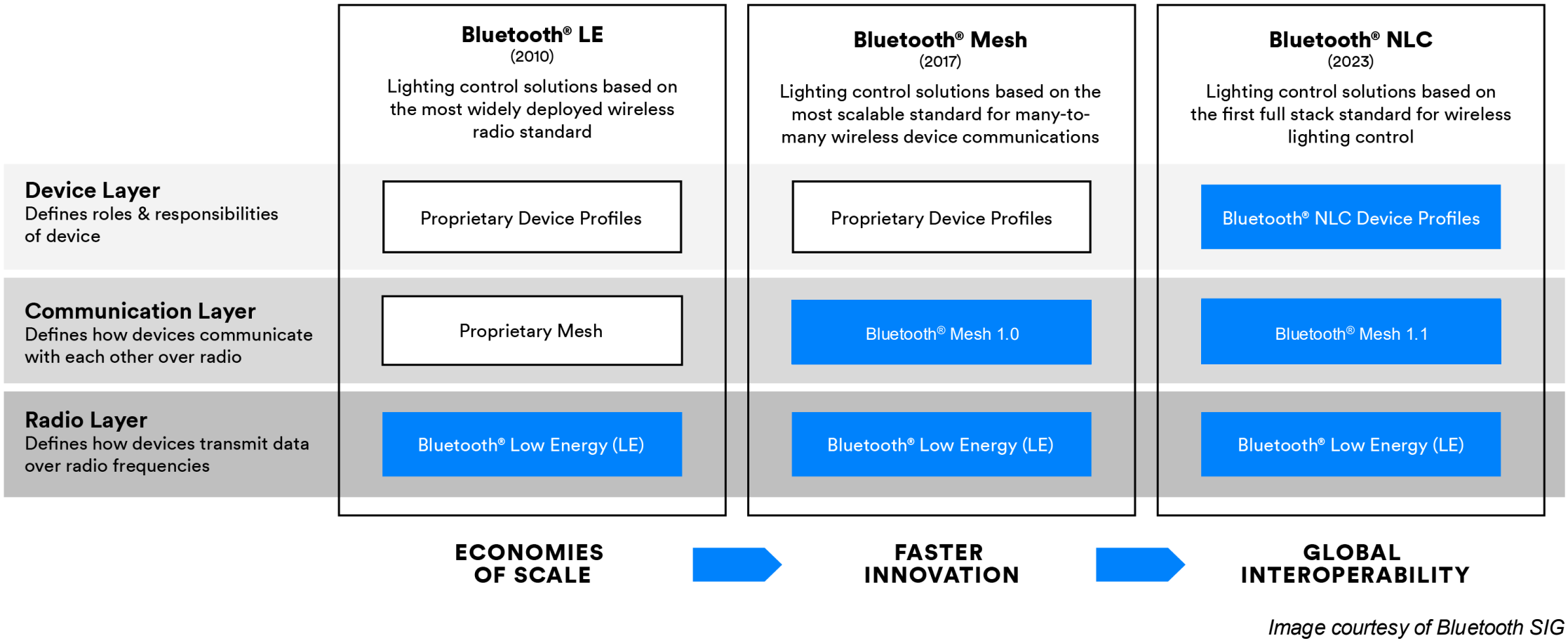


Image courtesy of Bluetooth SIG

Bluetooth Mesh Overview

NETWORKED LIGHTING CONTROL (NLC)

- Commercial
- Residential
- Steet lighting

SMART HOME & BUILDING AUTOMATION

- HVAC
- Switches
- Sensors

Easier Smart Phone Connectivity

Optional Gateway

Scalability and Security

Easy Extendibility and Flexibility

Value Added Service

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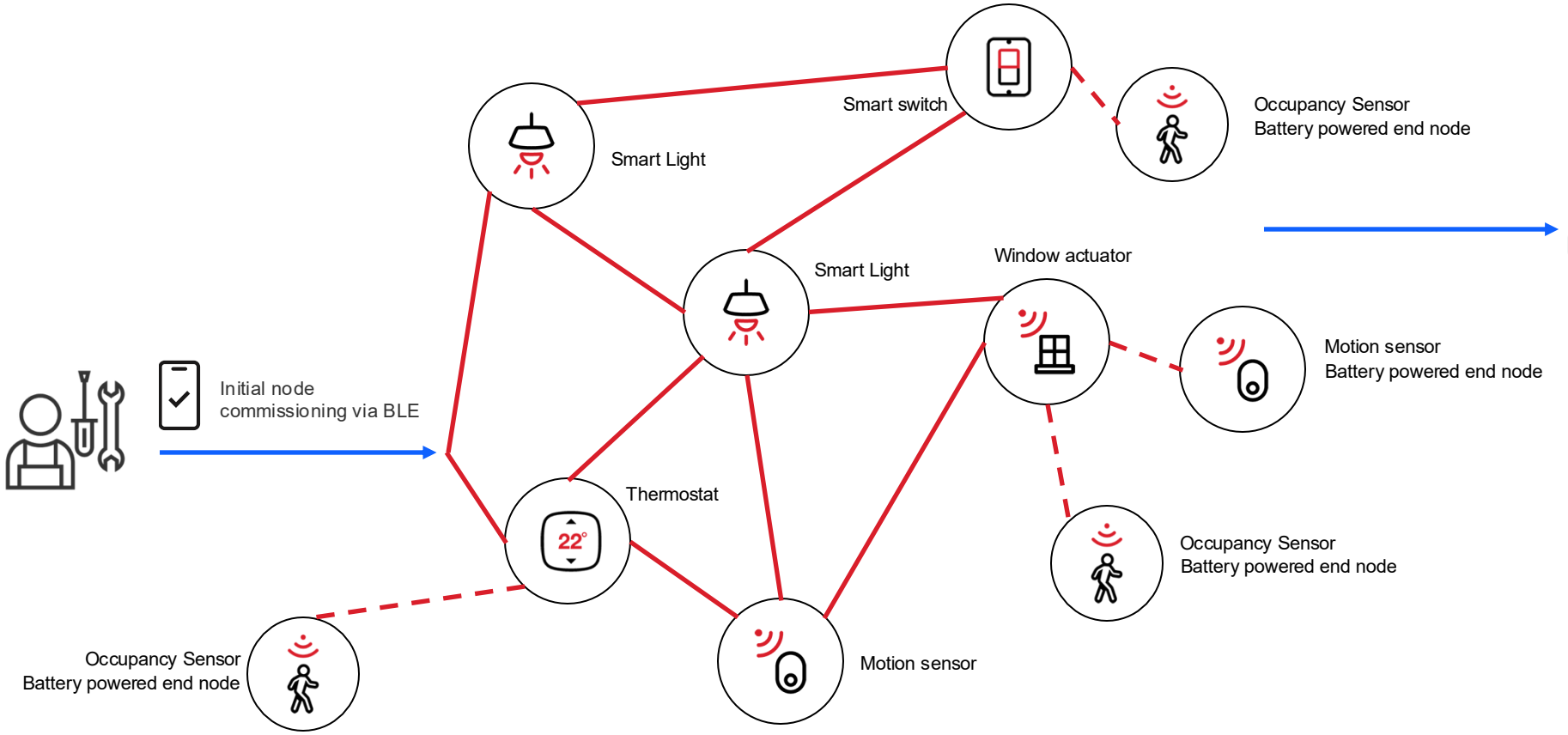
Smart Building Automation with Network Lighting Control (NLC) Profiles

