Bluetooth Low Energy

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Introduction

What is Bluetooth?

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History

Beginnings of Bluetooth

Important Dates

1989 Ericsson wants to devise replacement to wires/cables [7].

1994 Bluetooth invented.

1998 SIG founded: Ericsson, IBM, Intel, Nokia and Toshiba [7].

1999 Bluetooth v1.0

2000 First cell phone with the technology.

2009 Bluetooth Low Energy

2016 Bluetooth 5

First Devices (2000)

Figure 1: GN 9000-BT headset

Figure 2: Ericsson T-36

What about the name?

Harald Blåtand

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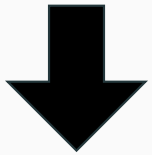
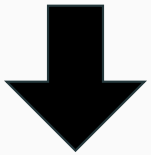


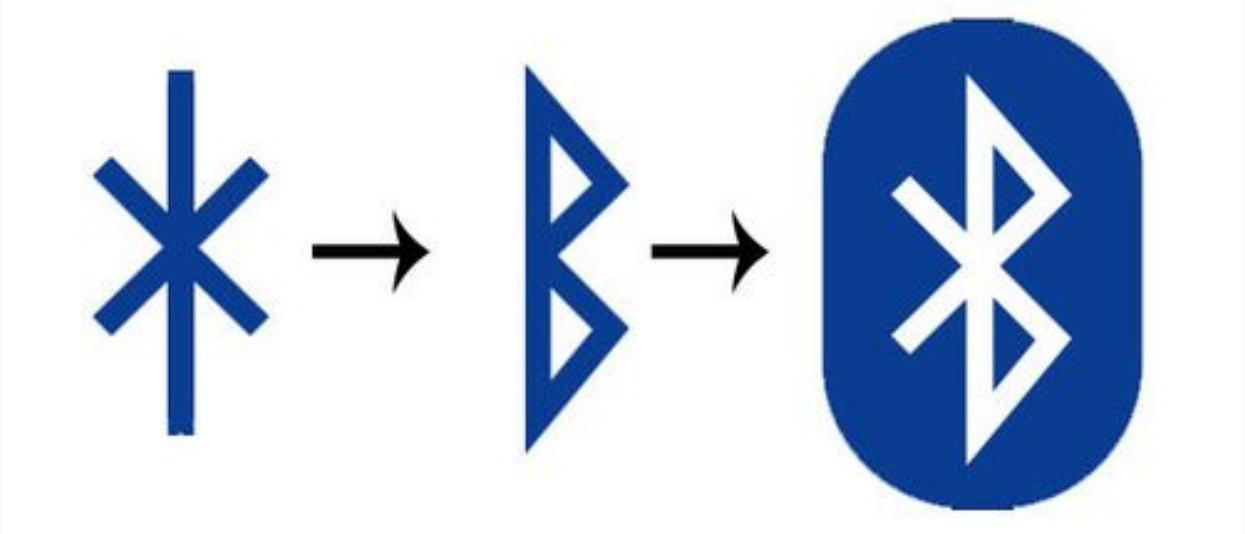
Harald Bluetooth

What about the name?

Harald Blåtand



Harald Bluetooth



Architecture

Protocol Stack

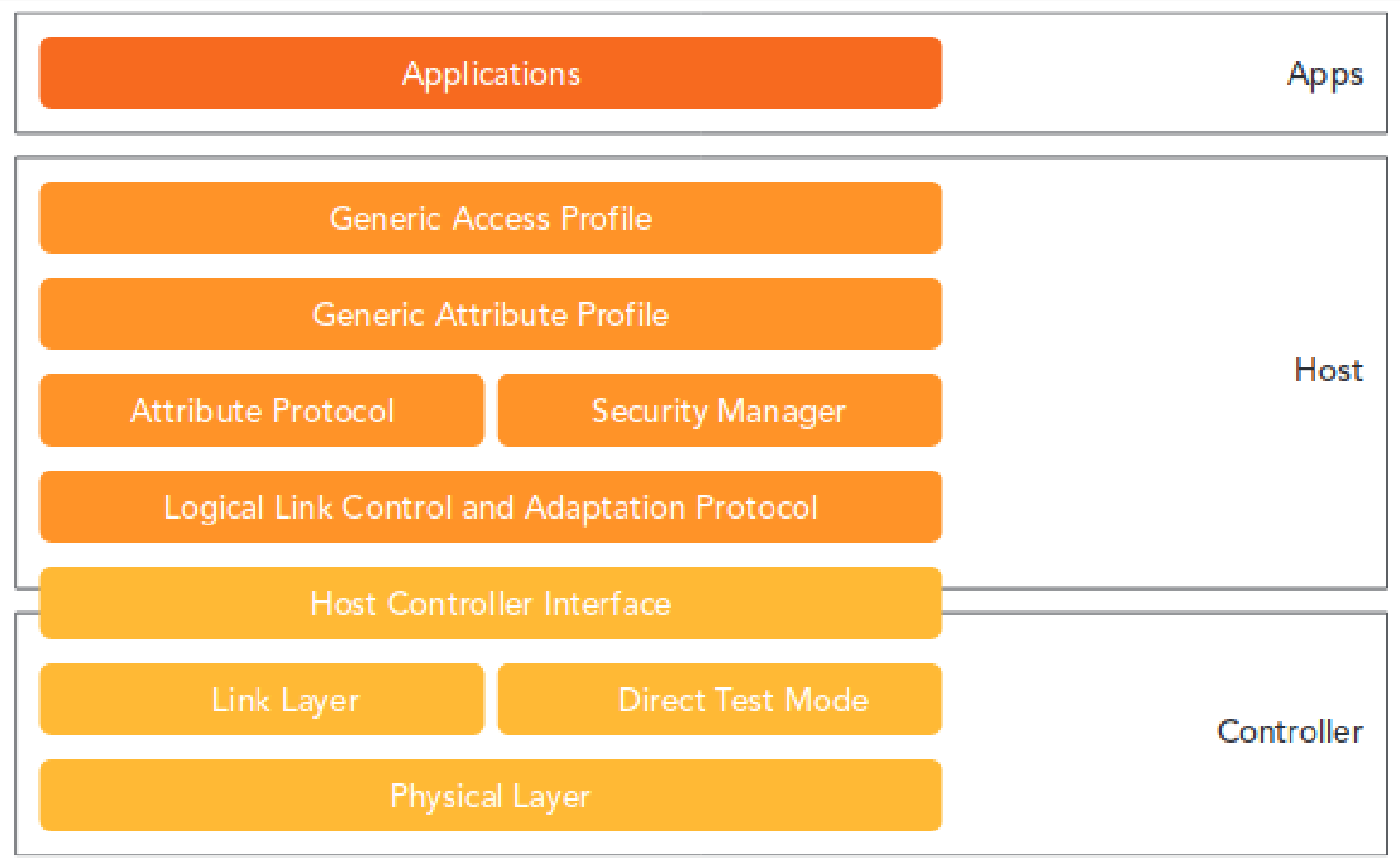


Figure 3: Protocol Stack of Bluetooth Low Energy [5].

