Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

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Re: [This is the original document.]

Abstract: [This contains the L2R Tutorial Presentation.]

Purpose: [For presentation]

Layer 2 Routing Tutorial

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Aims

- General requirements for L2 routing in Field Area Networks
- Support and use in higher layer protocols – the Internet of Things
- Areas for further study

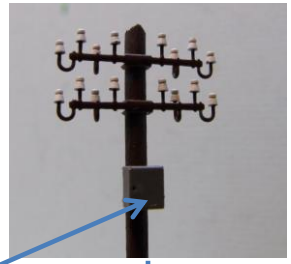
Why do L2 Routing at all?

- Range Extension
  - Why not just shout louder?
  - Technology / Cost / Regulatory / Power consumption
- Data Aggregation
- Robustness & survivability
  - Multiple / Alternative paths
    - Avoid single point of failure
  - Load balancing
    - Avoid choke points in a network
- Appropriateness

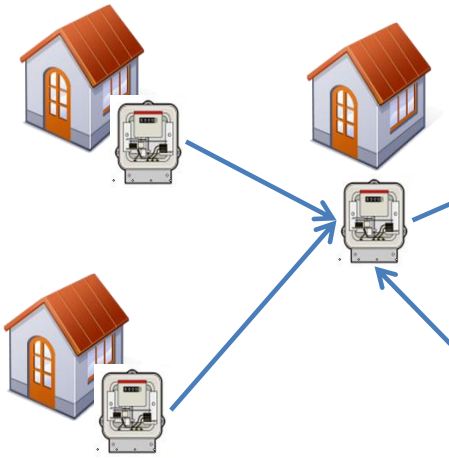
Some Application Use Cases

- Smart Metering (HAN and NAN)
- Smart City
- Environmental Monitoring
- Smart Home

