Bluetooth Low Energy and its Convergence with Lightweight IPv6

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Agenda

- Bluetooth Low Energy & Bluetooth roadmap
- Bluetooth Low Energy stack & chips & products
- Lightweight IPv6 for Bluetooth Low Energy

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Bluetooth Core Specifications

Version	Feature	Released	RF	Data Rate
Bluetooth v1.1	IEEE 802.15.1	2001	2.4GHz	1Mbps
Bluetooth v1.2	Personal Area Network	2003	2.4GHz	1Mbps
Bluetooth v2.0 + EDR	Enhanced Data Rate	2004	2.4GHz	3Mbps
Bluetooth v2.1 + EDR	Simple Secure Pairing	2007	2.4GHz	3Mbps
Bluetooth v3.0 + HS	High Speed	2009	~5GHz	24Mbps
Bluetooth v4.0	Ultra-Low Power	2010	2.4GHz	1Mbps

Bluetooth Low Energy History

- Nokia NRC made a proposal in 2001
  - BT_LEE (Bluetooth Lower Energy End)
- Wibree Forum was formed in 2006
- BT-SIG renamed it to Ultra Low Power (ULP) in 2007
  - In 2008 BT-SIG announced Bluetooth Low Energy as the marketing name for ULP
- BT-SIG released Bluetooth Spec v4, incl. BLE in July 2010
  - October 2011, BT-SIG renamed BLE as Bluetooth Smart (single mode), and Bluetooth Smart Ready (dual mode)

Bluetooth Low Energy – introduced with Bluetooth v4.0

- Bluetooth low energy technology is a global standard, very low power wireless technology

- Bluetooth low energy technology enables devices with coin cell batteries to be wirelessly connected to standard Bluetooth enabled devices

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BR/EDR and LE comparison

Technical Specification	BR / EDR	LE
Carrier Frequency	2.4 GHz	2.4 GHz
Over the air data rate	1 ~ 3 Mbps	1 Mbps
Application throughput	0.7 ~ 2.1 Mbps	0.2~0.4 Mbps
Modulation	GFSK, DPSK (EDR)	GFSK only, BT=0.5, H=0.5
Robustness in Channel	AFH, FEC, ARQ	AFH (ARQ for connection)
Voice	SCO, eSCO	N/A
Link Topology	Piconet (with Scatternet)	Star (no mesh)

Principles of ultra low power operation

- Low duty cycle, short packages and high on air data rate
  - Connection intervals from 3ms to 4s+
  - Short data packets – up to 31 bytes payload
  - 1 Mbps on-air data rate
  - System spends most time in sleep mode
  - RF is on only a small fraction of the time
- Fast connection time
  - Devices can connect in 3ms
  - Allows for fast connection, send data and then disconnect
  - System can spend most of the time in deep sleep
- Low peak power
  - Use relaxed RF parameters for GFSK modulation

1. Lower standby time

- Bluetooth low energy technology uses only 3 advertising channels
  - Bluetooth technology uses 16 to 32 channels
  - RF is on for 0.6 to 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

2. Faster connection

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

- The devices can connect 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

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3. Lower peak power

- Bluetooth low energy technology uses relaxed RF parameters
  - GFSK modulation index increased
  - Allowing better range / robustness
    - BLE uses relaxed RF parameters
      - GFSK modulation
      - 2MHz bandwidth
      - BT = 0.5
    - BT uses strict RF parameters
      - GFSK modulation (EDR uses π/4 QPSK, π/8 PSK)
      - 1MHz bandwidth
      - BT = 0.35
- Packet length restricted
  - Together to GFSK gives lowest complexity transmitter / receiver
  - Gives you lower peak power

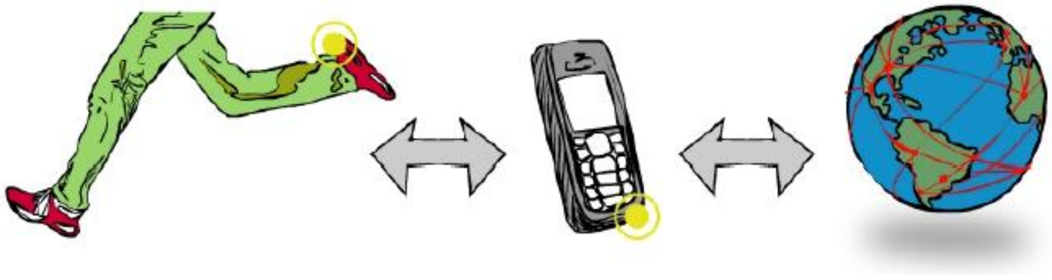
- THIS GIVES YOU COIN CELL OPERATION

Bluetooth Low Energy is born for Sensor applications

- Sum up: How to achieve ultimate low power?
  - 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)
- Sensors are the ideal application – transmitting small amounts of discrete data

Low Energy designed for Embedded Sensor Applications

- Low energy consumption means that the battery will work for years – the lifetime of the device
- With no need for replacement, the battery can be encapsulated in the product, permitting previously impossible applications



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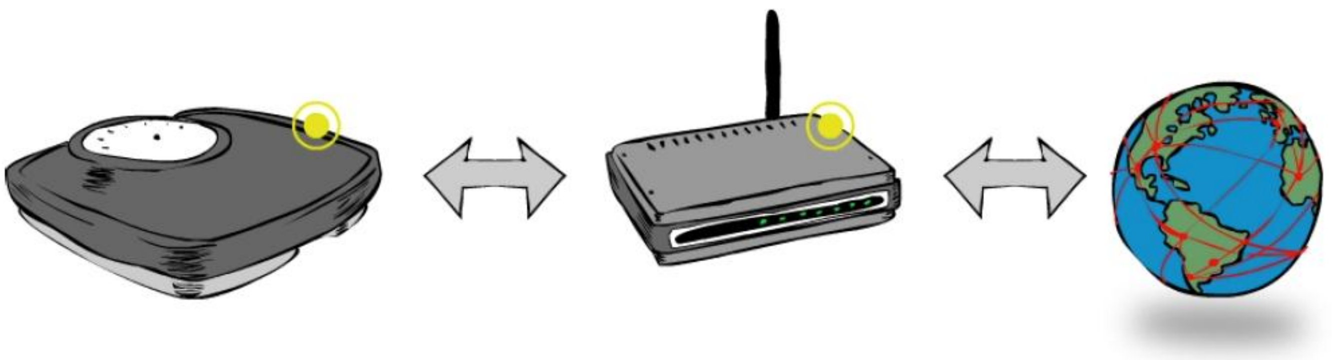
Low Energy designed for Internet of Things thru Gateway

- Enables low-power sensor accessories to wirelessly connect to gateway devices, and thereby to the Internet
- Remote UI and app downloadable from Web, reduce the complexity of sensor devices



