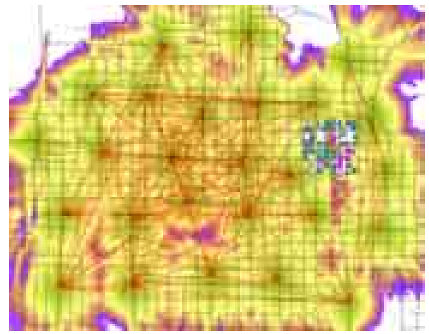
sponsored by FP6 IST Daidalos
www.ist-daidalos.org



Peer-to-Peer Services in Community Mesh Networks

Andreas Kassler, Marcel Castro

Karlstad University
Sweden
kassler@ieee.org

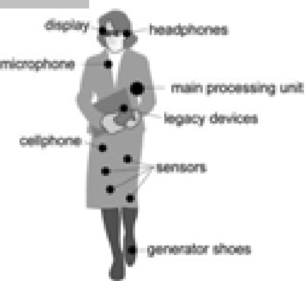
Acknowledgement

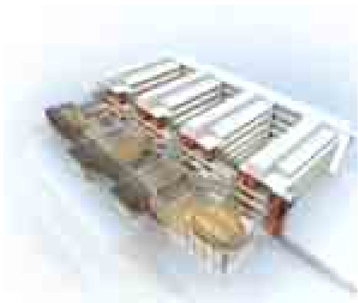
- Some simulation results on P2P over multihop have been done within the IST-Daidalos project (see www.ist-daidalos.org)
- Some slides have been adopted from Nitin Vaidya (UIUC) - see http://www.crhc.uiuc.edu/wireless/tutorials.html
- Some slides have been adopted from Victor Bahl (Microsoft Research) – see http://research.microsoft.com/~Bahl/Talks.aspx
- Some terminology slides follow the slides from M. Sichitiu – see http://www.ece.ncsu.edu/wireless/
- Some slides on Peer-to-peer networks have been adopted from
  - Ant Rowstron (Microsoft Research) (http://research.microsoft.com/ERO/phd/2007SummerSchool/)
  - Dan Pascu (AG Projects) www.ag-projects.com/docs/Present
  - Y. Richard Yang (Yale Univesity) www.cs.yale.edu/homes/yry/projects/p4p

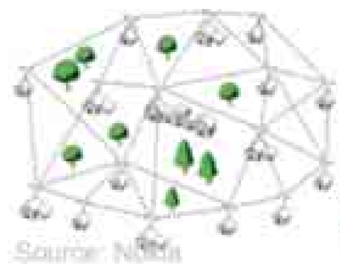
- Overview Part I
  - ➡ Introduction
  - – Motivation and Use Cases
  - – Community Networks
  - – Terminology and Classification
  - – Introduction to Mesh Networks and Routing

Wireless Networks – An Overview

Geographical Scale of the Network





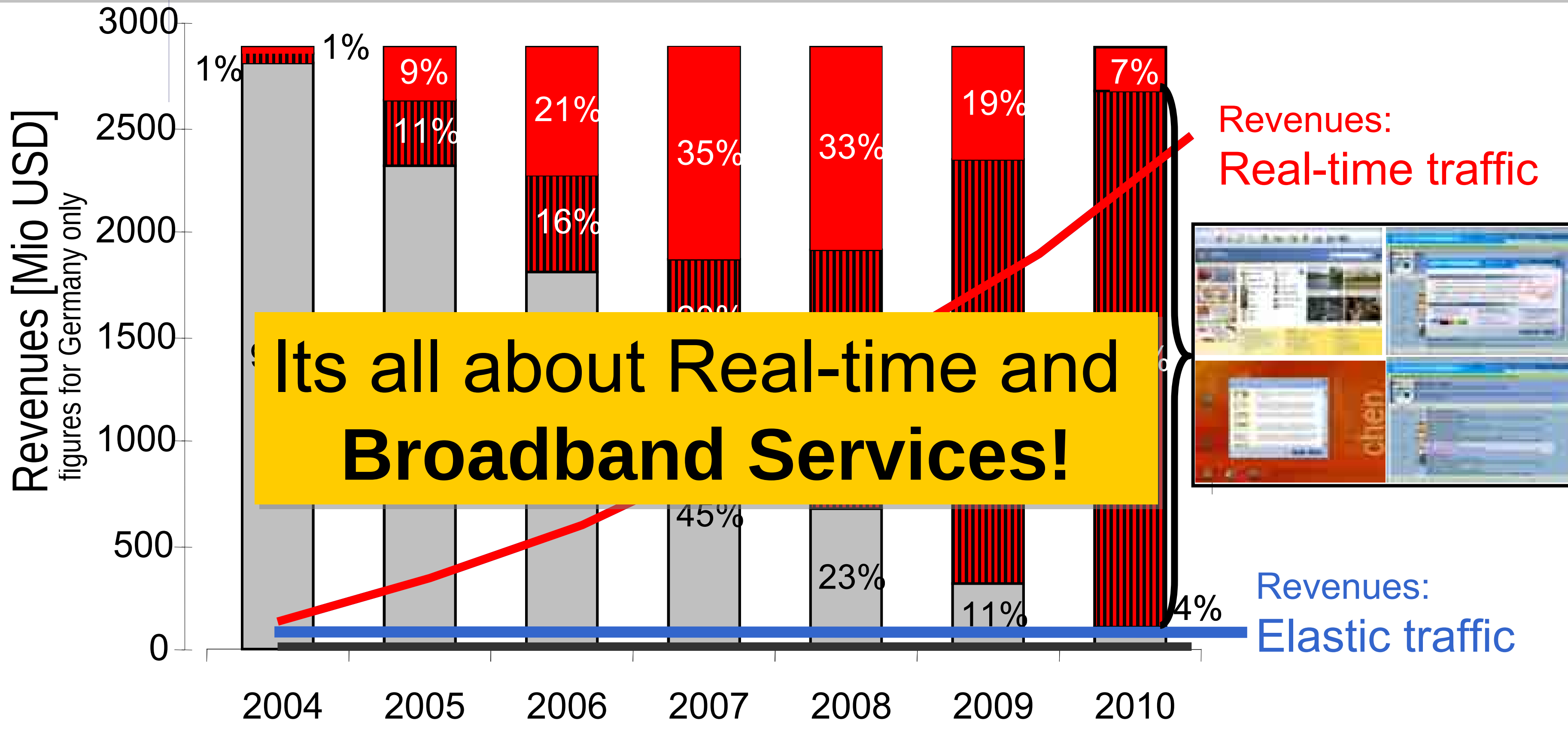


Body Area (WPAN)	inHouse (WLAN)	Rural/Residential Area	Metropolitan Area (WMAN)	Wide Area (WWAN)	**Scale**
Bluetooth IEEE 802.15	IEEE 802.11 HIPERLAN/2		IEEE 802.16 WiMAX	GSM GPRS UMTS	**Technology**

Why is this interesting?

Key Questions:
- Which Network Type will be used most of the time?
-Which Network Architecture will lead to cost benefits?

Evolving IP Traffic Mix



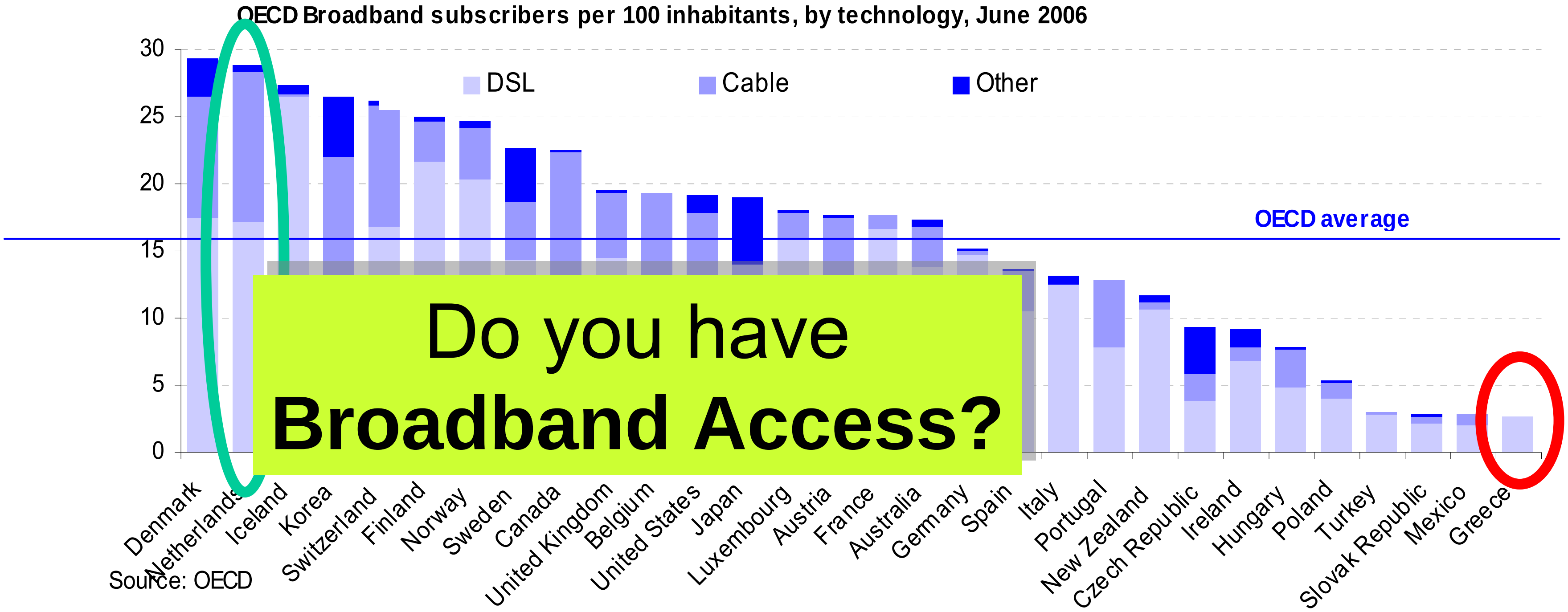
Low-latency real-time traffic: Video-Conferencing, Gaming, VoIP

Real-time traffic: Audio-Streaming, Web-Cam-Usage, (P2P)Video, TVoBroadband

Elastic traffic : File Sharing, P2P Traffic, www

Source: IP 2010, IDC, ScreenDigest, Ovum, DETECON

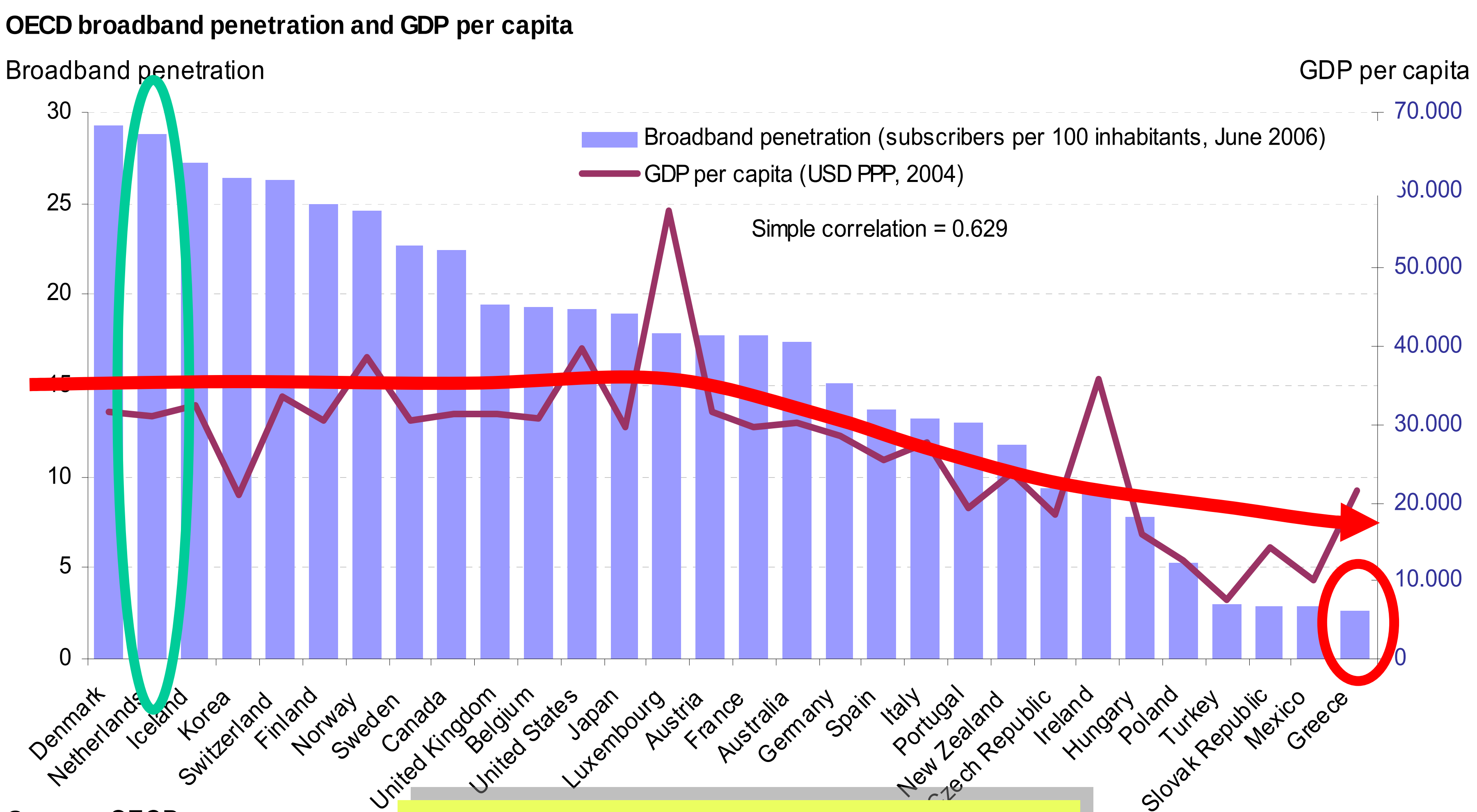
Broadband Penetration



- Other include
  - FTTN (Fibre To The Neighborhood)
  - FTTC (Fibre To The Curb)
  - FTTB (Fibre To The Basement)
  - FTTH (Fibre To The Home)
  - Mobile Broadband Access

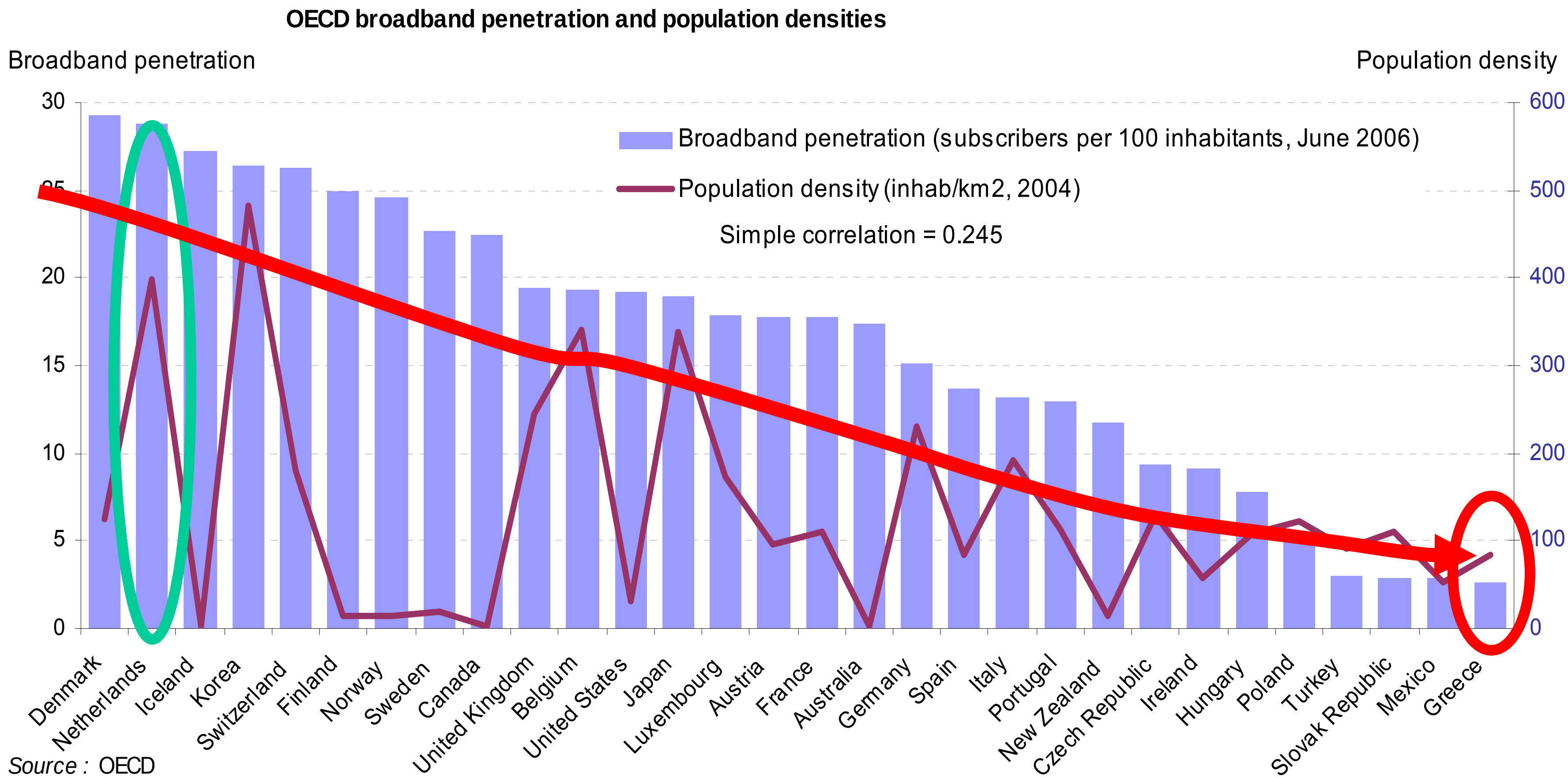
Broadband: at least 256 Kbps

Introduction
Broadband Penetration



Source : OECD

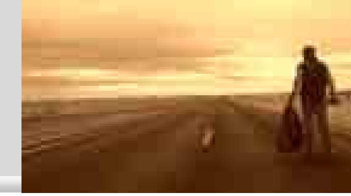
Barriers to „Broadband for all“ are
Low Income → Digital Divide



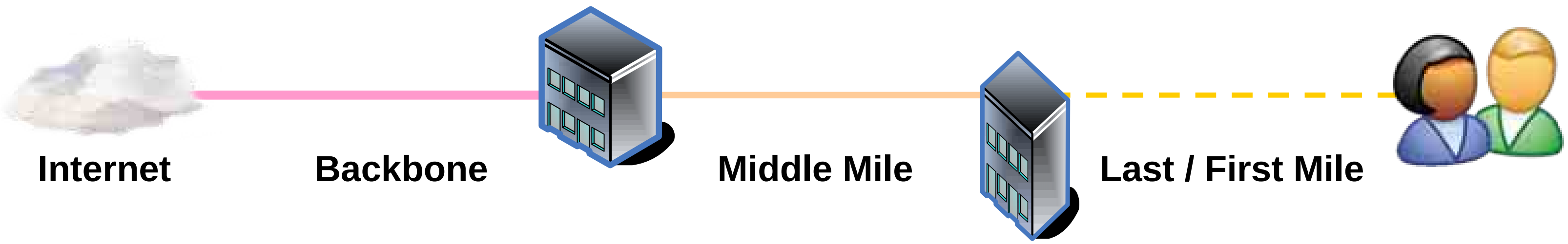
Source : OECD

Barriers to "Broadband for all“ are
Low Population Density

Last Mile is Key to Cost



- Solution 1: wire every house/device?

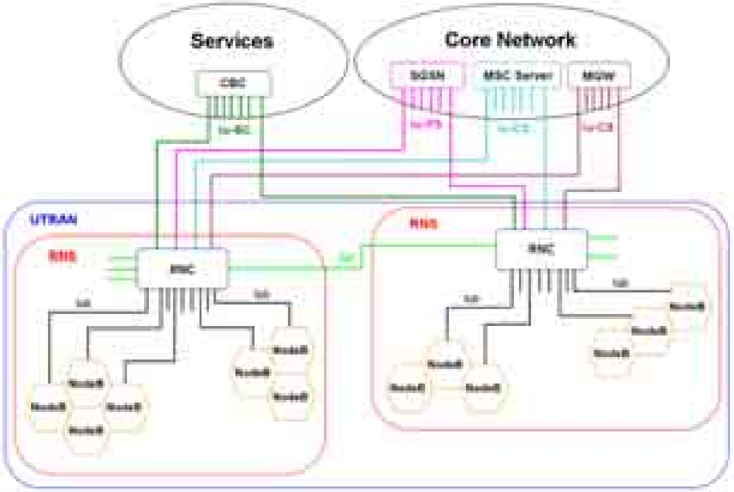


  - Significant Cost and problematic in
    - Countries with large rural areas → Sweden!
    - Large Coutries with ~100 million housing units
    - Developin

Do you have
Fixed Broadband Access?
-ADSL
-Ethernet
-Fiber

Broadband Wireless Access?

- Last Mile: Mobile Radio Networks such as UMTS?
  - Significantly less costs but still need wires
  - Expensive license fees
  - Competition limited to network Operators
    - Licensed frequency bands!
  - Capacity is an issue
    - current 3G is not really high speed
  - Network Architecture is strictly hierarchical



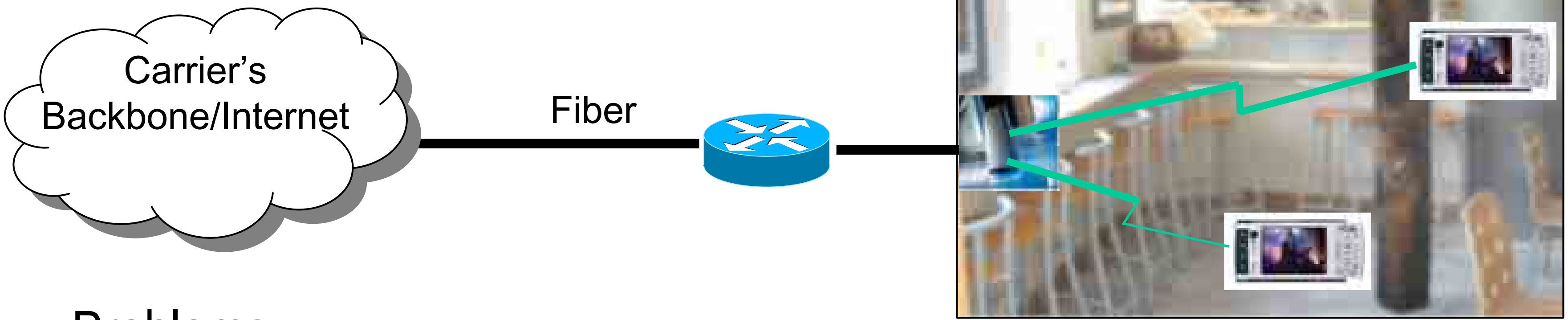
Do you have
Mobile Broadband Access?

För första gången växer antalet mobila bredband snabbare än traditionella bredband som ADSL. ... Det betyder att mer än halva bredbandstillväxten (56 procent) kommer från mobilt bredband...

DN Ekonomi, 29. August 2007

URL: http://www.dn.se/DNet/jsp/polopoly.jsp?d=678&a=686338

- WLAN Hotspots as Alternative?



- Problems:

"Even if I had $1 billion and set up 1000s of locations, I could never in my network have a completely ubiquitous footprint."—Sky Dayton, founder of Boingo

0 metro

nments, if

ntial APs =

starvation

Do you have **WLAN in your home?**

““We need to think of ways to bring wireless fidelity (Wi-Fi) applications to the developing world, so as to make use of unlicensed radio spectrum to deliver cheap and fast Internet access.”

Source: “Kofi Annan's IT challenge to Silicon Valley”, CNET NEWS.com, Nov 2002, http://www.news.com/2010-1069-964507.html

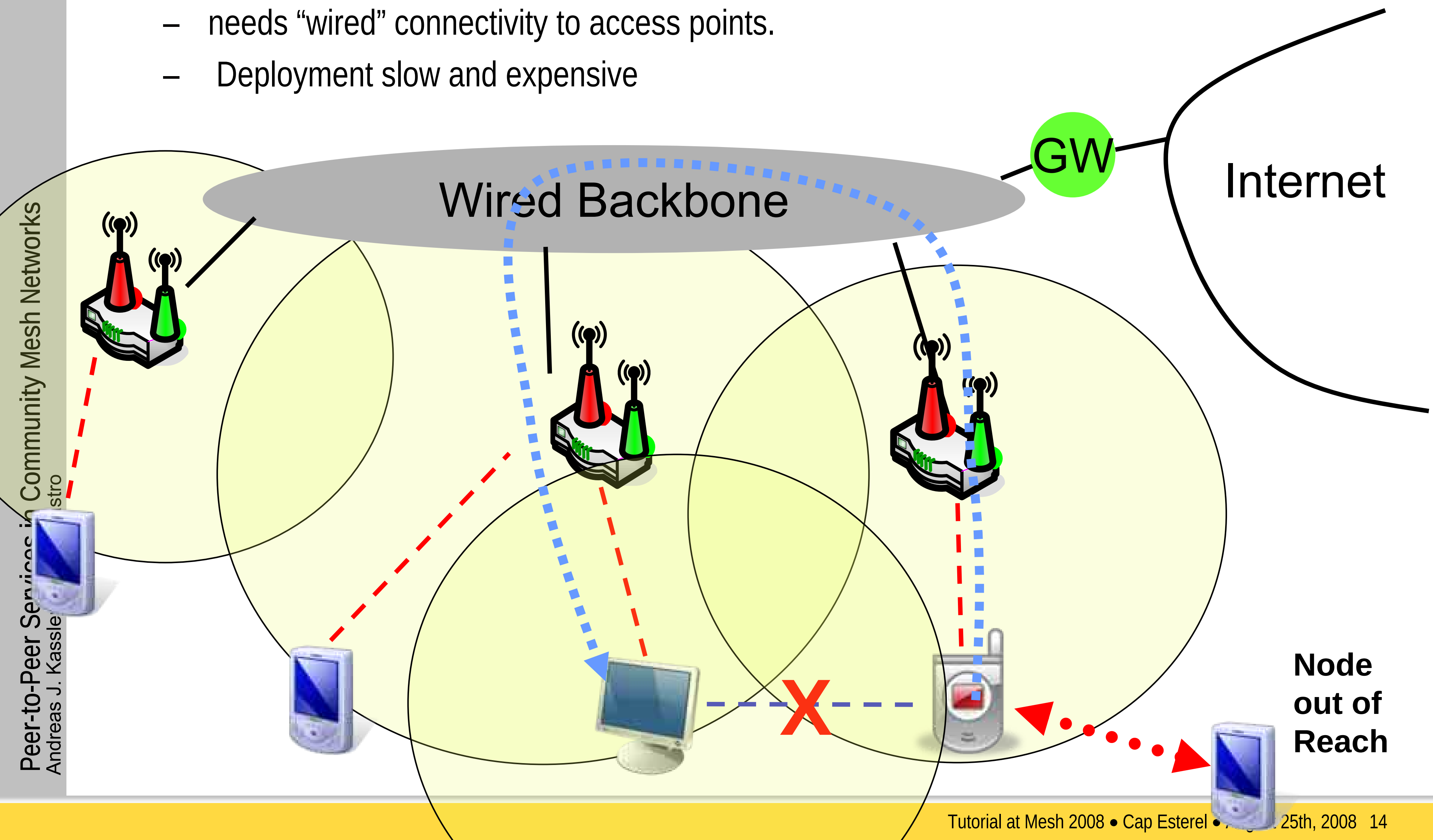
- Recent trends
  - Penetration of WLAN increases steadily
  - Novel services such as FON (www.fon.es)
    - build a community of users that are willing to cooperate and share their wireless access points for e.g. Skype.
  - While the number of users is substantial

Are you a **Fonero?**

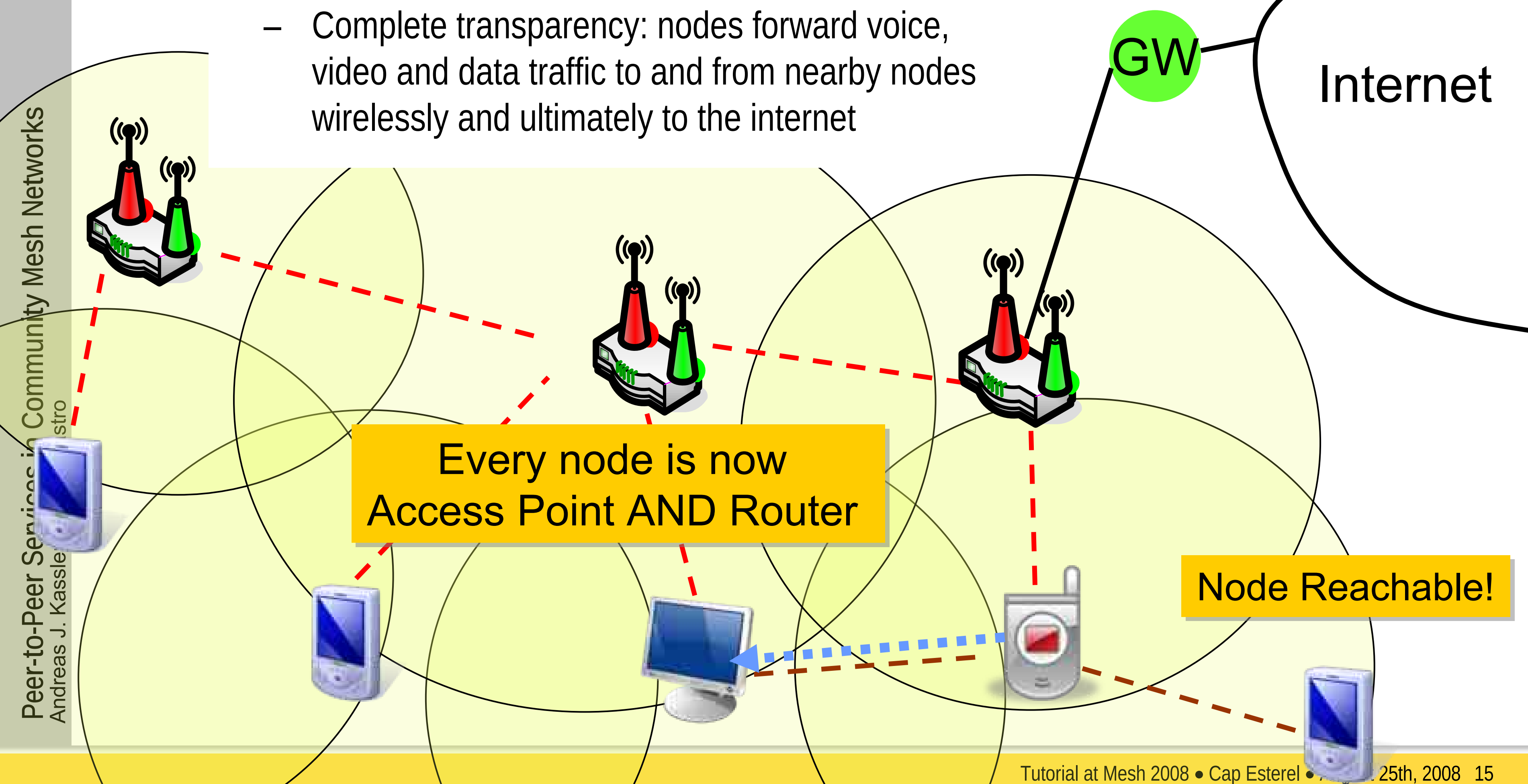
Key Question:
How to make WLAN coverage more ubiquituos?

- Overview Part I
  - Introduction
  - ➡ Motivation and Use Cases
  - Community Networks
  - Terminology and Classification
  - Introduction to Mesh Networks and Routing

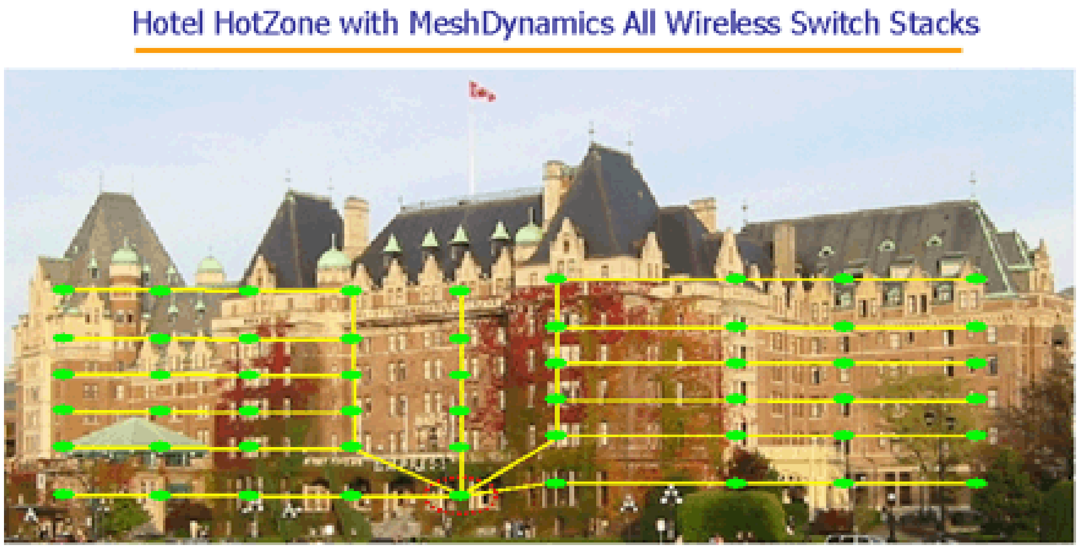
- Infrastructure-based
  - needs “wired” connectivity to access points.
  - Deployment slow and expensive



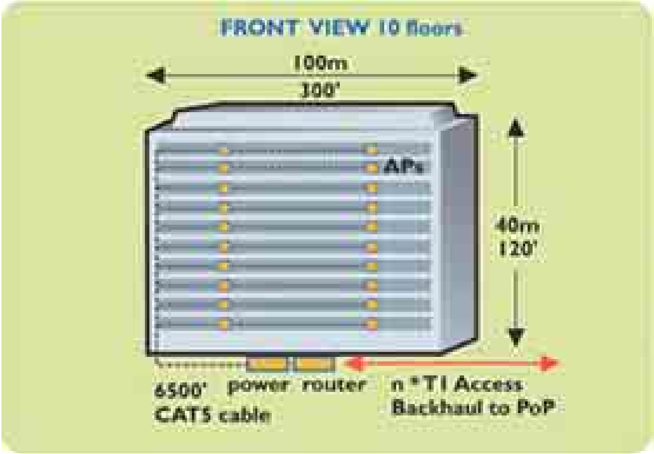
- Get rid of the wires!
  - mesh routing backbone created by grid of wireless APs
  - Clients can associate with any access point.
  - Complete transparency: nodes forward voice, video and data traffic to and from nearby nodes wirelessly and ultimately to the internet