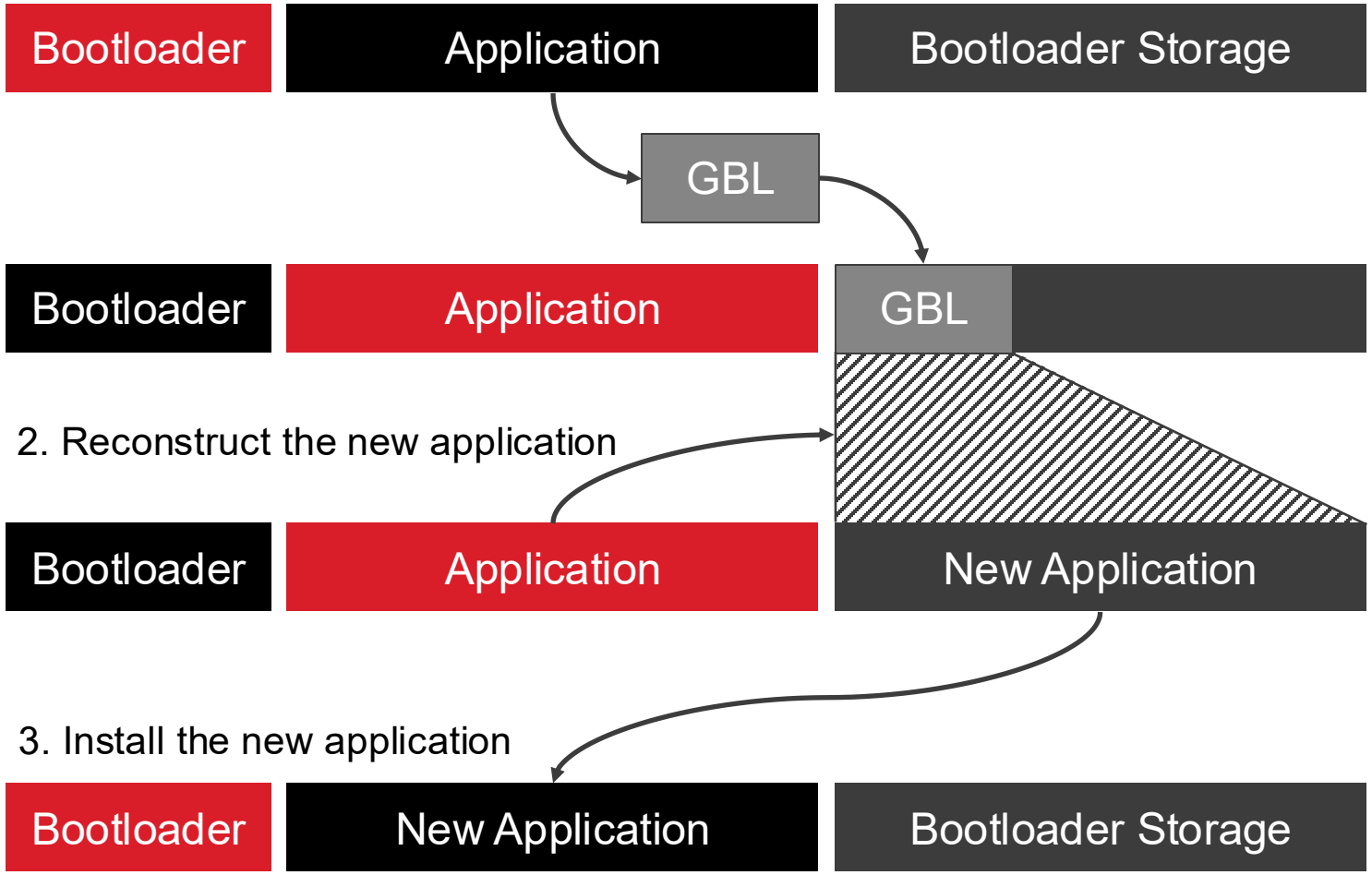


- Fast deployment & retrofitting
- Flexible layout changes
- Battery-powered end devices
- Reduced labor costs
- Remote configuration & diagnostics
- Optional IP/Cloud connectivity

Installer powers on device → Mobile app scans the device over BLE → Device receives credentials for the mesh → Device switches to corresponding radio and joins the mesh → Device either becomes a router or end node → Connect to gateway / cloud (if needed)

