

IEEE 802 Wireless Mesh Networks

Submission to 802.0 Wireless Architecture Sub Group

Date: 2005-11-14

Notice: This document has been prepared to assist IEEE 802.11. 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 grants a free, irrevocable license to the IEEE to incorporate material contained in this contribution, and any modifications thereof, in the creation of an IEEE Standards publication; to copyright in the IEEE's name any IEEE Standards publication even though it may include portions of this contribution; and at the IEEE's sole discretion to permit others to reproduce in whole or in part the resulting IEEE Standards publication. The contributor also acknowledges and accepts that this contribution may be made public by IEEE 802.11.

Patent Policy and Procedures: The contributor is familiar with the IEEE 802 Patent Policy and Procedures <<http://ieee802.org/guides/bylaws/sb-bylaws.pdf>>, including the statement "IEEE standards may include the known use of patent(s), including patent applications, provided the IEEE receives assurance from the patent holder or applicant with respect to patents essential for compliance with both mandatory and optional portions of the standard." Early disclosure to the Working Group of patent information that might be relevant to the standard is essential to reduce the possibility for delays in the development process and increase the likelihood that the draft publication will be approved for publication. Please notify the Chair <stuart.kerry@philips.com> as early as possible, in written or electronic form, if patented technology (or technology under patent application) might be incorporated into a draft standard being developed within the IEEE 802.11 Working Group. **If you have questions, contact the IEEE Patent Committee Administrator at <patcom@ieee.org>.**

Authors:

Name	Company	Address	Phone	email
Guido R. Hiertz	Philips & ComNets, Chair of Communication Networks, RWTH Aachen University	Kopernikusstr. 16, 52074 Aachen, Federal Republic of Germany	+49-241-802-5829	hiertz@ieee.org
Sebastian Max	Philips & ComNets, Chair of Communication Networks, RWTH Aachen University	Kopernikusstr. 16, 52074 Aachen, Federal Republic of Germany	+49-241-802-0547	smx@comnets.rwth-aachen.de
Yunpeng Zang	Philips & ComNets, Chair of Communication Networks, RWTH Aachen University	Kopernikusstr. 16, 52074 Aachen, Federal Republic of Germany	+49-241-802-5829	zangyp@ieee.org
Lothar Stibor	Philips & ComNets, Chair of Communication Networks, RWTH Aachen University	Kopernikusstr. 16, 52074 Aachen, Federal Republic of Germany	+49-241-802-3923	lstr@comnets.rwth-aachen.de
Hans-Jürgen Reuerman	Philips Research Laboratories	Weißhausstr. 2, 52066 Aachen, Federal Republic of Germany	+49-241-600-3629	hans-j.reuerman@philips.com

Abstract

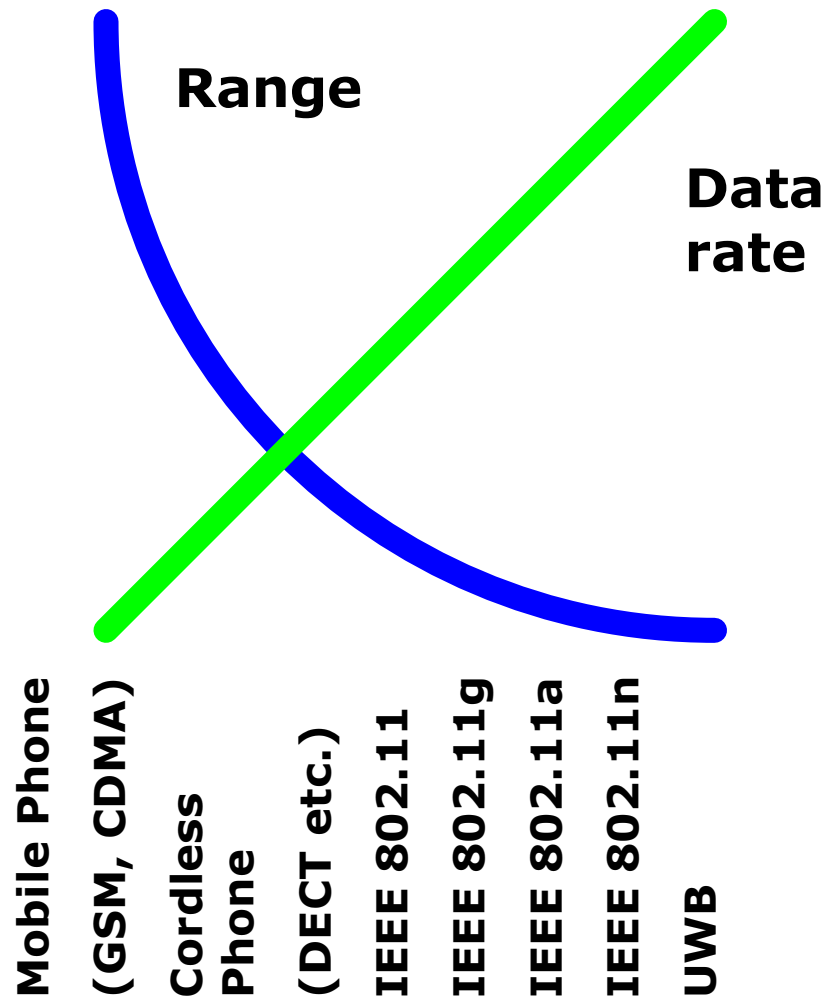
We give an introduction to IEEE 802 Mesh technologies. The usage of Mesh technology for wireless networks is motivated by the decreasing range of wireless high speed PHY technology. Deployment of numerousness APs is not desired and expansive, if each must be connected to a wired backbone. Wireless multi-hop transmissions help to decrease deployment costs.

