

Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)**Submission Title:** [IEEE 802.15.5 WPAN Mesh Tutorial]**Date Submitted:** [November 11, 2006]**Source:** [Myung Lee] Company [CUNY]Address [Dept. of EE, 140th St & Convent Ave, New York, NY 10031, USA]

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Re: [A tutorial for IEEE 802.15.5 WPAN Mesh]**Abstract:** [The tutorial will introduce applications, technical requirements of WPAN Mesh and describe technical contents of current draft. The current draft contains mainly two parts, Mesh functions and MAC enhancement, including architecture, mesh routing, beaconing, and other components both in high rate and low rate mesh.]**Purpose:** [To introduce IEEE 802.15.5 WPAN Mesh to IEEE 802 community]**Notice:** This document has been prepared to assist the IEEE P802.15. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein.**Release:** The contributor acknowledges and accepts that this contribution becomes the property of IEEE and may be made publicly available by P802.15.

IEEE 802.15.5 WPAN Mesh A Tutorial

Dallas, TX

November 14, 2006

Presenters

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- *Chunhui Zhu (Samsung)

Contributors

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Contents

- Introduction
 - Purpose & Scope, Applications
- High Rate WPAN Mesh
 - MAC enhancement, Mesh Routing
- Low Rate WPAN Mesh
 - Addressing, Routing, Multicasting
- Features under consideration

Tutorial 802.15.5

Introduction

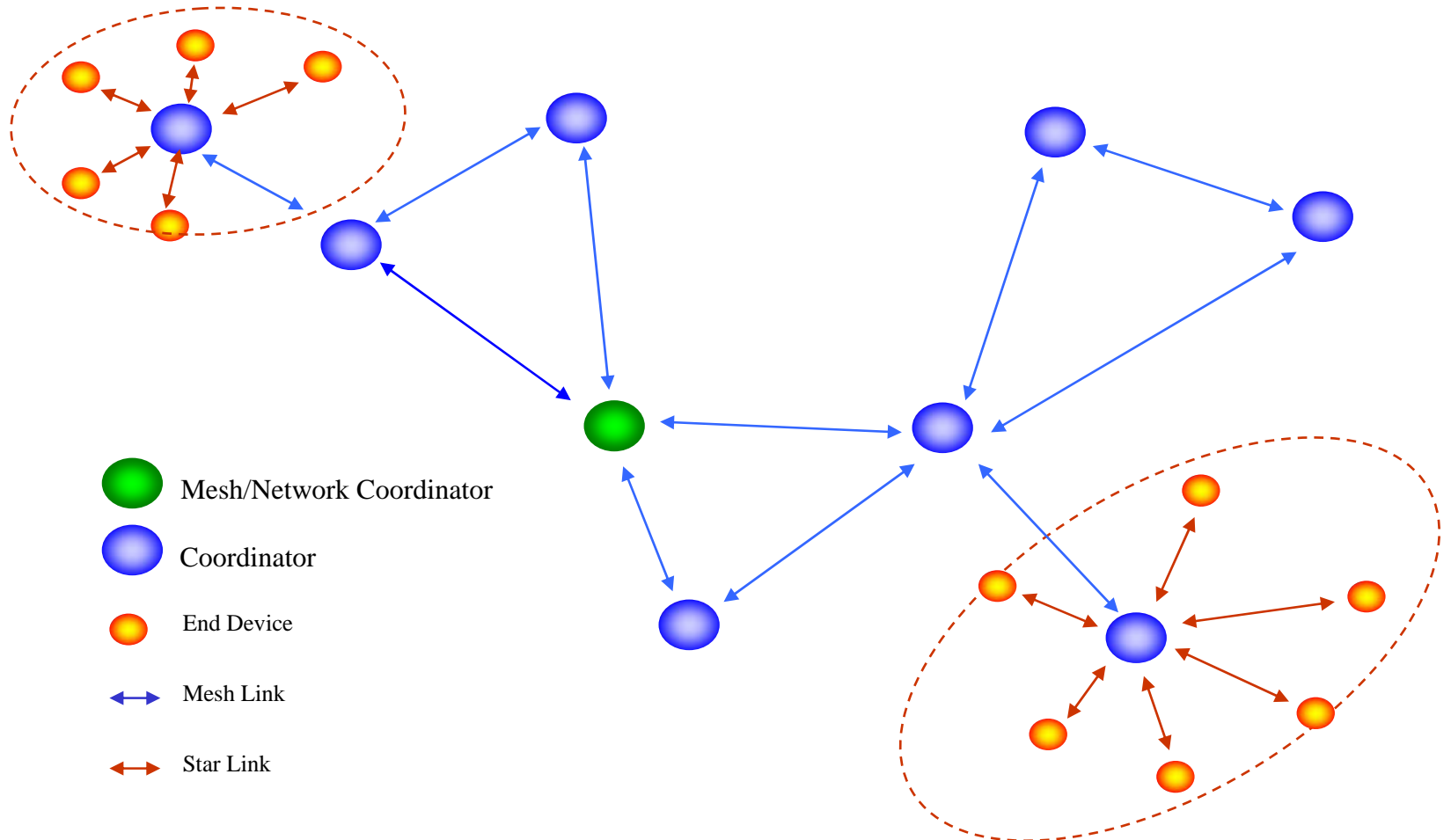
Presenter: M. Lee

Contributor: HR Shao, M. Lee

What is WPAN Mesh?

- A Wireless PAN that employs one of two connection arrangements: full mesh topology or partial mesh topology.

WPAN Mesh Networking



Purpose of the project

- This project facilitates wireless mesh topologies optimized for IEEE 802.15 WPANs.
 - Extension of network coverage without increasing transmit power or receive sensitivity
 - Enhanced reliability via route redundancy
 - Easier network configuration
 - Better device battery life due to fewer retransmissions

Scope of the group

- To provide a *Recommended Practice* to provide the architectural framework enabling WPAN devices to promote interoperable, stable, and scaleable wireless mesh topologies.
- Including mesh support for both High-Rate and low-rate WPANs.
 - High Rate Mesh over 802.15.3b MAC
 - Low Rate Mesh over 802.15.4b MAC

App1: Multimedia home network

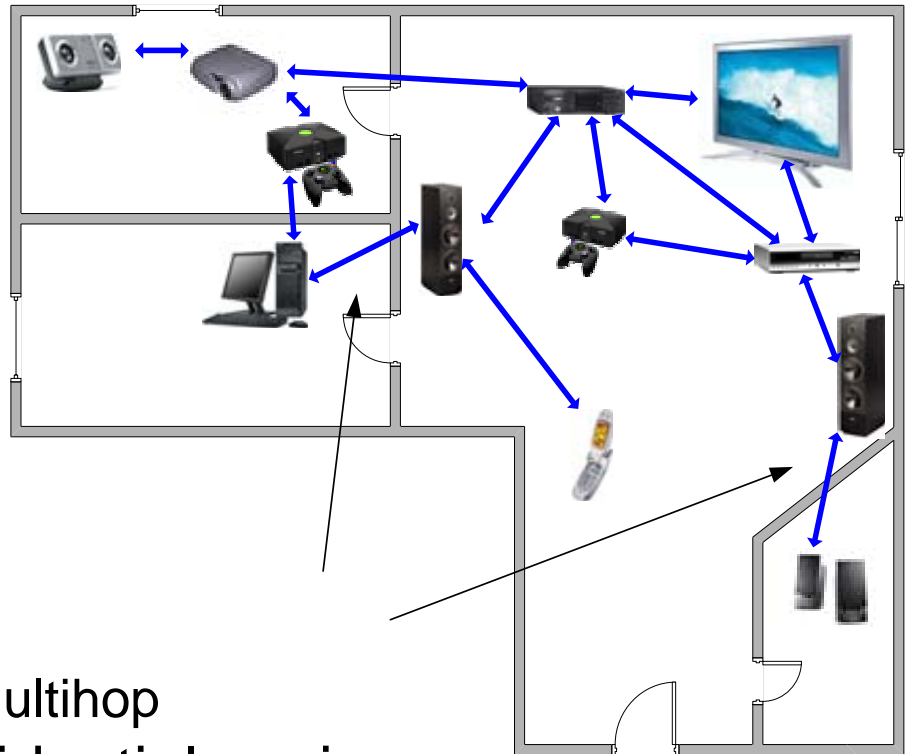
- Consumer Electronics (CE)

- Video
 - HDTV, DVD
- Audio
 - HiFi stream, VoIP
- Interactive Gaming

- Mesh for

- High throughput with QoS
- Coverage extension with multihop

- Single- or multi- room residential environment



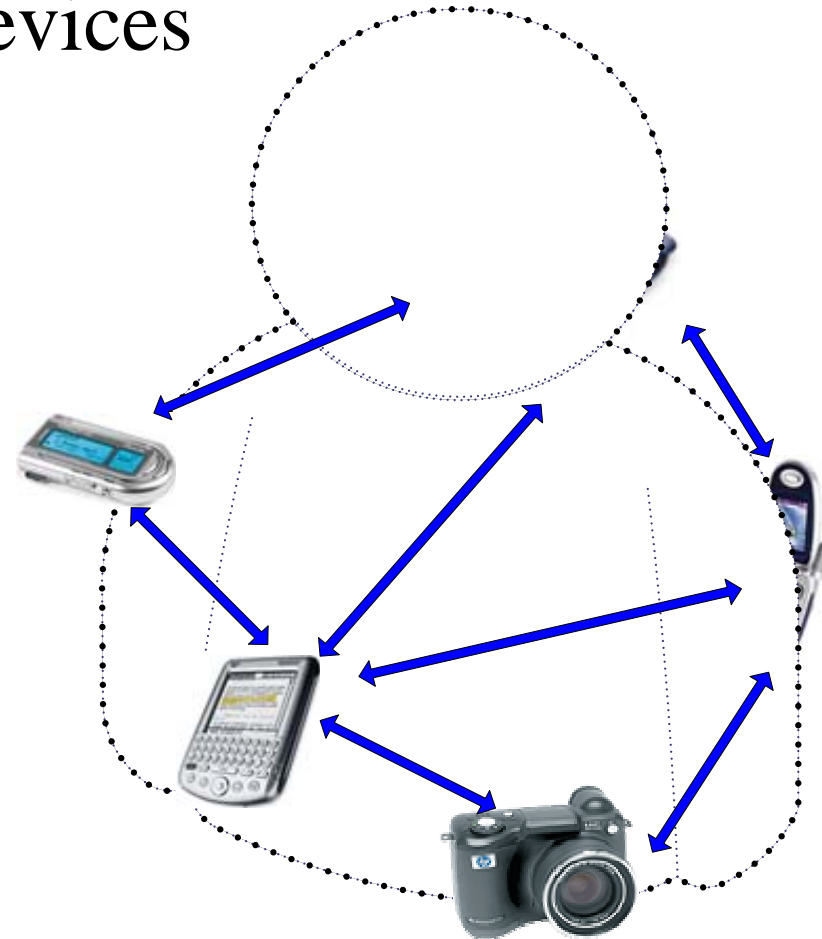
App2: Interconnection among PC and peripherals

- PC and peripherals
 - Human Interface Device (H)
 - Local file transfer
 - Printing
 - Content download (camera)
- Single room or small office
- Mesh for
 - Potentially improving the network capacity



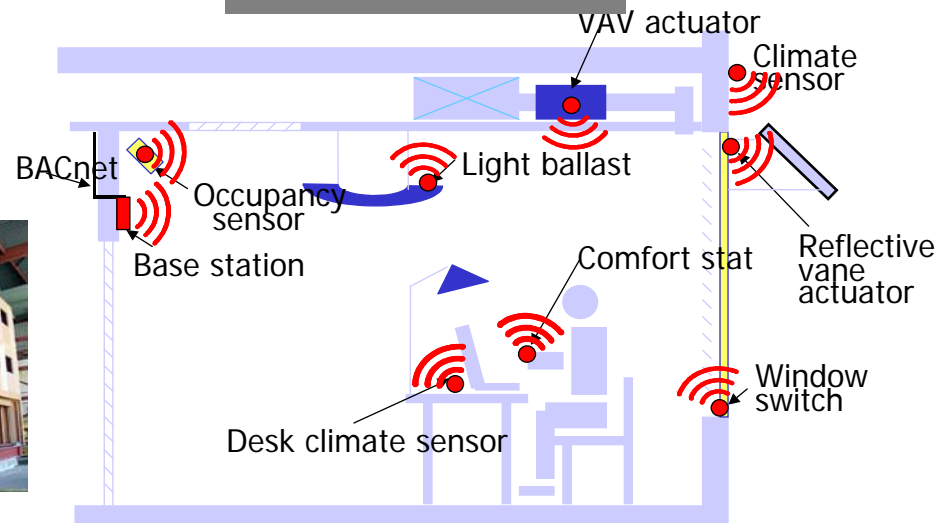
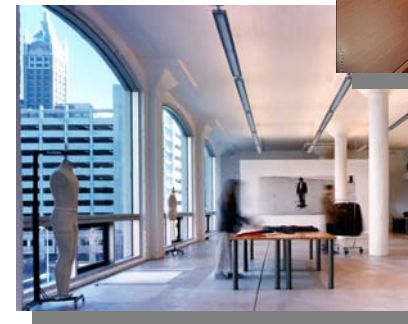
App3: Interconnection among handheld devices