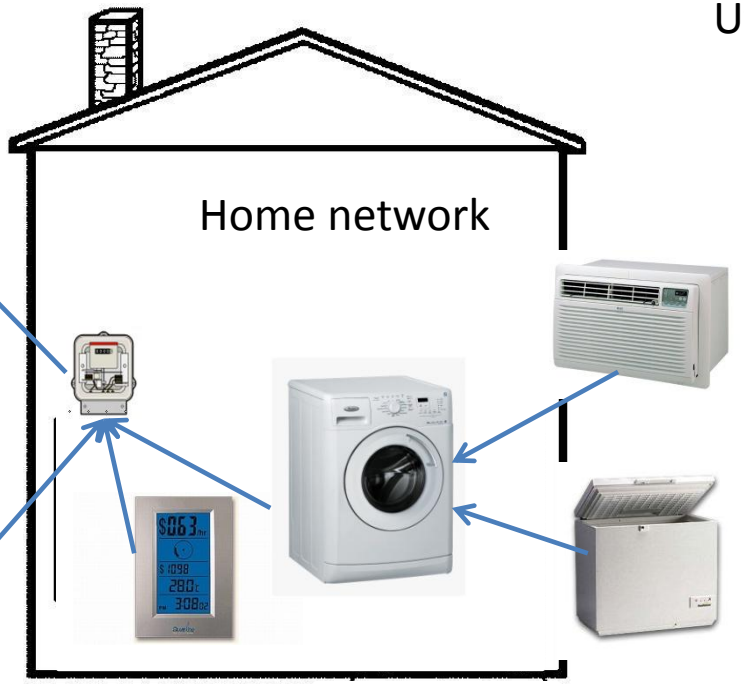
Smart Metering/Energy



Utility backend systems



Neighborhood Area Network

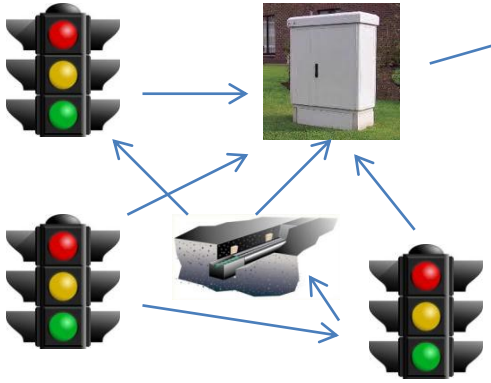


Sleeping gas/water meter

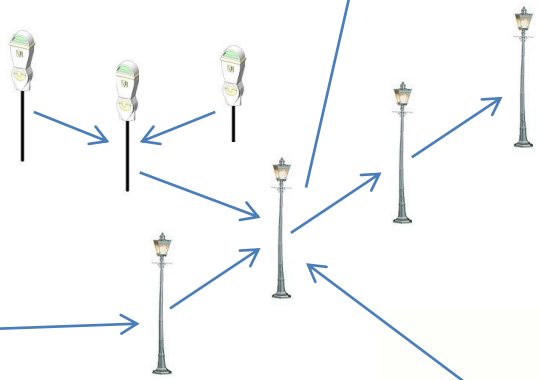
Smart City

Data collection
Aggregation

