Bluetooth® low energy

It is NEW Technology

short range

world wide

robust

low cost

low power

But it fits into the wider *Bluetooth* wireless ecosystem.

Technology

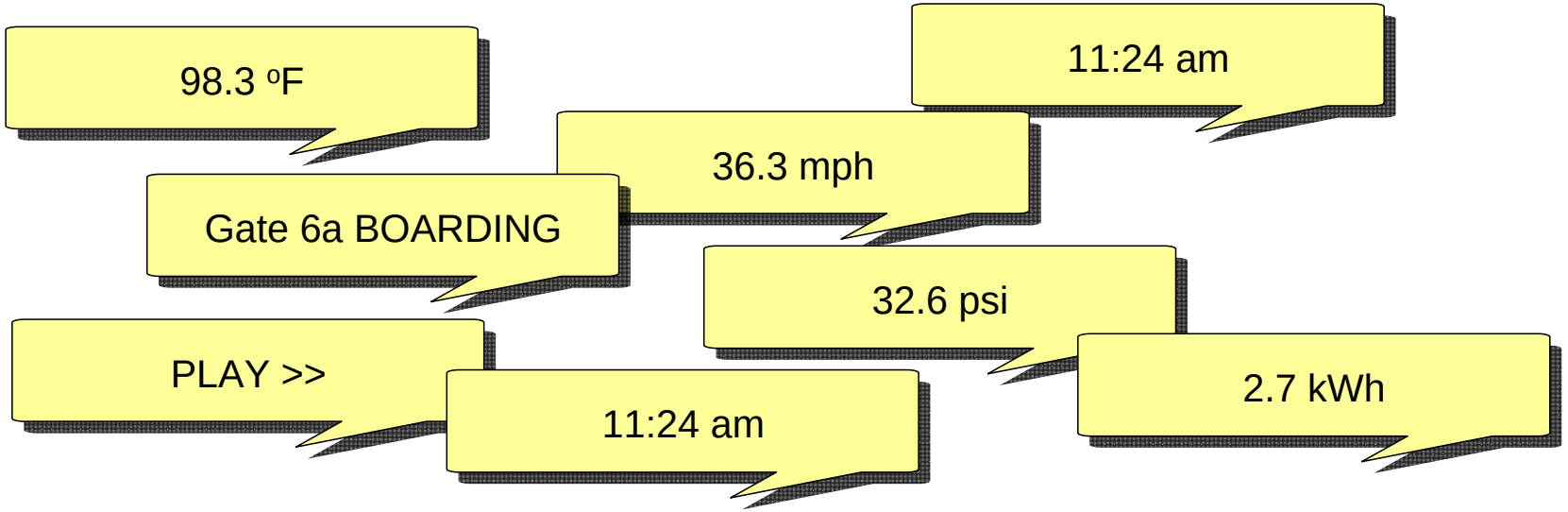
Bluetooth low energy wireless technology is an open low energy, short range radio technology

Key Benefits

- low power consumption
- small size
- connectivity to mobile phones
- low cost
- robust, efficient
- multi-vendor interoperability
- global availability, license free

Bluetooth low energy

It’s good at small, discrete data transfers



It is a connectionless, Always OFF technology.

Key Technology Differentiators

Simple star topology reduces implementation complexity significantly

Very small silicon footprint and thereby very low cost

Very robust through frequency hopping compared to other wireless technologies

Very secure through optional 128 bit AES encryption

Very low power – designed to be asleep

No competitors (*Bluetooth* is already in phones)

It’s about the Internet of Things

Things have data

&

Web Services want this data

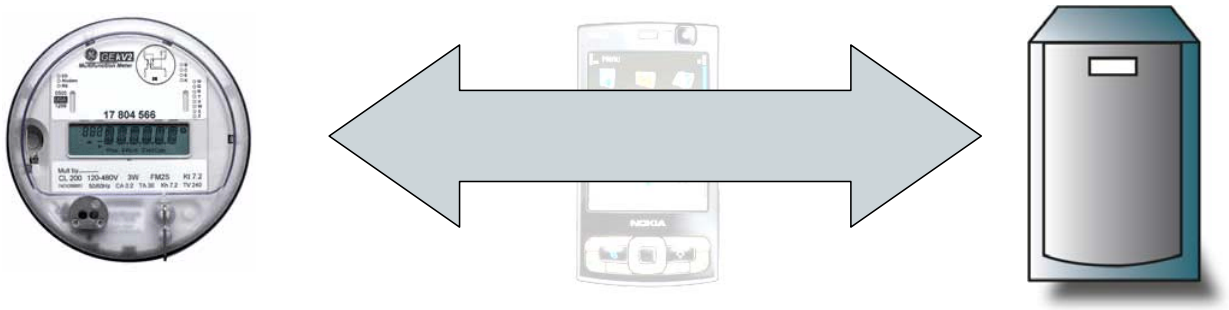
Bluetooth low energy provides the technology to connect these two.

low energy is about generic gateways

Devices that support *Bluetooth* low energy Gateway functionality provide a transparent pipe from a device to an IP address.