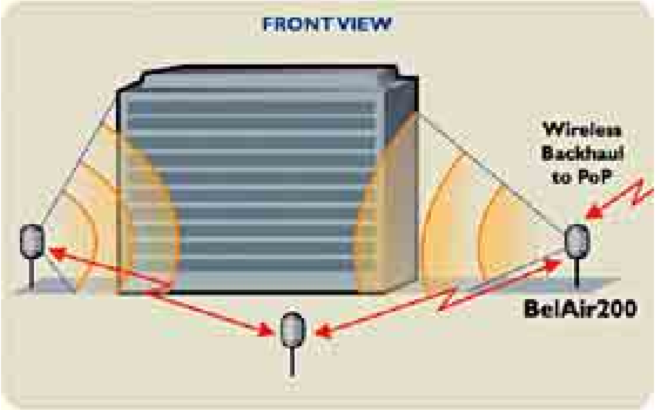


- Extend HotSpots



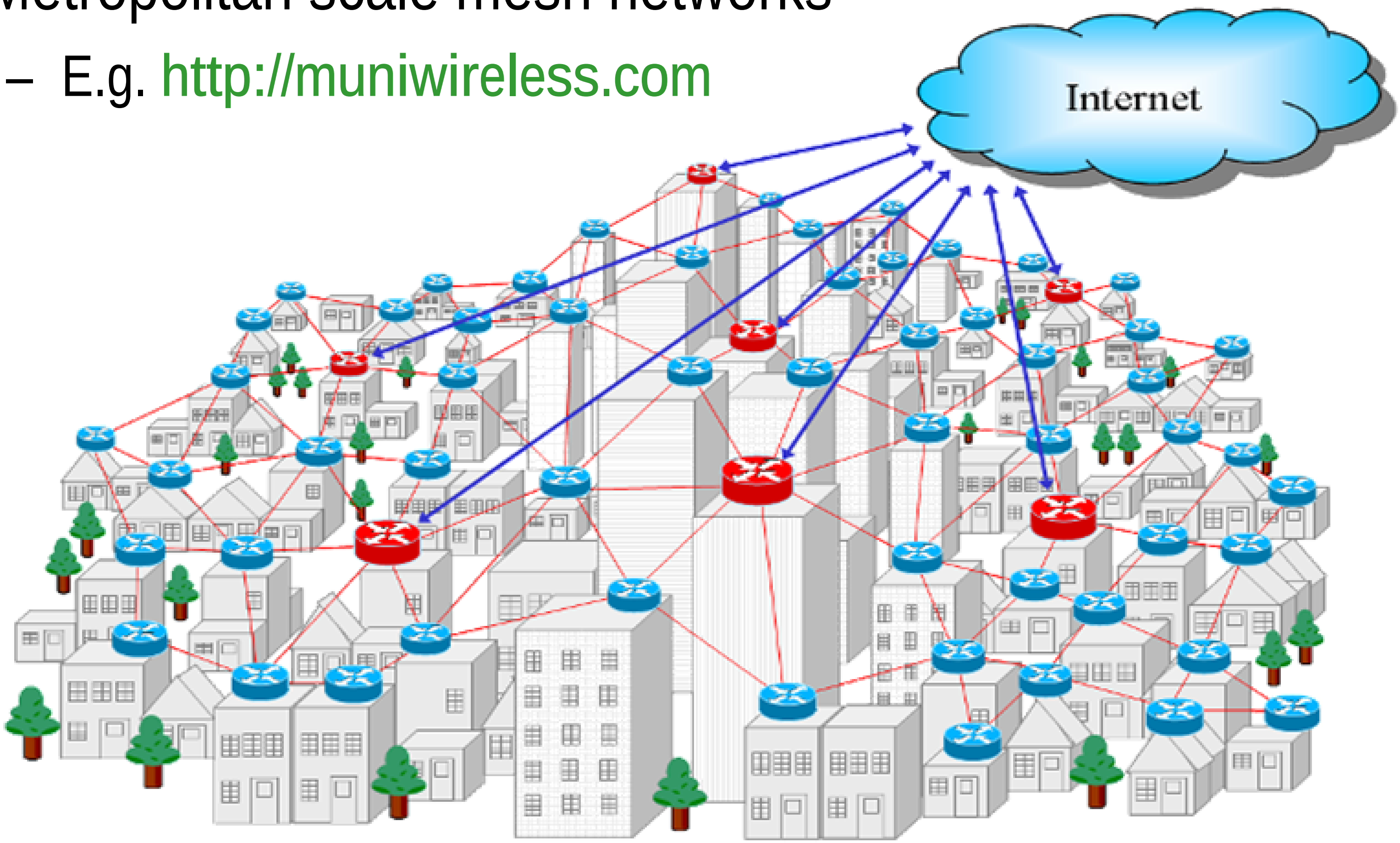
Source: www.meshdynamics.com





Source: www.belair.com

- Metropolitan scale mesh networks
  - E.g. http://muniwireless.com



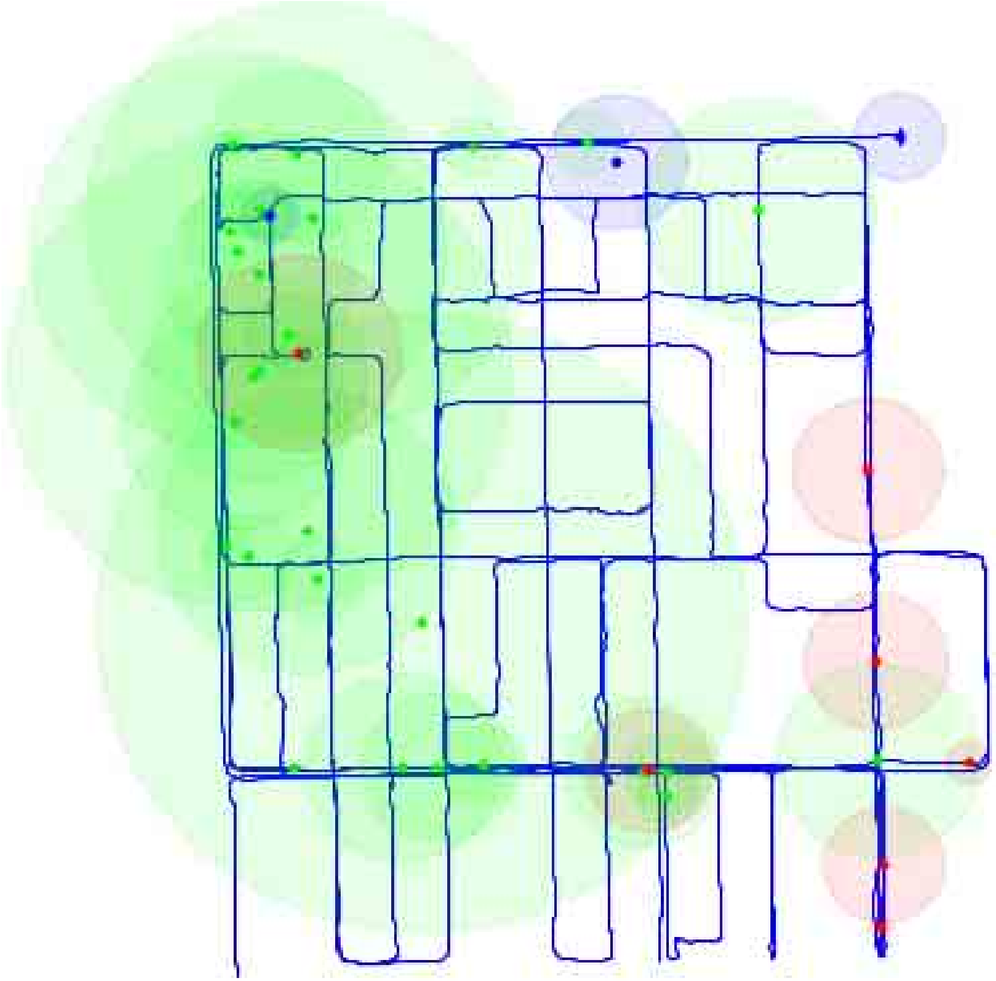
http://muniwireless.com

- Alternative Communication during desasters
  - Roll Out Network rapidly
- Broadband Home Networking
  - Solve the AP positioning problem
- Building and Factory Automation
  - Reduced deployment and maintenance cost
- Enterprise networking
  - Backhaul access modems can be shared
  - Recuced costs
- Security Surveillance Systems
  - Wirelessly connect cameras, sensors, etc

- Overview Part I
  - Introduction
  - Motivation and Use Cases
  - ➡ Community Networks
  - Terminology and Classification
  - Introduction to Mesh Networks and Routing

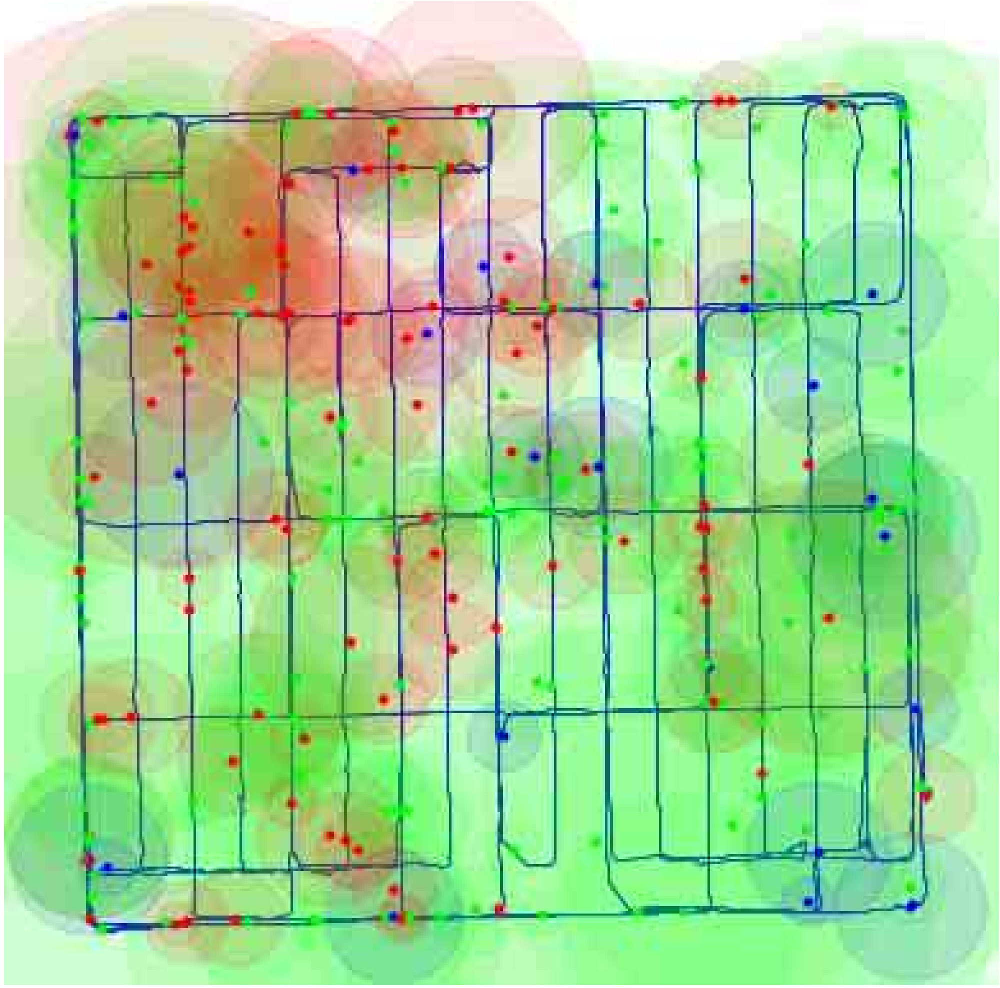
- Typical Deployments
  - Low Mobility
  - Low/Medium Density
  - Example: Government Subsidized Housing

Data Collected by Prof. Christian Sandvig <csandvig@uiuc.edu>



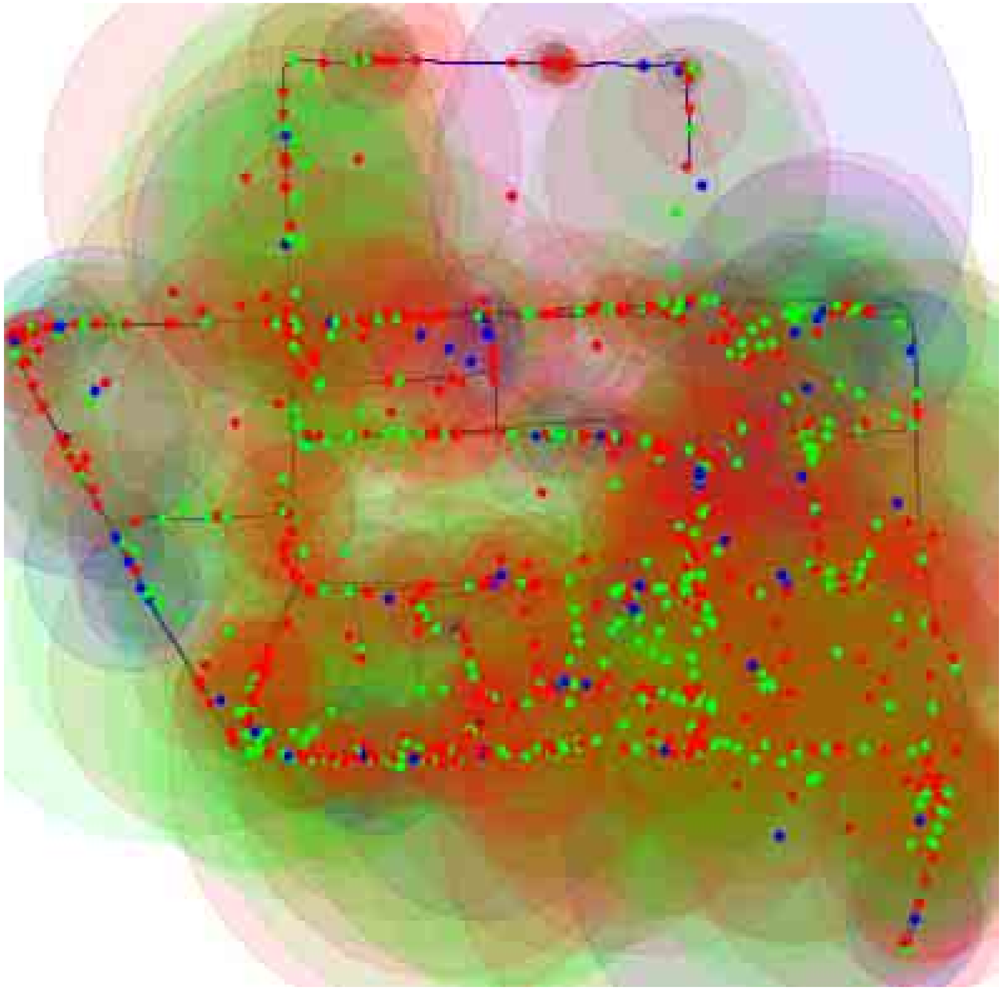
- Typical Deployments
  - Medium Mobility
  - Medium Density
  - Example: Immigrant Community

Data Collected by Prof. Christian Sandvig <csandvig@uiuc.edu>



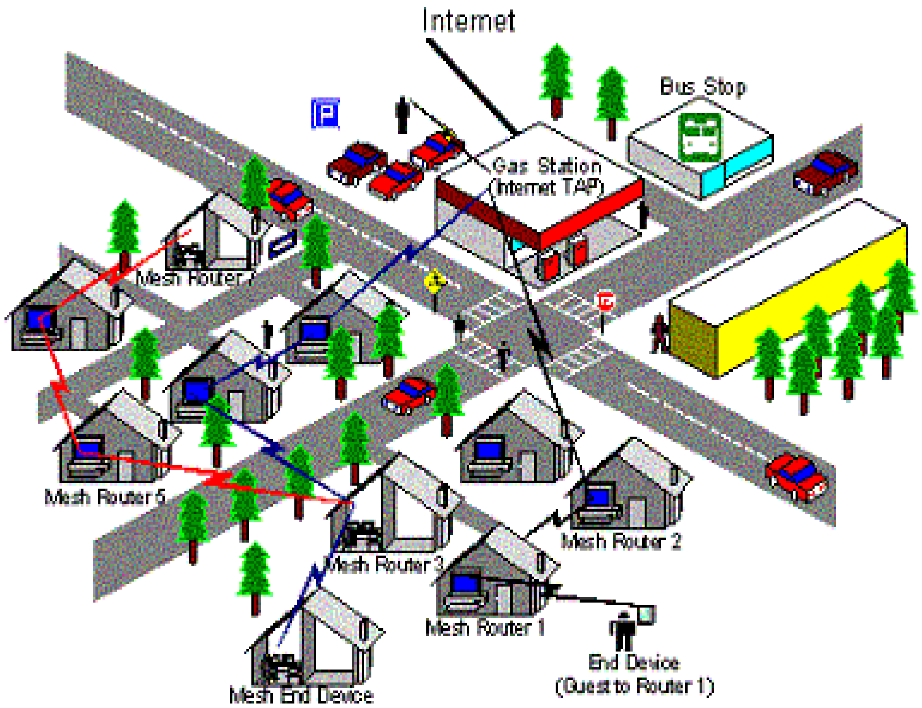
- Typical Deployments
  - High Mobility
  - High Density
  - Example: Young Professionals

Data Collected by Prof. Christian Sandvig <csandvig@uiuc.edu>



WiFi Mesh: Community Networks

- Grass-roots broadband Internet Access → support unplanned growth
- Not run by ISPs, but connected to
  - Public, private and often non-profit, may be municipally supported, hybrid partnerships
  - Several neighbors may share their broadband connections with many other neighbors → cost-effective
  - Typically driven by a community belonging to specific geographic area
- Reducing significantly number of internet access points
- Small area, locally-based
- Cheap, Off-the-shelf hardware
- Mission to support both social & economic development

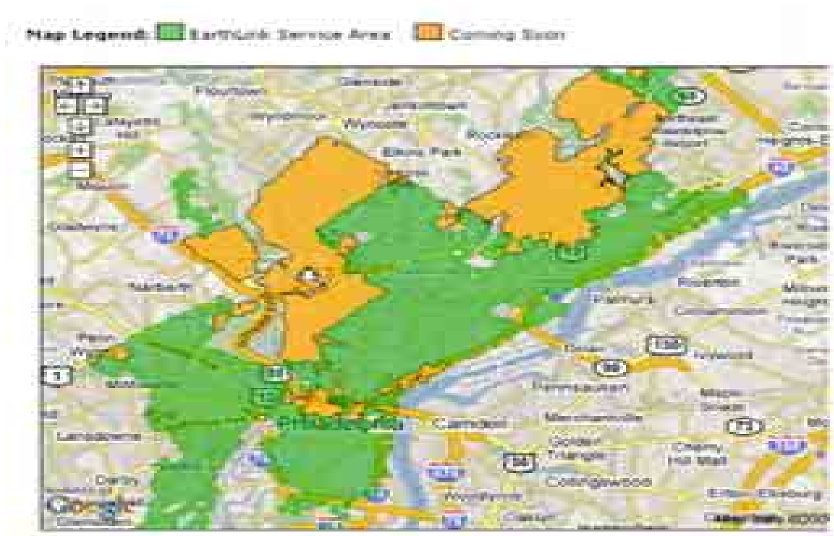


Source: research.microsoft.com/mesh/

- www.muniwireless.com, as of August 1, 2007:
  - 92 regional and city-wide networks,
  - 68 city hotzones,
  - 40 public safety and municipal use networks
  - 215 ongoing city and country-wide projects.

  → 415 projects compared to 122 as of 2005
  - Europe: lagging started to develop interest
- Application examples for wireless city projects
  - Digital divide for schools, businesses and residents;
  - Traffic signal management;
  - Automated meter reading for utility companies;
  - leased line replacement; access to remote county buildings;
  - public safety;
  - Integrated digital, voice and video for city buildings;

Community Networks
Broadband Internet Access for urban areas



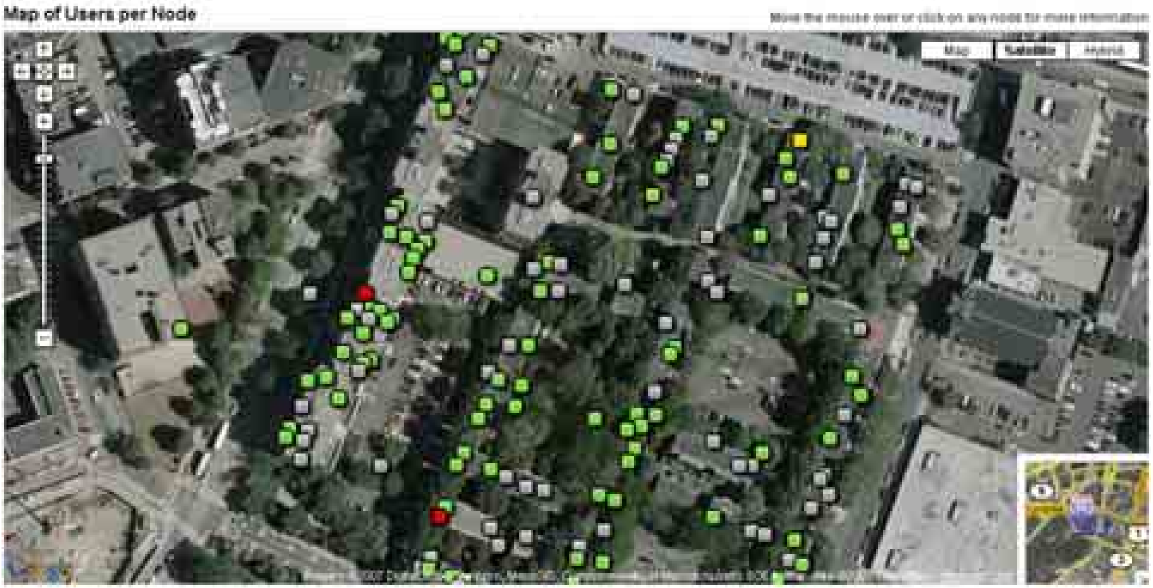
- Philadelphia Mesh
  - Internet Access
  - Uses 70 Tropos Mesh APs (2000 USD each) per square mile using cities light poles
  - Outsourced to Earthlink ISP
  - Mobile city workers will use it to communicate

- Public vs. Private Sector
  - Who Owns the Network?
  - Who Pays for the Network?
  - Who Operates the Network?
  - Many combinations possible, but typically influenced by regulatory issues

- Metro WiFi Funding Models
  - Fully Outsourced (Philadelphia)
  - Privately Funded (Boston)
  - Federally Funded (New Orleans, Sandoval)

Community Networks
MIT Roofnet

- Characteristics →http://pdos.csail.mit.edu/roofnet/doku.php
  - 37 node single-channel 802.11 based outdoor roof testbed
  - Coverage area: ~4 km around MIT campus
  - High power transmission → 200 mW, omnidirectional antenna
  - Mesh Relay nodes use private IP addr,
    clients use 192.168.1.x address
  - Collissions are an issue → RTS/CTS does not help much
  - Uses combination of link state and on-demand routing
    - evaluates link quality (ETX)
    - ignore long, low capacity links
    - Use faster, lossy rate links
  - Performance Characteristics:
    - Mean data rates of over 600kb/s
    - ~1.4Mb/s for internet gateway traffic
    - Latency below 50 ms

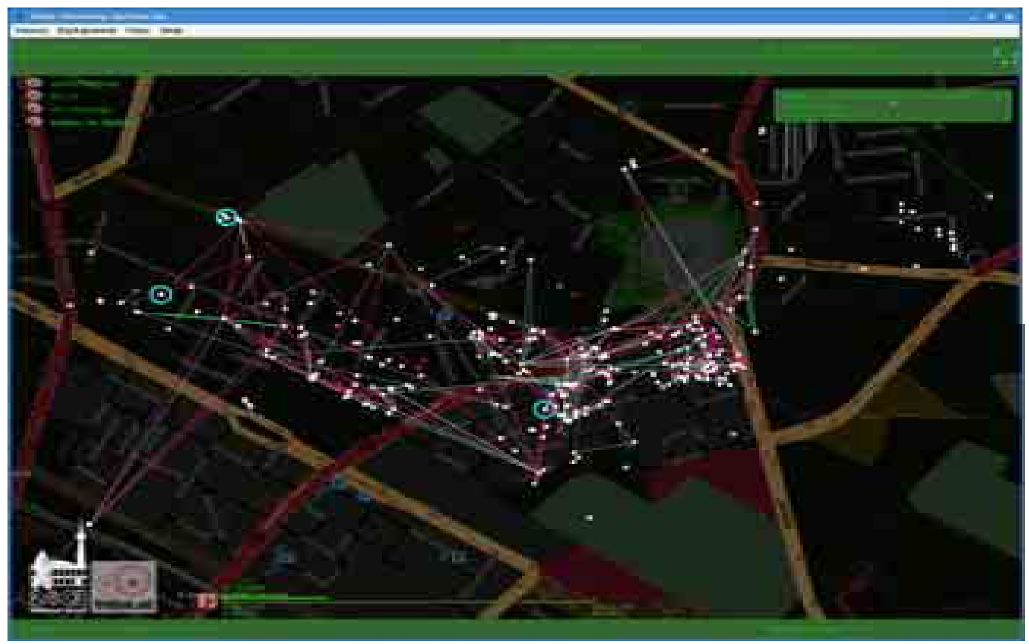


- Boston Castle Square Mesh
  - Delivers broadband wireless Internet access to housing complex in Boston
  - Run by tenants organization (private)
  - Three high speed ADSL connections
  - $30,000 grant from the Boston Foundation for hardware
  - run by a consortium of volunteers

- Bridges digital divide in Boston
  - Provides broadband internet access to a predominately Cantonese Speaking Population
  - due to cost and broadband unavailability would otherwise not have access to the Internet.
  - Exchange e-mail and voice over IP with China.
  - Pursue language and educational studies.

Community Networks
Berlin Freifunk

- Characteristics →http://start.freifunk.net/
  - Community Network from people for people
    - Started in Germany, now worldwide effort
    - Berlin (500 nodes, 1/10 city coverage)
    - Some DIY guides: http://wirelessafrica.meraka.org.za/wiki/index.php/DIY_Mesh_Guide
  - Uses OLSR link state routing → Significant scalability problems



Community Networks
WiFi Mesh for Rural Networks

- Extend Internet access into areas which do not have wired networking infrastructure.
- Reduced Infrastructure cost
- Typically semi-infrastructured backbone network (Mesh)
- Long distance links can be common
- Cheap, Off-the-shelf hardware
- Mission to support both social & economic development
- Useful for developing areas

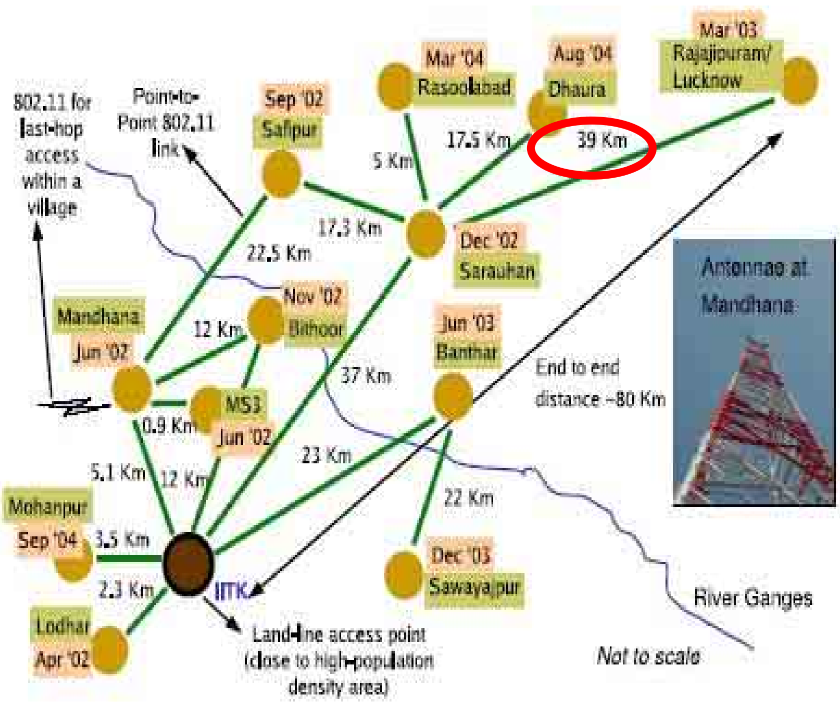
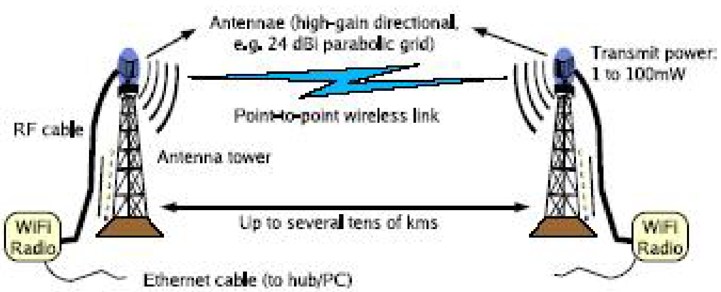
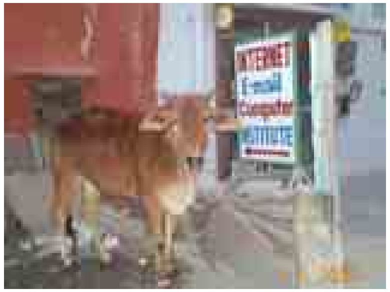


Figure 1. The Digital Gangetic Plains testbed

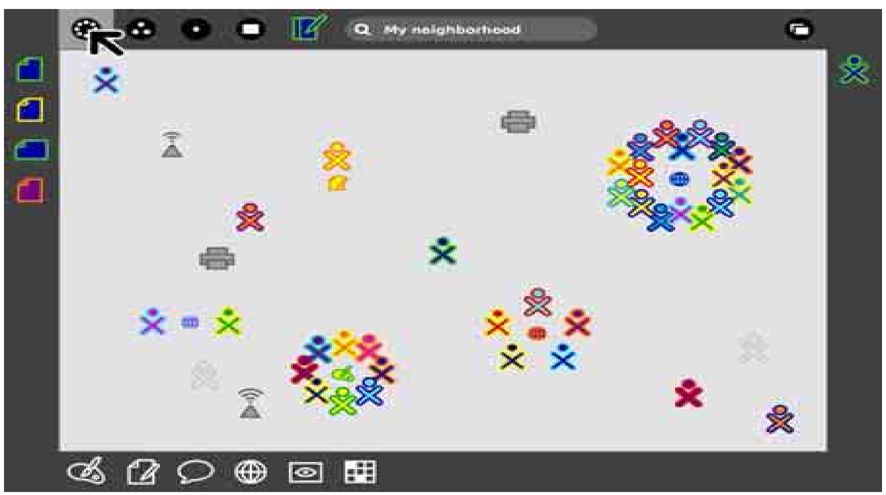


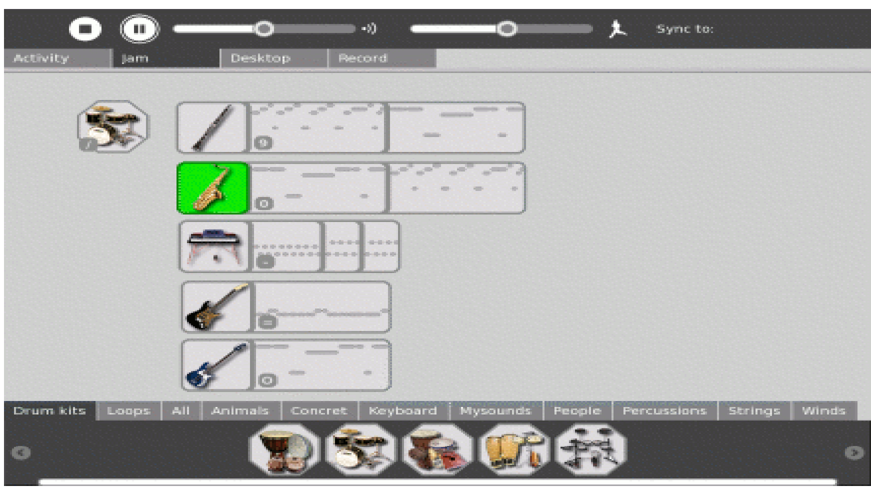


Community Networks
Open Source Platforms for Mesh

- Cost Issue
  - Proprietary Mesh Boxes expensive
  - Proprietary solutions might be not compatible/expandable
- Open Source
  - Ubiquitous available, Inexpensive, Easy to extend
  - Example: Linux, etc
- OpenWRT
  - Embedded OS can run on many wireless devices, e.g. Netgear WGT634U
  - Free to use and install (GNU General Public license)
- Roofnet Software
  - Runs on e.g. Netgear routers (~40.- EUR)
  - MADWifi drivers (www.madwifi.org)
- 802.11s
  - WiFi Mesh standard
  - Open source: http://o11s.org/
- Community Wireless Access
  - Mostly uses combination of Low Cost wireless router and open source software

- One Laptop Per Child XO
  - developed for children in least developed countries
  - Comes with support for 802.11s
  - Linux based GUI frontend
  - Supports interaction among OLPC users
  - Fosters community building
  - Distribute and share Internet access
  - Share thoughts, ideas, equations, learning, music, ebooks…
  - Play music together





Internet use in communities increased social contact, public participation and size of social network. (social capital - access to people, information and resources)

Keith N. Hampton, MIT
(author of “Netville Neighborhood Study”)
URL: http://www.asanet.org/media/neville.html

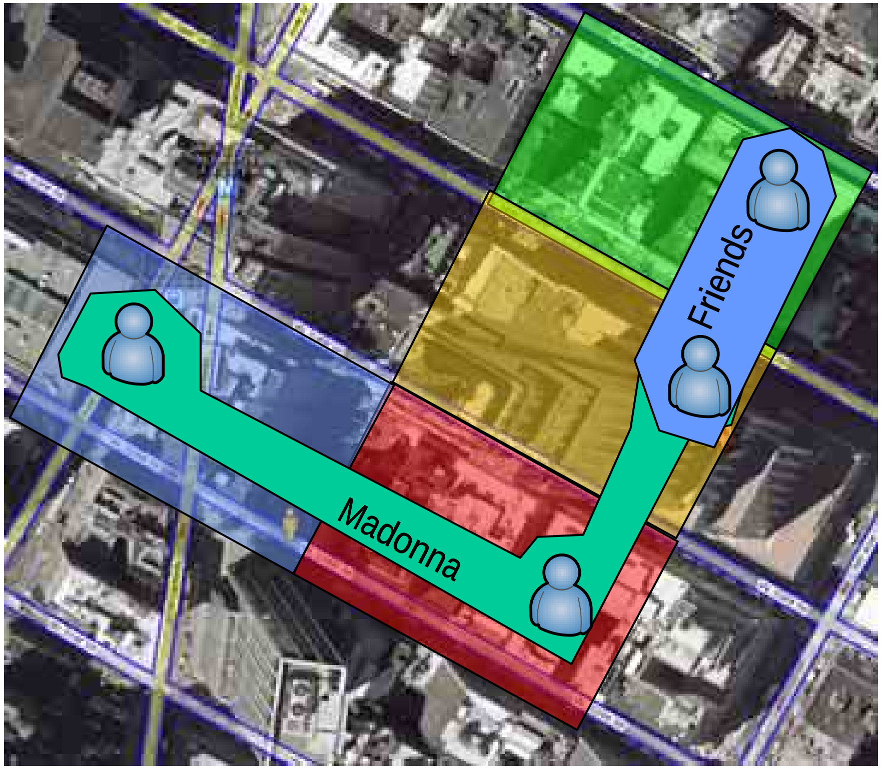
- Owning the User is key to Success
  - Users most likely own the equipment in the last hop due to incentives → e.g. Fon
  - Physical neighbours share the same environment
    - organized in clusters (streets, blocks, buildings)
  - Location of APs and Terminals reflects social behaviour
    - Great potential of social relations in neighboured users
  - Neighbors in local communities most likely share similar interest
    - Similar ethnicity (”Little India”, ”Chinatown”)
    - Similar age (”Young Professionals”, ”Elderly”)
  - Localized information exchange is likely to dominate if same social interest
    - Social networking communities such as Youtube on a local basis
    - Exchange of photos, films, etc.
    - Include location information (could be available from Mesh Network)
    - Information Finding and Exchange

User Centric Networks

- Network should adapt itself to user environment and context
  - Maximize performance of user applications
  - Take in consideration social interest
  - Promote interactions and content exchange
  - Peer-to-Peer interactions most likely common model
- Network should support Community Formation
  - Communities are clusters from a network perspective
  - Community members share common context and interests
    - Knowledge on Context and Interest allow to optimize the network towards specific uses
- Towards Social Community Mesh Networking
  - Social and Community Networks already available in the Internet
  - Myspace, YouTube, Facebook, etc.
  - Currently, network layer agnostic of communities

Community Networks
Communities

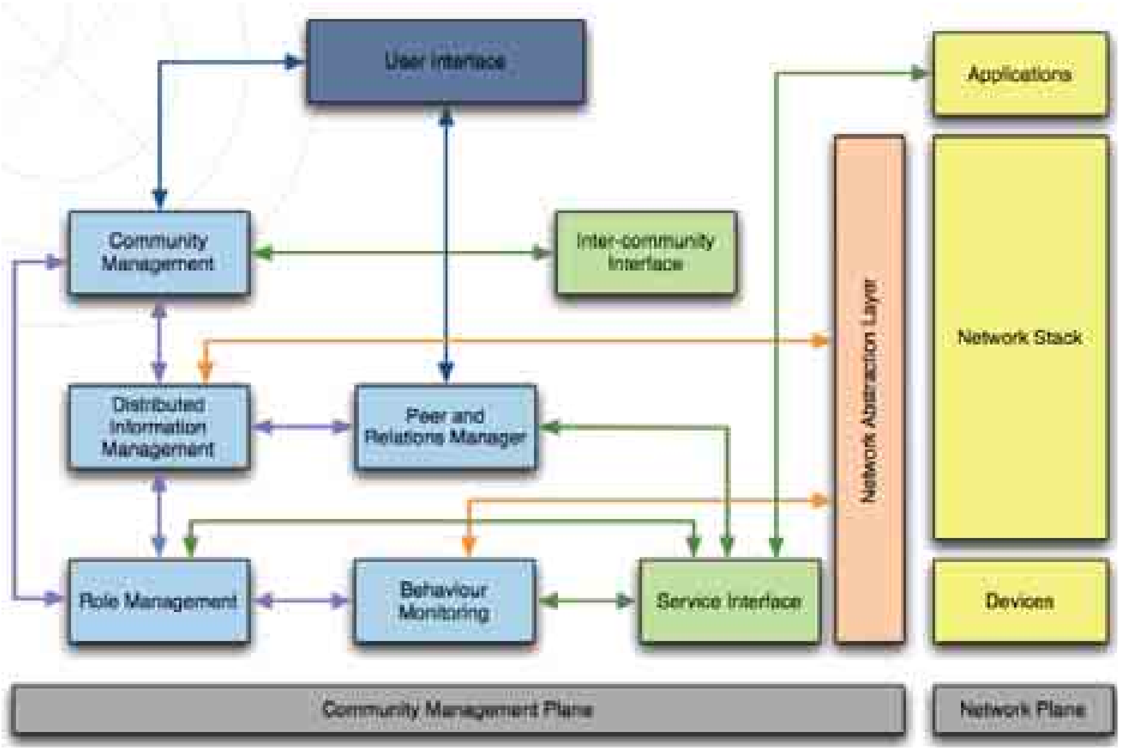
- Users most likely might join different communities
  - Based on interest and social interactions → Friends, ”Madonna fans”, FONEROS
  - Based on location → my neighborhoud, my building, my city
- Different Communities have different purposes
  - ”Friends” → exchange pictures, self-made videos, information
  - ”Madonna” → exchange music and ”Madonna” videos
  - FONEROS → share internet, support charging functions



- Mechanisms
  - Discovery of communities/services
  - Delegation/Permissions
  - Negotiate Delegation Parameters
  - Revocate Delegations

Community Management Framework

- Community Management Framework for Mesh Users
  - Ontologies → define structure of information, using OWL
  - Supports automatic and user defined communities
  - Provides overlay functionalities based on Peer-to-Peer principles
  - Uses WINE-SD with mesh optimized mSLP extension