Control Room



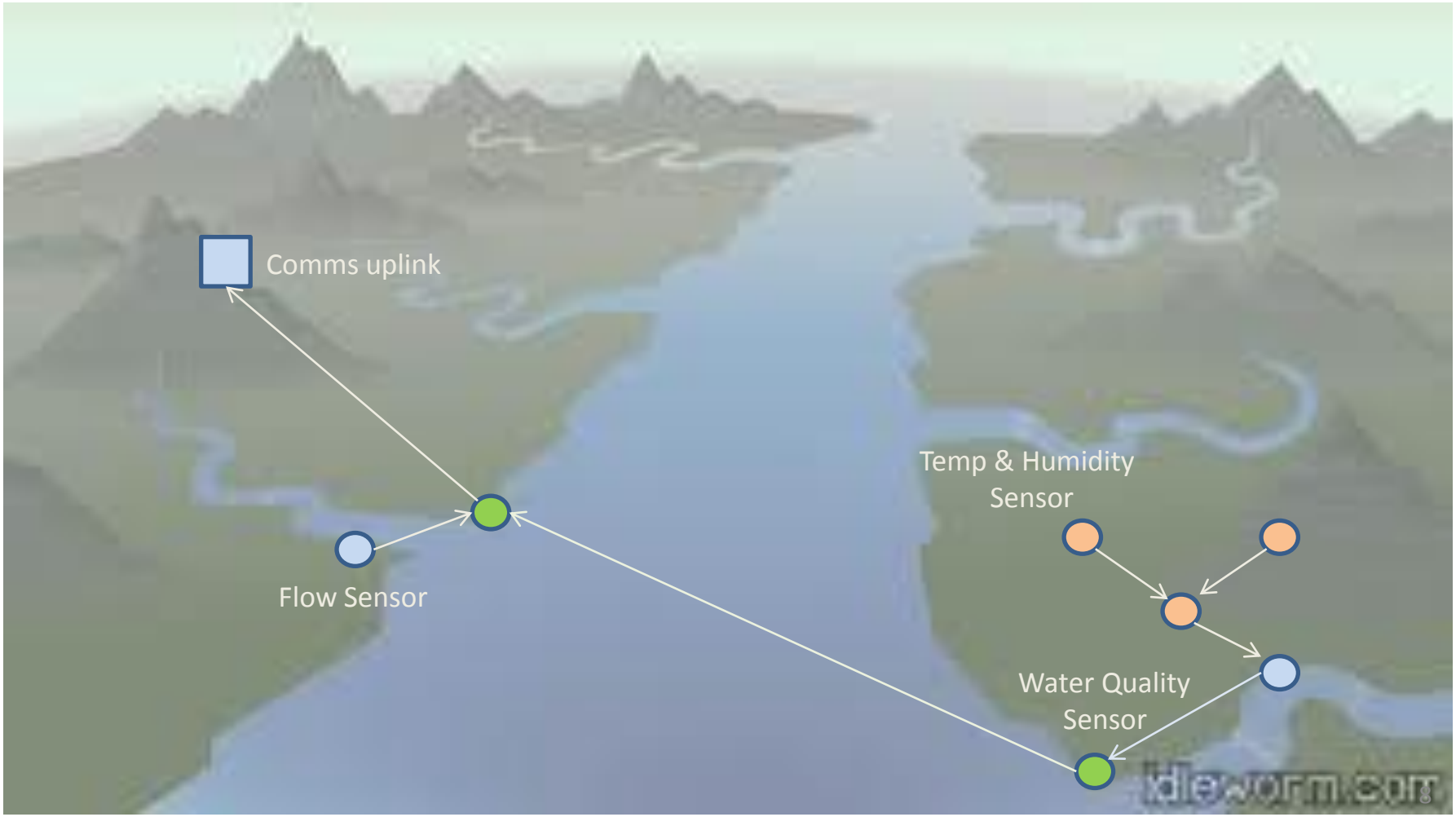
Maintenance
Sensing
Control strategies



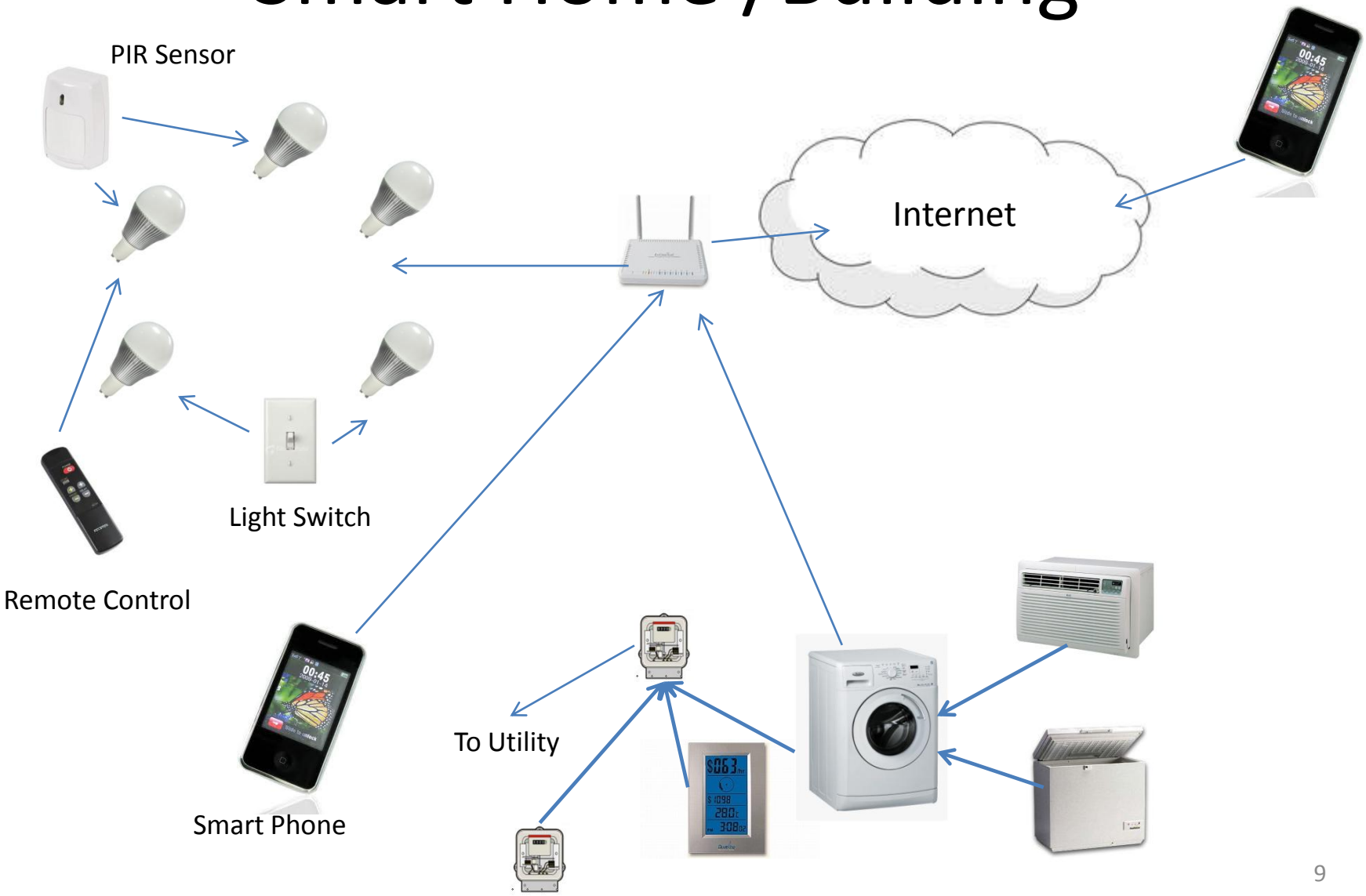
Monitoring
Scheduling

Pollution
Monitoring

Environmental Monitoring



Smart Home /Building



What characteristics do these applications have?