- WPAN anywhere
- Mesh for
 - network reliability
 - power saving
- Handheld devices
 - Audio (cordless headset)
 - Content download (MP3 player, photo camera)
 - Internet file transfer & audio/video streaming (PDA, cell phone)



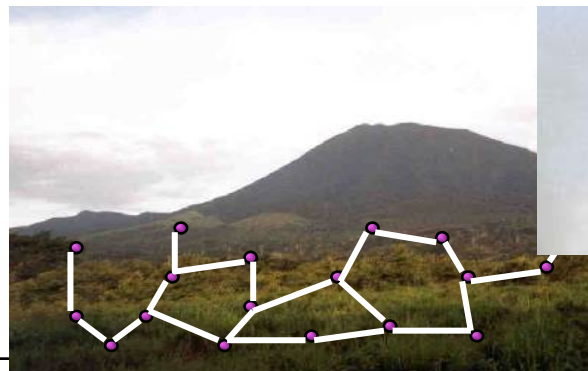
App4: Automation and Control

- Home, building
 - HVAC control, ...
 - Energy saving (NYC apartment complex project)
- Factory, warehouse
 - Inventory, PLC, Robot,...
- Mesh for
 - Network reliability
 - Power saving
 - Cover wide area



App5: Monitoring

- Safety, security
 - Military, home, building
- Environments
 - Structures (bridge, load,...), agriculture, building
- Mesh for
 - Network reliability
 - Power saving
 - Cover wide area

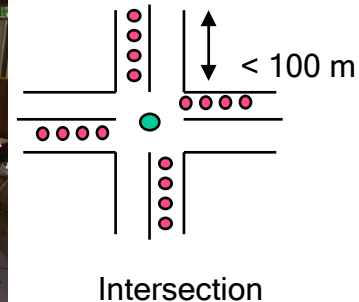
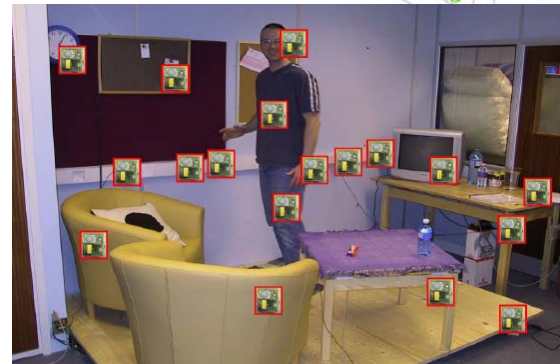
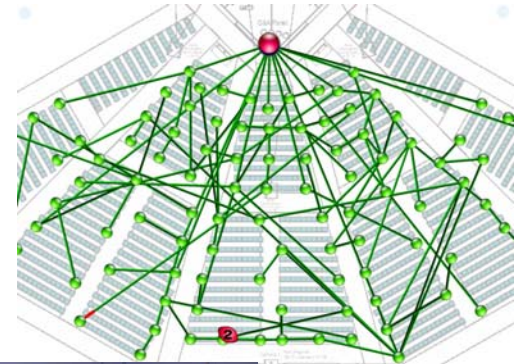
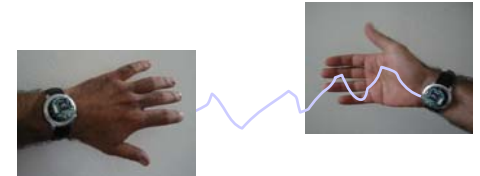


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App6: Etc

- Entertainment
 - Learning games
 - Interactive toys
- Virtual IO (keyboard,...)
- Auditorium service
- Meeting recording
- Traffic service
- ...
- Mesh for
 - More flexible services



Tutorial 802.15.5 High-Rate Mesh WPANs

Presenter: S. Max*

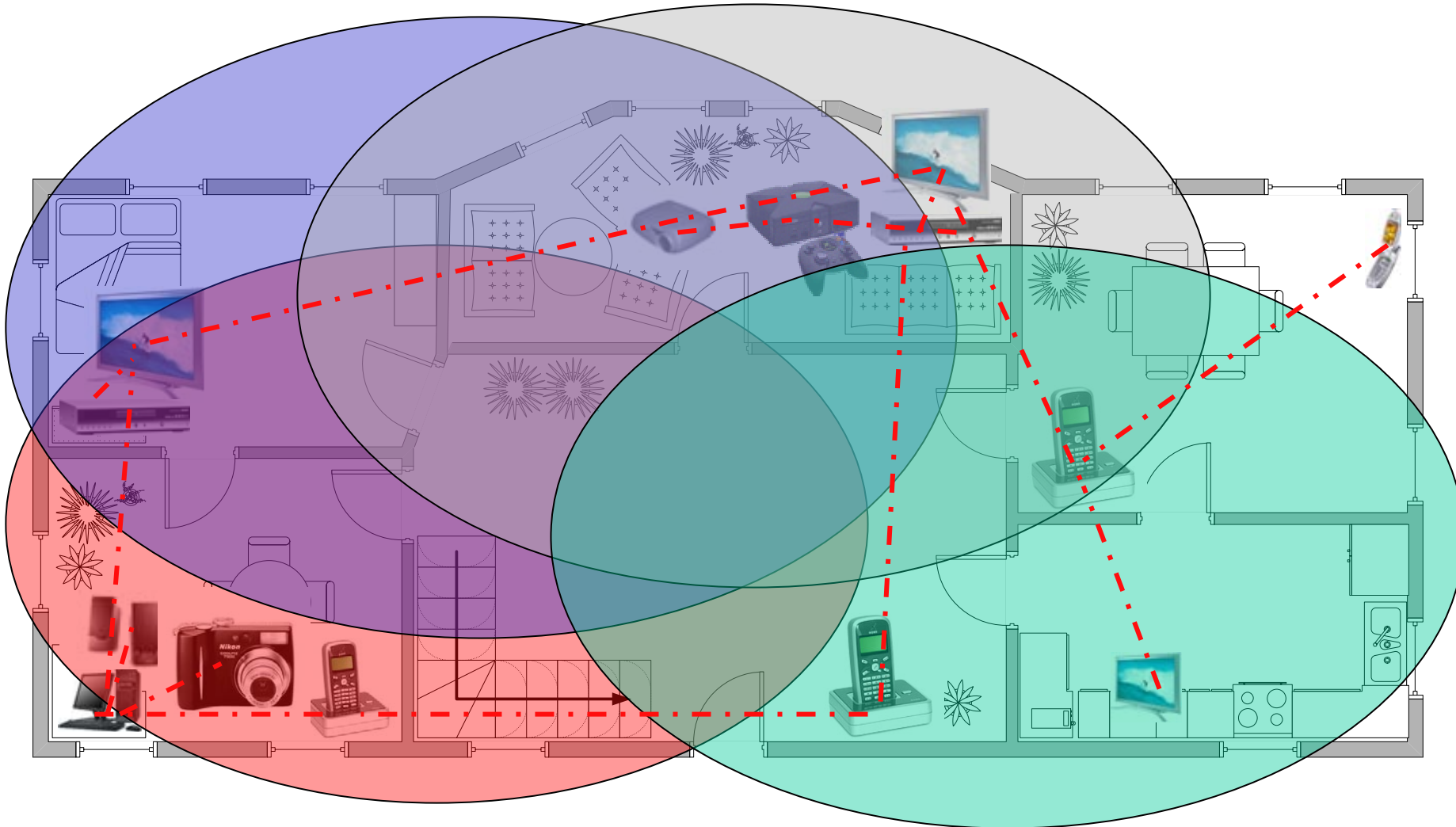
Contributors: S. Max*, M. Sim**, Y. Liu***

*Philips Research

**Panasonic

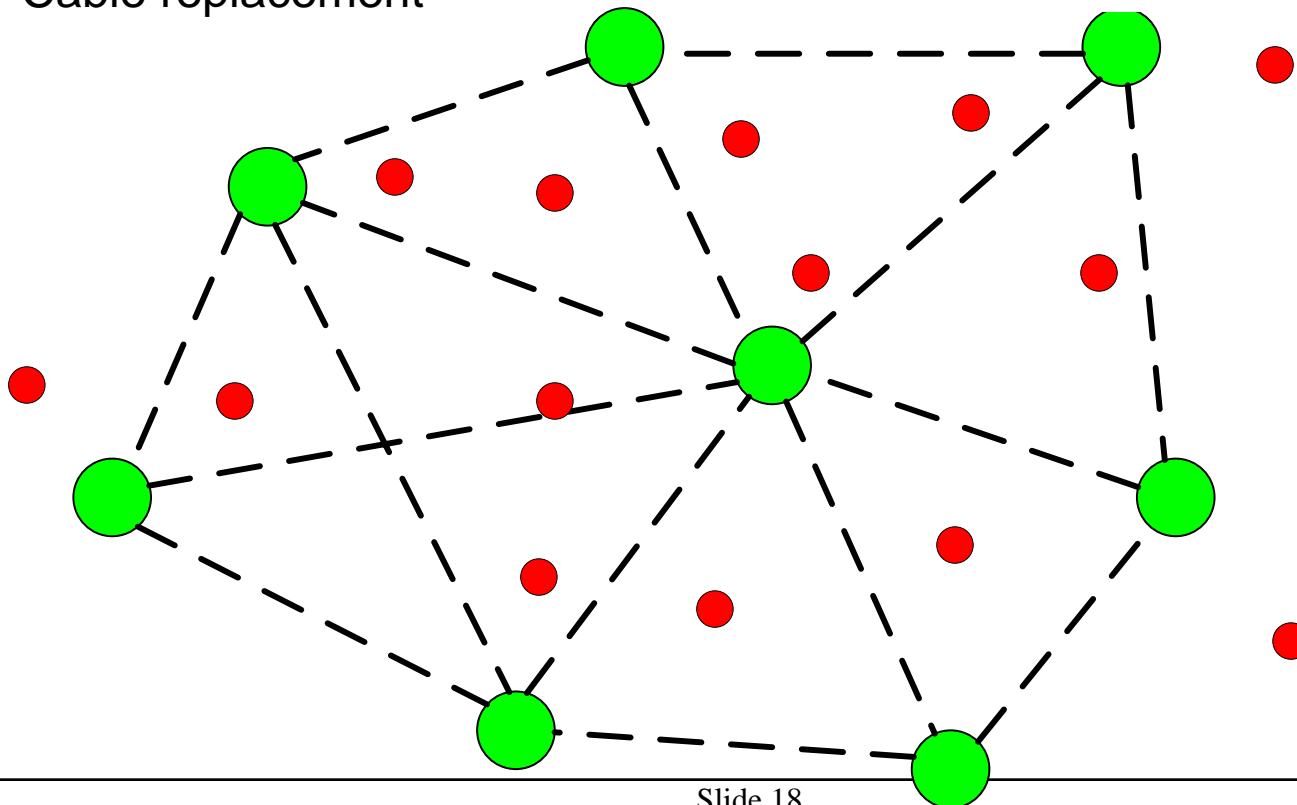
***Samsung Advanced Institute of Technology

Usage Scenario HR WPAN



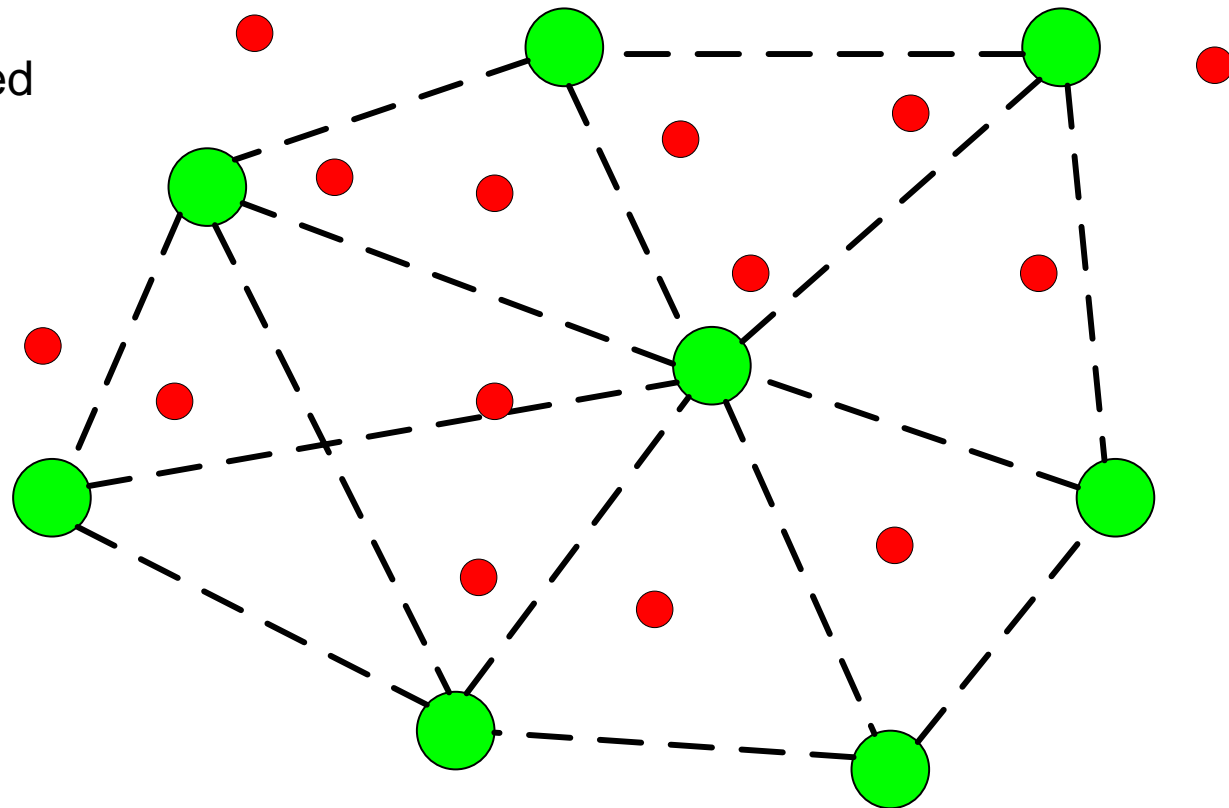
Usage Scenario - Analysis

- (Semi) stationary backbone
 - *Mesh Piconet Controllers (MPNCs)*
 - Convenience
 - Cable replacement
- Mobile clients
 - *Devices (DEVs)*
 - Coverage extension
 - Connection everywhere