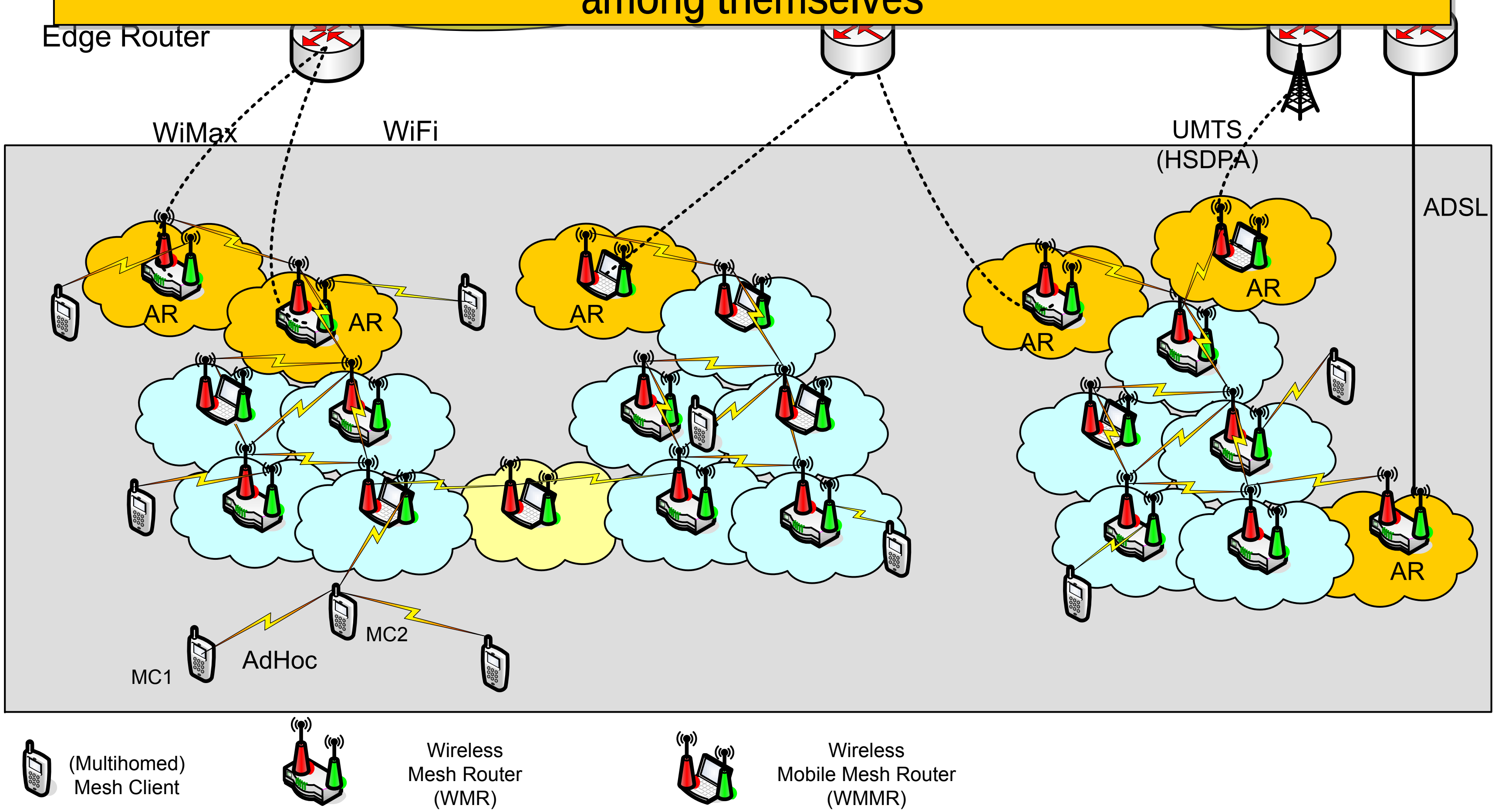


"Ontology driven Framework for Community Network Management", J.P. Barraca, Rui Aguiar, ICT 2008

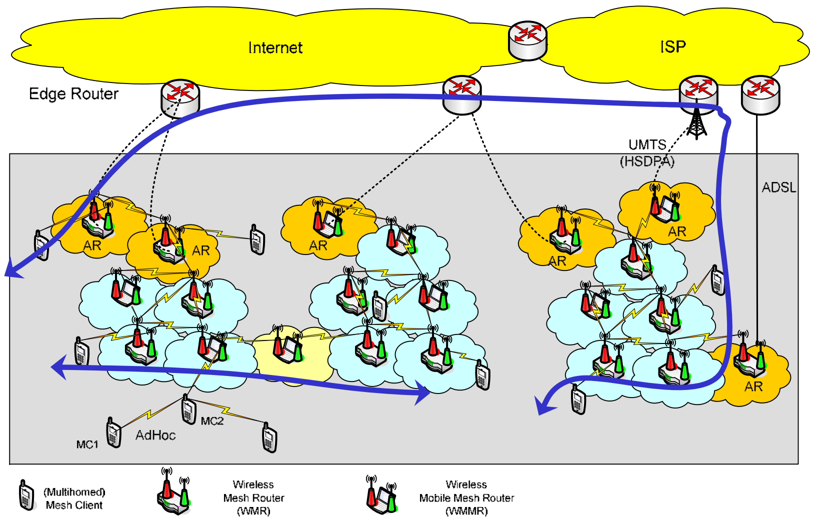
- Overview Part I
  - – Introduction
  - – Motivation and Use Cases
  - – Community Networks
  - ➡ Terminology and Classification
  - – Introduction to Mesh Networks and Routing

Terminology and Classification
Multi-Hop Wireless Networks

A WMN is dynamically self-organized and self-configured, with the nodes in the network automatically establishing and maintaining mesh connectivity among themselves



- Key characteristics:
  - wireless
  - multi-hop
  - broadband
  - self-organizing and self-healing → Reduced OPEX
  - infrastructure components

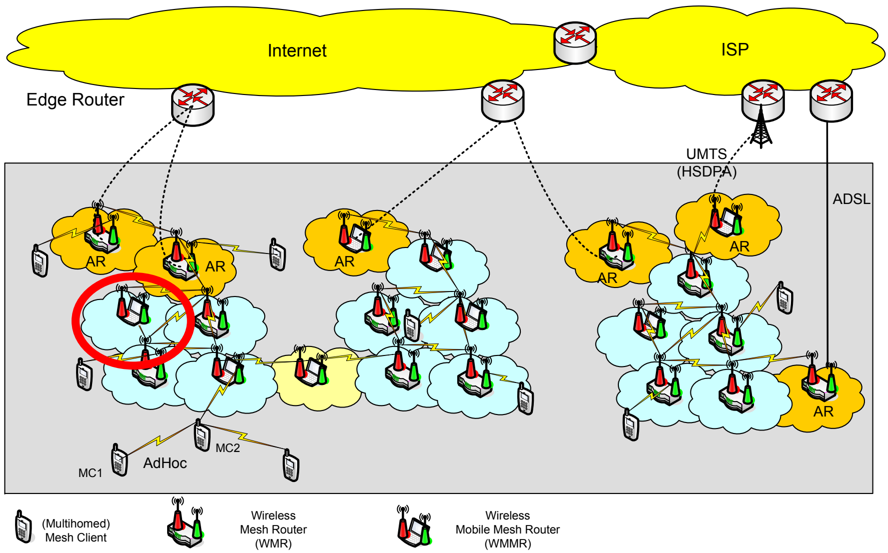


- Categories (cf. Akyi05)
  - client-mesh
  - infrastructure/backbone mesh
  - hybrid mesh

  → Reduced CAPEX

Terminology and Classification
Mesh Routers – Mesh Relay Nodes (MRN)

- At least one wireless interface.
  - Typically two
    - backbone mesh formation (Ad Hoc)
    - client access (Infrastructure)
  - Can have multiple (wireless) access technologies (e.g. WLAN and Cellular)
- Mobility
  - Stationary (e.g. rooftop)
  - Mobile (e.g., airplane, busses/subway).
- Provide coverage (acts as a mini-cell-tower) by establishing the mesh connectivity
- Contains routing logic for mesh connectivity
- Many needed for wide areas, hence, cost can be an issue.

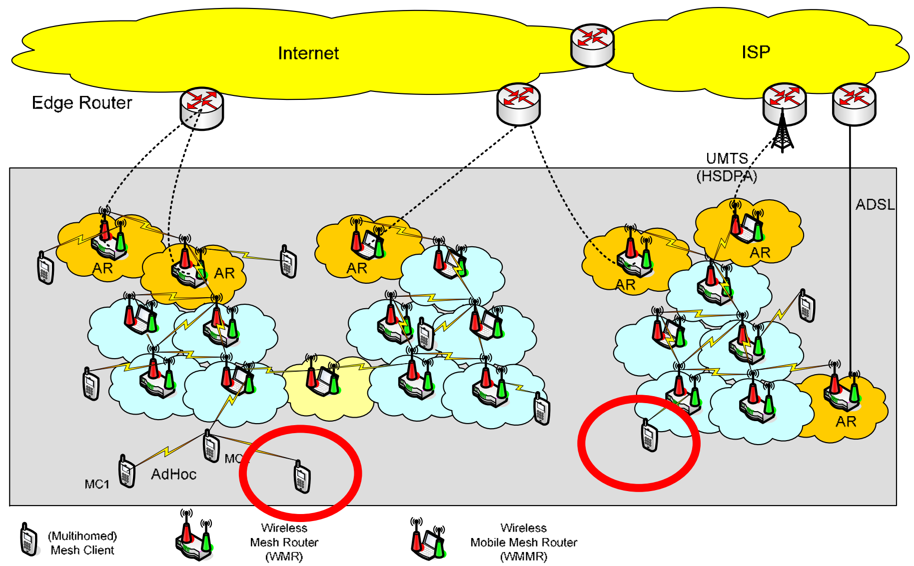


(a) PowerPC and (b) Advanced Risc Machines (ARM)

Peer-to-Peer Services in Community Mesh Networks
Andreas J. Kassler, Marcel Castro

Mesh Clients

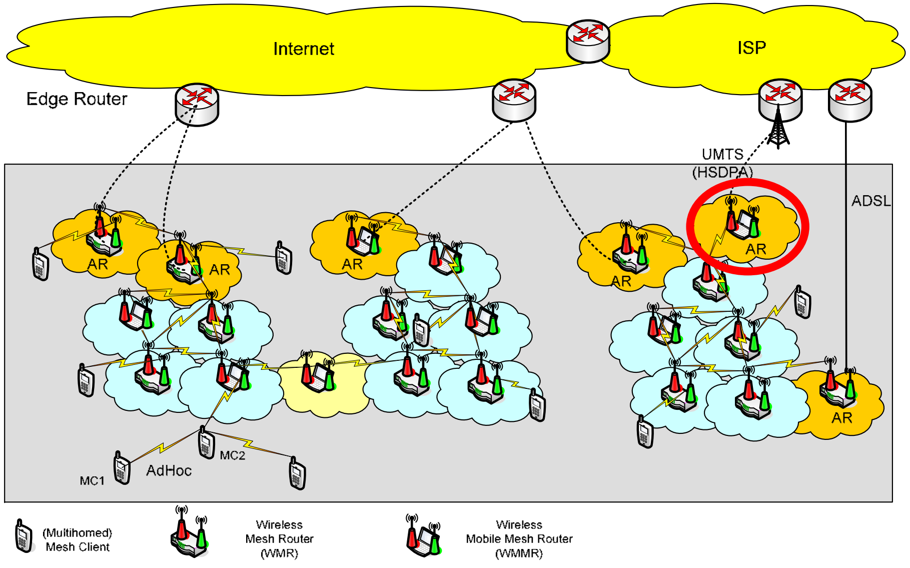
- Typically one interface.
  - Laptops
  - PDAs
  - MobilePhones
  - ...
- Mobility
  - Stationary
  - Mobile
- Can connect directly to the mesh network through mesh routers (or directly to gateways) through
  - Wireless (direct or via Ad-Hoc) or
  - Wired



Terminology and Classification

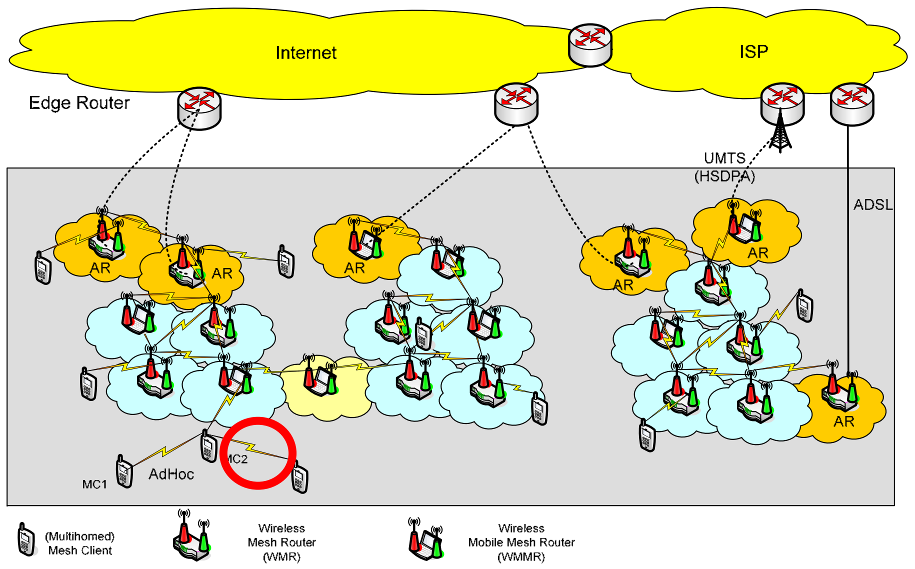
Access Routers (AR) - Gateways

- Multiple interfaces (wired & wireless)
- Mobility
  - Stationary (e.g. rooftop) – most common case
  - Mobile (e.g., airplane, busses/subway) → NEMO
- Serve as (multi-hop) “access points” to user nodes
- Relatively few are needed
- Integrate WMNs with various existing wireless networks such as
  - Cellular
  - Wireless sensor
  - WiMax



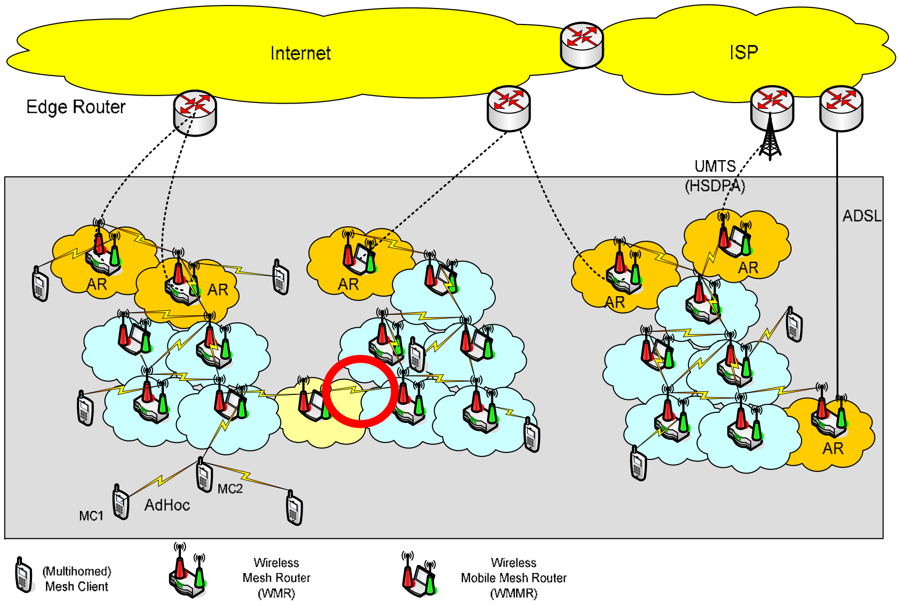
Terminology and Classification
User – Mesh Router Links

- Wired
  - Bus (PCI, PCMCIA, USB)
  - Ethernet, Firewire, etc.
- Wireless
  - 802.11x
  - 802.16
  - Bluetooth
  - Proprietary
- Point-to-Point or Point-to-Multipoint
- If properly designed is not a bottleneck.



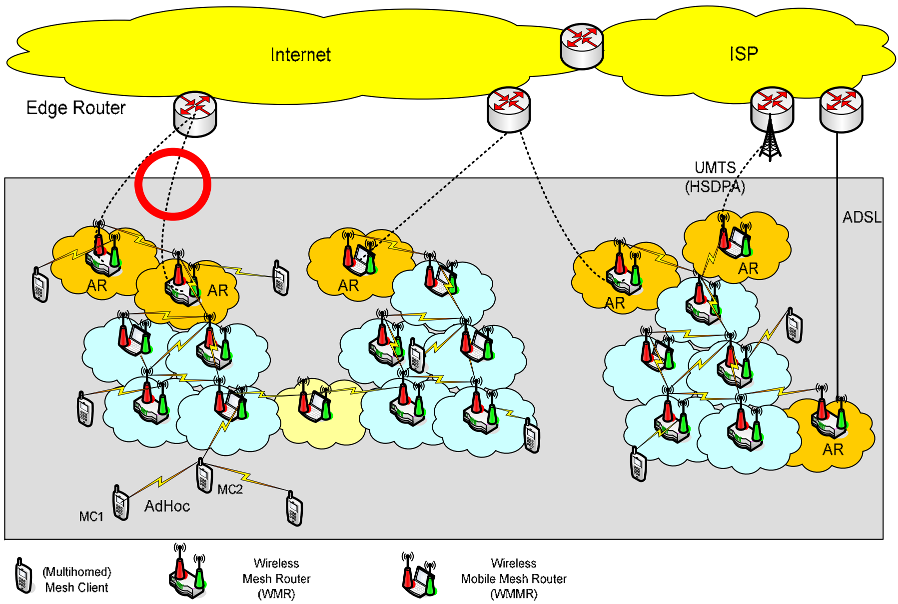
Router to Router Links

- Wireless
  - 802.11x
  - 802.16
  - Proprietary
- Usually multipoint to multipoint
  - Sometimes a collection of point to point
- Often the bottleneck
- Also called backhaul links

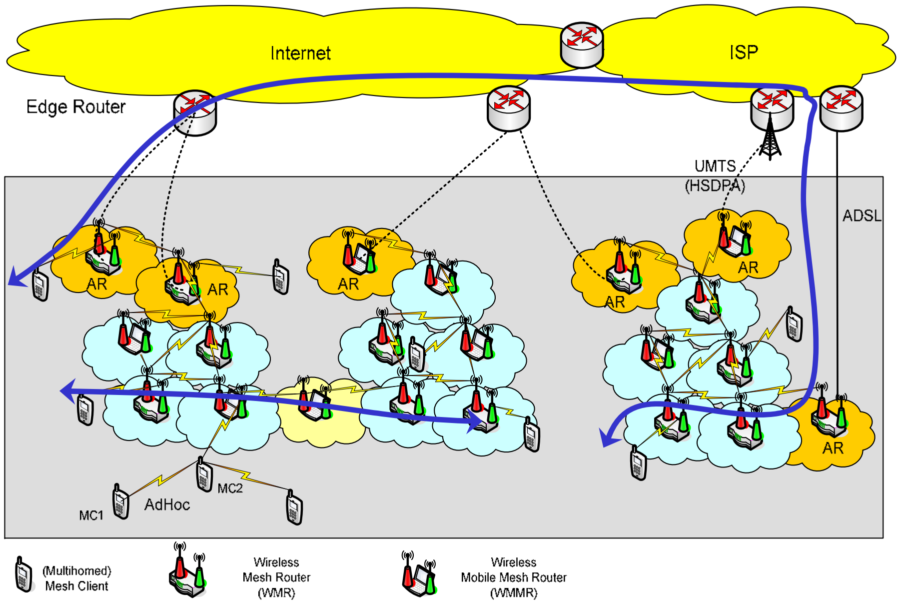


Terminology
Gateway to Internet Links

- Wired
  - Ethernet, TV Cable, Power Lines
- Wireless
  - 802.16 (again meshed possible)
  - Proprietary
- Point to Point or Point-to-Multipoint
- Also called backhaul links
- If properly designed, not the bottleneck



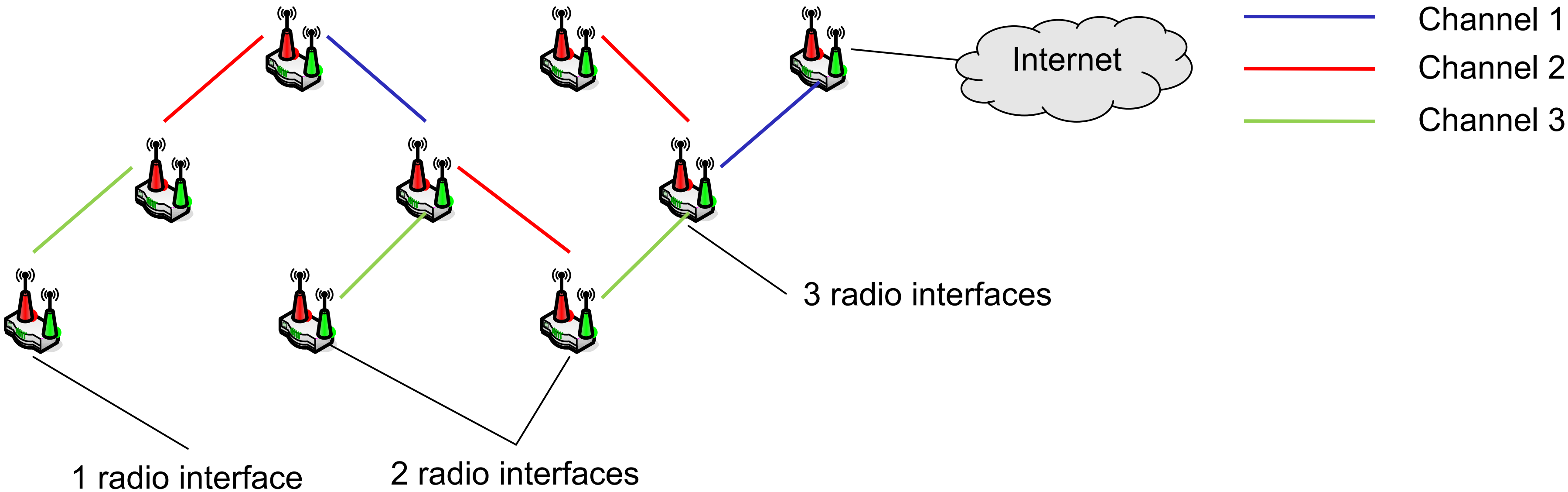
- User-Internet Data Flows
  - In most applications the main data flows
- User-User Data Flows
  - In most applications a small percentage of data flows



- Multi-channel wireless mesh networks:
  - in the context of 802.11
  - wireless mesh network which utilizes transmissions on several typically non-overlapping 20MHz channels in the 2.4GHz band or 5GHz band
  - in a general context multi-frequency mesh networks
- Multi-radio wireless mesh networks:
  - mesh network where some of the nodes have multiple (at least two) radio interfaces which might be used independently
- Typical scenario:
  - backbone: 802.11a (5GHz)
  - client connectivity: 802.11g (2.4 GHz)

Peer-to-Peer Services in Community Mesh Networks
Andreas J. Kassler, Marcel Castro

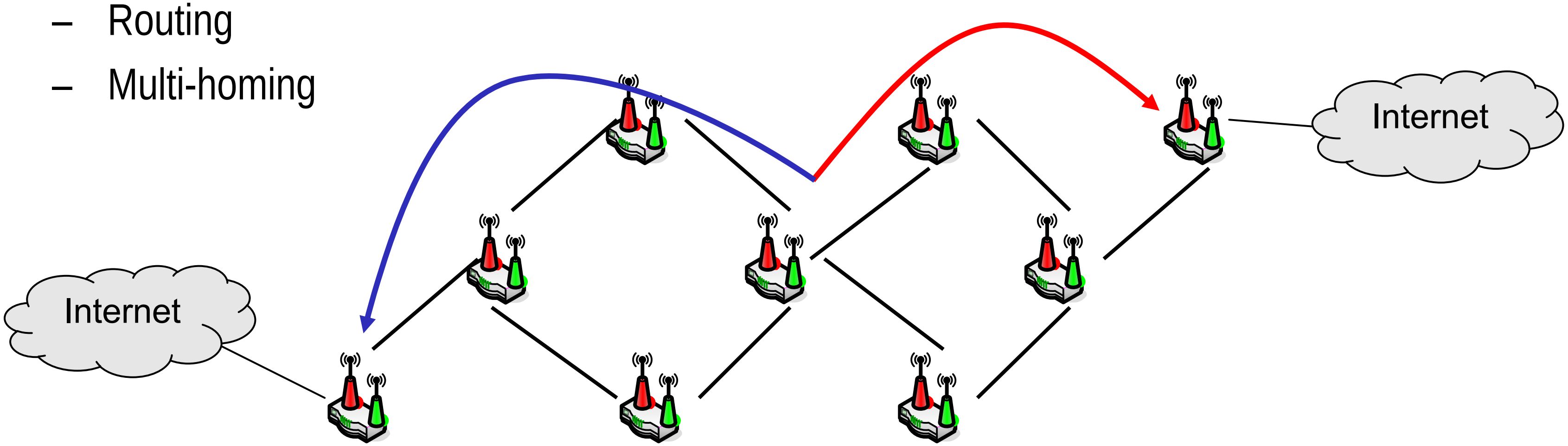
Multi-Channel Multi-Radio Mesh Network



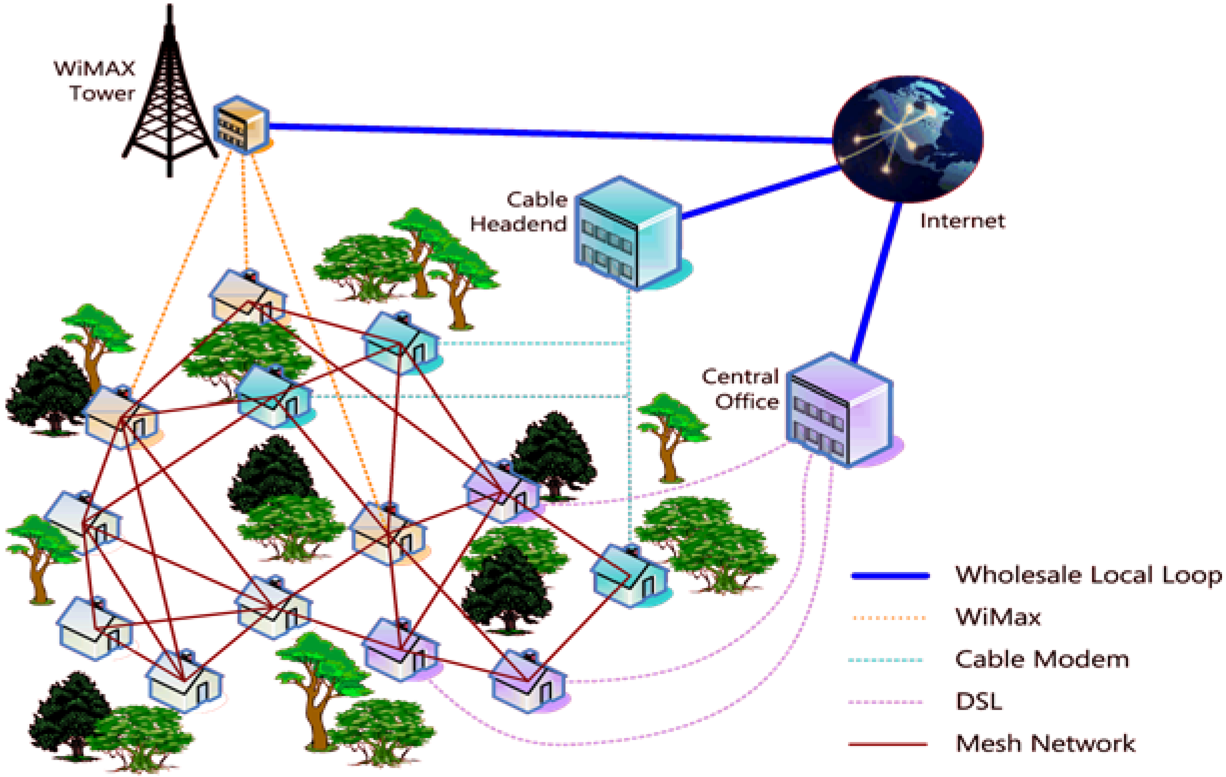
- Problems:
  - number of radios per node (mesh network planning)
  - channel assignment
    - static (mesh network planning)
    - dynamic (radio resource management)
      - centralized, decentralized, time-scale?
    - multi-channel single-radio
  - routing

Terminology and Classification
Multi-Gateway WMNs

- Wireless mesh networks with multiple gateways to the Internet
- Multiple gateways are required to
  - keep routes to the Internet short (few hops)
  - increase access capacity
- Problems:
  - Gateway detection
  - Routing
  - Multi-homing



- Wireless mesh networks built on mesh links from multiple technologies
  - IEEE 802.11 and 802.16
  - IEEE 802.11a and IEEE 802.11g ?



- Overview Part I
  - Introduction
  - Motivation and Use Cases
  - Community Networks
  - Terminology and Classification
  - ➡ Introduction to Mesh Networks and Routing

An Early Multi-Hop Wireless Network

What Challenges can we identify?

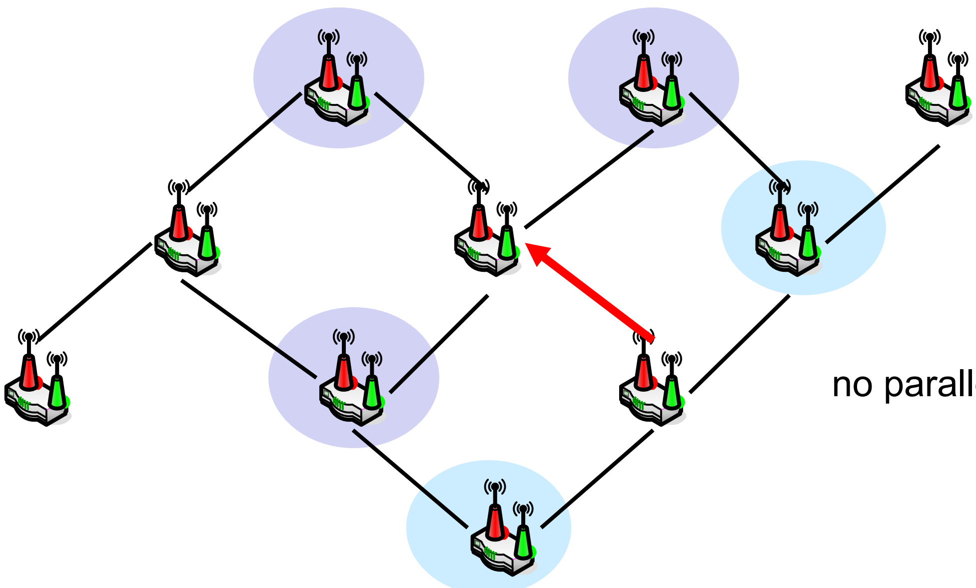
Main Mesh Functionality

- Network entry
  - neighbor detection
  - gateway detection
  - network association
- Medium access control
  - resource reservation (optional)
  - data transmission/scheduling
  - buffering and forwarding
- Routing
  - find path to gateway
  - optimize path
  - coordination with MAC-Layer (cross layer design)

Functionality

- Medium access control
  - random access
  - resource reservation (optional)
- Intra-node scheduling
  - service differentiation
  - fairness
  - traffic forwarding
- Network entry
  - neighbor detection
  - gateway detection
  - network association
  - synchronization

Medium Access Coordination

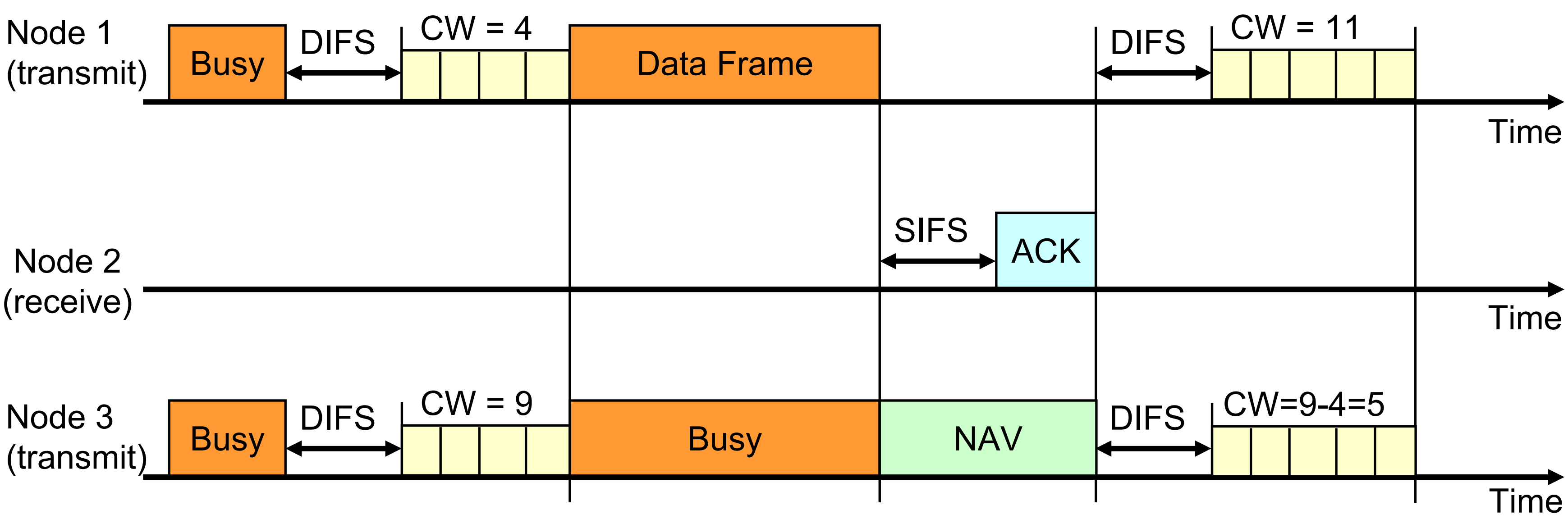


Goal for MAC layer design:

- avoid parallel interfering transmissions
- do not hinder parallel non-interfering transmissions

MAC Layer
Random Access without reservation

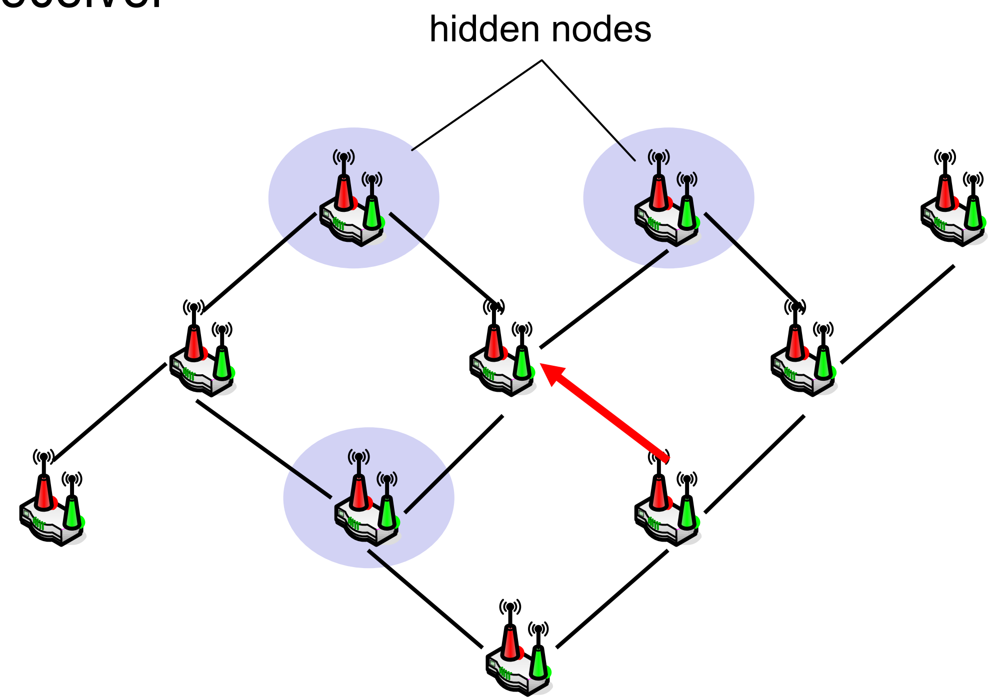
- IEEE 802.11 Distributed Coordination Function – DCF (CSMA-CA)
  - Stations have to equally compete for access to the medium
  - Acknowledgment scheme is used for error indication



- simple, well accepted, most frequently implemented and used

Peer-to-Peer Services in Community Mesh Networks
Andreas J. Kassler, Marcel Castro

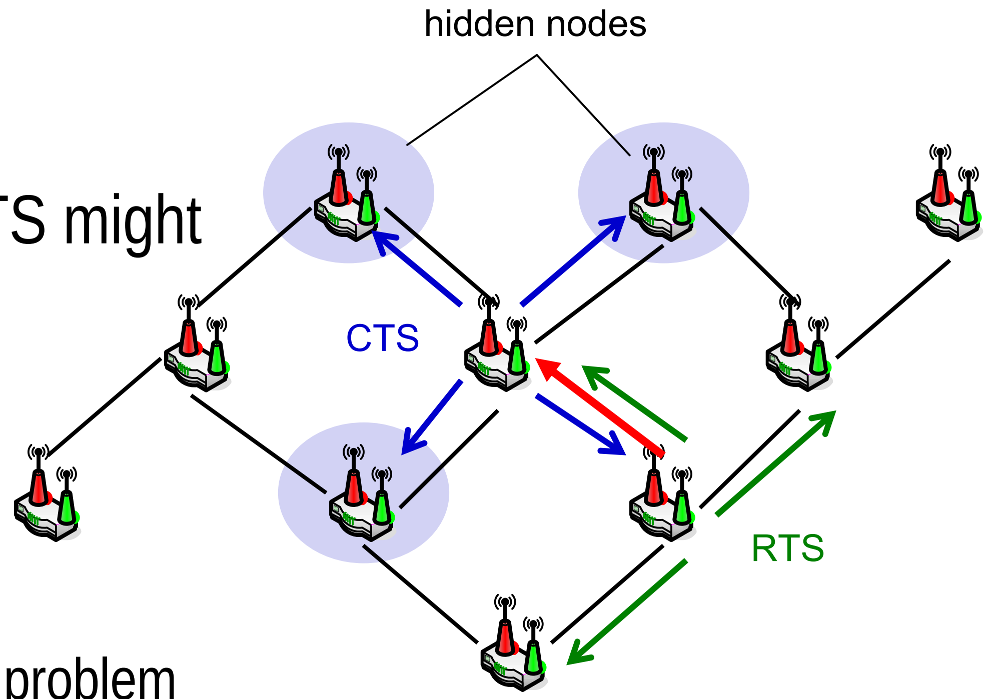
- Hidden Node Problem
  - A mesh node is hidden for an ongoing transmission if it is not able to sense the ongoing transmission but its transmission would disturb the reception.
  - A node not in the sensing range of the transmitter but within the interference range of the receiver



