The Internet of Things and the Two Sides of Sustainability

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Image from Wikimedia Commons

Image from iStock.com/ipopba

Forbes

Why The IoT Will Save Our Natural Resources

Feb 21, 2020, 07:45am EST

Article from forbes.com

Forbes

A Smarter World Will Be More Sustainable

Aug 19, 2021, 07:00am EDT

Article from forbes.com

Forbes

How The Internet Of Things Will Help Fight Climate Change

Nov 5, 2019, 06:44am EST

Article from forbes.com

Forbes

How Connected Technologies Can Help The World Decarbonise

Jan 11, 2023, 06:15am EST

Article from forbes.com

Image from Wikimedia Commons

Image from iStock.com/ipopba

INTERNET OF THINGS

SUSTAINABILITY

Images from Wikimedia Commons

OpenAI ChatGPT

> “The Internet of Things (IoT) has the potential to play an important role in sustainability, helping to reduce resource use and increase efficiency. IoT-enabled devices provide the ability to monitor and control energy and water use, manage waste, and track emissions in real-time. […]
> As the technology continues to mature, IoT-enabled systems are becoming increasingly capable of providing the data and insights necessary to create more sustainable systems.”

Image from Wikimedia Commons

Image from iStock.com/ipopba

INTERNET OF THINGS

SUSTAINABILITY

A perfect match?

A paradox?

Image from Alan Levine @ pxhere

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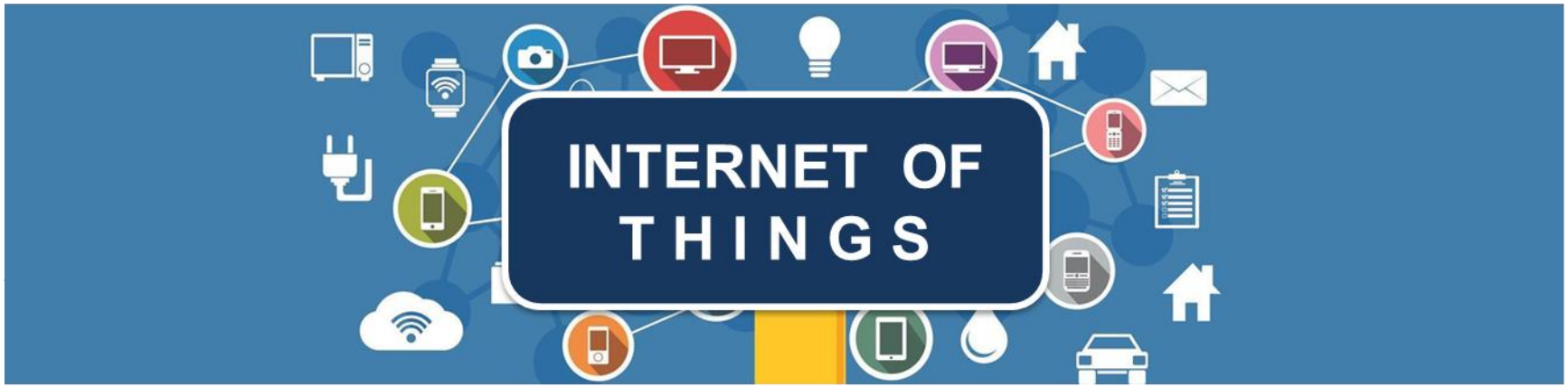
INTERNET OF THINGS

SUSTAINABILITY

John Romkey

Simon Hackett

1980 | **1990** | 2000 | 2010 | 2020



Images taken from clipart-library.com and bismart.org, and wikimedia.org

`finger coke@cmua`

1980 1990 2000 2010 2020

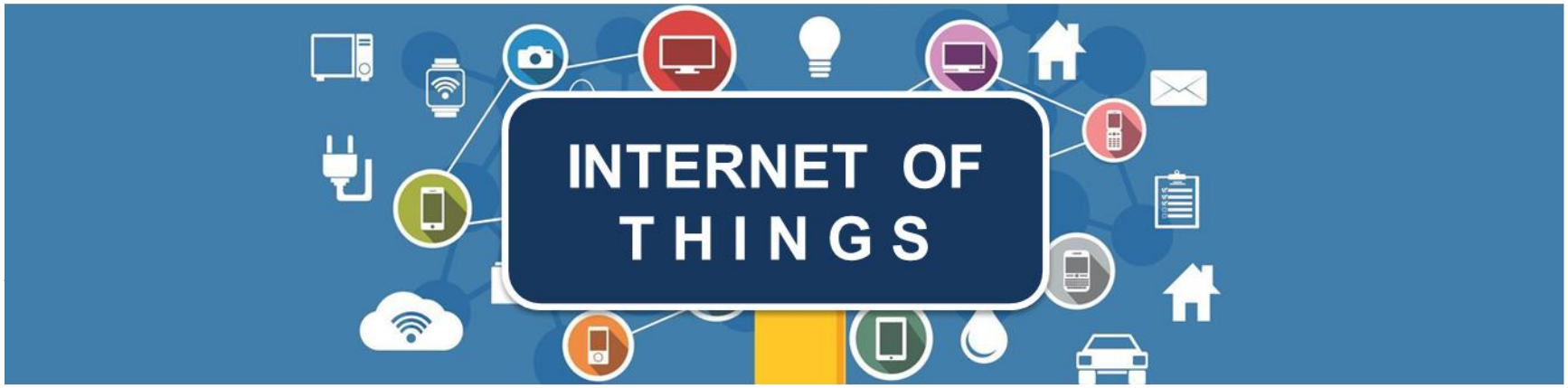


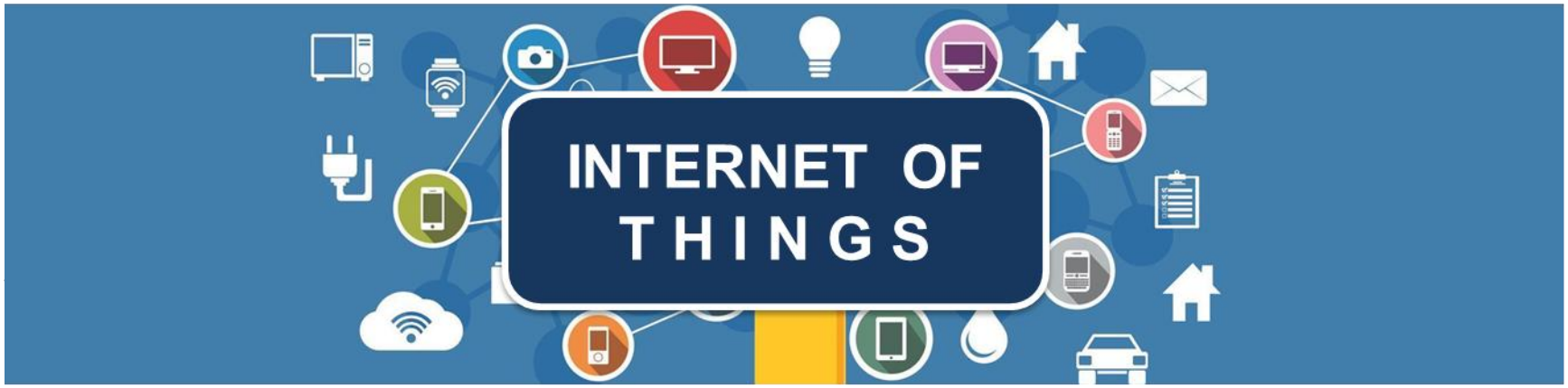
Image taken from cmu.edu

finger coke@cmua

Kevin Ashton

AUTO-ID LABS

1980 1990 2000 2010 2020



Images taken from indymedia.org.uk and wikimedia.org

World Population	4.4 billion	5.3 billion	6.1 billion	6.9 billion
Connected Devices	< 1000	300.000	400 million	12.5 billion