Middleware at the IP address can access the device directly as if it were a collector talking to it locally.

The Gateway device plays no part other than in acting as a pipe.



The Basics

Ultra Low Power Consumption

- ~100 µAh per day means 4 year battery life FROM A COIN CELL
- and still sending useful data
- operational life is limited by the battery technology

No need for a charger

- reduces costs of devices
- reduces packaging
- makes new devices possible

The Basics

It can enable proximity detection

- I’m in the car
- I’m in the office
- I’m in the meeting room
- I’m in the movie theater

It can enable presence detection

- Turn the lights on when I walk around the house
- Automatically locks the door when I leave home
- Turns the alarm off if I’m already awake

The Basics

It can send data from anything to the Internet

- I’ve walked 4,000 steps today
- The rice has finished cooking
- Electricity costs $1 per kWh now
- My father is calling
- The toilet has been flushed 6 times
- My weight was 98 lb this morning

The Basics

It can control everything

- unlock doors
- control the heating / cooling / ventilation system
- turn the refrigerator off when electricity is expensive
- turn traffic lights to green when you approach
- change the TV channel
- operate the burglar alarm

The Basics

It connects everything to the Internet

- check if you switched the lights off?
- finds out if your factory is working efficiently?
- records my weight and activity level over the last few weeks.

- unlocks the gate when the pizza dog arrives.
- locks it again afterwards.

Technical Overview

High Level View

Bluetooth low energy is a NEW technology

- Designed from a clean sheet of paper with some constraints and goals

Constraints

- It must reuse as much of *Bluetooth* RF as possible
- It must reuse as much of *Bluetooth* L2CAP as possible
- It must reuse as much of *Bluetooth* HCI as possible

Goals

- Lowest possible power operation
- Lowest possible latency
- Widest possible range of interoperable devices and applications

Effects of Design Constraints

Reusing RF means

- it only needs approximately 60% of RF silicon area compared to *Bluetooth*
- it can use the same antenna as *Bluetooth* (and possibly Wi-Fi)
- it can time division multiplex with *Bluetooth*

Reusing HCI means

- same HCI physical interfaces - UART / USB / SDIO
- same HCI packet formats
- same HCI drivers in OS

Reusing L2CAP means

- segregation of stacks happens at a known multiplexing point

Effects of Design Goals

Optimizing for lowest possible power consumption means

- turning radio off for as much of the time as possible
- reducing the complexity of a single mode device to almost nothing
- designing a “connectionless” data model