**This version has been edited for publication as
PDF file at ComNets, RWTH Aachen
University.**

**Some animations may not be displayed correctly
in PDF format.**

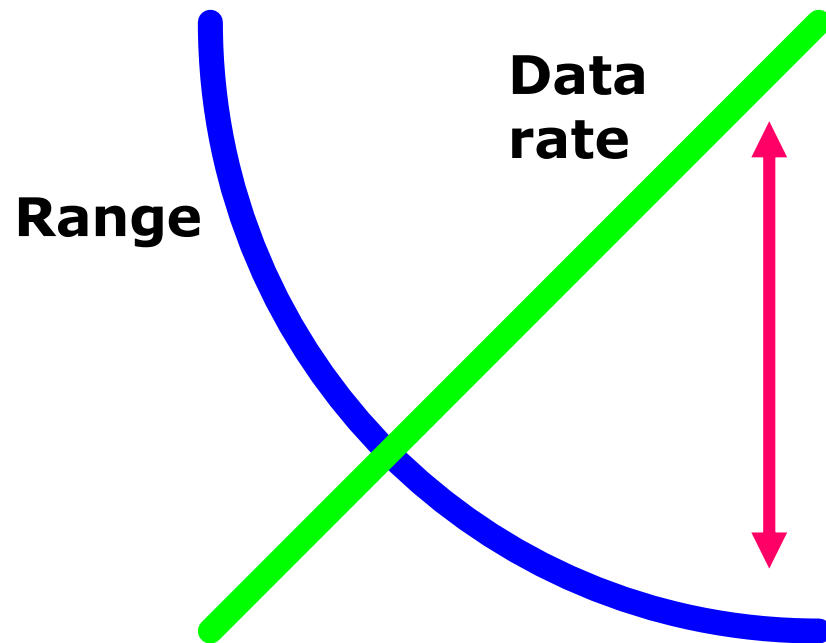
**Please see <http://802wirelessworld.com> for the
original version in PowerPoint format.**

Evolution of Wireless networks



- **Constant performance increase**
 - Sensitive coding & modulation
 - High quality wireless signal needed
- **Range decreases**

How to fill the “gap”?



- **Tremendous gain in transmission speed**
 - UWB: 480Mb/s @ 2m
- **Only minor distances**

- **Solution?**

- Piconet installation
 - Fixed high speed backbone
 - Static, not ad-hoc
 - Expensive
- Directed antennas
 - Convenient for customer?
- Smart antennas
 - Cost effective?
 - Power consumption?
 - Computation power?

Pervading computing ... Pervading networks

Ubiquitous?

- **Ubiquitous computing**
 - Laptop, Notebook
 - PDA, Smart Phone
- **Ubiquitous voice services**
 - GSM, UMTS
 - Voice over IP (VoIP)
 - GPRS, UMTS
- **Ubiquitous streaming services**
 - Digital Video Broadcasting (DVB)
 - Digital Audio Broadcasting (DAB)
- **Ubiquitous wireless services**
 - High speed
 - $\sim 1\text{Gb/s}$
 - Customer convenience
 - Roaming enabled
 - *Full* coverage wanted

Coverage?

- **High speed decreases network coverage**
- **Short distance to communication partner**

The need for multi-hop transmissions

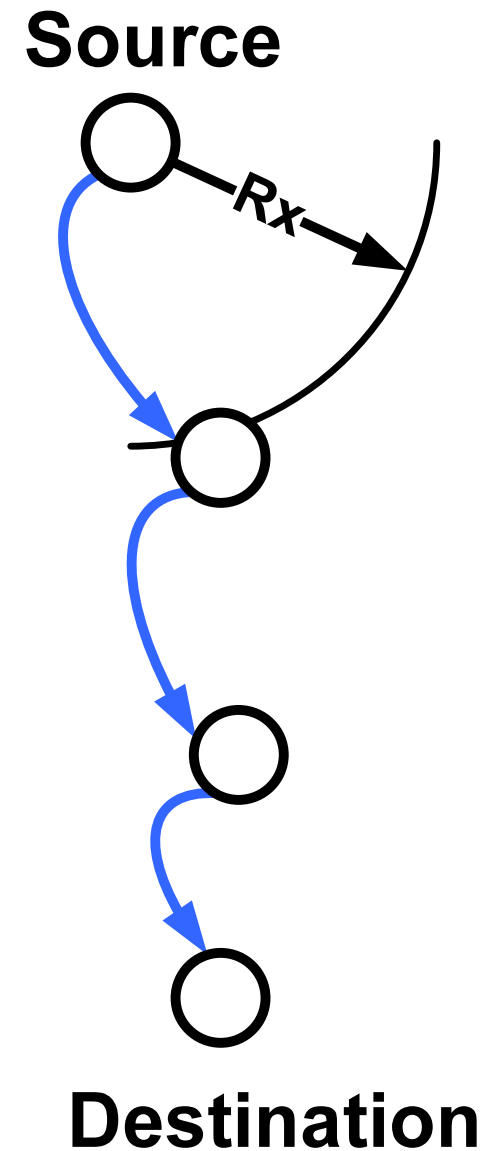
- **Limited range**
 - 1Gb/s WLAN & WPAN
 - Cellular (UMTS, HSDPA)
- **Limited transmission power**
 - Regulatory bodies
 - Exposure to human beings
- **Limited bandwidth**
 - Unlicensed bands
 - Reuse of scarce resource necessary
- **Deployment costs**
 - Power almost everywhere
 - Backbone access expensive
- **No wired IT infrastructure in CE market**
- **Backhaul to base station expensive**

