Network Connectivity for IOT Systems

Jin Zhang

Department of Computer Science and Engineering

Southern University of Science and Technology

Source: partly from CS6.808 Mobile and Sensor Computing, Hari Balakrishnan, MIT

Objectives of the Lecture

- Learn the fundamentals, applications, and implications of IoT network technologies
  - *What are the various classes of network technologies? And how do we choose the right technology for a given application?*
  - *What are various routing architectures for wireless networks & IoT systems?*

NETWORKING: “GLUE” FOR THE IOT

- IoT’s “technology push” from the convergence of
  - Embedded computing
  - Miniaturized sensing (MEMS)
  - **Wireless network connectivity**

THE IOT CONNECTIVITY SOUP

Bluetooth® SMART
ZigBee®
6LoWPAN IPv6-based Low-power Wireless Personal Area Networks
IEEE 802.15.4
WiFi diving into 900 MHz 802.11ah IEEE
LoRa™

3GPP A GLOBAL INITIATIVE
a b g WiFi n ac
Lte 4DVANCED
4G LTE
5G

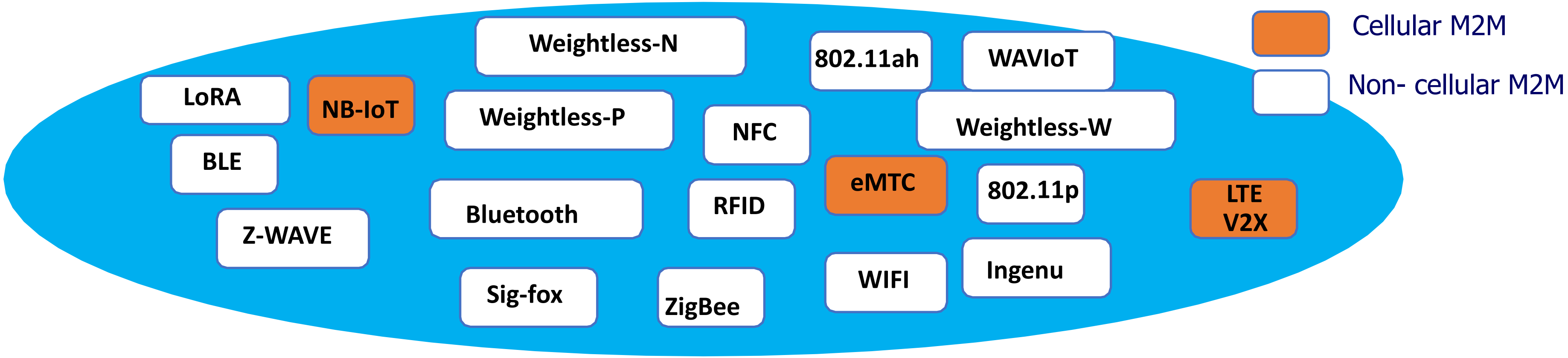
Z WAVE
SIGFOX One network A billion dreams
INGENU
WEIGHTLESS™
INSTEON®
enocean

ALLSEEN ALLIANCE AllJoyn® Framework
THREAD
OPEN INTERCONNECT CONSORTIUM℠
industrial internet CONSORTIUM®

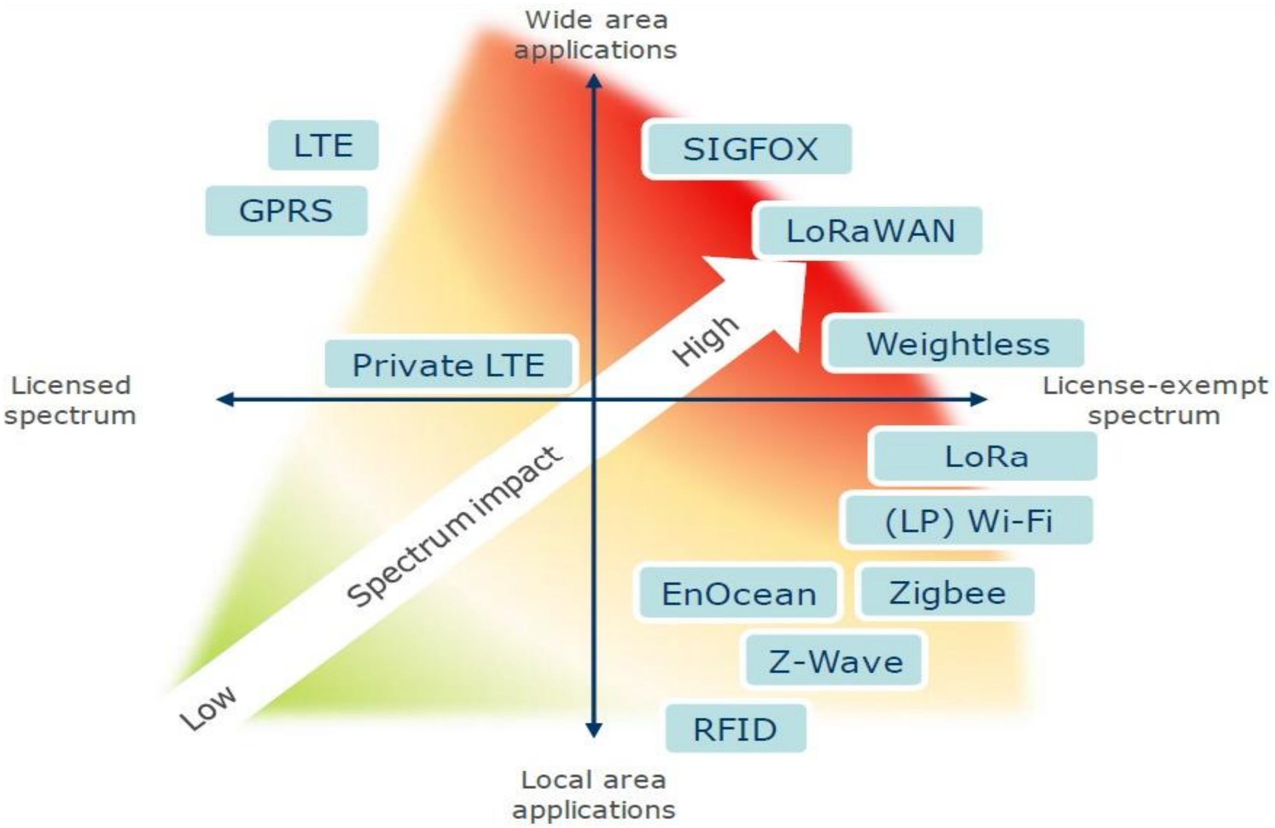
IoT Technical Solutions

Study in ITU under **WRC-19 agenda item 9.1, issue 9.1.8** (Machine Type Communication - MTC)

Studies on the technical and operational aspects of radio networks and systems, as well as spectrum needed, including possible harmonized use of spectrum to support the implementation of narrowband and broadband machine-type communication infrastructures



IoT Technologies Summary



NETWORKING: "GLUE" FOR THE IOT

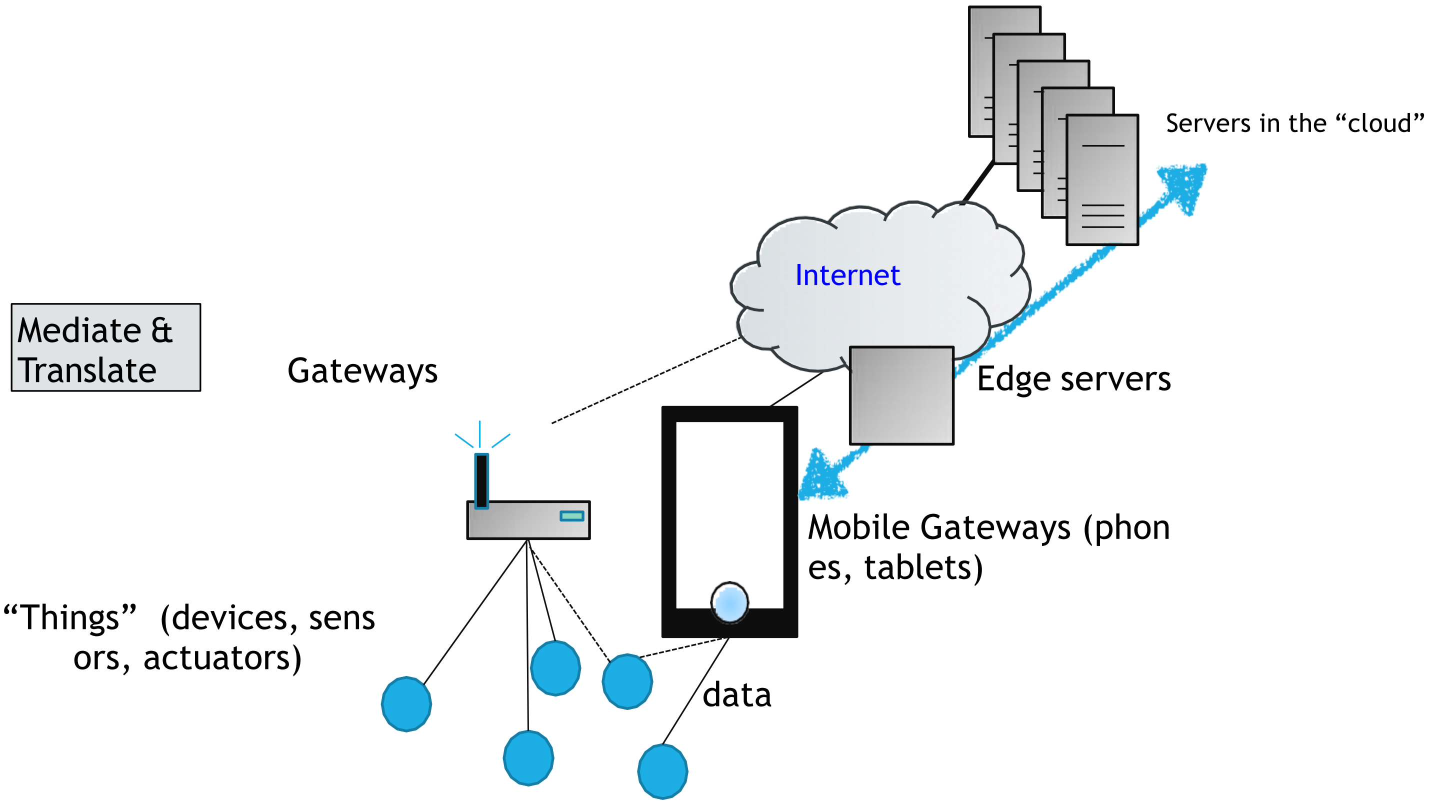
- Many different approaches, many different proposed standards.