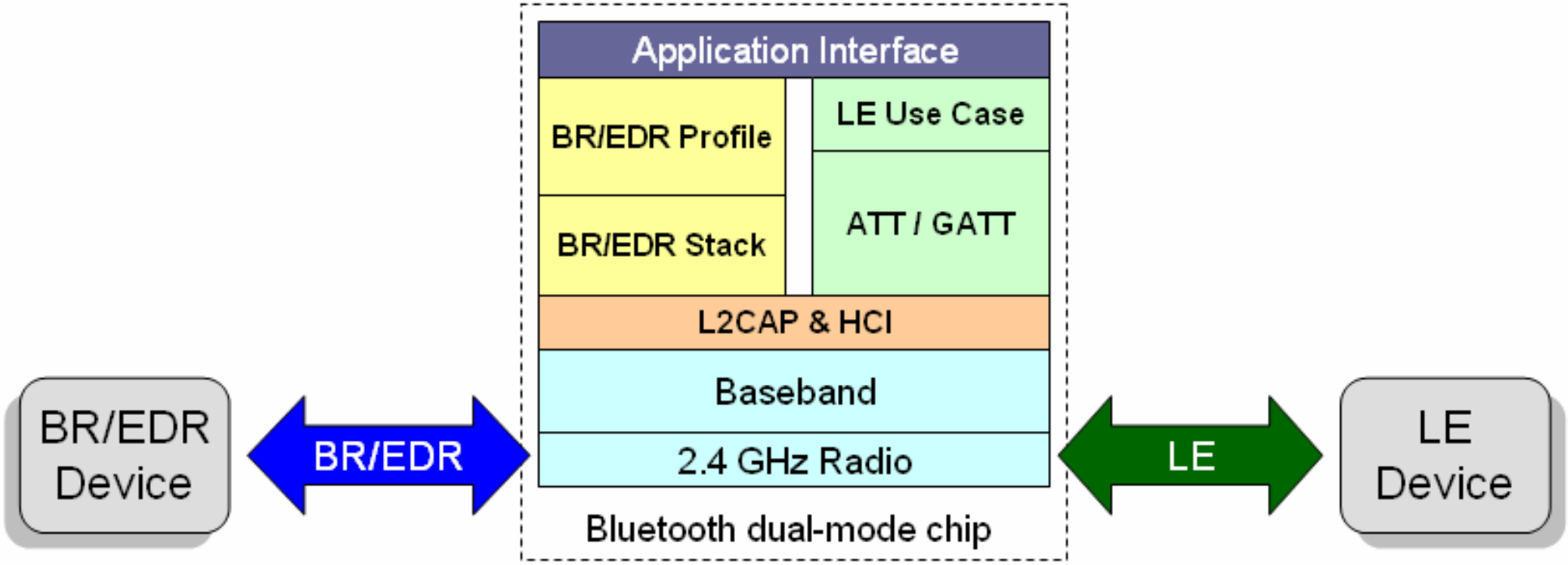
Complexity is important

- reduced complexity & state means reduced memory requirements
- reduced memory requirements means reduced leakage current
- reduced leakage current & radio off means battery lifetimes of years

And it reduces the cost

- 80% to 60% of the cost of traditional *Bluetooth* chips

Dual Mode Chipsets



Bluetooth's Dual-mode advantage. One chip supports all types device.

How is low power achieved?

By keeping the radio off

- Lower standby time (i.e. lower duty cycle)
- Faster connection (i.e. able to send data quicker)
- Lower peak power (i.e. able to be used with coin cell battery)

Lower standby time

Bluetooth low energy technology uses only 3 advertising channels

- *Bluetooth* technology uses 16 to 32 channels
- RF is on for 1.2 ms instead of 22.5 ms

Idle current is dominated by deep sleep current

- Sensor type of applications send data less often (0.5s to 4s intervals)
- RF current is negligible due to low duty cycles
- Protocols optimized for this communication model

How is low power achieved?

Faster Connections

In *Bluetooth* low energy technology a device that is advertising is able to connect to a scanning device

The devices can connect and send and acknowledge data in 3 ms

- In *Bluetooth* technology a link level connection can take up to 100 ms
- In *Bluetooth* technology an L2CAP connection can take significantly longer

Lower Peak Power

Bluetooth low energy technology uses relaxed RF parameters

- GFSK modulation index increased
- Allowing better range / robustness

Packet length restricted

- Together with GFSK gives lowest complexity transmitter / receiver
- This results in a lower peak power

Data Rate & Throughput

Bluetooth low energy is *NOT ABOUT* data rate / bandwidth

- It concentrates on lowest possible power consumption
- It can do 260 kbps maximum data rate
  - BUT, it burns power doing this
  - *Bluetooth* BR/EDR is more efficient at these data rates

Bluetooth low energy is about transferring state

- small, infrequent bits of data
- lowest possible power consumption
- lowest latency

Physical layer - MAC and PHY

Splits the 2.4 GHz ISM band into 40 channels

- 3 Advertising Channels
- 37 Data Channels
- $f_n = 2402 + 2n$ MHz

GFSK Modulation

- Modulation index 0.5, giving better range than classic *Bluetooth*
  - allows use of fewer advertising channels
  - reduces power consumption
  - increases connection speeds
- Can reuse existing RF parts in a *Bluetooth* chip
  - Minimal additional cost in dual-mode chips

Master / Slave Topology

Highly Asymmetric

Master is typically the Central device

- Phone, Computer

Slave is typically the peripheral device

- Heart Rate Belt, Thermostat

Slave is very *VERY* power sensitive

- must be optimized for minimal radio on time

Master is time sensitive

- must be optimized for latency requirements

Separate Advertising & Data Channels

Data Channels

Used to transfer reliable data robustly

- adaptive frequency hopping over 37 channels
- fast acknowledgement scheme
- if data doesn’t get through, resent on next frequency