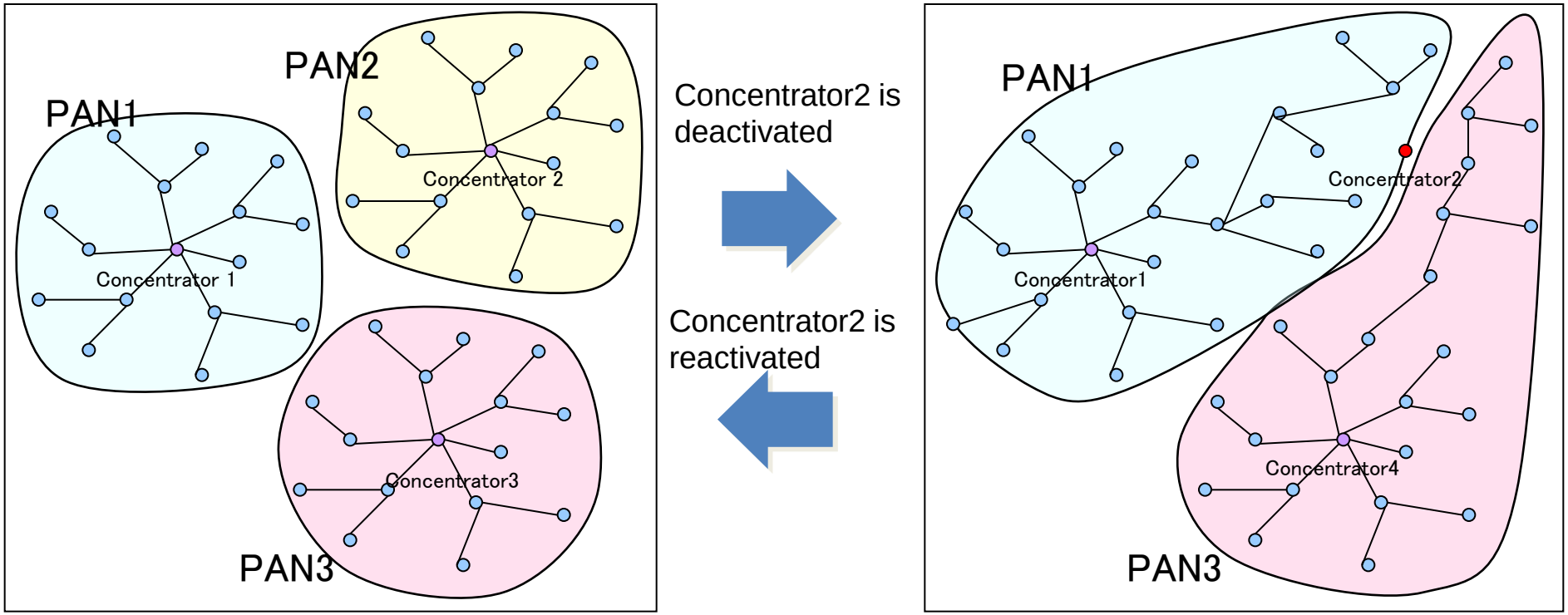
- Data flows
  - One-to-many, Many-to-one
  - Point-to-point
- Topologies
  - Collection tree
  - Mesh
  - Adaptive
- Routing strategies
  - Proactive
  - Reactive
- Management
  - Planned
  - Self Organising
- Communications domains
  - Internal
  - External
    - Multiple ingress/egress points
- Latency vs. QoS vs. reliability
  - Low latency
  - Priority of frames
- Power saving
  - Sleepy end devices
  - Sleepy routers

Other Requirements

- Reliability
  - Reduction of End-to-End retransmissions
  - Failure detection
- Scalability
  - Node density, network size etc.
  - Hardware resource requirements
  - Behaviour at restarts
- Management of flooding, multicasts
  - Timing, grouping etc.
- Congestion avoidance, flow control, Load balancing
- Security
  - Provisioning, Joining