Physical Layer

Aspect	BR/EDR	LE
RF Band	2.4 GHz (ISM)	2.4 GHz (ISM)
Energy Consumption	Reference	0.01 to 0.5 of reference
Coverage	10 m	$\geq$ 10 m
RF Channels	79 channels (1 MHz spacing)	40 channels (2 Mhz spacing)
Modulation Scheme	GFSK	GFSK
Modulation Technique	FHSS	FHSS
Gross data rate	1 - 3 Msym/s	1 - 2 Msym/s
Application data rate	0.7 - 2.1 Mbit/s	0.2 - 0.6 Mbit/s
Transmit power	1 mW - 100 mW	0.01 mW - 100 mW

Table 1: Comparison between physical layer aspects of BR/EDR and LE.

Piconets

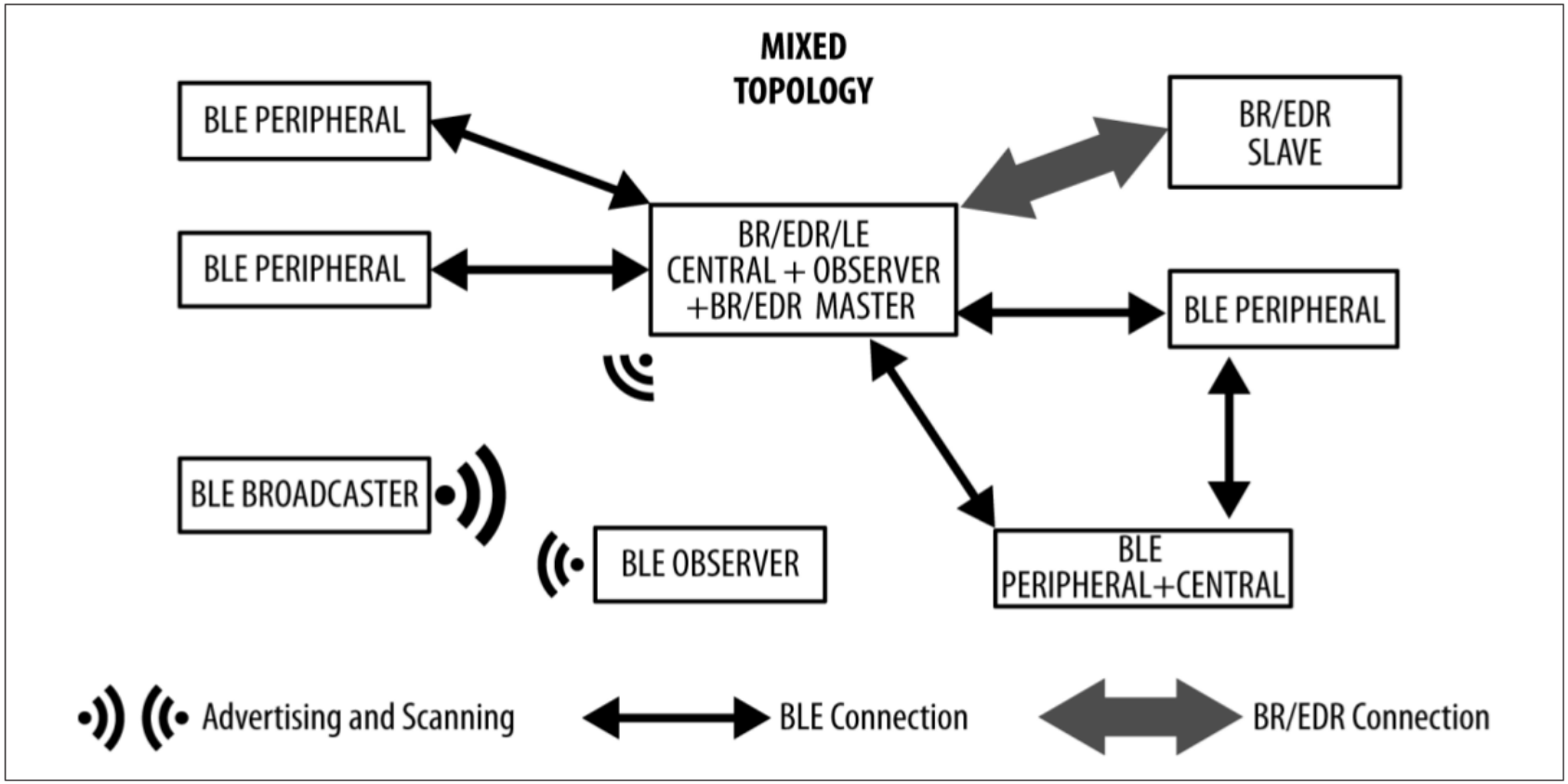


Figure 4: Mixed piconet topology [11].