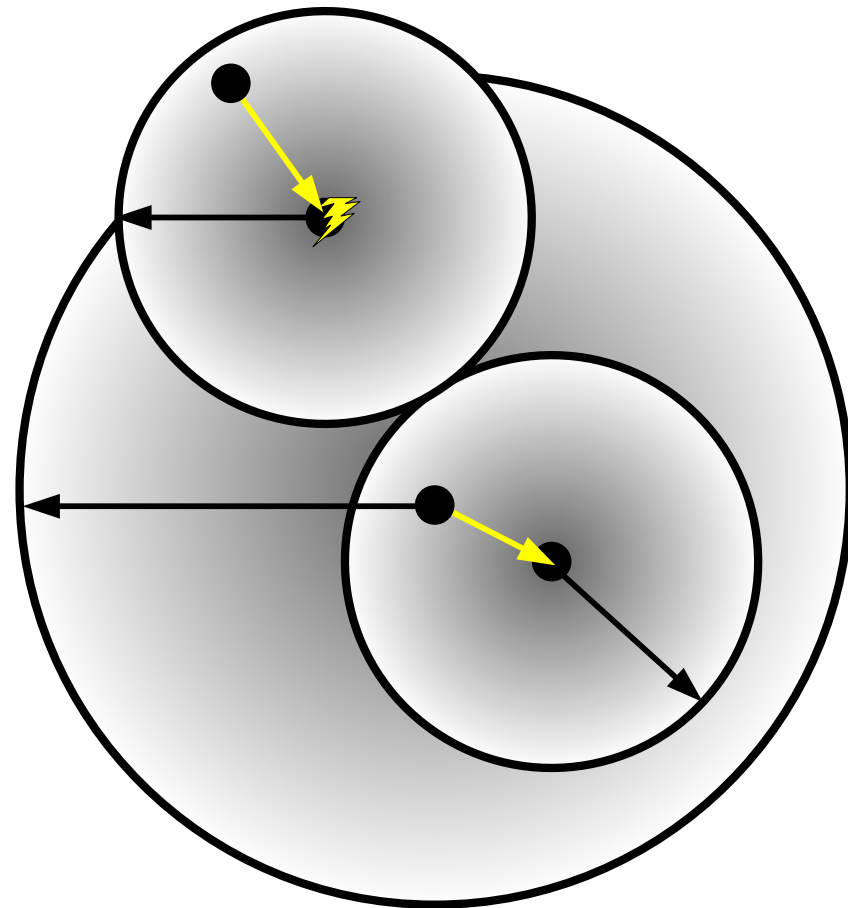
Challenges in WPAN Mesh Scenarios

- **Medium Access Control**
 - Mobility
 - Hidden and Exposed nodes
 - Interference
 - Unnecessary capacity decrease
- **Path selection**
 - Self organizing
 - Redundant links
 - Loop prevention
 - Broadcast data
- **(Security)**
 - Ad hoc deployment
 - Access Control
 - Secure distribution of path selection info



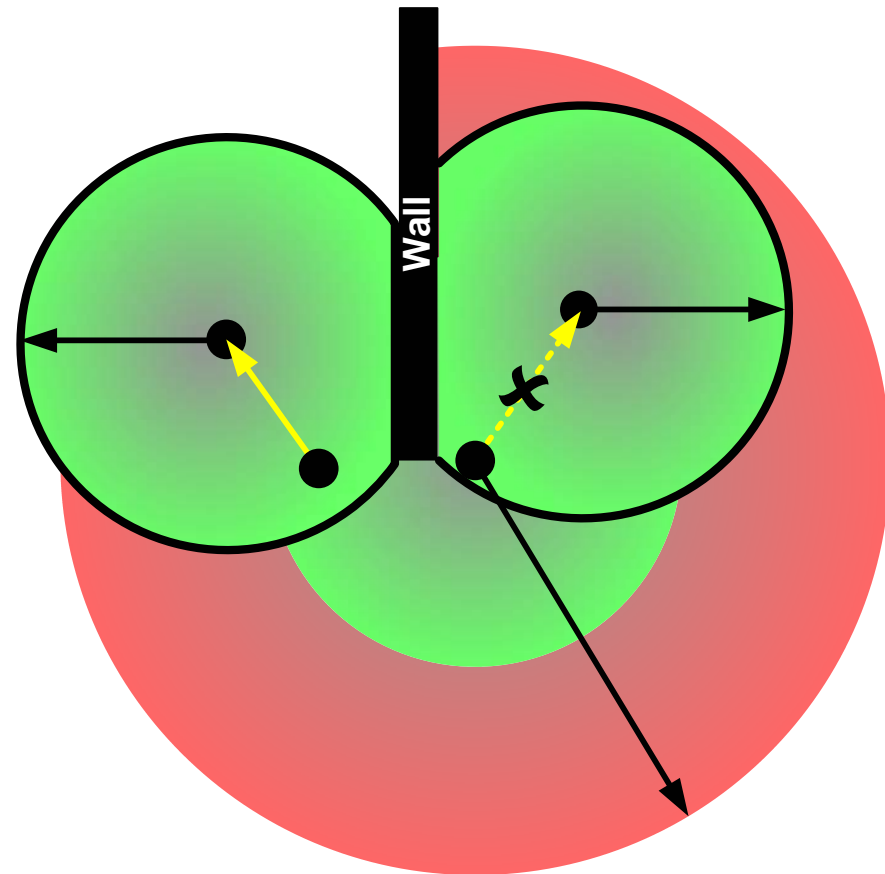
Hidden entities – Threat to WMN communication

- C cannot sense A's transmission
- C cannot sense neither A's nor B's medium reservation
- C detects wireless medium as idle
- C transmits to D
- B's reception of A is interfered by C's transmission → collision



Exposed entities – Limiting capacity of WMNs

- A sends data to B
- B & C separated by wall
 - B cannot be interfered by C
 - → Opportunity for spatial frequency reuse (concurrent transmission)
 - C could transmit to D
- C blocked by reservation from A