→ **Extend coverage via wireless multi-hop**

Coverage?
→ Multiple Access Points

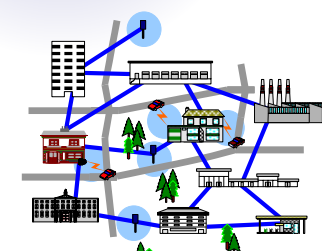
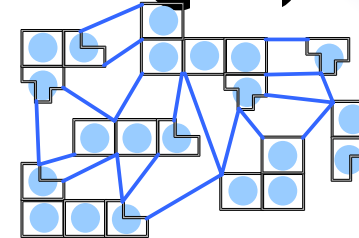
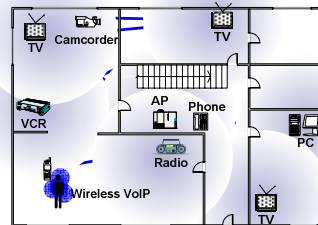
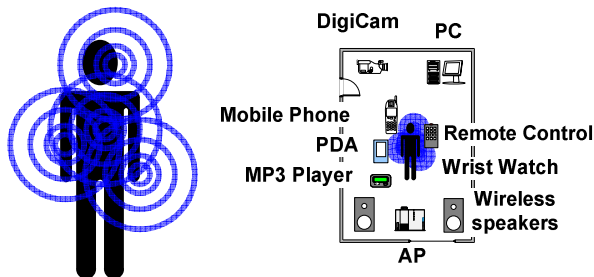
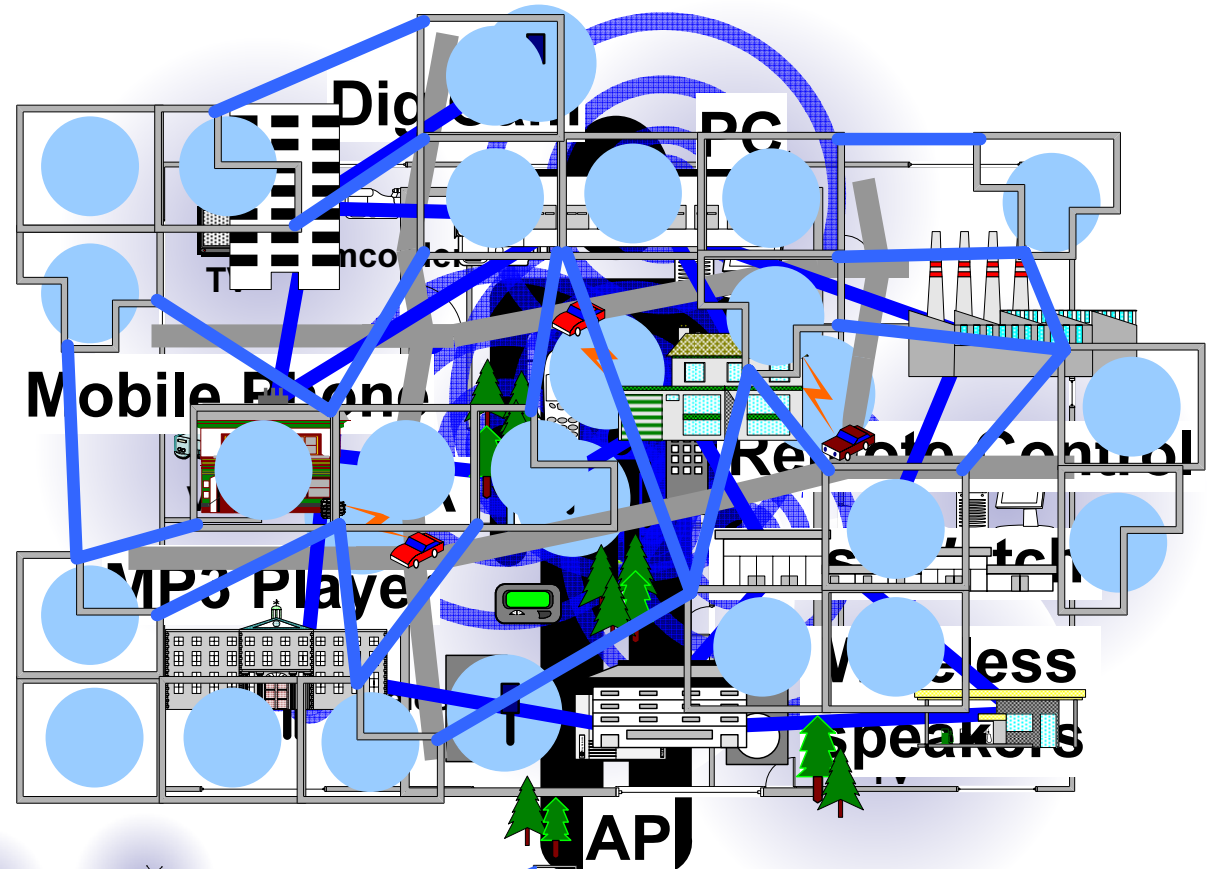
Multi-hop: Relay-/Forwarding concepts

- **Wireless devices forward data**
 - Multi hop connection
 - **Hierarchical forwarding**
 - Via cluster head
 - **Decentralized forwarding**
 - Each device is wireless router
- **Mesh Networks**