Communication BR/EDR and LE

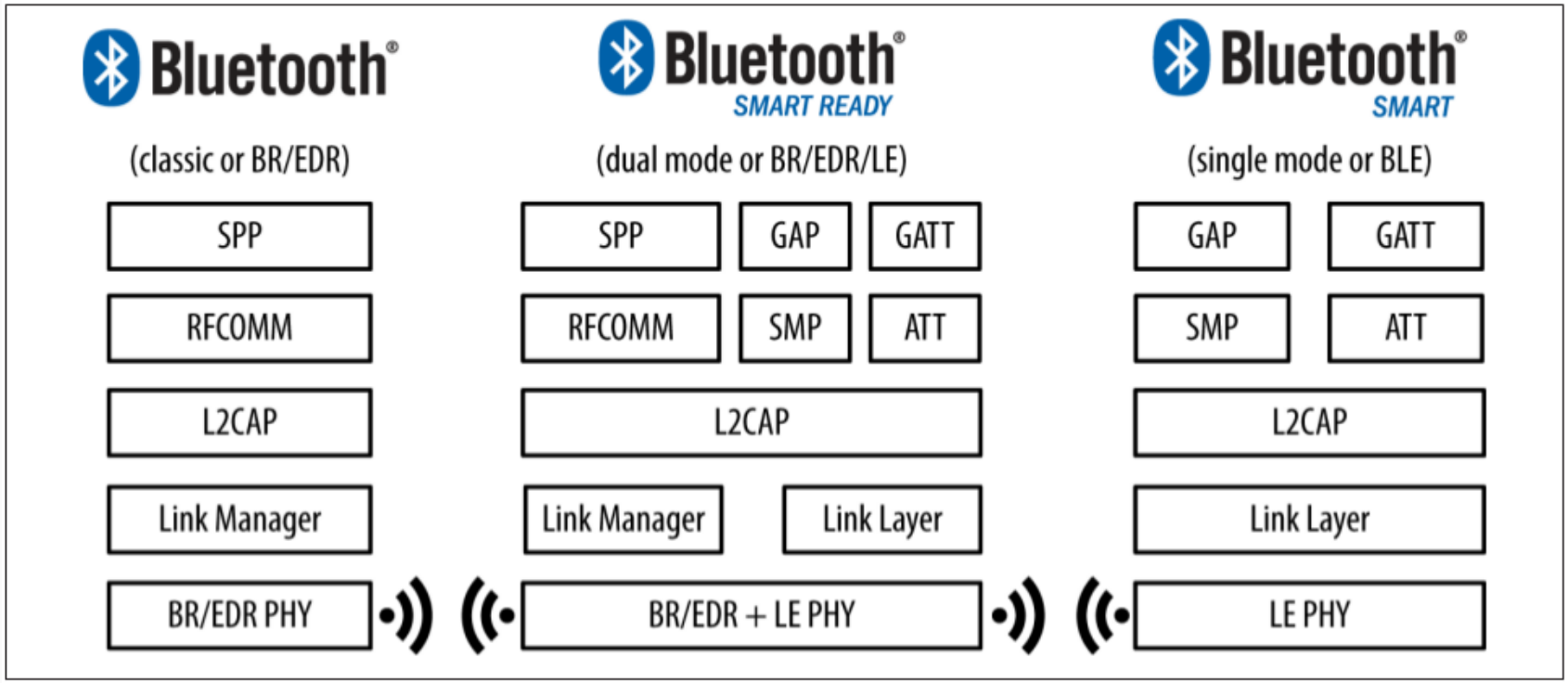


Figure 5: Bluetooth interoperability [11].