  Much confusion

- **One size does not fit all: best network depends on application**

- **What are the key organizing principles and ideas?**

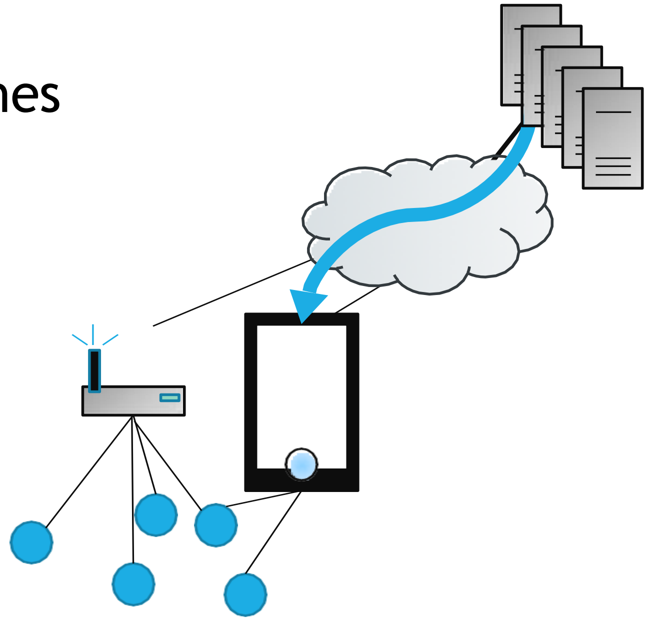
ARCHITECTURE



BUT, IN FACT, A RICH DESIGN SPACE

- How should gateways and things communicate?

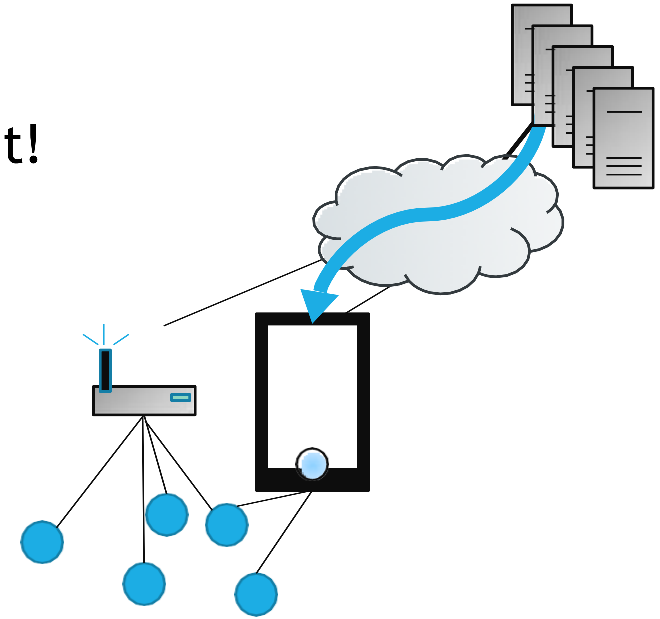
- Many answers, many approaches



Can’t We just Use Wireless Internet?

- Cellular and Wi-Fi
- Yes, we can…

  except when we can’t!



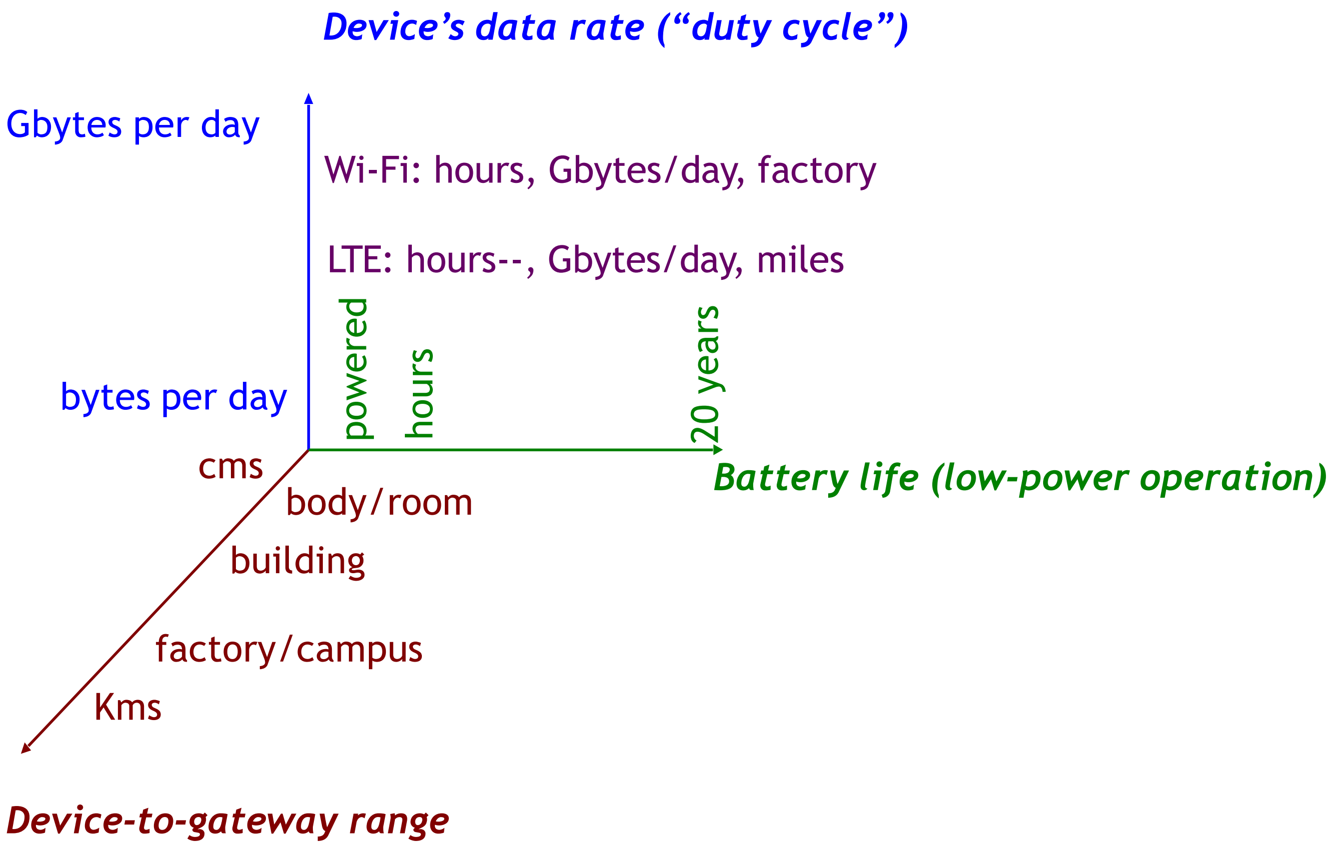
WIRELESS INTERNET FOR IOT?

- Cellular (5G, LTE/4G, 3G, 2G) and Wi-Fi are
  - Widely available (cellular in the wide-area and Wi-Fi for static uses)
  - High bandwidth (for most purposes), so can support high-rate apps

- But, each has two big drawbacks
  - **High power**: not ideal for battery-operated scenarios
  - Cellular: often high cost (esp. per byte if usage-per-thing is low)
  - Wi-Fi: OK in most buildings, but not for longer range

- Wi-Fi: In-building powered things (speakers, washers, refrigerators, …)
- Cellular: High-valued powered things (e.g., “connected car”)

IOT NETWORK DESIGN SPACE



IEEE 802.11 Wireless LAN

802.11b

- 2.4-5 GHz unlicensed spectrum
- up to 11 Mbps
- direct sequence spread spectrum (DSSS) in physical layer
  - all hosts use same chipping code

802.11a

- 5-6 GHz range
- up to 54 Mbps

802.11g

- 2.4-5 GHz range
- up to 54 Mbps

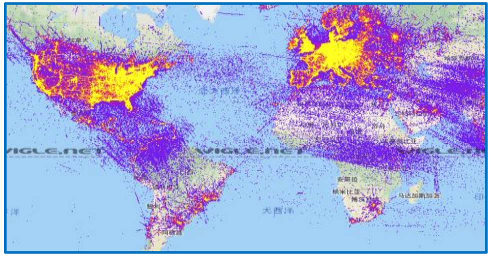
802.11n: multiple antennae

- 2.4-5 GHz range
- up to 200 Mbps

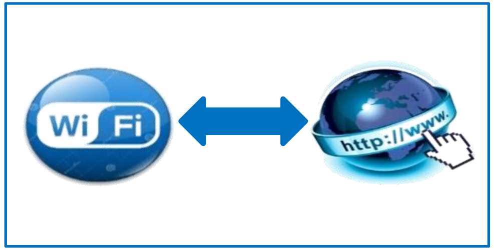
- all use CSMA/CA for multiple access
- all have base-station and ad-hoc network versions

Wi-Fi: a New Contender of IoT

- Some low-power protocols do not enjoy ubiquitous Internet access

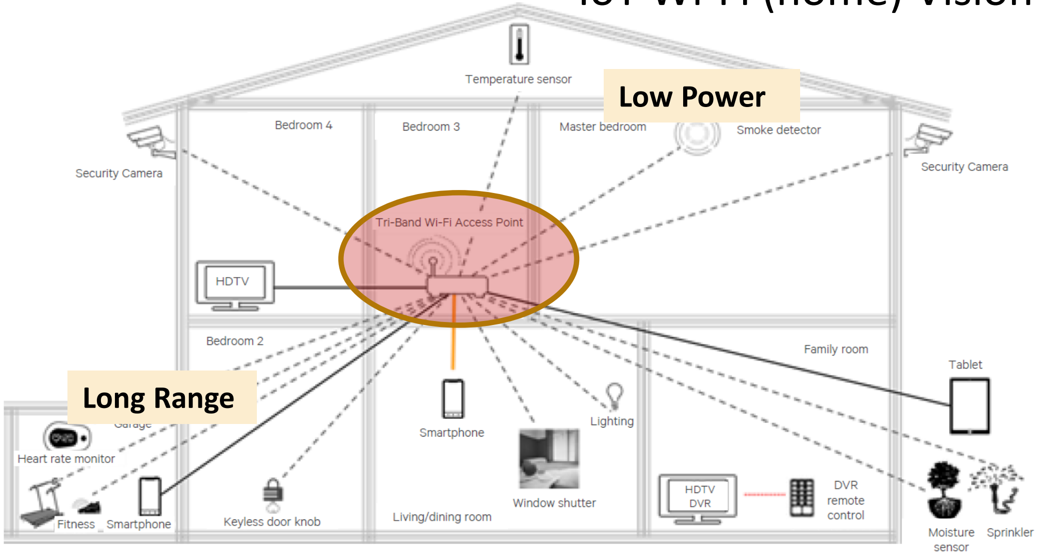


Wide deployments



Compatibility with Internet

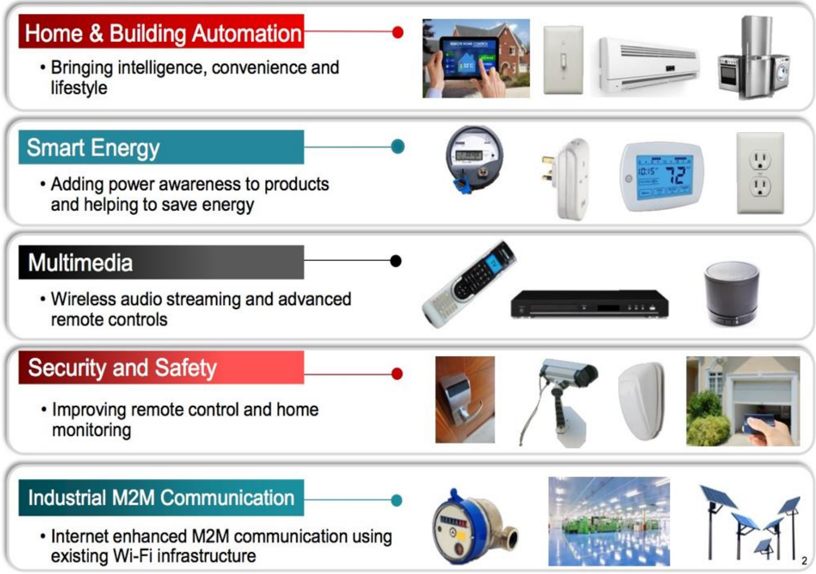
IoT Wi-Fi (home) Vision



Wi-Fi: a New Contender of IoT

- ➢ **Wireless Alternative to Wired Technologies**
- ➢ **Standardized as IEEE 802.11 standard for WLANs**