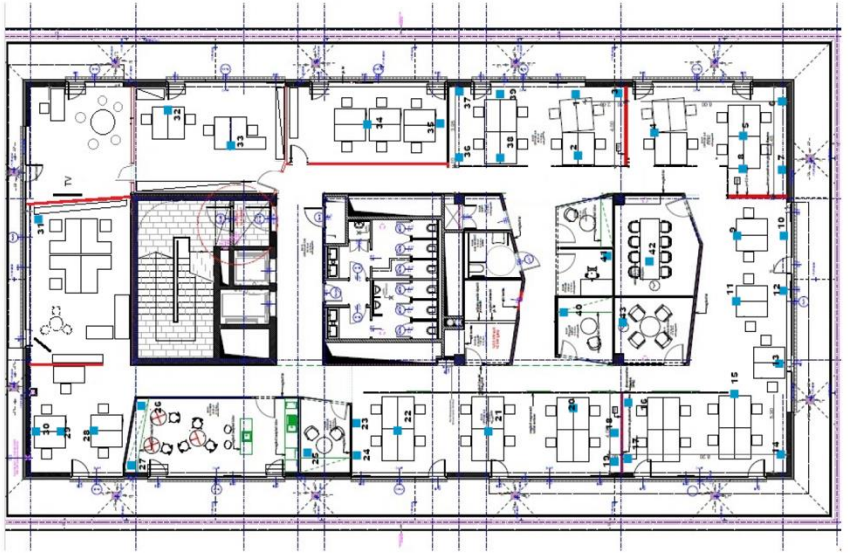
Silicon Labs Feature: Delta DFU operation

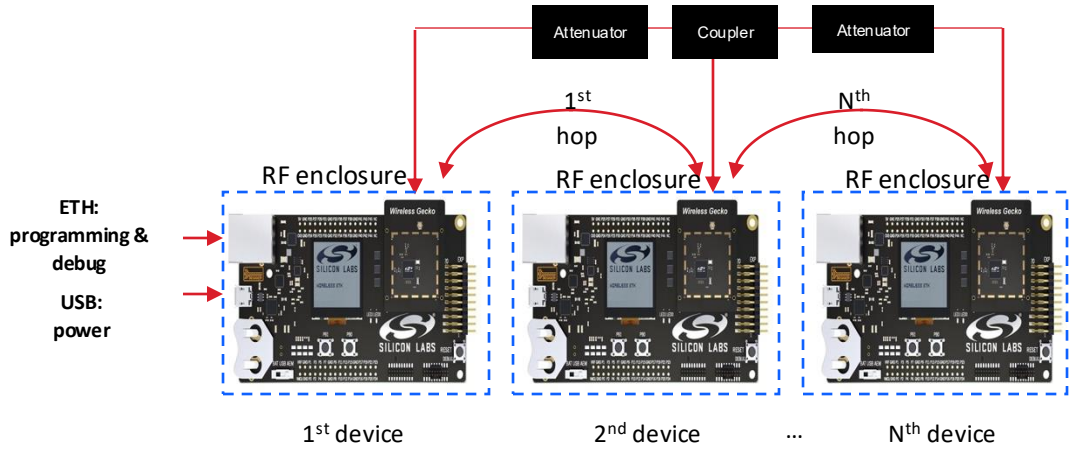
1. Download the GBL upgrade file

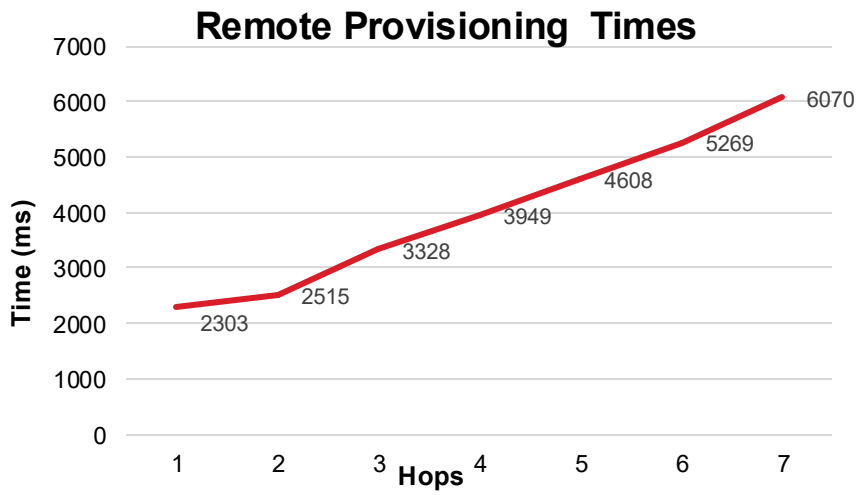


- **Full firmware updates take time**
  - Code mostly unchanged, just relocated
  - Only minor changes, mostly bug fixes
  - Burdens nodes with low bandwidth
  - Latency makes DFU slow, unstable
- **Benefits of DFU Compression**
  - Smaller upgrades transmit much faster
  - Delta DFU = changes only
  - More efficient use of RF channel
- **Silabs proprietary BT Mesh feature**
  - Cuts BT Mesh OTA size by 90%
  - Supports standard BLE OTA too

Bluetooth Mesh Test Setup







‘Ambient IoT’ for ‘Energy Harvesting’