Bluetooth Types: Use Cases

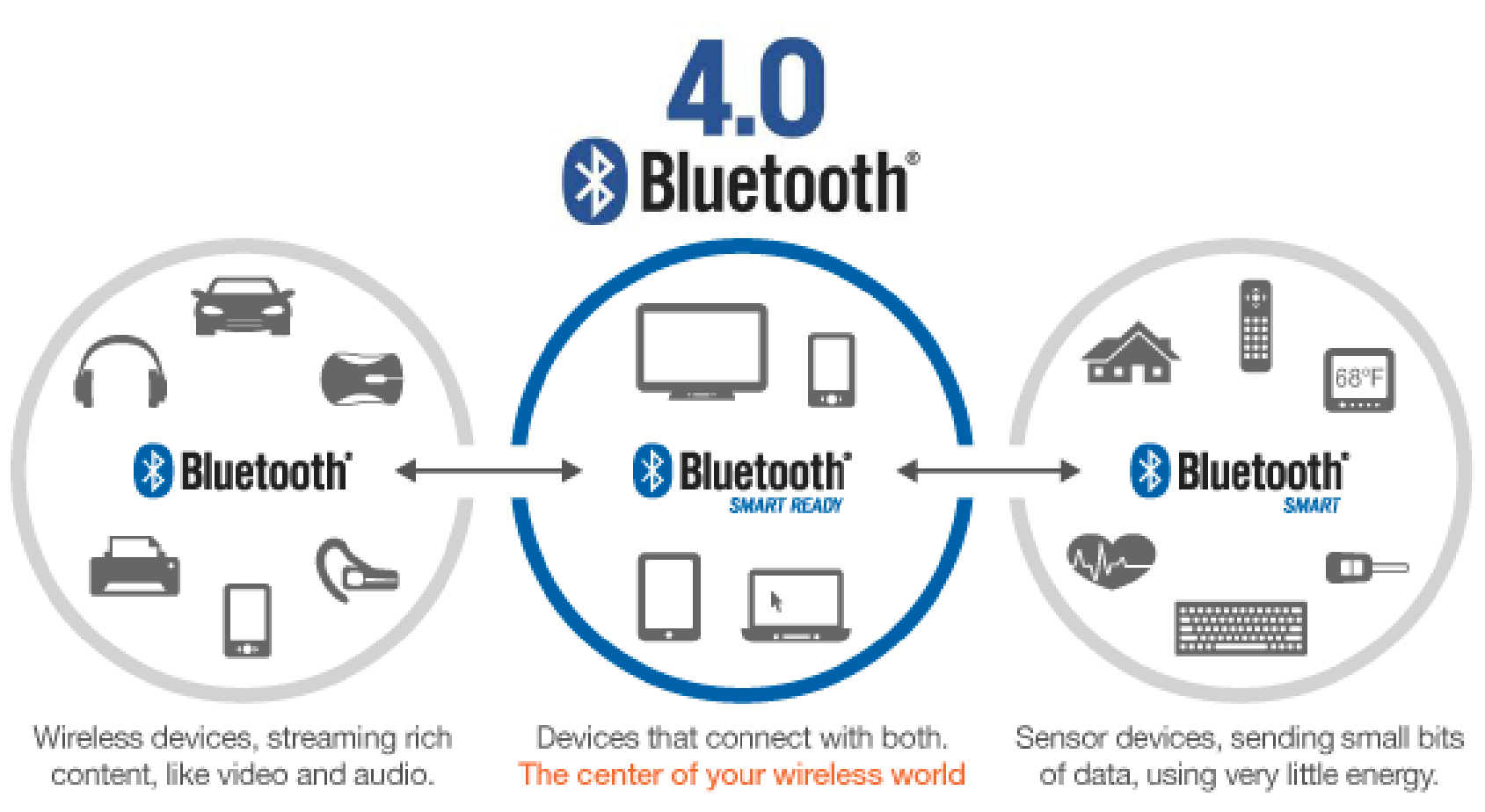


Figure 6: Bluetooth interoperability Source: EdgeFX

Channels

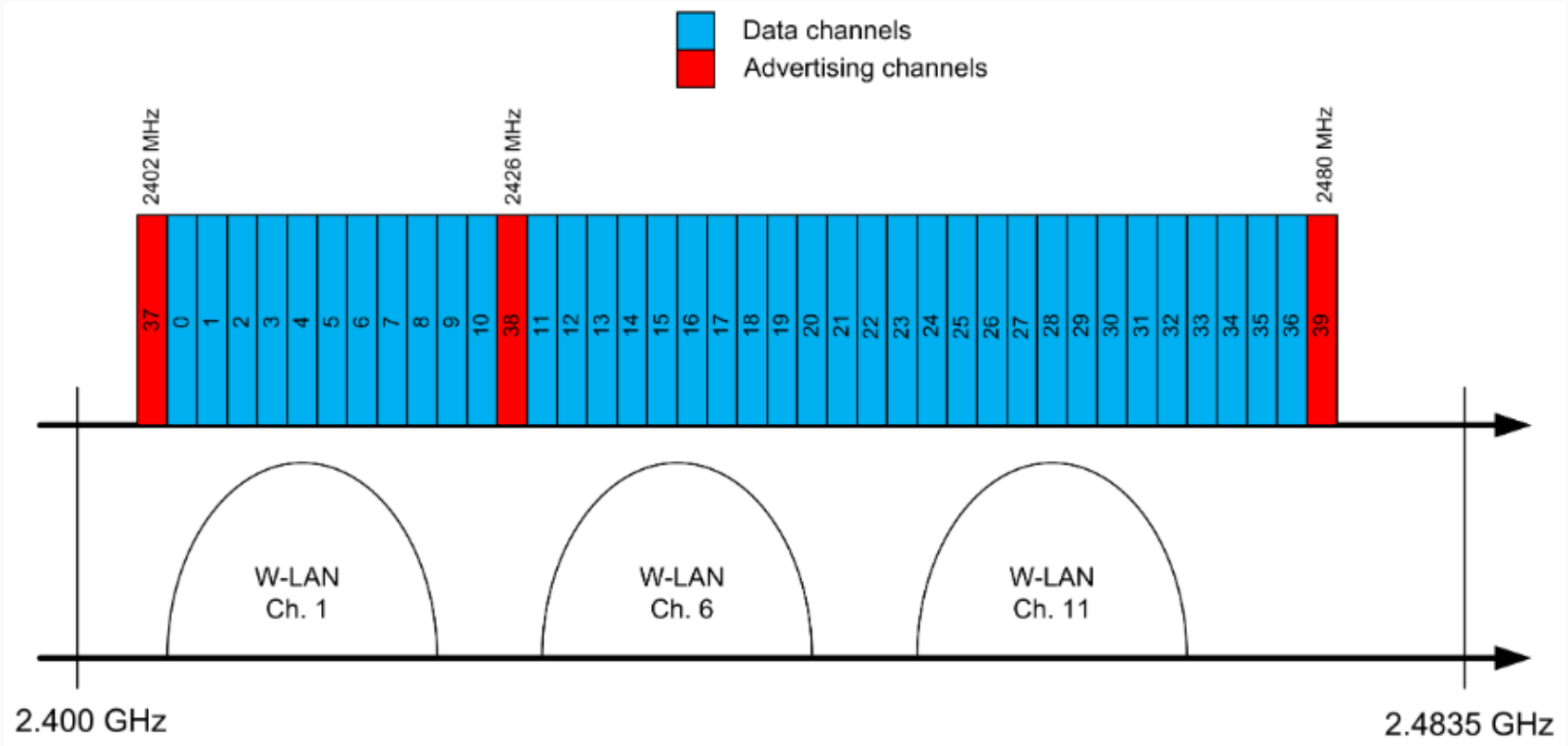


Figure 7: Bluetooth LE and the three nonoverlapping WLAN channels 1, 6 and 11. [6].

Advertisement and Scanning

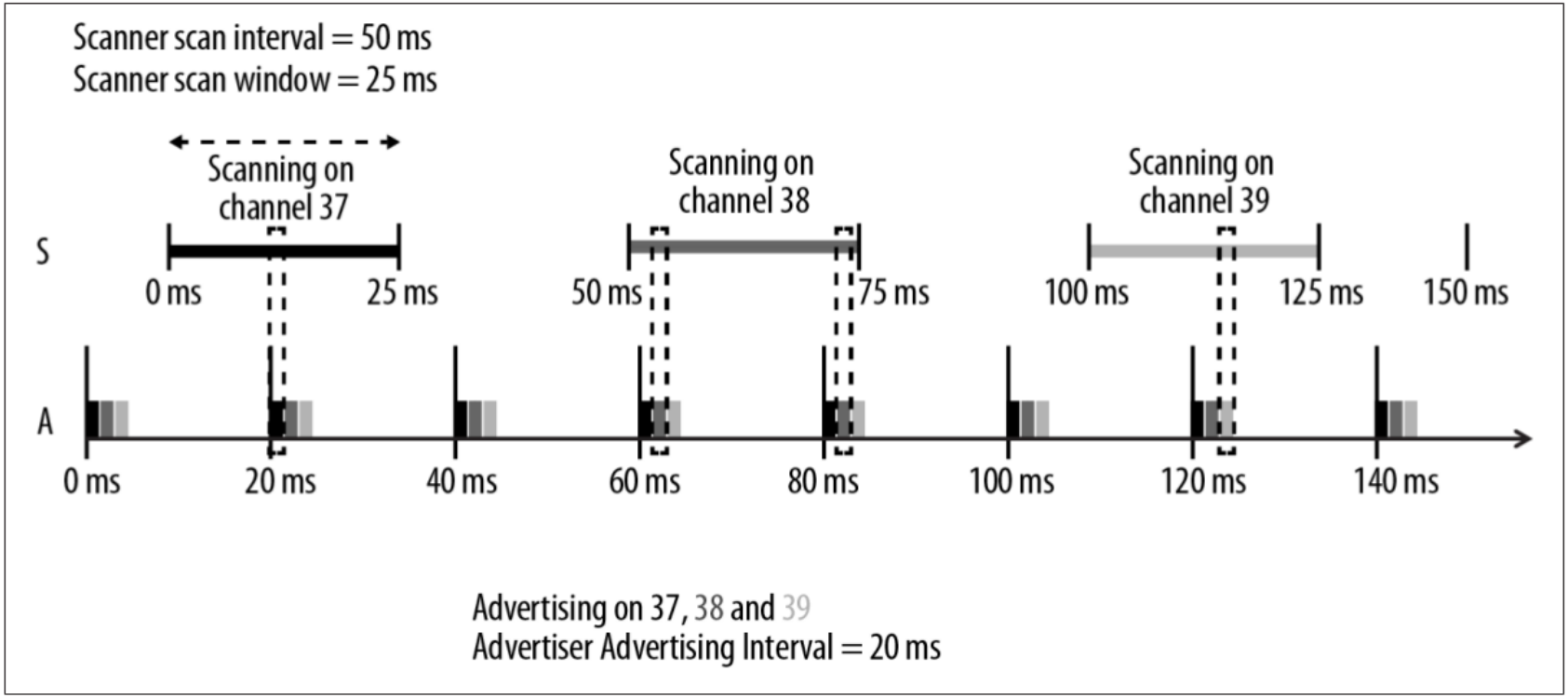


Figure 8: Advertisement events [11].