Standard	Frequency bands	Throughput	Range
WiFi a (802.11a)	5 GHz	54 Mbit/s	10 m
WiFi B (802.11b)	2.4 GHz	11 Mbit/s	140 m
WiFi G (802.11g)	2.4 GHz	54 Mbit/s	140 m
WiFi N (802.11n)	2.4 GHz / 5 GHz	450 Mbit/s	250 m
IEEE 802.11ah	900 MHz	8 Mbit/s	100 M



Wi-Fi HaLow

A new low-power, long-range version of Wi-Fi that bolsters IoT connections

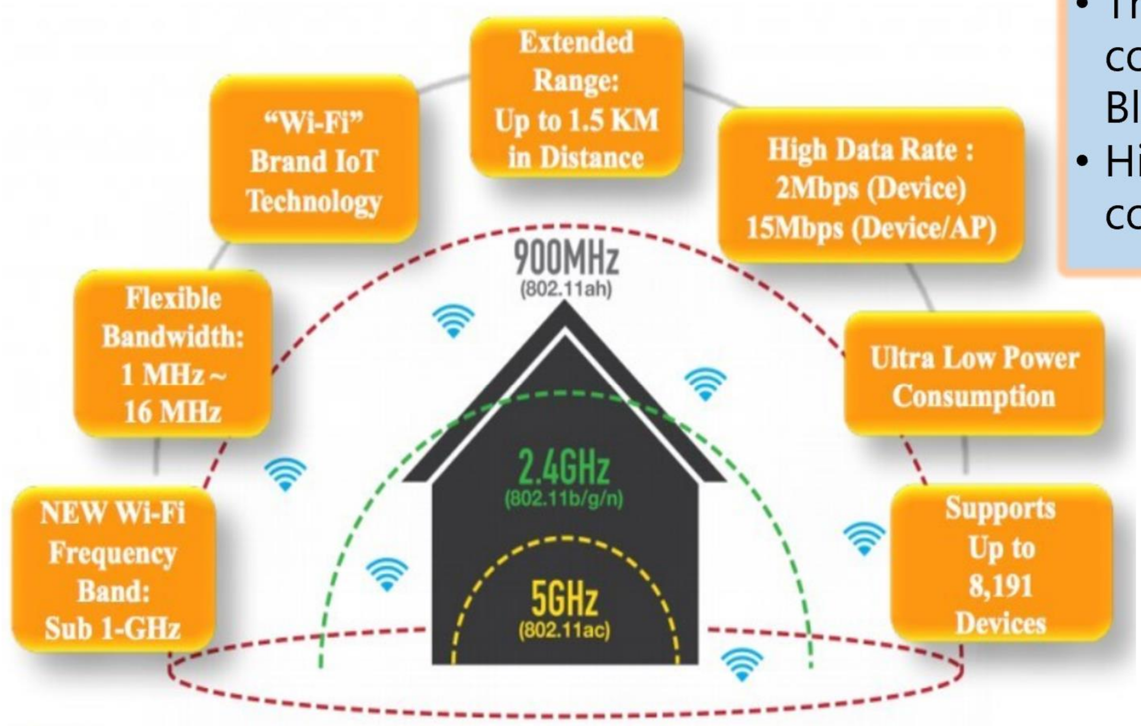
Wi-Fi HaLow is based on the **IEEE 802.11ah** specification

Wi-Fi HaLow will operate in the unlicensed wireless spectrum in the 900MHz band

Its range will be nearly double today's available Wi-Fi (1 kilometer)

- More flexible
- The protocol's low power consumption competes with Bluetooth
- Higher data rates and wider coverage range

Wi-Fi HaLow



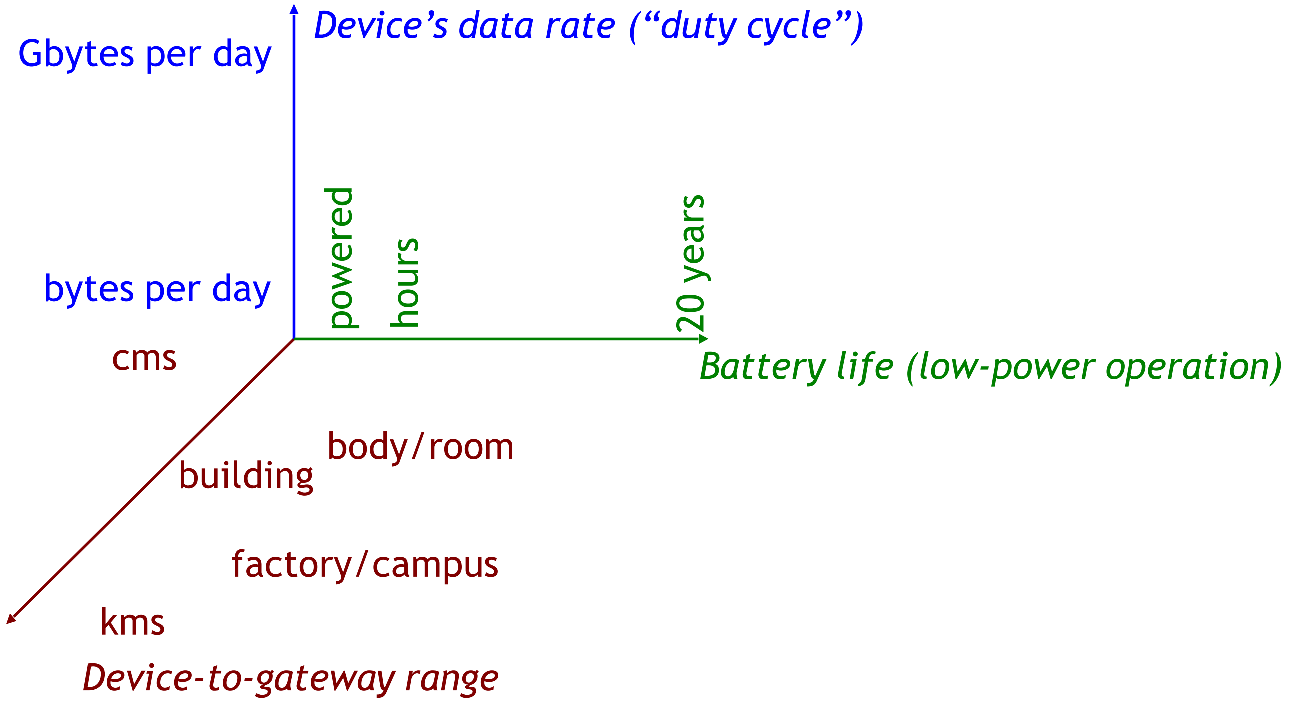
- More flexible
- The protocol's low power consumption competes with Bluetooth
- Higher data rates and wider coverage range

Picture Source: Newracom

WHY SO MANY IOT NETWORKS?

Because engineers love inventing technologies!

Because you can pick from this design space



WHY SO MANY IOT NETWORKS?

- Note, axes aren’t independent
- And technology evolves fast
- And bundling into popular devices speeds-up adoption, changing the economics
  - Wi-Fi → laptops (without external cards)
  - Bluetooth classic → cell phones → wireless headsets
  - Bluetooth Low Energy (BLE) → iPhone then Android smartphones → body/room with months-to-years at low duty cycles

Bluetooth Low Energy (BLE): Room-Area

Device's data rate ("duty cycle")

Bluetooth SMART

peak: 2 Mbps

Months-to-years

Started as "Wibree" by Nokia (2006)
Dominant technology today
Because of smartphones Smart phones as gateways Wearables, fitness trackers Vehicles (bikes, cars)

Battery life (low-power operation)

body/room
10 meters typical

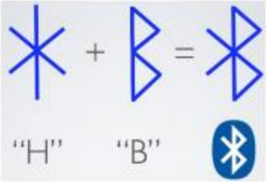
Bluetooth 5.0: up to 400 meters under good conditions with high transmit power

Longer range is not always be good

Device-to-gateway range

History

ERICSSON intel NOKIA

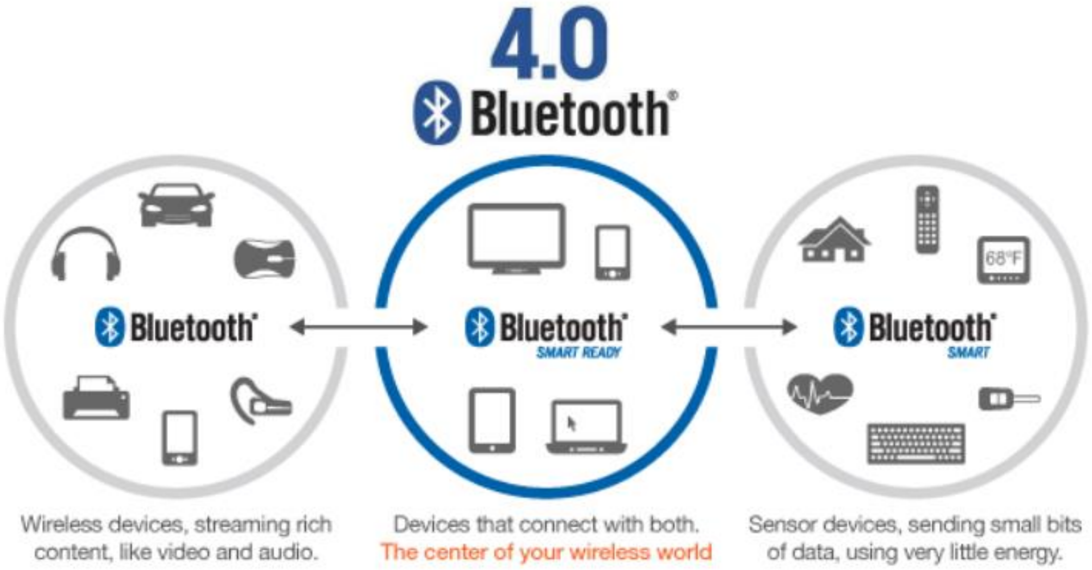


4.0 Bluetooth®

1994-97 2006 2010 2011-2012 2015

Naming for Bluetooth

- Bluetooth 4.0
- Bluetooth Low Energy
  - BLE, BTLE, LE
- SIG Preferred
  - Bluetooth Smart
  - Bluetooth Smart Ready

