[Telecommunications Research Center Vienna]

Network-Growing Scenarios in IEEE 802.15.4 Wireless Sensor Networks

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Motivation

Future WSN networks will be conglomerates of networks supporting multiple applications. Networks and applications will need to coexist, merge and split.

Question

- How current standards support dynamic self-organization in presence of multiple networks and multiple applications?
  - "Network growing scenarios"

Focus

- IEEE 802.15.4 PHY and MAC is a multi-optional standard for low rate wireless sensor networks (LR-WSN).
- Network and Application Layer proposed by ZigBee Alliance.

Network Growing Scenarios

Network growing refers to adding new networks and new applications in the common field.

- Networks may be
  - beacon-controlled trees or non-beacon meshes
- Nodes may be
  - Full functional devices (FFD), i.e., routers and coordinators implementing the complete protocol set, and Reduced functionality devices (RFD), operating with a minimal implementation of the IEEE 802.15.4 protocol.
  - Static or mobile.
  - Data sources, data relays, data sinks.

Functionality

IEEE 802.15.4 PHY and MAC

- Star or peer-to-peer operation
- Allocated 16 bit short or 64 bit extended addresses
- Allocation of guaranteed time slots (GTSs)
- Carrier sense multiple access /collision avoidance (CSMA-CA)
- Fully acknowledged protocol for transfer reliability
- Energy detection (ED) and Link quality indication (LQI)
- 16 channels in the 2450 MHz band, 10 channels in the 915 MHz band, and 1 channel in the 868 MHz band
- Data rates of 250 kb/s, 40 kb/s, and 20 kb/s

Network Layer proposed by ZigBee Alliance

- Starting a network, joining, leaving a network
- Neighbor discovery, route discovery, routing
- Duty Cycle control

Application Layer proposed by ZigBee Alliance

- Device and Service discovery
- Application level binding
- ...

Networks and Applications

In ZigBee standard network formation and discovery does not account for node resources or application-specific configuration. Is this optimal for applications?

- Architecture artifacts
  - Personal Area Network includes end-devices, routers and coordinators.
    - PAN Coordinator is a principal controller of a personal area network (PAN). An IEEE 802.15.4 network has exactly one PAN coordinator, alternative PAN coordinator may be present.
    - Coordinator is a full-function device (FFD) that transmits beacons for synchronization.
  - Applications
    - Deployed as application objects at the “end points” in nodes.
    - Specified by application profiles and input and output clusters
      - Clusters are source and sink data attributes
    - Involve data dissemination from the input clusters to the output clusters.

Joining a WPAN

Beacon-controlled NET

- Superframe structure
- CSMA/CA & GTS

Neighbor/NET Discovery

- Passive Scan
  - Receive beacons
  - Select PANId
  - Associate with PAN
- Active Scan
  - Send beacon
  - Receive responses
  - Select PANId
  - Associate with PAN

    or
  - Start new PAN

Non-beacon controlled

- CSMA/CA

Neighbor/NET Discovery

- Snoop on packets
- Select PANId
- Send network join

  or
- Start new network

Routing and Binding

Cluster Tree Routing

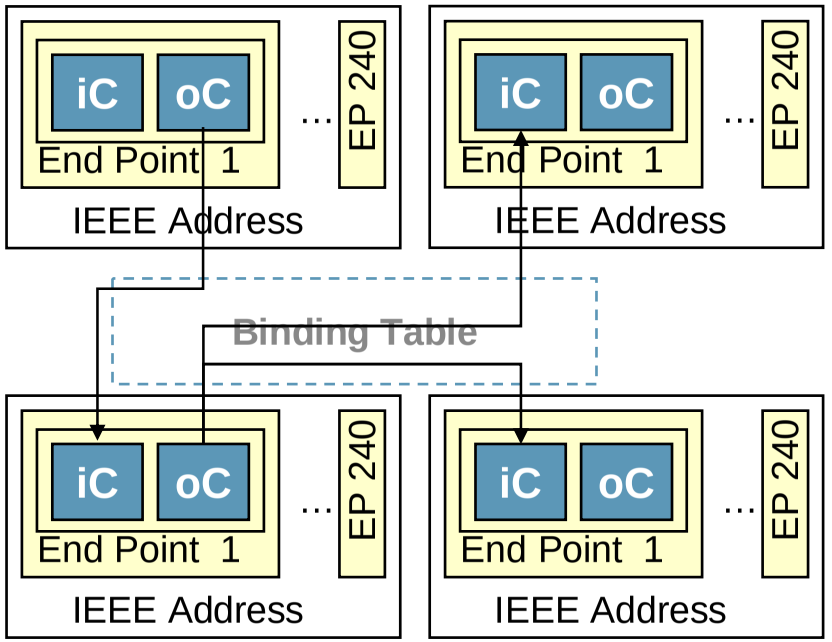
- A network is organized in a tree
- Data between two nodes in different branches travels up the tree to the first common parent and than down the tree.