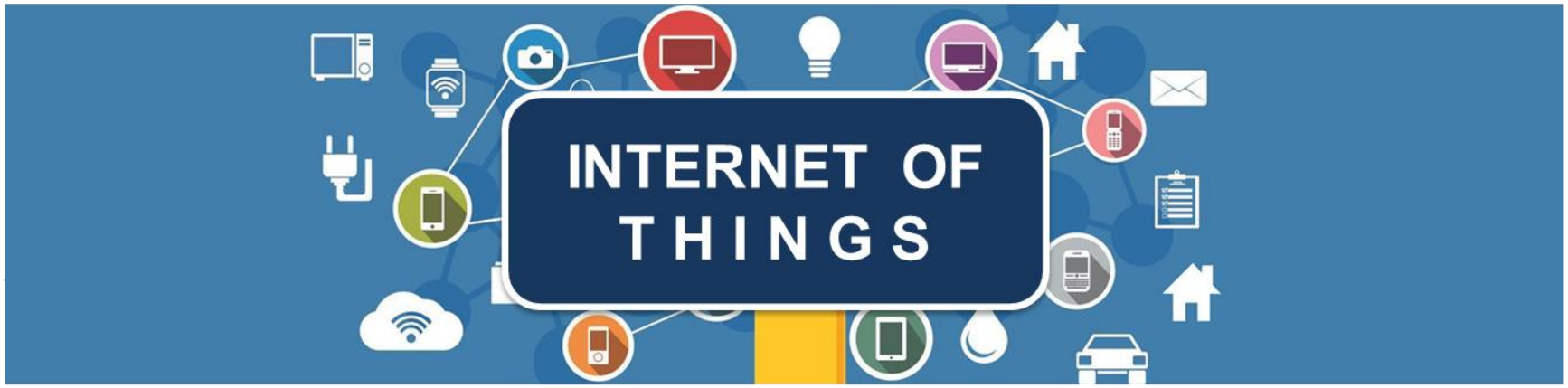
finger coke@cmua

Kevin Ashton

CISCO

More connected devices than people on Earth

1980 1990 2000 2010 2020

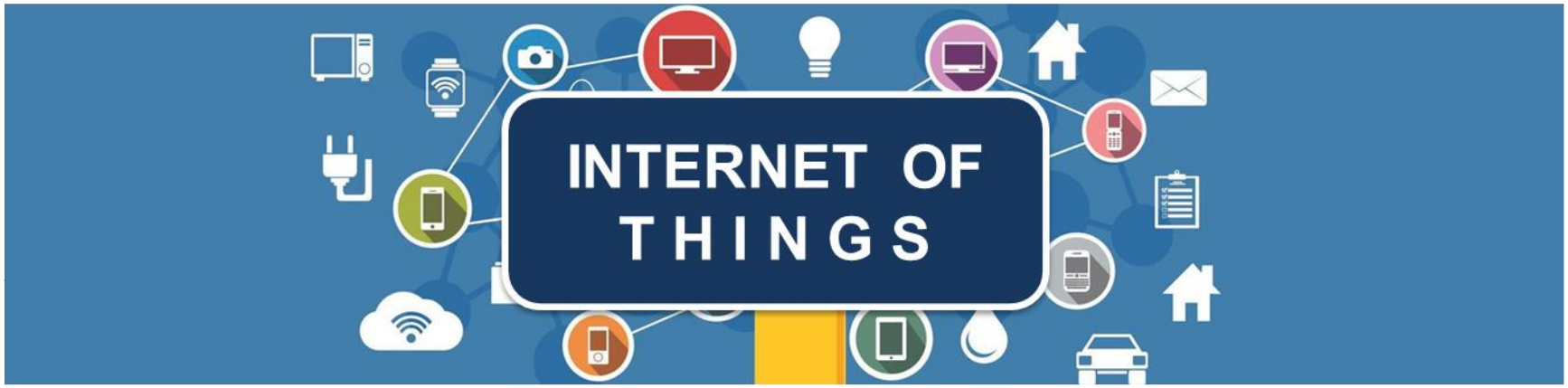


White Paper

The Internet of Things

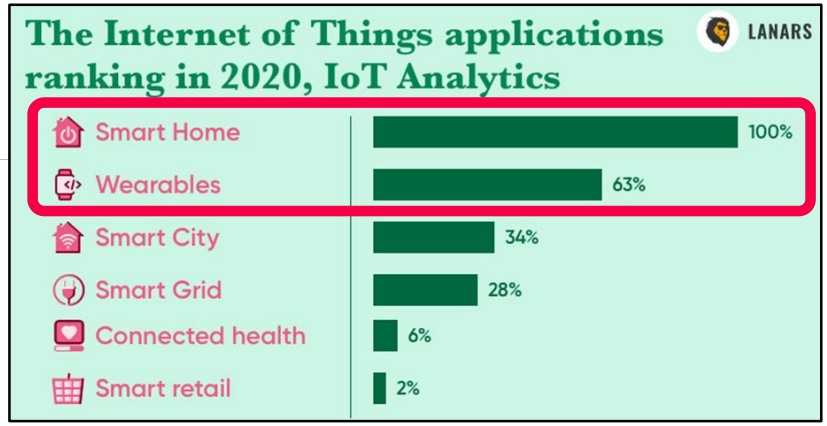
How the Next Evolution of the Internet Is Changing Everything

1980 1990 2000 2010 2020

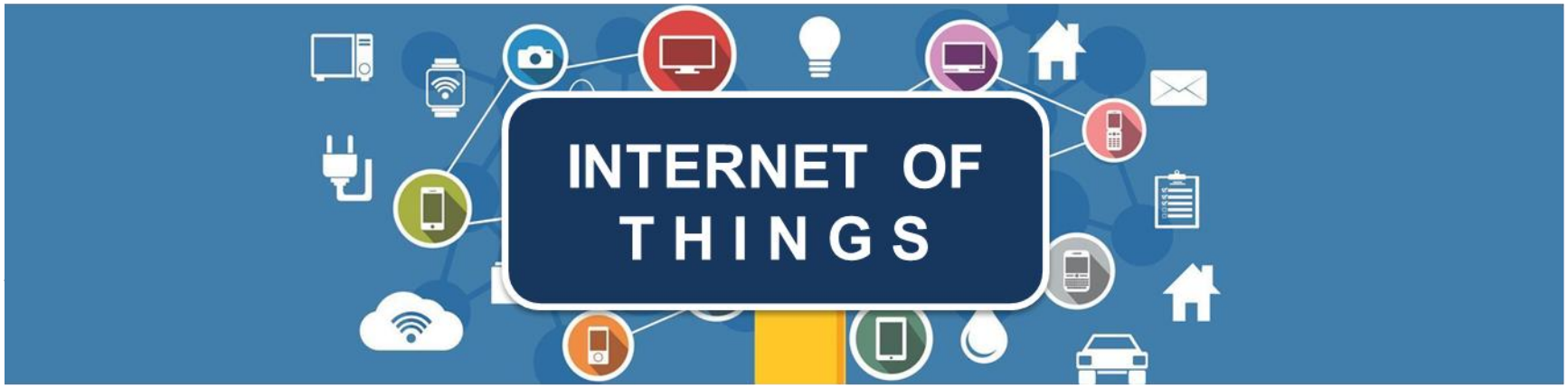


Images taken from cisco.com

World Population	**4.4 billion**	**5.3 billion**	**6.1 billion**	**6.9 billion**	**7.8 billion**
Connected Devices	**< 1000**	**300.000**	**400 million**	**12.5 billion**	**50 billion**



1980 **1990** **2000** **2010** **2020**



Images taken from fsetyt.com, amazon.com, xcite.com, dailymail.co.uk, lanars.com, amazon.com, and august.com

World Population	4.4 billion	5.3 billion	6.1 billion	6.9 billion	7.8 billion	8.6 billion
Connected Devices	< 1000	300.000	400 million	12.5 billion	50 billion	500 billion

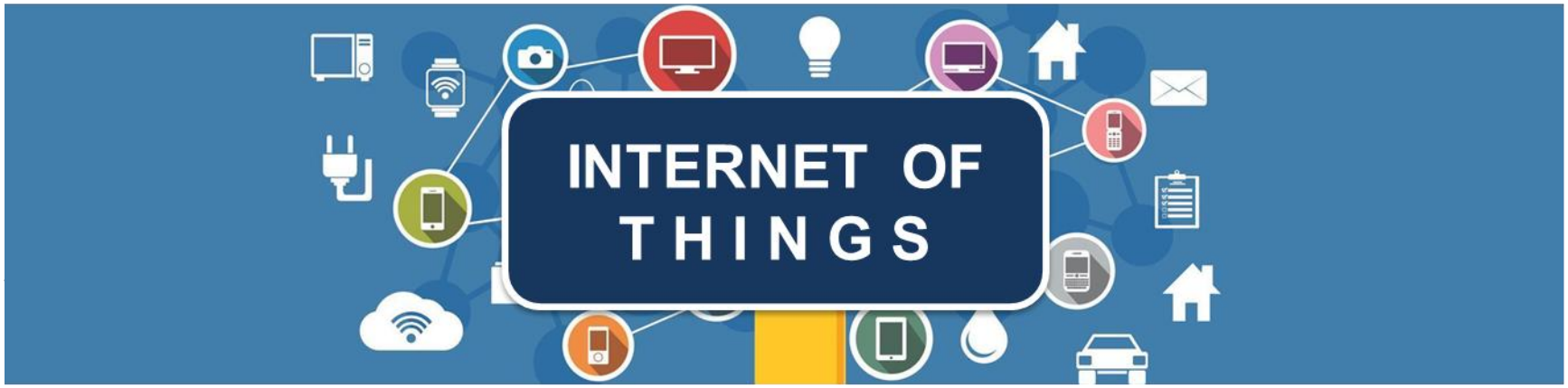


Image taken from twitter.com

The IoT as a Driver for Sustainability

- The United Nations' 2030 agenda for sustainable development

Images taken from Wikimedia Commons

The IoT as a Driver for Sustainability

- SDG 11: sustainable cities and communities
  - Address the increasing urbanization
    (by 2030, 60% of the world's population will live in cities)
  - Reduce energy consumption and CO_2 emissions
    (cities occupy just 3% of the Earth's land, but account for 60-80% of energy consumption and 75% of CO_2 emissions)

➢ IoT solutions to build smart cities
  - Demand-driven heating and cooling in buildings
  - Improved waste management, and street lighting
  - Intelligent mobility & transportation
  - Monitoring air/noise pollution and urban heat islands