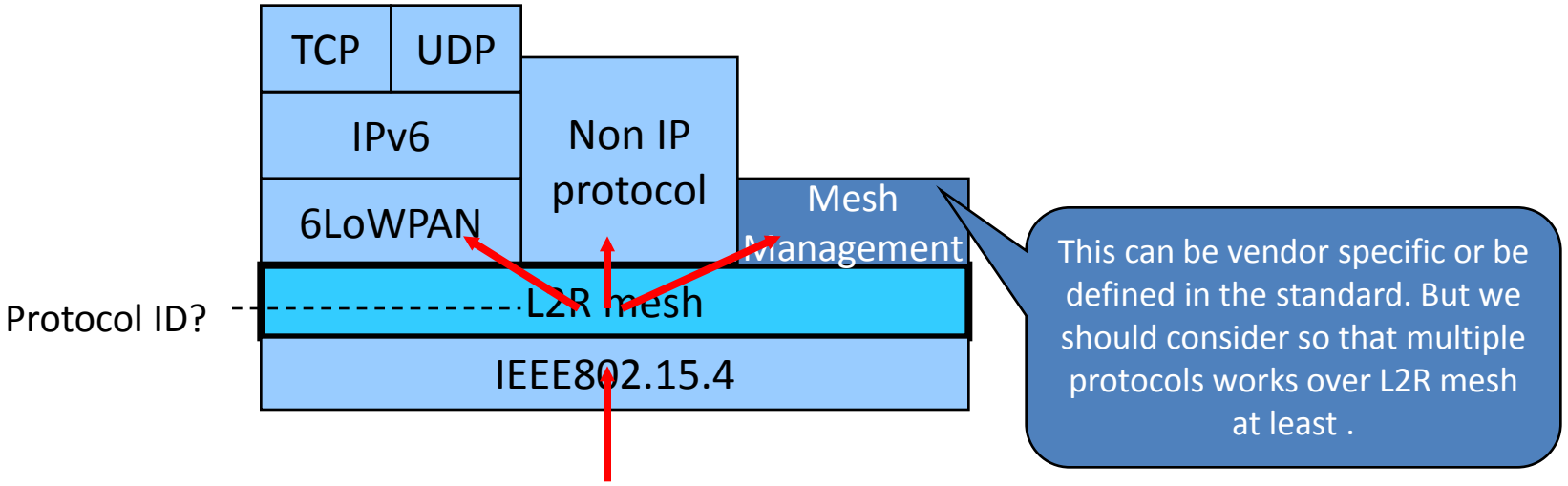
An example scenario for managing FAN

- Network should be configurable and work automatically.
- Less cost repairing process will be required when the network has problem.
- After the problem has gone, network should be reformed (maybe to almost original) to reduce the load.



Multiple Upper-layer Protocols

- Ethernet allows multiple protocols to work on it.
- 802.15.4 does not have an ethertype field
- It may be possible for the L2 mesh protocol to provide this feature
- To distinguish between protocols, it will be necessary to allocate a Protocol ID.



What is Available at Present

- IEEE 802.15.5 Mesh Topology
  - Mesh formation, routing & maintenance
  - Multicast transmission and group management
  - Reliable broadcast
  - Low power operation (sync/async)
- IETF RPL
  - Route-over solution at Layer 3
- Various proprietary routing protocols
  - Meshes, trees, ad-hoc

Specific Example in more detail:

Layer 2 Forwarding in Embedded IP networks

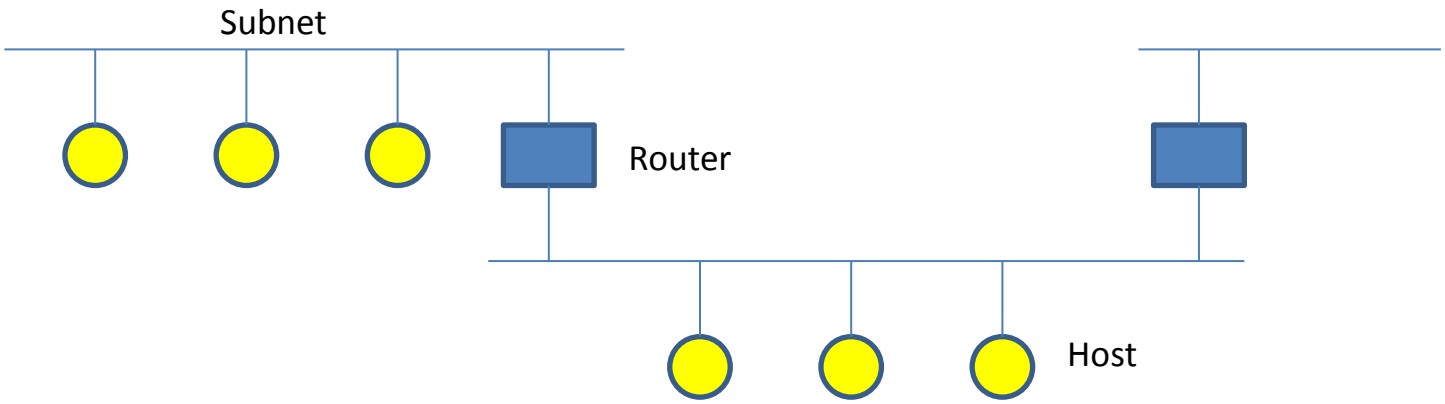
(Internet of Things)

The Internet of Things

- Aim to connect many billions of devices to the internet and each other
  - Enables finer control of processes
  - Enable new synergies between systems
  - Enable new applications and improve old ones
  - Its really cool to be able to control things from my phone
- Enabling communications to devices on this scale must be small fraction of overall cost to be viable
  - Wireless device eg 802.15.4, Bluetooth etc
- But we still want to use the tried and tested protocols used on the Internet
- Specifically, need to use IPv6 to cope with the expected volume of devices

Internet Protocol (IP)

- Underlying Model for Internet Protocol
  - A number of networks connected by routers (ie inter-networking)
  - Each network contains a number of hosts
  - Hosts can talk directly to:
    - any other host on the same network (subnet)
    - the router(s) which connect this network to other(s)
  - Eg think ethernet segments



Addressing and Scope

- Reason for using IPv6
  - Public IPv4 addresses are already exhausted
    - We keep going by using Network Address & Port Translation and private network addresses (eg 192.168.0.x)
    - Creates complications when trying to communicate with devices inside a private network from outside
  - 128-bit addresses
    - Not expected to run out in the near future, even with billions of devices
  - Devices can have multiple IP addresses
    - Leads to concept of scoping
- Address Scope
  - Link-local scope is defined as addresses within a subnet
  - Global scope means an address is globally reachable
  - Link-local scope and multicast are important in the mechanisms used to distribute information within subnets
    - Router advertisement and solicitation

IP Routing in Multi-hop Networks

- Classic IP uses IP addresses to perform the routing between hosts on different subnets
- Mechanisms (eg Neighbor Discovery) designed with the assumption that IP multicast will work over link-local scope
- But this simple model breaks down if the underlying media doesn't allow all hosts in a subnet to see each other (eg wireless)
  - In this case we need some way to connect the hosts in a subnet together – more routing
- Two methods can be used
  - Route-Over (L3 or IP routing)
  - Mesh-Under (L2 routing)
- Each has slightly different characteristics

Route-over

- Treats each host as a router in an independent subnet
  - Each hop to the destination is an IP transfer
  - Therefore it looks like the message is going from one router between subnet to the next
- Problems with Route-over
  - Breaks lots of things
    - Difficult to define the scope of message
    - Link-local is no longer equivalent to “my segment”
  - Efficiency issues

Mesh-under

- Use L2 routing to connect devices in the subnet
- Multiple L2 hops are transparent to L3
- IP packet transfers from (Border) router is one IP hop
  - IP hop count controlling a packet's Time-To-Live is still sensible
  - Media boundary (eg Wireless PAN) is link local scope
  - Maintains appearance of "ethernet like" network
- Things just work
  - Multicast can be dealt with at L2

IP over “Foo”