Mesh Routing

- Routing with on Demand Route Discovery

Binding

- End-device forwards data to a coordinator that has a binding table.
- Data forwarded according to the bounding table.



Network Growing Scenarios

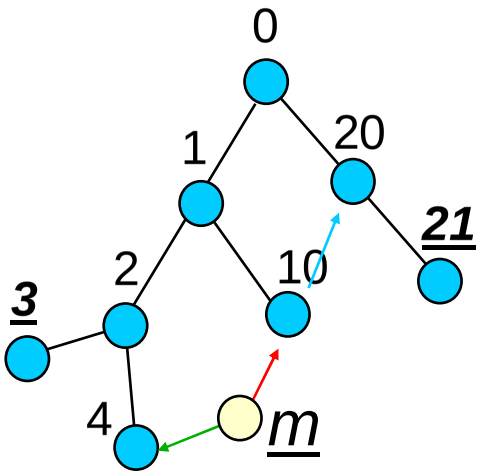
We evaluate the network formation mechanisms in the context of network growing scenarios:

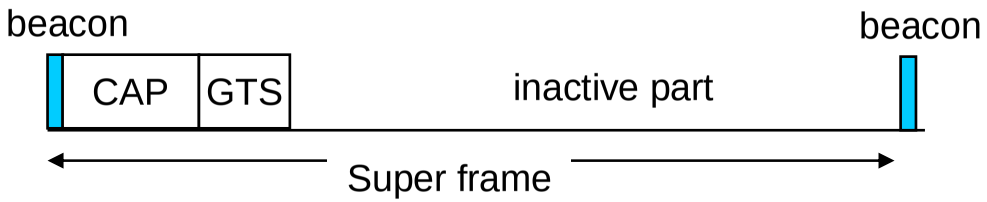
- Infrastructure Extension Scenario
  - One infrastructure, one application, new nodes added
- Infrastructure Collaborative Sharing
  - Separate applications and infrastructures, application aware sharing needed
- Application-aware Self-Organization
  - Many applications, self-configurable infrastructure