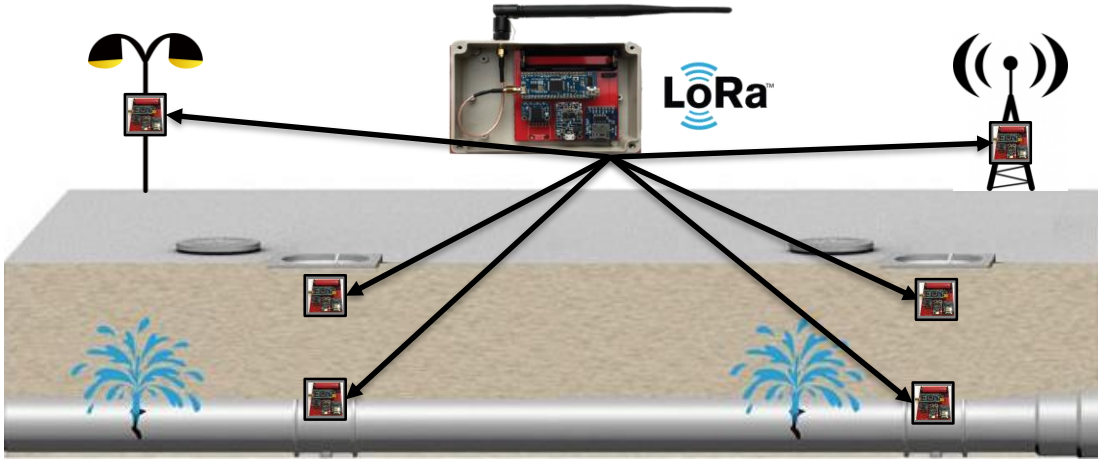
Images taken from forbes.com and Wikimedia Commons

The IoT as a Driver for Sustainability

- SDG 6: clean water and sanitation
  - Avoid wasting water
    (water scarcity affects > 40% of the population)
  - Millions of cubic meters of water lost daily

➢ IoT solutions to build smart water networks
  - Detecting leakages in water distribution networks

More info: M. Cattani et al. Adige: An Efficient Smart Water Network Based on Long-Range Wireless Technology. In Proceedings of the CySWATER '17 Workshop.



Images taken from puresafety.com and Wikimedia Commons

The IoT as a Driver for Sustainability

- SDG 2: zero hunger
  - Avoid food waste and increase crop yield
    (1/3 of the world's food wasted; 1 billion people undernourished)

➢ IoT solutions for smart farming
  - Improving agricultural practices while preserving natural resources

➢ IoT solutions for better tracing of goods

- SDG 9: industry, innovation, and infrastructure
  - Monitoring and optimizing production processes
    (e.g., asset tracking and preventative maintenance)
  - Intelligent infrastructure monitoring

Images taken from, rawpixel.com and Wikimedia Commons

The IoT as a Driver for Sustainability

- SDG 13: climate action
- SDG 14: life below water
- SDG 15: life on land

- IoT solutions to help preserving natural resources
- IoT solutions to tackle the effects of climate change
  - Early warning for destructive events and natural disasters
  - Mitigating harm to humans and civil infrastructure

Images taken from egu.eu, geography.org.uk, nyt.com, and Wikimedia Commons

The IoT as a Driver for Sustainability

- SDG 3: good health and well-being
  - Aging population and increasing health costs (by 2030, 1.5 billion people aged 60+)

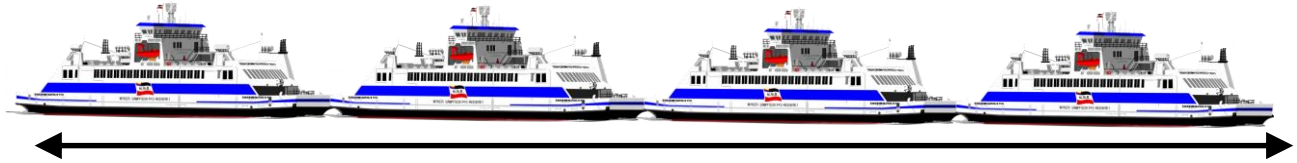
➢ IoT solutions for smart health
  - 24/7 monitoring of vital signs & chronic diseases

The road to 2030 is bright!

Images taken from internetofbusiness.com, rawpixel.com, and Wikimedia Commons

The Other Face of IoT & Sustainability

- SDG 12: responsible consumption & production
  - Need to reduce the amount of generated e-waste
    (in 2019, 7.3 kg pro capita; by 2030 a projected 38% increase)



(350 cruise ships to form a line that is 125 km long)

World Health Organization

Soaring e-waste affects the health of millions of children, WHO warns

First WHO report on e-waste and child health calls for more effective and binding action to protect children from growing health threat

15 June 2021 | News release | Reading time: 4 min (1105 words)

Effective and binding action is urgently required to protect the millions of children, adolescents and expectant mothers worldwide whose health is jeopardized by the informal processing of discarded electrical or electronic devices according to a new ground-breaking report from the World Health Organization: *Children and Digital Dumpsites*.

Images taken from clipart-library.com, who.int, smithsonianmag.com, publicdomainvectors.org, and wikimedia.org

The Other Face of IoT & Sustainability

- Billions of IoT devices are a big concern w.r.t. e-waste!
  - “IoT devices are still being designed, manufactured, and disposed of unsustainably” [Stead et al., 2019]

Internet of Things Tossed into Landfills

While electronic devices in the past had a decent lifespan, IoT devices are only lasting a couple of years. This pile-up of e-waste is quickly ending up in landfills, bringing them to max capacity.

Source: ewaste1.com

SECURIS
IT Asset Auditing, Recycling & Destruction

IOT DEVICES WILL LEAD TO MORE E-WASTE IN THE FUTURE

Smartphones, smartwatches, fitness armbands, and other Internet of Things (IoT) devices have become more common in our everyday lives, and they will continue to play an important role in the future.

An increase in IoT devices will also lead to more e-waste. However, the extent to which this e-waste will impact the environment will depend largely on how electronics recyclers innovate their processes and services.

Source: securis.com

SB

As ‘Internet of Things’ Grows, So Do E-waste Concerns

Source: sustainablebrands.com

WasteAdvantage magazine
The Advantage in the Waste and Recycling Industry

News ▸ Collection/Transfer

The Internet of Trash: IoT Has a Looming E-Waste Problem

Source: wasteadvantagemag.com

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  - An "Internet of Trash"
  - Poor design & dependability
  - Limited lifespan of devices
  - Large diversity of IoT technologies
- Can cross-technology communication help?
- Summary & takeaway

An "Internet of Trash"

- A plethora of unnecessary gadgets

GIZMODO We come from the future

HOME LATEST REVIEWS TECH IO9 EARTHER SCIENCE FIELD GUIDE

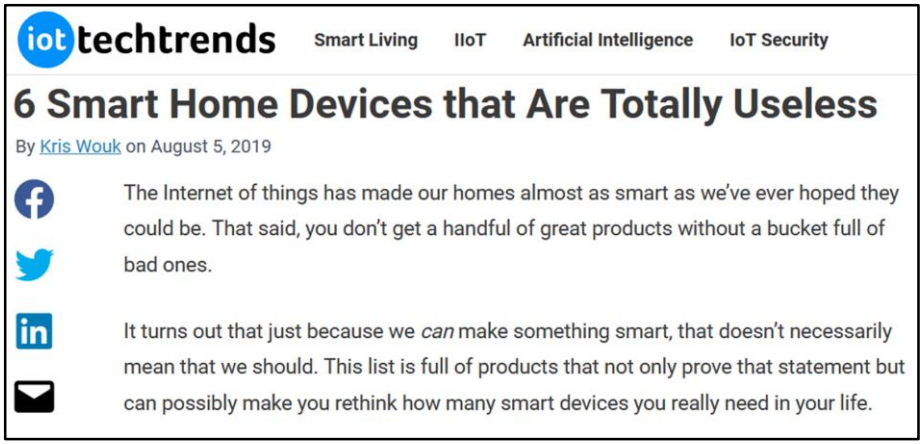
15 Idiotic Internet of Things Devices Nobody Asked For

By Libby Watson | 4/14/17 2:55PM | Comments (266)

Humans contain multitudes. We have a demonstrated ability to work ha sweat and toil for our daily bread, and, as a society, achieve magnificent science and technology. We've literally reached the stars!

However, we can also be incredibly lazy pieces of shit. We fight with our roommates over whose turn it is to get off the couch and find the remote

Source: gizmodo.com


iot techtrends Smart Living IIoT Artificial Intelligence IoT Security

6 Smart Home Devices that Are Totally Useless

By Kris Wouk on August 5, 2019

The Internet of things has made our homes almost as smart as we've ever hoped they could be. That said, you don't get a handful of great products without a bucket full of bad ones.

It turns out that just because we *can* make something smart, that doesn't necessarily mean that we should. This list is full of products that not only prove that statement but can possibly make you rethink how many smart devices you really need in your life.

Source: iottechtrends.com

- Smart bottle openers (posting the # of beers opened on social media)
- Smart toasters (notifying us once the desired crispness was reached)
- Connected egg trays (telling us about how many eggs are left)
- Smart salt shakers (activated via voice instead with the finger)
- Smart hair brushes (measuring the strokes' speed & orientation)
- ...

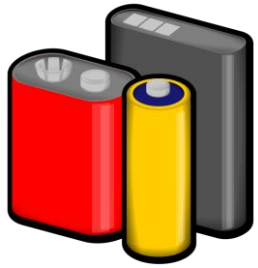
An "Internet of Trash"

- Wrong mindset: “IoT comforting our lives”
  - Our daily comfort should not be the priority
  - Yet, we tend to think about that first

- Often hard to correctly dispose of IoT devices

IEEE Spectrum | **The IoT’s E-Waste Problem Isn’t Inevitable**

IN MY OFFICE CLOSET, I have a box full of perfectly good smart-home gadgets that are broken only because the companies that built them stopped updating their software. I can't bear to toss them in a landfill, but I don't really know how to recycle them.