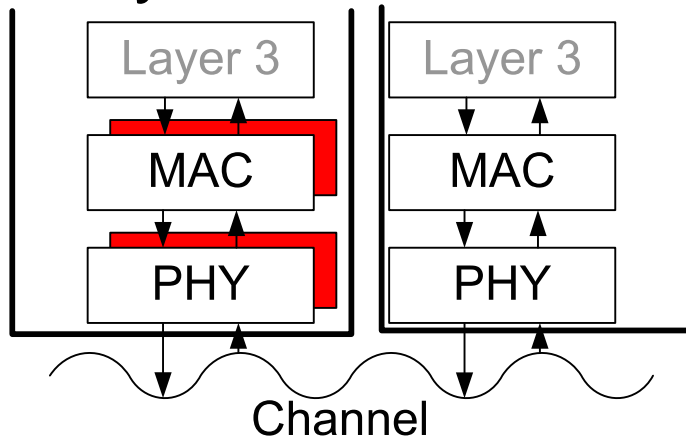


IEEE 802.15.5-HR Recommended Practice

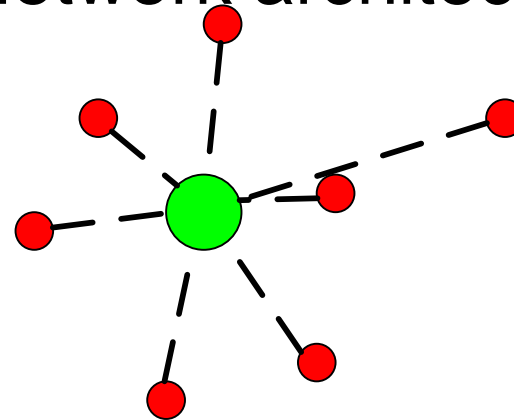
Entities, Architecture, Extensions

Single-Hop WPANs

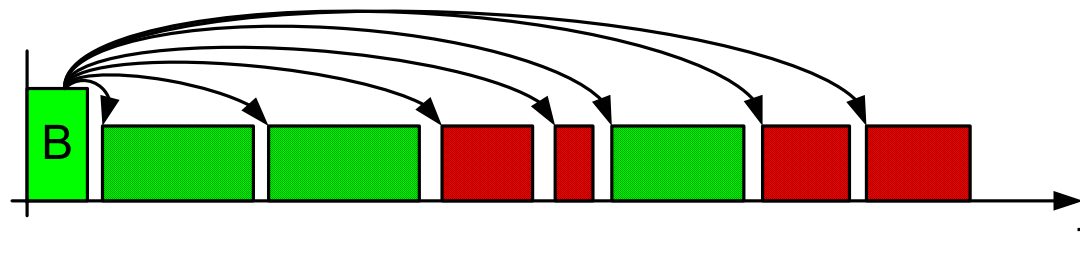
- Layer architecture



- Network architecture

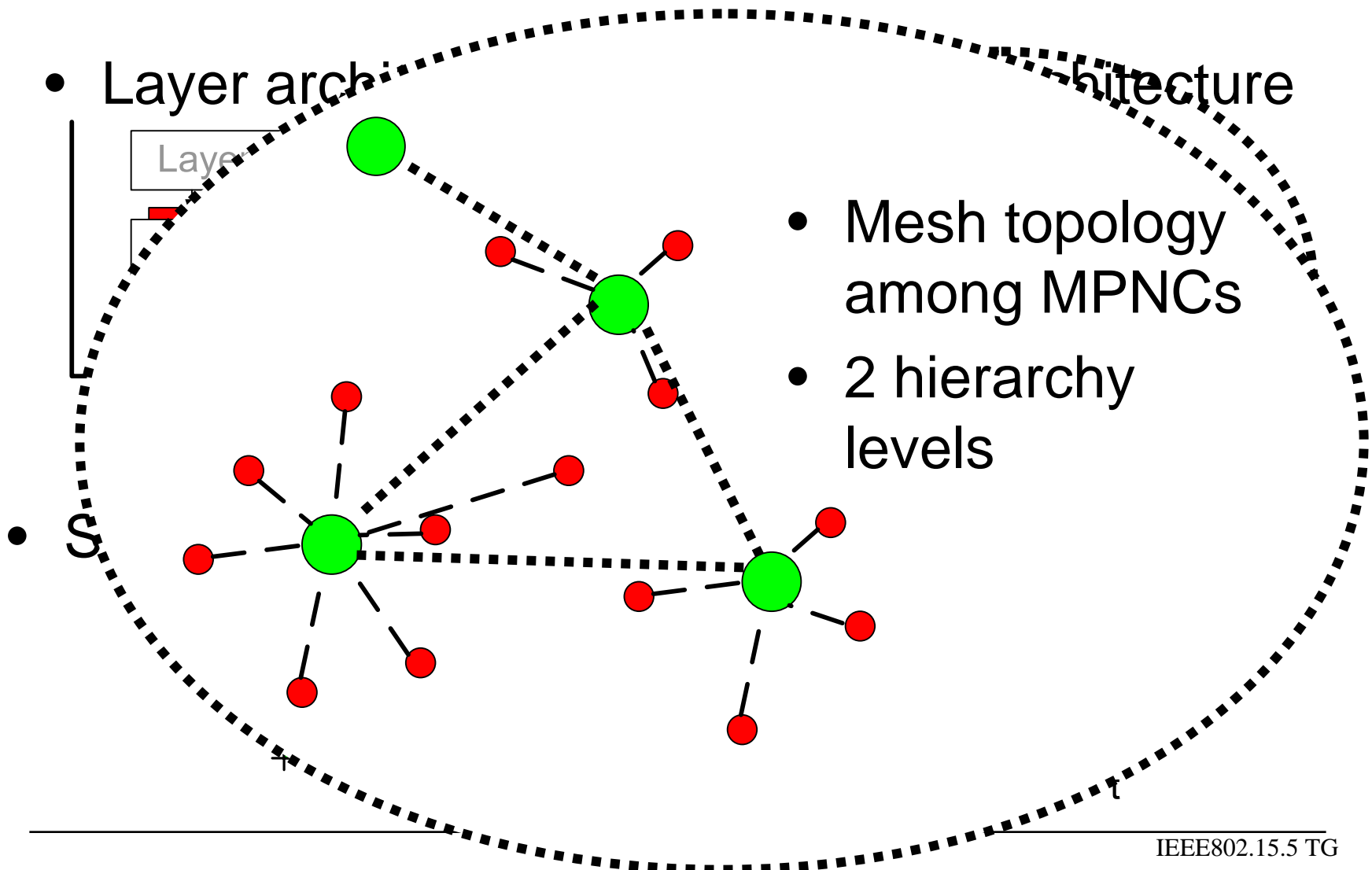


- Superframe architecture



Single-Hop WPANs

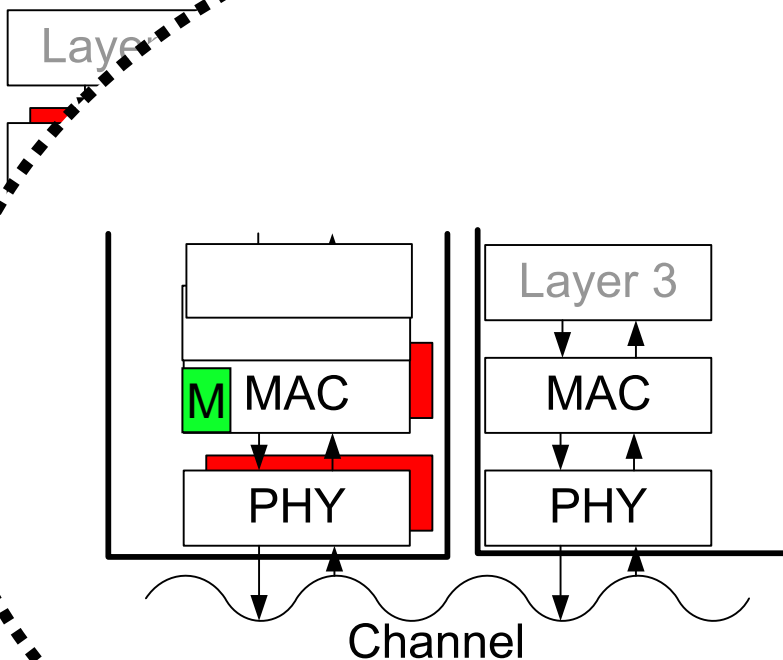
- Layer architecture



- Mesh topology among MPNCs
- 2 hierarchy levels

Mesh WPANs

- Layer architecture

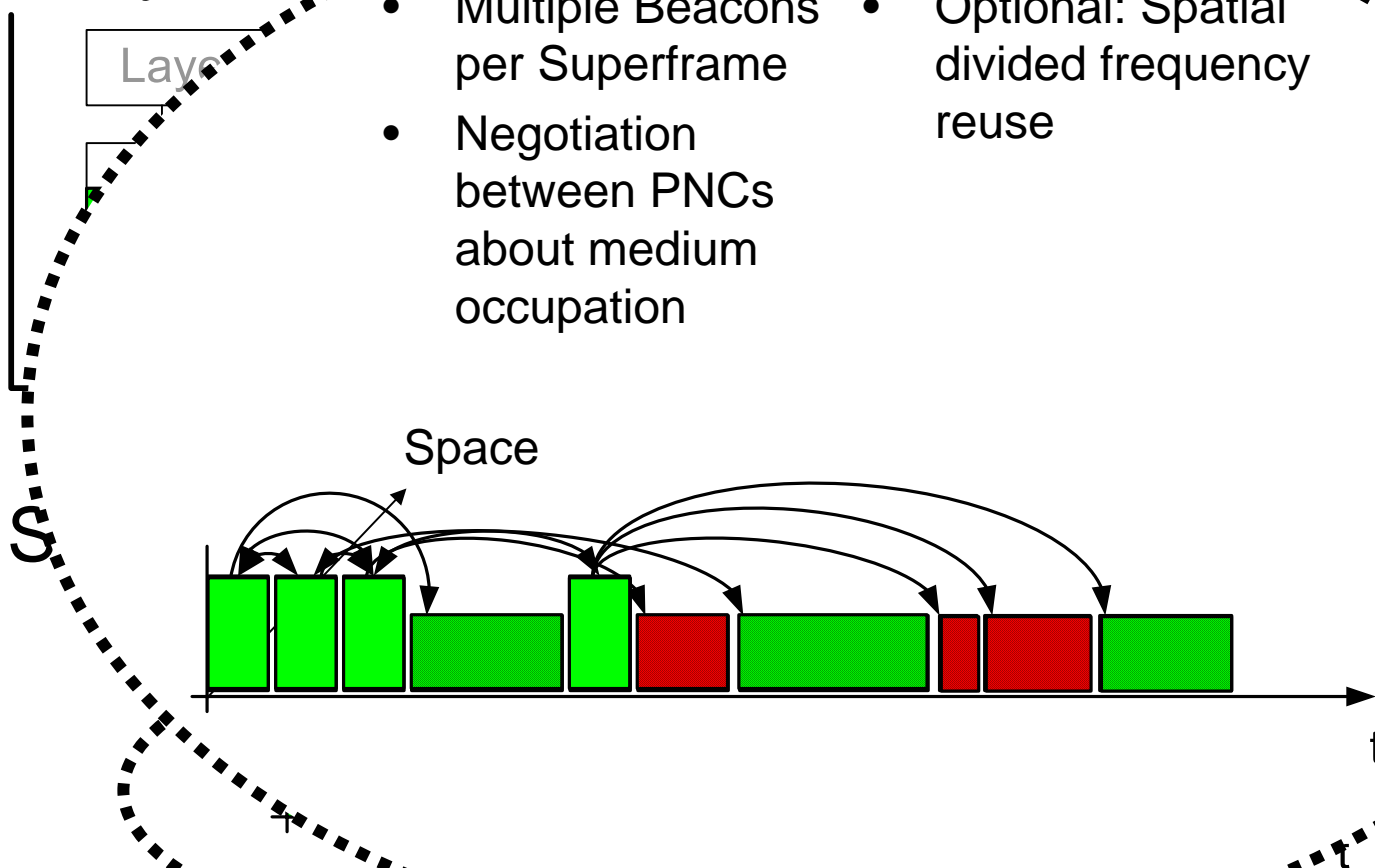


- Wireless Path Selection & Mesh Services
- Extensions to the MAC
 - Multiple Beacons
 - Reservation Negotiation

Mesh WPANs

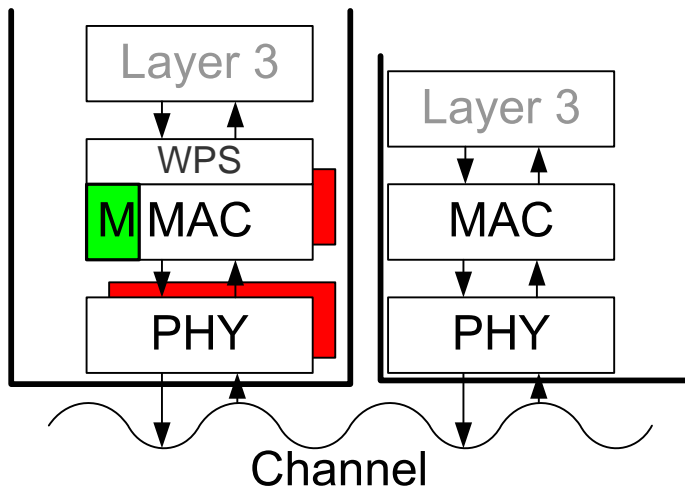
Layer architecture

- Multiple Beacons per Superframe
- Negotiation between PNCs about medium occupation
- Optional: Spatial divided frequency reuse