Advertising Channels

- 2402, 2426, 2480 MHz. Avoids interference with Wi-Fi traffic
- Used by peripherals to advertise presence
  - when first powered on
  - when they have data to send - central devices connect and get data
  - just to broadcast data to anybody scanning

Security

Uses AES-128 with CCM encryption engine

Uses Key Distribution to share various keys

- Identity Resolving Key is used for privacy
- Signing Resolving Key provides fast authentication without encryption
- Long Term Key is used for encryption

Pairing encrypts the link using a Temporary Key

- derived from passkey, NFC pairing, public key exchange (v1.1)
- then distribute keys

Asymmetric key model

- slave gives keys to master with a diversifier
- slave can then recover keys from the diversifier

Encryption

RFC 3610 based AES-128 encryption

- Counter Mode Cipher Block Chaining Message Authentication Code
  - Counter mode CBC-MAC = CCM

Each new data packet has a Message Integrity Check

- 39 bit counter, 1 direction bit
- 64 bit Initialization Vector – 32 bits contributed by each device
- MIC is 32 bits in length

MIC is separate from the CRC

- CRC can allow immediate acknowledgment
- packet is only sent to host after MIC checked
- lowest peak power

Designed to survive

Robustness is Vital

- It must be robust against 2.4 GHz ISM band interference
  - Wi-Fi, 802.15.4, X-10, Proprietary

Coexistence is Vital

- It cannot interfere with existing Wi-Fi infrastructure / ad-hoc networks
- Adaptive Frequency Hopping is needed
  - FCC recognizes this as the best way to avoid interference
- Discovering devices / connecting devices should not break Wi-Fi
- It must not affect *Bluetooth* headsets

Managing Complexity

A new approach to profiles

There are lots of common data formats

- on / off
- temperature
- counts
- rates

We need to characterize data in reusable structures

- means changing the way we define interoperability
- move to an object oriented, server based structure

And we call them “Use Cases”

Object Oriented Model – Use Cases

Use Cases replace Profiles

Use Cases define:

- Characteristics - state
- Control Points - writable or notifiable
- Behavior
- Relationships to other classes (Extends, Includes)

Characteristics define:

- Data format for a given unit / object
- Can combine characteristics
  - Latitude + Longitude + Elevation = Position
  - Weight + Timestamp = Weight Health Record
- Characteristics do not contain behavior - otherwise they are difficult to reuse

Server Behavior

We only define server behavior – it's asymmetric

- Server is a device that "has characteristics"
- Things you can read (sensor) or write (actuator)

Client behavior is undefined

- Server is rigorously defined
- State Machines on server are fully robust
  - each state with each input has a defined behavior

Model View Controller Pattern

- Model = Server Behavior
- View = Characteristics
- Controller = Writable Characteristics

Generic Attribute Profile (GATT)

A device may support many services

- It has a way to group characteristics for a given service together

The «Service» attribute

- Each service group is a separate instance of a class on a device
- e.g. multiple temperature sensors

Services are identified by a UUID

- 16 bit *Bluetooth* UUID (using the same SDP base *Bluetooth* UUID)
- 128 bit UUID (allocated by anyone, including you)

Presentation Information

Services can include Presentation information

- Characteristic can have «Characteristic Presentation Format»
  - Data Type (uint16, utf8 string, float64, etc...)
  - Exponential (fixed point e.g. value of $649 * 10^{-1} = 64.9$)
  - Unit (Temperature, Mass, Length, Hertz, etc...)

Allows two usage models:

- Application Search based on Service UUID
  - Plug and Play enumeration possible

- Presentation of information without knowledge of Service UUID
  - Generic device displays
  - Allows push of data to web-server to “understand”

Attributes

All data is exposed using “Attributes”

- An attribute is a labeled piece of discrete data

  Handle : Type : Value

Handle

- 16 bit handle - unique on the server

Type

- UUID - the type of this attribute (e.g. «Service», «Temperature»)

Value

- the “data” (e.g. «Thermometer Class», 649)
- 0 to 512 octets in length (< 20 octets efficient)

How much does it cost?