Connection

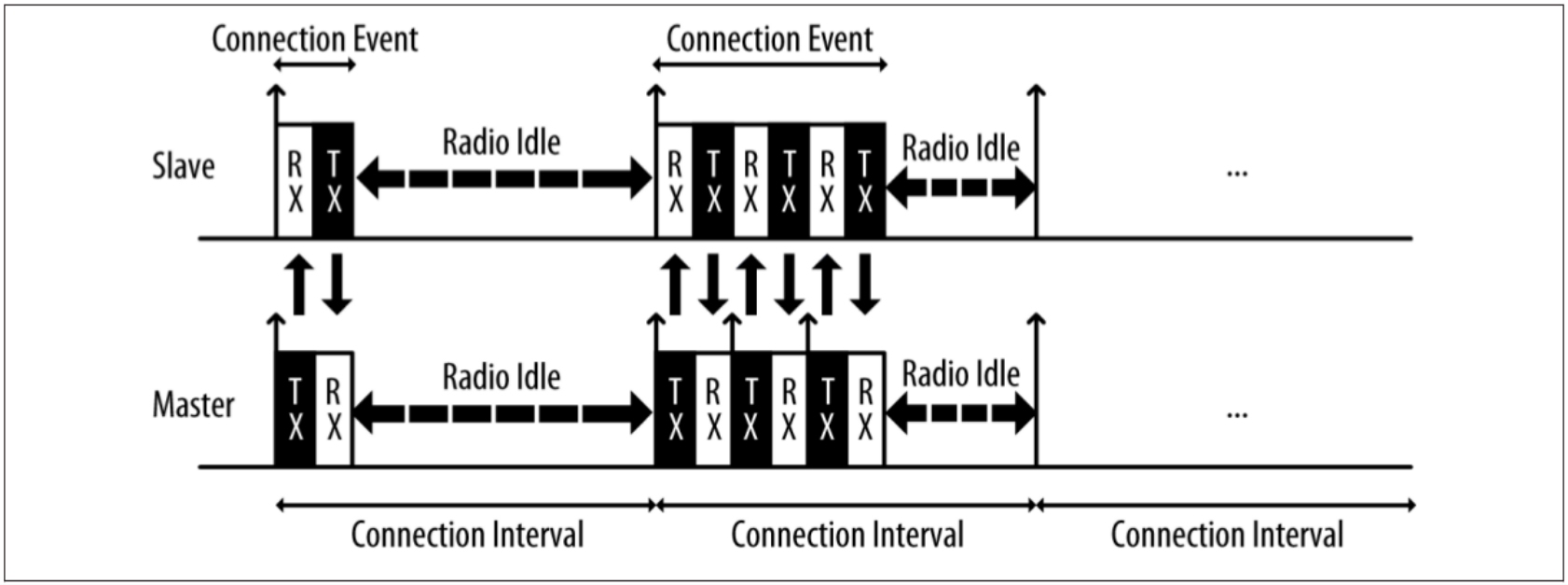


Figure 9: Connection events [11].

Advertisement Extensions

- New in *Bluetooth 5*.
- Can use data channels for advertisement.
- Compatible with Bluetooth 4.x.
- Increase advertisement broadcast throughput by 8 times.

Bluetooth 5 PHY modes

Physical Layer Mode	LE 1M	LE 2M	LE Coded (S = 2)	LE Coded (S = 8)
Nominal Frequency Deviation	250 kHz	500 kHz	250 kHz	250 kHz
Symbol Rate	1 Msym/s	2 Msym/s	1 Msym/s	1 Msym/s
Data Rate	1 Mbit/s	2 Mbit/s	500 kbit/s	125 kbit/s
Error Detection	CRC	CRC	CRC	CRC
Error Correction	None	None	FEC	FEC
Range Multiplier (approximate)	1	0.8	2	4
Requirement in Bluetooth 5	Mandatory	Optional	Optional	Optional

Table 2: Comparison of the Bluetooth 5 PHY modes.

Comparative Studies

An Analysis of Bluetooth, Zigbee and Bluetooth Low Energy and Their Use in WBANs (2010) [2]

- Theoretical comparison.
- Scenario: *Wireless Body Area Networks*.
- BLE is better by a small margin.

	Bluetooth	ZigBee	Bluetooth LE
Advantages	A widely used technology that is supported by most devices. It is ideal for applications that are requiring high bit rates over short distances.	A low-power alternative to Bluetooth, that offers significantly improved performance of 30mW compared to Bluetooth 100mW.	It offers high spectral efficiency and low power consumption
Disadvantages	Open to interception and attack.	Low data rate.	Not supported by many devices

Figure 10: Comparison of Zigbee, Bluetooth and Bluetooth Low Energy.

How low energy is bluetooth low energy? Comparative measurements with ZigBee/802.15.4 (2012) [8]

- Empirical comparison (real devices).
- Scenario: *Wireless Body Area Networks*.
- BLE is better at energy consumption.
- BLE also performs well with interference even without AFH.
- ZigBee: the master device has more processing power.
- BLE: the master device needs less power.

A comparative analysis of BLE and 6LoWPAN for U-HealthCare applications (2013) [10]

- Simulation.
- Scenario: Health Wearables (WBANs).
- BLE, ANT, IrDA, NFC, ZigBee and 6LoWPAN
- Energy, throughput, latency.
- 6LoWPAN: easier to integrate with IP-based applications.
- BLE: Better throughput and less vulnerable to obstacles.

Power consumption analysis of Bluetooth Low Energy, ZigBee and ANT sensor nodes in a cyclic sleep scenario (2013) [1]

- Empirical comparison (real devices).
- Scenario: Cyclic sleep (beacons).
- BLE sleeps and wakes up more efficiently.