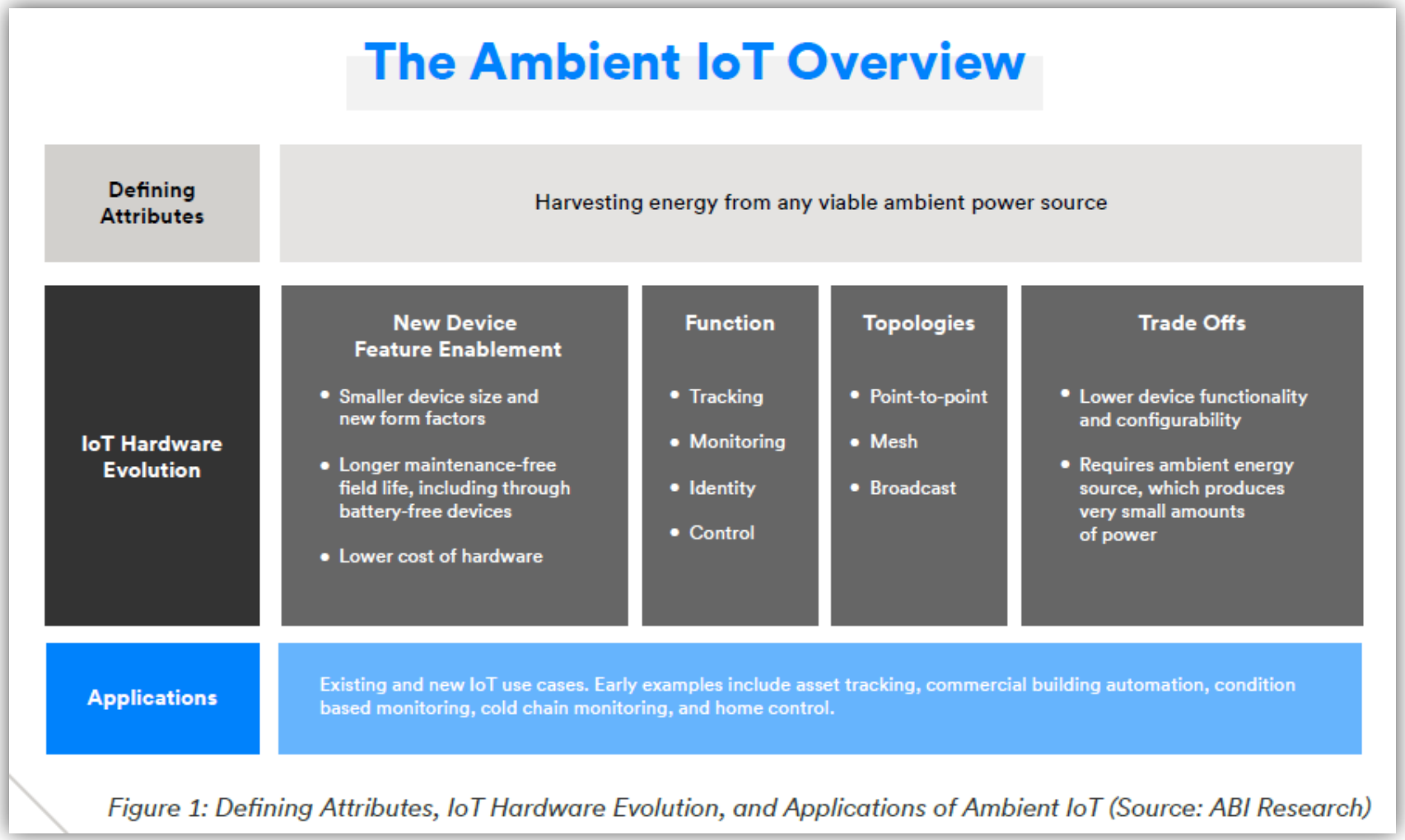


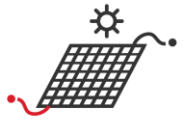
Figure 1: Defining Attributes, IoT Hardware Evolution, and Applications of Ambient IoT (Source: ABI Research)

Image courtesy of Bluetooth SIG

Silicon Labs intends to be a pivotal member with Bluetooth SIG and Connectivity Standards Alliance to drive Ambient IoT needs into standards
https://www.bluetooth.com/bluetooth-resources/mrn-ambient-iot/