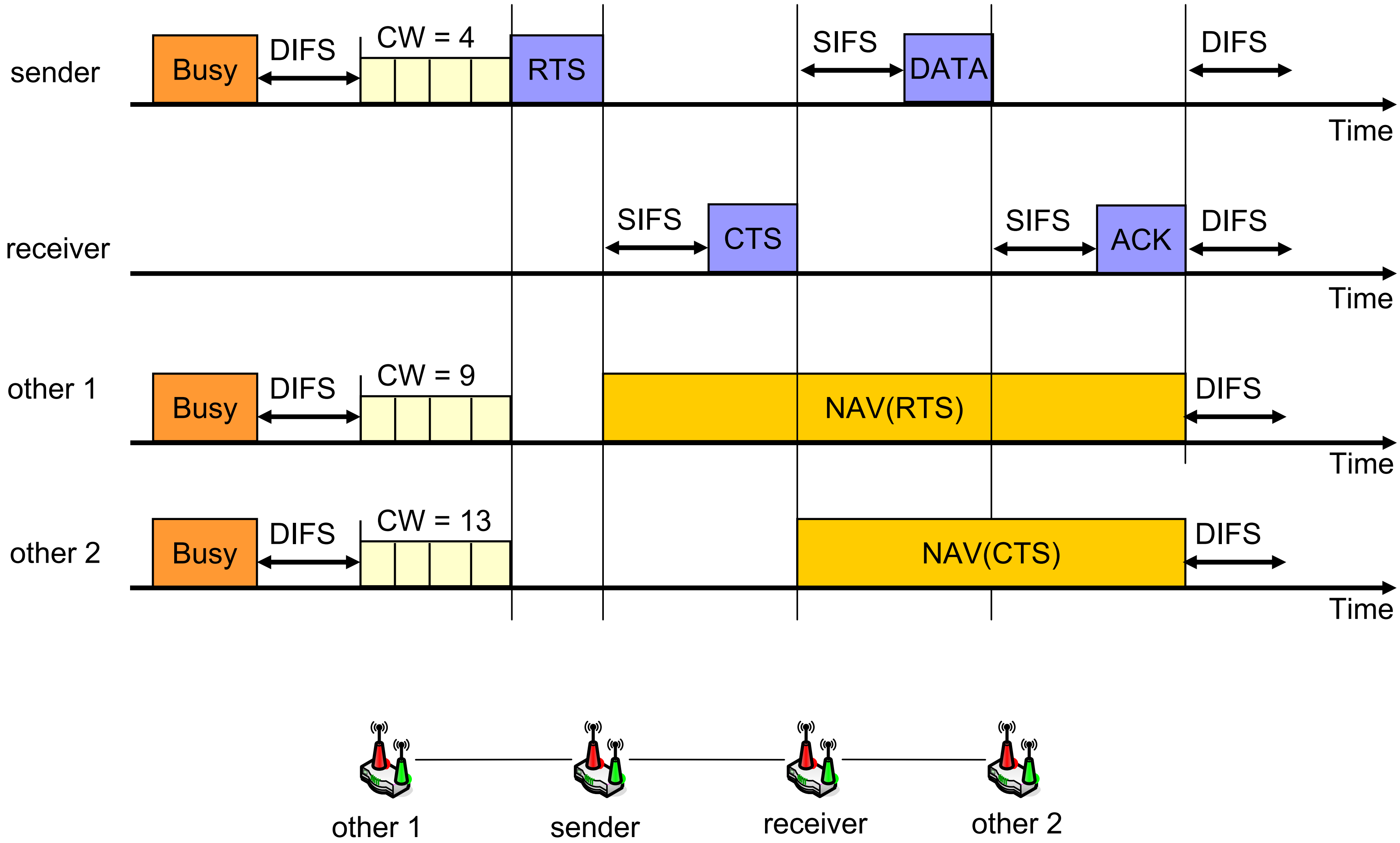
- HN-induced problems
  - Throughput degradation
  - Unfairness

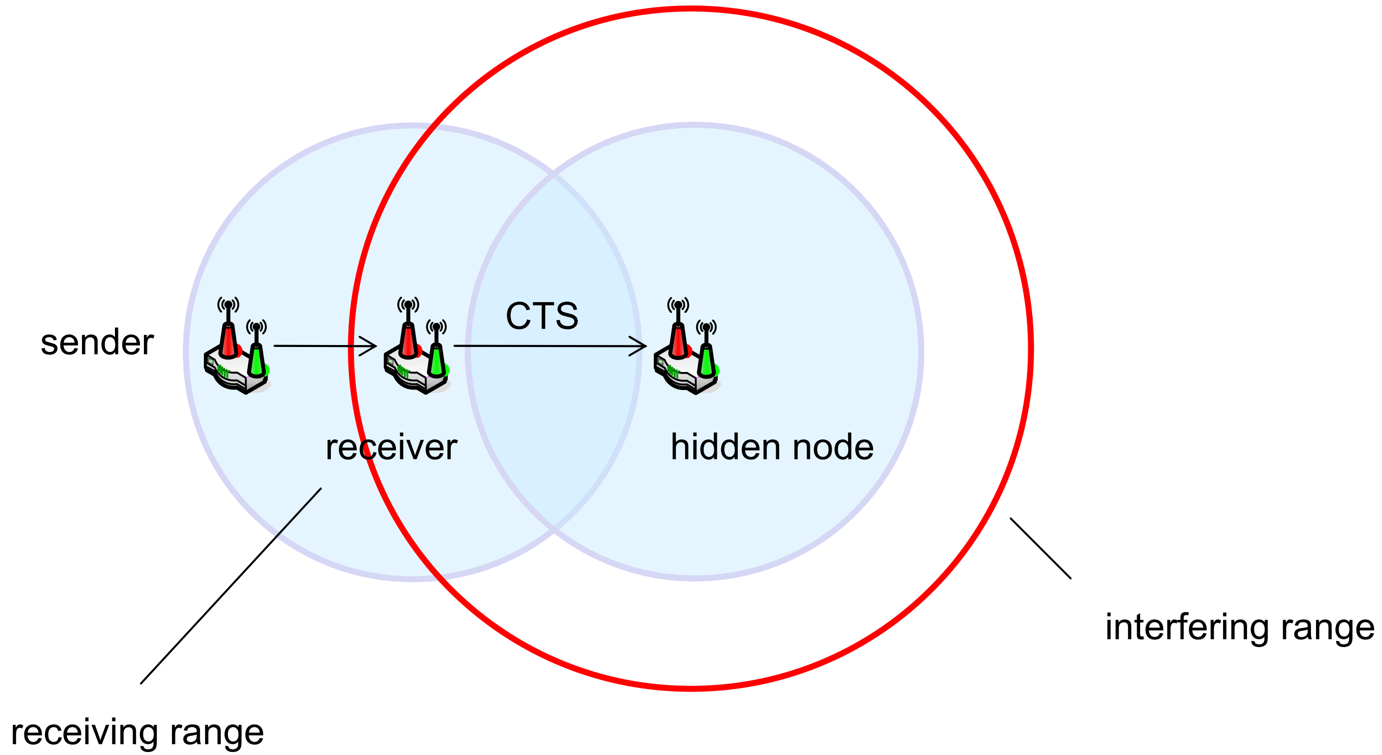
Simple Reservation – Two-way Handshake

- IEEE 802.11 RTS/CTS
  - RTS: Ready to send
  - CTS: Clear to send
- Nodes receiving RTS or CTS might not get involved in new transmissions
- RTS/CTS
  - partially solves hidden node problem
  - induces increased overhead and delay
  - also virtual carrier sensing



MAC Layer
RTS/CTS

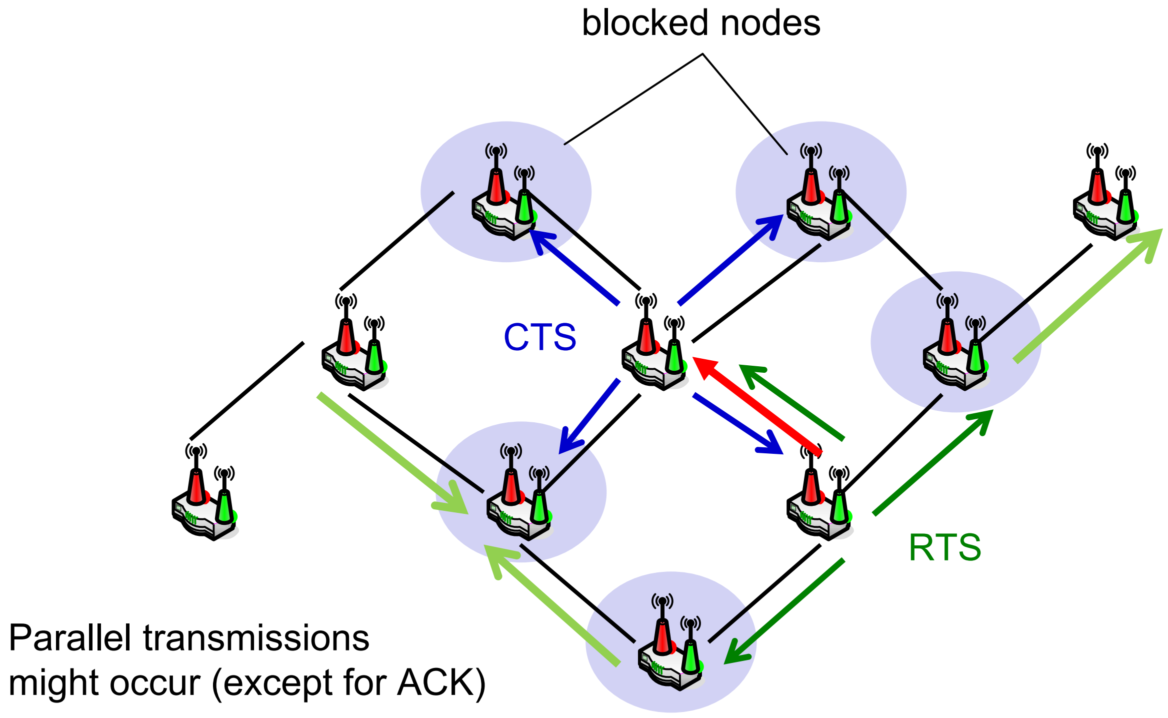




- A node unable to decode the CTS might nevertheless disturb the transmission.
- Hidden node problem still exists.
- Critical if adaptive modulation and coding is used.
- Threshold on packet size for RTS/CTS usage typically maximum packet size.

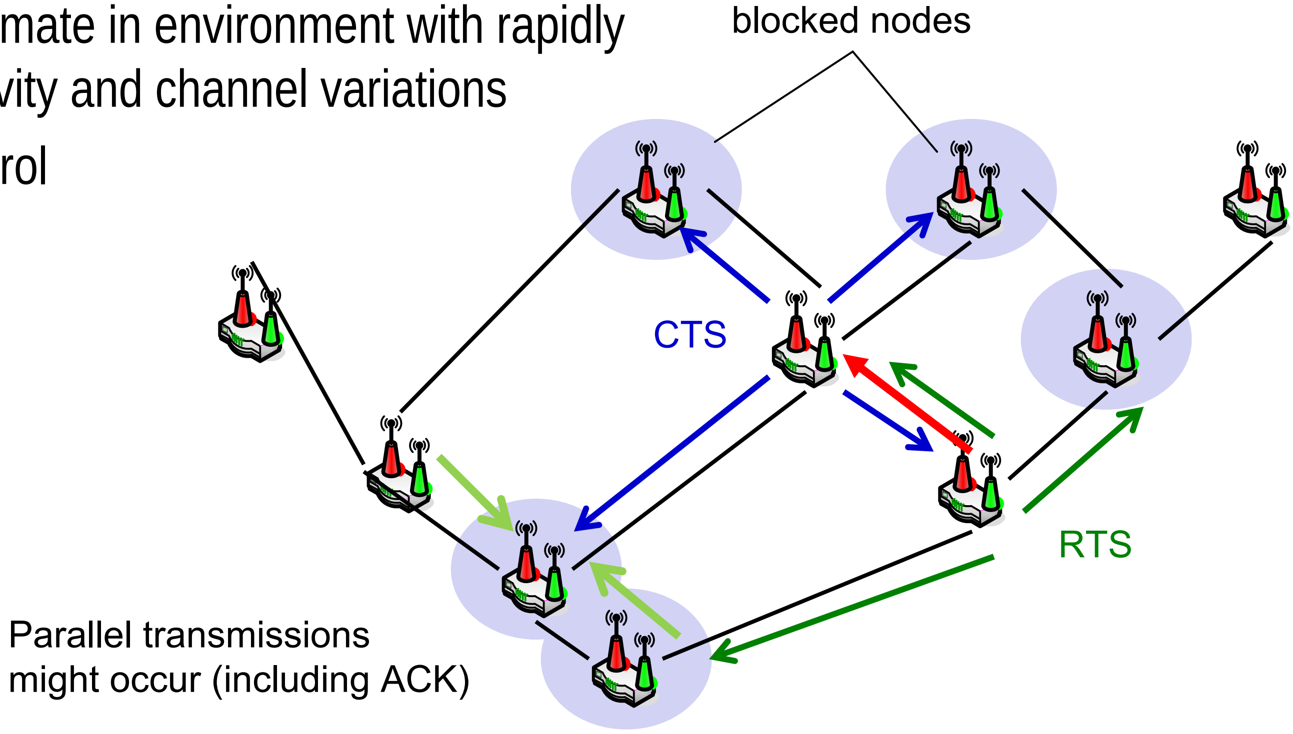
Exposed Node Problem

- disabling of possible non-interfering parallel transmissions
- nodes that only receive RTS can transmit
- nodes that only receive CTS can receive



MAC Layer
Exposed Node Problem

- actually, it's all a problem of
  - "actual" interference
  - frame error probabilities for different SNRs
  - antennas
  - power control
  - difficult to estimate in environment with rapidly changing activity and channel variations
  - ⇒ topology control

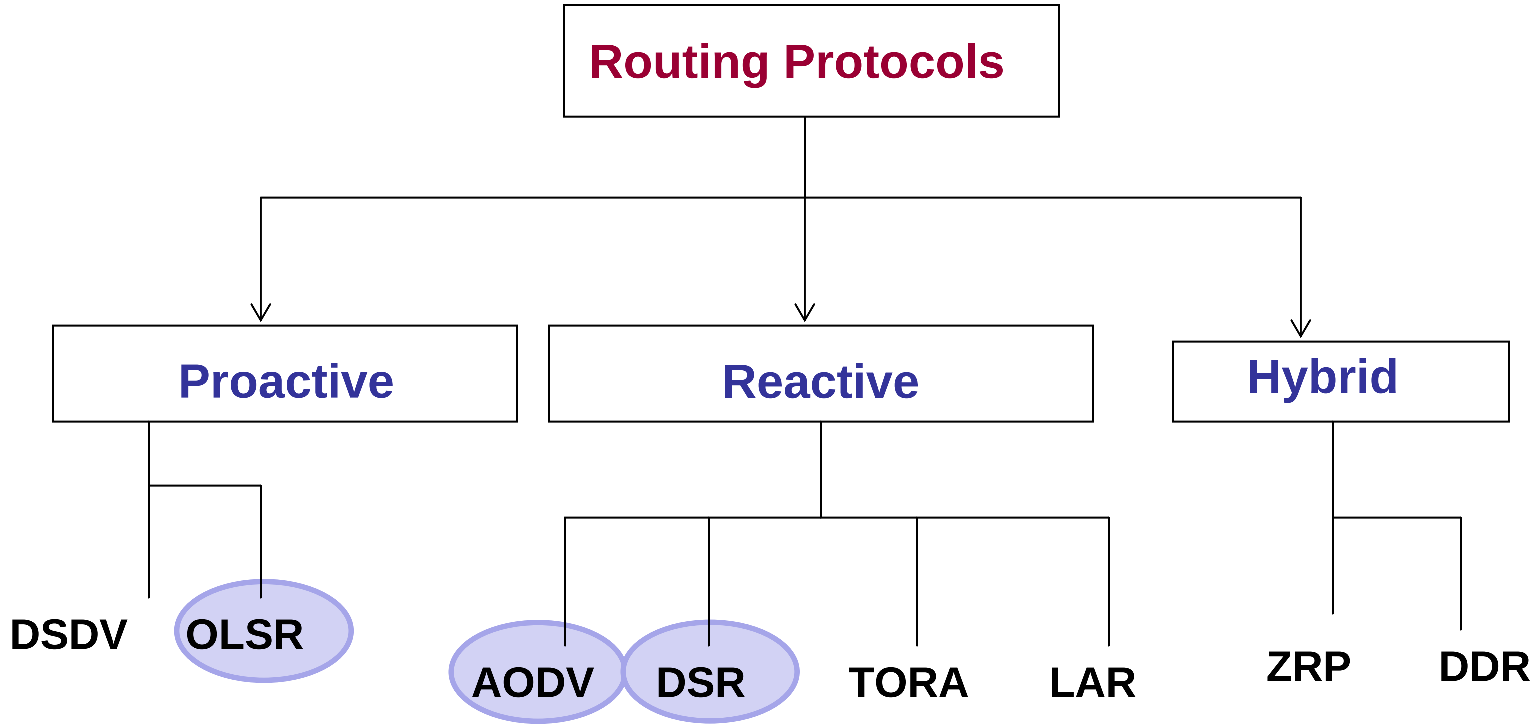


Mesh Network Routing
Why Mesh Routing?

- Why do we need specialized Mesh routing?
  - (A) To reach nodes that are no direct neighbors
  - (B) To deal with topology dynamics induced by dynamical Power-on, Power-off
  - (C) To support spontaneous formation of the network
  - (D) To match the characteristics of wireless communication
  - (E) Because all end-systems are also acting as routers
  - (F) To operate without fixed infrastructure
- Applying Ad-hoc network routing protocols, BUT
  - WMN routers differ from MANET routers
    - Power supply, Mobility,…
  - Separation of WMN routers and clients
- Routing Approaches
  - Flooding-based routing
  - Reactive (on-demand) routing
  - Proactive routing
  - Hierarchical routing

All answers are correct!

Taxonomy of MANET Routing Protocols



- Proactive protocols
  - Determine routes independent of traffic
  - Traditional link-state and distance-vector routing protocols are proactive
- Reactive protocols
  - Maintain routes only if needed → OnDemand

see also http://www.wikipedia.org/wiki/Ad_hoc_protocol_list

Mesh Network Routing
Overview

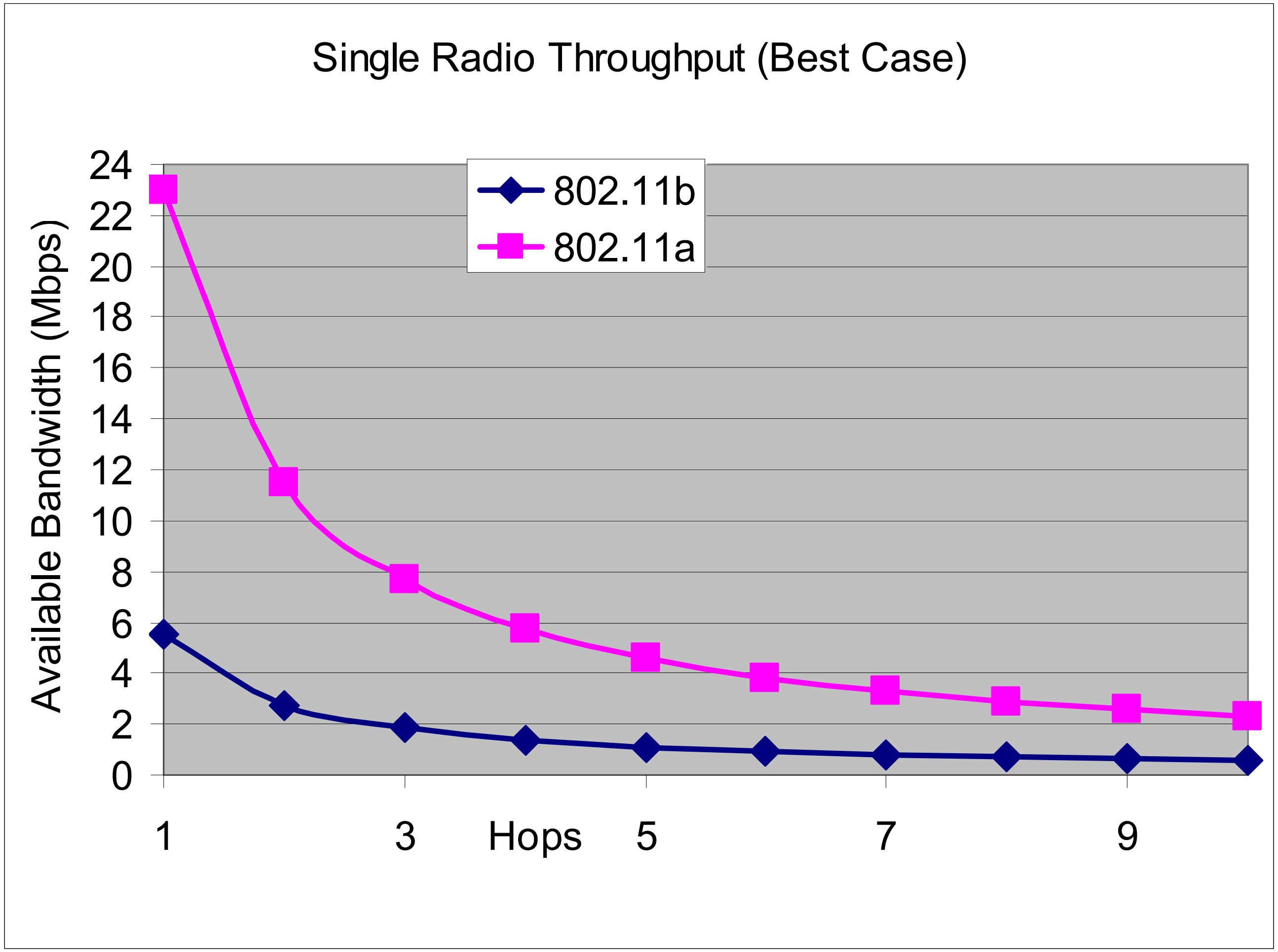
Key issues:

- Individual nodes cooperate in the wireless forwarding
- Main traffic: to/from internet gateway
- How to find routes?
- How to find internet gateways?
- Which routes are "good"?
- How to make the MESH transparent to end-nodes?

Video: source Microsoft

Andreas J. Kassler, Marcel Castro

Mesh Network Routing
Single-Radio Single-Channel



Key issues:

- Cannot Tx and Rx simultaneously (single radio)
- Need to serialize reception and transmission
- Reduces capacity
- More problems due to collisions and interference

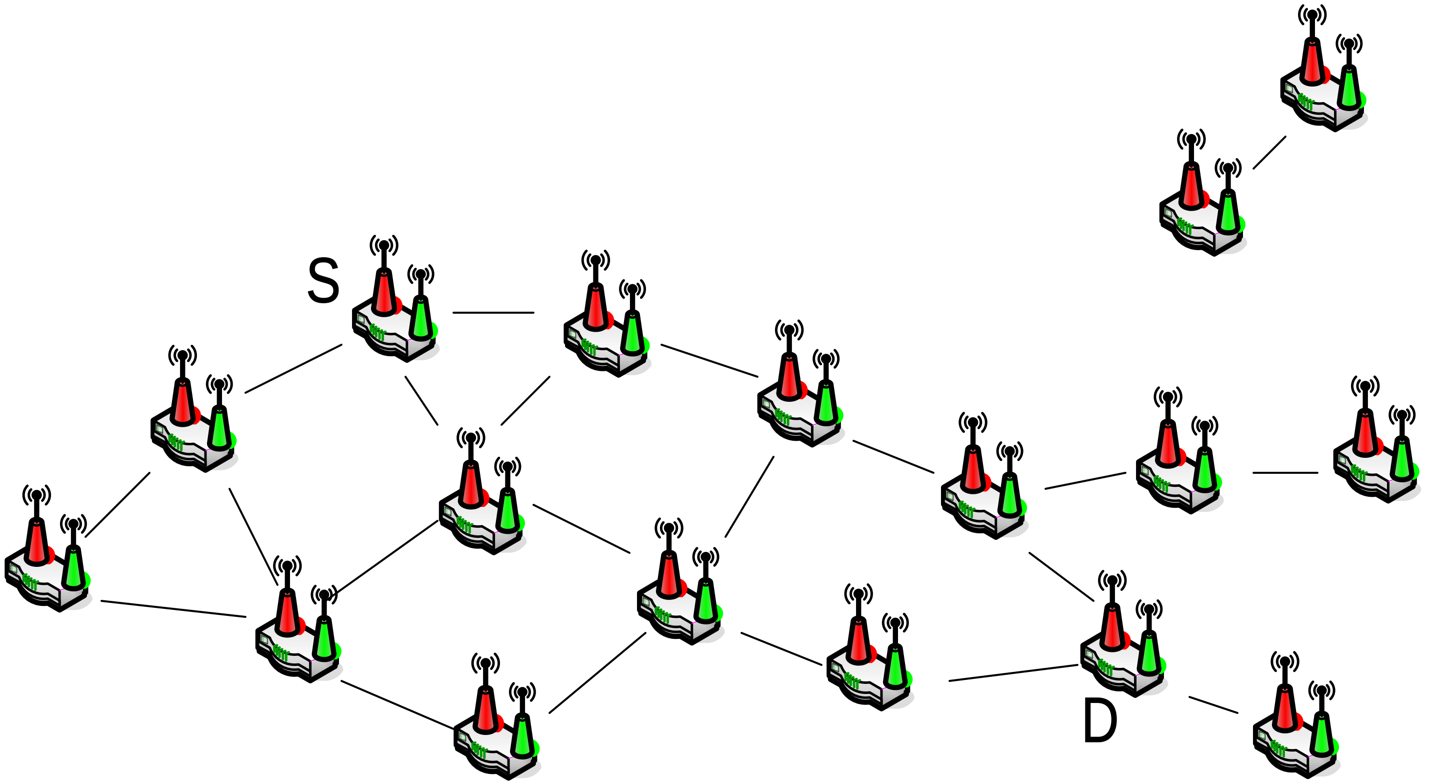
Per MN Capacity=1/N , (N=hops)

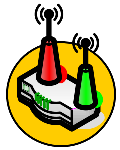
Single Radio and Single Channel → 12 Steps to send 4 packets

Mesh Network Routing
AODV

- Ad-Hoc onDemand Distance Vector Routing [Perkins99]:
  - Reactive routing protocol
  - Based on distance vector principle: for each destination store direction, distance.
  - Route discovery cycle for route finding
    - Flooded / Broadcast Route Request (RREQ)
    - A node re-broadcasting RREQ sets up reverse path pointing towards source
    - Unicast Route Reply (RREP) along reverse path of RREQ
    - At most one next-hop per destination maintained at each node
    - Unicast Route Error (RERR)
  - No overhead on data packets
  - Unused routes expire even if topology does not change
  - Loop freedom is achieved through sequence numbers
  - assume symmetric (bi-directional) links.
  - Experimental RFC status issued (July 2003): http://ietf.org/rfc/rfc3561.txt
  - Kiyon Inc.'s Autonomous Network

Route Requests in AODV



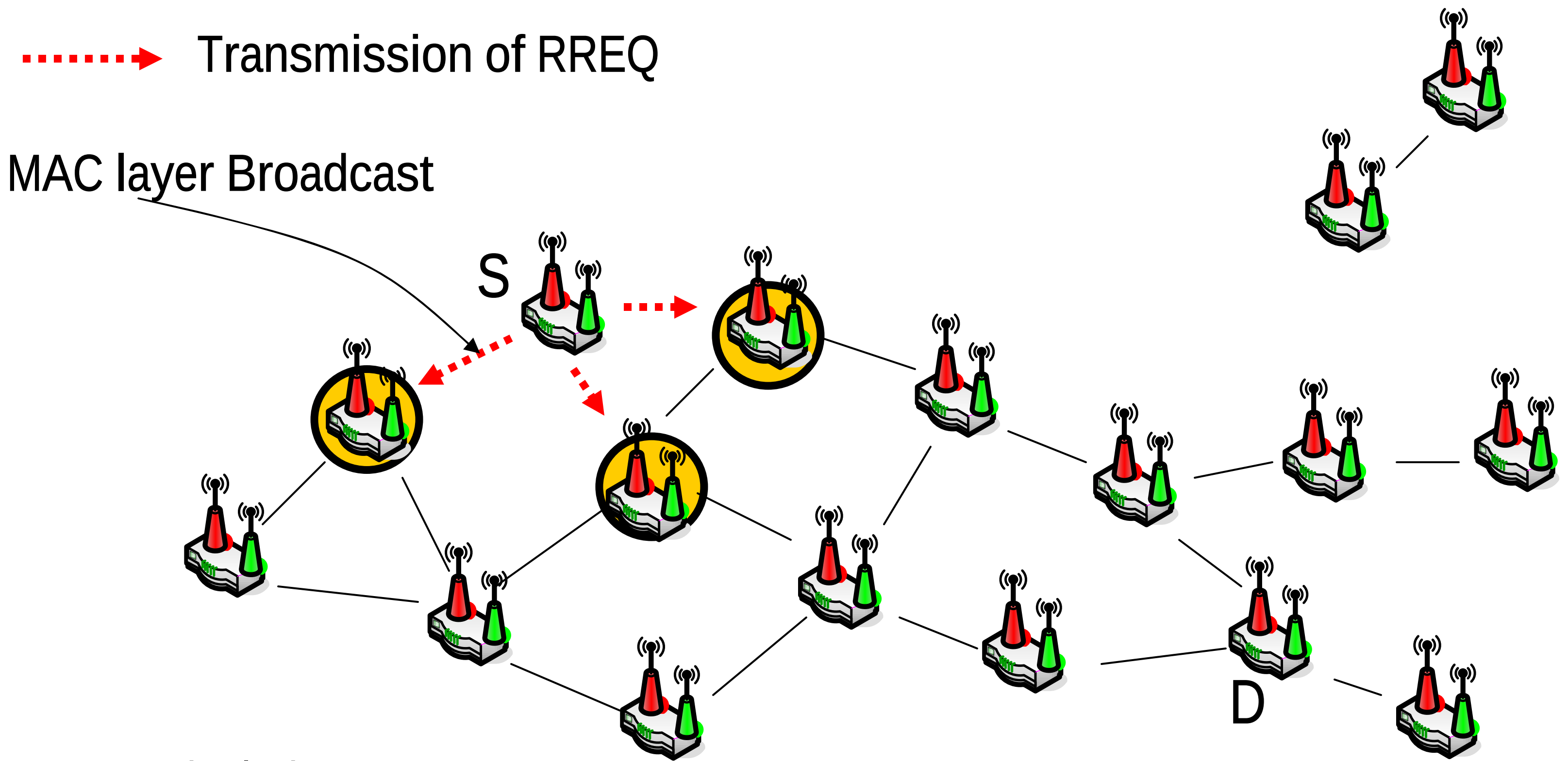


Represents a node that has received RREQ for D from S

Represents that two nodes are connected as within each others transmission range

Example adopted from Nitin Vaidya (UIUC)

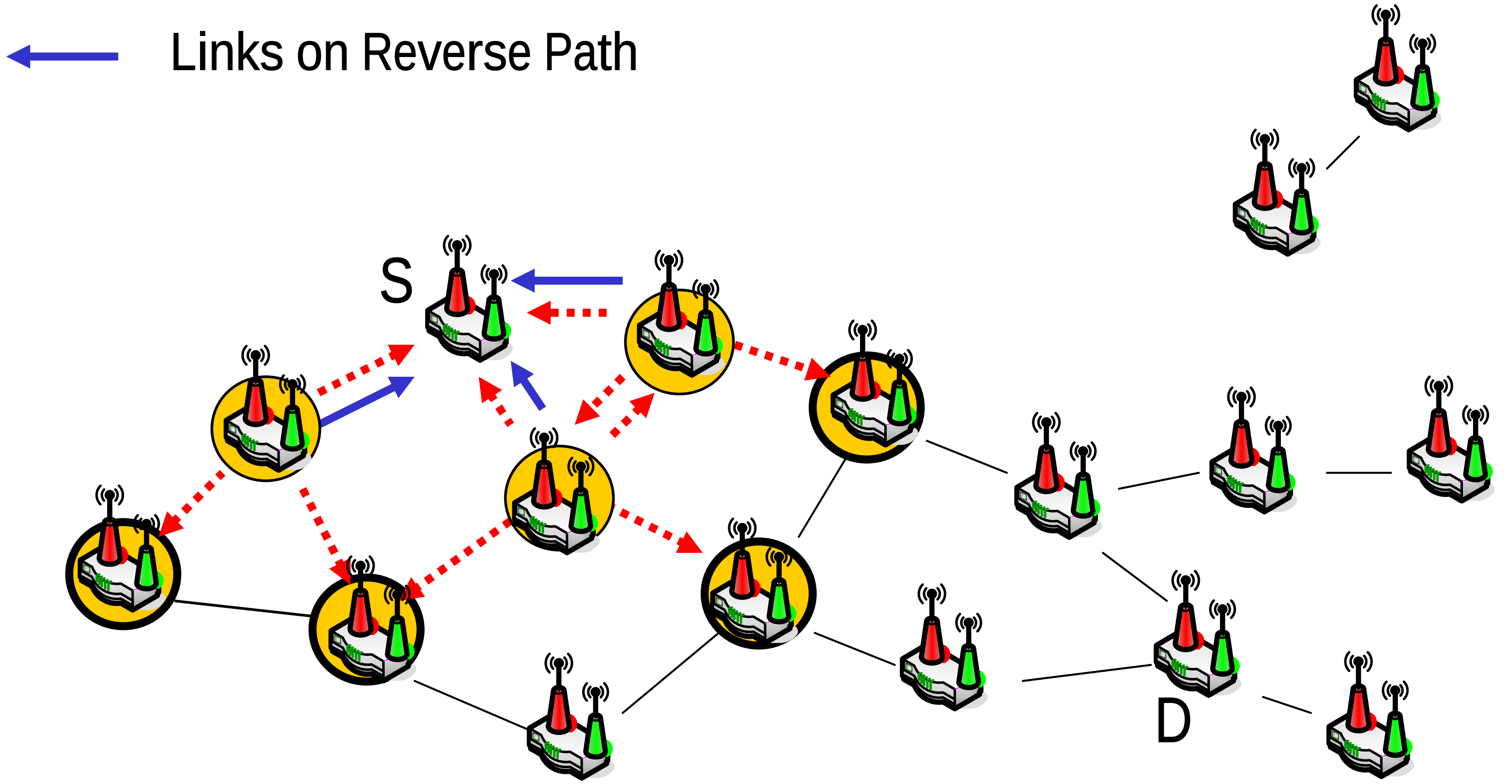
Route Requests in AODV



- RREQ includes
  - source and destination IP address
  - current destination seq. number
  - broadcast id (incremented for every RREQ)
  - TTL.