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- Bluetooth Low Energy stack & chips & products
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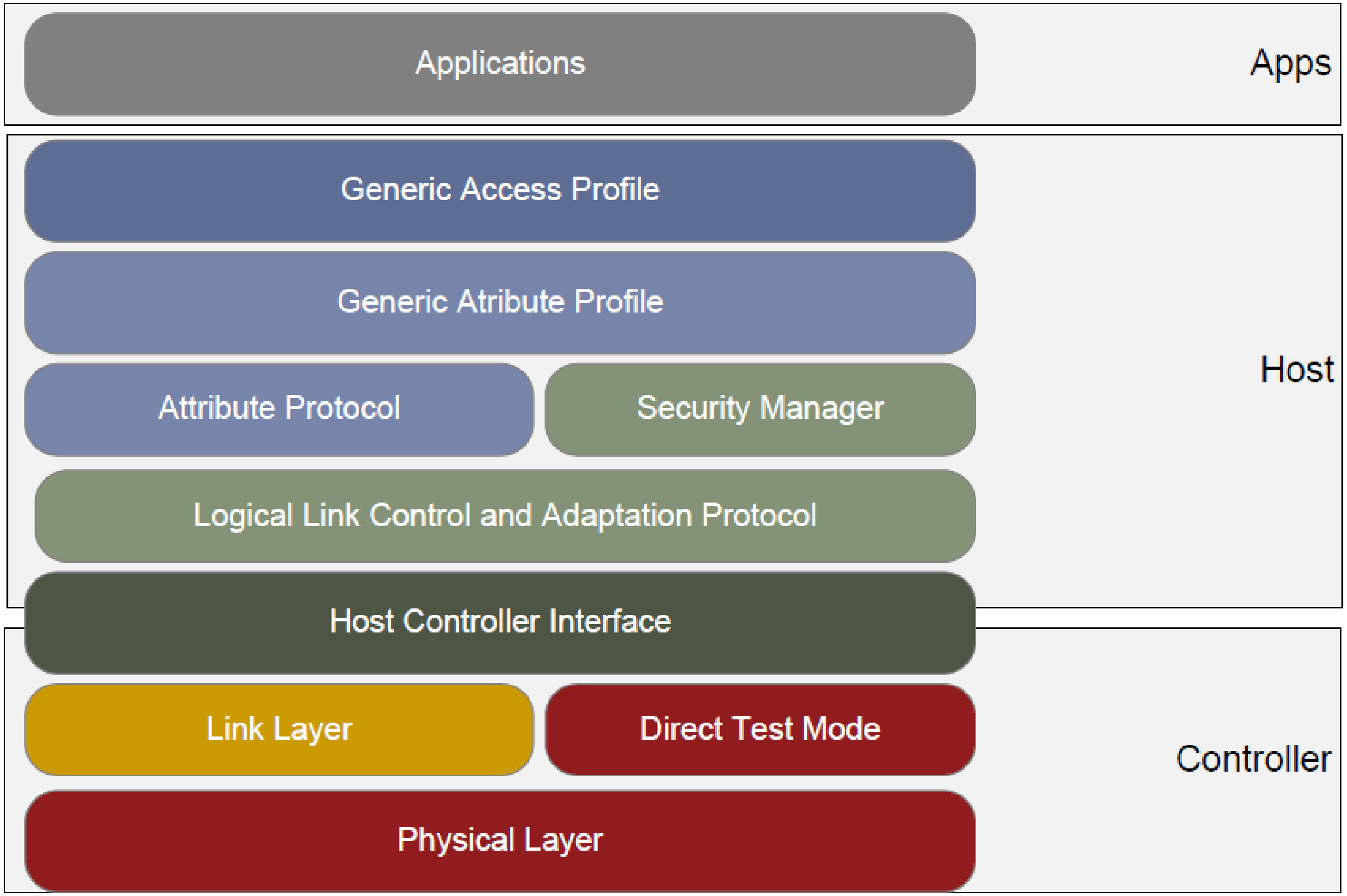
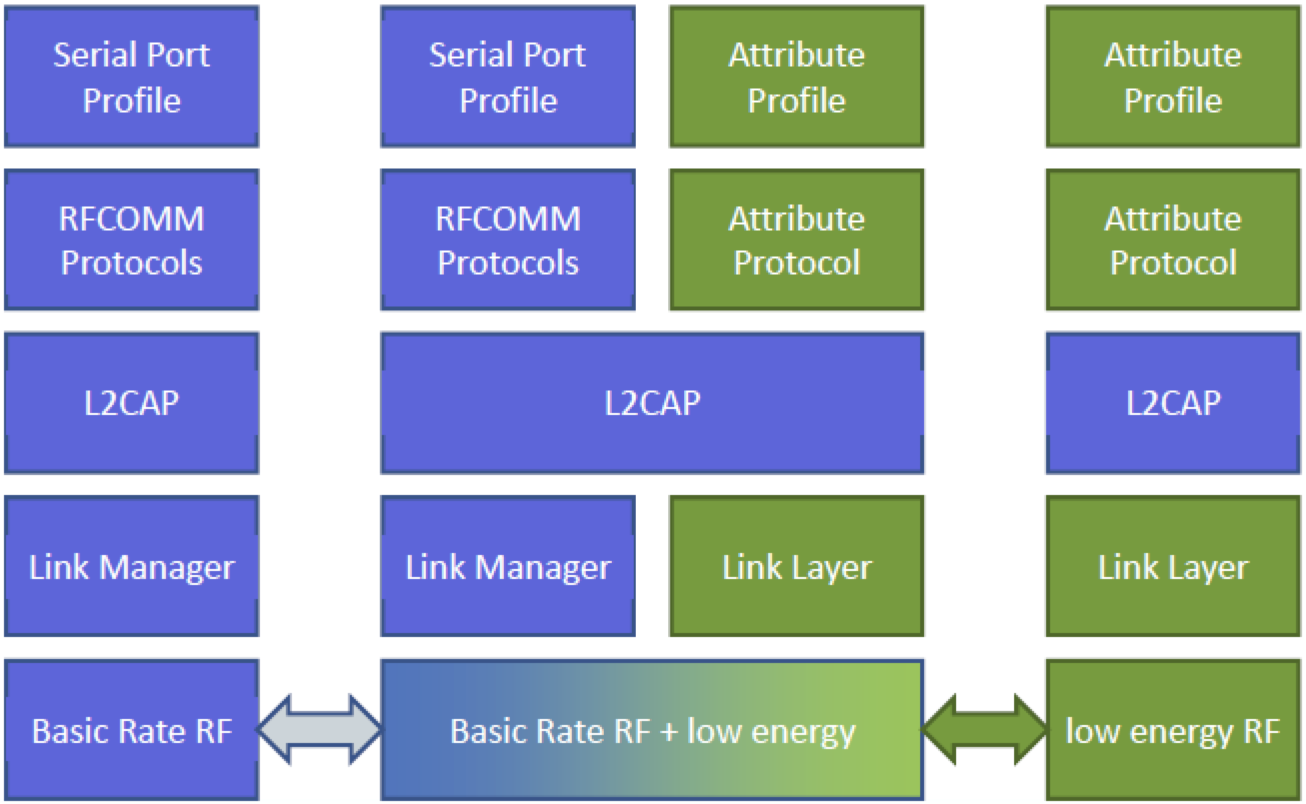
BLE stack



Applications
Apps
Generic Access Profile
Generic Atribute Profile
Host
Attribute Protocol
Security Manager
Logical Link Control and Adaptation Protocol
Host Controller Interface
Link Layer
Direct Test Mode
Controller
Physical Layer

Dual-mode and single-mode



Physical layer – two types of channels

- 2.4 GHz ISM Band Transceiver
  - Divided into 40 RF Channels
  - 2 MHz Channel Spacing
- Advertising Channels
  - Used to broadcast data
  - Connectable
  - Discoverable
  - 3 FIXED Channels
- Data Channels
  - Used to send application data
  - Adaptively Frequency Hopped
  - 37 Dynamic Channels

Physical layer – advertising avoid WiFi

MHz	Advertising	Data	Wi-Fi
2402	37		1
2404		0	1
2406		1	1
2408		2	1
2410		3	1
2412		4	1
2414		5	1
2416		6	1
2418		7	1
2420		8	1
2422		9	1
2424		10	
2426	38		
2428		11	6
2430		12	6
2432		13	6
2434		14	6
2436		15	6
2438		16	6
2440		17	6
2442		18	6
2444		19	6
2446		20	6
2448		21	6
2450		22	
2452		23	11
2454		24	11
2456		25	11
2458		26	11
2460		27	11
2462		28	11
2464		29	11
2466		30	11
2468		31	11
2470		32	11
2472		33	11
2474		34	
2476		35	
2478		36	
2480	39		