Source: spectrum.ieee.org

Images from cmu.edu, clipart-library.com, dailymail.co.uk, freesvg.org, istockphoto.com, and openclipart.org

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  - Large diversity of IoT technologies
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Ability to keep IoT Devices up-to-date

- Many devices do not support any over-the-air firmware update capability

  - Cannot cope with changing customer demands
  - Exposure to security threats & vulnerabilities

Source: hackercombat.com

  - Fueling IoT botnets like Mirai, Persirai, and Kaiji

Image from aspida.org

Ability to keep IoT Devices up-to-date

- Many devices do not support any over-the-air firmware update capability

- Often linked to the severe memory constraints of some IoT devices, which embed just a few kB of RAM/ROM

UpKit: An Open-Source, Portable, and Lightweight Update Framework for Constrained IoT Devices

Antonio Langiu, Carlo Alberto Boano, Markus Schuß, and Kay Römer
Institute of Technical Informatics, Graz University of Technology, Austria
E-mail: antonio@langiu.com; cboano@tugraz.at; markus.schuss@tugraz.at; roemer@tugraz.at

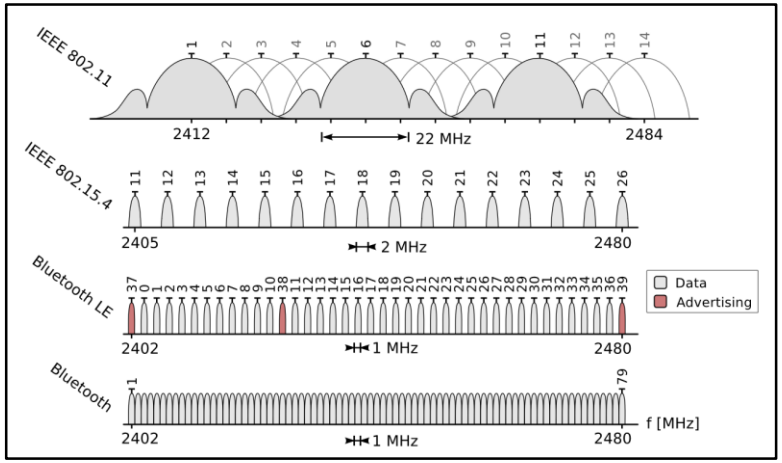
***Abstract*—Updating the software running on constrained IoT devices such as low-power sensors and actuators in a secure and efficient way is an open problem. The limited computational, memory, and storage capabilities of these devices, together with their small energy budget, indeed, restrict the number of features that can be embedded into an update system and make it also difficult to build a generic and compact solution. As a** to *embed some software update capabilities* in the firmware running on each IoT device [6], [7]. Such capabilities include, among others, the (over-the-air) download of the update image, the verification of its integrity and authenticity, as well as its installation [8]. All these steps should be performed while minimizing the downtime of a device and its services.

More info: A. Langiu et al. UpKit: An Open-Source, Portable, and Lightweight Update Framework for Constrained IoT Devices. In Proceedings of the 39th IEEE ICDCS Conference. 2019.

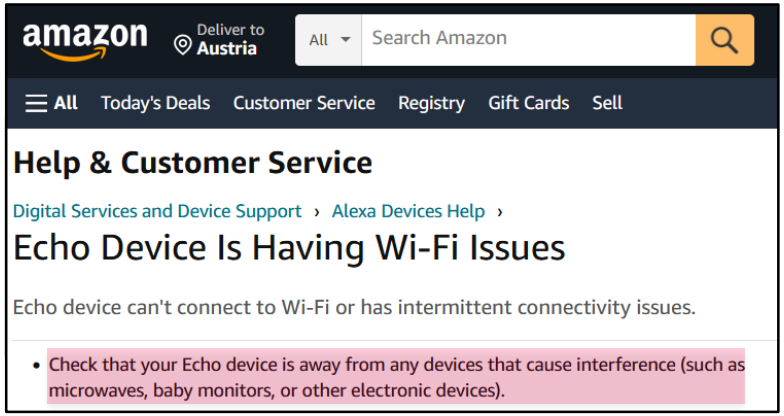
- Support for popular OS (Contiki-NG, RIOT, Zephyr)
- Support for off-the-shelf HW (nRF52840, CC2650, CC2538)
- Supporting many crypto-libraries (TinyDTLS, tinycrypt, CryptoAuthLib)
- Supporting push/pull approaches with 20 kB RAM & 80 kB ROM

Robustness to RF Interference

- Coexistence is difficult in the freely-available ISM bands



Source: Wetzker et al.

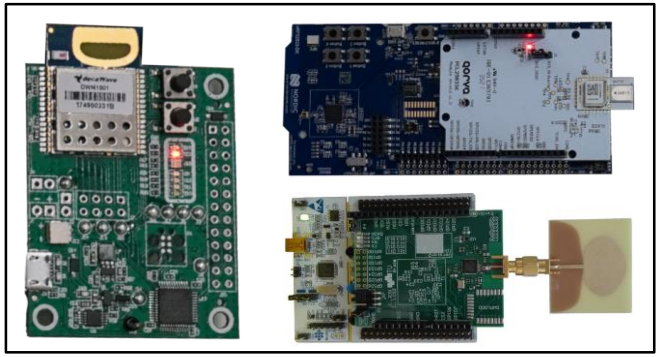


Source: https://www.amazon.com/gp/help/customer/display.html?nodeId=GF7HA8GERSJGPCGE

- Example: the 2.4 GHz band
- Frequencies are shared by devices employing Wi-Fi, Bluetooth classic / low energy, IEEE 802.15.4, ZigBee, OpenThread, …
- Frequencies disturbed by the operations of home appliances such as microwave ovens

Robustness to RF Interference

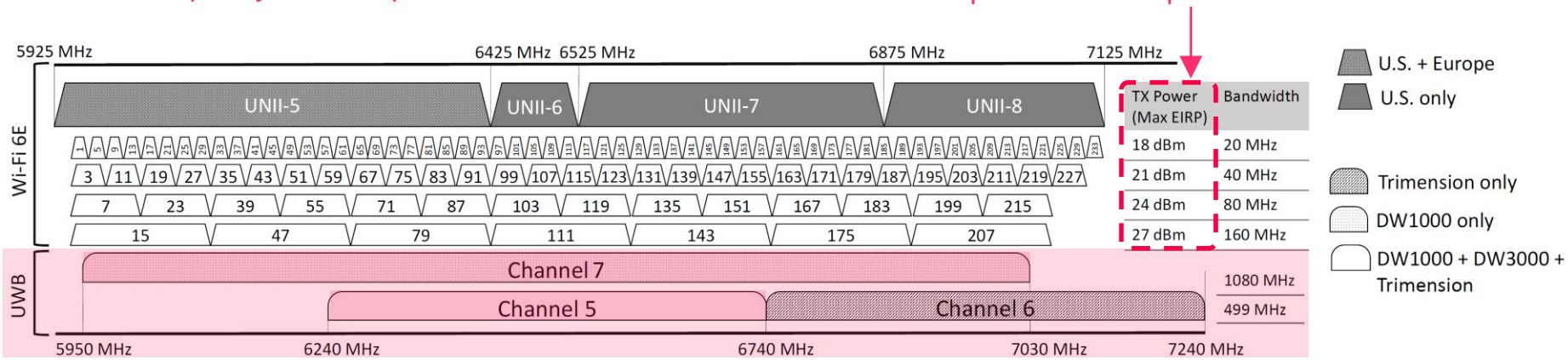
- Coexistence between UWB and Wi-Fi 6E devices



vs.

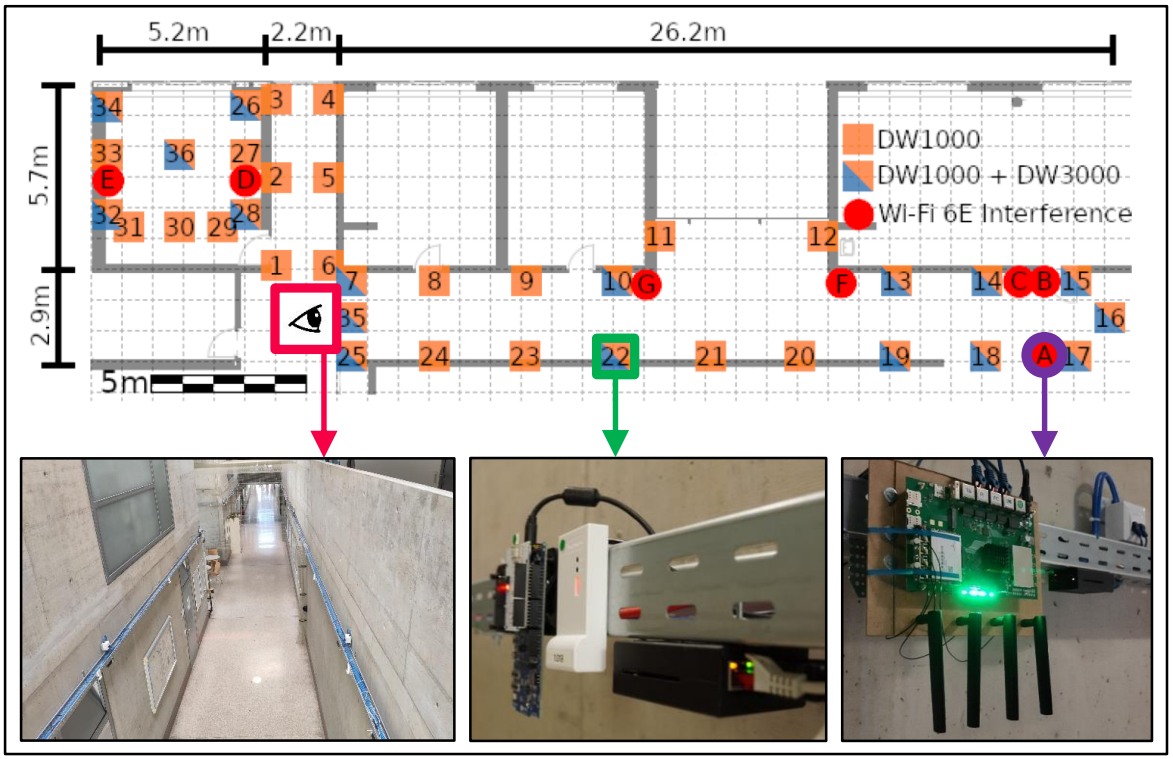
Image from 3D Warrior

UWB devices should have a maximum equivalent isotropically radiated power of -41.3 dBm/MHz << Transmission power of Wi-Fi 6E access points can be up to 27 dBm