	BLE	ZigBee	ANT
Time of one connection ±SD*	1150 ms ±260 ms	250 ms ±9.1 ms	930 ms ±230 ms
Sleep current	0.78 uA	4.18 uA	3.1 uA
Awake current	4.5 mA	9.3 mA	2.9 mA
Min current (at 120 sec interval)	10.1 uA	15.7 uA	28.2 uA
Optimal sleep interval	10.0 s	14.3 s	15.3 s
*SD: standard deviation			

Figure 11: Experimental results using 3.3V supply.

An empirical performance study of intra-vehicular wireless sensor networks under wifi and bluetooth interference (2013) [4]

- Empirical comparison (real devices).
- Scenario: Intra-vehicular Wireless Sensors Networks (IVWSNs).
- ZigBee vs BLE under Bluetooth and Wi-Fi interference.
- BLE is more robust in most configurations.

A preliminary study of low power wireless technologies: ZigBee and Bluetooth low energy (2015) [3]

- Empirical comparison (real devices).
- "Inconclusive" decision.

Technology	**Bluetooth LE**	**ZigBee**
Power spent	29.0 mA*ms	610.2 mA*ms

Table 3: Power spent to trasmit 1 byte of data payload.

Bluetooth LE vs ZigBee

- Bluetooth 4.2+ provides better security.
- Bluetooth LE behaves better with Wi-Fi and Bluetooth BR/EDR interference (AFH and more channels).
- Bluetooth 5 includes error correction (LE Coded).

Applications

Automotive

- VANETs
- IVWSNs

Figure 12: BLE Automotive Applications (Source: Nordic Semi)

Sports and Fitness

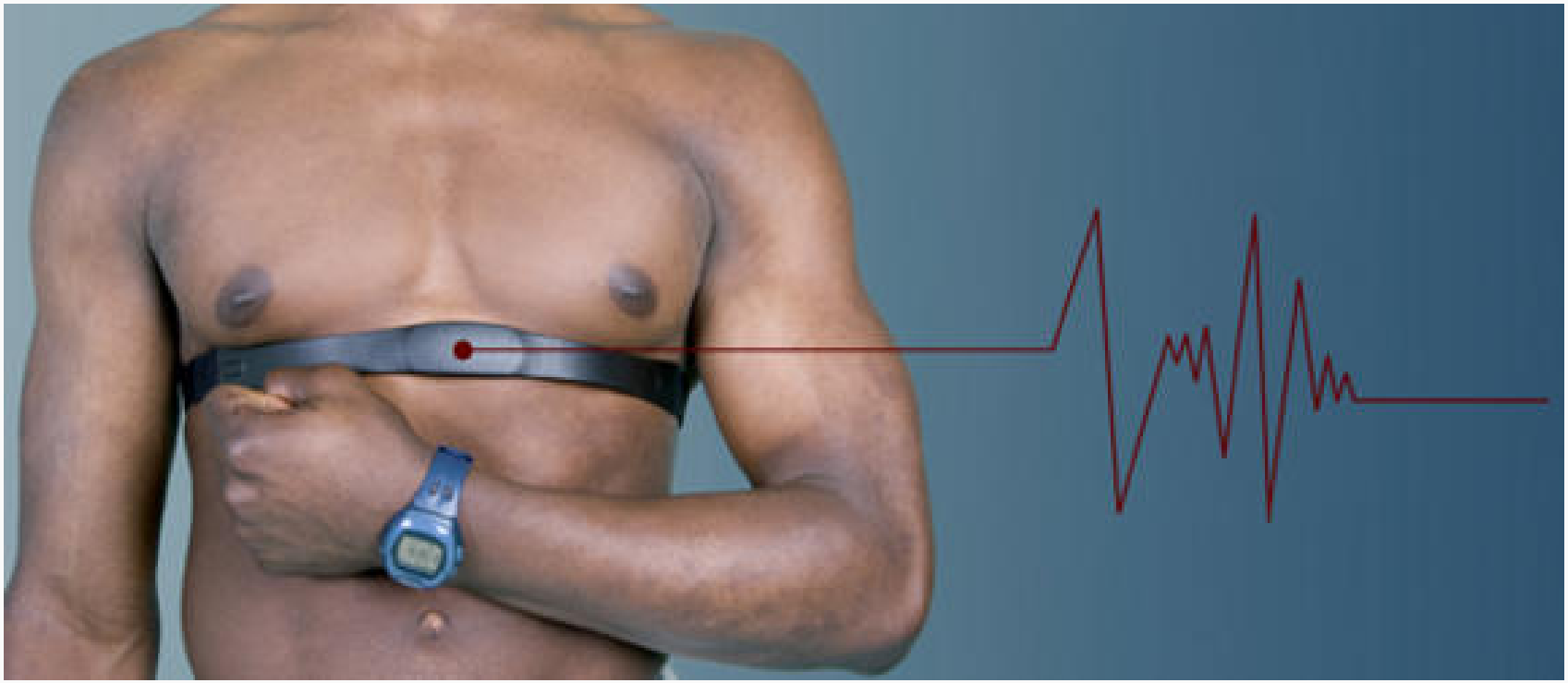


Figure 13: Sports and Fitness Source: Nordic Semi

Healthcare

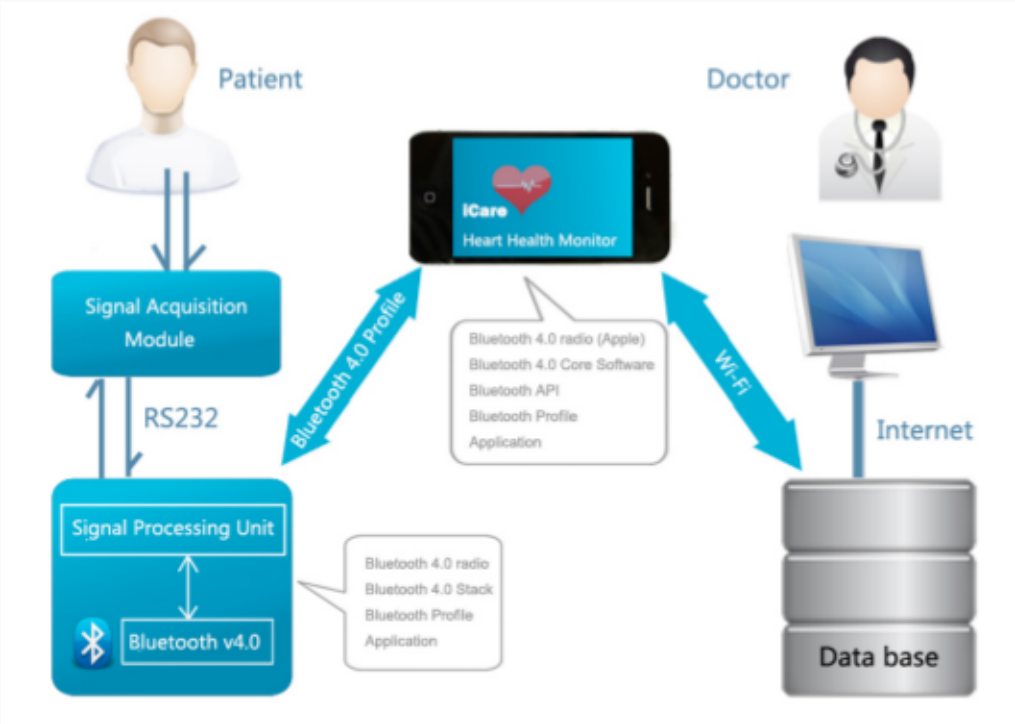


Figure 14: ECG system [12]