Example adopted from Nitin Vaidya (UIUC)

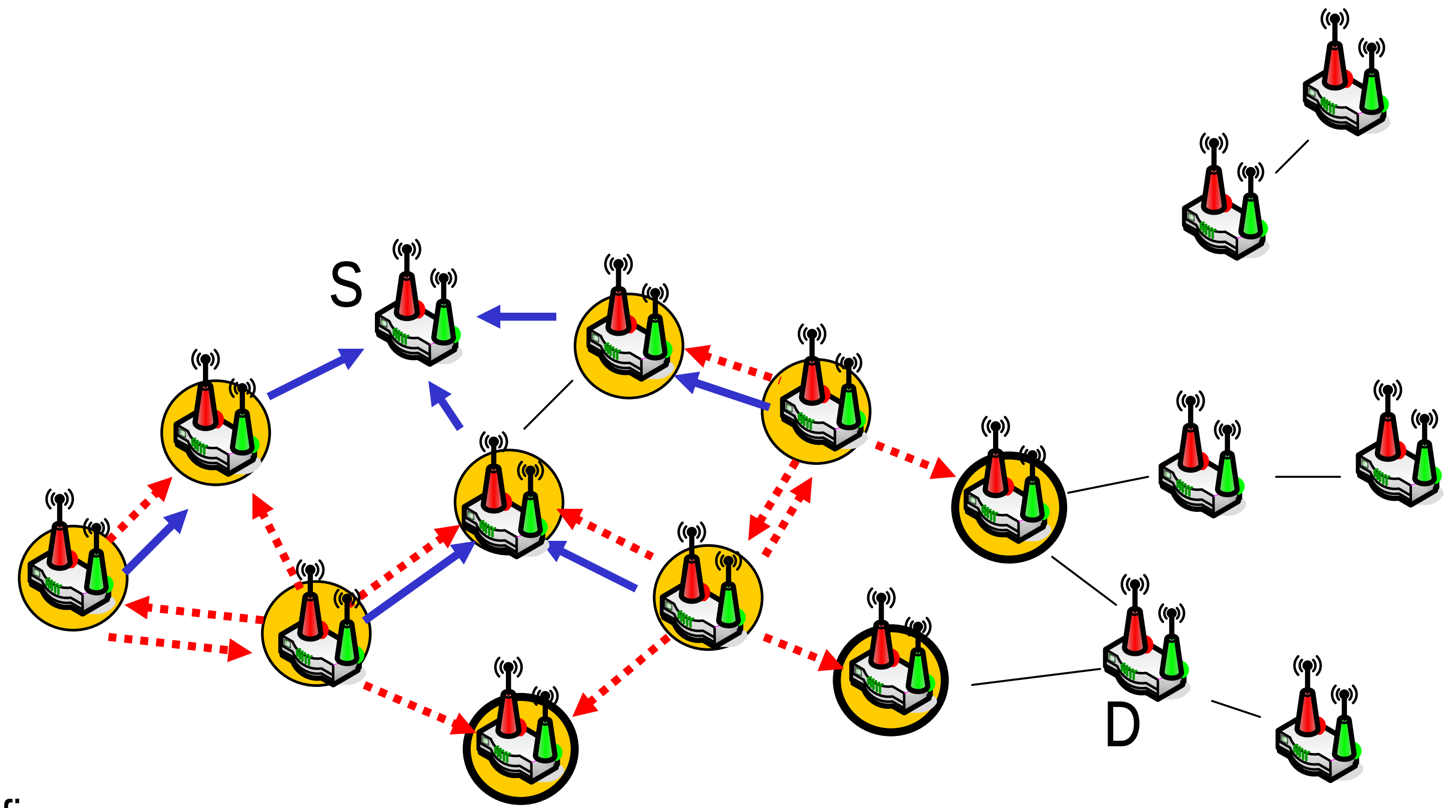
Route Requests in AODV



- RREQ processing:
  - node creates *reverse* route table entry for RREQ source with TTL.
  - If node has "unexpired" route to destination in its table with sequence number >= RREQ's, it replies to RREQ with Route Reply (RREP) back to source. Otherwise, broadcast RREQ onward

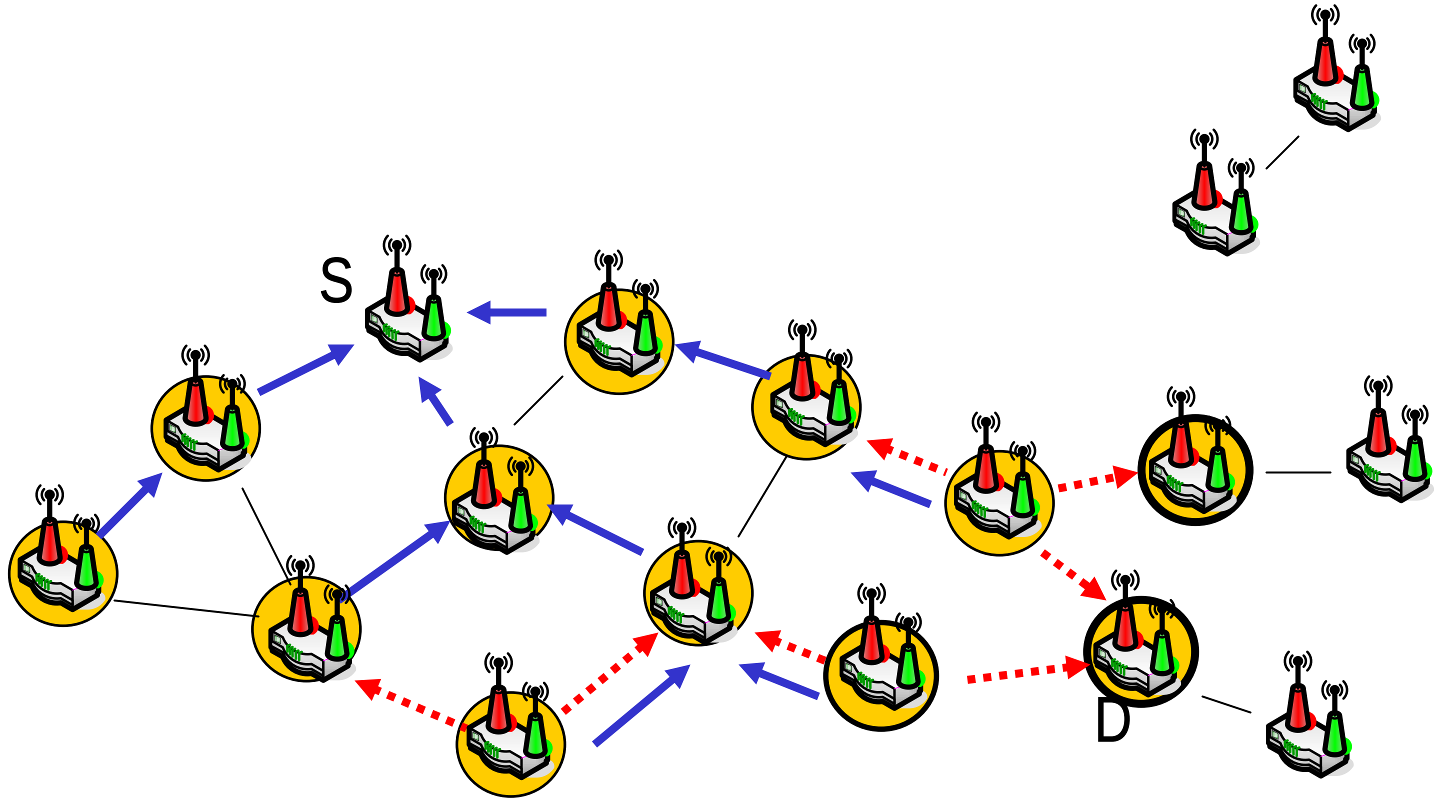
Example adopted from Nitin Vaidya (UIUC)

Reverse Path Setup in AODV



- Identifier
  - Source IP + bcast id uniquely identifies RREQ: nodes do not forward RREQs they have forwarded recently.
  - Node C receives RREQ from G and H, but does not forward it again, because node C has already forwarded RREQ once

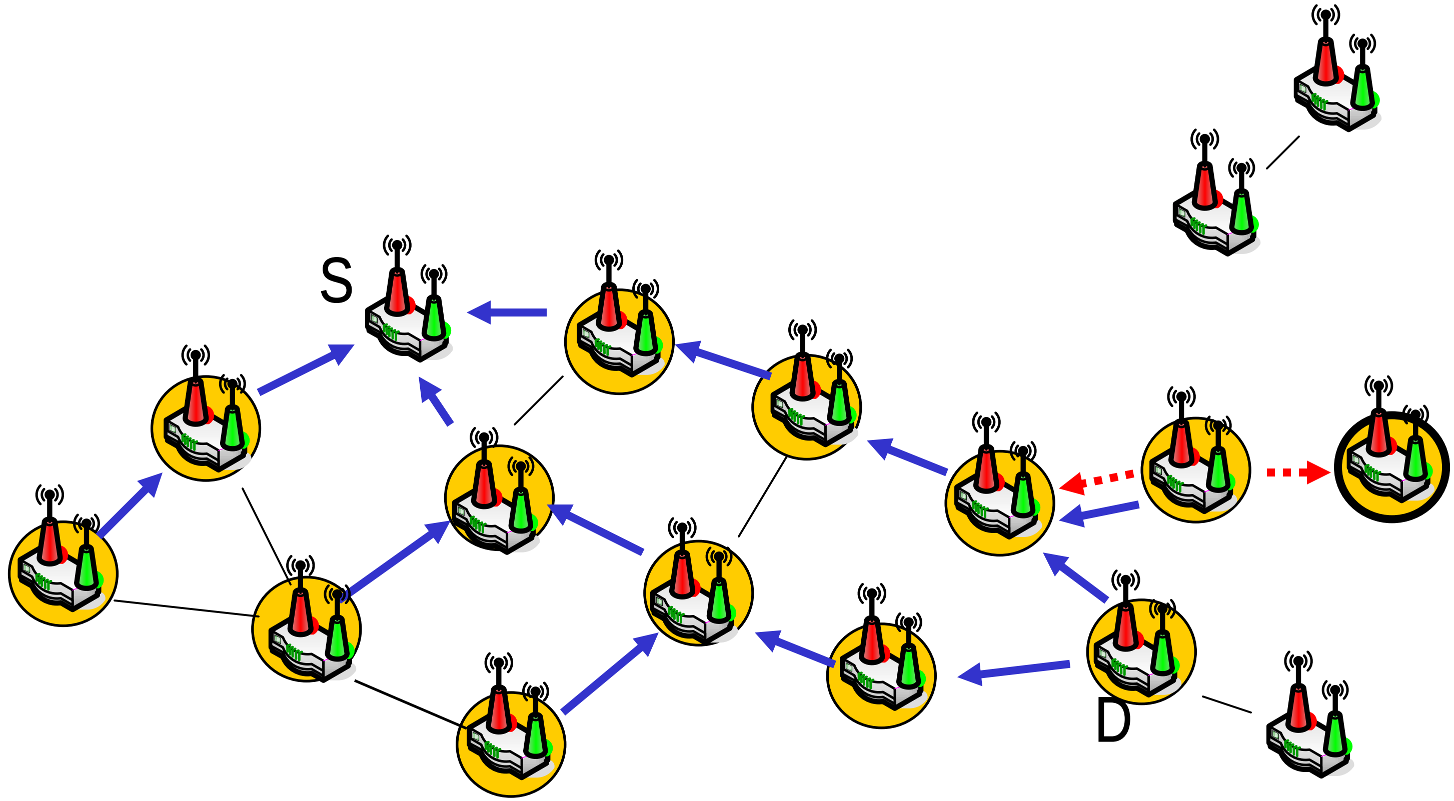
Reverse Path Setup in AODV



- Destination Sequence Number
  - When node D receives route request with destination sequence number N, D sets its sequence number to N, unless it is already larger than N.
  - Node's own sequence number is monotonically increasing.
  - Sequence number is incremented after neighborhood topology change.

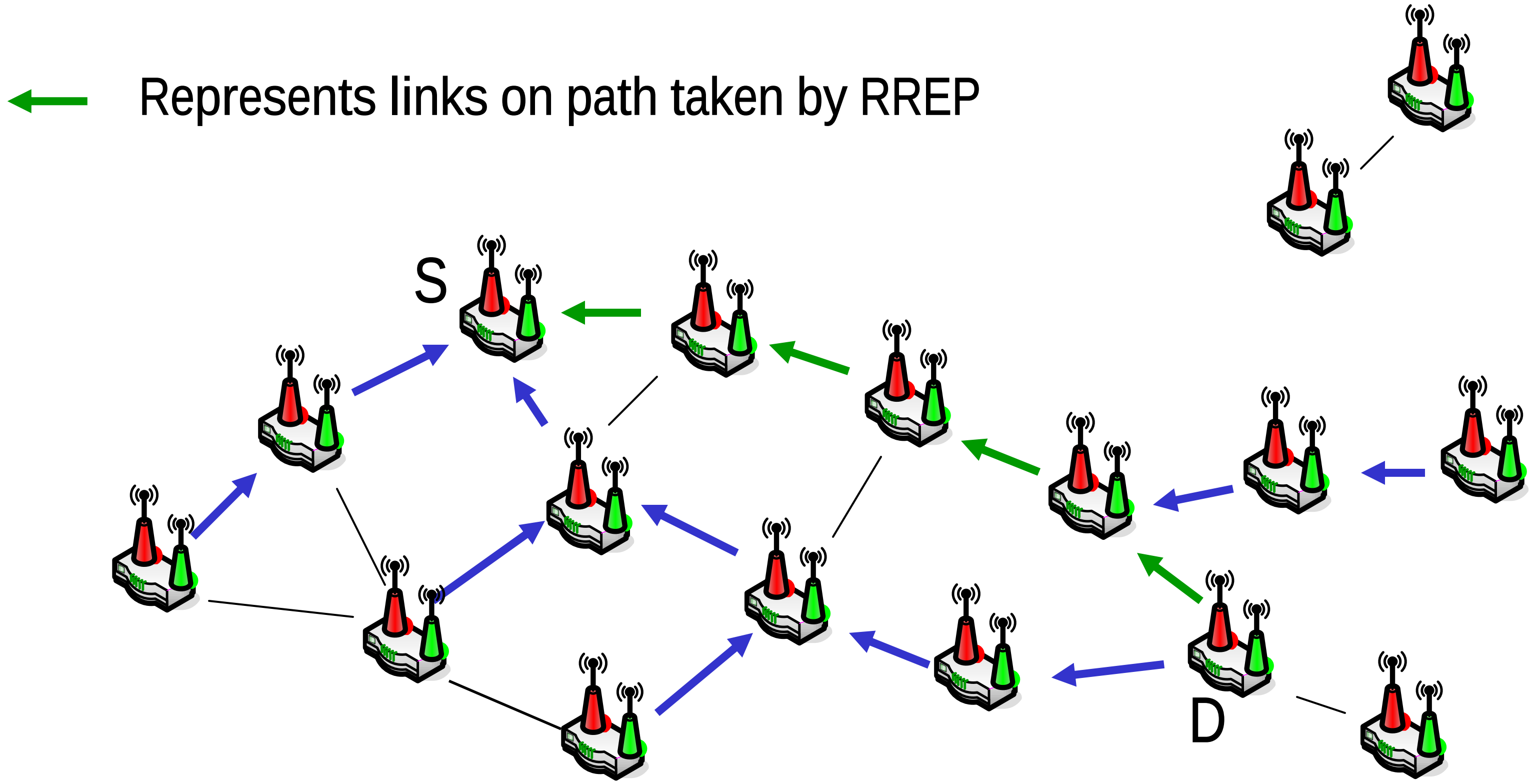
Example adopted from Nitin Vaidya (UIUC)

Mesh Network Routing
Reverse Path Setup in AODV



- Node D does not forward RREQ, because node D is the target of the RREQ

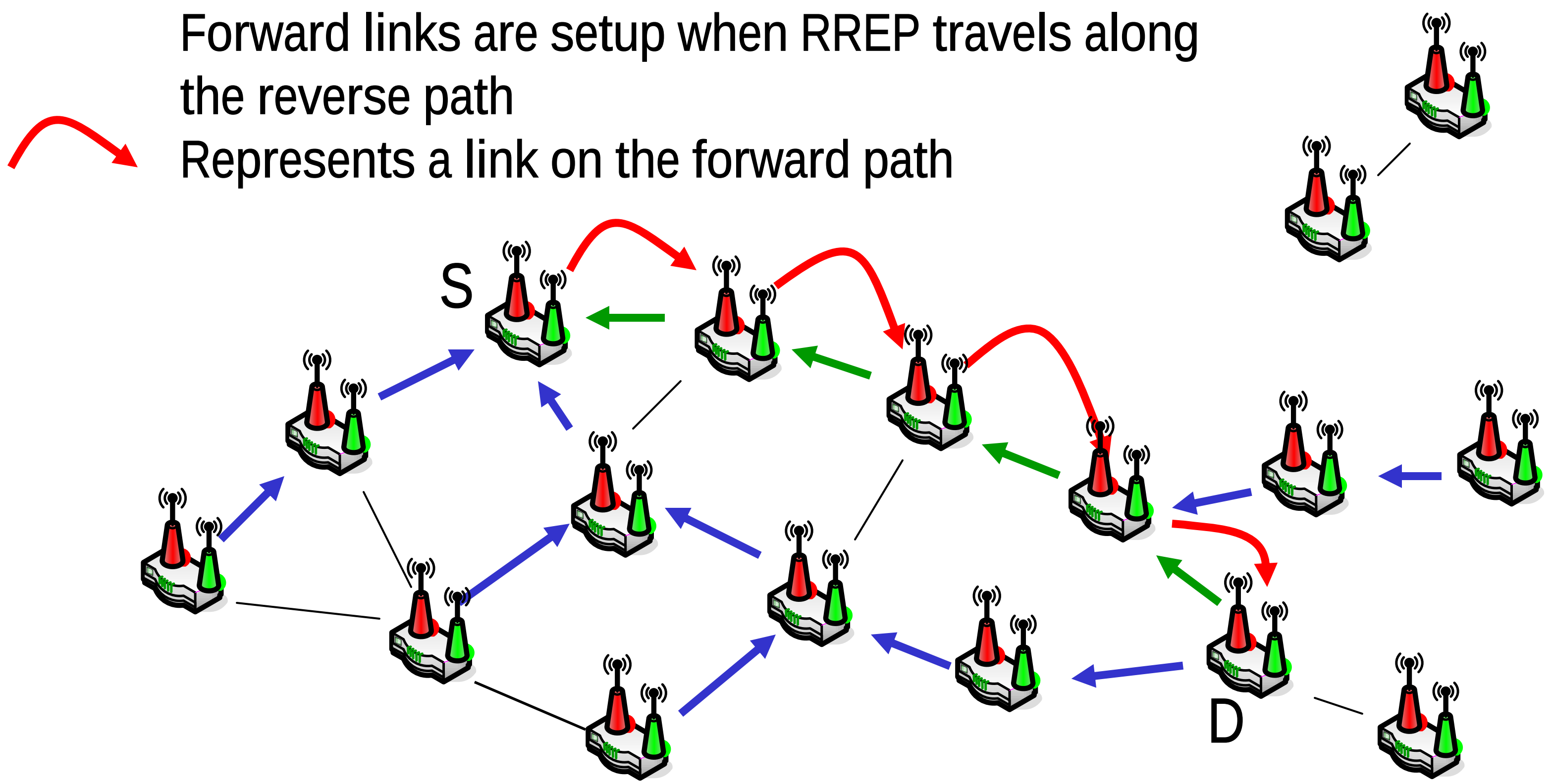
Mesh Network Routing
Route Reply Example



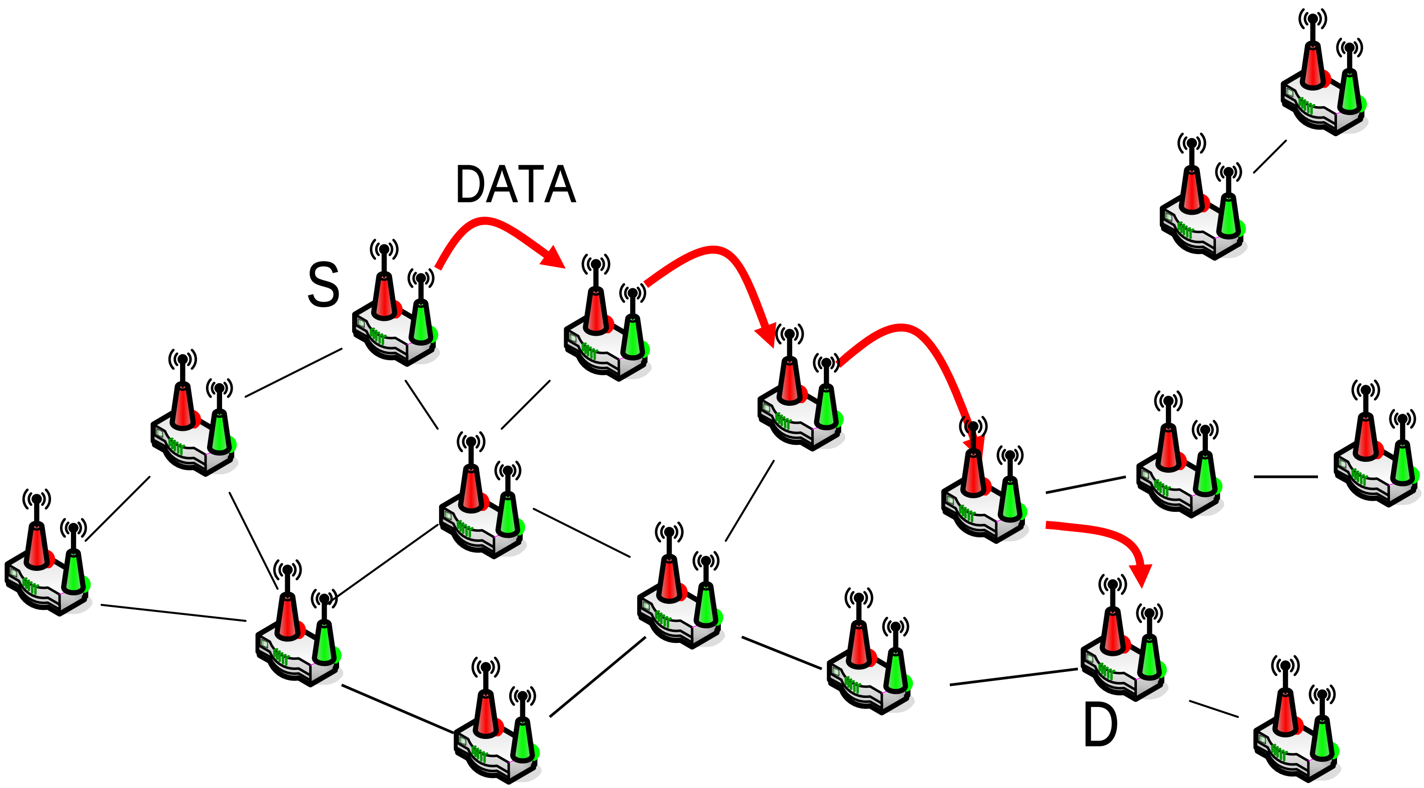
- An intermediate node that has current route to destination, may respond to RREQ with RREP.
- RREP contains source and destination IP, current sequence number, number of hops to destination. If destination, then destination seq. #. Else, node's current record of destination's seq. #.

Example adopted from Nitin Vaidya (UIUC)

Forward Path Setup in AODV

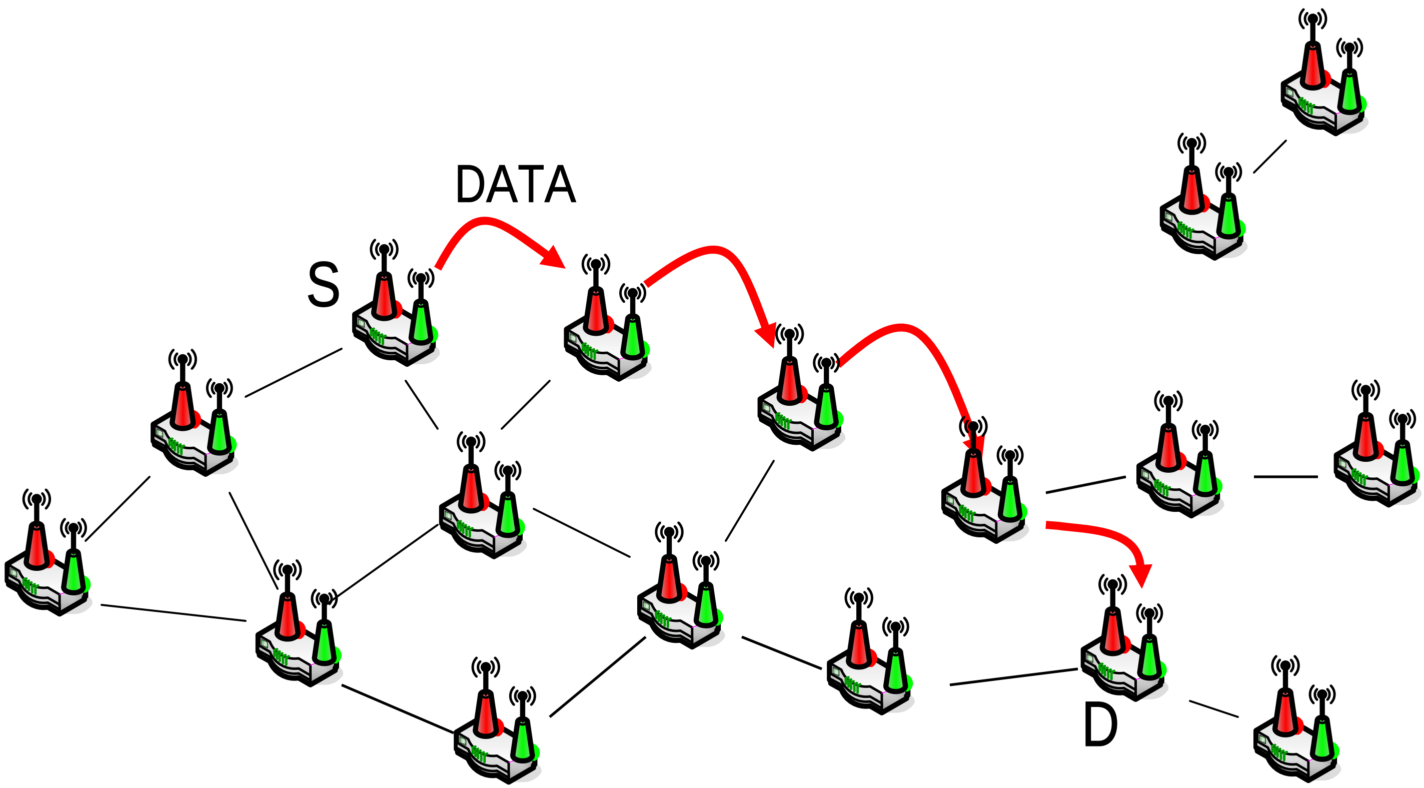


- Node receiving RREP sets up forward path to destination.
- If multiple RREPs received, node forwards first one.
- Later RREPs discarded unless greater seq. # or smaller # of hops.



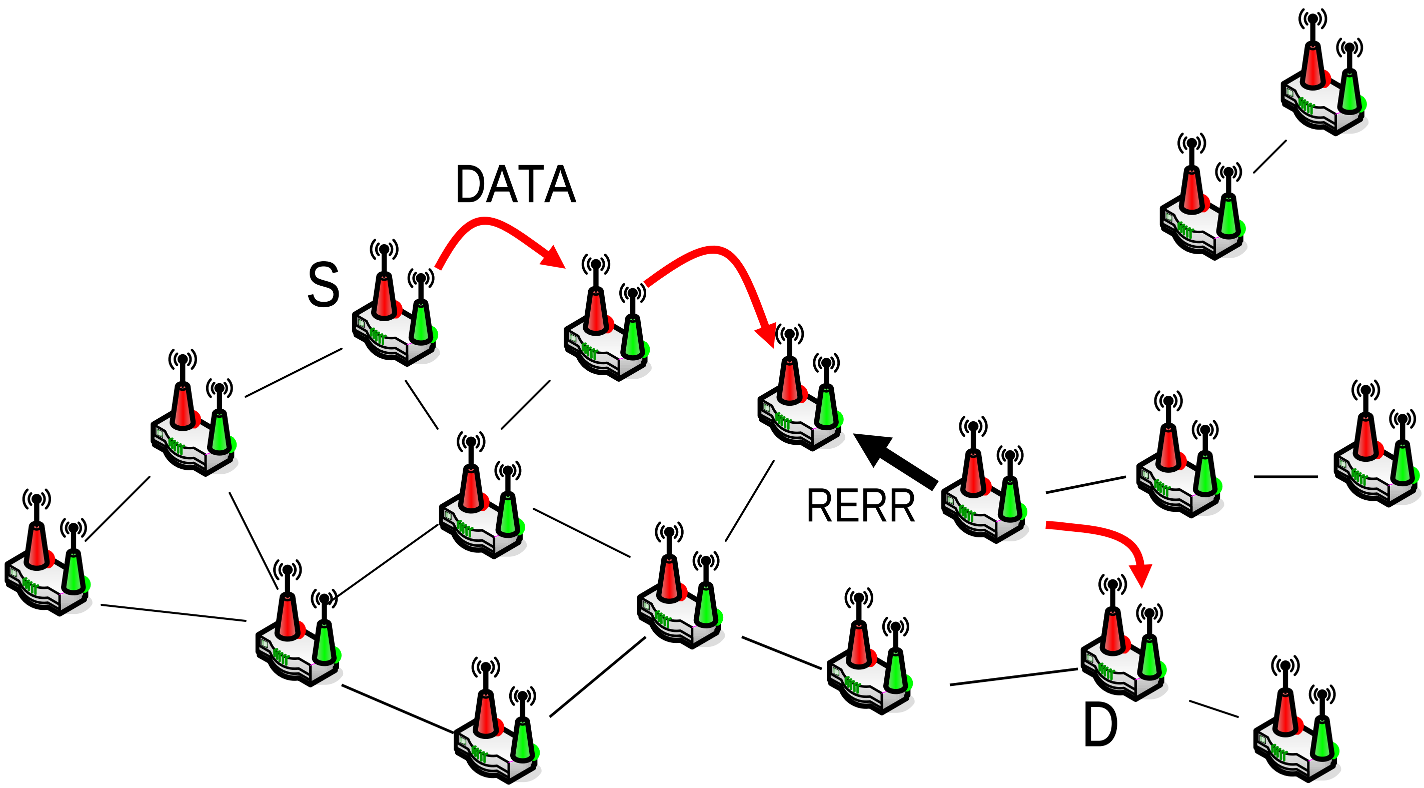
- Routing table entries used to forward data packet.
- Route is *not* included in packet header.

AODV – Route Maintenance



- Timers to keep route alive
  - Reverse link deleted after TO → long enough to allow RREP to travel back
  - Forward path deleted if not used for a active_route_timeout interval
    - Deleted if not used, even if route still valid → problematic for long silence periods

AODV – Route Error



- Link failure reporting / repairing routes
  - When a node is unable to forward packet on link (X,Y) towards D, it generates a RERR
  - Node X increments the destination sequence number N++ for D cached at node X
  - *N*++ is included in the RERR, which is sent out based upon precursor lists
  - S receives RERR, initiates a new route discovery for D using larger sequence number

Example adopted from Nitin Vaidya (UIUC)

Summary / Other Features of AODV

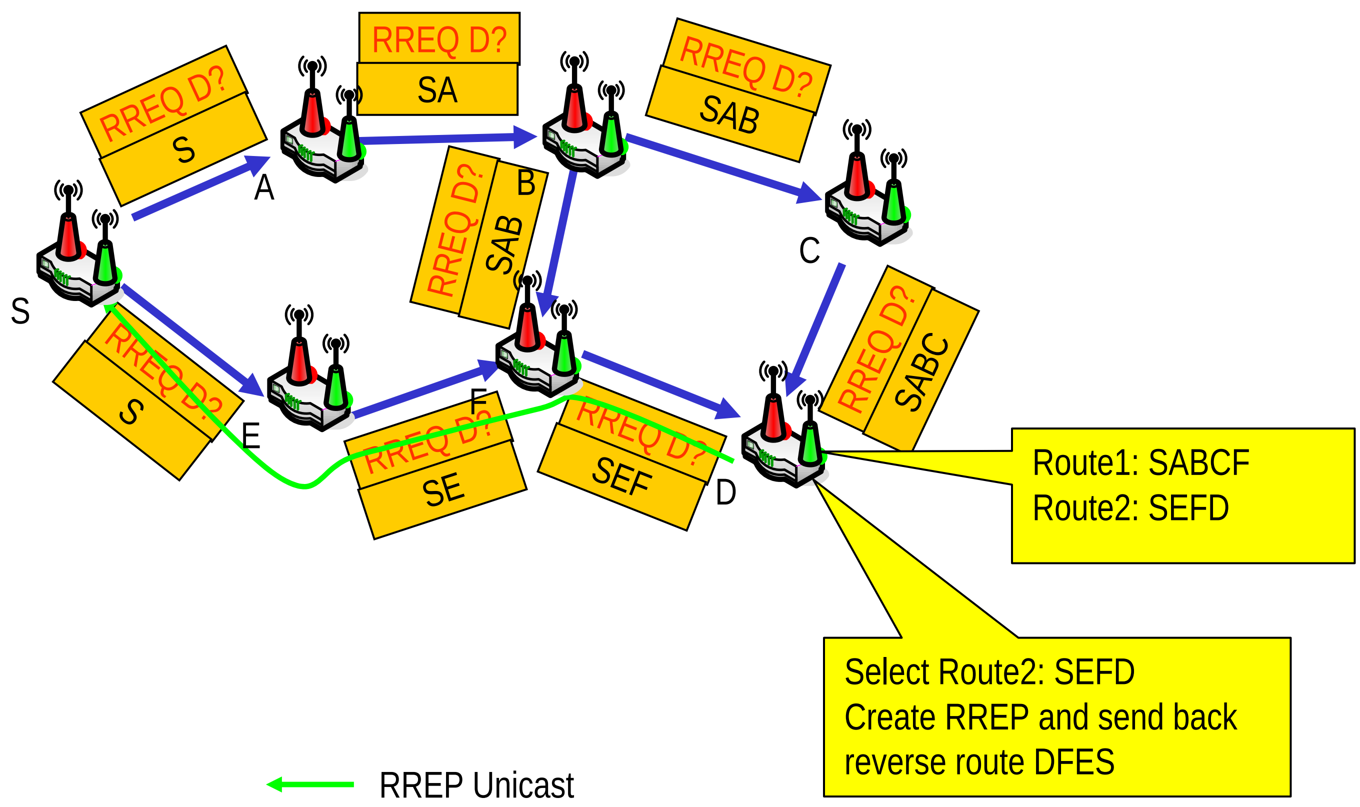
- Target networks
  - Where routing churn is high enough that proactively maintaining routes is unproductive, and that can absorb a network wide broadcast rate
  - The authors claim scalability up to 10,000 nodes (performance suffers, simulation results)
- Multiple optimizations
  - AODV-LR - Local Repair
  - AODV-ESP - Expanding-Ring Search
  - Multi-path extension proposed (AODVM, AOMDV)
- Multiple open issues
  - Security
  - QoS
  - …
  - Protocol needs operational experience to discover further issues

- DSR Characteristics:
  - On-demand routing, Route contained in each packet header
  - loop-free routing
  - No need for routing table in intermediate nodes
  - Efficient routing cache by forwarding or overhearing nodes
  - Two phases:
    - Route Discovery
    - Route Maintenance

DSR Operation

- Route discovery phase
  - initiated if the source node does not have routing information in its cache
  - source node broadcasts a route request that contains source address, destination address, unique ID
  - Intermediate nodes
    - Send back route reply if route in cache,
    - otherwise
      - add their own address to the route record of the packet in the header
      - forward the packet along its outgoing links
- Route Reply
  - generated by the destination or a node that has a valid route in the cache
  - contains route record obtained from the route request
  - is sent via the path in the route record, or from a cached entry, or is discovered through a route request
  - route error packets and acknowledgments for route maintenance

DSR Operation



Proactive Routing Schemes

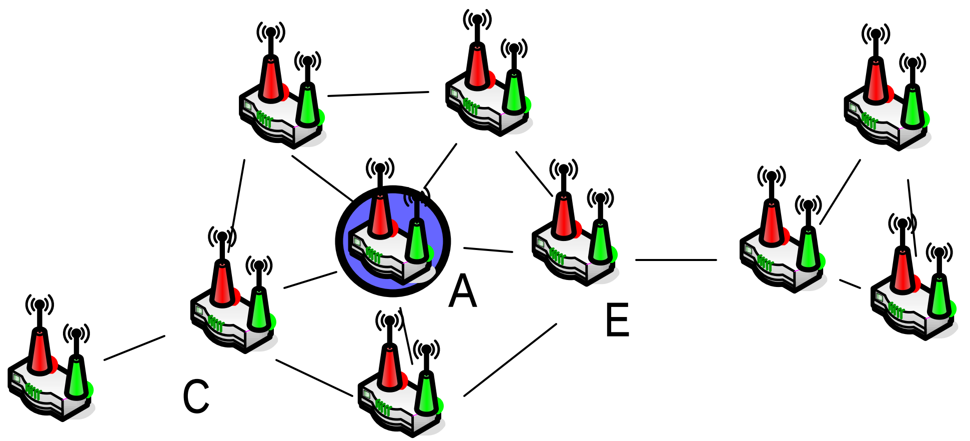
- General Principle
  - Nodes maintain global state information
  - Consistent global routing information is stored at all nodes
  - Changes in network topology are propagated to all nodes with corresponding state information being updated
  - Routing state maintenance can be flat or hierarchical
- Examples of proactive routing protocols
  - Destination Sequenced Distance Vector (DSDV)
  - Topology Broadcast based Reverse Path Forwarding (TBRPF)
  - Optimized Link State Routing (OLSR)

- Mostly based on Distance Vector or Link State
  - DV protocols
    - may form loops and thus waste bandwidth and power
    - Loop avoidance may be complex
  - LS protocols
    - Higher storage and communication overhead
- Link State Routing Principle [Huitema95]:
  - Each node periodically floods status of its links
  - Each node re-broadcasts link state information received from its neighbor
  - Each node keeps track of link state information received from other nodes
  - Each node uses above information to determine next hop to each destination
  - Proactive
  - Network wide dissemination of local information

Optimized Link State Routing

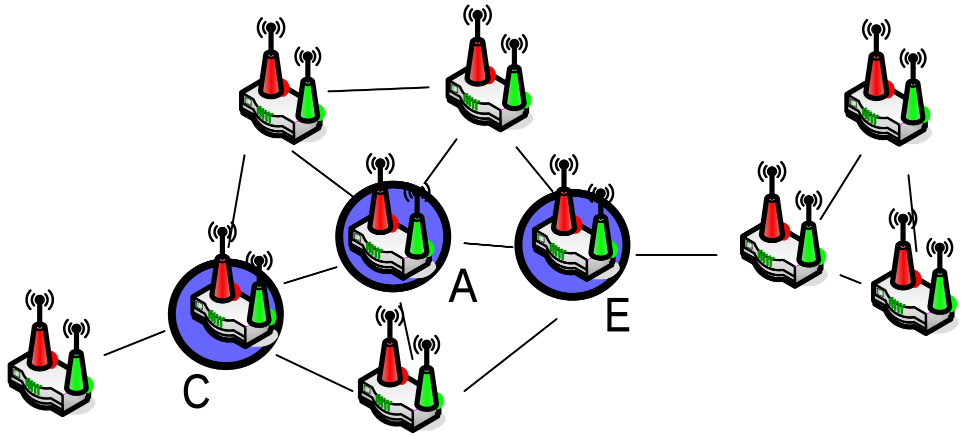
- OLSR Jacquet, http://hipercom.inria.fr/olsr/rfc3626.txt
  - Reduce overhead of flooding link state information
  - A broadcast from node X is only forwarded by special neighbors: *multipoint relays (MPR)*
  - Multipoint relays of node X are its neighbors such that each two-hop neighbor of X is a one-hop neighbor of at least one multipoint relay of X
    - MPRs should globally optimize flooding by optimizing it locally
    - The number of multipoint relays should be minimized (per node)
    - MPRs of X are 1-hop neighbors of X covering X's 2-hop neighbors
    - Each node transmits its neighbor list in periodic beacons, so that all nodes can know their 2-hop neighbors, in order to choose the multipoint relays
    - A node forwards the flooding packets with the following rules
      - Forward if the packet has not already been received
      - The node is multipoint relay of the last emitter

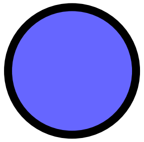
- Which nodes are multipoint relays of node A???