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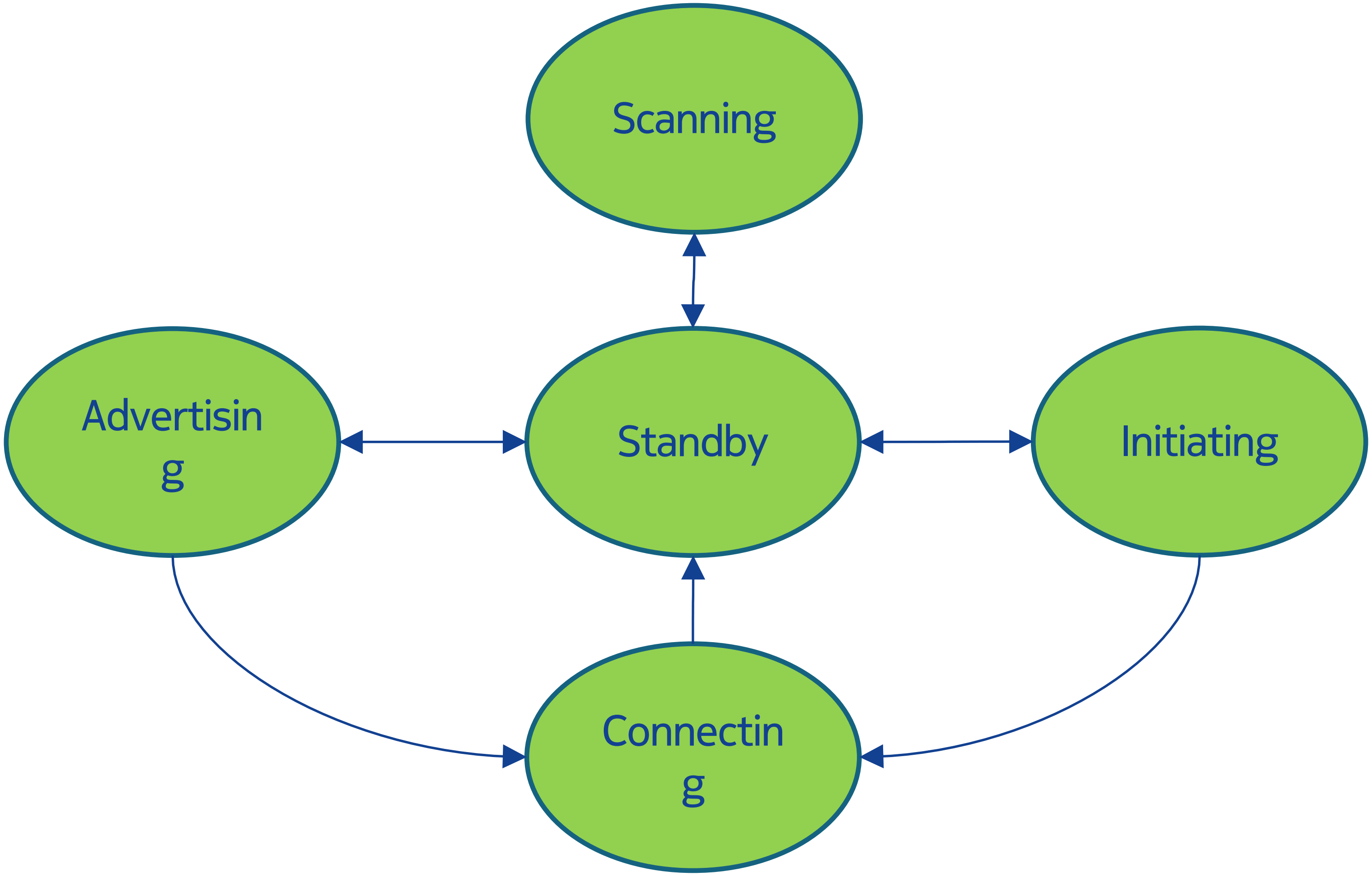
Link Layer – states



Link layer – packet format

- All packets have same structure
  - Preamble – 01010101 or 10101010
  - Access Address – correlated 32 bit sequence
  - Payload – actual data
  - CRC – 24 bit CRC for robust bit error detection
    - CRC calculated over Payload

Preamble	Access Address	Payload	CRC
1 octet	4 octets	2 to 39 octets	3 octets

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BLE new functionalities

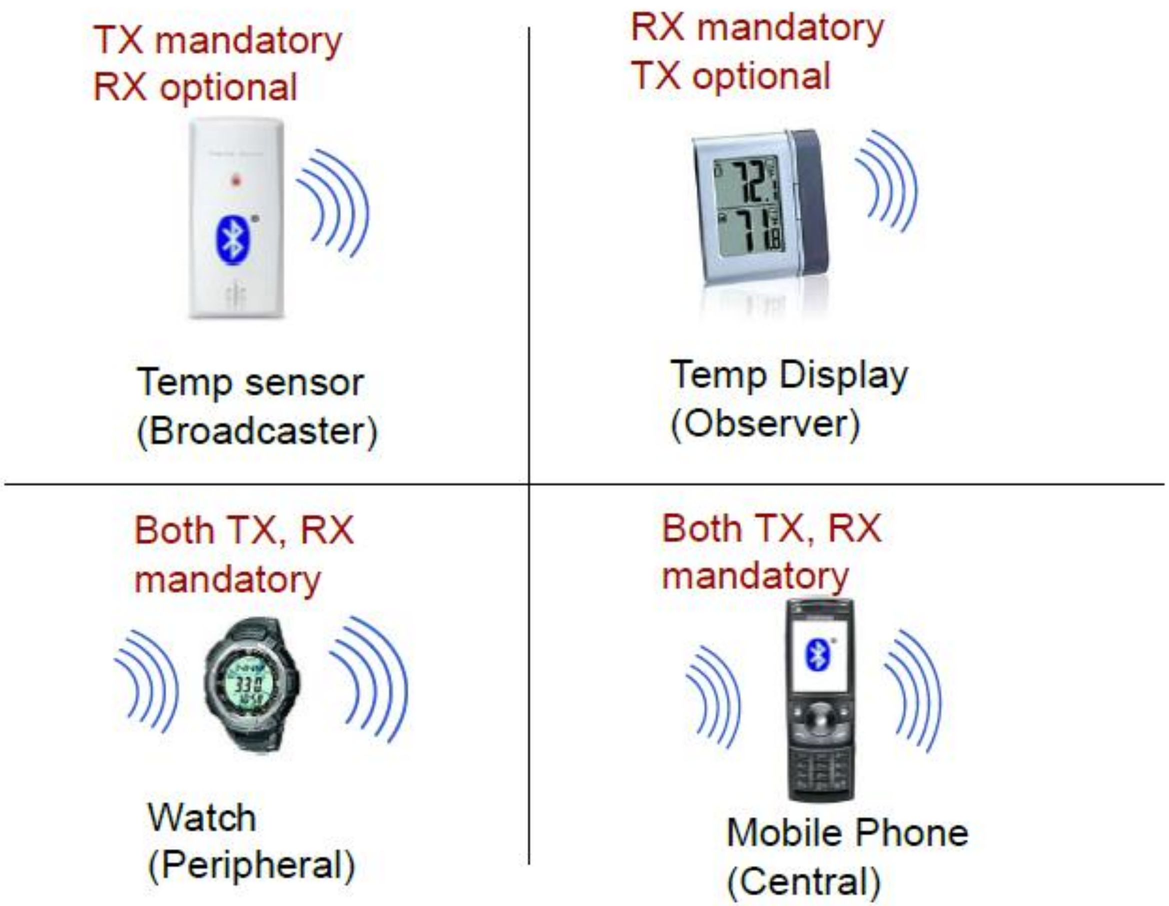
- There are three major components of LE baseline core functionality
- **GAP** –General Access Protocol (Establishing Connections, Advertising Services)
- **GATT** –Generic Attribute Transport (data exchange between high-level services)
- SM –Security Manager (Pairing/Bonding/Authentication and Link Security/Encryption)