Home automation

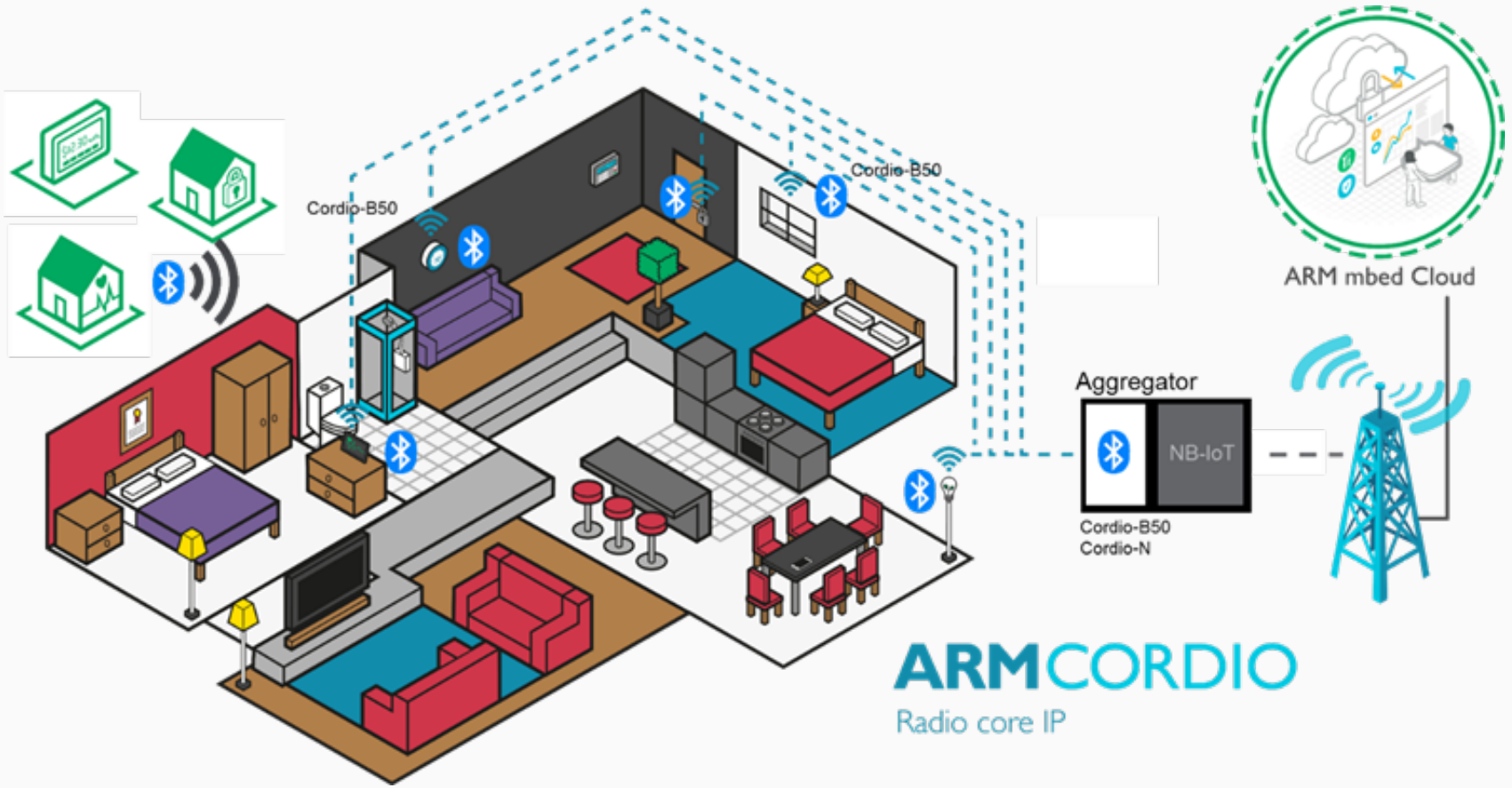


Figure 15: ARM Cordio Source: ARM

Localization and Marketing

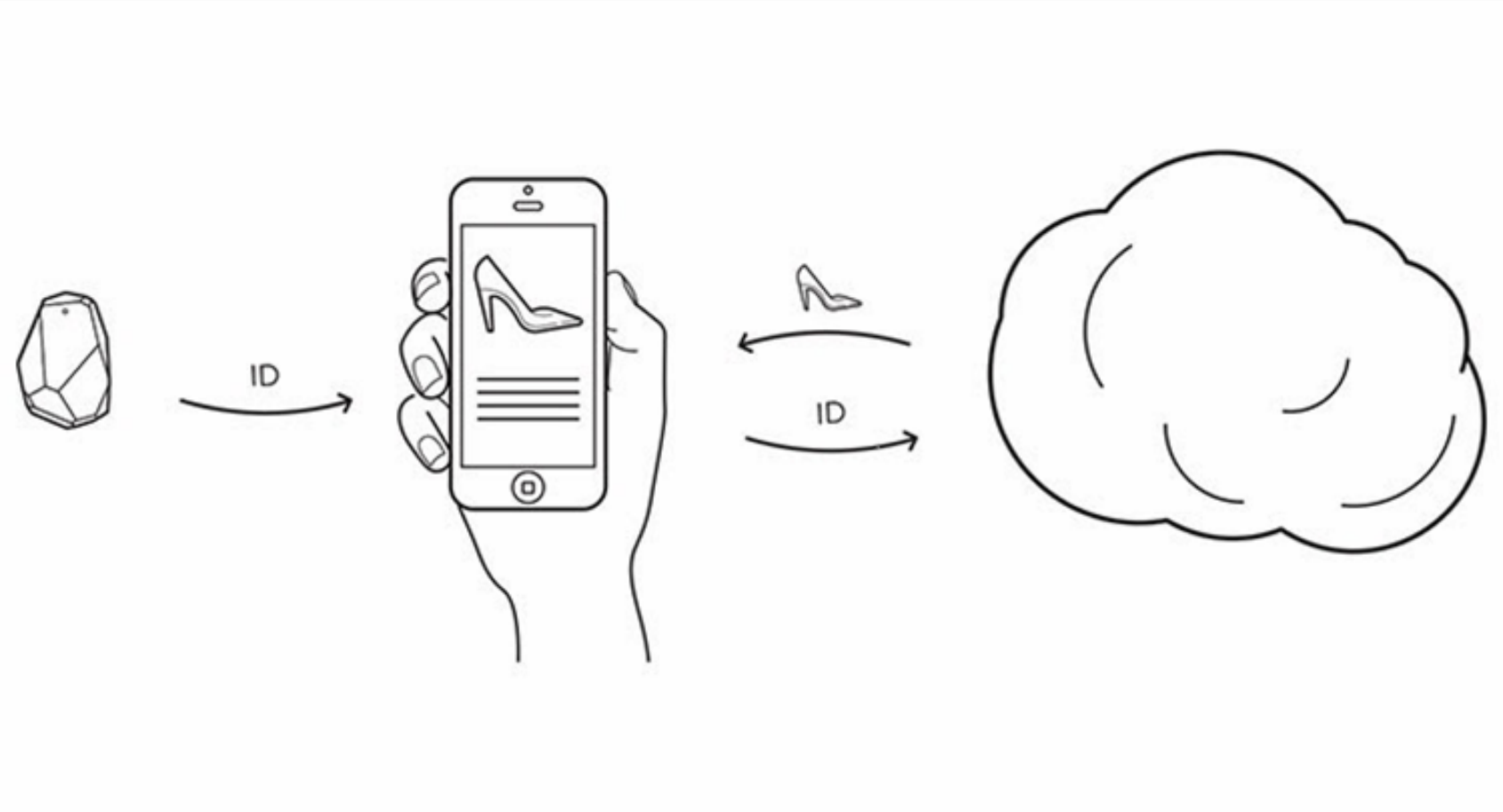


Figure 16: Marketing Application Source: iBeacon Insider

From Imagination to Innovation

From Imagination to Innovation

Figure 17: Awards Logo Source: Bluetooth website

Figure 17: Awards Logo Source: Bluetooth website