Robustness to RF Interference

- Coexistence between UWB and Wi-Fi 6E devices
  - We set up a testbed to study coexistence issues experimentally (across a large hallway of 130 m^2 and inside an office room of 30 m^2)



- An UWB node broadcast packets, all others measure the packet reception ratio (PRR)
- Wi-Fi 6E devices exchange data using `iperf` or stream a `YouTube` video

More info: H. Brunner et al. Understanding and Mitigating the Impact of Wi-Fi 6E Interference on Ultra-Wideband Communications and Ranging. In Proceedings of the IPSN'22 Conference.

Robustness to RF Interference

- Coexistence between UWB and Wi-Fi 6E devices
  - UWB devices close to the Wi-Fi 6E transmitter have a PRR ≈ 0
  - Average PRR drops by up to 66% across all testbed nodes
  - Severe implications for UWB-based localization systems
    (only 1% of our localization attempts were successful!)

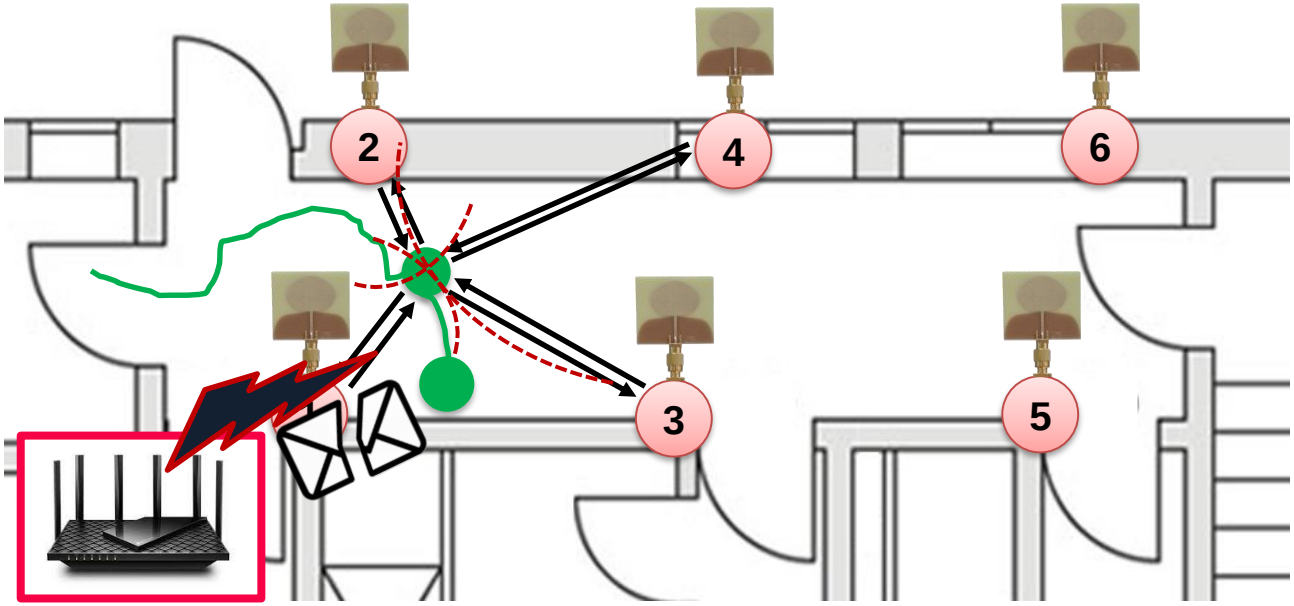


Image from 3D Warrior

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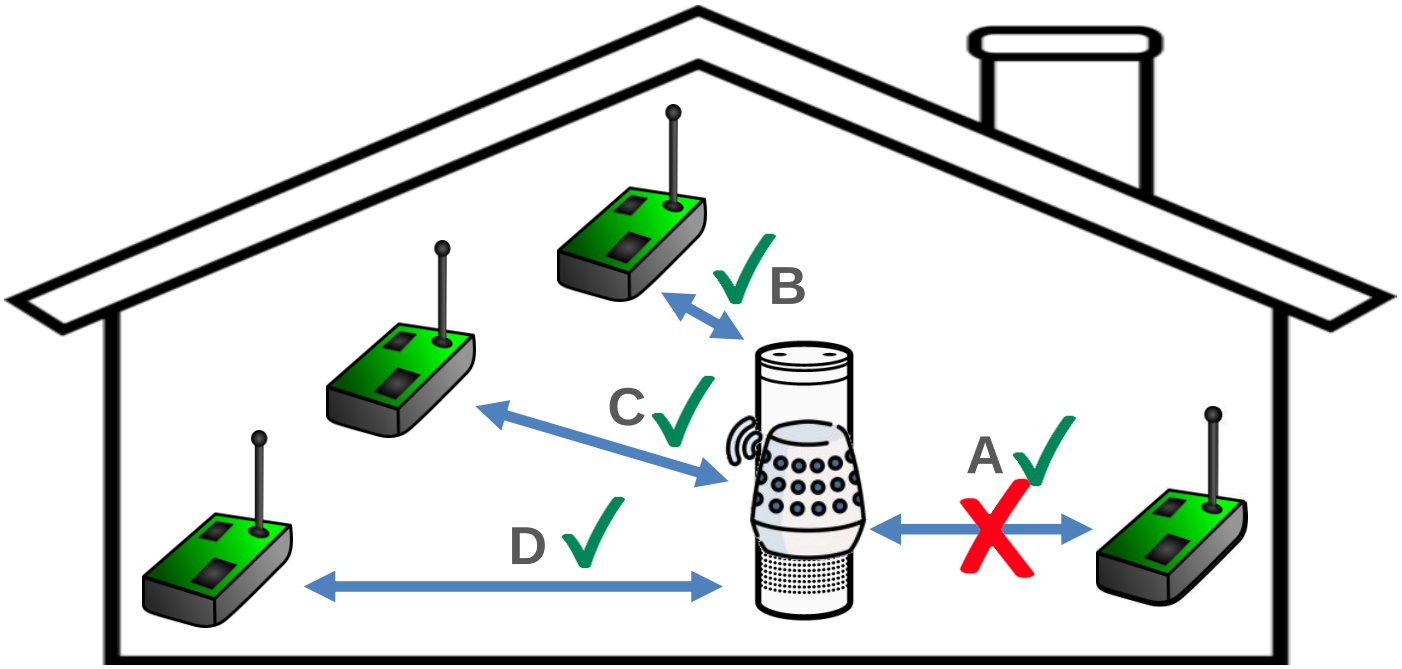
Planned Obsolescence

- Many IoT devices have a short replacement cycle
  - Explicitly designed to become quickly outdated
- New-generation devices typically:
  - Embed additional features and functionalities
  - Offer better performance
  - Have a nicer aesthetics
  - Are more likely to be compatible with the latest products on the market

Image from ytimg.com

Planned Obsolescence

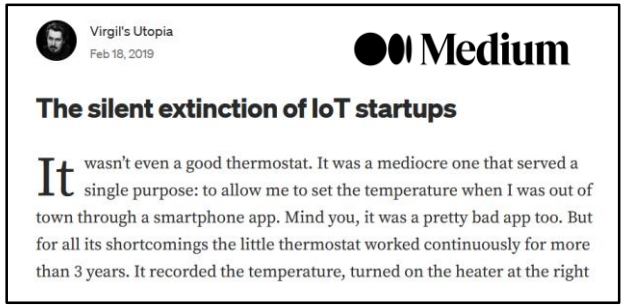
- Example: obsolete smart home device
  - Smart device compliant to technology A (now getting outdated)
  - Latest smart speaker (supporting only technology B, C, and D)



Images taken from pngegg.com, clipart-library.com, thenounproject.com, wrdfree.com, and vectorstock.com

Sudden Obsolescence

- Often triggered by the unsteadiness of IoT businesses
- Example: company going out of business
  - Startup shuts down its services due to financial difficulties
  - Cloud connection no longer available
  - Device stops working and becomes unusable, although still functional
  - Thermostats, Berg's little printers, ...