GAP

- Extension of existing BR/EDR GAP
- Defines profile **roles** that the devices can take
  - Broadcaster, Observer
  - Peripheral, Central
- Defines the standard ways for devices to connect
  - Discoverable, Connectable, Bonding

Four different profile roles

- Broadcaster, Observer, Peripheral, Central



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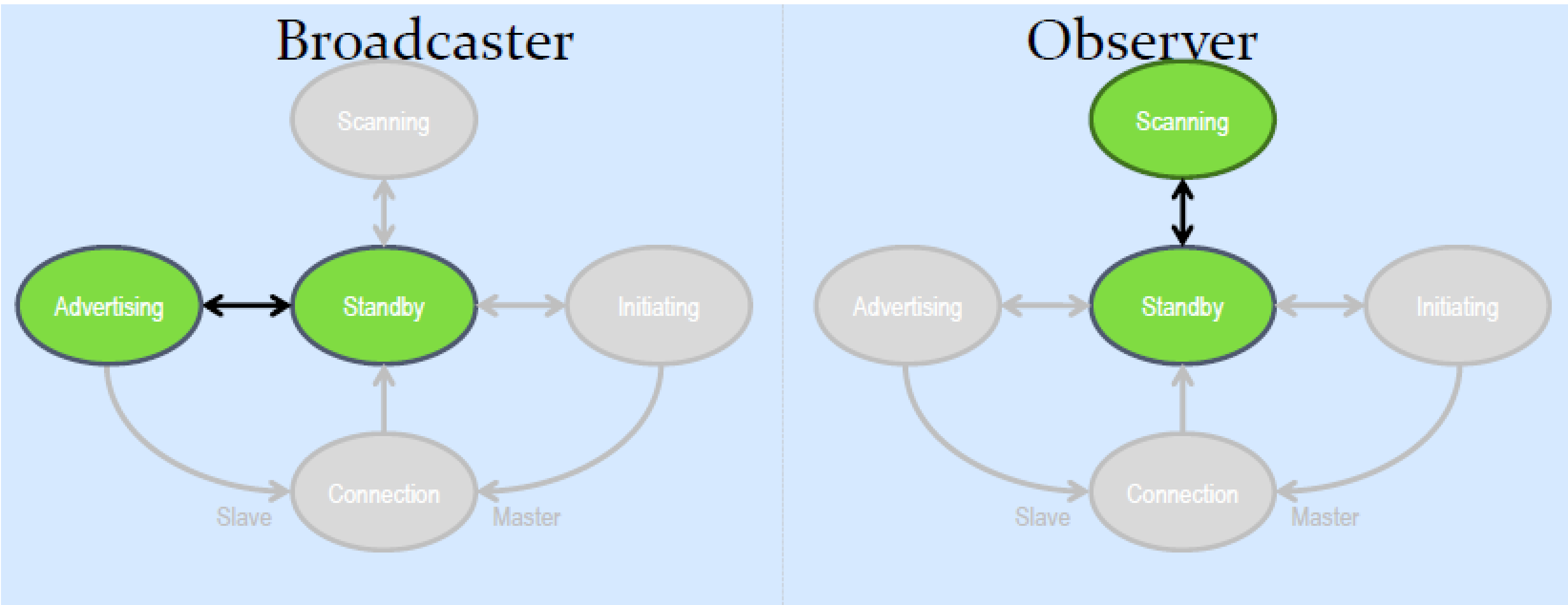
Link layer state machine for Broadcaster and Observer



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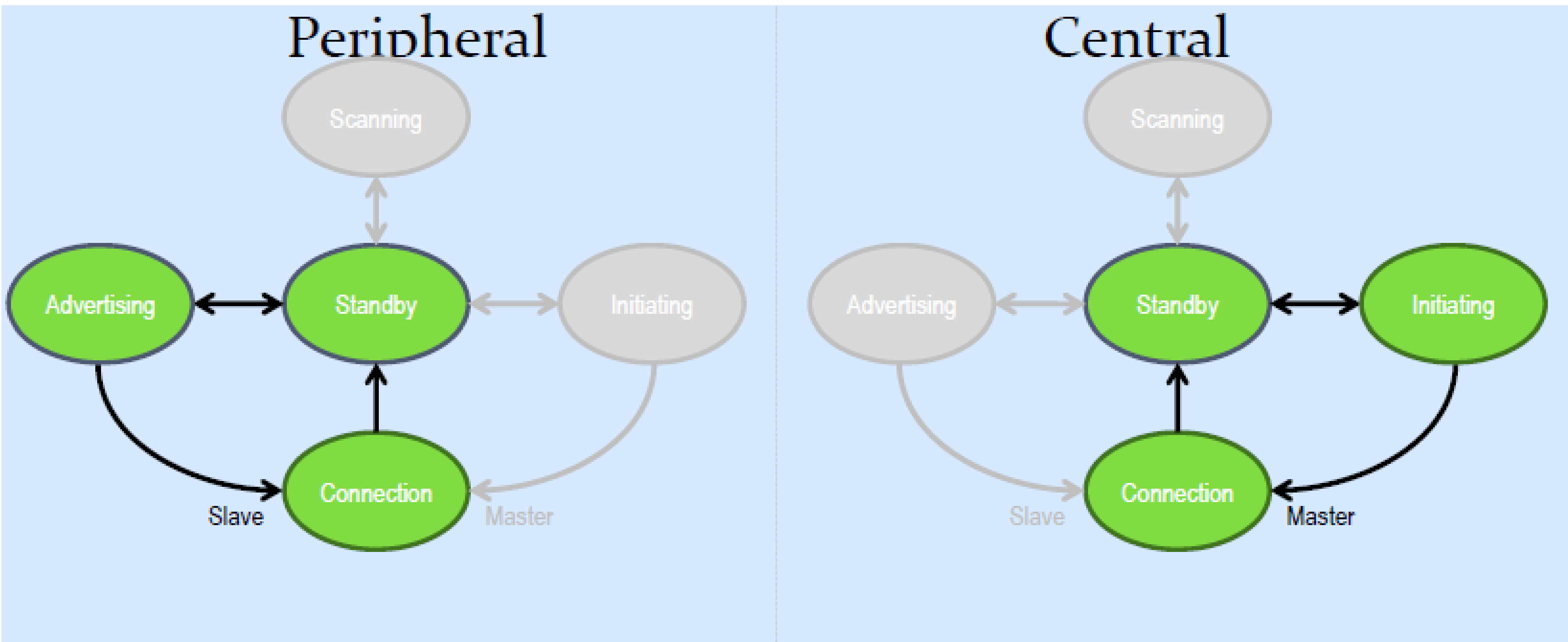
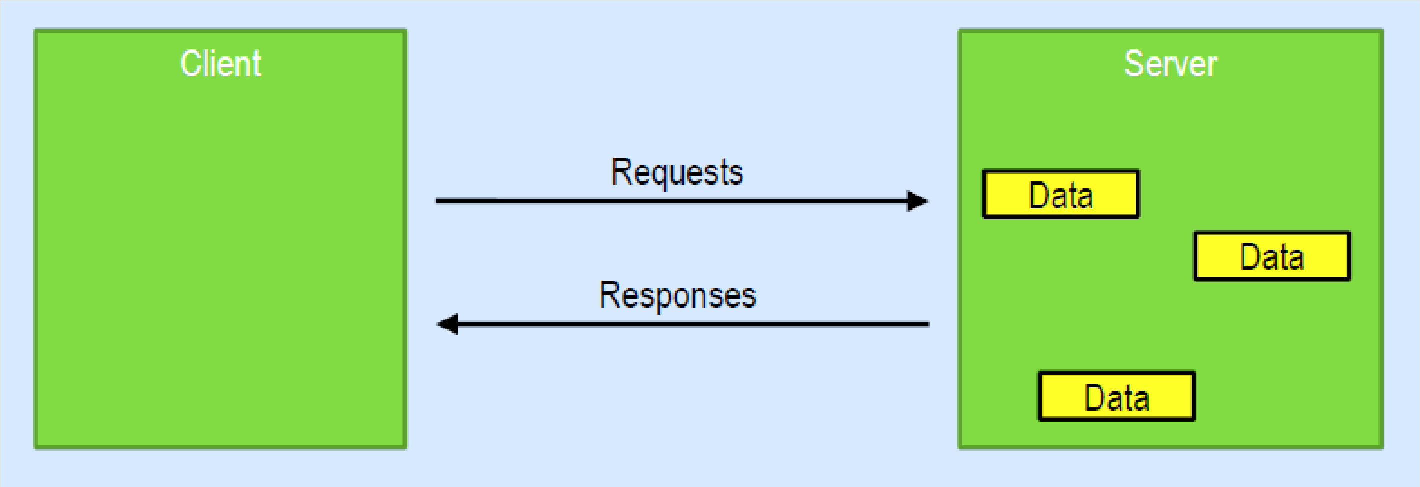
Link layer state machine for Peripheral and Central