Dual Mode

- *Bluetooth* + low energy radio chips = minimal additional cost
- Currently in volume these are approaching $1

Single Mode

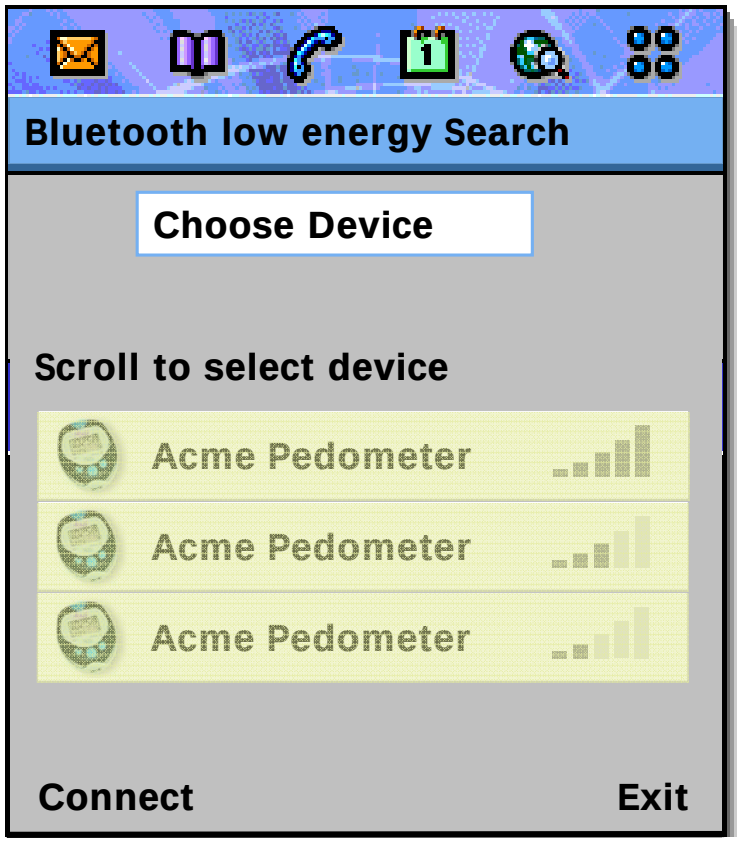
- low energy only radio chips = 80% size of *Bluetooth* controllers
- when volumes increase, costs will reduce below $1 quickly

Bluetooth in 2001 was $10 and 9 years later it is approaching $1

low energy in 2013 will be less than $1 and 9 years later ...

Putting it to use

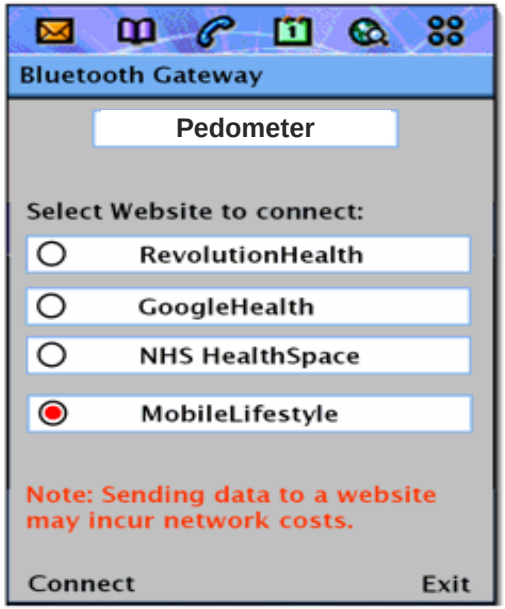
New tools make it easy to connect



devices ship with a web address…

www.patientslikeme.com

…using a generic app on your phone…



which connects them to the web app…

then automatically sends your data…

Or, tell the phone what they can do…

Pedometer
Acme Model XYZ
Steps per Minute
Total Steps
Calories Used
Find me an APP…