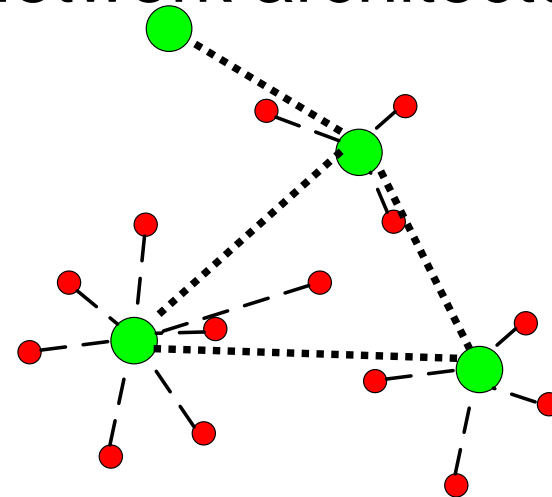


Mesh WPANs

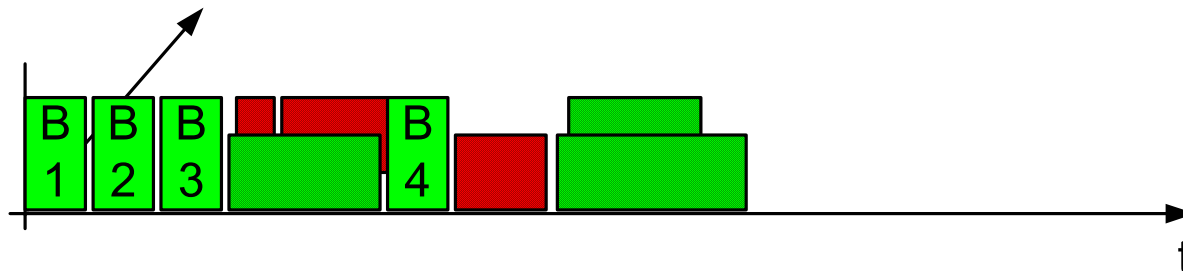
- Layer architecture



- Network architecture

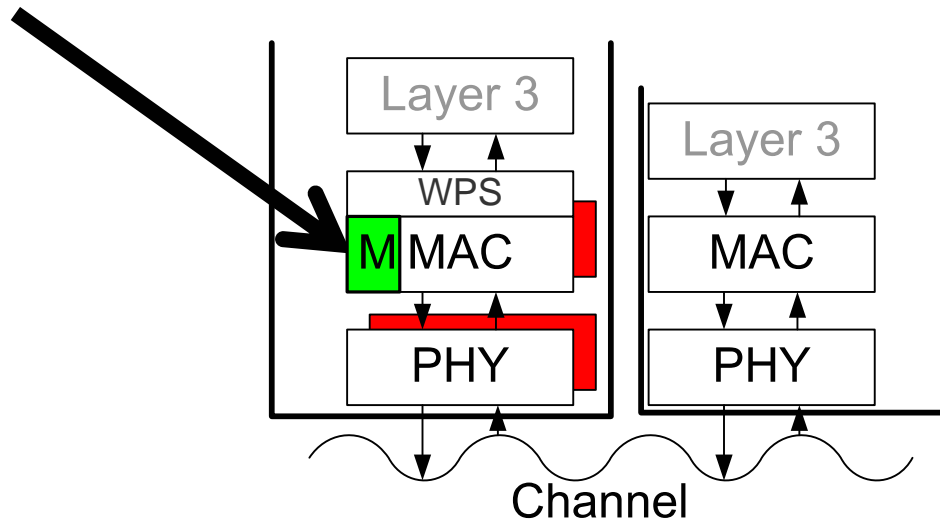


- Superframe architecture



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High Rate MAC Extensions



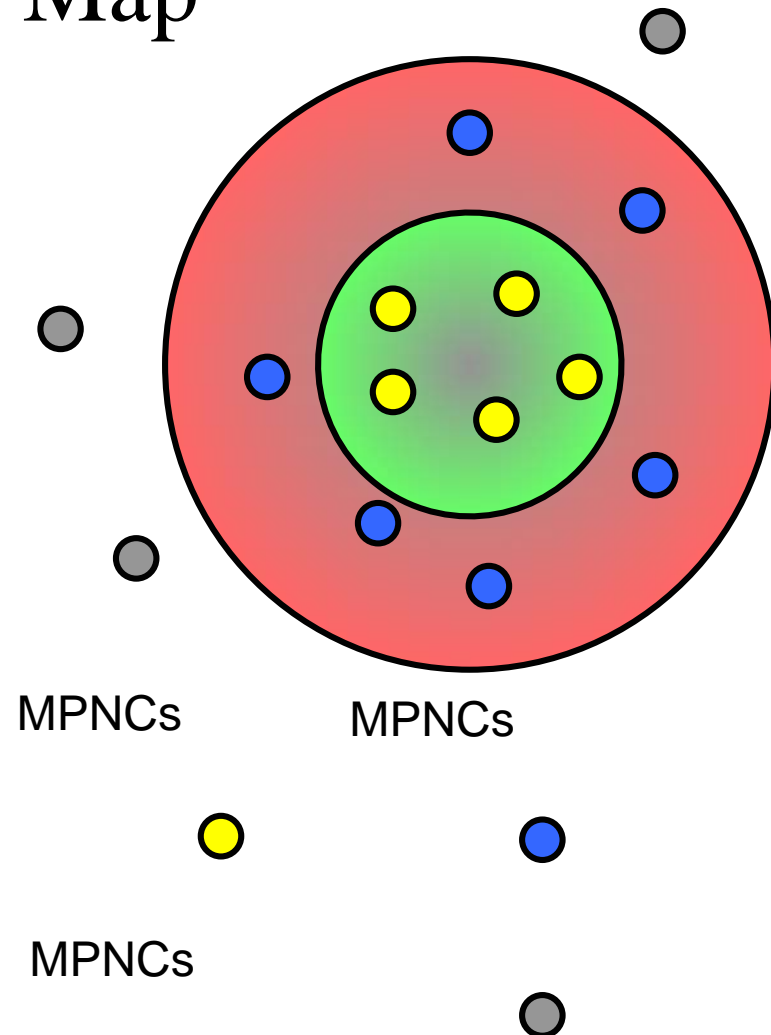
Multiple Beacons



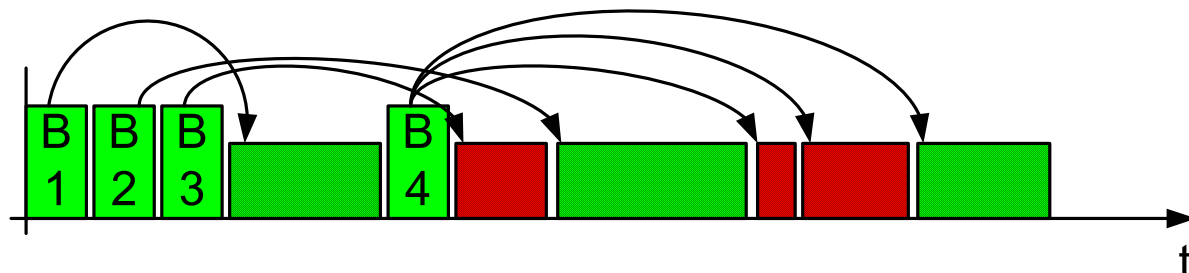
- Every Mesh Piconet Controller (MPNC) transmits beacon
- Beacon carries
 - ID
 - Synchronization information
 - Neighborhood information
 - Neighbor's neighbors
 - Medium Access Information
- New MPNC is switched on
 - Scan for beacons
 - Select idle space for beacon transmission, incorporating
 - Channel sensing
 - Information from neighbors
 - Provide local viewpoint of occupancy to neighbors
 - → Increase their knowledge
- Hidden node problem
 - Information of occupancy is disseminated over three hops

Neighborhood Map

- Beacons send at most robust PHY mode
 - Reception close to interference range
- MPNCs store neighborhood information
- → Neighborhood table



Data Transmissions



- Distributed Reservation Protocol (DRP)
 - Scheduled transmissions
 - Medium is reserved by transmitter and receiver
 - Occupation is announced in beacon
 - Neighbors are aware of transmissions
 - Support for different reservation categories
 - Broadcast
 - MPNC to DEVs
 - MPNS to MPNC
- Hidden node problem solved by information dissemination
 - Exposed node problem remains
 - Medium is blocked in large area
 - around transmitter and receiver
 - Capacity degrades

Interference Prediction

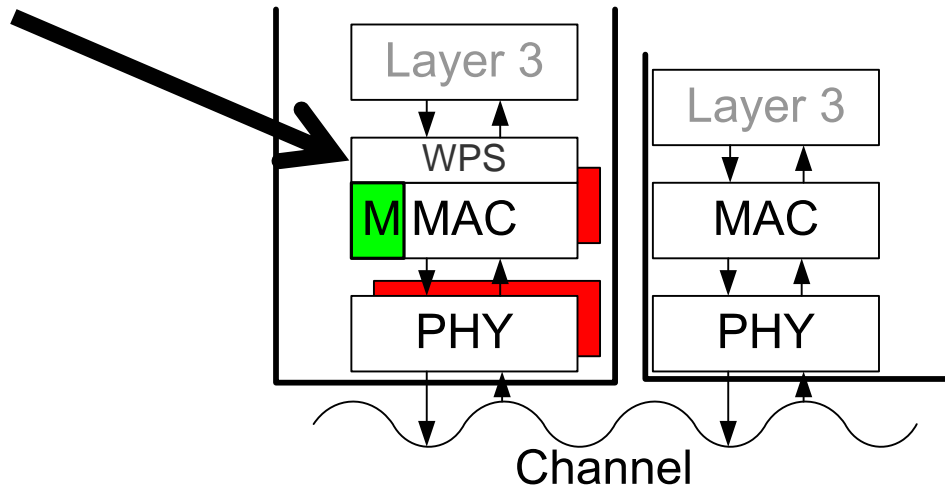
Tx Device

Rx Device

1. Search table for tx opportunity
 2. Indicate proposed time to rx device in beacon
 7. Wait for rx respond
 8. Accept rx respond or decline
3. Evaluate proposed time
 4. Search local occupancy map
 5. **Estimated expected interference using Neighborhood map**
 6. Accept or propose different time
- Hooks to solve the exposed node problem are available
- Capacity increase possible

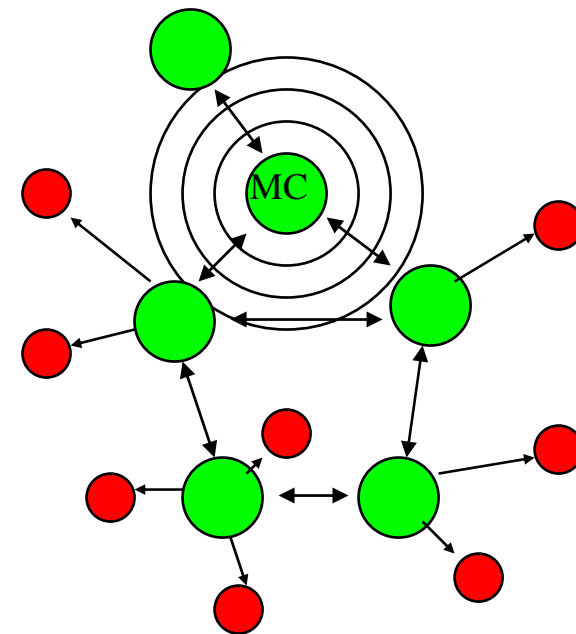
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High Rate Mesh Service Support



Network Setup

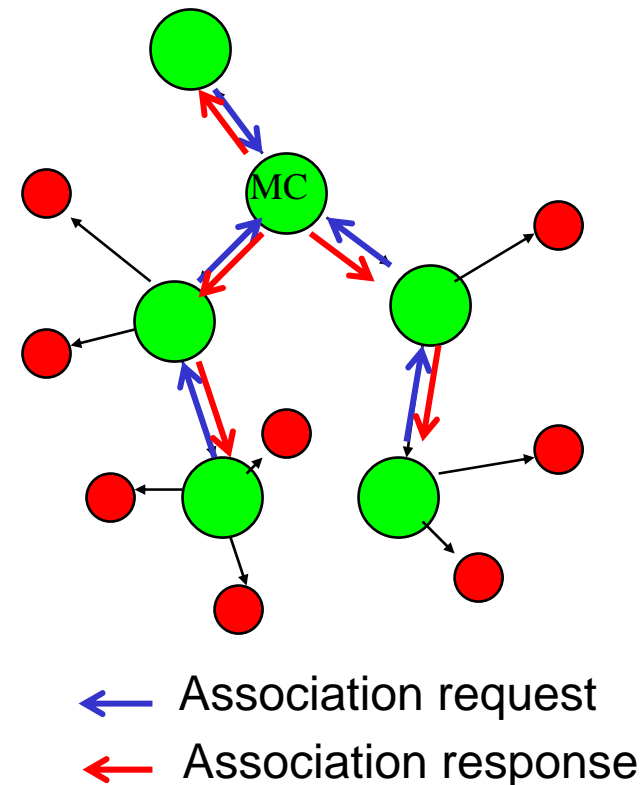
- Mesh Coordinator (MC) initializes the mesh network
 - Regularly announces mesh capability in its beacon
- New MPNCs scan for beacons
- MPNCs choose free time to send beacons



↔ Beacon reception

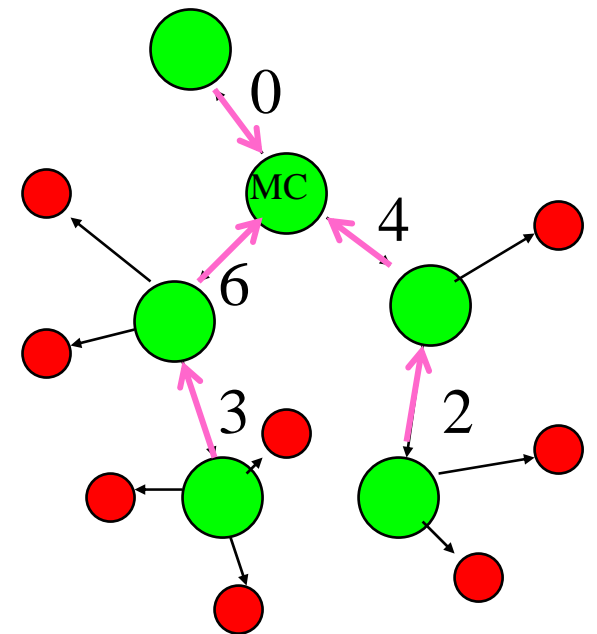
Network Setup

- Mesh Coordinator (MC) initializes the mesh network
 - Regularly announces mesh capability in its beacon
- New MPNCs scan for beacons
- MPNCs choose free time to send beacons
- MPNCs join the network by sending a tree association request
- MPNCs / MC responds with a tree association response
- → Tree structure based on local knowledge
 - One parent (None for MC)
 - Children (Zero to max. children)



Tree Topology Discovery

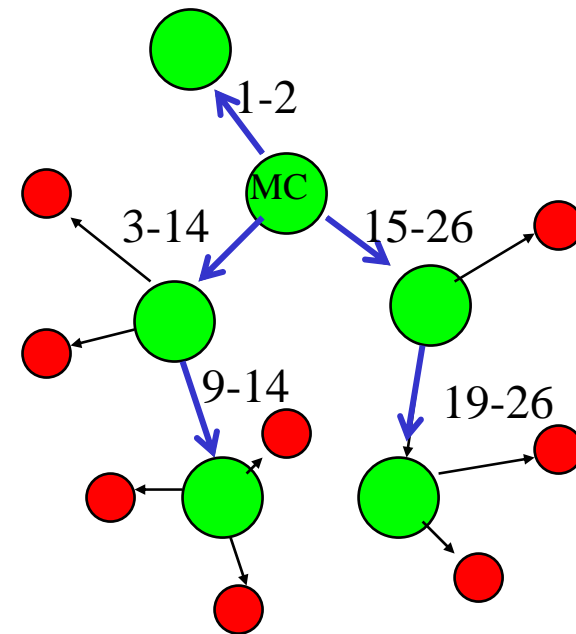
- Each Mesh Piconet Controller (MPNC) belonging to the tree
 - Waits for descendant report(s) from its children
 - Estimates the number of own descendants
 - Reports number of descendants to parent
- Process is repeated upon
 - Topology discovery request from MC
 - Association of new descendants



← Descendant report

ID Assignment

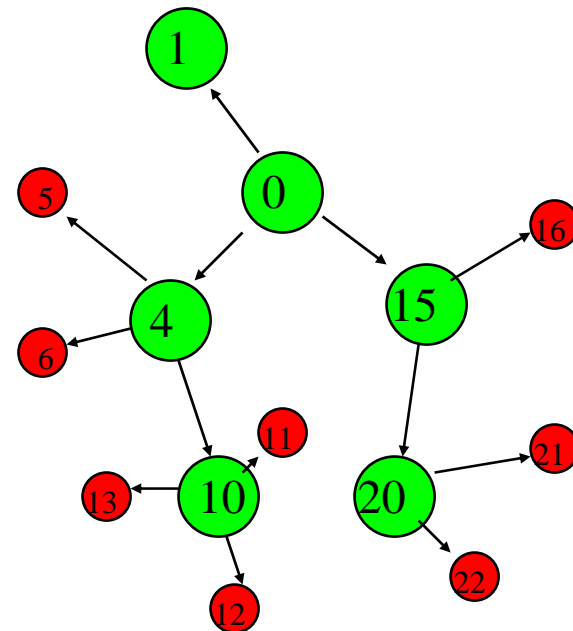
- After receiving topology update frames from all children:
 - MC reserves a block of IDs
 - Assigns intervals of IDs to children
 - Size of interval is proportional to reported number of children
- MPNC receives an ID block
 - Division and assignment is repeated for children