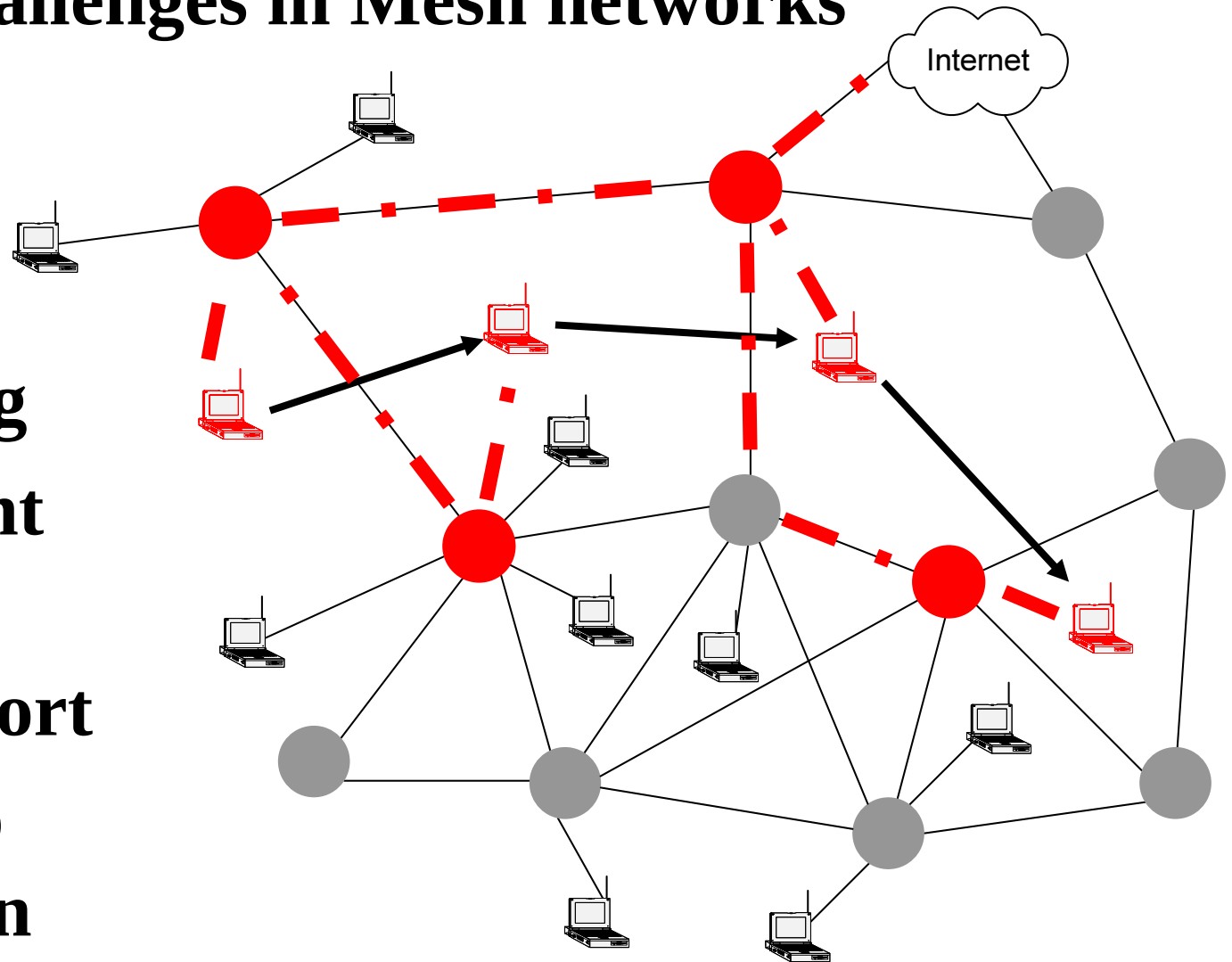
Ubiquitous Mesh Networks

- **WPAN, 802.15.5**
 - Body
 - Single room
- **WLAN, 802.11s**
 - Apartment
 - Office
 - Campus
 - Street
- **WMAN, 802.16**
 - City



Challenges in Mesh networks

- **Ad hoc**
- **Mobility**
- **Self organizing**
- **Redundant links**
- **QoS support**
- **Multi hop connection**