Figure 18: Prototype Source: Bluetooth website

Figure 19: Student Source: Bluetooth website

Bluetooth 5 devices and future

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Statistic - IoT connected devices

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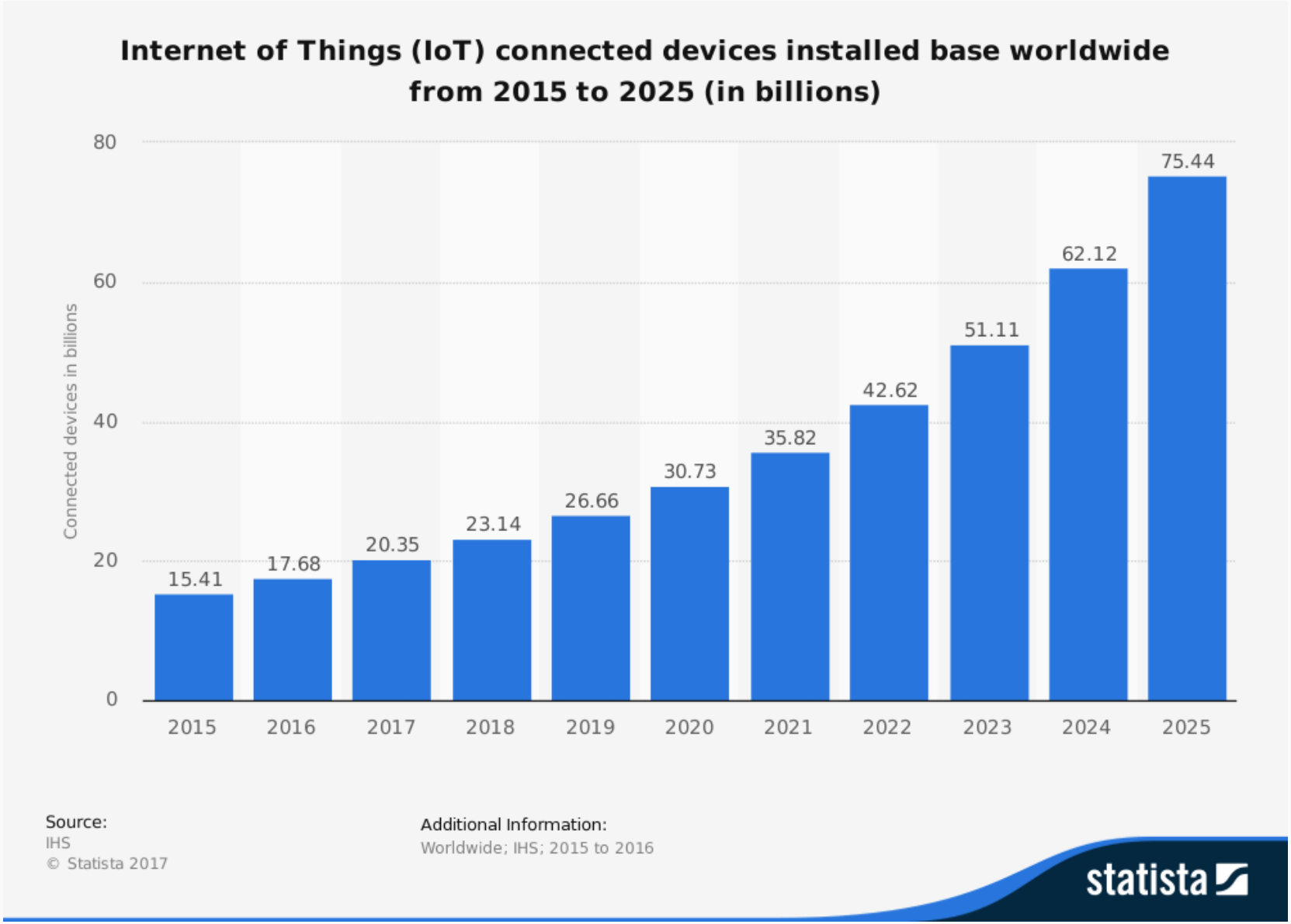

Questions?

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