Virgil's Utopia
Feb 18, 2019

Medium

The silent extinction of IoT startups

It wasn't even a good thermostat. It was a mediocre one that served a single purpose: to allow me to set the temperature when I was out of town through a smartphone app. Mind you, it was a pretty bad app too. But for all its shortcomings the little thermostat worked continuously for more than 3 years. It recorded the temperature, turned on the heater at the right

Source: medium.com

  - Underlying problem: when a device is hardcoded to a specific service, it is beholden to that service being available

Source: domusweb.it

Sudden Obsolescence

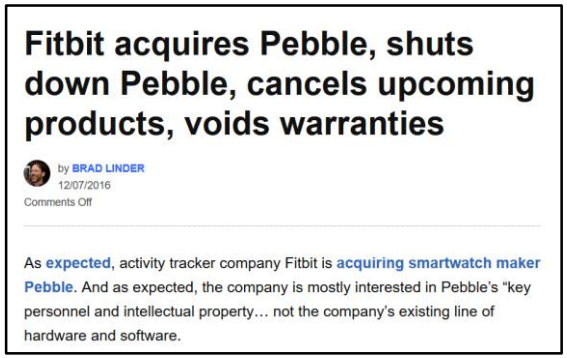
- Often triggered by the unsteadiness of IoT businesses
- Example: company acquisition
  - Small businesses may be acquired by larger companies to avoid competition
  - After Google's Nest acquired Revolv, it turned off the cloud service for the Revolv smart home hub, effectively making all existing devices useless
  - After Fitbit acquired Pebble, it did not take too long until support for the Pebble smartwatch app store, online forum, cloud development tool, and voice recognition ceased

The Guardian

Revolv devices bricked as Google's Nest shuts down smart home company

Customers furious as Nest is set to turn off Revolv units in just over a month

Source: theguardian.com


Fitbit acquires Pebble, shuts down Pebble, cancels upcoming products, voids warranties

by BRAD LINDER
12/07/2016
Comments Off

As expected, activity tracker company Fitbit is acquiring smartwatch maker Pebble. And as expected, the company is mostly interested in Pebble's "key personnel and intellectual property… not the company's existing line of hardware and software.

Source: liliputing.com

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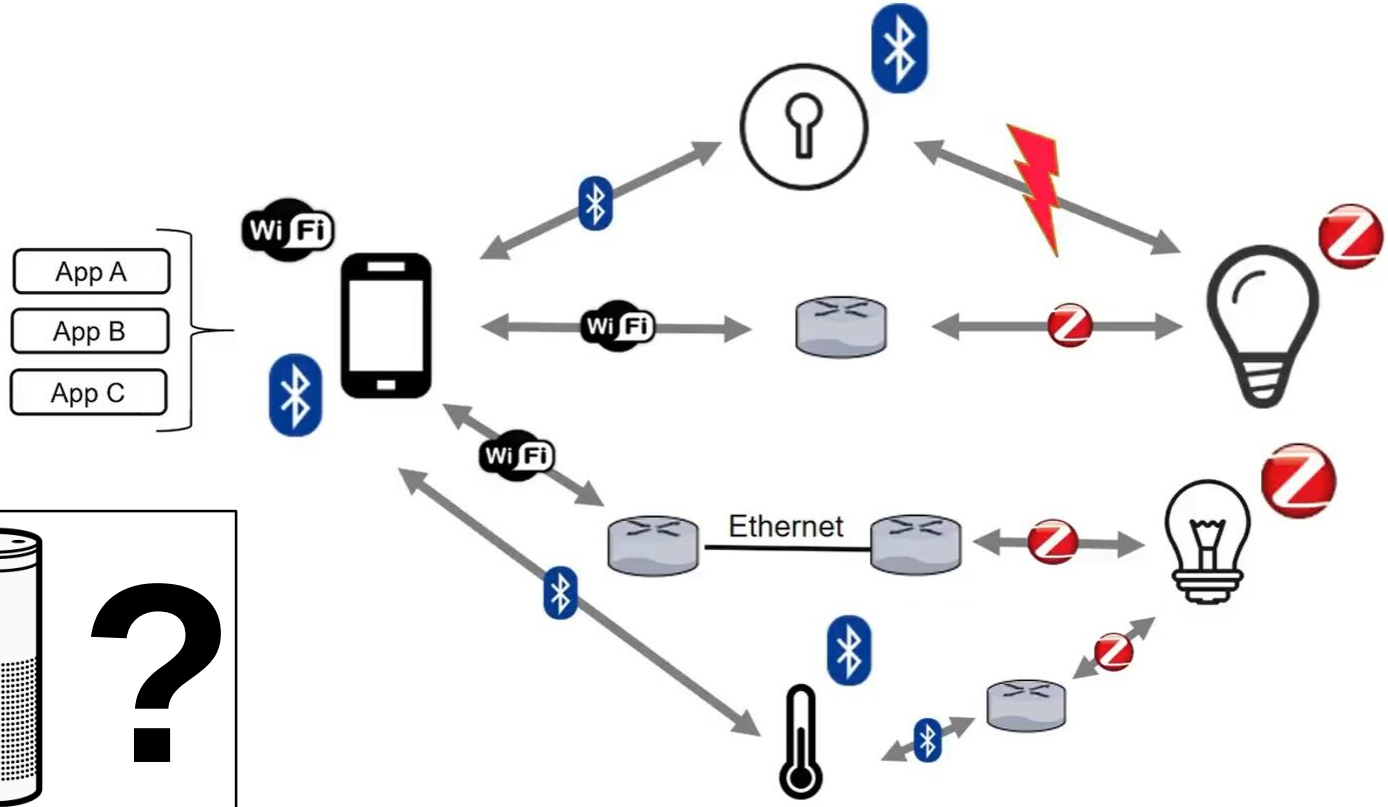
Large Diversity of IoT Technologies

- May require the use of additional devices that act as a "bridge" between different technologies
  - Example: smart homes and the "gateway problem"



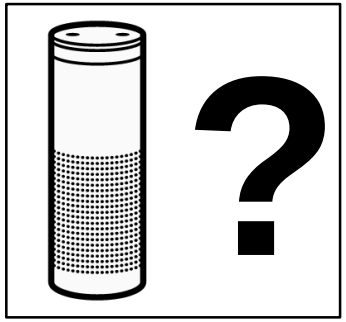
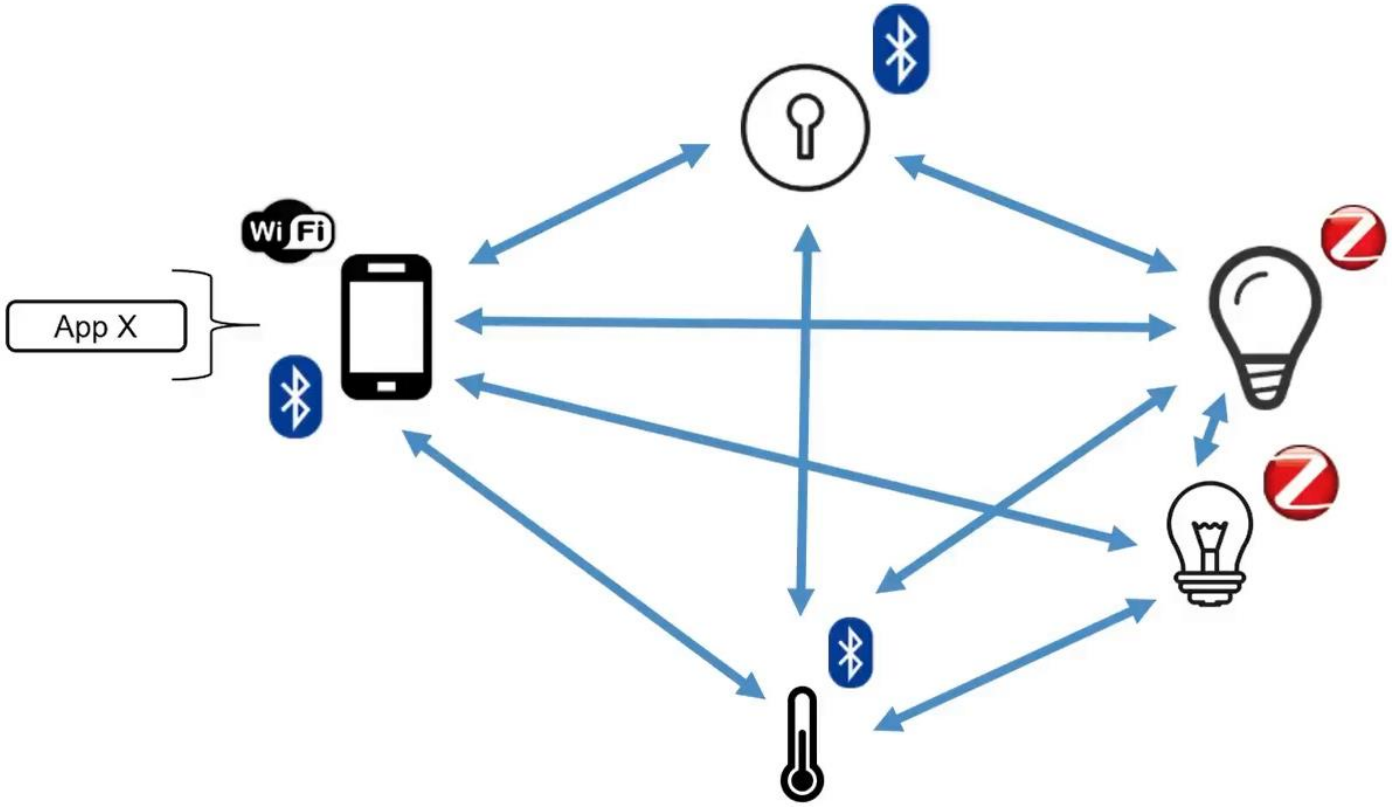