Overview of MAC designs

IEEE 802.15.3

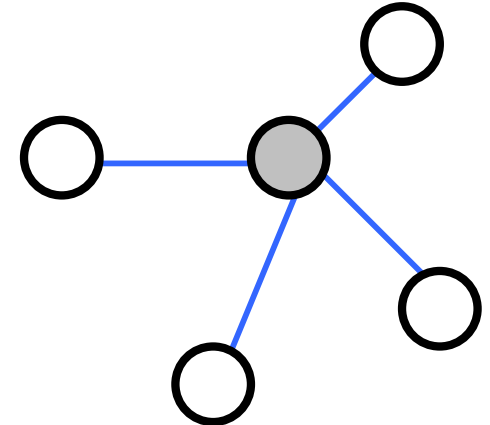
- **Centralized MAC**

- Piconet-Controller (PNC)
- Scheduled access

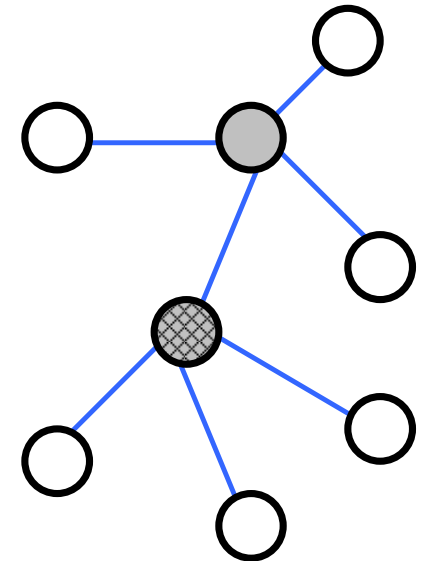
- **Extensions**

- Child Piconet-Controller
- Hierarchy
 - Organizing
 - Scheduling

802.15.3 MAC,
centralized, Piconet-
Coordinator (PNC)

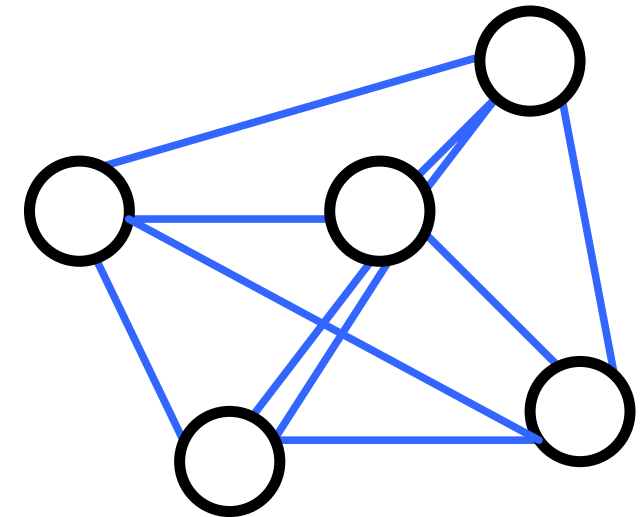
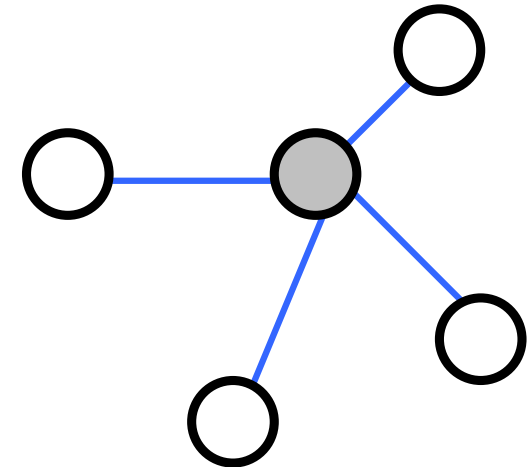


802.15.3 MAC,
forwarding via
hierarchy, PNC
and Child Piconet-
Coordinator



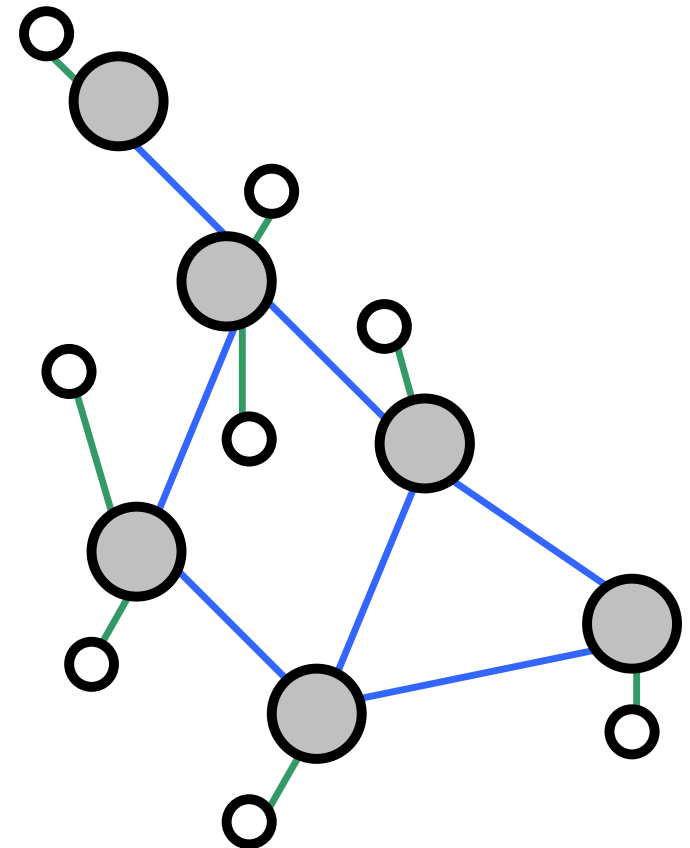
IEEE 802.11

- **Infrastructure mode**
 - Distributed channel access
 - AP centered
 - All traffic via AP
- **Independent Basic Service Set (IBSS) mode**
 - All stations in mutual reception range



IEEE 802.11s – Mesh WLAN

- **Hierarchical Mesh**
 - AP form Mesh WLAN
 - Routing
 - Packet forwarding
 - Topology control
- **Stations**
 - Unchanged
 - Connect to AP



IEEE 802.16 – WiMAX

- **Similar to HiperLAN/2**
 - Centralized approach
 - Single coordination entity
- **Mesh configuration foreseen**
 - No deployment until now
 - Mobile Multihop Relay (MMR) Study Group
- **Scheduling highly important**