← TREEID Block

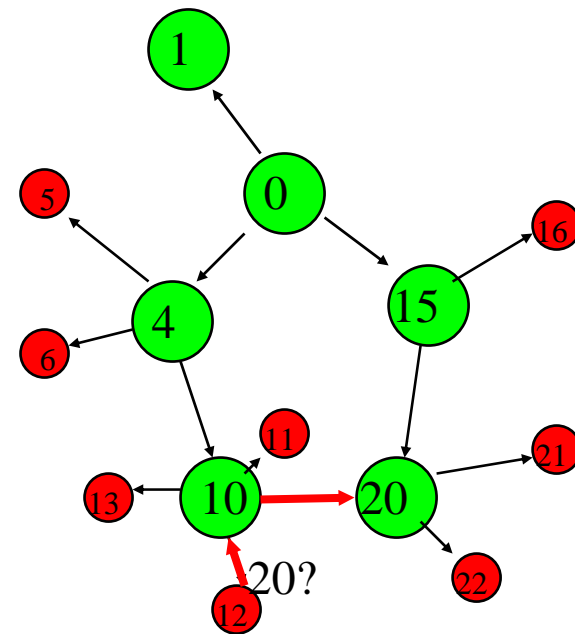
ID Assignment

- After receiving topology update frames from all children:
 - MC reserves a block of IDs
 - Assigns intervals of IDs to children
 - Size of interval is proportional to reported number of children
- MPNC receives an ID block
 - Division and assignment is repeated for children
- MPNC assigns ID to himself and its DEVs



Neighborhood-based Wireless Path Selection

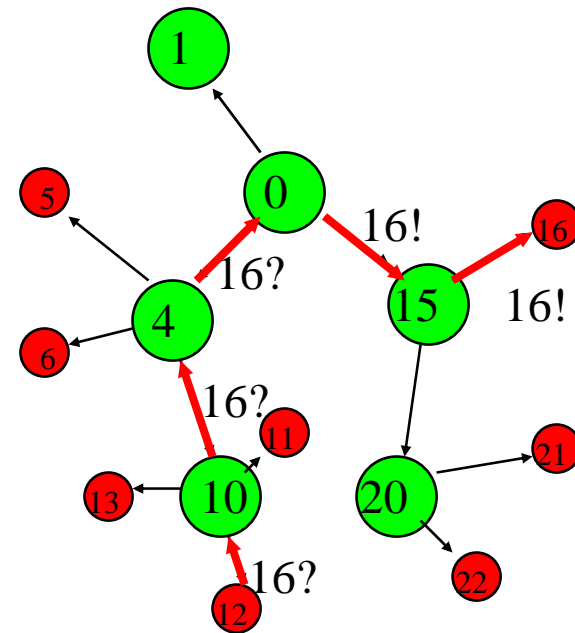
- Each MPNC keeps Neighborhood Map
 - Result from beaconing
 - Consists of neighbors and neighbors' neighbors
- Routing in 2-hop neighborhood is trivial



← Data Transmission

Tree-based Wireless Path Selection

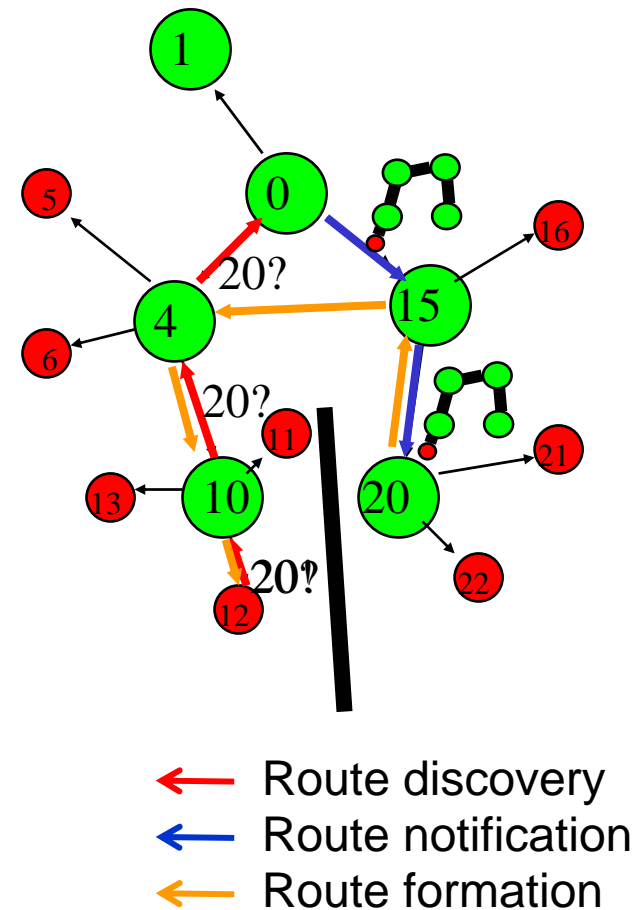
- DEV sends to MPNC
- MPNC
 - Destination in ID block?
 - NO: Forward to parent
 - YES: Deliver to DEV or appropriate child



← Data Transmission

Centralized Wireless Path Selection

- One or more MPNCs act as topology server
 - MPNCs register link states
- Centralized WPS
 - MPNC 0 is topology server
 - Route discovery via Tree-based WPS
 - Calculation of route at topology server
 - Route notification via Tree-based WPS
 - Route formation



Conclusion

- Architecture for High-Rate Mesh WPANs
 - Based on Single-Hop MAC & PHY
 - Extensions for MAC
 - Multiple Beacon operation
 - Distributed Reservations
 - Optional frequency reuse to increase the capacity
 - Mesh Service Support
 - ID assignment
 - Wireless Path Selection
 - Neighborhood
 - Tree
 - Centralized

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Low Rate WPAN Mesh

Presenter: Chunhui (Allan) Zhu*

Contributors: Chunhui (Allan) Zhu
Jianliang Zheng **

* Samsung Electronics ** EMC Corporation

Outline

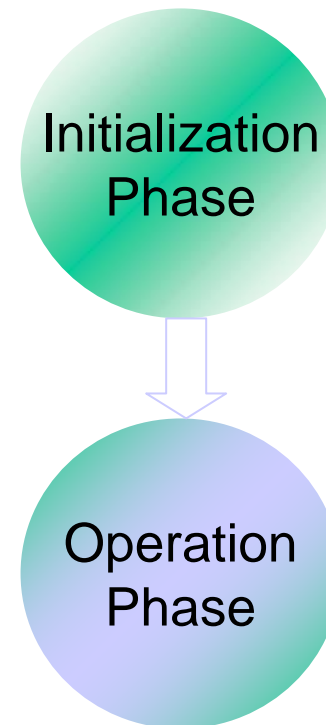
- The Challenges of LR WPAN Mesh
- Tree Formation and Addressing
- Unicast Routing
- Multicast Routing

The Challenges of LR WPAN Mesh

- The draft candidate of this LR WPAN mesh recommended practice tries to address the following challenges of LR WPAN networks.
 - Reliable
 - Large Scale
 - Low Duty Cycle
 - Resource Limited
 - Mostly Battery-Powered
 - Simplicity yet Robustness
 - Self-Configuration and Self-Healing

Tree Formation and Addressing

- In a LR-WPAN mesh network, a tree is formed for both addressing and routing purposes.
 - First form an Adaptive Tree (AT)
 - Initialization Phase
 - Operation Phase
 - Then form a Meshed Adaptive Tree (MAT)

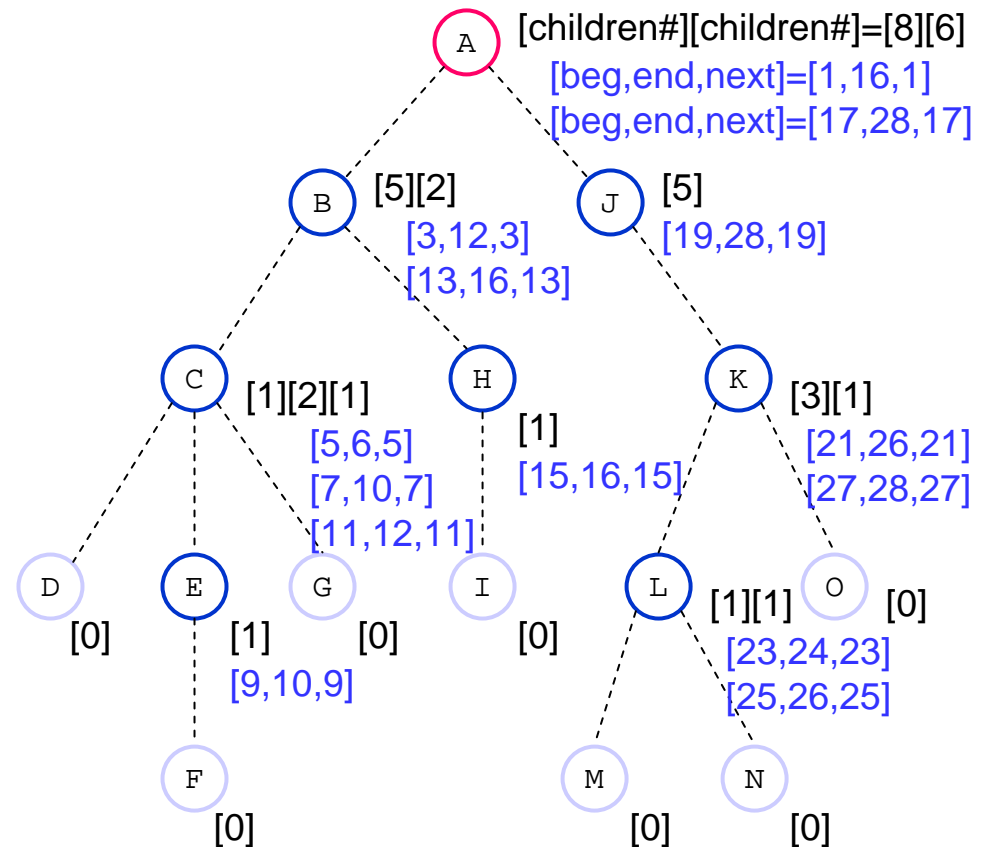




Adaptive Tree Formation

– Initialization Phase

- Stage 1: Association
- Stage 2: Reporting number of children
- Stage 3: Address assignment
 - An AT is formed.
 - Additional addresses can be reserved.





Adaptive Tree Formation

– Operation Phase

- Normal data transmissions

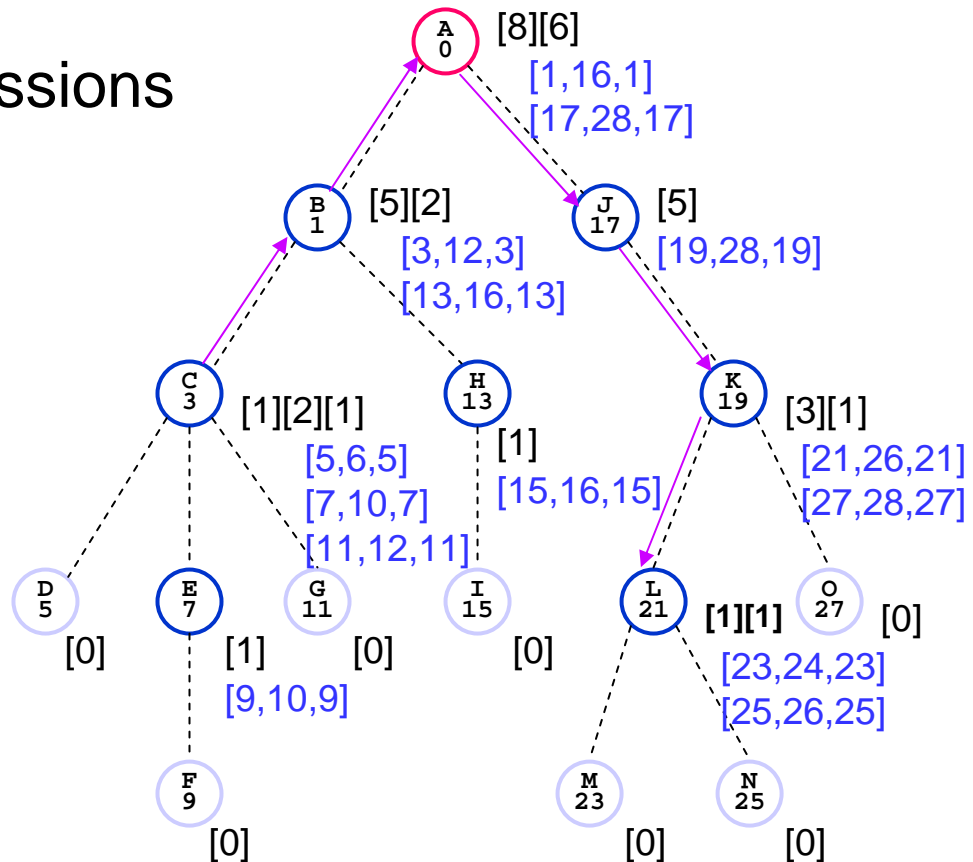
- Look at the address blocks for the destination address and route the packet accordingly.

- If not found, route through parent.