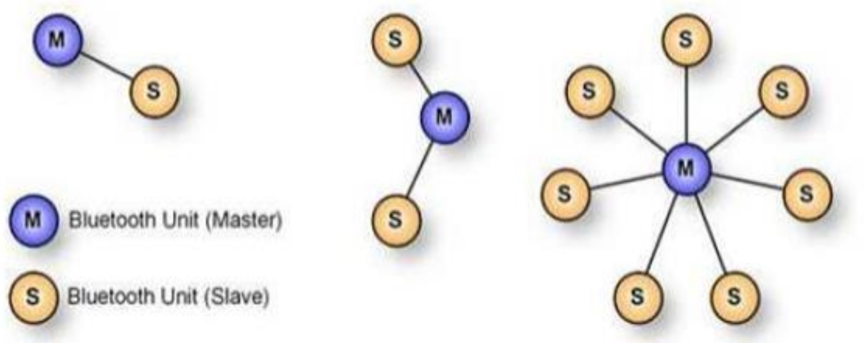


How does BLE Work?

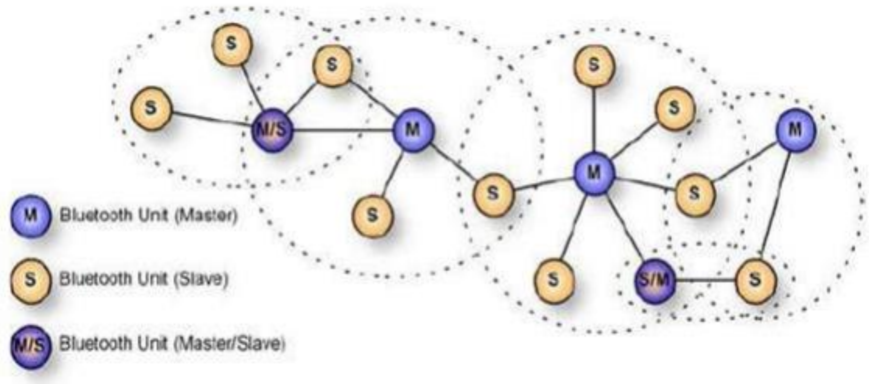
- Two parts:
  - Advertisements (aka “beaconing”) for device discovery
  - Connection phase to exchange data

Peripheral: device with data
Central: gateway

Topology



Piconet v4.0



Scatter net v4.1

BLE Advertisement are Periodic

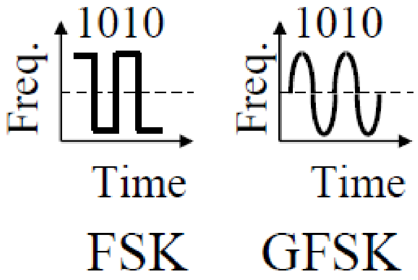
- Typical period: 100 ms (“iBeacon”)
  - Less frequent is fine
- Triggered advertisements are often a good idea
- Trade-off between energy consumed and discovery latency

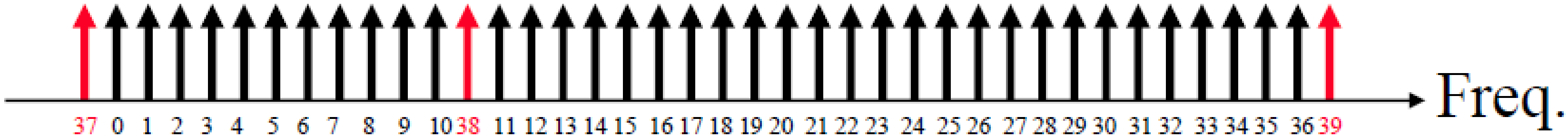
On Connection: MAC Protocol

- Central orchestrates data communication
- Key idea: time-schedule to reduce energy consumption
- On connect: exchange parameters
  - ✓ Frequency hopping sequence
  - ✓ Connection interval, i.e., periodicity of data exchange (T milliseconds)
- Every T milliseconds, Central and Peripheral exchange up to 4 pack ets, alternating turns
- Then Peripheral can go back to sleep until next interval

Bluetooth Smart PHY

- 2.4 GHz. 150 m open field
- Star topology
- 1 Mbps Gaussian Frequency Shift Keying
  Better range than Bluetooth classic
- Adaptive Frequency hopping. 40 Channels
  with 2 MHz spacing
- 3 channels reserved for advertising and 37 channels for data
- Advertising channels specially selected to avoid interference with WiFi channels





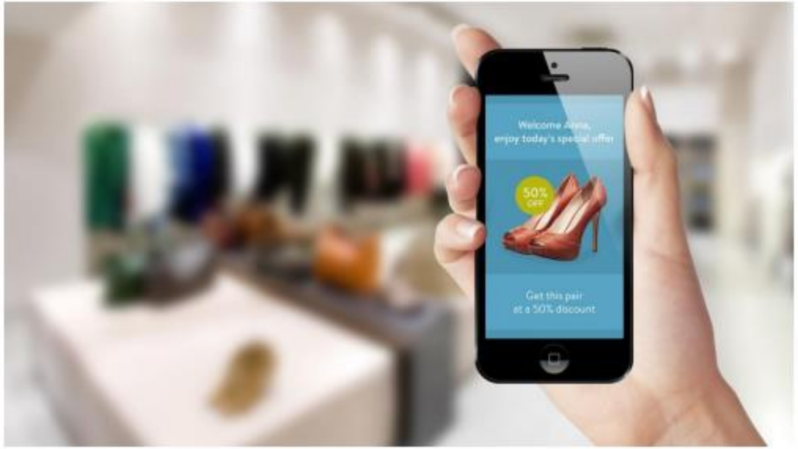
Bluetooth Smart Applications

- Proximity: In car, In room, In the mall
- Locator: Keys, watches, Animals
- Health devices: Heart rate monitor, physical activities monitors, thermometer
- Sensors: Temperature, Battery Status, tire pressure
- Remote control: Open/close locks, turn on lights

Use Cases – Physical Security

Use Cases – Home Automation

Use Cases – Geo-fencing/ Positioning



Use Cases - Fun

Development Kits/Boards

"THE IOT GATEWAY PROBLEM"

Application-level gateways prevalent for IoT today
Usually need a smartphone app to interact with IoT data/devices
Problem: "Siloed" architecture

“THE IOT GATEWAY PROBLEM”

Application-level gateways prevalent for IoT today
Usually need a smartphone app to interact with IoT data/devices
Problem: “Siloed” architecture

Should smartphones become generic BLE gateways (with OS support)
Any phone talking with any peripheral device via BLE

- Should phones become IPv6 routers for peripheral devices?
- Should phone proxy a device’s Bluetooth profile to cloud servers?

“THE IOT GATEWAY PROBLEM”

Should smartphones become generic BLE gateways (with OS support)
Any phone talking with any peripheral device via BLE

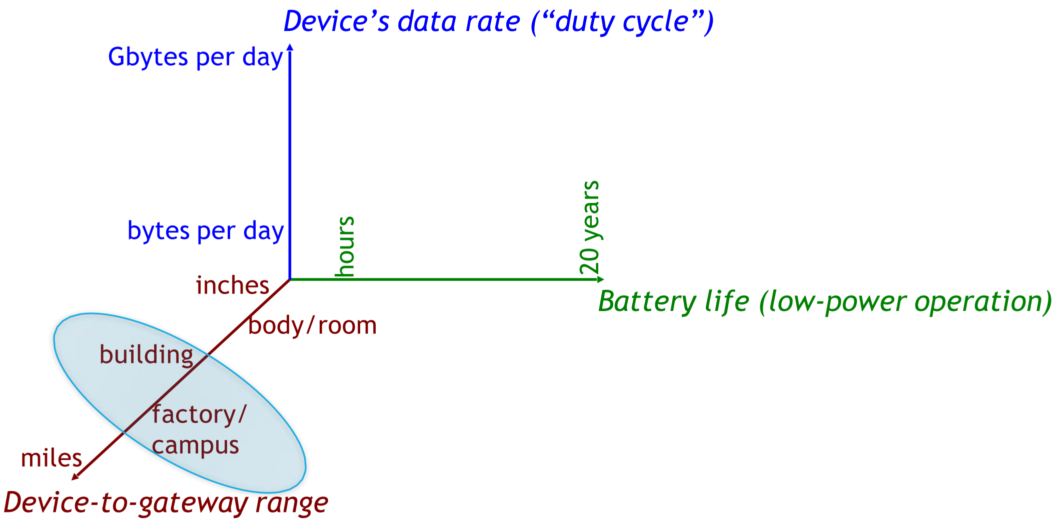
- Should phones become IPv6 routers for peripheral devices?
- Should phone proxy a device’s Bluetooth profile to cloud servers?

Is this a good idea? Will it work?

Value is in the data, not connectivity
Incentives are a problem

  For device makers?
  For app developers?
  For smartphone users?

EXTENDING COMMUNICATION RANGE



EXTENDING RANGE: MESH NETWORKS

1980s: DARPA packet radio networks

The DARPA Packet Radio Network Protocols

JOHN JUBIN AND JANET D. TORNOW, ASSOCIATE, IEEE

Invited Paper

In this paper we describe the current state of the DARPA packet radio network. Fully automated algorithms and protocols to organize, control, maintain, and move traffic through the packet radio network have been designed, implemented, and tested. By means of protocols, networks of about 50 packet radios with some degree of nodal mobility can be organized and maintained under a fully distributed mode of control. We have described the algorithms and illustrated how the PRNET provides highly reliable network transport and datagram service, by dynamically determining optimal routes, effectively controlling congestion, and fairly allocating the channel in the face of changing link conditions, mobility, and varying traffic loads.