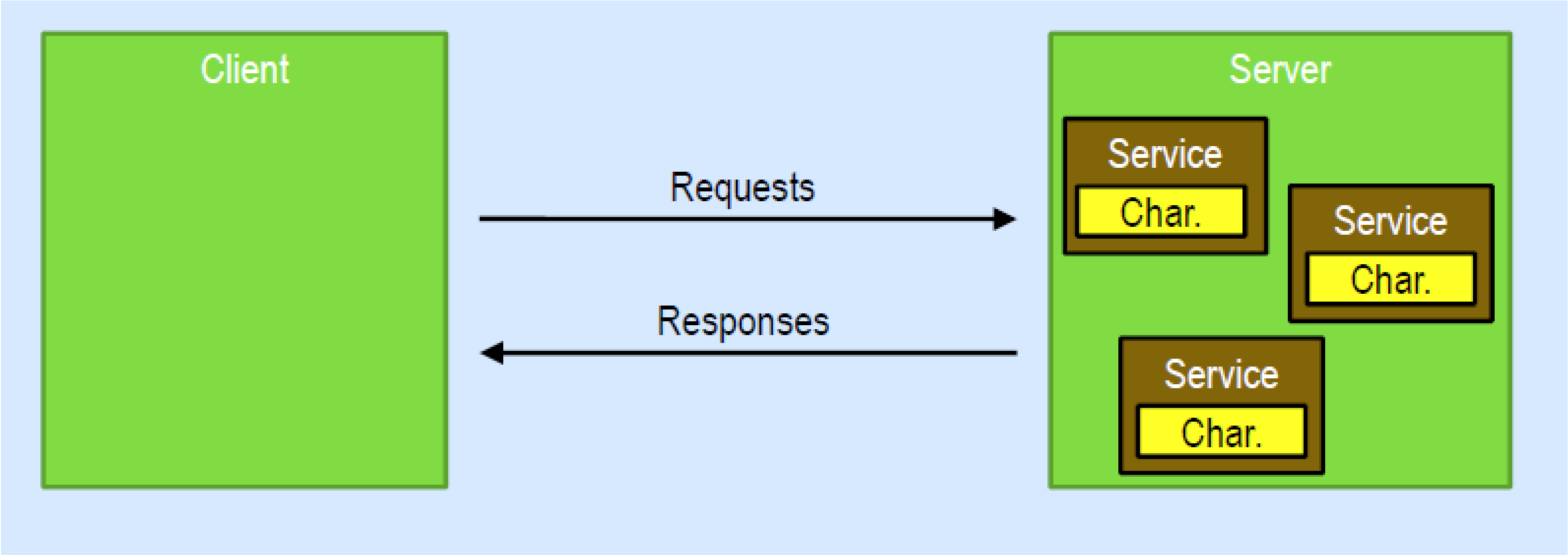
ATT

- ATT (Attribute Protocol)
  - Client Server Architecture
    - servers have data, clients request data to/from servers
    - Servers expose Data using Attributes
  - Protocol Methods
    - request, response, command,
    - notification, indication, confirmation



GATT

- GATT (Generic Attribute Profile)
  - Same client server architecture as Attribute Protocol
    - except that data is encapsulated in “Services”, and data is exposed in “Characteristic”



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BT 4.0 products (Bluetooth Smart Ready)

- Apple releases world's first computers and phone with Bluetooth v4.0
- Nokia N9
- Motorola Droid RAZR
- Samsung Galaxy Nexus







From left to right: iPhone4S, Mac Mini, MacBook Air, New iPad

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BT 4.0 products (Bluetooth Smart)

http://www.bluetooth.com/Pages/Bluetooth-Smart-Devices.aspx

From left to right: Wahoo HR, Polar HR, Dayton and Nordic HR, MOTOACTV, G-Shock

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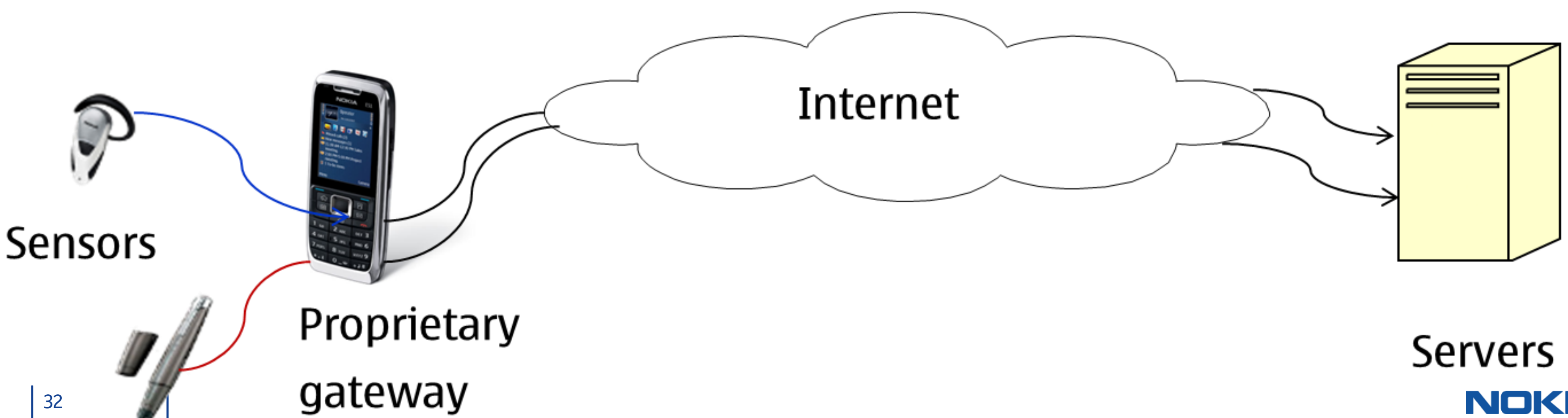
Why IP over BT LE?