– **Example:**

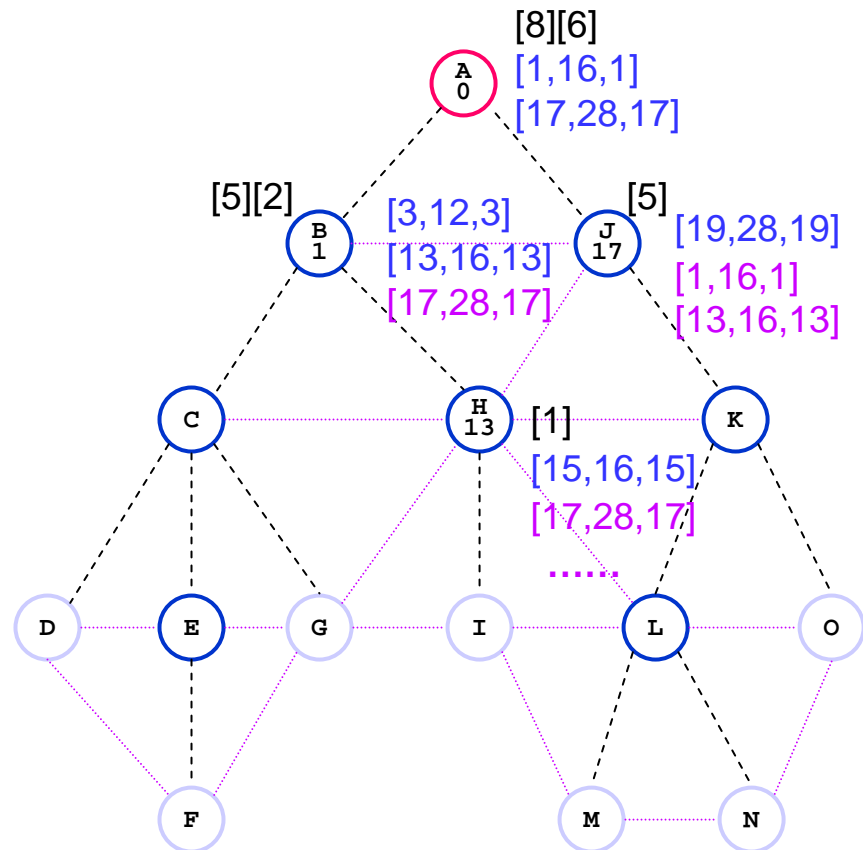
Node C → node L

- Nodes are still allowed to join the network



Meshed AT Formation

- Neighbors treat each other as a child.
- Advantages
 - Shorter paths
 - Elimination of SPOFs

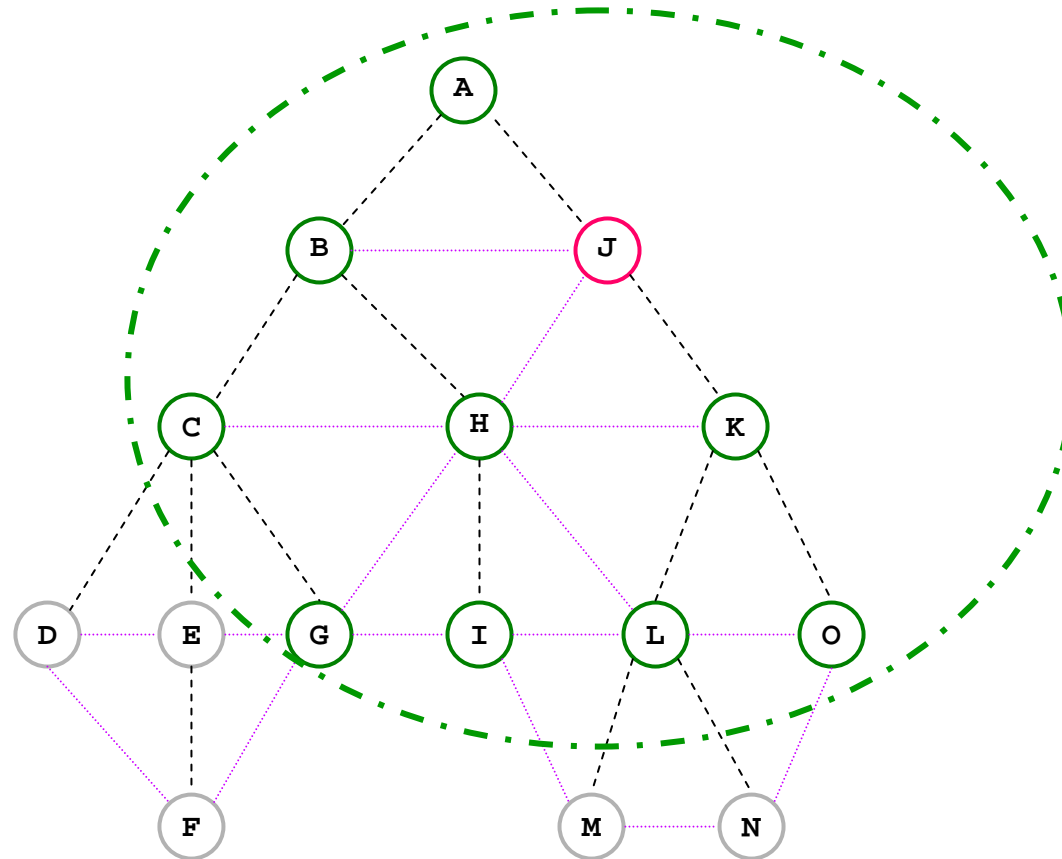


Unicast Routing

- **Meshed Adaptive Tree**
 - Provides the basic functions of routing;
 - Immediately available after MAT is formed.

- **Distributed Link State**
 - More efficient routing can be achieved.
 - Requires exchange of neighbor information.
 - Note global link state information is NOT needed.

The Basic Link State Scheme



3-hop Link State (view of node J)

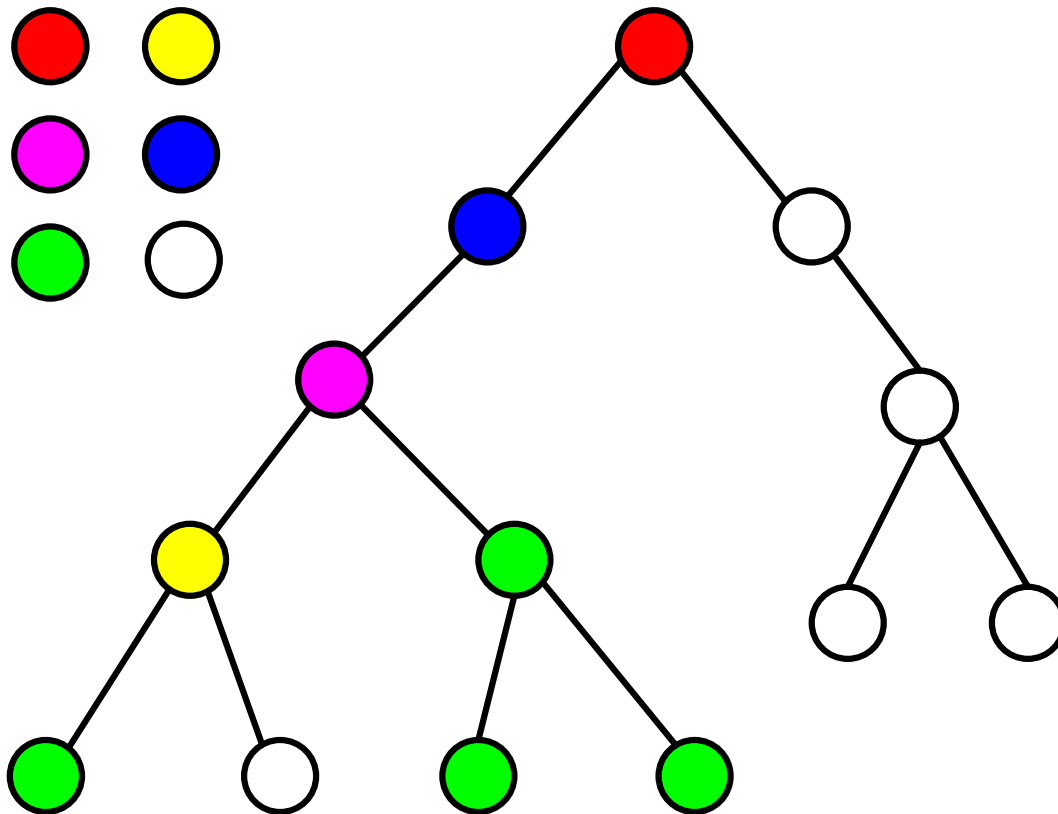
Unicast Routing – Summary

- **Simplicity**
 - No route discovery
 - No route repair
- **Adaptive Address Assignment (AAA)**
 - avoiding “running out of addresses” problem
- **Meshed AT (MAT)**
 - shorter path
 - robustness
- **Distributed Link State**
 - scalability
 - multiple paths and robustness
 - shorter path

Multicast Routing

- This multicast routing proposal is based on the Adaptive Tree protocol for the unicast routing.
- The Adaptive Tree (AT) algorithm constructs a shared tree which spans all the nodes in a WPAN mesh network.
- Our goal is to find a minimum sub-tree of the Adaptive Tree which covers all multicast members within each multicast group.

Logical Entities

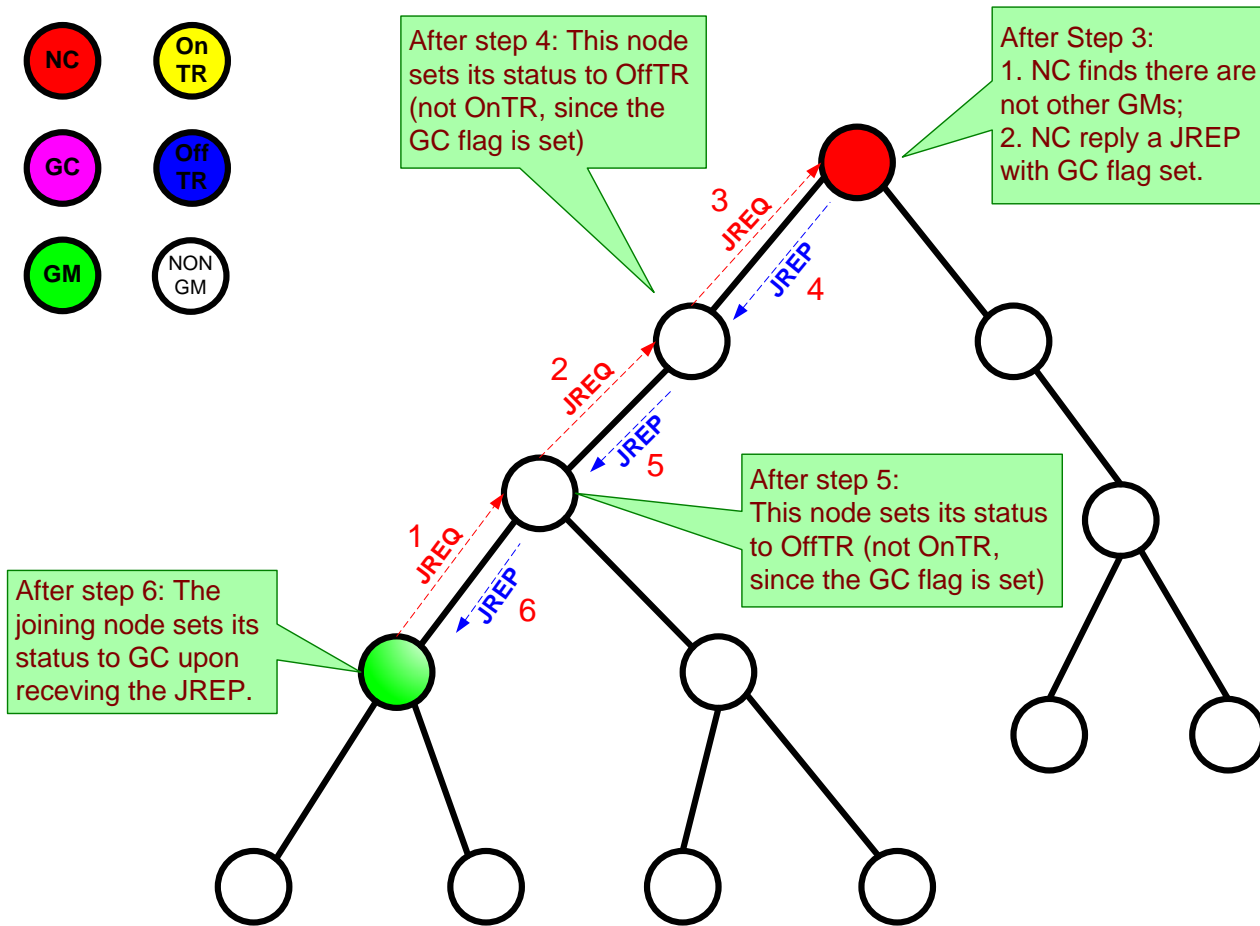


- **Group Member (GM)** – a node participating a multicast group
- **On-Tree Router (OnTR)** – nodes on the multicast tree but not GMs
- **Group Coordinator (GC)** – the top level GM or OnTR of a specific multicast group (sub-tree root). It sets the upper bound of the multicast tree.
- **Network Coordinator (NC)** – the root of the AT. It keeps information of all multicast groups in the network so that it always knows from which child(ren) it can reach the multicast tree for a specific group.
- **Off-Tree Router (OffTR)** – nodes that are GC's direct ancestors (including TC). These nodes are not on the multicast tree but they know from which child they can reach the multicast tree
- **Non-Member (NON-GM)** – nodes have no knowledge about a specific multicast group.