I. Introduction

In 1973, the Defense Advanced Research Projects Agency (DARPA) initiated research on the feasibility of using packet-switched, store-and-forward radio communications to provide reliable computer communications [1]. This development was motivated by the need to provide computer network access to mobile hosts and terminals, and to provide computer communications in a mobile environment. Packet radio networking offers a highly efficient way of using a multiple-access channel, particularly with bursty traffic [2]. The DARPA Packet Radio Network (PRNET) has evolved through the years to be a robust, reliable, operational experimental network [3]. The development process has been of an incremental, evolutionary nature [4]; as algorithms were designed and implemented, new versions of the PRNET with increased capabilities were demonstrated. The PRNET has been in daily operation for experimental purposes for nearly ten years. In this paper we describe the current state of the DARPA PRNET.

We begin by providing a synopsis of the PRNET system concepts, attributes, and physical components in Section II. In Section III, we illustrate the mechanisms by which a packet radio automatically keeps track of a potentially continuously changing network topology. In Section IV, we describe the algorithms used to route a packet through the packet radio communications subnet. In Section V, we examine the protocols for transmitting packets. In Section VI, we describe some of the hardware capabilities of the packet radio that strongly influence the design and characteristics of the PRNET protocols. We conclude by looking briefly at some applications of packet radio networks and by summarizing the state of the current technology.

II. Description of the Packet Radio System

A. Broadcast Radio

The PRNET provides, via a common radio channel, the exchange of data between computers that are geographically separated. As a communications medium, broadcast radio (as opposed to wires and antenna-directed radio) provides important advantages to the user of the network. One of the benefits is mobility; a packet radio (PR) can operate while in motion. Second, the network can be installed or deployed quickly; there are no wires to set up. A third advantage is the ease of reconfiguration and redeployment. The PRNET protocols take advantage of broadcasting and common-channel properties to allow the PRNET to be expanded or contracted automatically and dynamically. A group of packet radios leaving the original area simply departs. Having done so, it can function as an autonomous group and may later rejoin the original network or join another group.

The broadcasting and common channel properties of radio have disadvantages too. These properties, for all practical purposes, prohibit the building of a radio that is able to transmit and receive at the same time. Therefore, the PRNET protocols must attempt to schedule each transmission when the intended PR is not itself transmitting. Also, transmissions often reach unintended PRs and interfere with intended receptions. Therefore, the protocols must attempt to schedule each transmission when the intended PR is not receiving another PR's transmission.

B. Automated Network Management

The PRNET features fully automated network management. It is self-configuring upon network initialization, reconfigures upon gain or loss of packet radios, and has dy-

Manuscript received February 1, 1986; revised July 30, 1986. The work of J. Jubin was supported by the Defense Advanced Research Projects Agency of the Department of Defense under Contract MDA903-85-C-0285. The work of J. D. Tornow was supported by the Defense Advanced Research Projects Agency of the Department of Defense under Contract MDA903-85-C-0254.

J. Jubin is with Collins Defense Communications, Rockwell International, Richardson, TX 75081, USA.

J. D. Tornow is with SRI International, Menlo Park, CA 94025, USA.

1990s: mobile ad hoc networks (MANET)

A Performance Comparison of Multi-Hop Wireless Ad Hoc Network Routing Protocols

Josh Broch David A. Maltz David B. Johnson Yih-Chun Hu Jorjeta Jetcheva

Computer Science Department
Carnegie Mellon University
Pittsburgh, PA 15213

http://www.monarch.cs.cmu.edu/

Abstract

An ad hoc network is a collection of wireless mobile nodes dynamically forming a temporary network without the use of any existing network infrastructure or centralized administration. Due to the limited transmission range of wireless network interfaces, multiple network "hops" may be needed for one node to exchange data with another across the network. In recent years, a variety of new routing protocols targeted specifically at this environment have been developed, but little performance information on each protocol and no realistic performance comparison between them is available. This paper presents the results of a detailed packet-level simulation comparing four multi-hop wireless ad hoc network routing protocols that cover a range of design choices: DSDV, TORA, DSR, and AODV. We have extended the *ns*-2 network simulator to accurately model the MAC and physical-layer behavior of the IEEE 802.11 wireless LAN standard, including a realistic wireless transmission channel model, and present the results of simulations of networks of 50 mobile nodes.

1 Introduction

In areas in which there is little or no communication infrastructure or the existing infrastructure is expensive or inconvenient to use, wireless mobile users may still be able to communicate through the formation of an *ad hoc network*. In such a network, each mobile node operates not only as a host but also as a router, forwarding packets for other mobile nodes in the network that may not be within direct wireless transmission range of each other. Each node participates in an ad hoc routing protocol that allows it to discover "multi-hop" paths through the network to any other node. The idea of ad hoc networking is sometimes also called *infrastructureless networking* [13], since the mobile nodes in the network dynamically establish routing among themselves to form their own network "on the fly." Some examples of the possible uses of ad hoc networking include students using laptop computers to participate in an interactive lecture, business associates sharing information during a meeting, soldiers relaying information for situational awareness on the battlefield [12, 21], and emergency disaster relief personnel coordinating efforts after a hurricane or earthquake.

Many different protocols have been proposed to solve the multi-hop routing problem in ad hoc networks, each based on different assumptions and intuitions. However, little is known about the actual performance of these protocols, and no attempt has previously been made to directly compare them in a realistic manner.

This paper is the first to provide a realistic, quantitative analysis comparing the performance of a variety of multi-hop wireless ad hoc network routing protocols. We present results of detailed simulations showing the relative performance of four recently proposed ad hoc routing protocols: DSDV [18], TORA [14, 15], DSR [9, 10, 2], and AODV [17]. To enable these simulations, we extended the *ns*-2 network simulator [6] to include:

- *Node mobility.*
- A *realistic physical layer* including a radio propagation model supporting propagation delay, capture effects, and carrier sense [20].
- *Radio network interfaces* with properties such as transmission power, antenna gain, and receiver sensitivity.
- The *IEEE 802.11 Medium Access Control (MAC) protocol* using the Distributed Coordination Function (DCF) [8].

Our results in this paper are based on simulations of an ad hoc network of 50 wireless mobile nodes moving about and communicating with each other. We analyze the performance of each protocol and explain the design choices that account for their performance.

2 Simulation Environment

ns is a discrete event simulator developed by the University of California at Berkeley and the VINT project [6]. While it provides substantial support for simulating TCP and other protocols over conventional networks, it provides no support for accurately simulating the physical aspects of multi-hop wireless networks or the MAC protocols needed in such environments. Berkeley has recently released *ns* code that provides some support for modeling wireless LANs, but this code cannot be used for studying multi-hop ad hoc networks as it does not support the notion of node position; there is no spatial diversity (all nodes are in the same collision domain), and it can only model directly connected nodes.

In this section, we describe some of the modifications we made to *ns* to allow accurate simulation of mobile wireless networks.

2.1 Physical and Data Link Layer Model

To accurately model the attenuation of radio waves between antennas close to the ground, radio engineers typically use a model that attenuates the power of a signal as $1/r^2$ at short distances (r is the distance between the antennas), and as $1/r^4$ at longer distances. The crossover point is called the *reference distance*, and is typically around 100 meters for outdoor low-gain antennas 1.5m above the ground plane operating in the 1–2GHz band [20]. Following this practice, our signal propagation model combines both a free space propagation model and a two-ray ground reflection model. When a transmitter is within the reference distance of the receiver, we use

This work was supported in part by the National Science Foundation (NSF) under CAREER Award NCR-9502725, by the Air Force Materiel Command (AFMC) under DARPA contract number F19628-96-C-0061, and by the AT&T Foundation under a Special Purpose Grant in Science and Engineering. David Maltz was also supported under an IBM Cooperative Fellowship, and Yih-Chun Hu was also supported by an NSF Graduate Fellowship. The views and conclusions contained here are those of the authors and should not be interpreted as necessarily representing the official policies or endorsements, either express or implied, of NSF, AFMC, DARPA, the AT&T Foundation, IBM, Carnegie Mellon University, or the U.S. Government.

EXTENDING RANGE: MESH NETWORKS

Late 90s, 2000s: Sensor networks

Next Century Challenges: Scalable Coordination in Sensor Networks

Deborah Estrin
Ramesh Govindan
John Heidemann
Satish Kumar

USC/Information Sciences Institute
4676 Admiralty Way
Marina del Rey, CA 90292, USA
{estrin,govindan,johnh,kkumar}@isi.edu

Abstract

1 Introduction

An Application-Specific Protocol Architecture for Wireless Microsensor Networks

Wendi B. Heinzelman, Member, IEEE, Anantha P. Chandrakasan, Senior Member, IEEE, and Hari Balakrishnan, Member, IEEE

I. Introduction

2000s: Mesh networks for Internet

Architecture and Evaluation of an Unplanned 802.11b Mesh Network

John Bicket, Daniel Aguayo, Sanjit Biswas, Robert Morris
M.I.T. Computer Science and Artificial Intelligence Laboratory
jbicket, aguayo, biswas, rtm @csail.mit.edu

ABSTRACT

General Terms

Design, Experimentation, Measurement, Performance

Keywords

Mesh networks, Multi-hop wireless networks, Ad hoc networks, Wireless routing, Route metrics

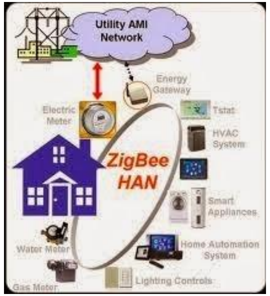
1. INTRODUCTION

Categories and Subject Descriptors

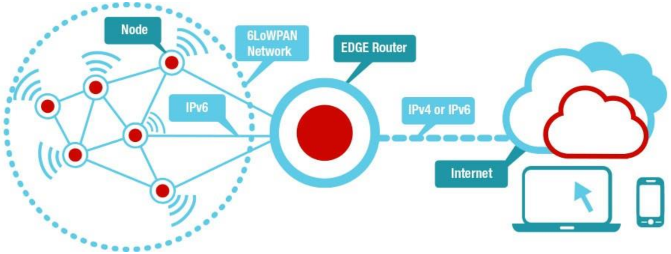
EXTENDING RANGE: MESH NETWORKS

2010s: Mesh networks for IoT

Zigbee



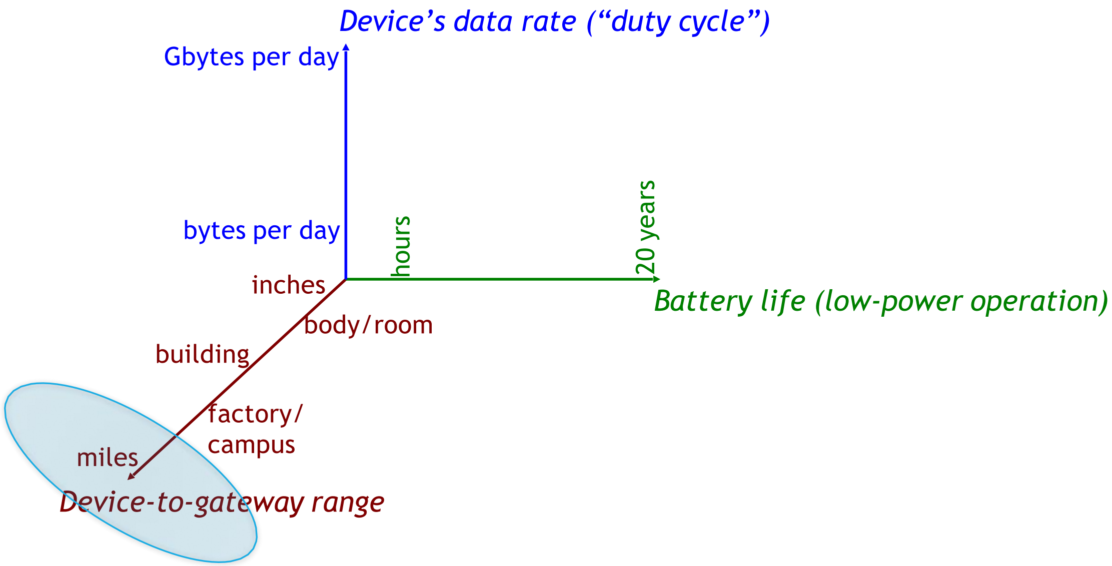
6LoWPAN: IPv6 over low-power wireless personal area networks