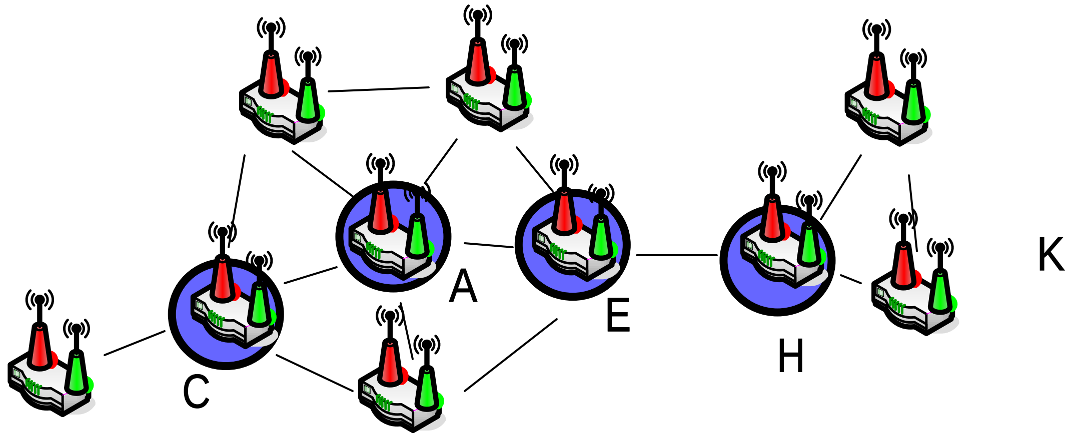
Node that has broadcast state information from A

- Nodes C and E forward information received from A




Node that has broadcast state information from A

- Nodes E and K are multipoint relays for node H
- Node K forwards information received from H
  - E has already forwarded the same information once



Example adopted from Nitin Vaidya (UIUC)

- Link Sensing
  - Periodic HELLO messages: a local link set, describing links between "local interfaces" and "remote interfaces" is defined
- MPR Selection and MPR Signaling
  - Nodes select a subset of their neighbors such that a broadcast message, retransmitted by these selected neighbors, will be received by all nodes 2 hops away
  - MPR calculation based on HELLO messages
- Topology Control Message Diffusion (Link State Messages)
  - Topology control messages are used to declare MPRs
  - carry link-state information to allow route calculation to all nodes in the network
- Route Calculation:
  - Bases on link state information + interface configuration
  - The routing table can be calculated at each node
- The OLSR standard specifies all messages + mechanisms

OLSR Summary

- Target Networks
  - Scalability problems for large and many mobile nodes networks due to overhead
  - Low latency for route discovery (proactive)
  - Various extensions exist, so-called auxilliary functions to complement the core functionality of OLSR, including QoS features etc
- Multipoint relays reduce the flooding overhead because
  - only MPRs forward control messages
  - MPRs may flood partial link state, that is, only MPRs generate link state information including MPR Selector information
  - A MPR Selector of node X is a node which has selected its 1-hop neighbor, node X, as its multipoint relay

802.11s Routing

- Two defined routing schemes
  - Hybrid Wireless Mesh Protocol (HWMP) – Mandatory
    - combines On-demand and Proactive Routing
      - (Radio Metric) RM-AODV (On-Demand part)
      - Tree based routing to Root Portal node (pro-active part)
    - Airtime Link Metric as mandatory link metric defined in standard
    - Other Link metrics allowed
      - Extensible framework allows any path selection metric (QoS, load balancing, power-aware, etc)
  - (Radio Aware) RA-OLSR - Optional
- Alternative routing schemes supported
  - Vendor specific

- Proactively maintains link-state for routing
  - Changes in link state (radio aware link metric) are flooded through MPRs
  - Combines
    - OLSR (RFC 3626) Extended with:
      - Use of a radio aware metric in MPR selection and routing path selection
      - Efficient association discovery and dissemination protocol to support 802.11 stations
    - (Optional) Fisheye State Routing Concepts
      - message exchange frequency control (fish-eye state routing)
      - Lower frequency for nodes within larger scope
      - Reduce message exchange overhead *in time*.

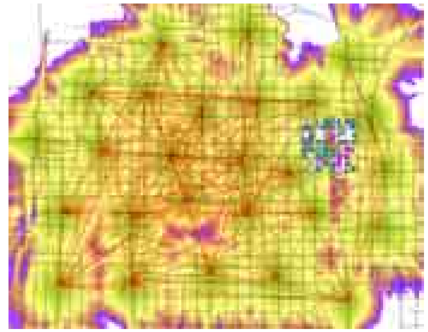
- Future Directions, Conclusion

- Applications, Requirements and Use Cases
- Interoperability and Internet Integration
- Capacity Increase
  - Exploit Diversity through Multi-*Technology
    - channels, radios, paths, rates, antennas,
  - Routing, MAC and Quality of Service
  - Cross-layer Design
- Robustness and Security
  - Important for user adoption and community building
- Services
  - Also Peer-to-Peer, Overlays

Important Future Trends

- Mesh Management and Monitoring
  - Build management capabilities into the network → self-managed
  - Reduced OPEX
  - Requires decentralized operation
- Cognitive Mesh Networks
  - Build intelligence into the network using monitoring data
  - Observe the environment, adapt operation, re-configure, learn!
  - More than cross-layer!
- Tools
  - Need to develop proper tools for management, monitoring operation and deployment of nodes
- Wishlist:
  - Scalability to metropolitan size, reliable communication, broadband capacity, security and robustness, easy of deployment, minimize cost, interoperable with wireless internet and other (wireless) network technologies, etc.

sponsored by FP6 IST Daidalos
www.ist-daidalos.org



Peer-to-Peer Services in Community Mesh Networks Part 2

Andreas Kassler, Marcel Castro

Karlstad University
Sweden
kassler@ieee.org

Overview Part II

- Client-Server concept
- Understanding P2P
- How to integrate P2P and MANET
- VRR: Virtual Ring Routing
- SSR: Scalable Source Routing
- Some Open Points

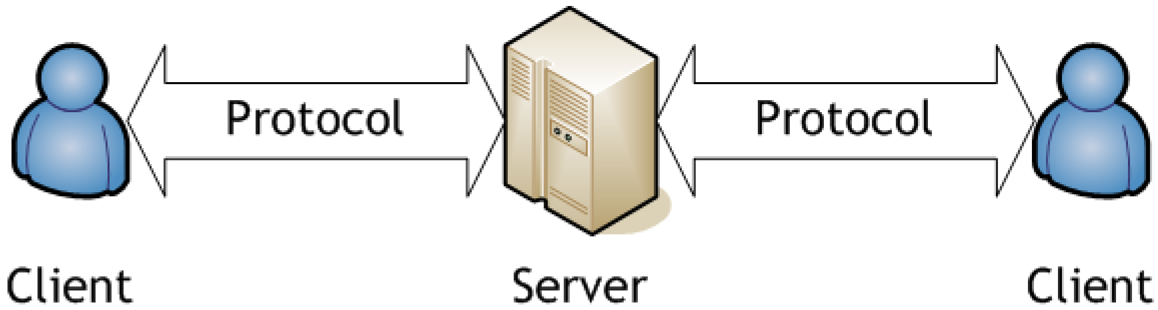
Overview Part II

- Client-Server concept
- Understanding P2P
- How to integrate P2P and MANET
- VRR: Virtual Ring Routing
- SSR: Scalable Source Routing
- Some Open Points

Client-Server concept
Life Before P2P

- Client-Server (CS) based
- Centralized architectures
- Simple model

Client-Server model



- Client and server communicate using a well defined protocol
- Server stores all the service logic (centralized architecture)
- Clients (dumb) ask the server to perform tasks for them
- Clients can only use what the server provides and allows
- Communication between clients goes through the server
- Servers can and do exercise control of usage
- This made it a very popular model among businesses

Client-Server model evaluation

+

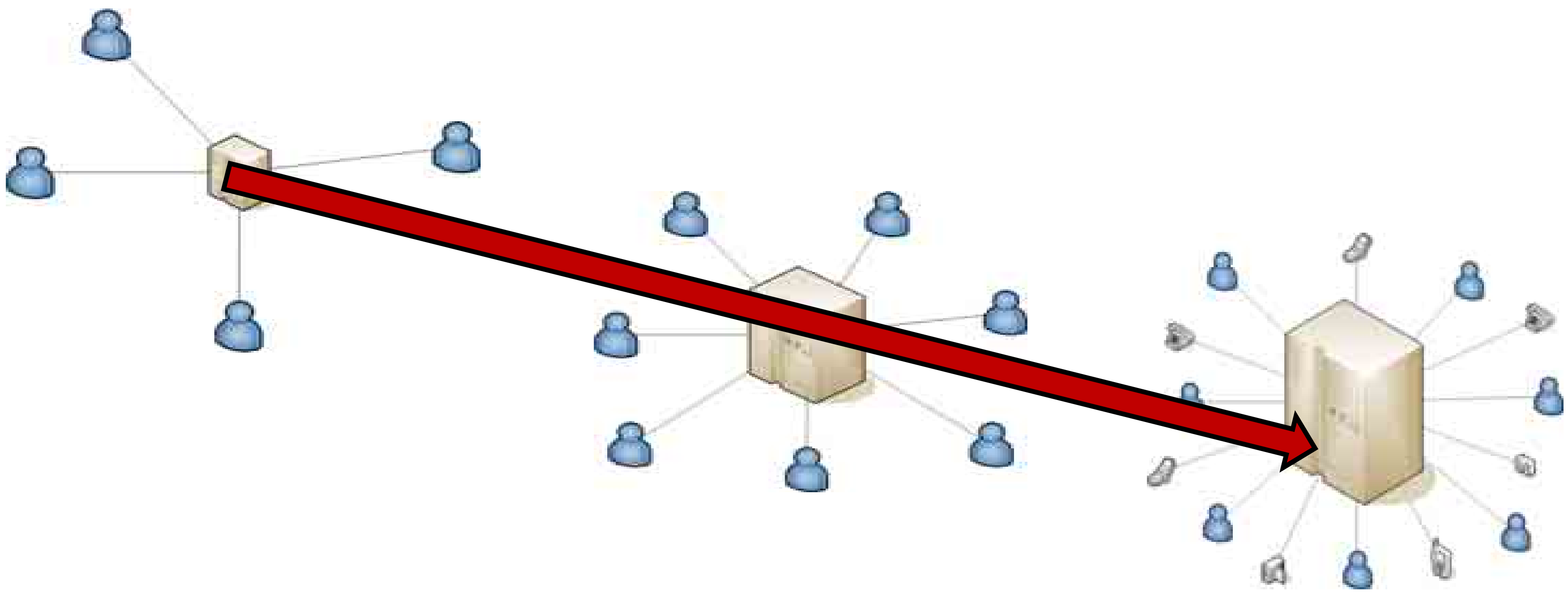
- Simple architecture
- Works well with simple clients
- Centralized logic is easy to maintain/upgrade
- Centralized data storage is easy to maintain

−

- Can impose restrictions on client communication
- Clients cannot communicate directly
- It can have privacy implications
- It has scalability issues
- The server can be a single point of failure
- Acquiring high availability is hard and costly

Client-Server model evolution

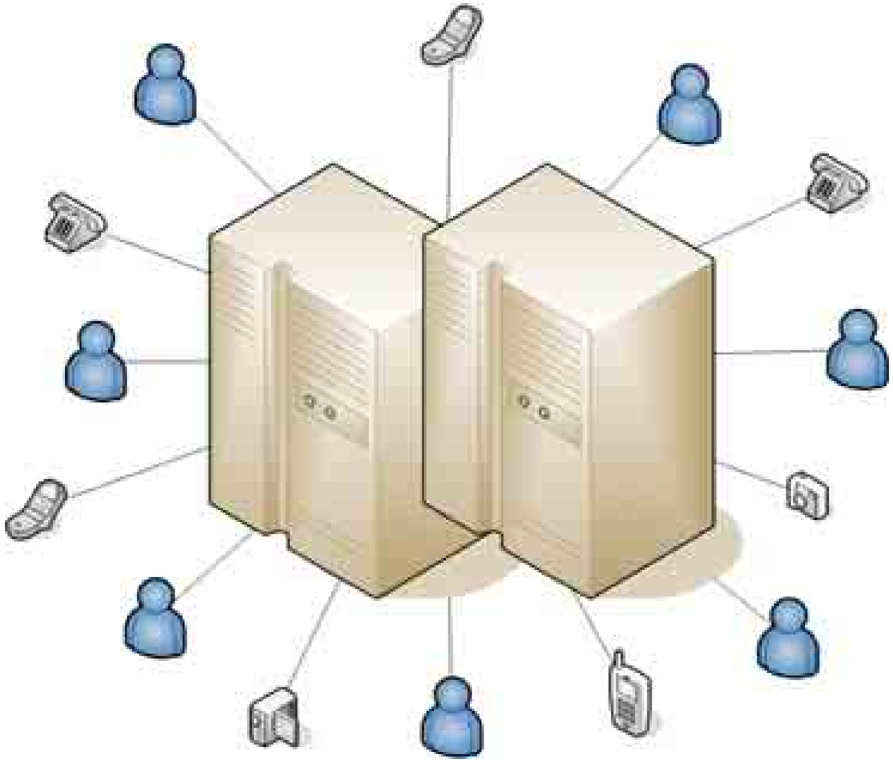
- It started with small servers holding a few resources, to which a small number of clients had access.
- But other people liked the idea and they also wanted to have access to those resources…
- …so larger servers have been built to handle more clients
- But more and more people wanted to join in, to be able to access the resources…



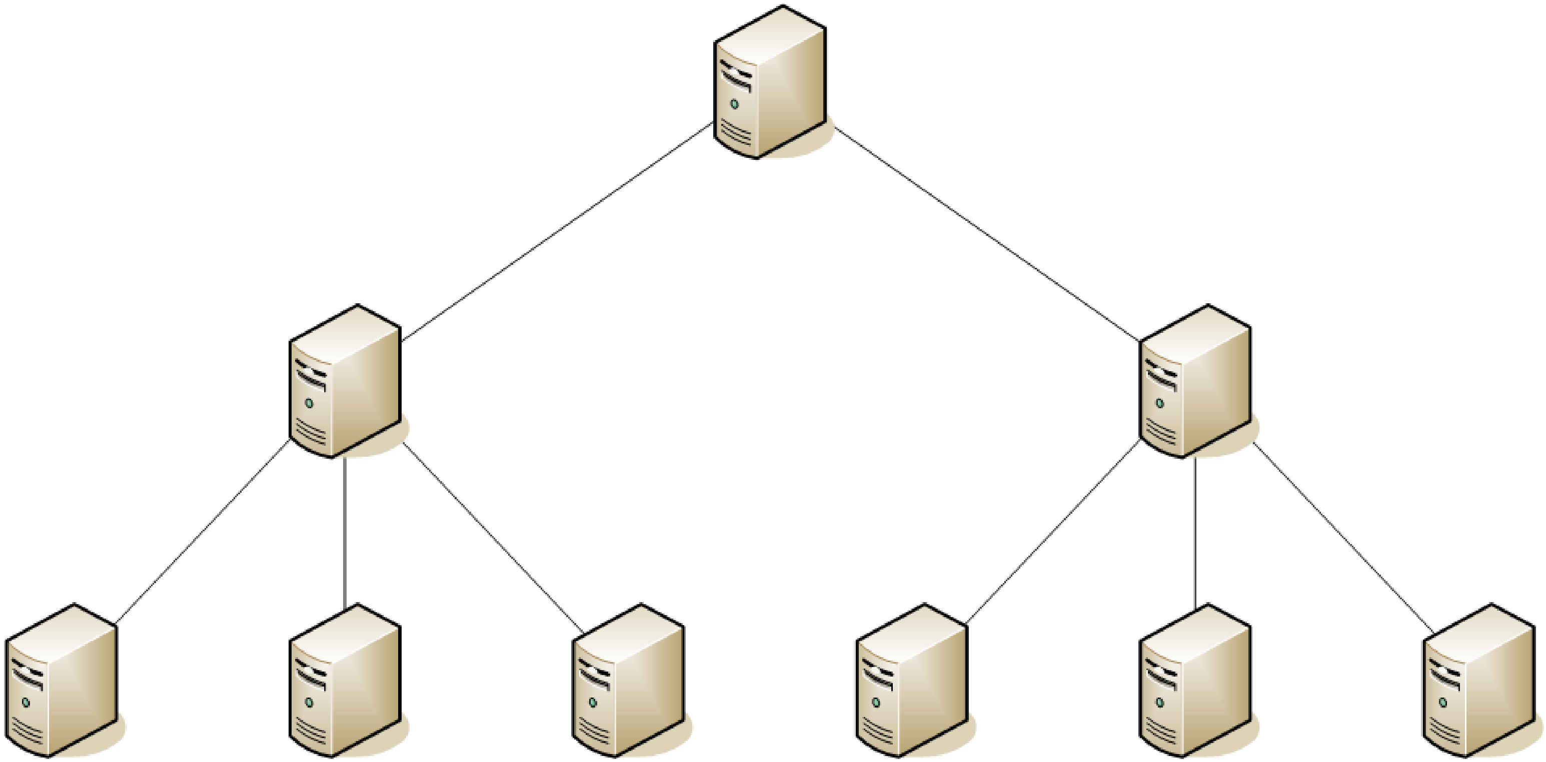
And all was well until scalability and availability problems started to raise their heads

Client-Server model evolution

And so the clusters were born to address high availability issues and eliminate single points of failure…



… and multilevel load balancing schemes were created to address scalability issues



Client-Server concept

Client-Server model evolution

But at this point the architecture was no longer simple…

The systems became hard to build and maintain. They became costly and required highly skilled individuals to keep them up and running

And more often than not, failures in such complex systems lead to frustration on all levels

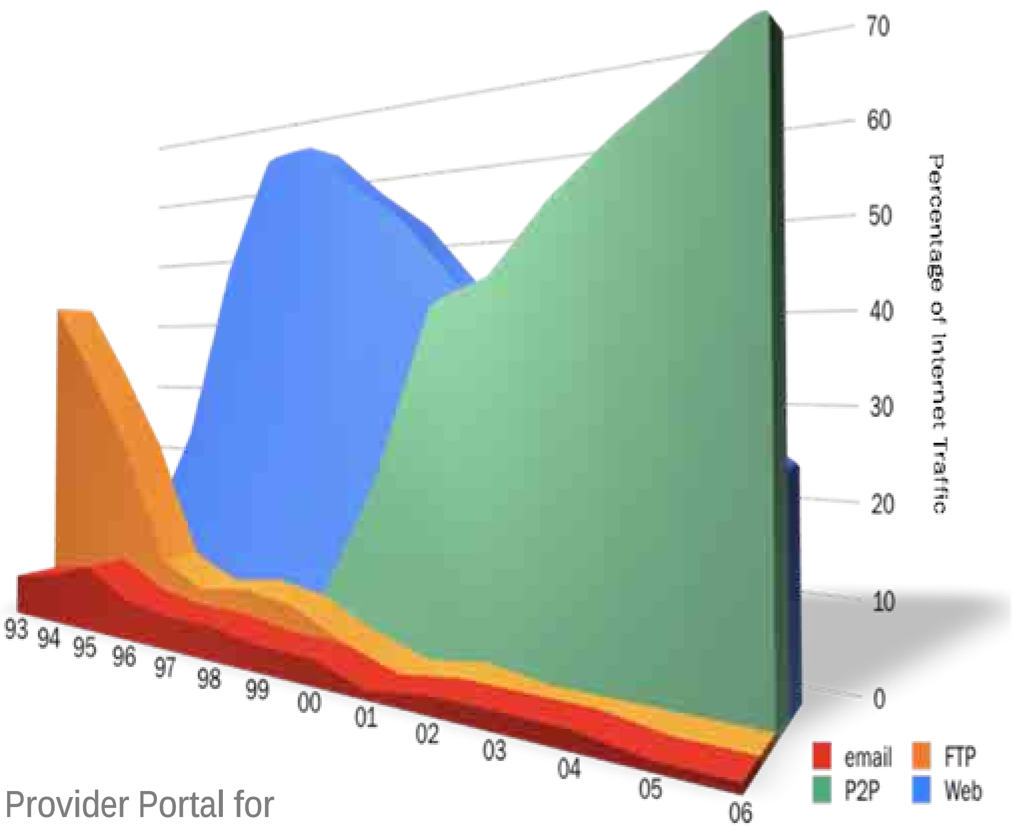
And yet the main issues are still unsolved…

- The single point of failure became a double point of failure
- The central database is still a single point of failure
- Load balancing nodes are bottlenecks and single points of failure
- There are still privacy issues (operators detain information)

Outline

- Client-Server concept
- Understanding P2P
- How to integrate P2P and MANET
- VRR: Virtual Ring Routing
- SSR: Scalable Source Routing
- Some Open Points

Understanding P2P
P2P Traffic: Internet Protocol Breakdown 1993 - 2006



Source: Velocix

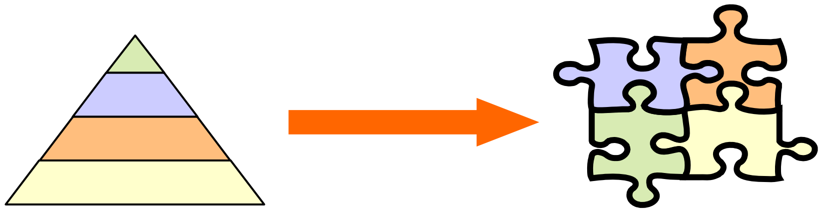
Y. Richard Yang, "P4P : Provider Portal for (P2P) Applications".

- Up to 50-70% of Internet traffic is contributed by P2P applications

Understanding P2P

Issues addressed by P2P

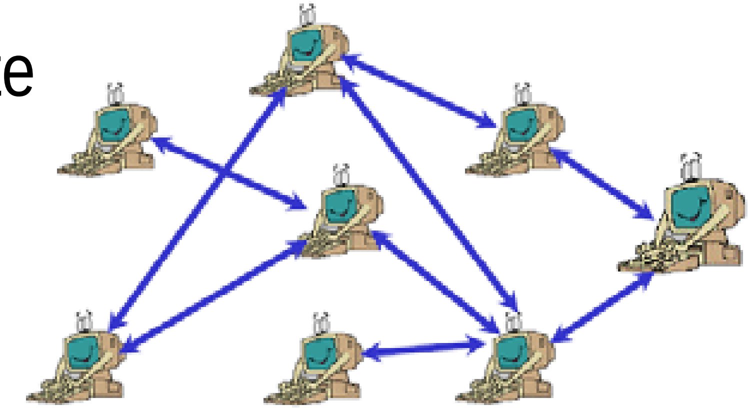
- Eliminate the control that can be imposed on clients
- Provide high availability
- Provide scalability
- Provide privacy



- How to address them
  - By distributing the logic and the resources
  - By expanding horizontally not vertically (collaboration)
  - By adapting to network changes on the fly
  - By using direct client-to-client communication

P2P definition

- A self-organizing, distributed network of entities which contribute their individual resources and collaborate in order to reach the goal for which the network was built.



- P2P networks are those which exhibit 3 characteristics:
  - self-organization
  - distributed control / resources
  - symmetric communication

Dan Pascu, “Overview of P2P SIP Principles & Technologies”. Int. SIP Conf. 2007.

Understanding P2P
P2P model evaluation

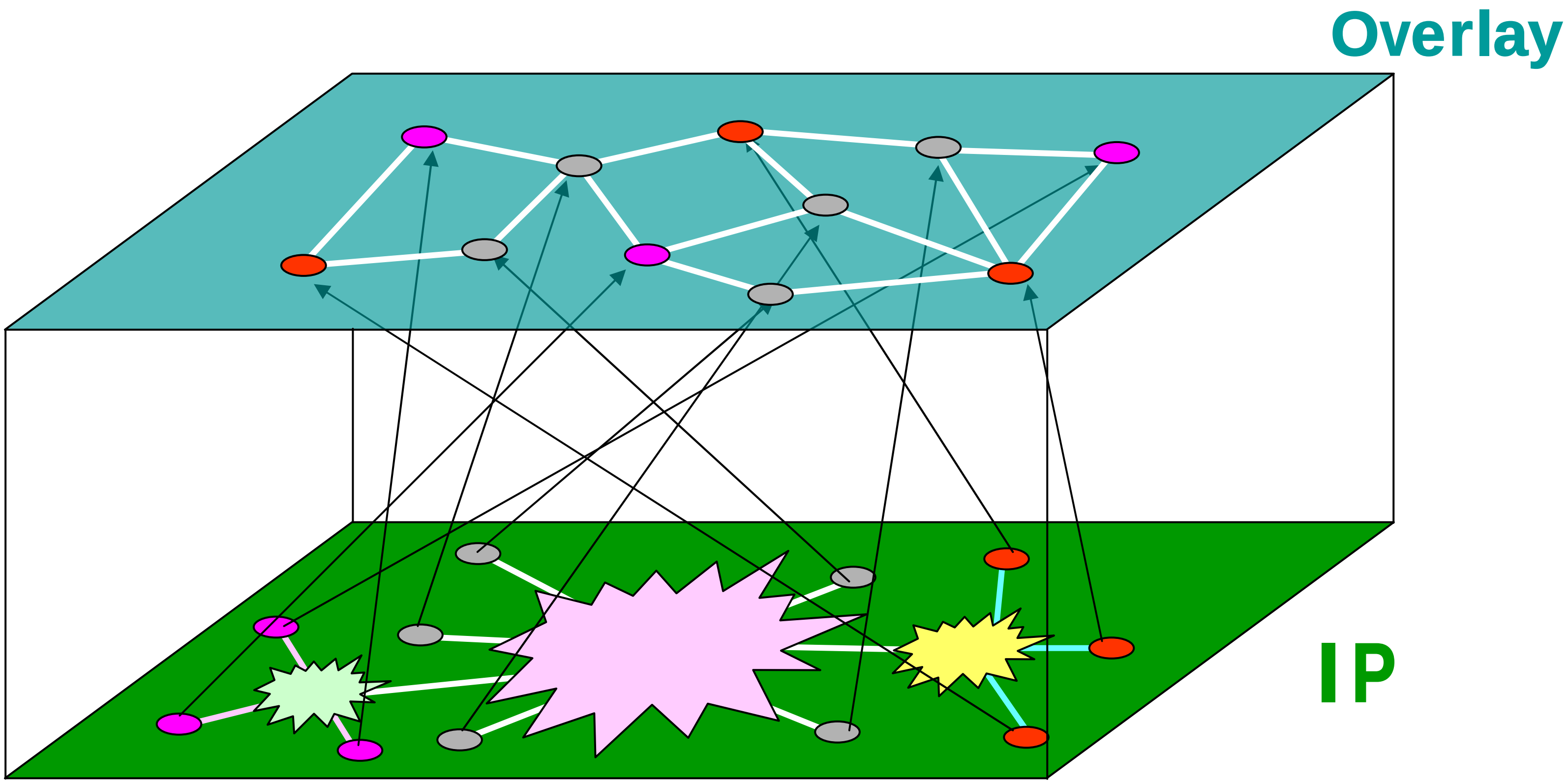
- More scalable
- Highly distributed (no single point of failure)
- Intelligence moved to the network border (clients)
- No centralized control
- No server maintenance

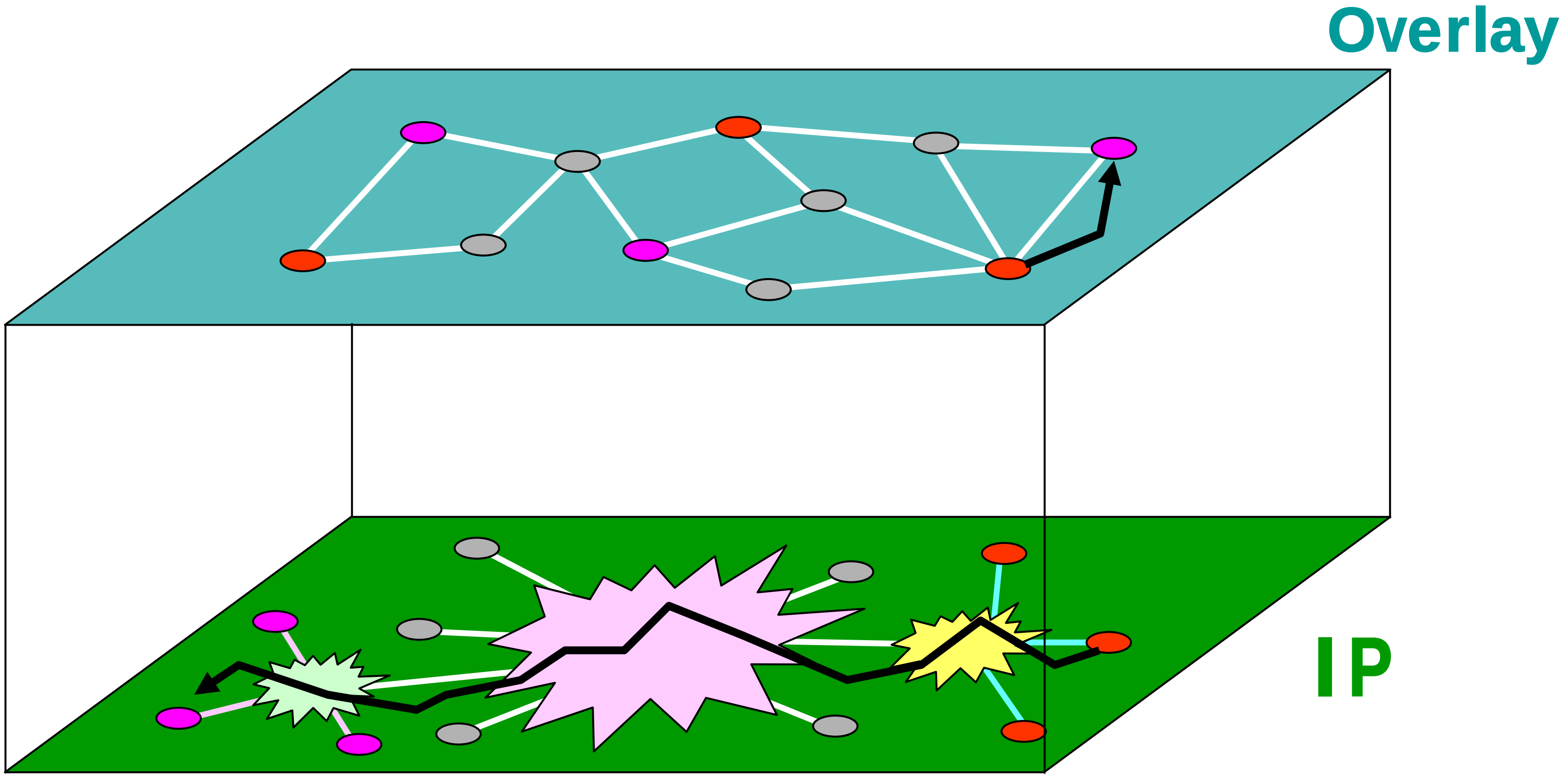
- More complex
- Higher latency in routing (routing stretch)
- Distributed data storage is hard to do in a consistent way

Overlay definition

- An overlay network is a virtual network of nodes and logical links that is built on top of an existing network with the purpose to implement a network service that is not available in the existing network. (by I. Stoica)
  - A P2P network is an overlay itself (over TCP/IP)
  - E.g. of services:
    - Routing (Resilient Overlay Networks, MPLS)
    - Security (VPN)
    - Application-level Multicast

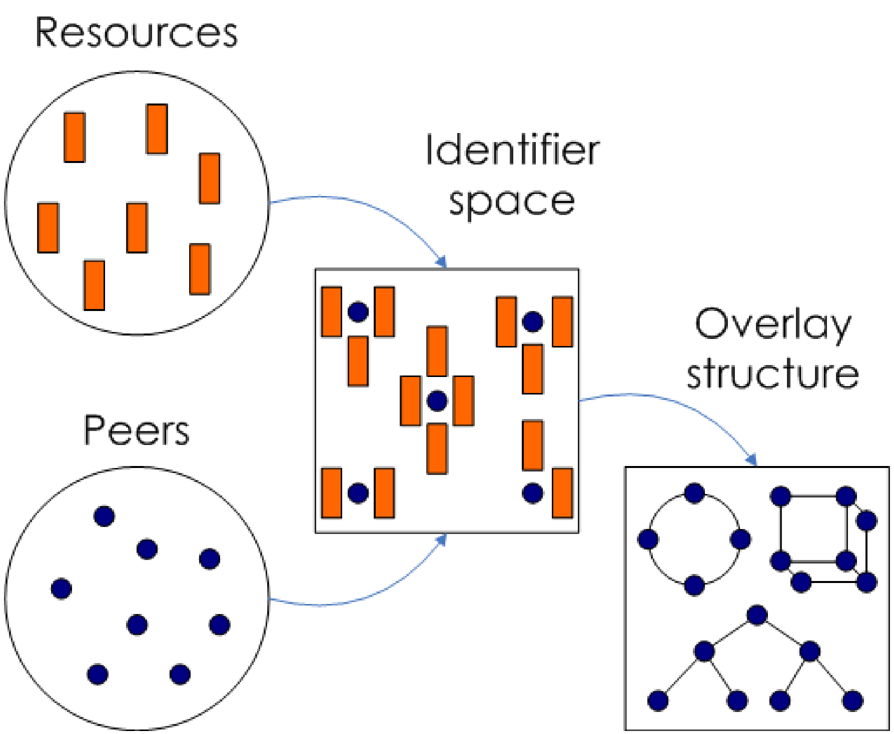
Overlay networks





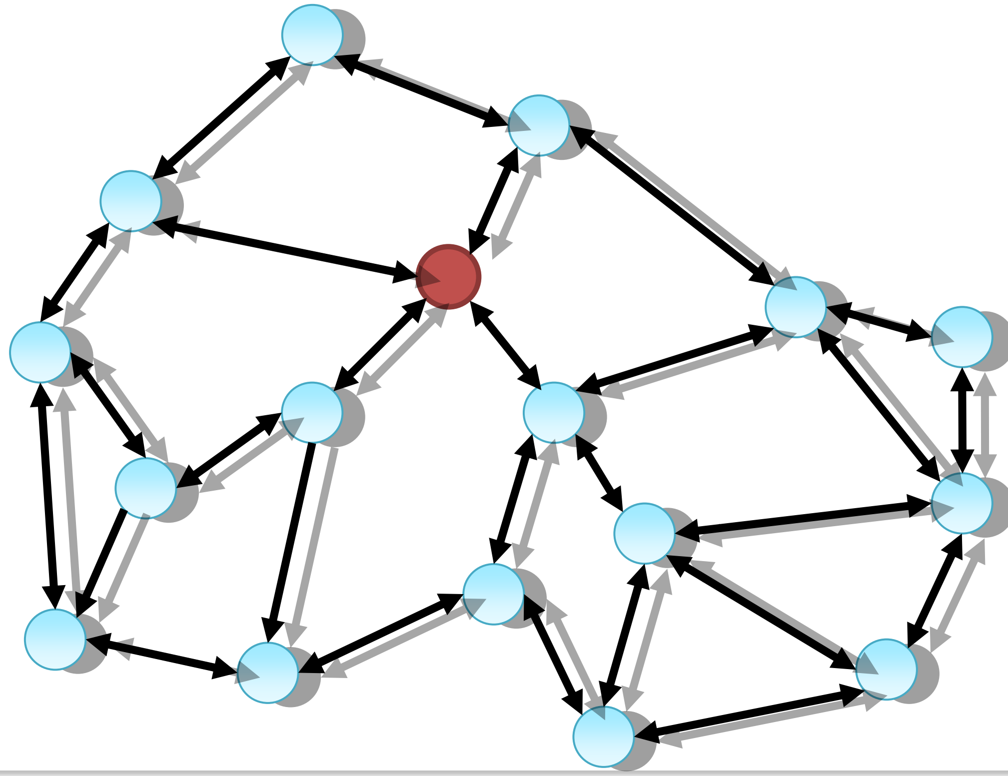
Overlay
IP

P2P overlay design



1. Choice of identifier space (IS)
   - 128 bits overlay identifier
2. Map resources and peers to IS
   - HASH(MAC, IP, or Locality)
3. Management of the IS by peers
   - Unstructured, structured, hybrid
4. Routing strategy
   - Flooding, random walk, Finger table (Chord)
5. Maintenance strategy
   - Proactive (probe), or reactive correction

- Each peer only indexes its own content and flood queries widely
- Can perform complex searches (rich queries not just key lookups)
- Are becoming rare (used mostly by unstructured P2P networks)



e.g.: Gnutela

Unstructured P2P

+

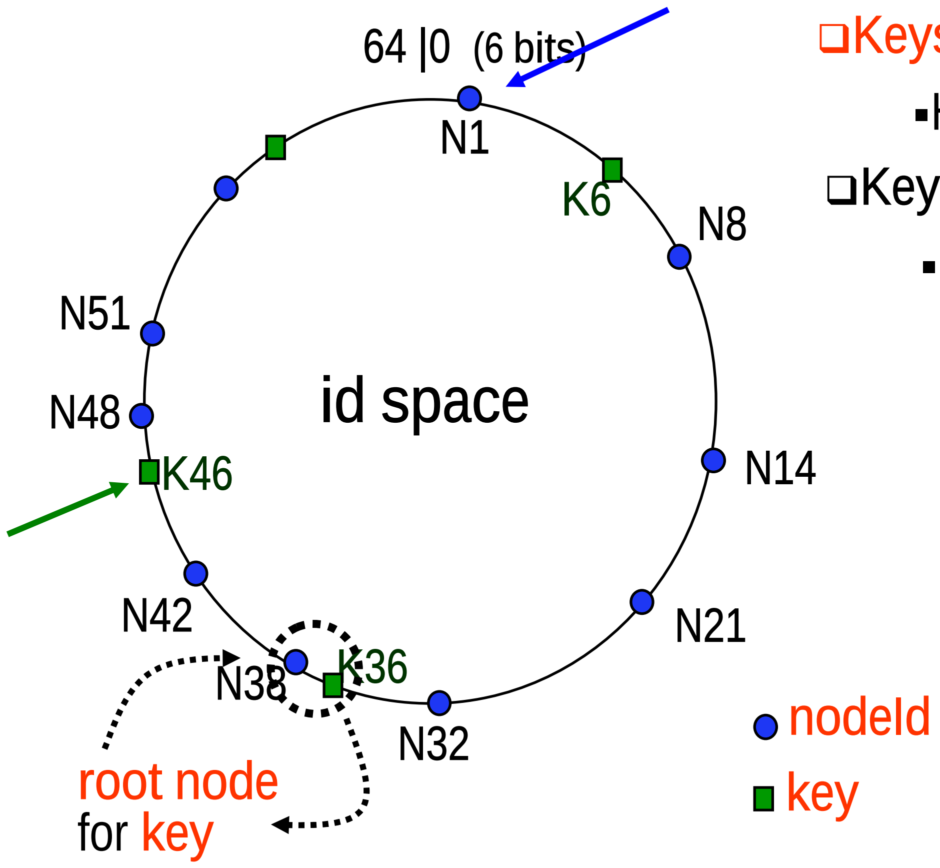
- Fast lookup
- Low join and leave overhead
- Popular files are replicated many times

−

- Not 100% success rate
- Very high communication overhead
- Uneven load distribution

- Also known as Distributed Hash Table (DHT)
- Idea: Route a packet based on a key to the node in the network that is currently responsible for the packet's key.
  - This process is referred to as indirect or key-based routing.
- Many recent academic systems –
  - CAN, Chord , Kademlia, Pastry, Tapestry, Viceroy, Bamboo.