Network Extension Scenario

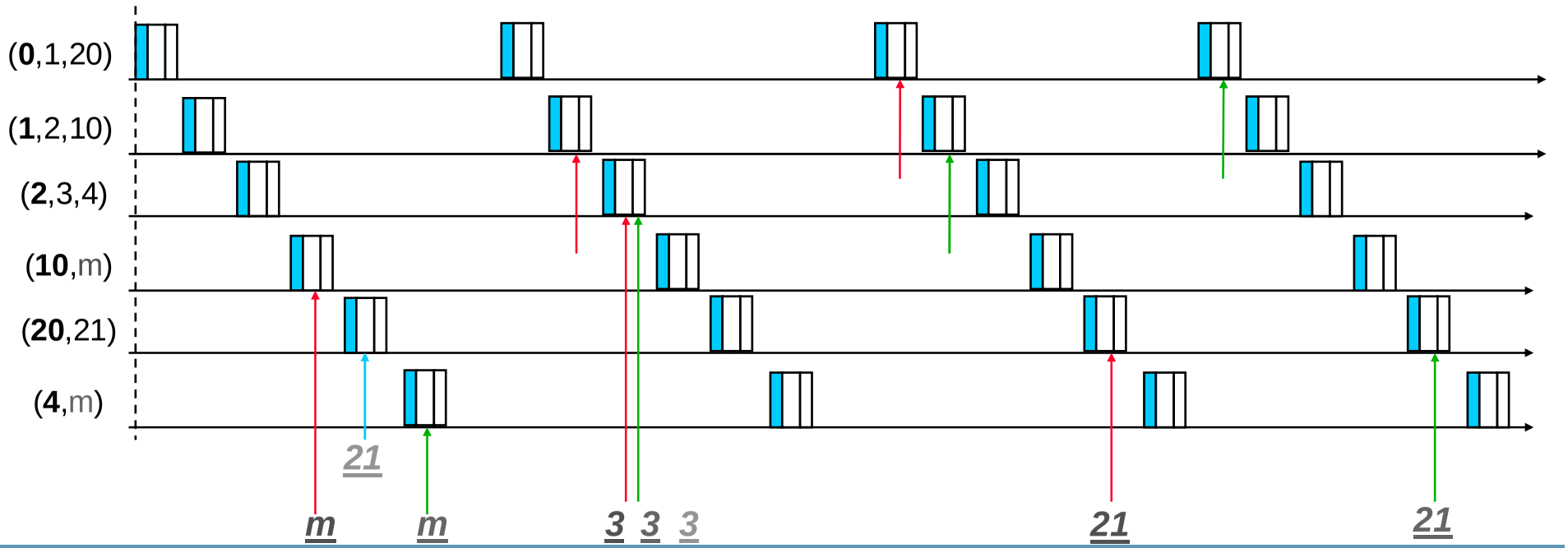
- Example: New sensor and sink nodes are added to the existing network (WPAN1) which supports one existing application AP1.
- Assumptions
  - There is a mapping WPAN1 – AP1 : all resources of WPAN1 support the application AP1.
- Challenge
  - A node shall joint at the most appropriate place in the existing topology
- Considered Behavior
  - Neighbor discovery, joining a tree or a mesh
- Question
  - What additional neighborhood, or application information is needed? Discovery of input clusters, output clusters?