Energy Harvesting Sources & Applications

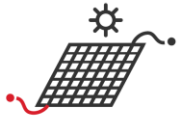
Learn more: TechTalk 2024



SOLAR - OUTDOOR

LOGISTICS / LIVESTOCK TRACKING

Bluetooth® Proprietary



SOLAR - INDOOR

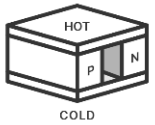
ASSET TRACKING / SMART BUILDING SENSORS

Bluetooth® Proprietary zigbee

KINETIC PULSE

SMART SWITCHES

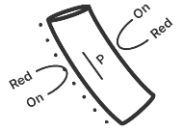
Bluetooth® zigbee



THERMAL

MACHINE MONITORING

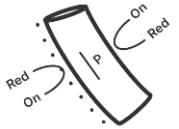
Bluetooth® Proprietary zigbee



VIBRATION / PIEZO

FACTORY AUTOMATION / AGRICULTURE / TPMS

Bluetooth® Proprietary zigbee



INDUCTION

ELECTRIC SUB-METERING

Bluetooth® Proprietary zigbee

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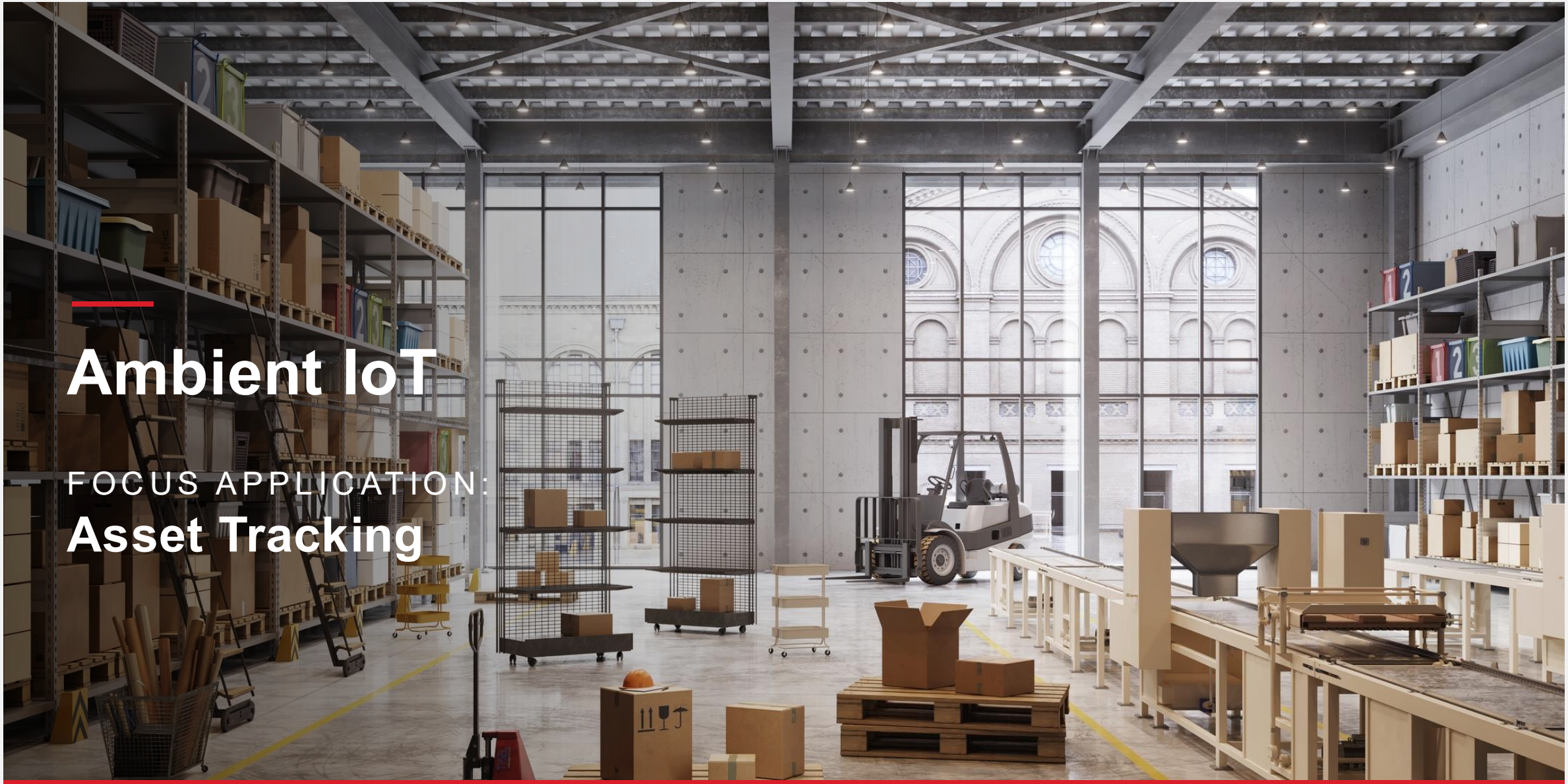

Ambient IoT

FOCUS APPLICATION:

Asset Tracking

Fastest growing application - combatting over $1B in good losses - must scale with IoT...without batteries

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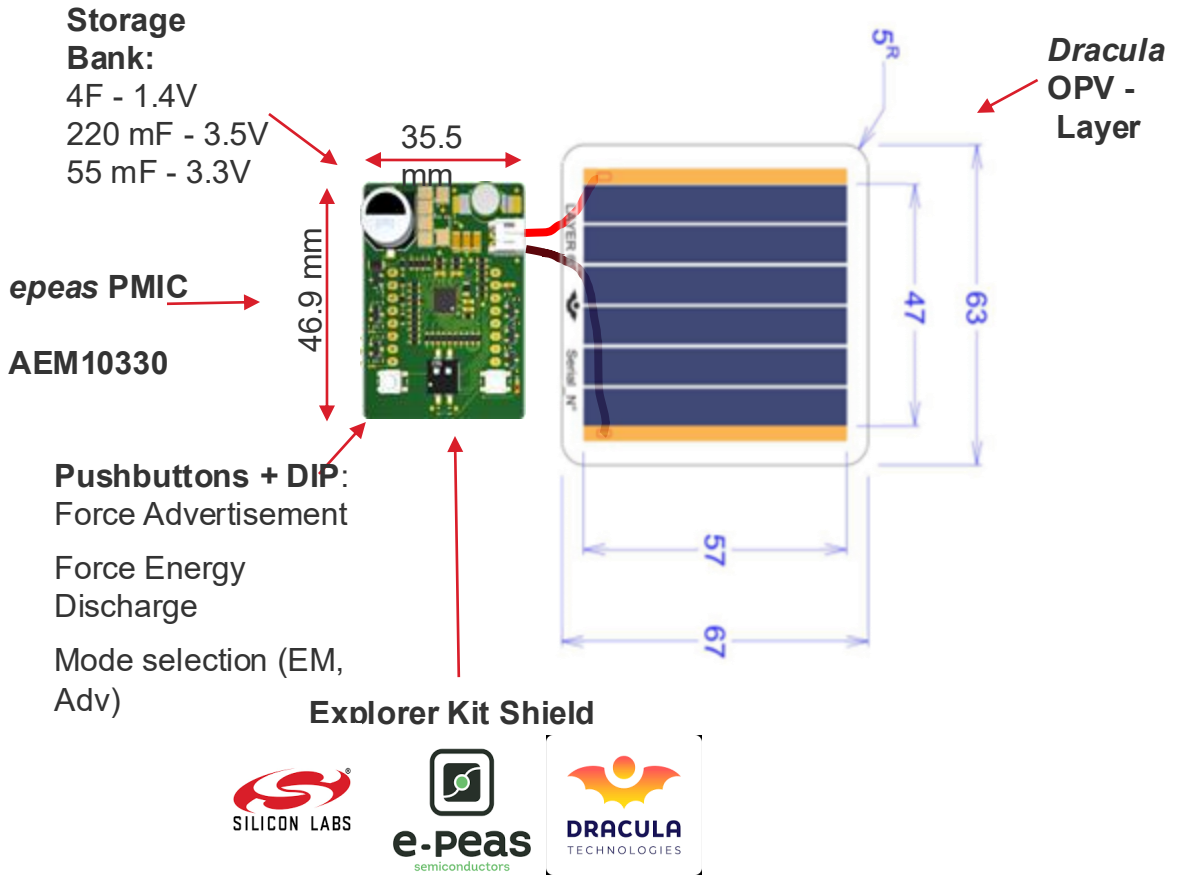
Battery-less Energy Harvesting Tags