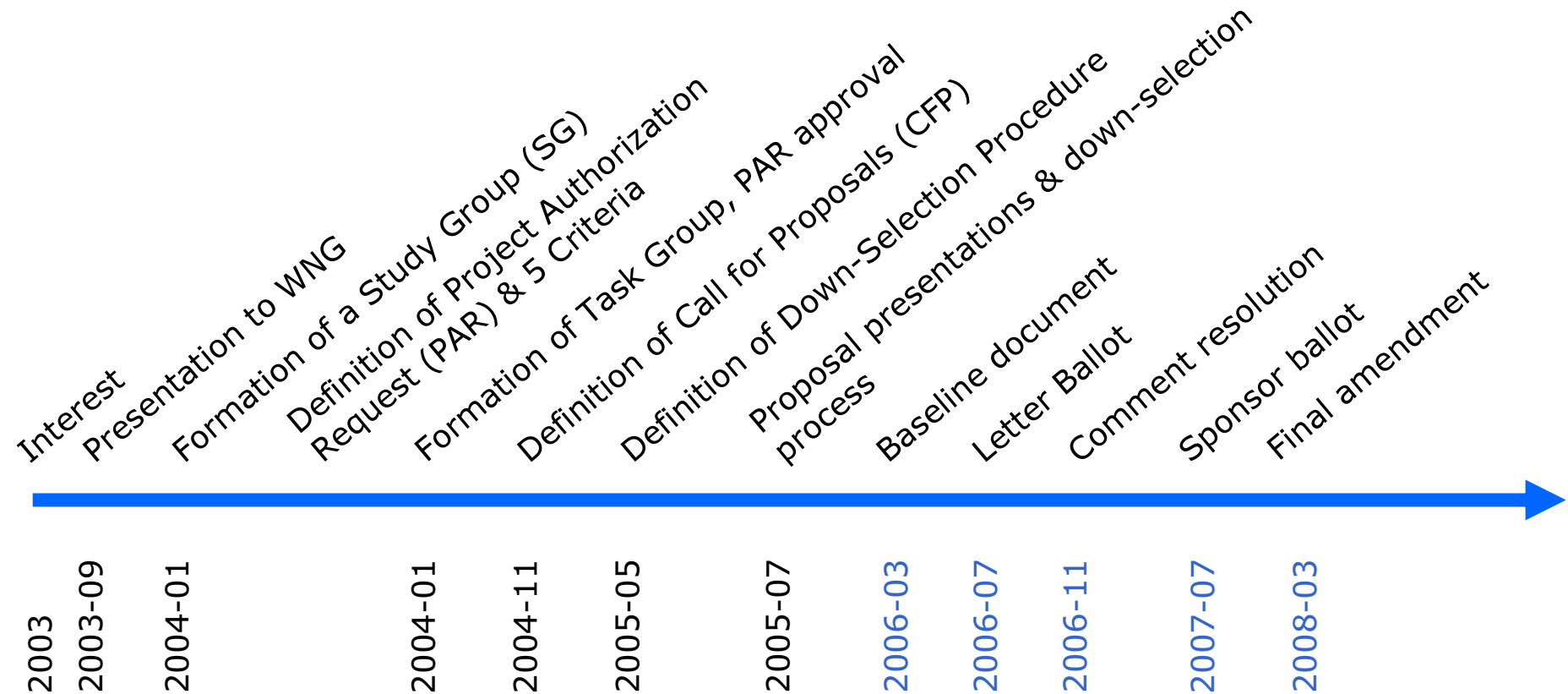
MAC designs – Comparison

- **Centralized**
 - Highly efficient scheduling
 - Central entity
 - Exclusive channel coordination
 - Coexistence, cooperation difficult
 - Difficult in Mesh configuration
 - Central nodes needs global knowledge
 - Impossible?
- **Decentralized**
 - Robust
 - Adaptive
 - Less effective than central scheduling
 - Common resources can be shared
 - Distributed topology information
 - Local view of network
 - Local decisions
 - Interference horizon