Joining a Tree Example

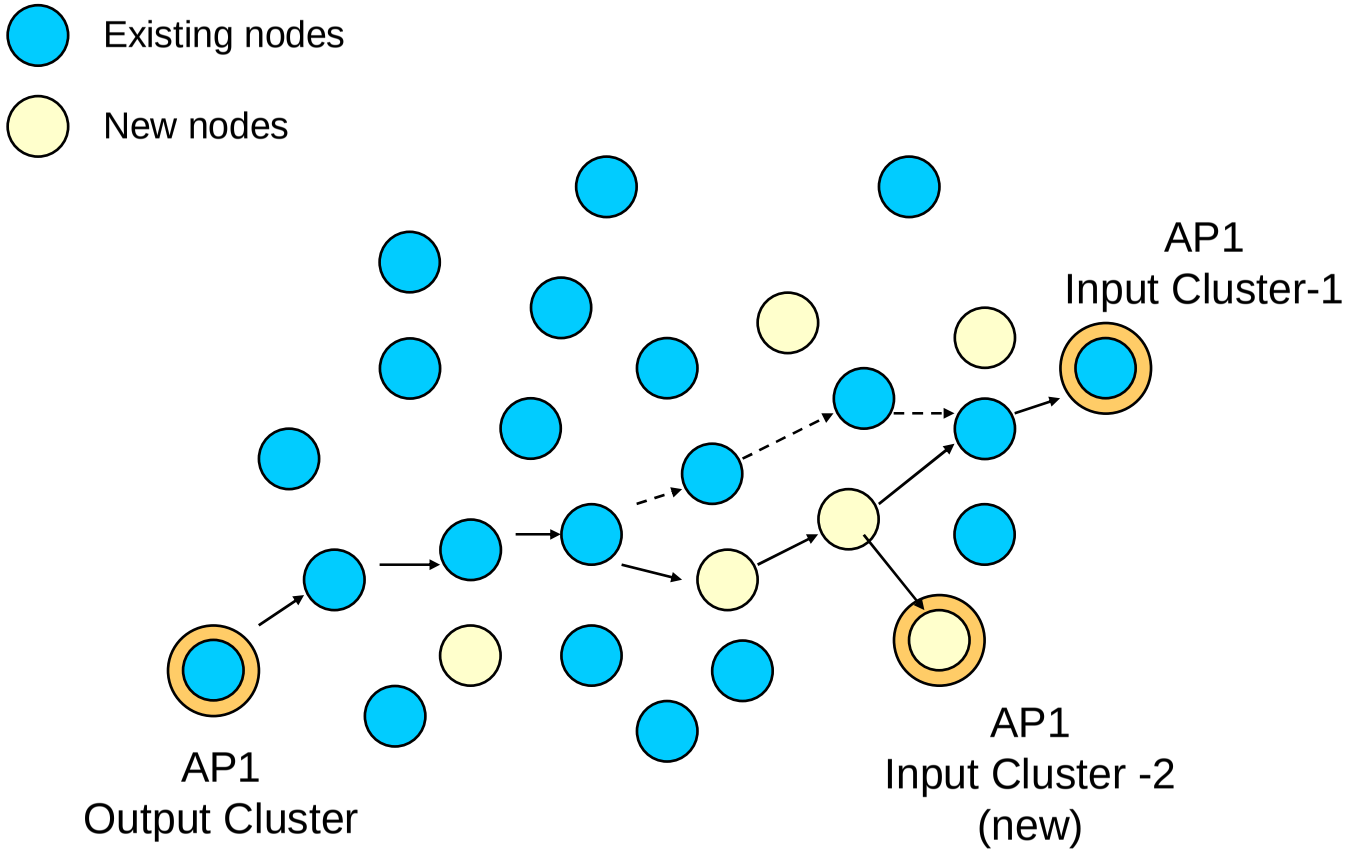




- A new node (m) can join at nodes 4 or 10
- Message passing to 3 and 21 assumed
- Could node 10 also associate with a coordinator 20? Under what condition?