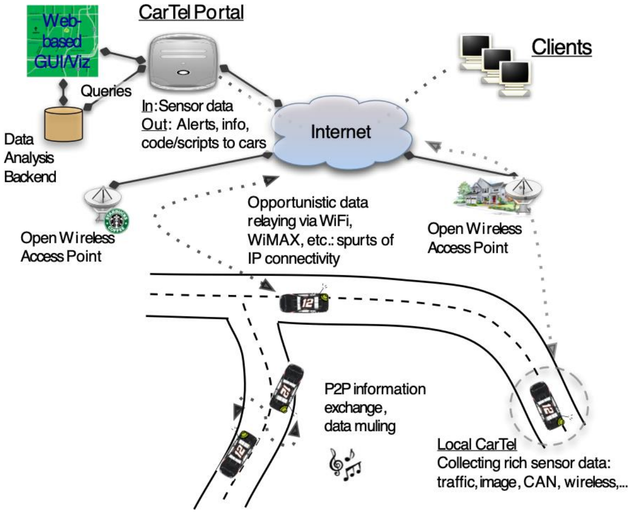
http://processors.wiki.ti.com/index.php/Contiki-6LOWPAN (Creative commons)

Both (typically) run over the 802.15.4 MAC standard
Routing protocol with different metrics, such as “expected transmission time”
Use case: devices communicating with gateway across multiple hops
Node duty cycles higher, some nodes do much more work

EVEN LONGER RANGE (CITY-SCALE)



WHEN THE INTERNET IS MILES AWAY



Use mobile devices
as **data mules**
Trade-off: delay
Delay-tolerant network (DTN)

WHAT IF WE WANT LONG RANGE AND LOW DELAY?

“Long-range IoT networks”
Examples: Sigfox, LoRaWAN, cellular IoT proposals (narrowband LTE, etc.), 5G

Some of these are low-power designs (months to years of battery life)

Low or ultra-low throughput (a few bytes per day to achie
ve long-enough battery life at a rate of a few kbps) networ
ks like LoRaWAN also include localization capabilities

These haven’t seen wide deployment yet

WHAT IF WE WANT LONG RANGE AND LOW DELAY?

“Long-range IoT networks”
Examples: Sigfox, LoRaWAN, cellular IoT proposals (narrowband LTE, etc.), 5G

Some of these are low-power designs (months to years of battery life)

WHAT IF WE WANT LONG RANGE AND LOW DELAY?

"Long-range IoT networks"

Examples: Sigfox, LoRaWAN, cellular IoT proposals (narrowband LTE, etc.), 5G

Some of these are low-power designs (months to years of battery life)

Low or ultra-low throughput (a few bytes per day to achieve long-enough battery life at a rate of a few kbps) networks like LoRaWAN also include localization capabilities

These haven't seen wide deployment yet

WHAT IF WE WANT LONG RANGE AND LOW DELAY

Second choice: Cellular (of course!) Examples: LTE/4G, etc.

High-power consumption, so only when energy isn't an issue
Relatively high cost (>$10 per device today plus monthly usage cost)

Variable delay of cellular networks is still a concern for data-intensive, latency-sensitive applications

WHAT IS 5G?

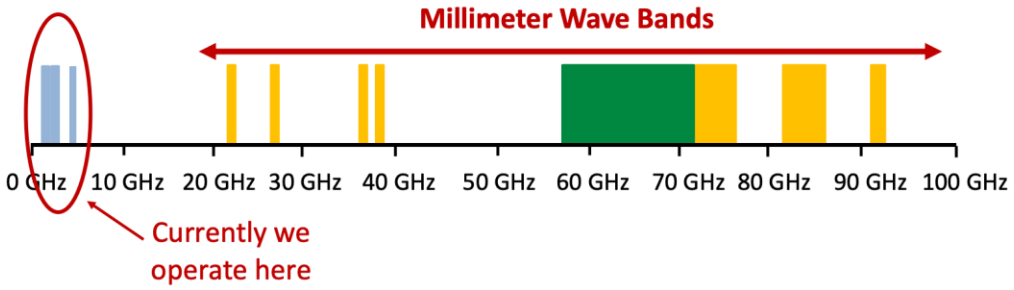
"Unifying solution" offered by cellular providers

Qualcomm

WHAT IS NEW IN 5G?

Millimeter Wave Technology

Huge bandwidth available at millimeter wave frequencies



Millimeter Wave can support data rates of multi-Gbps

Short range vs. long-range IoT

Local Area IoT

Source: Amazon

Source: LG

Wide Area IoT

Source: fiorentini.cn

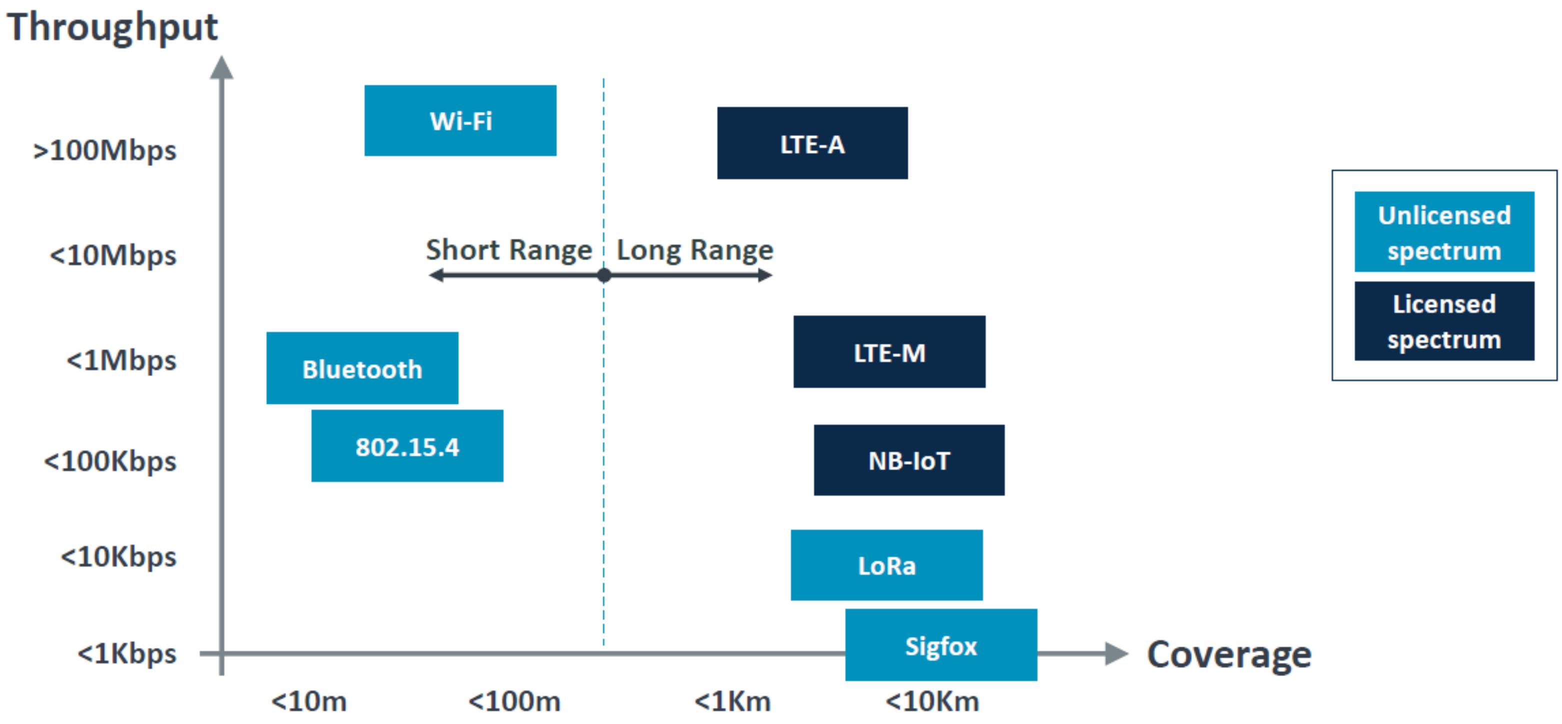
Source: ofo

Source: Max Pixel

Source: bdk

IoT-connectivity technologies

Multiple standards, different attributes



LPWA requirements

Low Power Wide Area wireless connects low bandwidth, low power devices and provides long-range coverage