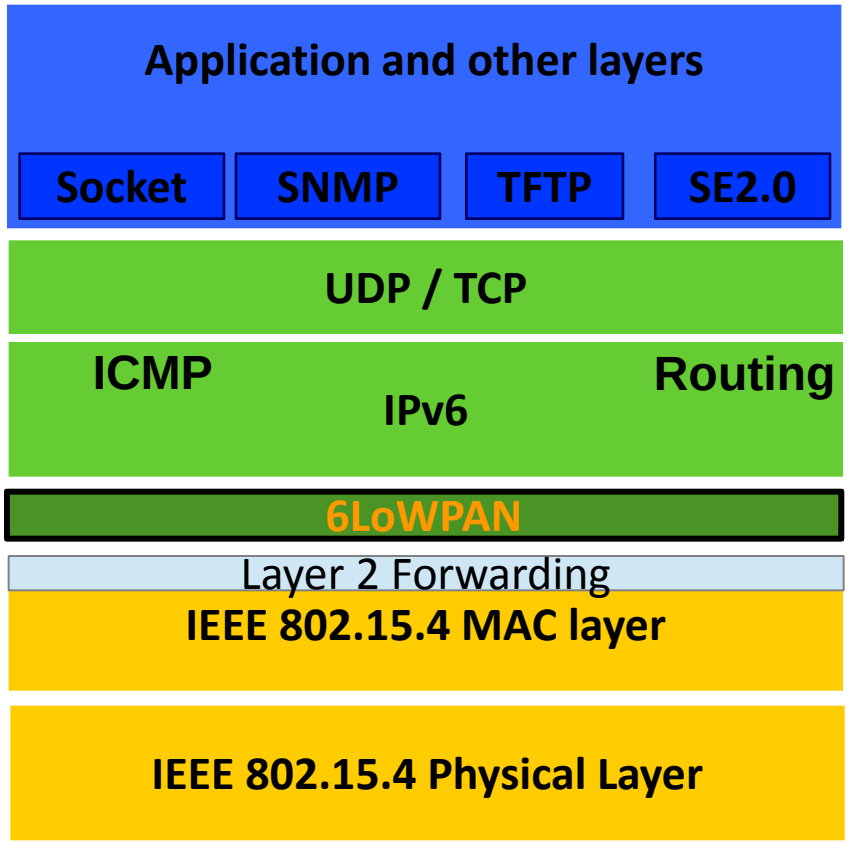
- Many RFCs describe how to adapt IP to specific media
- RFC 4944 and RFC 6282 describe adapting IPv6 to 802.15.4 (2006)
- Required to make the media appear to be “ethernet like”

6Lowpan is a mechanism
to fit IPv6 into small data frames
and
improve transmission efficiency

6LoWPAN and 15.4

- When started, it was assumed that 6LoWPAN would sit on top of an "ethernet-like" service
  - All nodes are one IP hop away
  - Like ethernet and like 802.11
  - No IEEE mesh standard available when effort started (2005)
  - Support for mesh added in the form of a mesh header to 6LoWPAN
- RFC 4919 defines the architecture of "forwarding at the link layer"