- The sensor vendors have to write a specialized gateway application to every phone OS they want to support, and the user will have to install it
- Non-generic gateway solution is not a scalable approach
- Solutions for IPv6 over Wireless PAN (6lowpan) exist, but they do not support BT-LE that is expected to appear in billions of devices and sensors in the next few years



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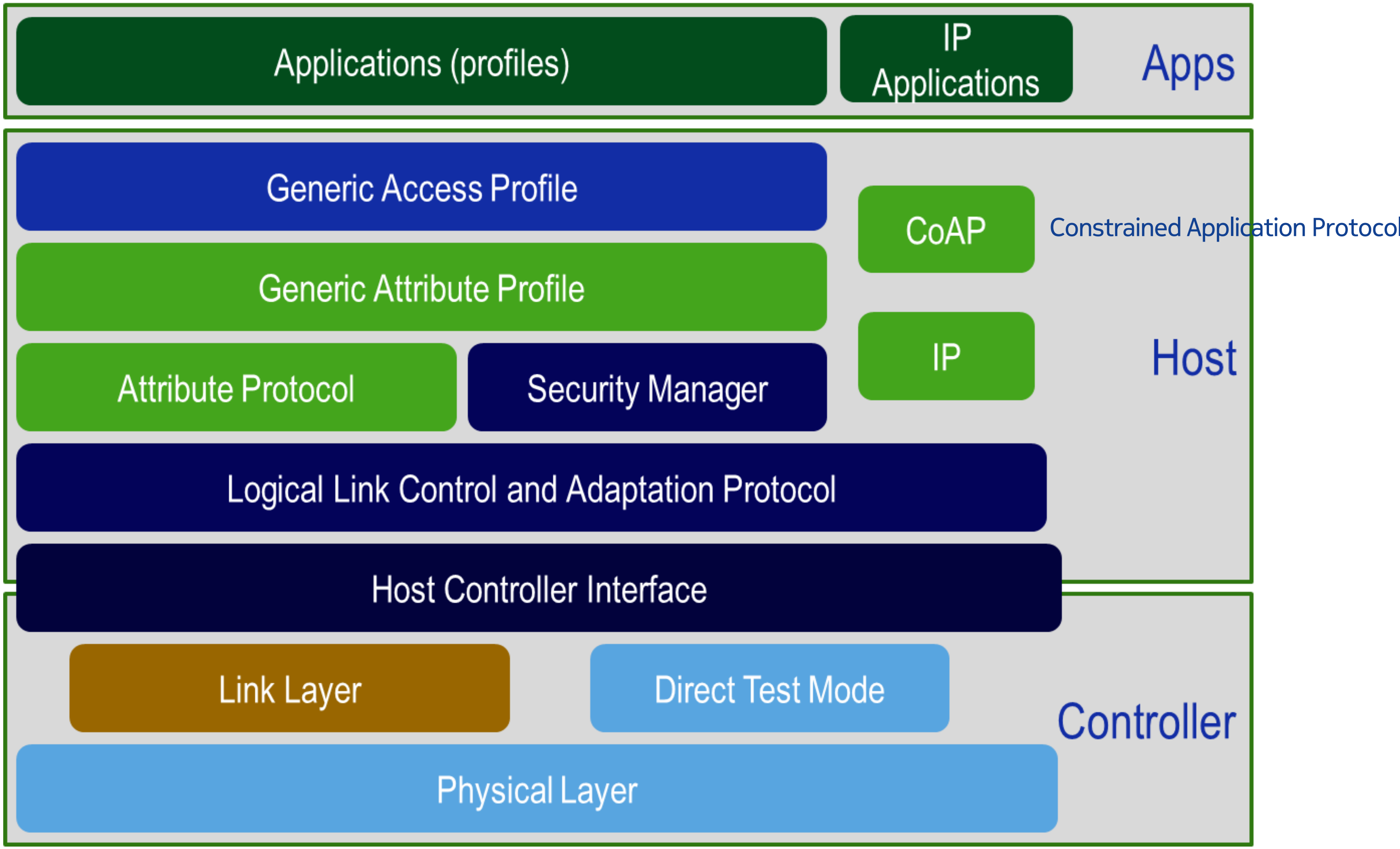
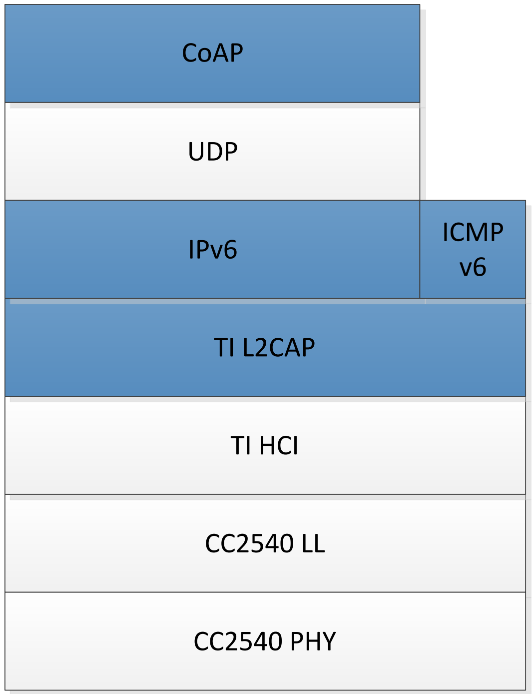
Benefits of e2e IP connectivity

- New (web) application protocols can be introduced without changing the network infrastructure
- Tools for diagnostics, management, and commissioning of IP networks already exist
- In IP-based networks edge routers need no intermediate entities like translation gateways or proxies; instead, they only forward datagrams at the network layer thus do not maintain any application-layer state
- Stateless routers can deliver messages using any number of paths, creating greater redundancy
- …

Stack for IP capable BLE tag/sensor



Networking Stack – sensor side



- L2CAP
  - Implemented L2CAP SAR
- IPv6
  - Light weight
  - 6LoWPAN optimized
  - Based on µIP (part of Contiki)
- ICMPv6
  - Exchange Context Information
- CoAP
  - Based on CoAP in Contiki