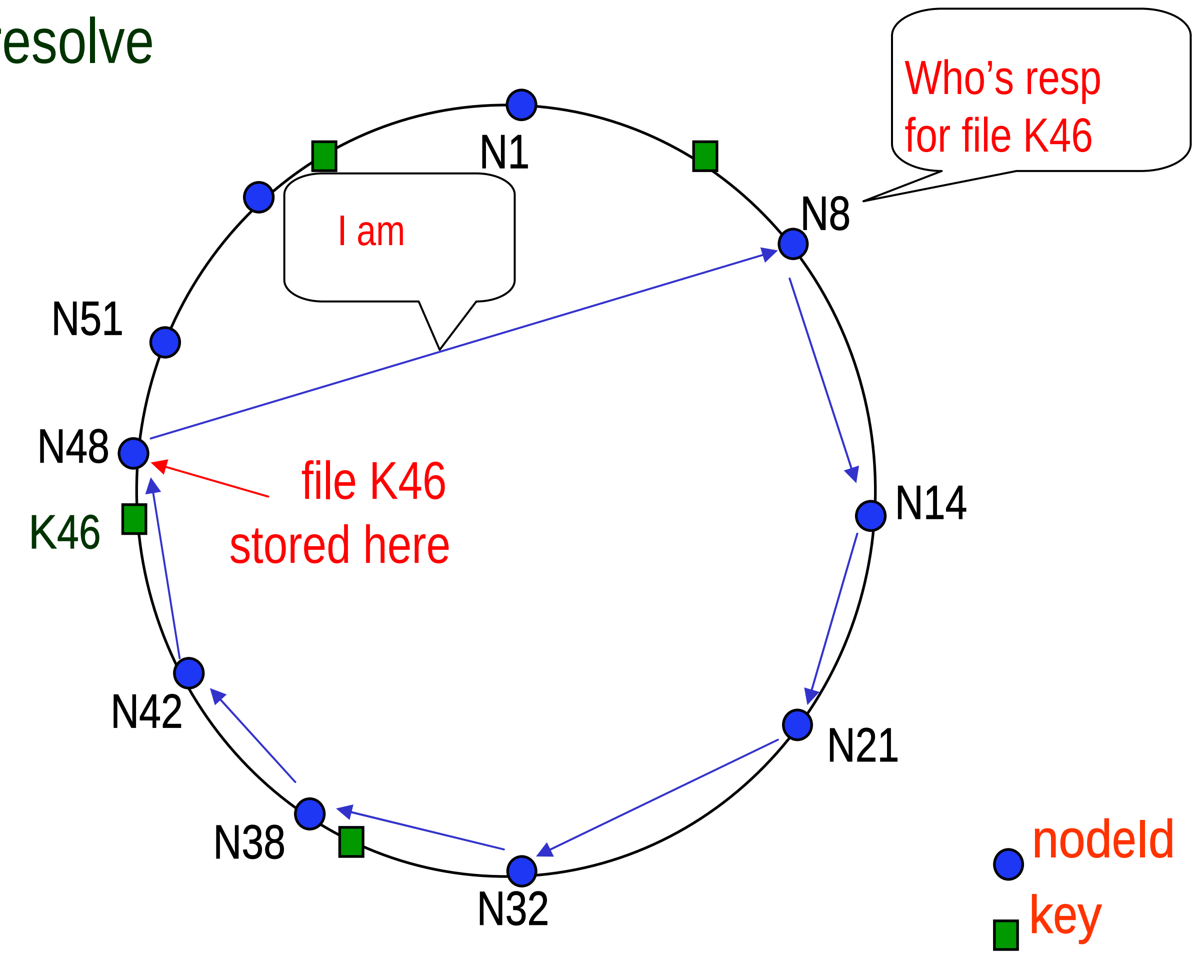
DHT - Distributed Hash Table



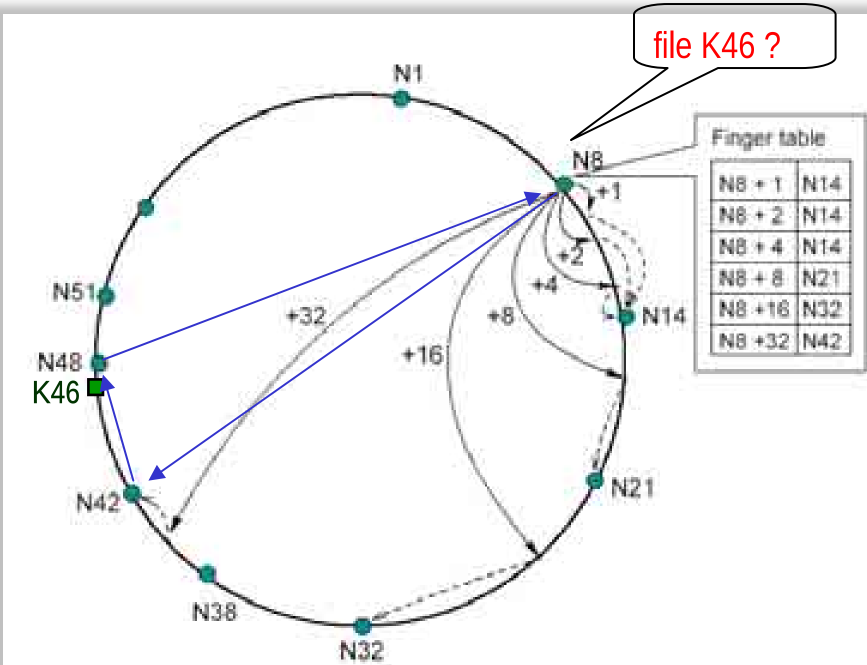
- Large id space
- NodeIds picked randomly from space
  - Hash[192.168.1.1] = N1
- Keys picked randomly from space
  - Hash[picture.jpg] = K46
- Key is managed by its root node:
  - Live node with id closest to the key
    - location of object or actual object

Key-based routing

O(N) messages on avg to resolve query



Understanding P2P
The Chord DHT overlay



I. Stoica, et. al., "Chord: A Scalable Peer-to-Peer Lookup Service for Internet Applications", SIGCOMM'01

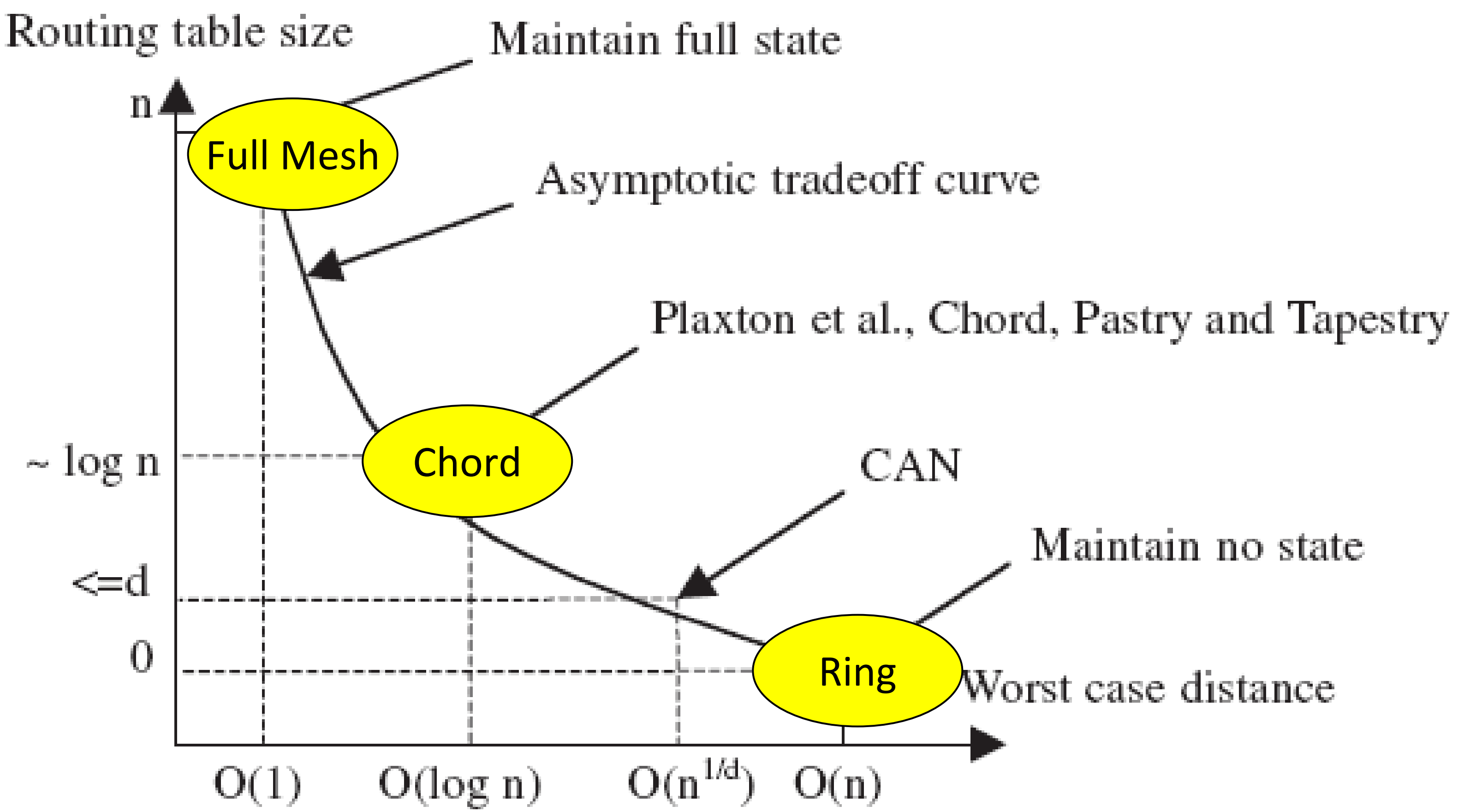
- Uses SHA-1 hashes (160 bits)
- Maps nodes and keys to a ring
- O(log N) lookup performance
- O(log N) routing table size
- Supports join and leave operations for maintaining the network
- It basically supports one operation: lookup a node for a given key

✓ Each node handles the resources which have their hashes mapped between the node itself and its predecessor

✓ Each node knows its predecessor, successor and keeps a list of successor nodes known as the finger table, which is used to improve lookup performance and increase fault tolerance

✓ If a lookup doesn't yield a local resource, it is forwarded to the node in the finger table which has the closest hash value preceding the hash of the queried resource

Understanding P2P
Tradeoff of routing table size vs. network diameter



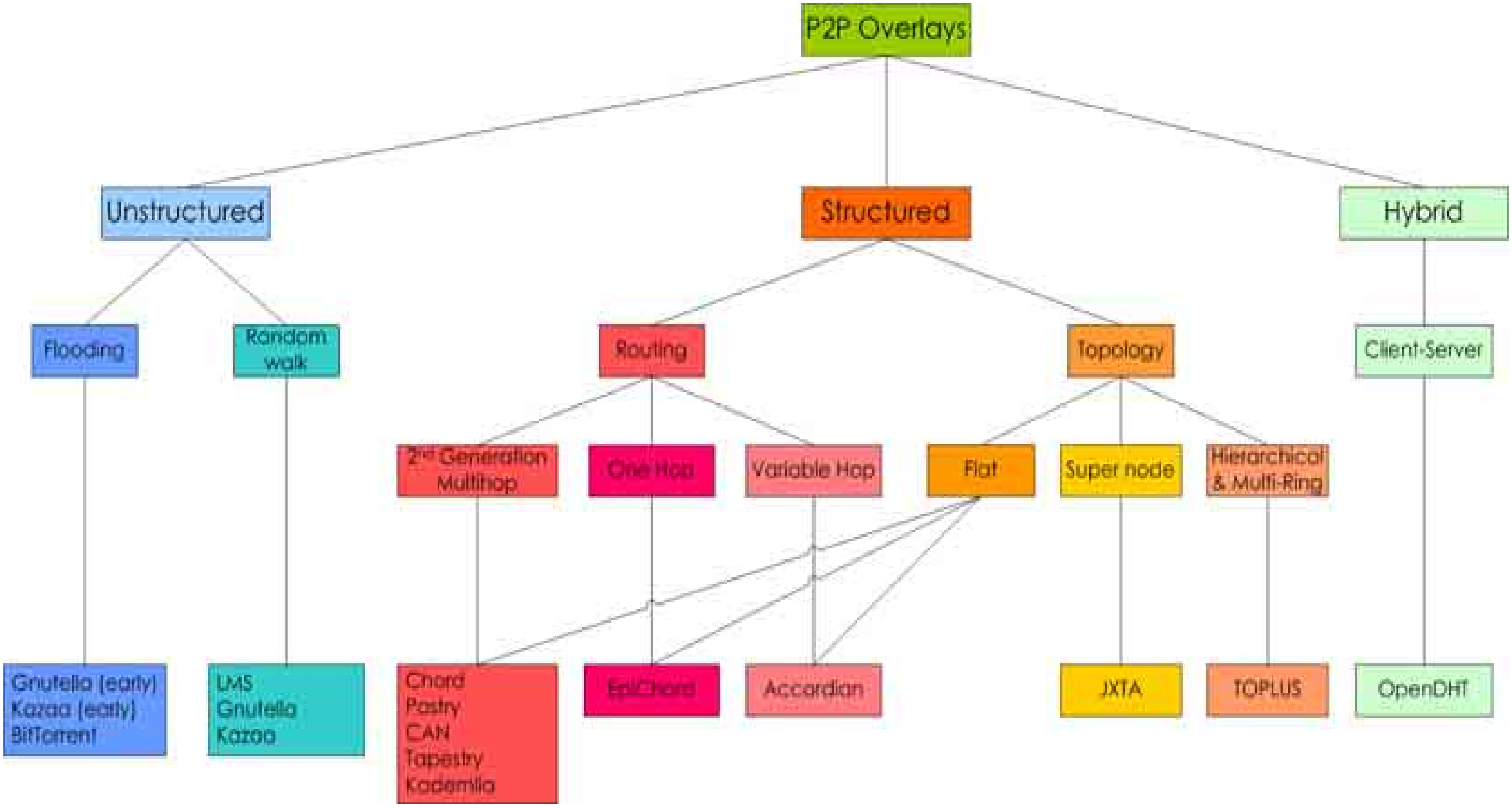
- Scalability: O(log N) routing
- Load-balancing
- Overlay robustness

- No control where data is stored
- Complex queries are not possible
- Join and leave overhead

Andreas J. Kassler, Marcel Castro

Understanding P2P
The P2P family

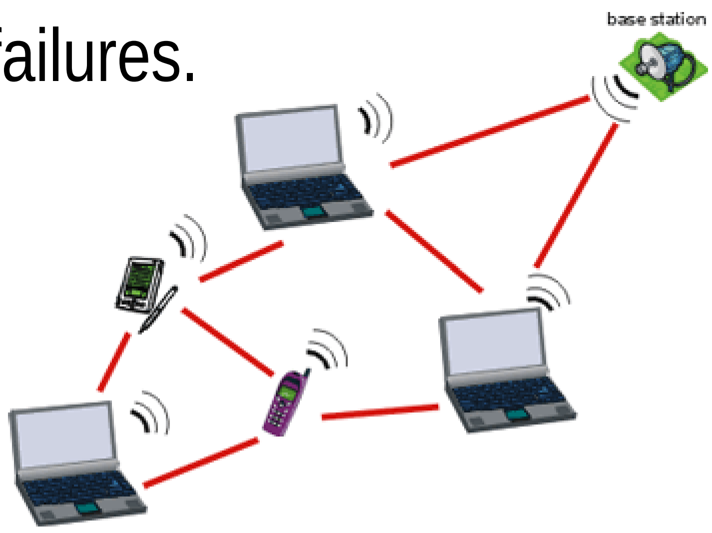
Dan Pascu, "Overview of P2P SIP Principles & Technologies". Int. SIP Conf. 2007.



- Client-Server concept
- Understanding P2P
- How to integrate P2P and MANET
- VRR: Virtual Ring Routing
- SSR: Scalable Source Routing
- Some Open Points

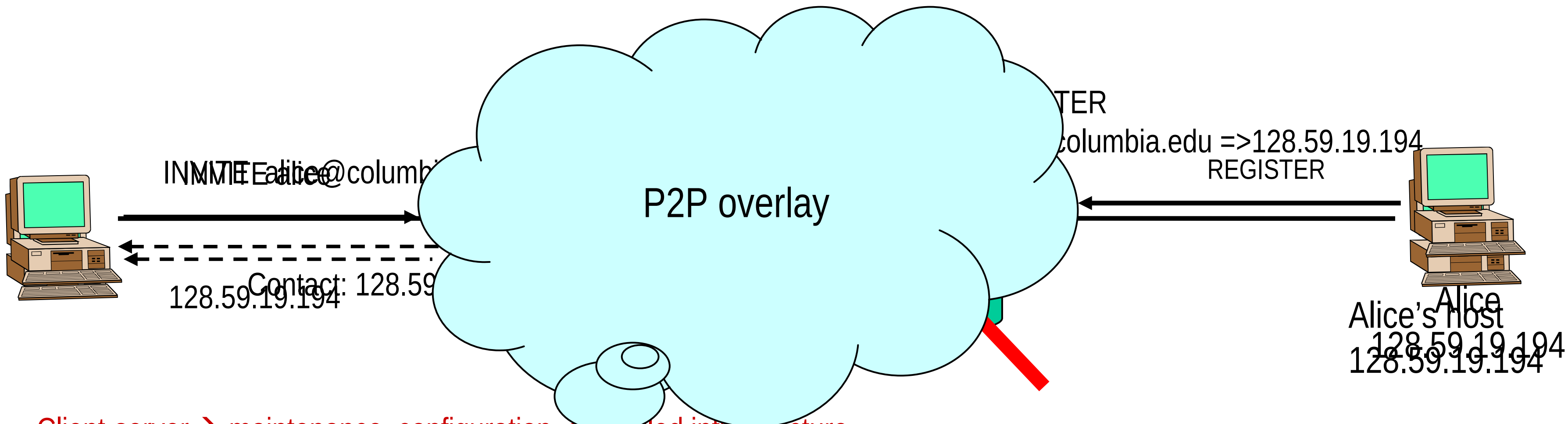
MANET - Mobile Ad-hoc Networks

- Mobile Ad-hoc Networks (MANET) consist of mobile nodes communicating with each other using multi-hop wireless links.
- Self-organization for communication.
- Self-healing to cope with network failures.
- Without (necessarily) using a pre-existing infrastructure.



How to integrate P2P and MANET
Need for P2P in MANET

- P2P model can be an attractive approach in MANETs in order to provide distributed services such as:
  - Data sharing(file, video, music)
  - Mobility Management
  - Security (Anonymity)
  - P2PSIP



Client-server→ maintenance, configuration, controlled infrastructure

No central server as in MANET, search latency

MANET and P2P

- Wireless Ad-hoc networks have many similarities to peer-to-peer systems:
  - Same paradigm
    - Resource (e.g., files) Discovery vs. Route Discovery
  - Self-organizing network
  - Lack of managing and centralizing units

Challenges in supporting P2P over MANETs

	P2P Networks	MANET
Motivation for creating the network	Logical infrastructure to provide a service	A physical infrastructure to provide connectivity
Connection between two nodes	Fixed medium and direct	Wireless and indirect
Connection confidence	High (physical connections)	Low (wireless connections)
Peer location	Any Internet point	Restricted area
Structure	Physical apart from logical structure	Physical structure corresponding to logical structure
Routing	Proactive, reactive, hybrid	Proactive, reactive, hybrid
Peer Mobility	Fixed/Limited	Mobile
Broadcast	Virtual, multiple unicasts	Physical, to all nodes in transmission range area

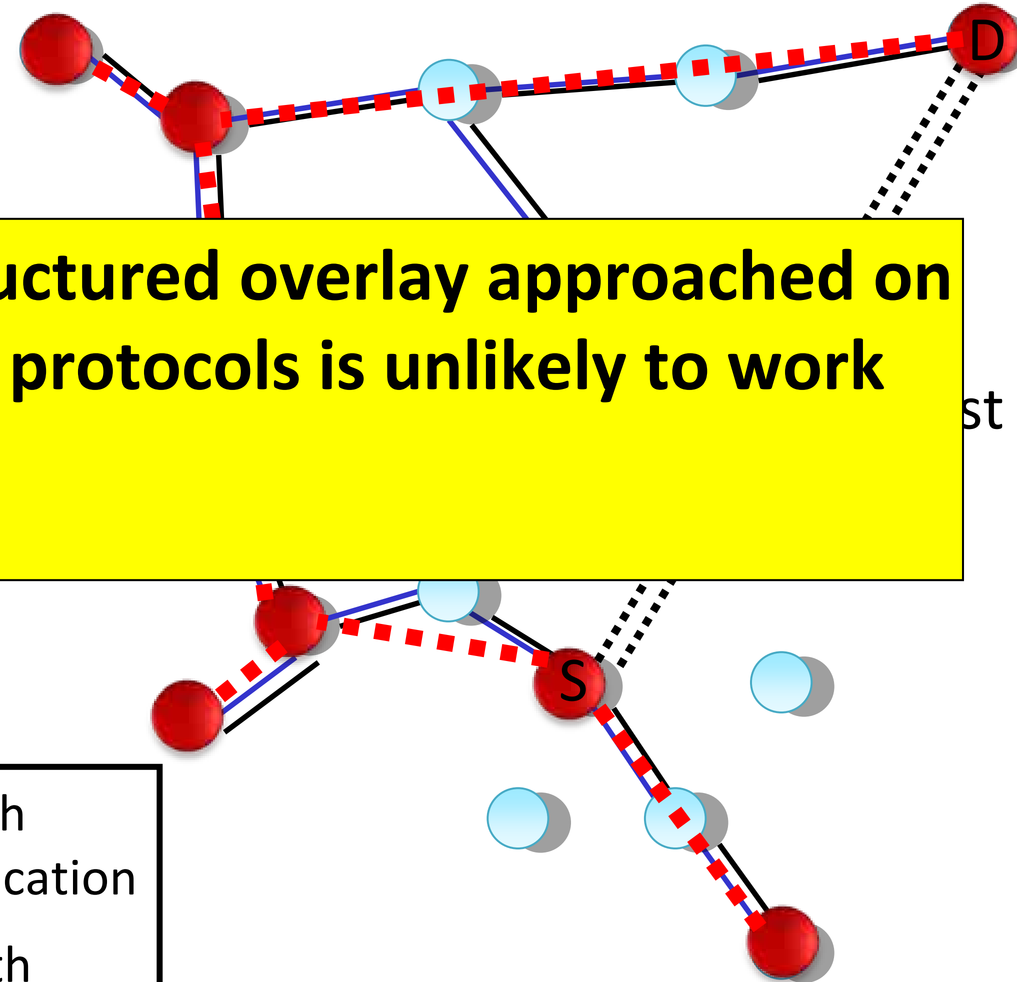
How to integrate P2P and MANET
Unstructure P2P over Broadcast

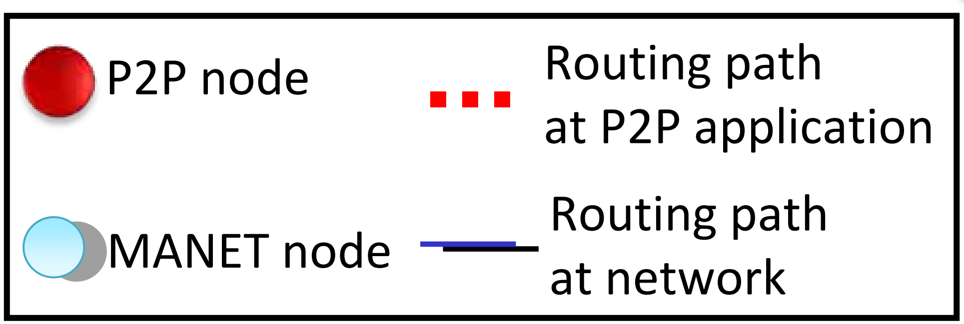
P2P techniques	Unstructured, Flooding	Structured, DHT
MANET Routing	Broadcast, on demand routing (AODV)	Key-based routing MANET (DHT routing)

1. Broadcast over Broadcast:

- Broadcast-based P2P lookup protocol over MANET on-

Strict layering of unstructured overlay approached on top of wireless routing protocols is unlikely to work in MANETs.





How to integrate P2P and MANET
ORION

Query Phase

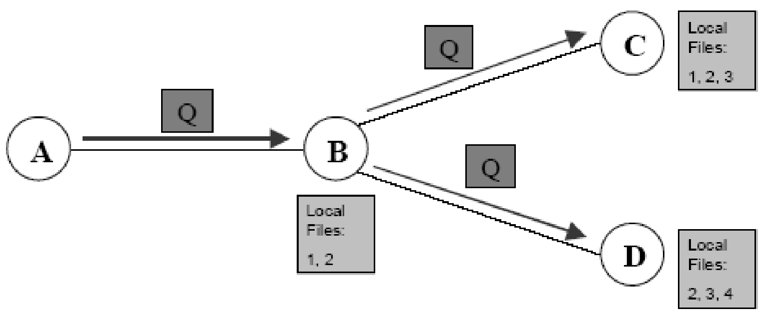


Figure 1. Node A floods a QUERY message with keywords matching to files 1 to 4

A. Klemm et al, "A special-purpose peer-to-peer file sharing system for mobile ad hoc networks".VTC 2003

Response Phase

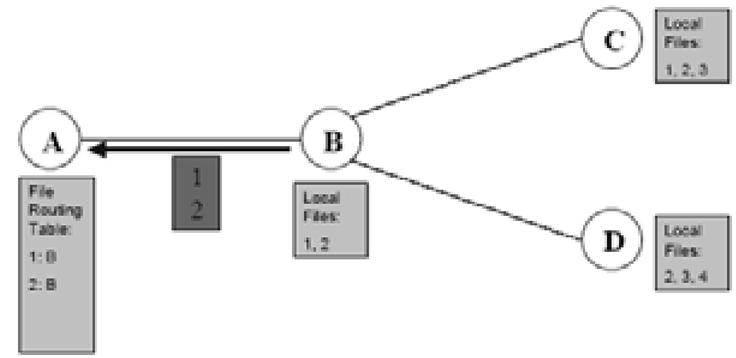


Figure 2. Node B sends a RESPONSE message with identifiers of local files

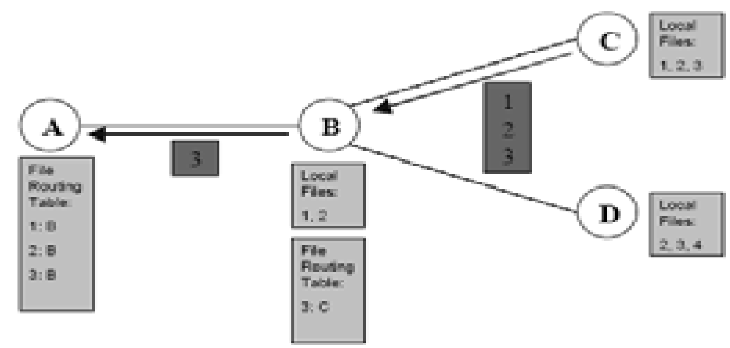


Figure 3. Node C sends a RESPONSE message with identifiers of local files. Node B filters and forwards RESPONSE of C

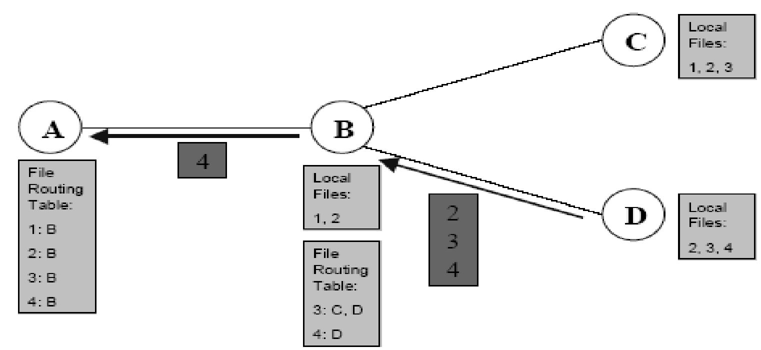


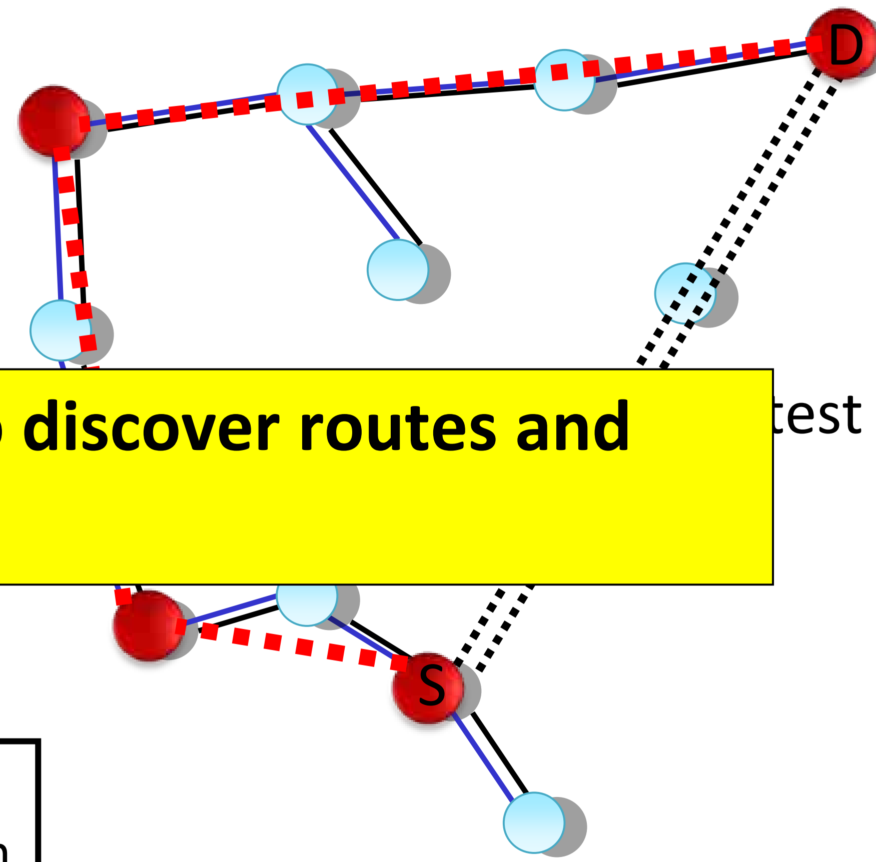
Figure 4. : Node D sends a RESPONSE message with identifiers of local files; Node B filters and forwards the RESPONSE message

How to integrate P2P and MANET
Structure P2P over Broadcast

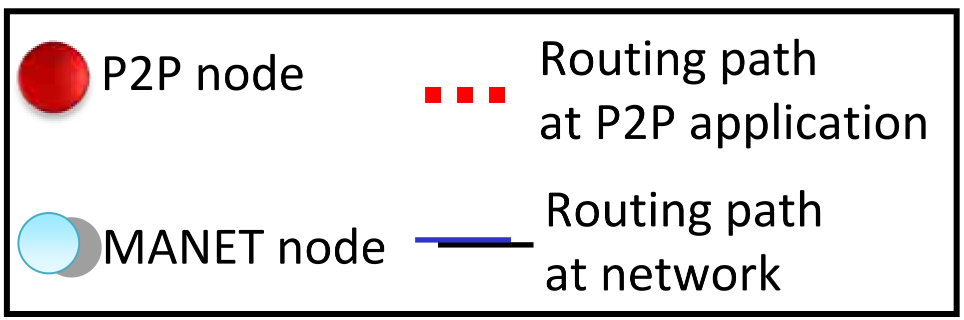
P2P techniques	Unstructured, Flooding	Structured, DHT
MANET Routing	Broadcast on demand routing (AODV)	Key-based routing MANET (DHT routing)

2. DHT over Broadcast:

- DHT-based P2P protocol over MANET.
- P2P lookup can be scalable
- Underlying network routing protocol is based on broadcast



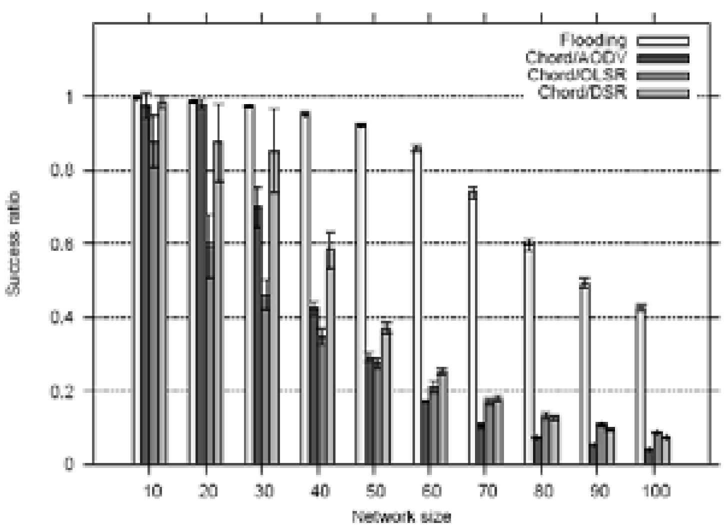
- Flooding is still necessary to discover routes and maintain the DHT.