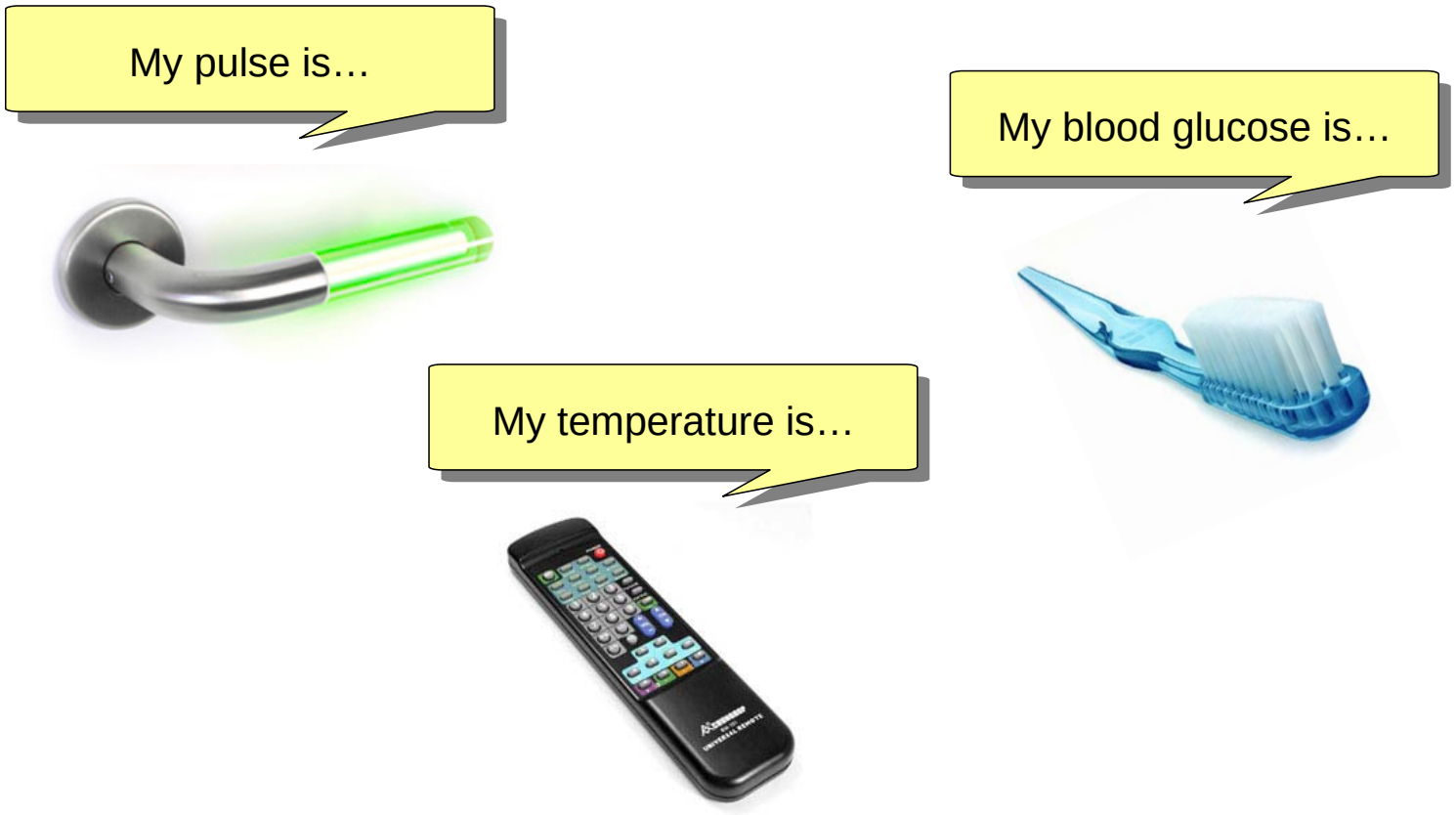
and the phone gets a tailored set of Apps

Easy to buy

=

More revenue

everyday objects can become sensors



…and monitor things unobtrusively

Conclusion

Summary

Feature	Benefit
Ultra Low Power	Devices can run on coin cells for years
100 metre Range	Covers the whole house
Adaptive Frequency Hopping	Works alongside Wi-Fi - and will keep on working as it's inherently robust
128 bit AES CCM Encryption	Secure against attack and hacking
Object Oriented Paradigm	Designed for web connected devices, and supports this decade's paradigm of Apps Store Ecosystems
Easy to Use	Includes a Usability Tool Kit to make the user experience better
License Free	No fees to use the technology
New Qualification Scheme	Most products will be FREE to qualify

How we achieved that

- Started with a blank sheet of paper
- Optimised it end-to-end

  (*Bluetooth* is the only wireless standard that controls the end-to-end standard.)
- Learnt from our 11 years of experience, and everything else in the market
- Drew on the knowledge of our 12,500 members

  (cf. Continua 230, Wi-Fi 347, ZigBee 330).

  We have 40 experts for every expert they have.
- Designed it for end-to-end applications

Conclusions

Do you want a robust, long range, secure, license free technology?

Do you want your devices to work for years on a single cheap battery?

Do you want the ability to write innovative apps quickly?

Do you want wireless internet access for your devices ?

Do you want fast time to market, enabled by multiple chip and module suppliers, supporting a wide range of features?

Bluetooth low energy

connecting everything

Questions?

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