An Embedded Stack

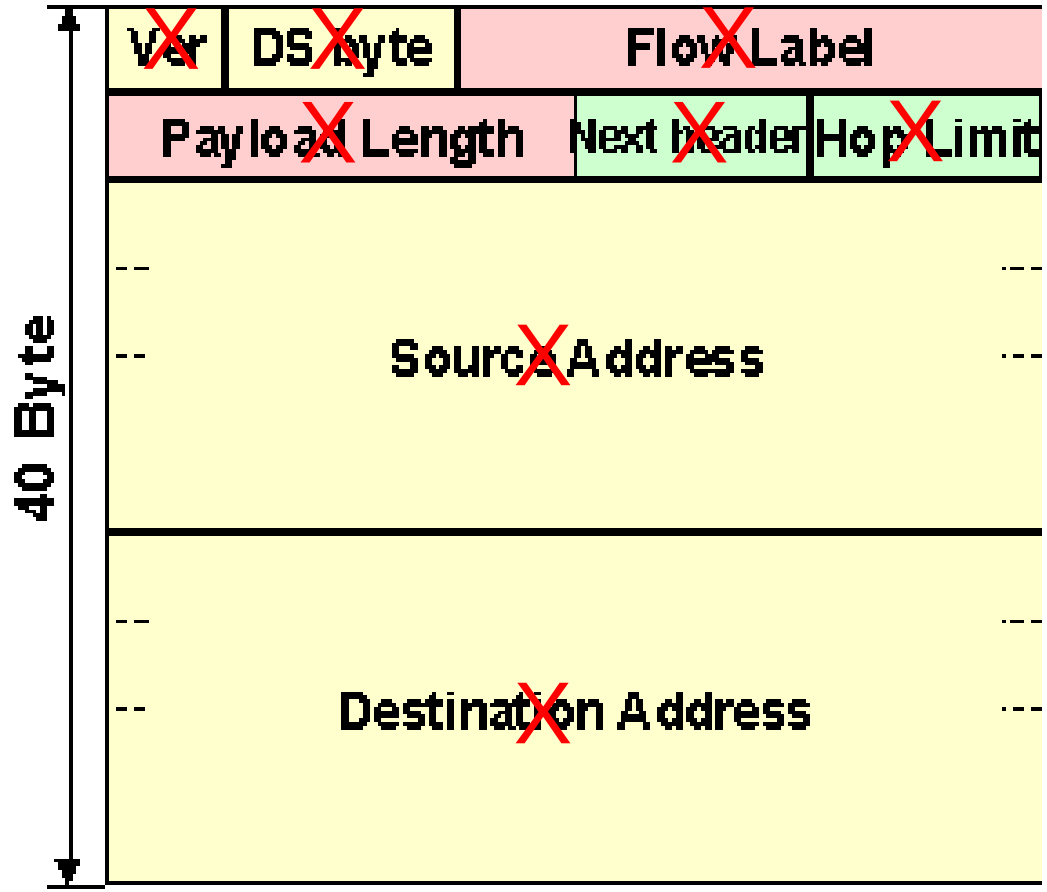


- Stack size < 20K
- RAM size < 4K
- Requires minimal MAC support
- Multiple Implementations
  - Open Source – Contiki/TOS
  - Atmel
  - Sensinode
  - Freescale
  - TI
  - ST Micro

How 6LoWPAN Works

- Stackable headers
  - Stolen from IPv6
- “Pay” only for what you use
  - Only 3 bytes for compressed IPv6 header
  - Only include mesh or fragmentation header if needed
- Extensible dispatch byte
- Defined in RFCs 4944 and 6282
- Fragmentation of IP packets into 15.4 payloads
  - IPv6 has minimum 1280 byte packets

6LoWPAN Compression



IPv6 Neighbor Discovery

- Replaced ARP and DHCP (sort of) from IPv4
  - Neighbor Advertisement & Solicitation
  - DHCP not needed for IP address allocation
    - Can still be used for default route and subnet
- Adds additional functionality
  - Stateless Address AutoConfiguration (SLAAC)
  - Router Identification
    - Router Advertisement & Solicitation
  - Duplicate Address Detection
- Problems with ND for low bandwidth networks
- Problems with 6lowpan ND
  - If you don't have link local scope / ethernet behaviour / m'cast you have to do something special - 6LoWPAN-ND
  - Finally published as RFC 6775 last week after 4yrs and 22 drafts
  - Some optimisations are useful for both R-O and M-U

Why L2 Routing

- Simplifies higher layers – doesn't break IP
- Provides for hierarchical architecture
- Can better fit to idiosyncrasies of link
- Might provide improved performance
  - Remember fragmentation?
  - Each IP packet has to be fragmented at source and reassembled at destination
  - With Route-over solution this is every hop
  - With Mesh-under this only happens at the source and destination nodes – otherwise we just forward and route L2 packets
  - But it may not be as big a problem with the introduction of big L2 packets
- Could provide more efficient multicast

Required Functionality

- Efficient multicasting
- Hierarchy of devices
- Multihop security

Layer 2 in 802.15

- IETF deals with the Internet
  - Layer 3 and above
  - Not networks or links
- IEEE appears to be the most appropriate place

Issues

- Do we really need multicasting?
- Really? Battery powered routers? Really!
- Rapid connectivity changes
- Wireless is not wired
- Are all nodes in the mesh in a single IP subnet?
- Making use of 6lowpan mesh header
- What functions of the MAC do we require (join)?

IEEE Layer 2 Forwarding

- If it was available it would have been used in 6LoWPAN from the start
- When it is available we will use it.

Things to look at

- Efficient multicast at L2
- Leveraging recent MAC improvements
  - Information elements to carry routing information
  - Synchronisation mechanisms for low duty cycle (sleeping) networks
- Security in the mesh
  - Securing multicast
  - Network security
- Bridging
  - Cross Media bridging
  - Bridging between similar protocols (eg 4g & 4m)