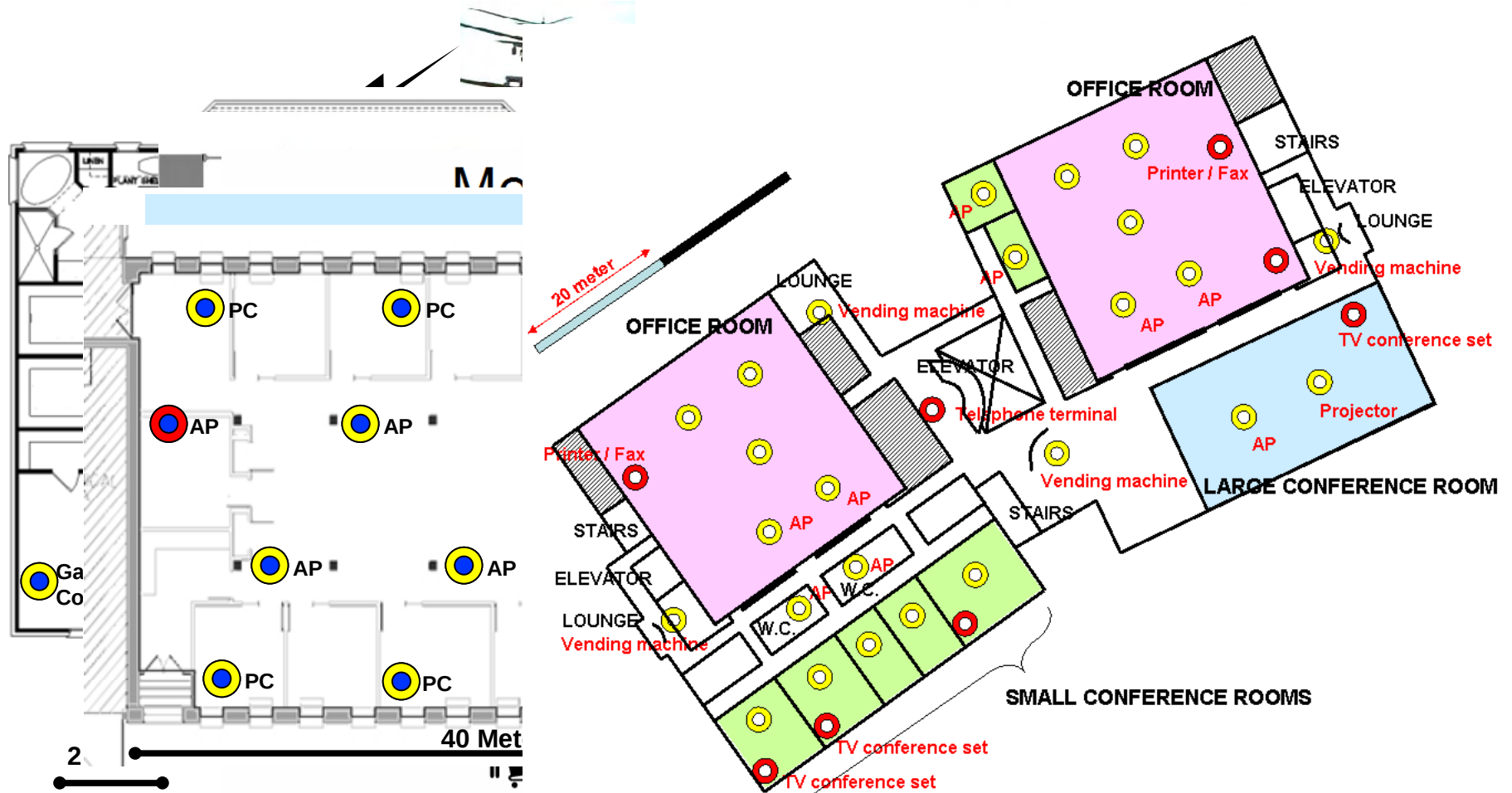
IEEE 802.11s

Mesh WLAN

IEEE 802.11 process – TGs as example



Usage scenarios for Mesh WLAN – IEEE 802.11s

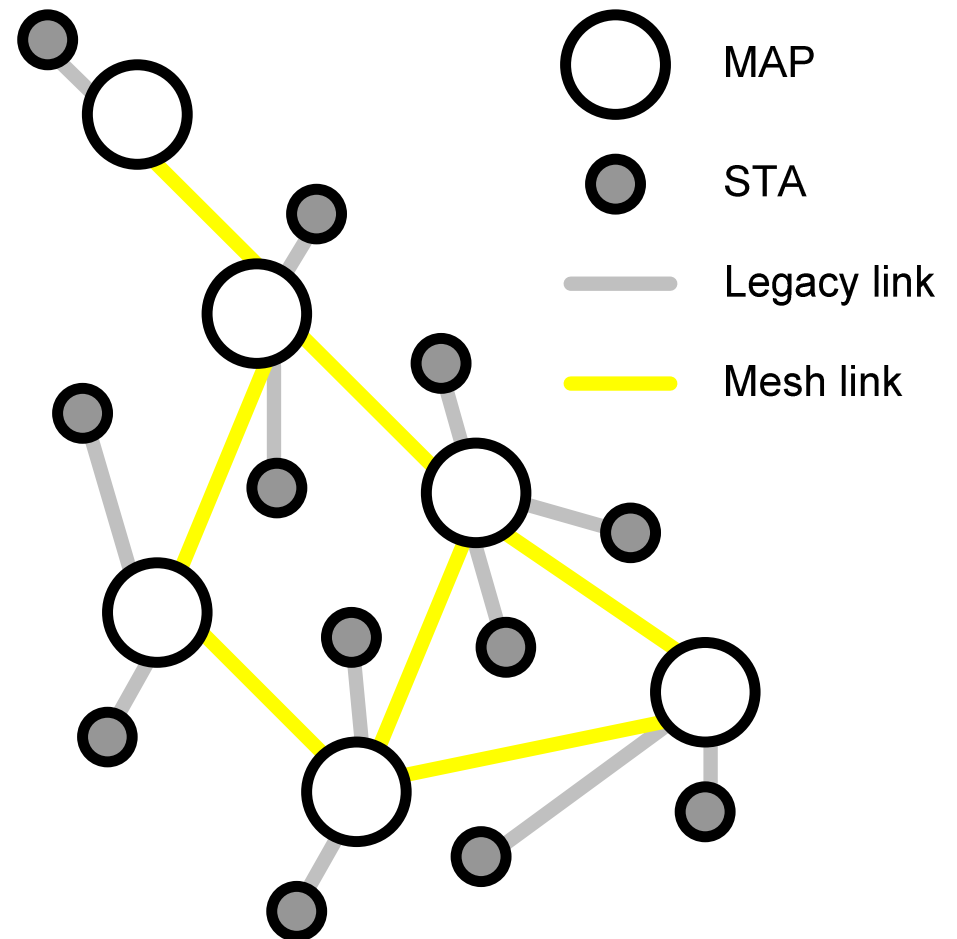


IEEE 802.11s – Project Authorization Request

1. The proposed amendment shall be an extension to the IEEE 802.11 MAC.
2. The amendment will define an architecture and protocol for providing an IEEE 802.11 ESS Mesh [...] to create an IEEE 802.11 Wireless Distribution System
3. [...] over self-configuring multi-hop topologies.
4. An ESS Mesh is functionally equivalent to a wired ESS, with respect to the STAs relationship with the BSS and ESS.
5. A target configuration is up to 32 devices participating as AP forwarders in the ESS Mesh.
6. The amendment shall utilize IEEE 802.11i security mechanisms, or an extension thereof
7. [...] in which all of the APs are controlled by a single logical administrative entity for security.
8. The amendment shall allow the use of one or more IEEE 802.11 radios on each AP in the ESS Mesh.