- **Constant Bluetooth LE beaconing data advertisement between deep-sleep intervals.**
- **Powered from ambient energy sources – dynamically aware and configurable by energy level**
- **Optimized for long lifetime using capacitor-based energy storage.**
- **IoT SoC optimized for most efficient cold-start and deep sleep wake-up.**



Bluetooth LE Audio

- **Overview:**
  - Introduced in Bluetooth 5.2 in 2020
  - Connection-Oriented (Unicast audio) and Connectionless (Auracast™ broadcast audio)
  - Based on use of isochronous streaming channels

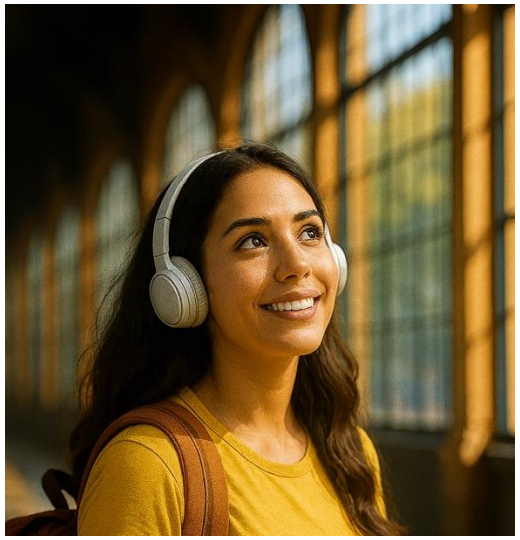
How does Bluetooth LE audio compare to existing ‘Classic’ audio?

	Bluetooth Classic Audio (A2DP / HFP over “BR/EDR”)	**Bluetooth LE Audio** (Isochronous channels over BLE, BT 5.2+)
Typical power consumption	Headphones/speakers draw **~30-40 mA** during playback; battery-operated devices often list 5-8 h play-time	Up to **40 % longer playback time** on the same battery. Practical designs reach 10-20 h on earbuds of the same size.
Audio quality and codecs	Mandatory **SBC** (16-bit/48 kHz, 320-512 kb/s) Optional higher-fidelity codecs: **AAC, aptX/HD/Adaptive, LDAC**, etc.—quality scales with bitrate but at the cost of power/latency	Mandatory **LC3**: delivers equal or better Perceptual Evaluation of Speech Quality (PESQ) than SBC at **half the bitrate** LC3+ (optional) extends to hi-res 24-bit/48 kHz streaming.
Latency (mouth-to-ear)	Typical **100-150 ms** with SBC Can drop to ≈ 40 ms with aptX-LL	**Sub-50 ms** end-to-end paths in LC3
Connection / stream model	Point-to-point **single-stream** Stereo earbuds relay right channel from left bud	**Multi-Stream**: phone sends L & R simultaneously to each earbud
Broadcast / sharing	Not natively supported	**Auracast™ broadcast audio** standardized
Other pros / cons	**Pros**: 20-year ecosystem; works on legacy phones, PCs, cars. **Cons**: Higher power, higher latency, no broadcast, codec-fragmentation.	**Pros**: Lower power, better quality/robustness, multi-stream & broadcast, future-proof. **Cons**: Needs BT 5.2+ silicon/OS; 2025 adoption still ramping, limited backward compatibility.

The Promise of Auracast

Public space retrofitting

- **Public spaces like train stations and airports**
- **Subscribe for announcements and guidance**



Products entering the market in 2025

- **Google Pixel 10 supports Auracast for broadcast audio streams**
- **Seeing first televisions released with Auracast support**

Accessibility and new audio experiences

- **Performance spaces and theaters**
  - Sydney Opera House one of the first spaces to make use of Auracast
- **Alternate languages and help for hearing impaired**

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High Data Throughput overview

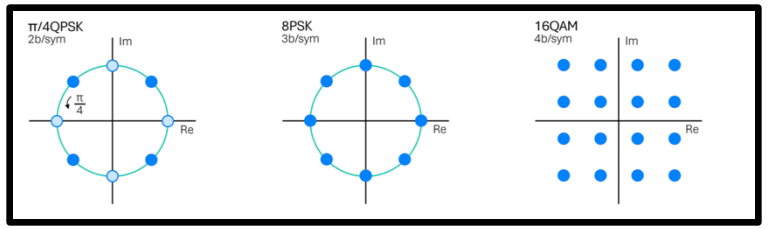
- **Faster data transfer**
  - Nearly 4x speed increase
  - Higher-order modulations
- **Increased capacity**
  - Nearly 4x throughput increase
  - Greater spectral efficiency
- **Better energy efficiency**
  - More efficient radio use
  - Fewer and shorter retransmissions
- **Enhanced reliability**
  - Robust RF performance
  - Utilizes forward error correction

Target use cases
- Lossless or multi-channel audio
- OTA and file transfer

Note: HDT specification not yet adopted, all info here subject to change

Updates to the Bluetooth Standard

Bluetooth LE Host stack	Minor changes only
HCI ↓	New commands and events Updates to existing commands/events
Link layer	New HDT packet types Updated cryptography New and updated procedures
PHY layer	New bit rates: 2, 3, 4, 6, 7.5 Mbps New modulation schemes Forward error correction