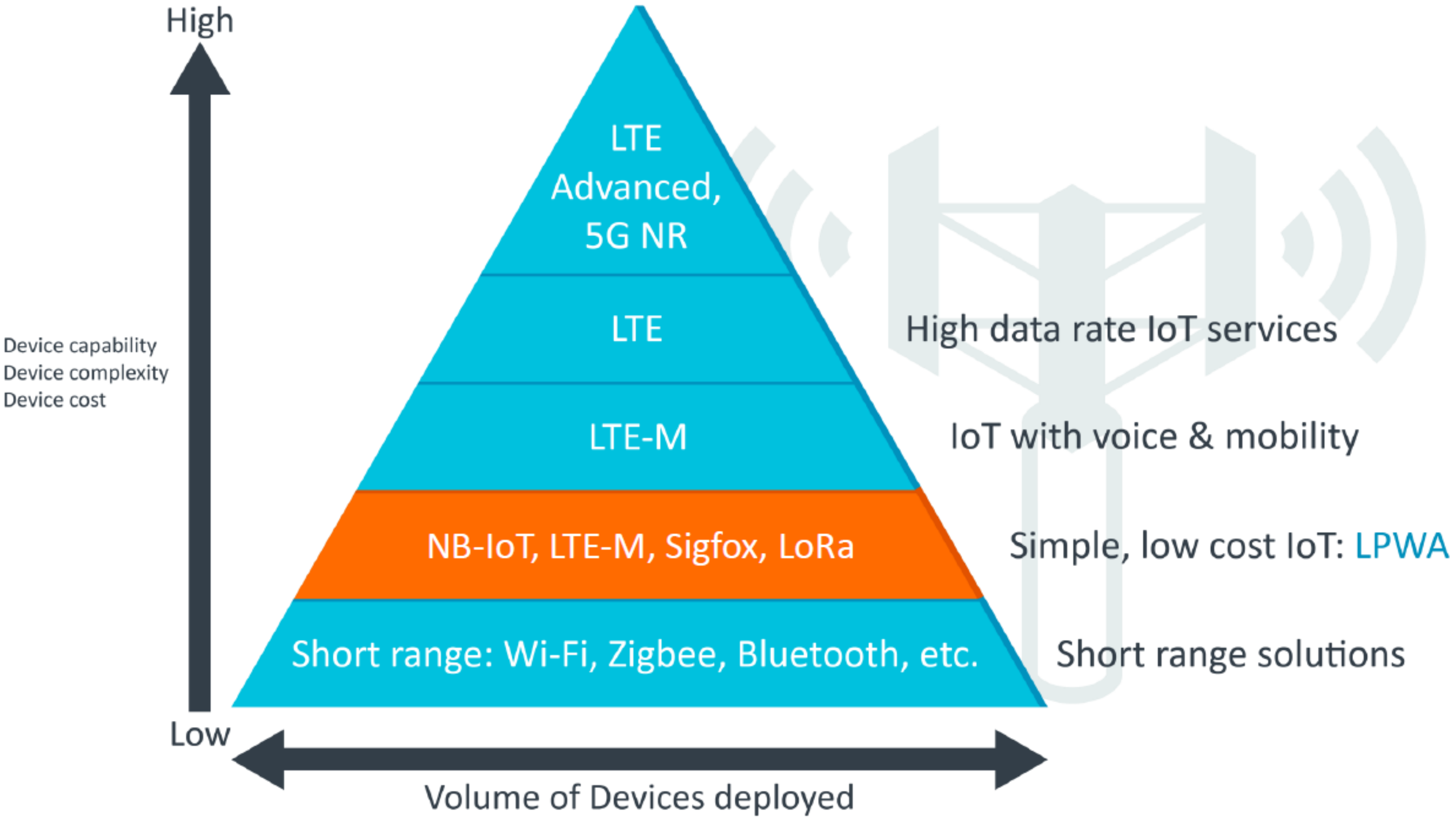
Includes cellular (NB-IoT, LTE-M/Cat-M1) *and* non-cellular (Sigfox, LoRa etc) technologies

LPWA requirements

The most critical factors in a LPWAN are:

- Network architecture
- Communication range
- Battery lifetime or low power
- Robustness to interference
- Network capacity (maximum number of nodes in a network)
- Network security
- One-way vs. two-way communication
- Variety of applications served

IoT - the connectivity pyramid



Low-Power Wide-Area Networks

25 mW transmission power

Low-Power Wide-Area Networks

20 years on simple battery

15-50 km rural outdoor

Low-Power **Wide-Area** Networks

2-3 km urban indoor

No scheduling

No routing

ALOHA

Low-Power Wide-Area Networks

Device-initiated com

Huge densities

Low throughput

250 kHz or less

Narrow-band

Low-Power Wide-Area Networks

Collisions

Duty cycling

Acknowledgements

Data-over-NAS

In-band

Guard-bands

License free

In licensed spectrum

250 kHz or less

Narrow-band

Low-Power Wide-Area Networks

Collisions

Duty cycling

Acknowledgements

Data-over-NAS

In-band

Guard-bands

License free

In licensed spectrum

No scheduling

250 kHz or less

Narrow-band

No routing

ALOHA

25 mW transmission power

15-50 km rural outdoor

Low-Power Wide-Area Networks

20 years on simple battery

2-3 km urban indoor

Device-initiated com

Huge densities

Low throughput

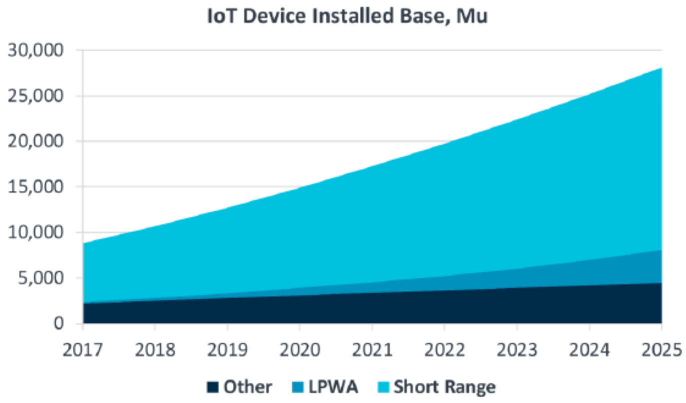
100 bps
(50 kbps max)

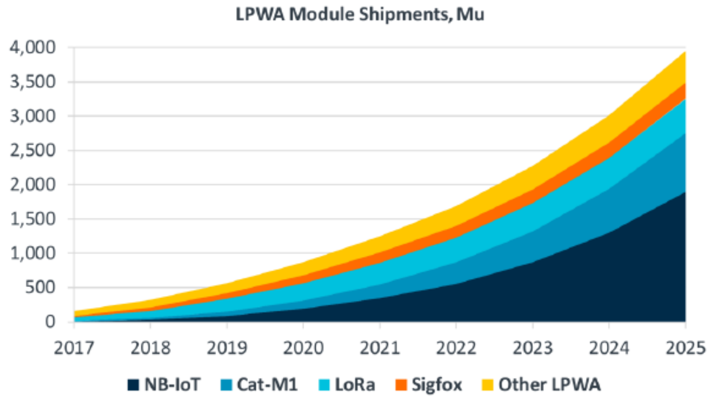
12 byte payload
(50 byte payload)

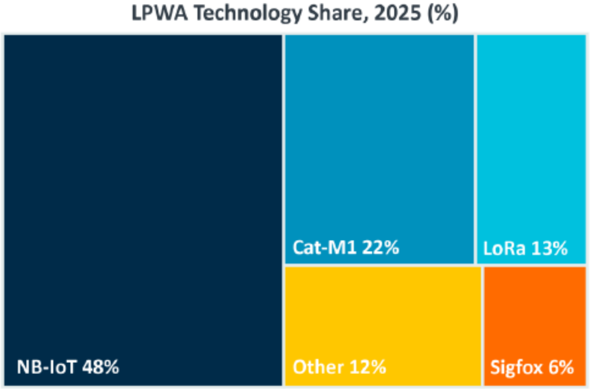
140 messages
uplink

4 messages
downlink

LPWA market opportunity







Cellular LPWA example applications

Real use cases being deployed now [NB-IoT]

Bike share

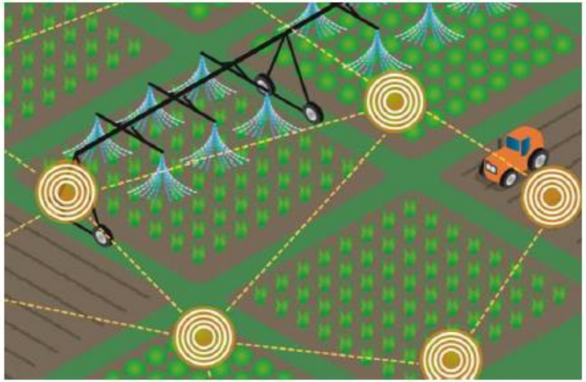
ofo

mobike

Source: ofo.so. mobike.com

Smart agriculture

7Sense® Telia

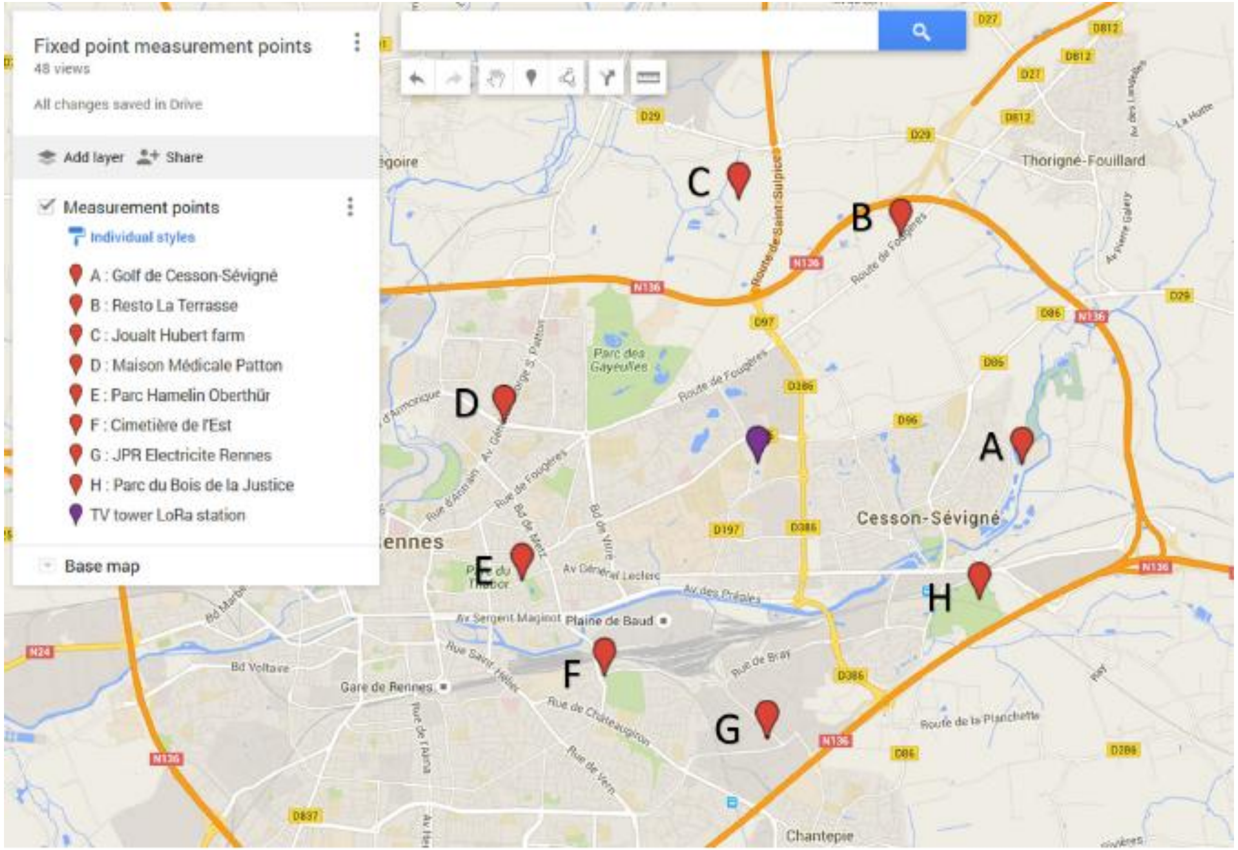


Source: richardvanhooijdonk.com

Smart meters

Shanghai Fiorentini®

Source: fiorentini.cn



Fixed measurements points, 3km distance from TV tower LoRa IoT station

WHERE DOES LPWAN FIT?