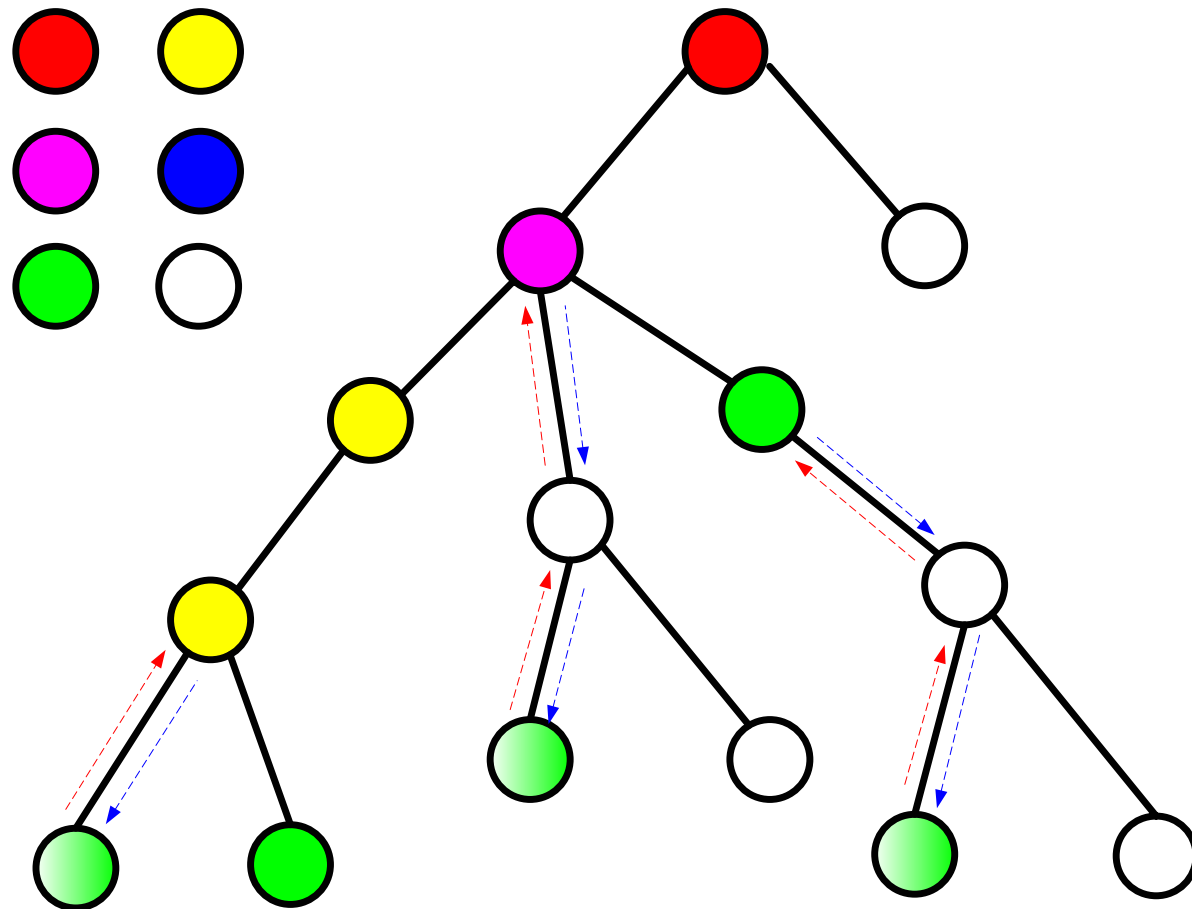
Functions and Message Types

- Joining the Multicast Group
- Leaving the Multicast Group
- Switching Role as Group Coordinator
- Terminating the Multicast Session

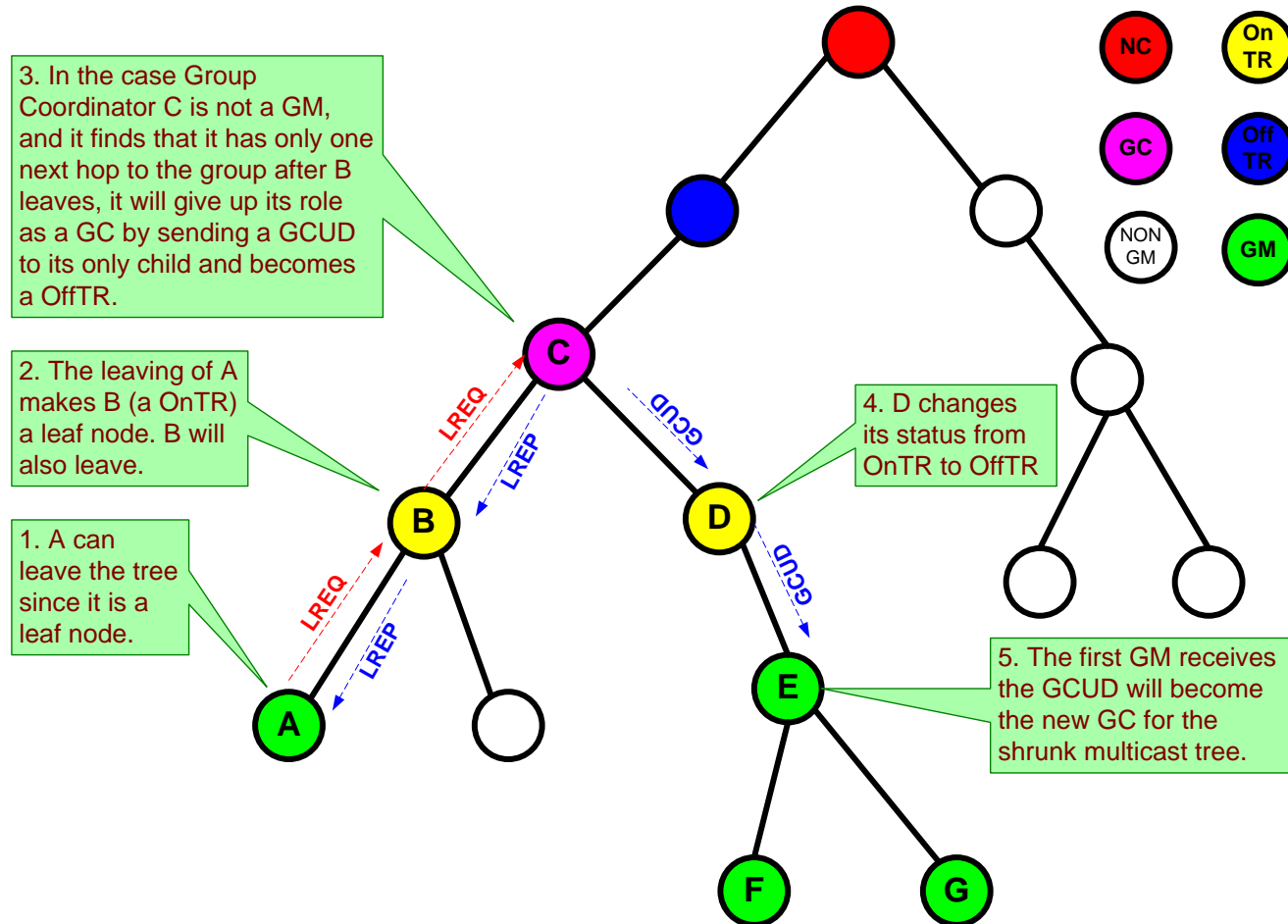
Joining the Multicast Group – First GM



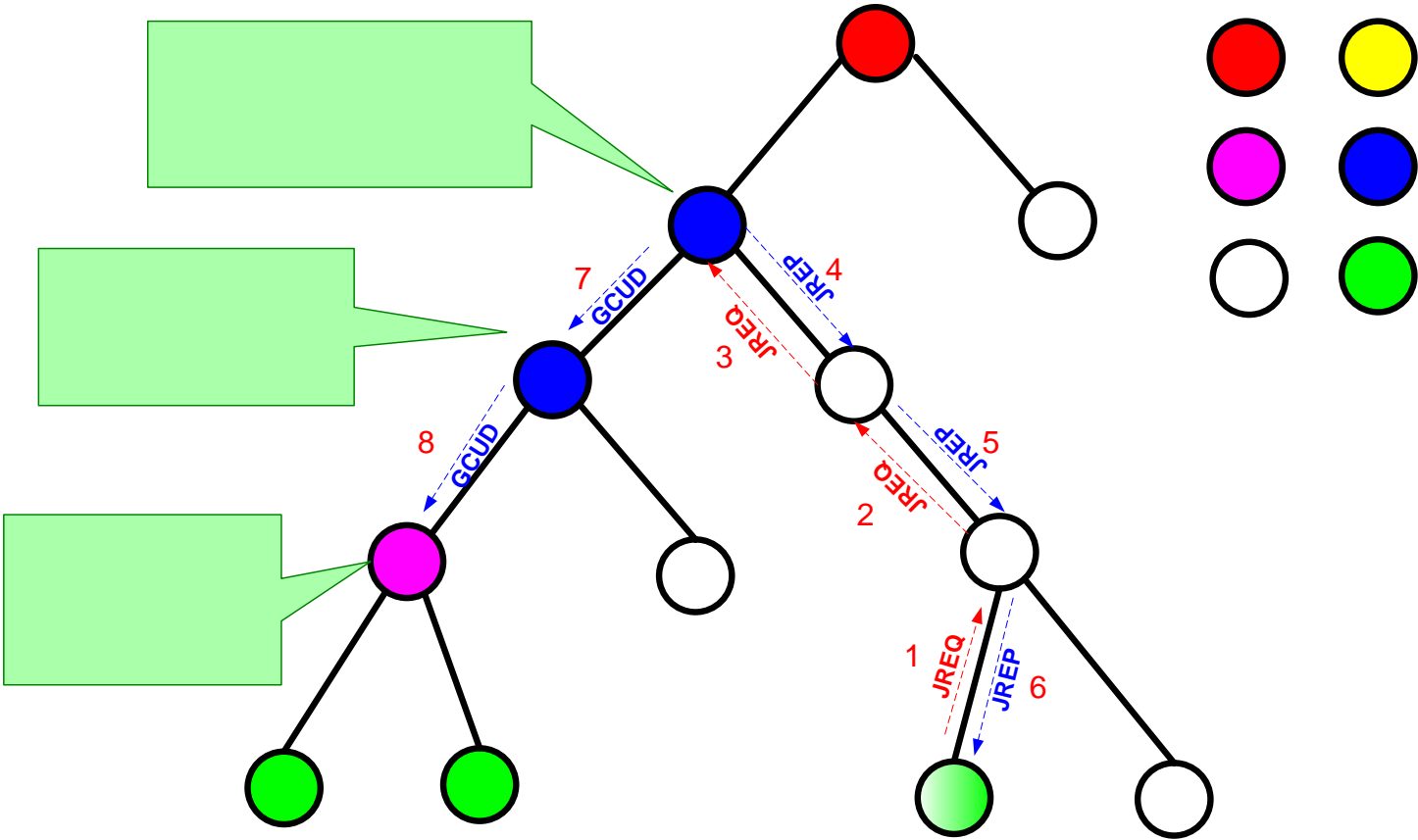
Joining the Multicast Group – Normal Cases



Leaving the Multicast Group



Switching Role as GC – New GM Join



Terminating the Multicast Session – Group Dismiss

- When a multicast group finishes its session, one of the members can issue a GDIS packet (multicast) to all the members to indicate the end of the group communication;
 - The application will determine which member have the right to issue this GDIS packet;
- Upon receiving the GDIS packet
 - GMs and OnTRs will delete all the information related to this group;
 - GC will issue a LREQ toward NC and follow the operation of the GC leave.
 - All OffTRs along the route to NC and the NC will delete all the information related to this group by this process.
- The GDIS packet reduce the control traffic led by GM's leaving process described before.

Data Transmission Mechanism

- Multicast packets propagate (via MAC layer broadcast) following the multicast tree;
 - The GC limits the packet propagation to be inside the multicast tree.
- Nodes process/forward the multicast packets depending on their participation level in the multicast group.
 - GM/GC/OnTR/OffTR/NC/Non-GM
- Non-members can send packets to the multicast group but cannot receive.
 - Non-GM unicast packets toward the NC until the packets hit a GM/OnTR/OffTR/GC/NC.
 - Not recommended due to security reasons.

Highlighted Features

- **Low control overhead**
 - No control traffic is broadcast;
 - In most cases, the Network Coordinator is not bothered for transmitting control and data messages.
- **Adaptive**
 - The introduction of Group Coordinator and simple joining/leaving algorithm guarantee the multicast sub-tree is minimal at any time.
- **Simple and timely data propagation.**
 - Data packets do not need to go to the Network Coordinator first.
- **Non-members can also send packets to members;**

Features under Considerations

- Power efficiency support
- Support of connecting to IEEE 802 networks.
- Improved broadcast support, e.g., reliable broadcast.
- Mobility/portability support
- QoS provisioning such as access and fairness control and traffic priority controls
- Frequency Agility to enable for mesh network to dynamically change operating channel to mitigate environmental interference

Please see document 06/0333r05 for details.

Thank you!!

Any Question?