How to integrate P2P and MANET
Chord over AODV, OLSR, DSR

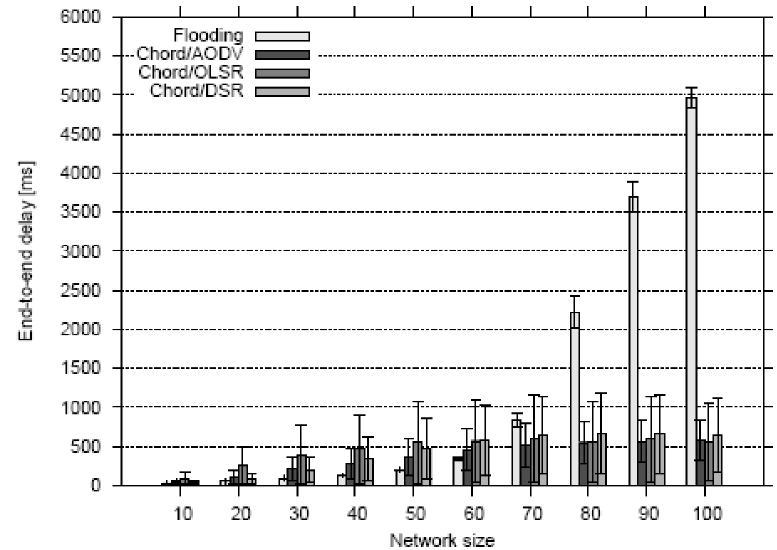
Ns-2 simulations of Chord DHT over AODV, OLSR, DSR:

- Standard routing configuration
- 50 nodes
- Node mobility (max. speed 2m/sec)

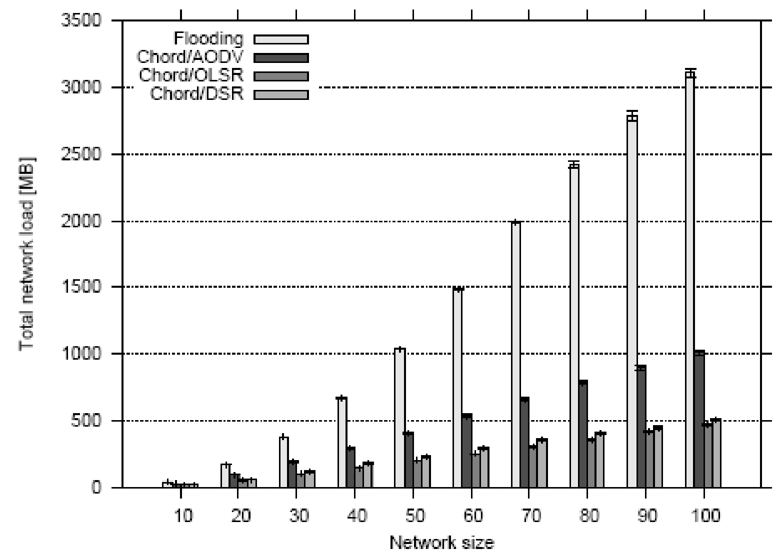


(a) Request success ratio

C. Cramer, T. Fuhrmann. “Performance evaluation of chord in mobile ad hoc networks”. MobiShare '06.



(b) End-to-end delay



(c) Total network load

How to integrate P2P and MANET
Structure P2P over key-based routing

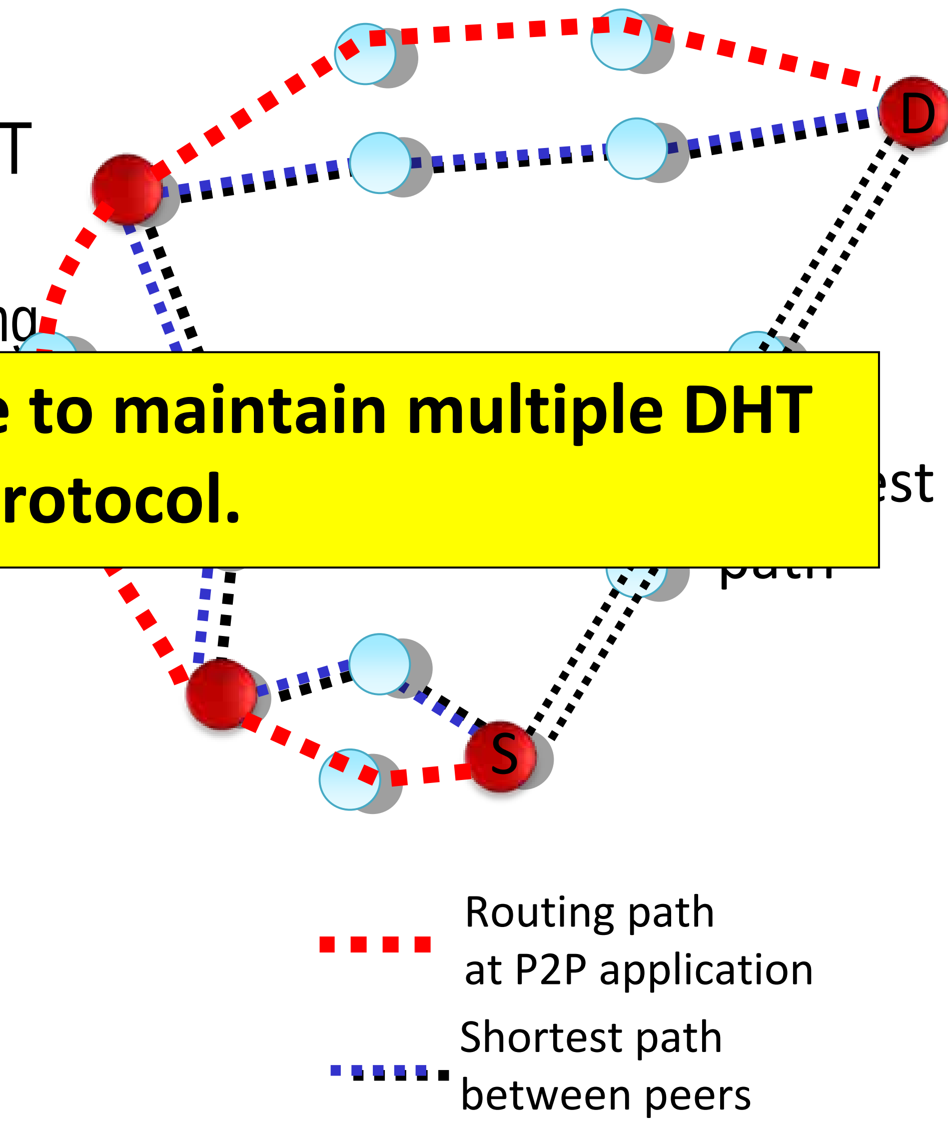
P2P techniques	Unstructured, Flooding	Structured, DHT
MANET Routing	Broadcast, on demand routing (AODV)	Key-based routing MANET (DHT routing)

3

3. DHT over DHT:

- DHT is applied to the MANET routing protocol
  - To improve the network routing
- overlay and MANET separately
- Complexity of routing algorithm
  - O((log n) ²)

It should be cost-effective to maintain multiple DHT above the same routing protocol.



Peer-to-Peer Services in Community Mesh Networks
Andreas J. Kassler, Marcel Castro

How to integrate P2P and MANET

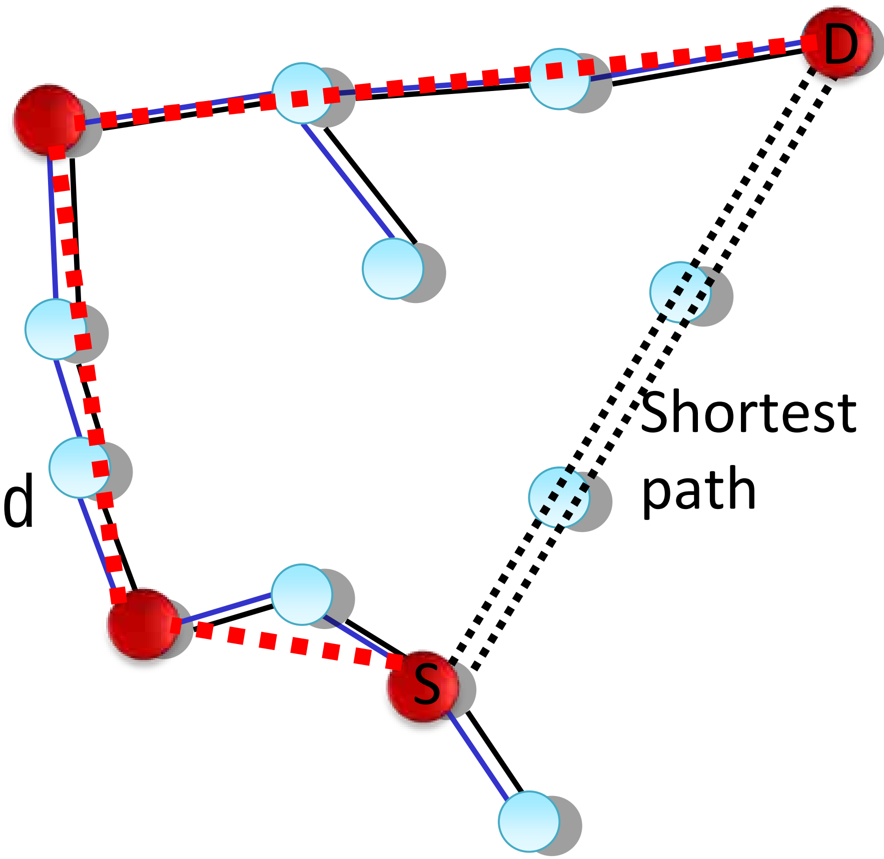
DHT Application and MANET routing integration

P2P techniques	Uns... ...ture... F...	S... ...ctured,
MANET Routing		...based ... MANET ...HT routing)

4. DHT Application integrated to Key-based routing MANET

4. DHT:

- Application layer lookup is integrated to the network layer routing
- Single cross-layer DHT routing
  - Virtual Ring Routing
- Key and Network ID are hashed to the same key space
- Complexity of routing algorithm
  - O(log n)



Outline

- Client-Server concept
- Understanding P2P
- How to integrate P2P and MANET
- VRR: Virtual Ring Routing
- SSR: Scalable Source Routing
- Some Open Points

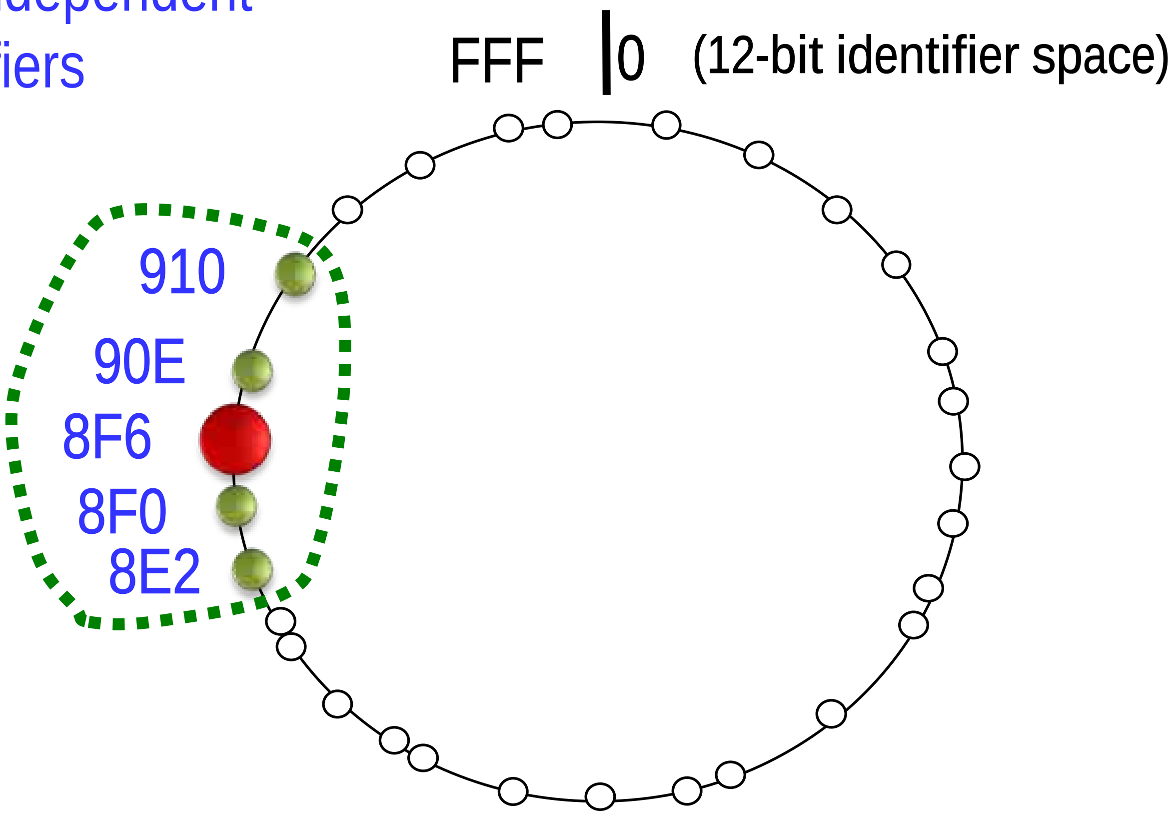
Motivation

M. Caesar et al., “Virtual Ring Routing: Network routing inspired by DHTs”. In ACM SIGCOMM’06.

- No flooding
  - Proactive protocols flood on topology change
  - Reactive protocols flood to discover routes
  - Hybrid protocols flood on route discovery + topology change
- Single topology-independent address
- Paths to virtual neighbours ensure correctness
- Route stretch empirically small
- Many alternate paths to route around failures

VRR: The Virtual Ring

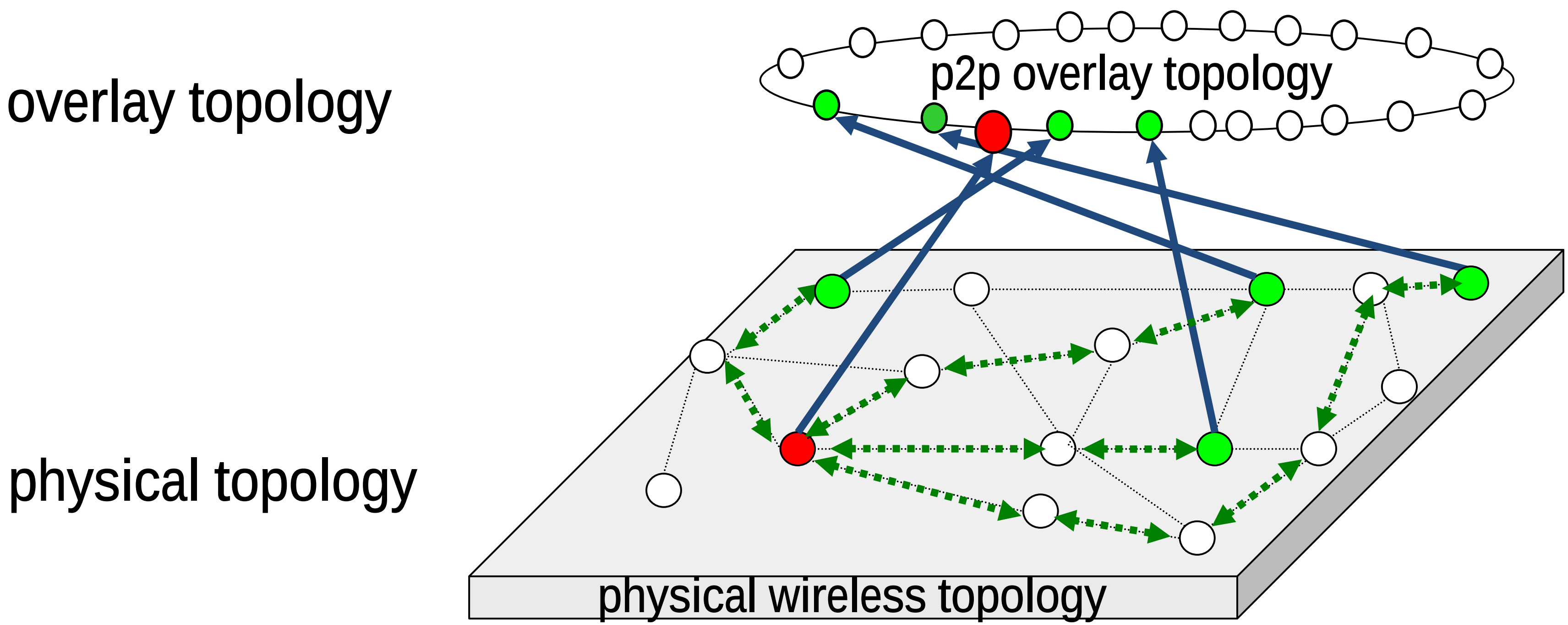
Topology-independent node identifiers



Each node maintains a virtual neighbour set (vset)

Nodes organized into the virtual ring by increasing identifier value

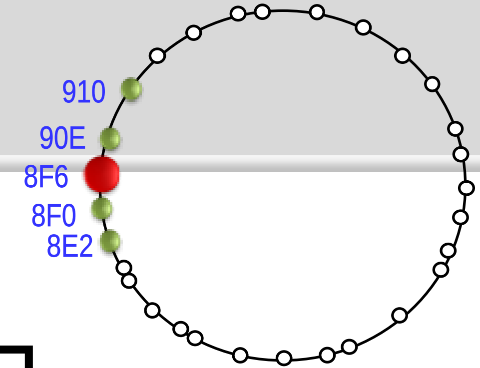
VRR: Routing Paths



Nodes only maintain routing paths to virtual neighbours:

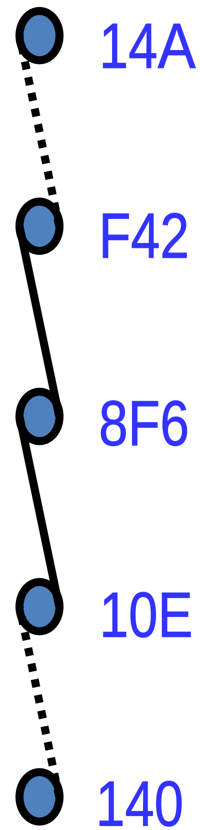
- Paths are bidirectional and typically multi-hop

VRR: Forwarding Table



endpointA	endpointB	nextA	nextB	pathId
8F6	90E	me	F42	31
910	8F6	10E	me	10
14A	140	F42	10E	2
8F6	F42	me	F42	FF

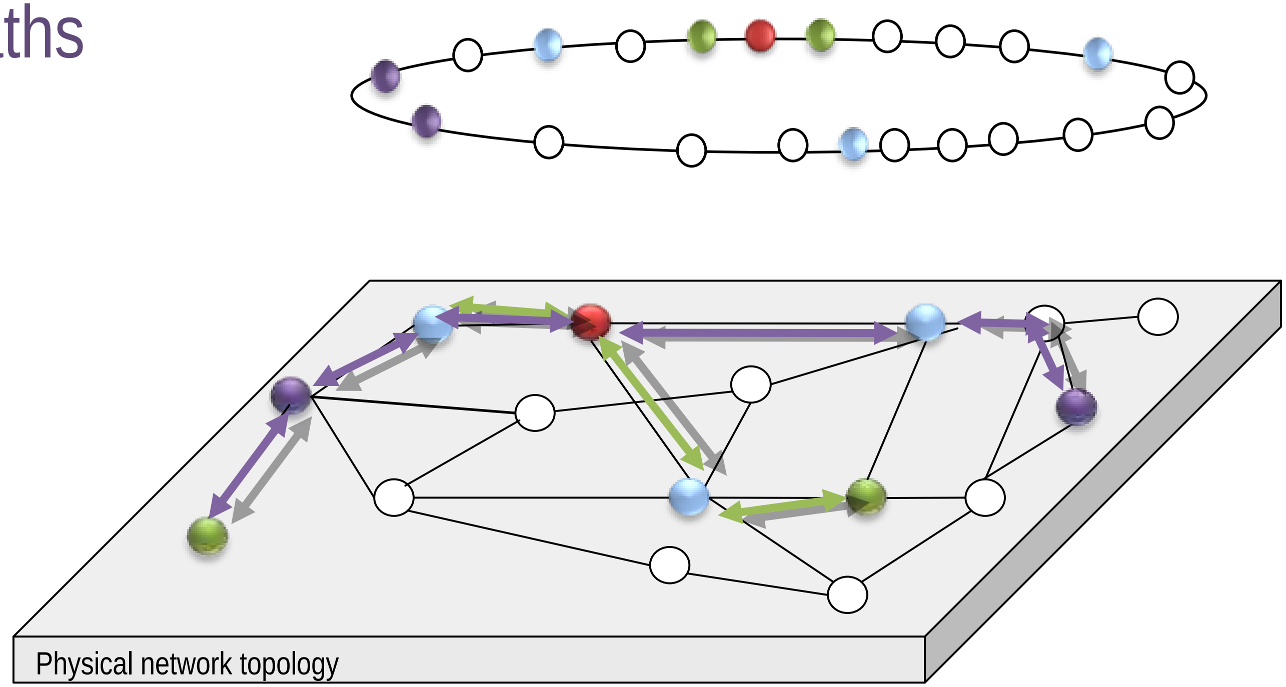
forwarding table for node 8F6



- Paths recorded in forwarding tables along path
- Forwarding table contains
  - Paths between node and vset members
  - Paths between other nodes that go through node
  - Paths to physical neighbours

VRR: Forwarding Table State

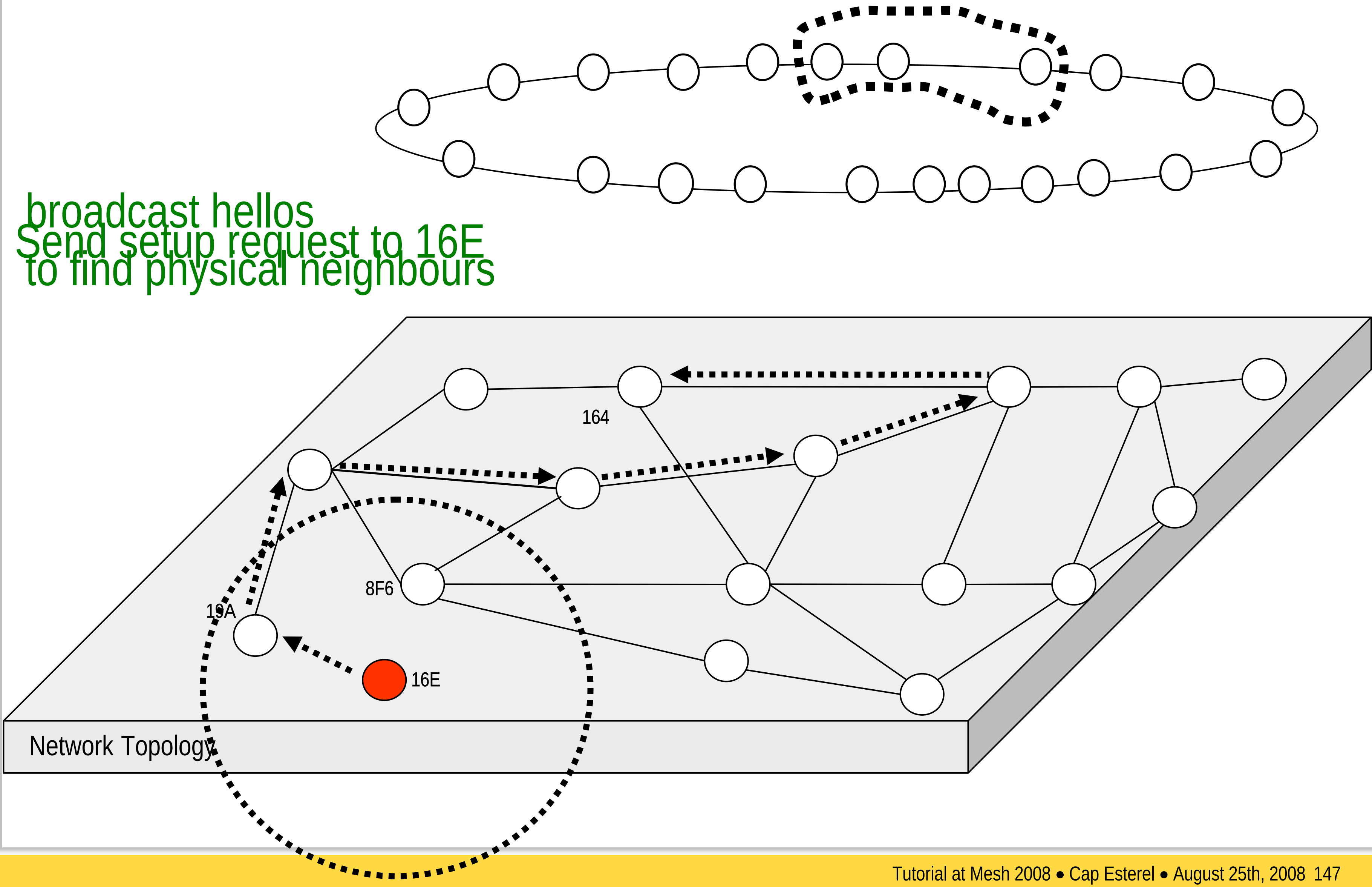
- Physical neighbours
- VSet paths
- Other VSet paths



VRR: Node Joining

broadcast hellos
to find physical neighbours

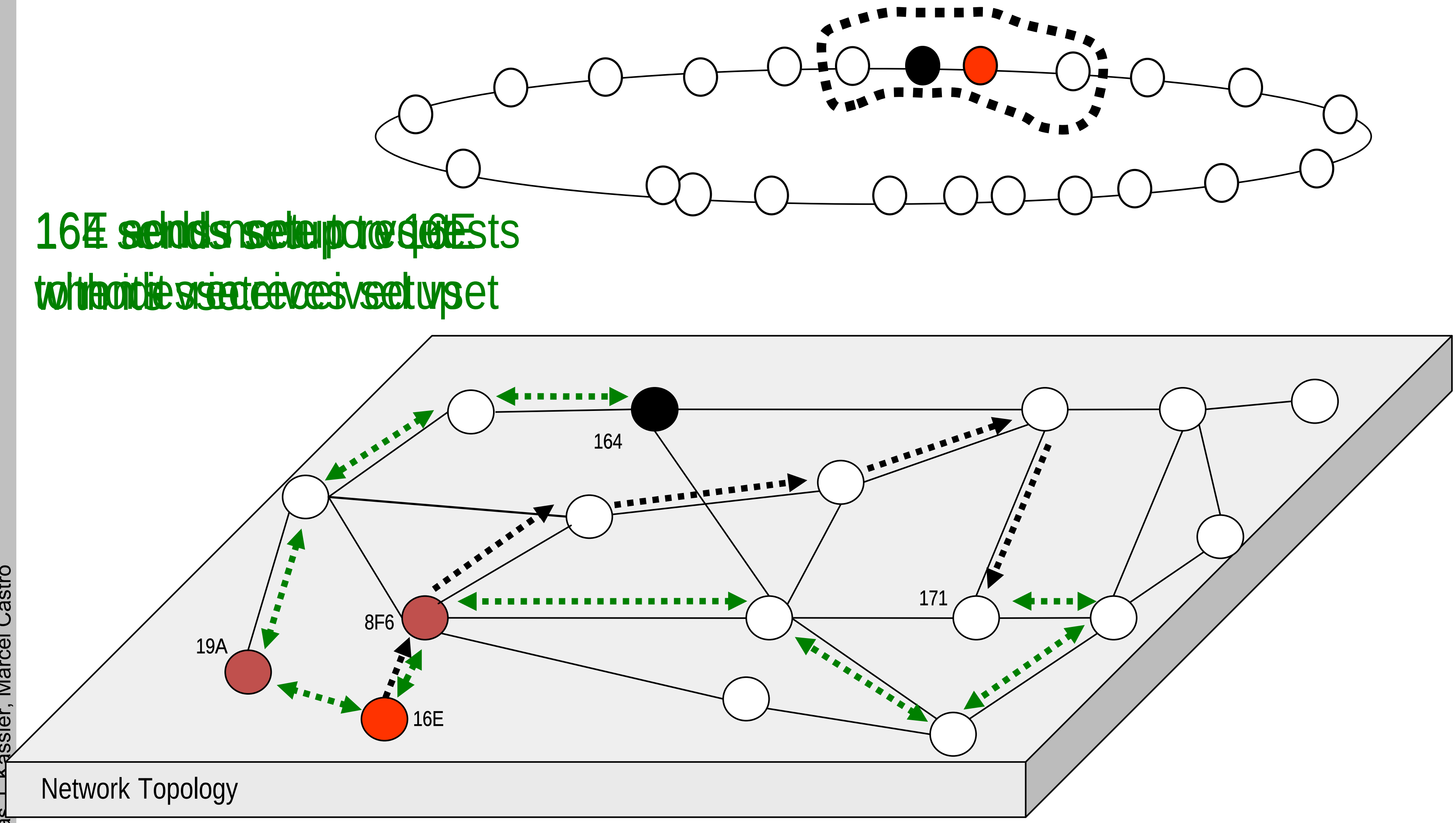
Send setup request to 16E



VRR: Node Joining

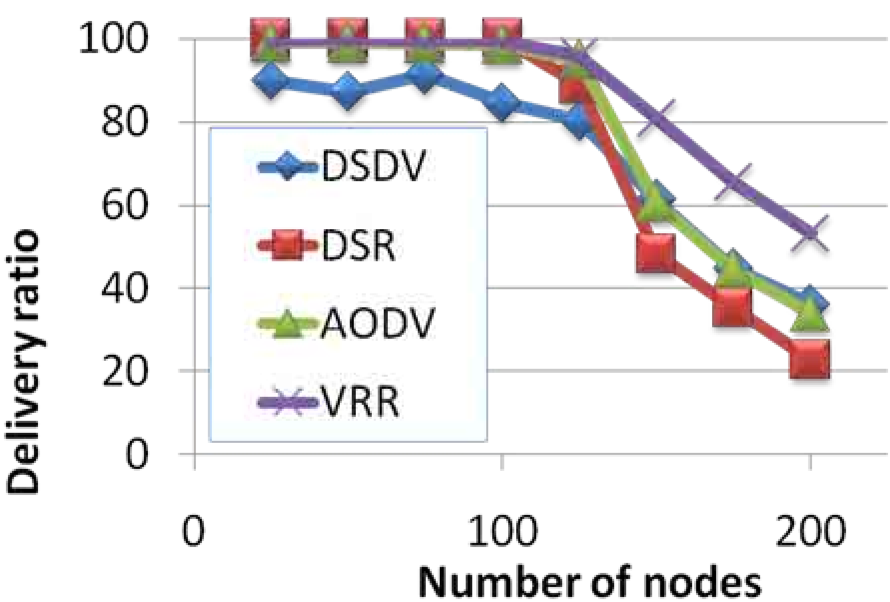
16E sends setup requests to its virtual set

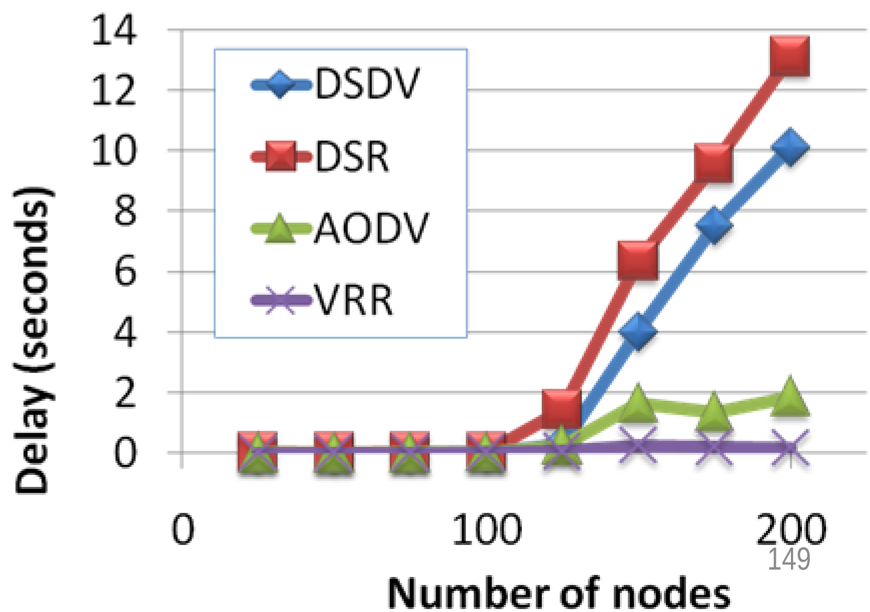
164 sends setup to 16E when it receives setup



- Simulation in ns-2
  - 802.11b MAC
  - Mobility: 0-20 m/s
  - CBR: 1 packet/sec (100 bytes)

M. Caesar, M. Castro, E. B. Nightingale, G. O'Shea, and A. Rowstron. "Virtual Ring Routing: Network routing inspired by DHTs". In ACM SIGCOMM'06

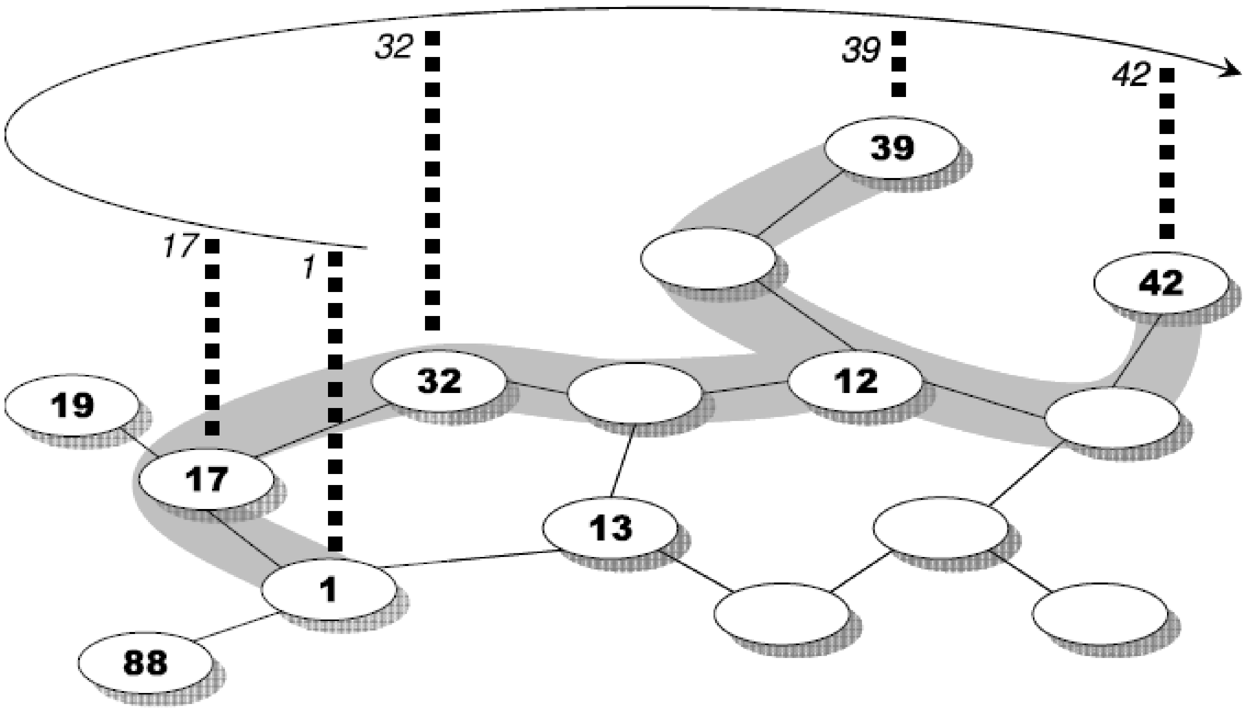




- Client-Server concept
- Understanding P2P
- How to integrate P2P and MANETs
- VRR: Virtual Ring Routing
- SSR: Scalable Source Routing
- Some Open Points

- Main Idea: Indirect routing at network layer
  – Source Routing (DSR) + Chord
- Nodes are organized into a Virtual Ring
- Like VRR, ring is constructed independent of the physical topology
- Interactive process is required if network is inconsistent or partitioned networks reunite.

SSR: Scalable Source Routing
Route prune



T. Fuhrmann et al., "Pushing Chord into the Underlay: Scalable Routing for Hybrid MANETs", Technical Report, Universität Karlsruhe (TH) 2006.

- Claim 1: If each node knows a source route to its successor (in the virtual ring), any node can reach any destination
  - Routing along the ring
- Claim 2: These source route can be obtained without flooding
  - Interactive Successor search
- Claim 3: A small per node cache suffices to achieve efficient routing
  - Cache source routes in a LRU (Least recent used) to avoid flooding

SSR state information

- Nodes use static memory:
  - Each node stores:
    - its direct physical neighbors
    - Source route to its successor
    - Source route to its predecessor (to be able to send updates)
    - All remaining memory (assigned to routing) is used to cache source routes (LRU cache).
      - Source route to all nodes that are part of a source route.
- Like DSR, data packets contain source address, destination address, and source route.
  - Source route does not need to span the entire path from packet source to packet destination, but a node *virtually closer* to the destination is achieved.

Outline

- Client-Server concept
- Understanding P2P
- How to integrate P2P and MANETs
- VRR: Virtual Ring Routing
- SSR: Scalable Source Routing
- Some Open Points

Some Open Points 1/2

- *Given the high dynamics in MANETs due to node mobility, which of the unstructured or structured overlay is more efficient in supporting common distributed applications ?*

- *Can DHTs be leveraged to support scalable unicast in MANETs?*

- *Will the ubiquitous deployment of large-scale MANETs happen?*

Some Open Points 2/2

- *Will overlay systems such as DHTs be employed in small-scale environments such individual MANETs?*
- *Would conventional DHT-based Internet applications be ported directly for a deployment in MANETs? Or such applications would have to be adapted in MANETs?*
- *How does node heterogeneity could be exploited to further increase the performance of DHT in MANETs?*
- *The state-of-art for simulating p2p characteristics in MANETs is far from perfect; how do we achieve better validation of simulators and underlying models?*

References

1. M. Gerla and C. Lindemann and A. Rowstron. “P2P MANET's - New Research Issues”. Perspectives Workshop: Peer-to-Peer Mobile Ad Hoc Networks - New Research Issues, 2005.
2. Thomas C. Zahn, “Structured Peer-to-Peer Services for Mobile Ad Hoc Networks”, PhD Thesis FU Berlin, 2006.
3. Jorg Eberspacher et al., “Structured P2P Networks in Mobile and Fixed Environments”HET-NETs04.
4. I. Stoica, R. Morris, D. Liben-Nowell, D. R. Karger, M. F. Kaashoek, F. Dabek, and H. Balakrishnan. “Chord: A scalable peer-to-peer lookup protocol for internet applications”. IEEE/ACM Transaction Network, 11(1):17–32, 2003.
5. M. Caesar, M. Castro, E. B. Nightingale, G. O’Shea, and A. Rowstron. “Virtual Ring Routing: Network routing inspired by DHTs”. In ACM SIGCOMM’06, pages 351-362, 2006.
6. T. Fuhrmann, P. Di, K. Kutzner, and C. Cramer , “Pushing Chord into the Underlay: Scalable Routing for Hybrid MANETs”, Technical Report, Universität Karlsruhe (TH) 2006-12, June 2006.

References

7. E. K. Lua, J. Crowcroft, M. Pias, R. Sharma, and S. Lim. “A survey and comparison of peer-to-peer overlay network schemes”. IEEE Communications Surveys, 7(2):72–93, 2005.
8. A. Klemm et al, “A special-purpose peer-to-peer file sharing system for mobile ad hoc networks”.VTC 2003.
9. K. Aberer, et al. The essence of P2P: a reference architecture for overlay networks. Fifth IEEE International Conference on Peer-to-Peer Computing, Sep 2005, Konstanz, Germany.
10. Y. Charlie Hu, Saumitra M. Das, and H. Pucha, "Peer-to-Peer Overlay Abstractions in MANETs“. Book Chapter in Theoretical and Algorithmic Aspects of Sensor, Ad Hoc Wireless, and Peer-to-Peer Networks,CRC Press, 2005.
11. T. Fuhrmann, “Performance of scalable Source Routing in Hybrid MANETs”. In Wireless on Demand Network Systems and Services (WONS), 2007.

Acknowledgement

This tutorial was sponsored by Daidalos project

(http://www.ist-daidalos.org/)

Thank you!

Marcel C. Castro
marccava@kau.se
www.cs.kau.se/~marccava