Image from thenounproject.com

Large Diversity of IoT Technologies

- Ideal case: direct communication across devices
  - Avoiding gateways altogether
    → support for any (legacy) device



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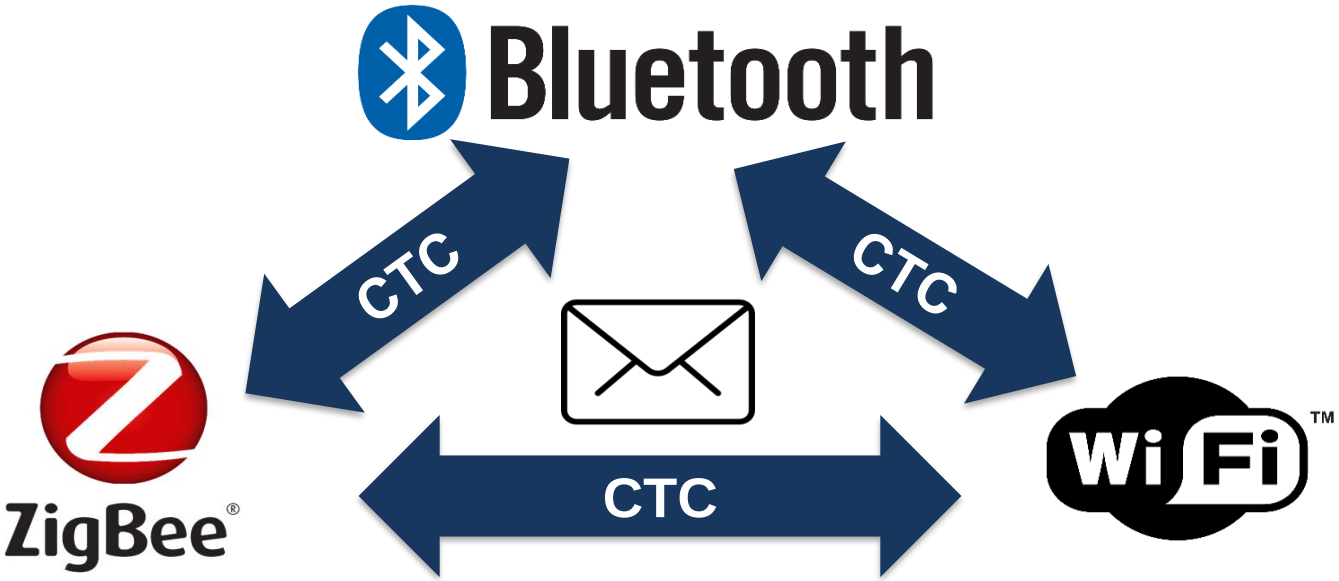
  - Limited lifespan of devices
  - Large diversity of IoT technologies
- Can cross-technology communication help?
- Summary & takeaway

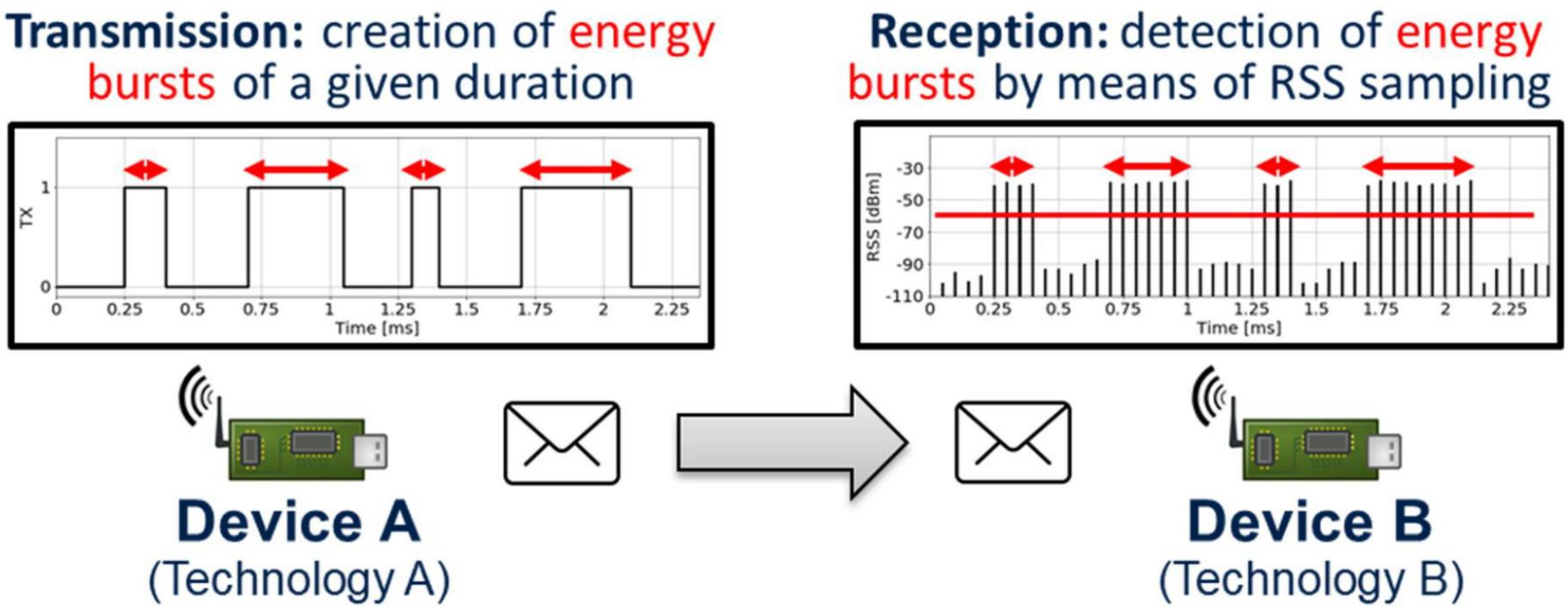
Cross-Technology Communication

- What is CTC?
  - Allows direct communication across devices using incompatible wireless technologies, but operating in the same ISM band…
  - … without the need of multi-radio gateways or extra-hardware



Cross-Technology Communication

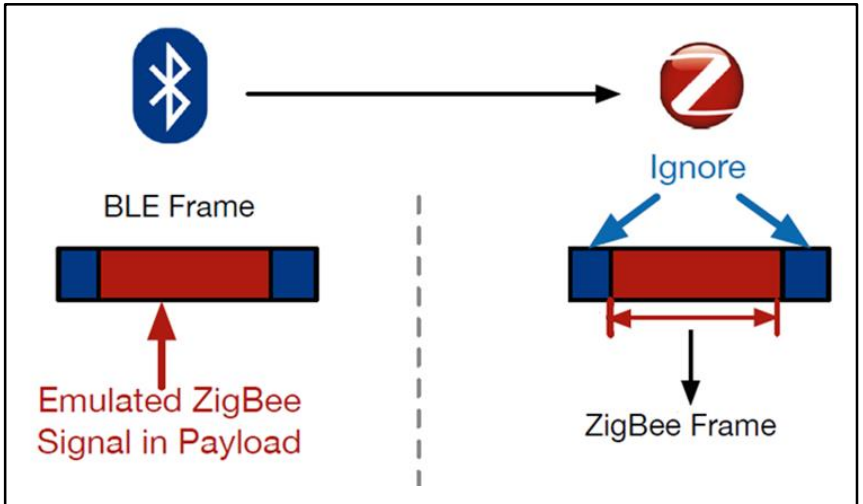
- Packet-level modulation: example
  - Creating a “side channel” across heterogeneous devices by encoding information into the duration of energy bursts



More info: R. Hofmann et al. X-Burst: Enabling Multi-Platform Cross-Technology Communication between Constrained IoT Devices. *In Proc. of the 16th IEEE SECON Conference.*

Cross-Technology Communication

- PHY emulation: example
  - Adjusting the payload of a frame such that a portion of it can be recognized as legitimate
  - Data can be sent at the highest rate supported by the receiving technology



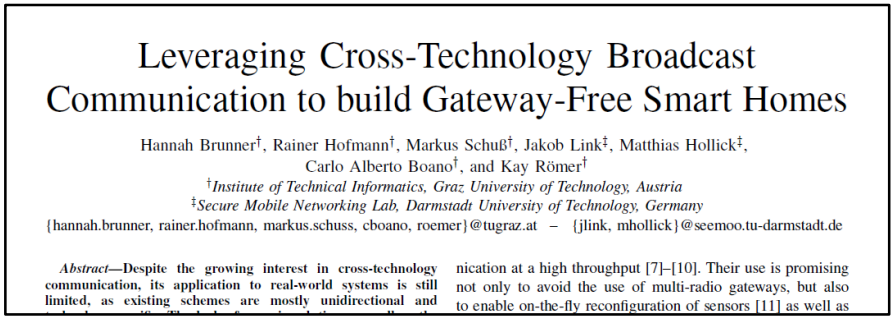
More info: Jiang et al. BlueBee: a 10,000x Faster Cross-Technology Communication via PHY Emulation. In Proc. of the 15th ACM SenSys Conference.