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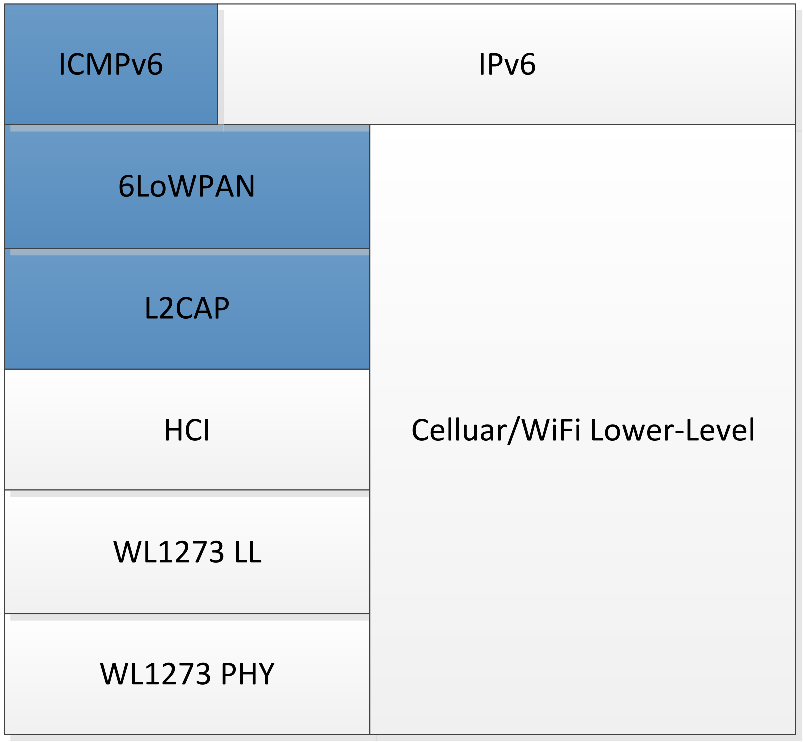
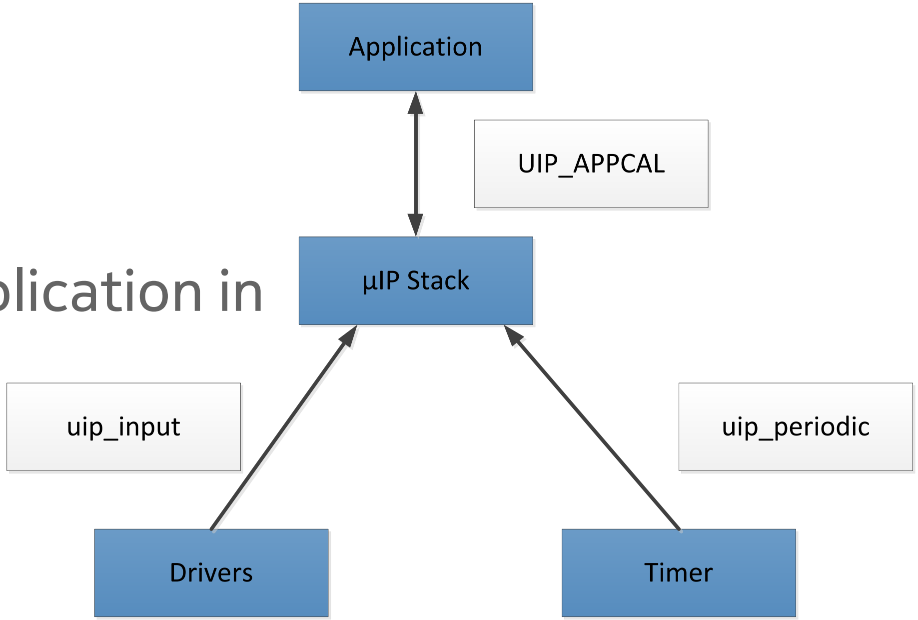
Networking Stack – Phone Side

- L2CAP
  - New CID (0x0007)
  - L2CAP SAR
- 6LoWPAN adapter
  - Context Information management
  - Head Compression/Decompression
- ICMPv6
  - Exchange Context Information between Master and Slave
  - Support 6CO (6LoWPAN Context Option) in RS/RA message



Implementation on CC2540

- Based on µIPv6
- Implement the µIP interfaces to the higher/lower layer
- CoAP
  - Based on "**rest-coap**" application in **Contiki**



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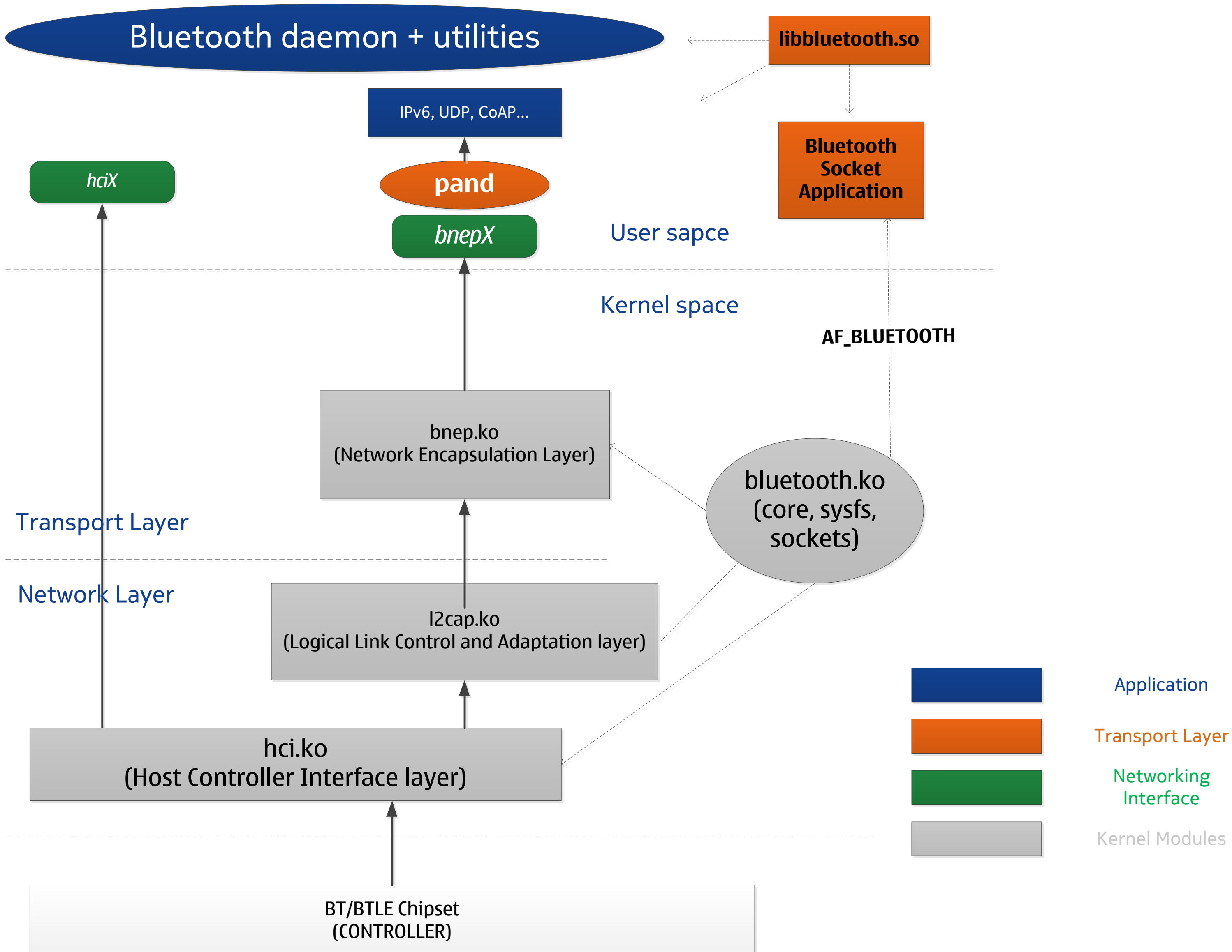
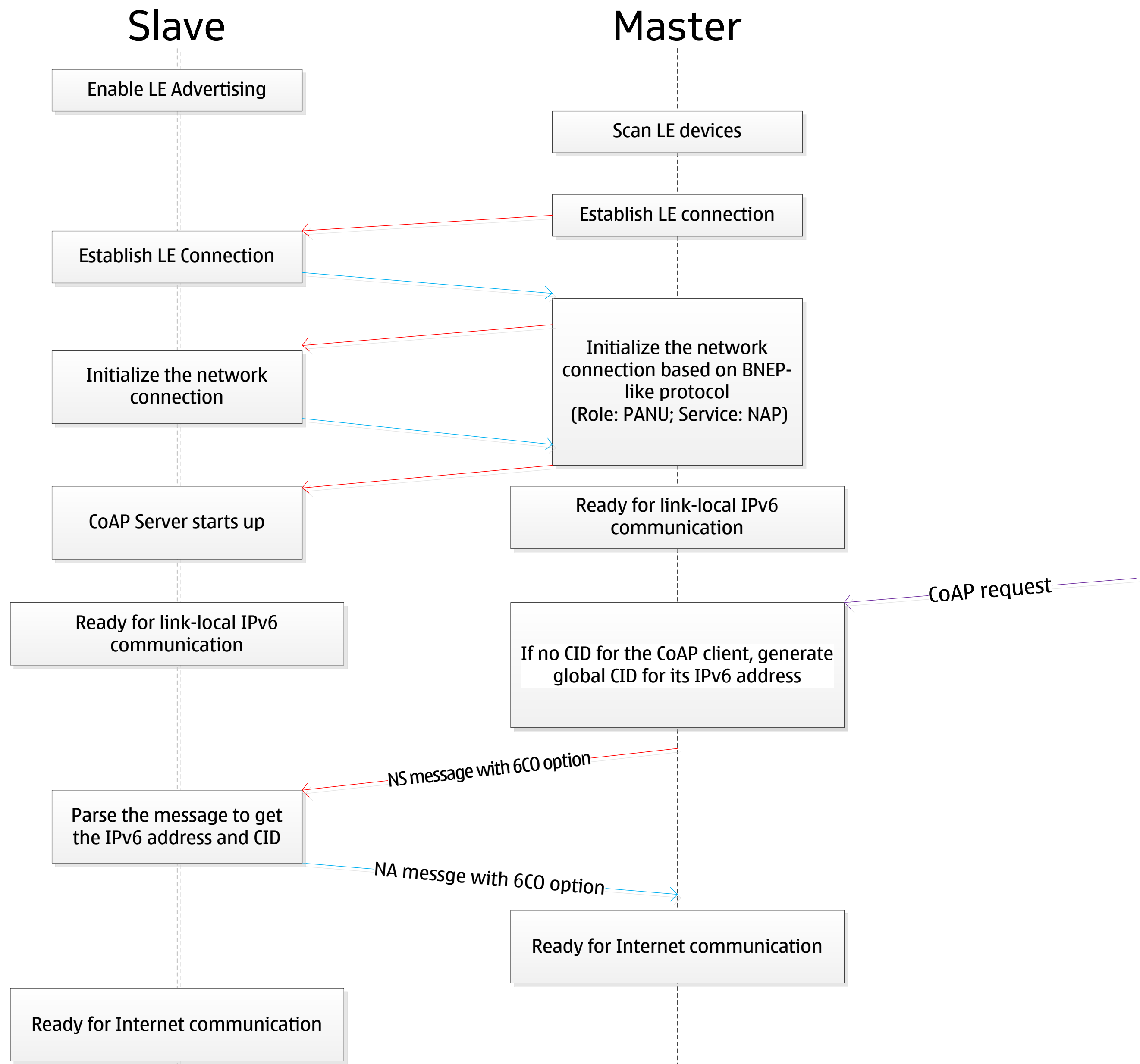
Implementation on N9