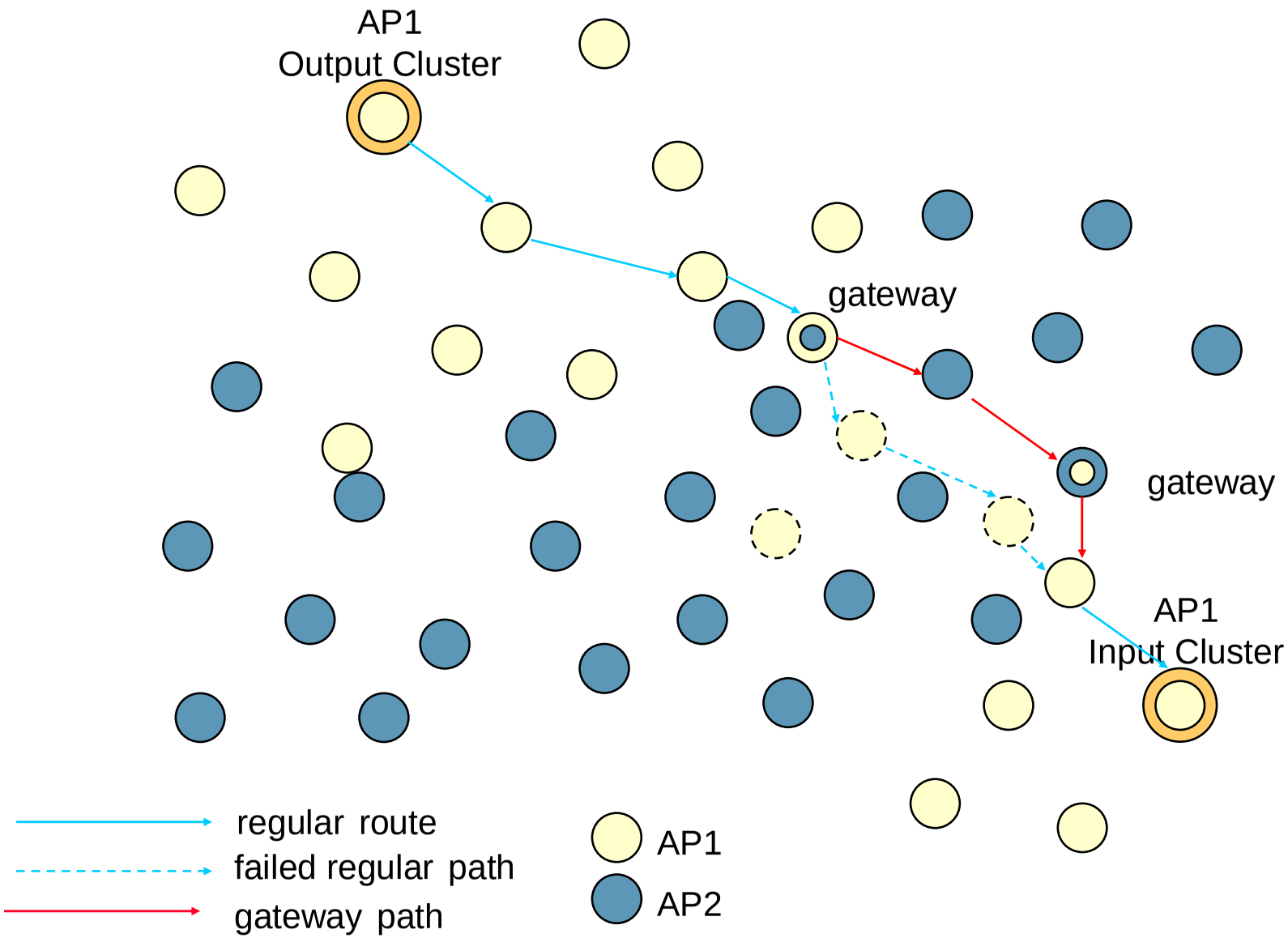
Reinforcing a Mesh Topology



Collaborative Sharing Scenario

- Example: Network WPAN2 supporting AP2 is deployed in parallel to the existing WPAN1 with the application AP1.
- Assumptions
  - There is a mapping WPAN1 – AP1, WPAN2 - AP2.
  - Both WPAN can be working in isolation.
  - Application-aware sharing should be enabled.
- Challenge
  - Establish application-aware gateways between WPANs.
- Considered Behavior
  - Tree building primitives, routing primitives, gateways.
- Question
  - Which network and application-specific behavior and information to is needed to support this scenario?
  - Discovery of input clusters, output clusters?

Collaborative Sharing Example



APP-aware Self-Organization

- Example: A new application AP2 is deployed in a WPAN currently supporting only AP1. In addition WPAN is extended with several new nodes. AP1 and AP2 share the same resources.
- Challenge
  - How to describe applications and node capabilities so that the network can adaptively self-organize when new applications and new nodes are added. E.g., WPAN in the example may even split into two WPANs and establish gateways.
  - A concept for application classification and resource prioritization is needed.
- Considered Behavior
  - Tree primitives, routing primitives, gateways.
- Question
  - Which network and application-specific behavior and information to is needed to support this scenario?

Resource and App. Information

ZigBee models node resources and applications in terms of descriptors. These may be discovered only after the initial network is formed.

But we may need resource- and application awareness for network formation!

NWK Neighbor Data

- PAN Id
- IEEE Extended Address
- Network Address
- Type: coordinator, router, end-device
- Relationship: Child, parent
- Depth, Permit Joining
- Beacon Order
- Transmit Failure
- Potential parent (bool)
- LQI, Logical Channel
- Incoming beacon timestamp
- Beacon offset

Node Descriptor

- Type: coordinator, router, end-device
- APS flags (security)
- Frequency band (PHY)
- MAC capability
  - Alternate coordinator
  - Power source (mains, battery)
  - Rec-on when idle
  - Security capability
- Manufacturer code
- Maximum buffer size
- Maximum transfer size

Power descriptor

- Current power mode
- Available power sources
- Used power source
- Used power source level (33,66,100%)

Simple Descriptor: APP Data on the End-Point

- Profile identifier
- Device identifier
- Device version
- Flags
- Input cluster list
- Output cluster list

Proposal: APP-Aware WPAN Formation

In order to establish associations and bindings each node either advertise or discover resource and application-specific information and attempt network joining based on this information.

- Advertise
  - Send advertisement of resources and applications
  - Wait for “requests for bindings”
  - Select and bind
  - Send “accept binding”
- Discover
  - Send discovery message for resources and applications
  - Wait for potential bindings
  - Select and bind
  - Send “accept binding”

Conclusions

- We consider network formation capabilities of IEEE 802.14.5 and ZigBee in the context of network growing scenarios in which we assume incremental adding of nodes and application and the need for application co-existence and infrastructure sharing.
  - Initial network organization is application and resource agnostic. This however may lead to inefficient network configuration.
- The conclusion is that resource-awareness and application-awareness may be needed at the topology organization level.
- We therefore investigate the **Application-aware Network Formation Mechanisms** based on the IEEE 802.15.4 MAC and PHY and reusing some resource and application concepts of ZigBee.