- Which approach is best?
  - Implications on data throughput and bi-directionality
  - PHY emulation allows a much a higher data throughput, but it is technology-specific and is commonly uni-directional only
  - Packet-level CTC is slower, but not technology-specific, and supports bi-directionality

Cross-Technology Communication

- Can be used to build gateway-free smart homes!
  - Prototype of smartphone communicating with a ZigBee-based light bulb and a BLE door lock at the same time using CTC

Images from wikimedia.org and danalock.com



Leveraging Cross-Technology Broadcast Communication to build Gateway-Free Smart Homes

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***Abstract*—Despite the growing interest in cross-technology communication, its application to real-world systems is still limited, as existing schemes are mostly unidirectional and**

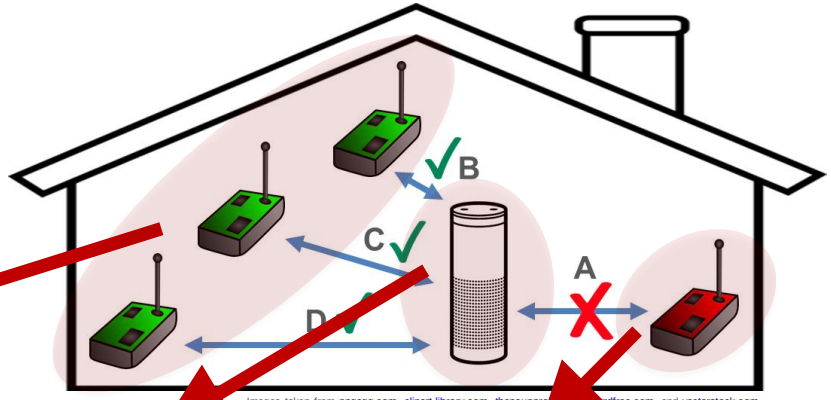
nication at a high throughput [7]–[10]. Their use is promising not only to avoid the use of multi-radio gateways, but also to enable on-the-fly reconfiguration of sensors [11] as well as

More info: H. Brunner et al. Leveraging Cross-Technology Broadcast Communication to build Gateway-Free Smart Homes. *In Proc. of the 18th IEEE SECON Conference.*

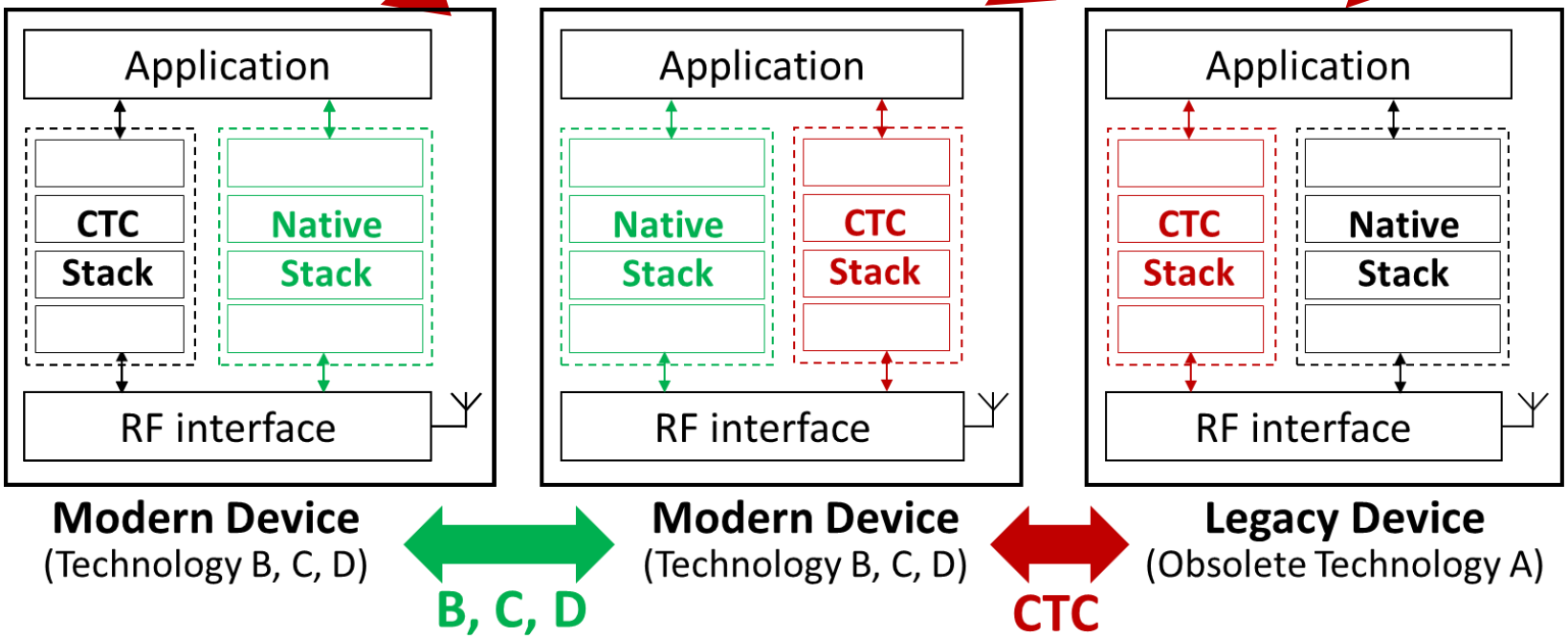
Demo video:
https://youtu.be/whD_H-UynJY

CTC to Support Legacy IoT Devices

- Enabling support for a dual network stack
  - Only a SW update is needed!



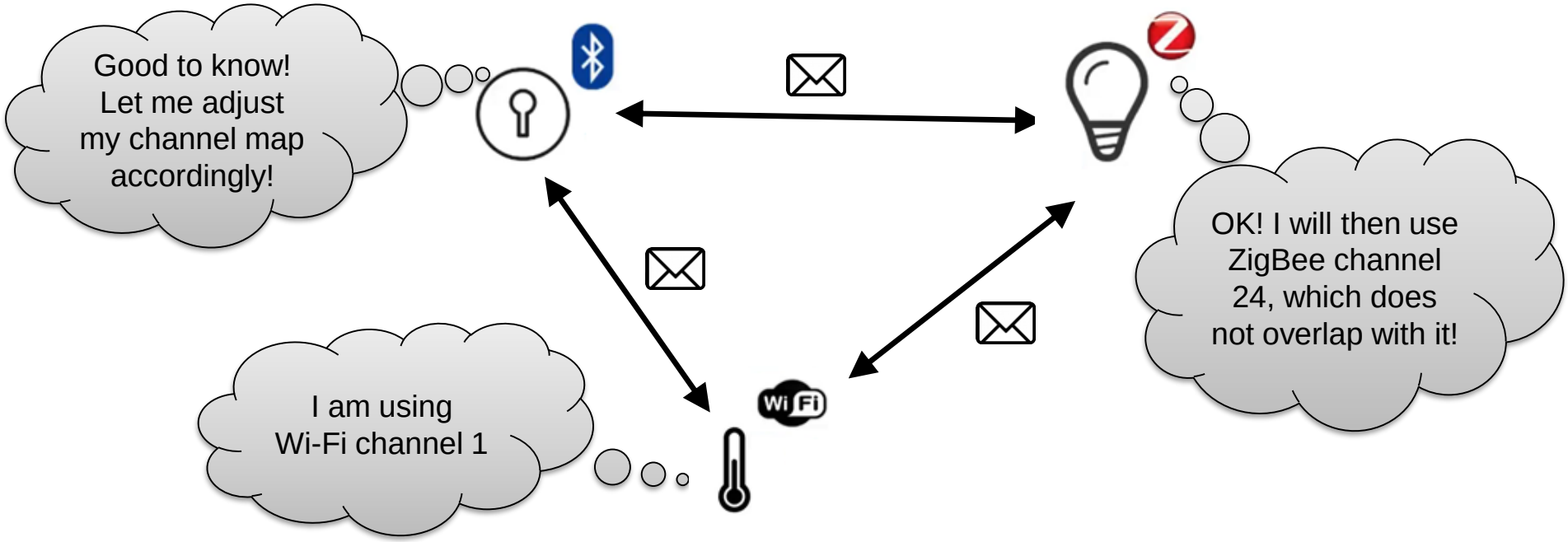
Images taken from pngegg.com, clipart-library.com, thenounpro[illegible]dfree.com, and vectorstock.com



More info: C.A. Boano. Enabling Support of Legacy Devices for a more Sustainable Internet of Things. *In Proc. of the ACM GoodIT Conference, 2021.*

CTC for Coexistence Management

- By exchanging messages across co-located devices using incompatible technologies
  - Coordinate the channel usage
  - Avoid to mutually interfering with each other



Outline

- The IoT as a driver for sustainability
  - Five hundred billion connected devices by 2030
  - The United Nation’s sustainable development goals by 2030
- The other face of IoT & sustainability
  - An "Internet of Trash"
  - Poor design & dependability
  - Limited lifespan of devices
  - Large diversity of IoT technologies
- Can cross-technology communication help?
- Summary & takeaway

Conclusions and Outlook

- 500 billion IoT devices by 2030
  - Essential to solve key global challenges and achieving many of the UN's sustainable development goals

Images taken from Wikimedia Commons

- We need to focus on the sustainable design of IoT products, in order to avoid an "Internet of Trash"
  - Build useful devices and simplify their recycling
  - Add FOTA mechanisms to keep them up-to-date
  - Ensure robustness to harsh RF environments
  - Avoid hardcoding services that brick the device when shut off
  - Avoid the use of gateways & ensure support for legacy devices
  - Aim for long-lasting devices and avoid the use of batteries whenever possible (consider energy harvesting!)

Thank you for your attention!

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Image from iStock.com/ipopba