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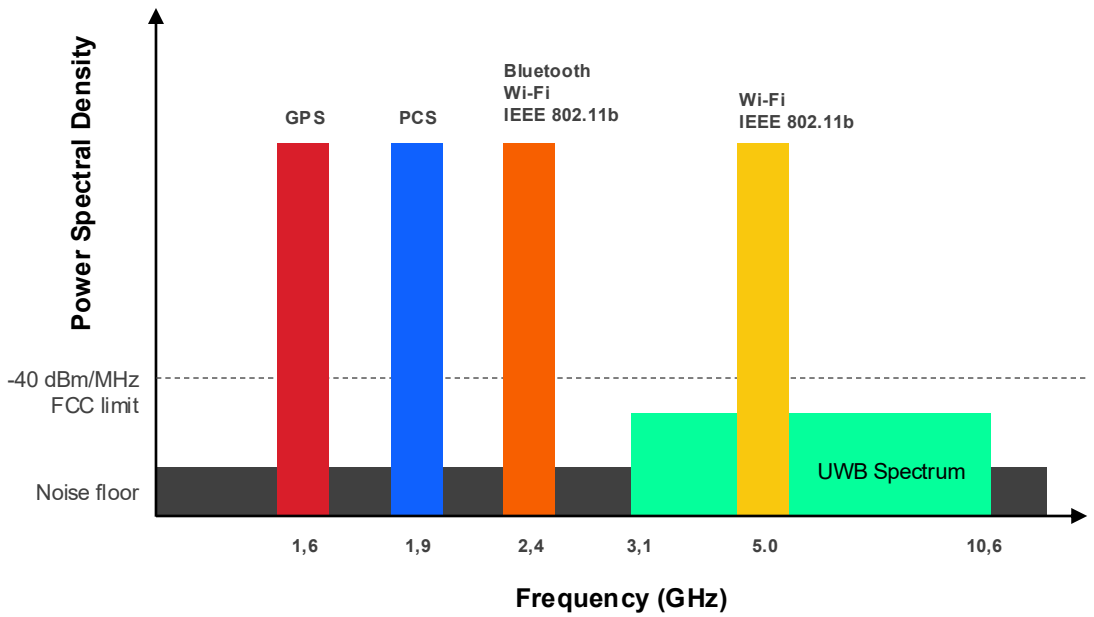
Higher Frequency Bands

- **Higher Frequency Bands**
- Specification expands Bluetooth beyond 2.4 GHz, into the 5-6 GHz spectrum
- Ensures better coexistence as 2.4 GHz band becomes more crowded
- Improves data throughput, lowers latency, and promises to improve Channel Sounding accuracy



Like so many innovations before them, HDT and HB expand Bluetooth's reach into new applications, pushing standardization of wireless communication still further