IPv6 connectivity setup



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Standardization status

- IETF
  - Defines transmission of IPv6 packets over BTLE
  - http://datatracker.ietf.org/doc/draft-ietf-6lowpan-btle/
  - Draft ver. 06 updated on Mar.6, 2012

- BT SIG
  - On-going in Smart Home BET (Bluetooth Ecosystem Team)
  - Sensor Internet Protocol
    - MRD (Markets Requirements Document), expected Jul.2012
    - FRD (Function Requirements Document), expected Aug.2012
  - Working group will be established after approval
  - Interoperability implementation tests needed!

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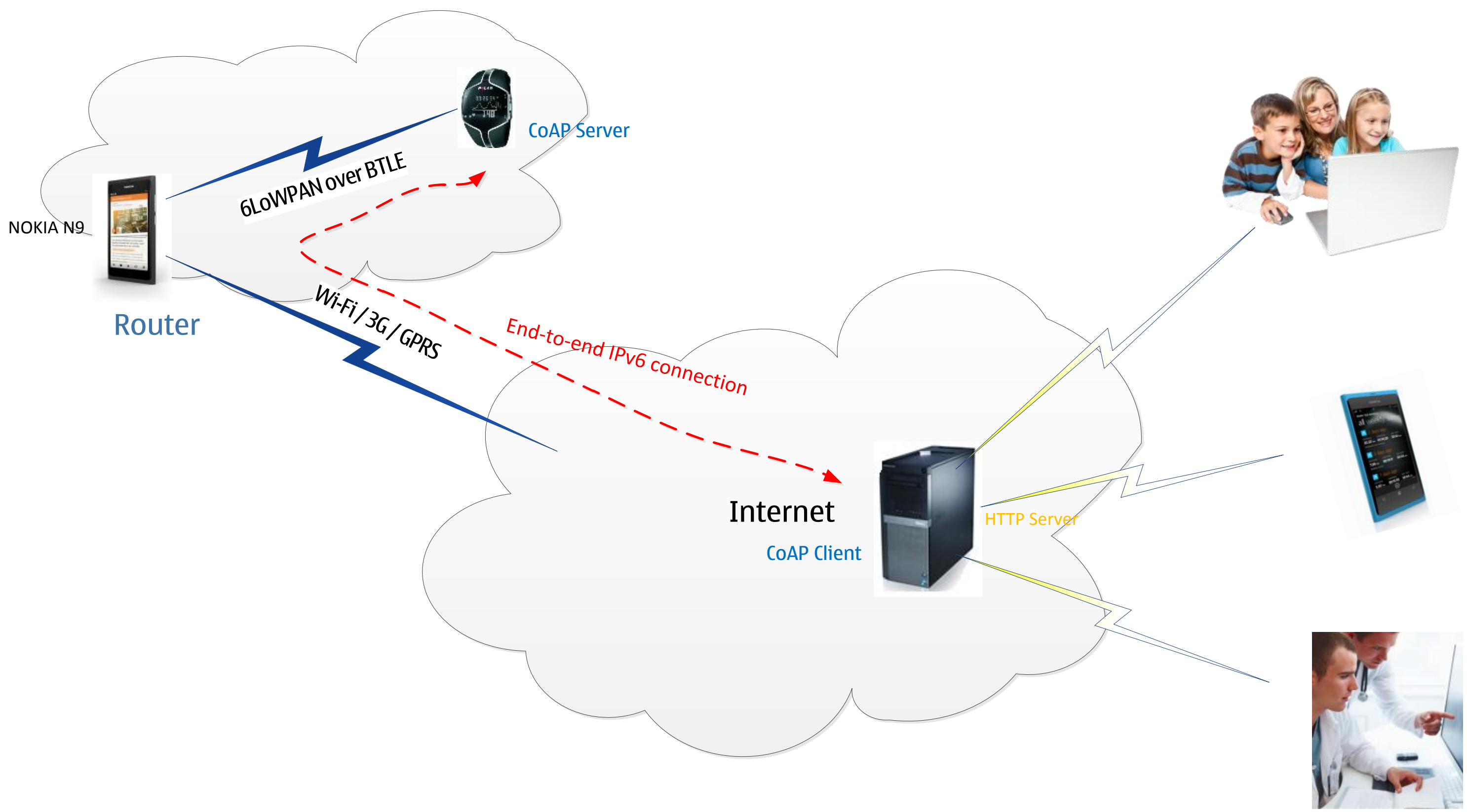
Demo video

- World 1st end-to-end IPv6 capable IoT/WoT app
  - heart rate belt and weight scale



Questions?

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