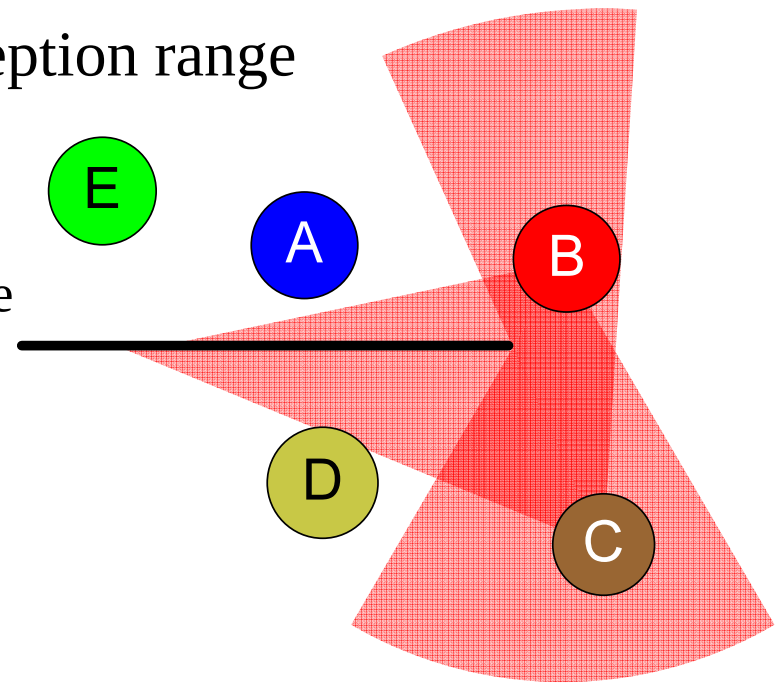
Legacy impacts Mesh WLAN

- **Seamless integration**
 - Legacy 802.11 stations (STAs) *AND*
 - 802.11s Mesh Access Points (MAPs)
- **Fully backwards compatible**
 - No changes to existing STAs needed
 - Mitigate interference from legacy to Mesh
- **Support for 1 or more MAP radios**



Mesh WLAN – Interference in dense networks

- **Mutual interference (Stations, Mesh Access Points etc.)**
 - Hidden & Exposed Nodes
 - Interference range exceeds reception range
 - RTS/CTS designed for single hop
 - Virtual carrier sense (Network Allocation Vector) often cannot be received
- **802.11 limits spatial frequency reuse (capacity)**



MAC layer based packet forwarding ("routing")

- **802.11 Wireless Distribution System**
 - Mesh WLAN must be transparent for
 - Stations
 - Higher layers
- **IP layer blind for channel condition**
- Routing at MAC Layer
- **Extend IETF MANET concepts**
 - On-demand, proactive or hybrid routing
- **Additional input for routing decision**
 - PHY mode, Packet Error, Transmit power, hop count, link load etc.

Mesh WLAN – A multi level approach

- **MAC changes**
 - Overcome multi hop limitations
- **Channel measurements**
 - 802.11 Task Group “k” concepts
- **Multihop security**
 - Extend 802.11i amendment
- **Support Roaming (Task Group “r”)**
- **Routing concepts**
 - Interface/Information for routing
 - Small scale Mesh WLAN
- **Congestion & Call admission control**
- **Segregate Mesh WLAN from BSS**

IEEE 802.15.5

Mesh WPAN

IEEE Standardization – Mesh in 802.15

- **Task Group since January 2004**
- **Low & High rate Mesh WPAN**
 - Call for Proposals
 - No submissions for low rate received
 - Growing attraction
 - Devices for mass market
 - Fully decentralized
- **Addressed topics**
 - MAC enhancements
 - Routing
 - Security
- **Streaming applications, CE**
 - Video
 - Audio
- **VoIP**
- **Sensor networks**

Decentralized MAC additions for Mesh WPAN

- **IEEE 802.15.3**
 - Centralized approach
 - Efficient for single hop
 - Based on exclusive channel
 - Coexistence of multiple Piconet Controllers difficult
 - No local decisions
 - But Mesh is not a star topology!
 - Only central node has topology overview
 - No solution for Mesh based on 802.15.3 proposed to IEEE
- **Decentralized approach**
 - Decentralized coordination
 - Well suited for multiple hops
 - Beacons provide local knowledge/measurements
 - Horizon for reception range
 - Interference range
 - Reservation based access
 - Allow for scheduled transmissions
 - Efficient spectral frequency reuse possible

Summary

- **Mesh technology**
 - Important for **any** future wireless system
 - Cost-effective deployment
 - Enabling wireless next generation
- **Questions are welcome!**

Thank you for your attention!

hiertz@ieee.org