Portfolio Slide

Channel Sounding

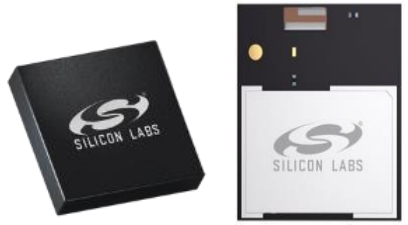
Dual-Antenna Dev Board

BG24 SoC

Other offerings:
BG24L

Mesh

BGM240S SiP & PCB Modules

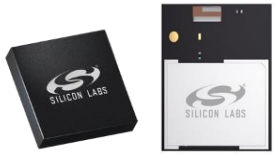


BG24 SoC

Other offerings:
BG21
BG27
BG24L

Energy Harvesting

BGM220S SiP & PCB Modules



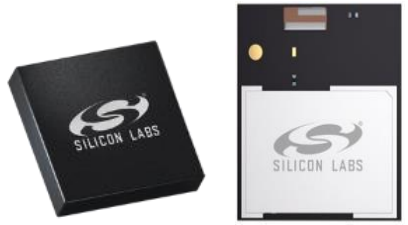
BG22 SoC

xG22E Explorer Kit Shield

Other offerings:
xG22E Explorer Kit
BG22

PAwR

BGM220S SiP & PCB Modules



BG22 SoC

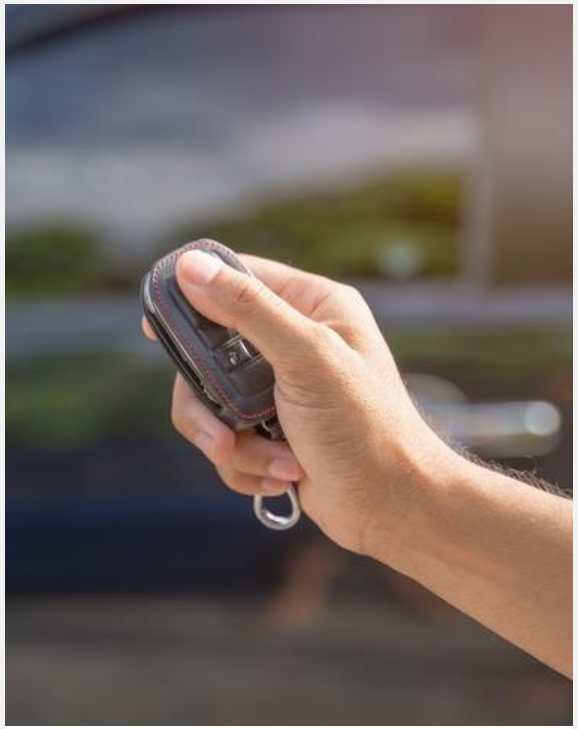
Other offerings:
BG24
BG27
BG21

Silicon Labs' SoC Portfolio

	BG21	BG22/22E	BG24	BG26	BG301	BG22L	BG24L	BG27	BG29
Protocols									
Core	Cortex-M33 (80 MHz)	Cortex-M33 (76.8 MHz)	Cortex-M33 (78 MHz)	Cortex-M33 (78 MHz) Cortex-M0+ (Radio) Cortex-M0+ (Security)	Cortex-M33 (150 MHz)	Cortex-M33 (38.4 MHz) Cortex-M0+ (Radio)	Cortex-M33 (78 MHz) Cortex-M0+ (Radio) Cortex-M0+ (Security)	Cortex-M33 (76.8 MHz)	Cortex-M33 (76.8 MHz) Cortex-M0+ (Radio) Cortex-M0+ (Security)
Max Flash	1024 kB	512 kB	1536 kB	3200 kB	4 MB	352 kB	768 kB	768 kB	1024 kB
Max RAM	96 kB	32 kB	256 kB	512 kB	512 kB	24 kB	96 kB	64 kB	256 kB
Security	Secure Vault Mid/High	Secure Vault Mid / Base	Secure Vault Mid/High	Secure Vault High	Secure Vault High	Secure Vault Mid	Secure Vault Mid	Secure Element, Secure Vault Mid	Secure Vault High
Rx Sensitivity (BLE 1Mbps)	-97.5 dBm	-98.9 dBm	-97.6 dBm	-97.6 dBm	-98.6 dBm	-98.9 dBm	-97.6 dBm	-99.2 dBm	-99 dBm
RX Sensitivity (15.4)	-104.3 dBm	-102.3 dBm	-105.4 dBm	-105.9 dBm	-106.3 dBm	NA	NA	-102.2 dBm	-102.2 dBm
Active Current	59.7 µA/MHz	37 µA/MHz	49.1 µA/MHz	65.8 µA/MHz	47 µA/MHz	37 µA/MHz	49.1 µA/MHz	42 µA/MHz	47uA/MHz*
Sleep Current (EM2, 16 kB ret)	4.5 µA	1.2 µA (8 kB)	1.3 µA	1.4 µA		1.2 µA (8 kB)	1.3 µA	1.6 µA (64 kB)	1.5 µA* (16 kB)
TX Current @ +0 dBm (2.4 GHz)	9.3 mA	4.1 mA	5.0 mA	5.9 mA	11.4 mA	4.1 mA	5 mA	4.1 mA	4 mA*
TX Current @ +10 dBm (2.4 GHz)	33.8 mA	8.2 mA @ +6 dBm	19.1 mA	19.5 mA	28.6 mA	8.2 mA @ +6 dBm	19.1 mA	11.3 mA @ +8 dBm	11 mA* (at +8 dBm)
TX Current @ +20 dBm (2.4 GHz)	185 mA	N/A	156.8 mA	152.7 mA (@19.5 dBm)	N/A	N/A	N/A	N/A	N/A
RX Current (BLE 1 Mbps)	8.8 mA	3.6 mA	4.4 mA	5.4 mA	8.1 mA	3.6 mA	4.4 mA	3.6 mA	3.6 mA*
RX Current (15.4)	9.4 mA	3.9 mA	5.1 mA	6.2 mA	8.9 mA	NA	NA	3.9 mA	4.0 mA
Serial Peripherals	USART, I2C	USART, EUSART, I2C, PDM	USART, EUSART, I2C	USART, EUSART, I2C	EUSART, I2C, PIXELRZ	USART, EUSART, I2C	USART, EUSART, I2C	USART, EUSART, I2C, I2S, PDM	USART, EUSART, I2C
Analog Peripherals	12-bit ADC, ACMP	16-bit ADC	20-bit ADC, ACMP, VDAC	20-bit ADC, ACMP, VDAC	12-bit ADC, ACMP	16-bit ADC, ACMP, VDAC	20-bit ADC, ACMP, VDAC	16-bit ADC, ACMP, Coulomb Counter	16-bit ADC, ACMP
Other	Die Temp Sensor	Die Temp Sensor	Die Temp Sensor	Die Temp Sensor	Temp Sensor, LEDDRV	Die Temp Sensor, AI/ML Accelerator, PLFRCO	Die Temp Sensor, AI/ML Accelerator, PLFRCO	Temp Sensor, PLFRCO, Buck/Boost	Temp Sensor, PLFRCO, Buck/Boost
Operating Voltage	1.71 V to 3.8 V	1.71 V to 3.8 V	1.71 V to 3.8 V	1.71 V to 3.8 V	1.8 V to 3.63 V	1.71 V to 3.8 V	1.71 V to 3.8 V	0.8 – 1.7 V 1.8 – 3.8 V	1.2 - 1.7 V 1.8 - 3.8 V
GPIO	20	18, 26	26, 28/32	Up to 64	Up to 28	18	26	26, 18, 19	19, 25 / 26
Package	4x4 QFN32	4x4 TQFN32 4x4 QFN32 **(AEC–Q100)** 5x5 QFN40 **(AEC–Q100)** 4x4 QFN32, 5x5 QFN40	5x5 QFN40 **(AEC-Q100)** 6x6 QFN48 **(AEC–Q100)** WLCSP 3.1 x 3.0	6x6 QFN48, 8x8 QFN68 7x7 BGA136	4x4 QFN32 5x5 QFN40	4x4 QFN32	5x5 QFN40	5x5 QFN40,4x4 QFN32 2.3x.2.6 WLCSP	5x5 QFN40 2.6 x 2.8 WLCSP

works with by SILICON LABS

Additional Resources



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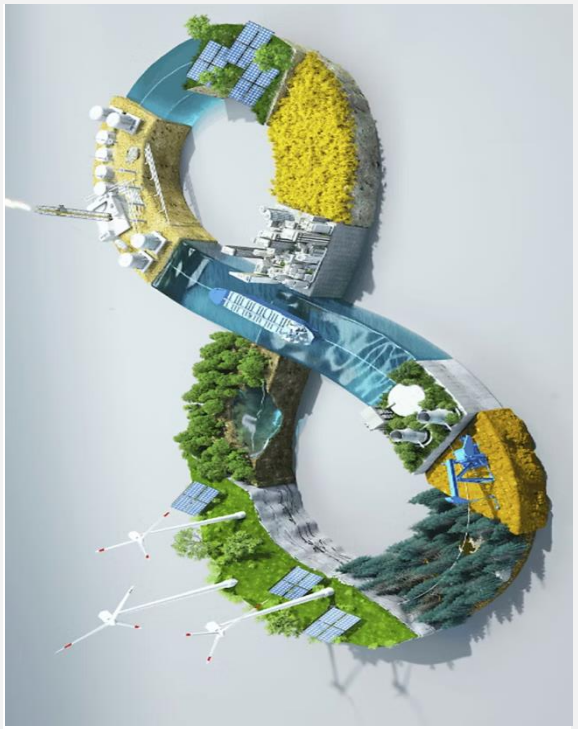

ENERGY HARVESTING

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Blog: Simplifying Ambient IoT with xG22E Energy Harvesting Explorer Kit

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