Local Area Network Short Range Communication	**L**ow **P**ower **W**ide **A**rea (LPWAN) Internet of Things	**Cellular Network** Traditional M2M
40%	**45%**	**15%**
Well established standards In building	Low power consumption Low cost Positioning	Existing coverage High data rate
Battery Live Provisioning Network cost & dependencies	High data rate Emerging standards	Autonomy Total cost of ownership
Bluetooth 4.0, ZigBee, WiFi	LoRa	GSM, 3G+ / H+, 4G

LoRa

What is it?

- LoRa technology was originally developed by a French company, Cycleo (founded in 2009 as an IP and design solution provider), a patented spread spectrum wireless modulation technology that was acquired by SemTech in 2012 for $5 million
- In April 2013, SemTech released the SX1272 chip, which was equipped with LoRa technology
  - At that time, FSK modulated European smart meter transceivers were used, with a maximum transmission distance of 1 to 2 kilometers
  - LoRa operated under the same conditions, and the transmission distance could be more

LoRa Technology

Two major components

End device: ED
Base Station: BS

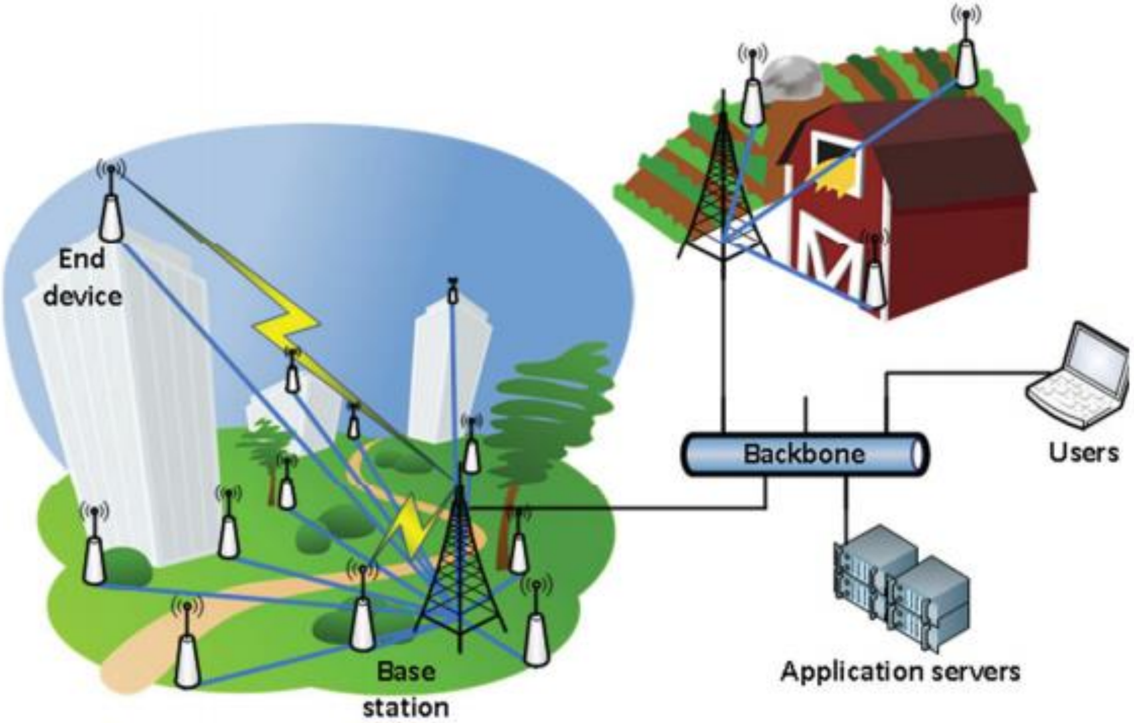
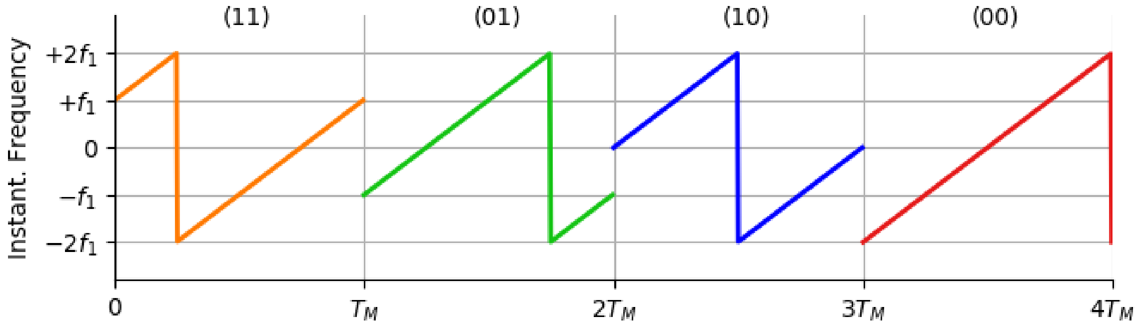
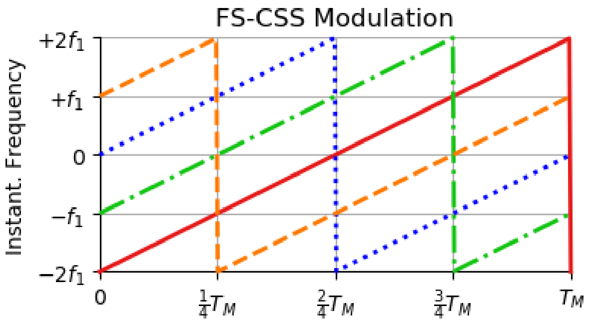


Fig. 1. Typical LPWAN network landscape

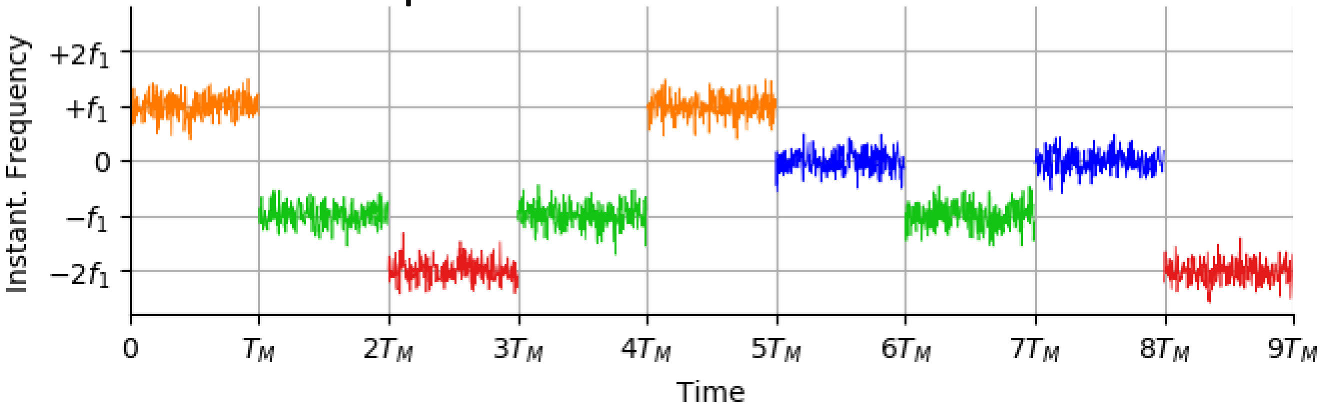
Modulation and Demodulation of LoRa

Frequency shift chirp modulation

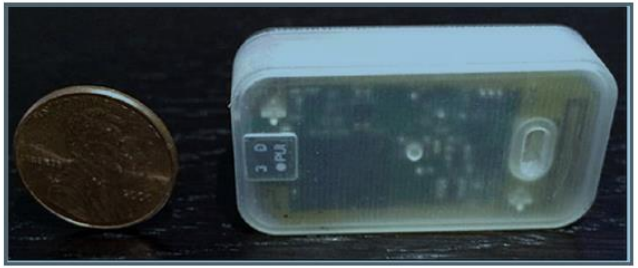




Demodulation: dechirp



LoRa End Node



- ❑ Partner module solution for NA
- ❑ TX = 1W, GPS+sensors, battery
- ❑ Fully Compliant with FCC

- ❑ Partner Module for EU
- ❑ ST Micro(STM32) + SX1272

Abeeway – Asset tracking device

COMPARING LPWAN TECHNOLOGY OPTIONS

Feature	LoRaWAN	Narrow-Band	LTE Cat-1 2016 (Rel12)	LTE Cat-M 2018 (Rel13)	NB-LTE 2019(Rel13+)
Modulation	SS Chirp	UNB / GFSK/BPSK	OFDMA	OFDMA	OFDMA
Rx bandwidth	500 - 125 KHz	100 Hz	20 MHz	20 - 1.4 MHz	200 KHz
Data Rate	290bps - 50Kbps	100 bit/sec 12 / 8 bytes Max	10 Mbit/sec	200kbps – 1Mbps	~20K bit/sec
Max. # Msgs/day	Unlimited	UL: 140 msgs/day	Unlimited	Unlimited	Unlimited
Max Output Power	20 dBm	20 dBm	23 - 46 dBm	23/30 dBm	20 dBm
Link Budget	154 dB	151 dB	130 dB+	146 dB	150 dB
Batery lifetime - 2000mAh	105 months	90 months		18 months	
Power Efficiency	Very High	Very High	Low	Medium	Med high
Interference immunity	Very high	Low	Medium	Medium	Low
Coexistence	Yes	No	Yes	Yes	No
Security	Yes	No	Yes	Yes	Yes
Mobility / localization	Yes	Limited mobility, No loc	Mobility	Mobility	Limited Mobility No Loc

Conclusion

- LoRaWAN technology, like any other, has its own strengths and weaknesses
  - The high coverage and satisfactory scalability under low uplink traffic
  - The most critical drawbacks are low reliability and potentially poor performance in terms of downlink traffic
- LoRa can be effectively utilized for the moderately dense networks of very low traffic devices which do not impose strict latency or reliability requirements

PREDICTIONS

1. Shake-up in standards: multiple winners, but they will divide up the "three-dimensional space"

2. Ultra-low power IoT systems and networks

3. Compute-intensive (data-intensive) IoT systems and networks

4. De-siloed architectures, open gateways for specific apps?

5. Smartphone-centric v. hidden ("ubiquitous") computing

The most profound technologies are those that **disappear**

- Mark Weiser