Nomadic Communications

UNIVERSITÀ DEGLI STUDI DI TRENTO

Wireless Mesh Networks

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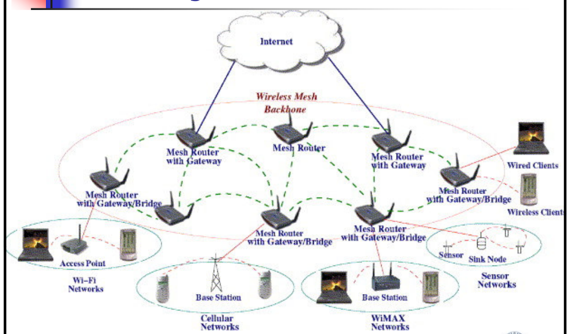
Home Page: http://isi.unitn.it/locigno/index.php/teaching-duties/nomadic-communications

Copyright

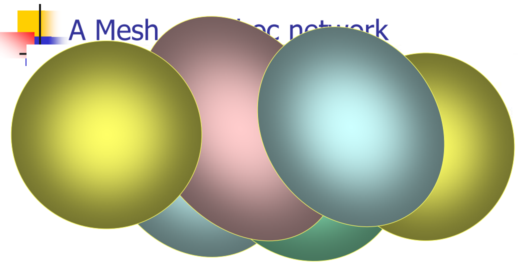
Ad-Hoc and WMN

- Ad-Hoc network
  - non permanent
  - general purpose or specific (sensors)
  - single or multi-hop, normally mobile
  - may require routing (see AODV and OLSR)
- Wireless Mesh Networks (WMN)
  - more structured than Ad-Hoc
  - may be hierarchical
  - semi-permanent, some nodes are fixed
  - requires routing

WMN: a general view

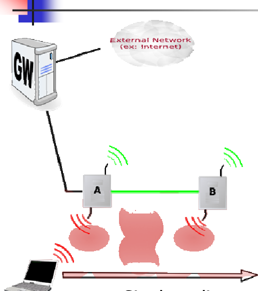


A Mesh …oc network



- Ad-Hoc can be meshed
  - non single broadcast channel
  - multi-hop require routing

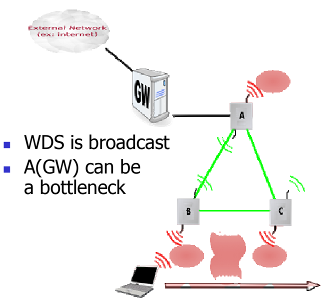
Mesh: Basic scenarios (1)



- Extended WLAN access
- Simple configuration
  - no routing
- Simple 802.11 handover support
- Double radio guarantees good performance

- Single radio creates resource conflicts
  - 3 BSS on the same channel
  - suitable for low-cost low-performance

Mesh: Basic scenarios (2)

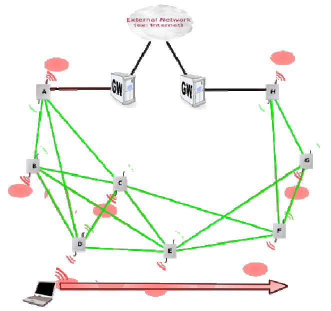


- WDS is broadcast
- A(GW) can be a bottleneck

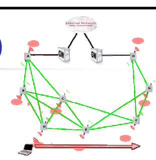
- Extended WLAN access
- Routing required
- Simple 802.11 handover support
- Double radio guarantees good performance

- Single radio creates serious resource conflicts
  - n+1 BSS on the same channel

Mesh: Basic scenarios (3)



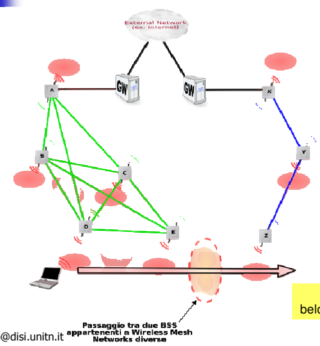
Mesh: Basic scenarios (3)



- Extended WLAN access
- Basic infrastructuring
- Single radio operation very difficult

- Multiple external gateways
  - sophisticated, flow-based routing
- Non standard handover support
  - flow based routing requires exporting the context
  - address management require coordination
- WDS may be multi-hop
  - How many channels?
- Point-to-point and broadcast channels in WDS

Mesh: Basic scenarios (3)



- Address management (DHCP) is a problem
- Flow-based routing may be impossible
- Joining/splitting of partitions is an open issue

Moving between BSS belonging to different Mesh/WDS

Mesh – Ad-Hoc: AODV

Ad-hoc On-demand Distance Vector routing – rfc3561

- DV (see RIP) protocol for next-hop based routing
- On-Demand: maintains routes only for nodes that are communicating
- Must build routes when requested
- Route Request (RREQ) are flooded through the network
- Nodes set-up reverse path pointers to the source
  - **AODV assumes symmetric links**

Mesh – Ad-Hoc: AODV

- The intended receiver sends back a Route Reply (RR)
- RR follow the reverse path set-up by intermediate nodes (unicast) establishing a shortest path route memorized by intermediate nodes
- Paths expire if not used
  - protocol & transmission overhead
  - guarantee of stability in dynamic, non reliable networks
- Usual DV problems
  - count to infinity, slow convergence, …
  - in a dynamic environment may be too much → throughput going to zero

AODV Loop Freedom

- Destination sequence numbers to order routing events in time
- Ordering among *<seqno, hop count>* tuples at different nodes on a path
  - higher seqno has precedence
  - if same seqno, lower hop count has precedence
- The final selection will be the shortest path (w.r.t. some metric, not necessarily hop-count)

Mesh – Ad-Hoc: AODV

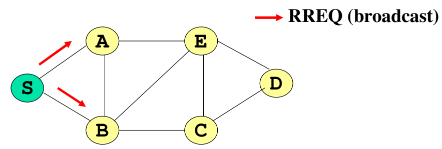
- Next-hop based (other proposals are based on source routing)
- "Flat" protocol: all nodes are equal
- Can manage only one route per s-d pair
  - can be inefficient in presence of highly variable link quality and persistence
- Good for sporadic communications
- Bad for high mobility
  - slow convergence
  - difficulty in understanding topology changes.

Mesh – Ad-Hoc: AOMDV

Ad-Hoc On-demand Multipath Distance Vector Routing in Ad Hoc Networks

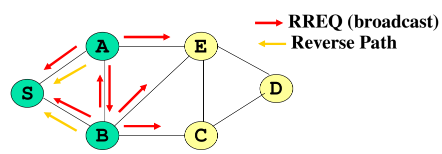
- An extension to AODV
- AOMDV computes multiple loop-free and link-disjoint paths
- Using "Advertised Hop-count" guarantees Loop-freedom
  - A variable, which is defined as the maximum hop count for all the paths. A node only accepts an alternate path to the destination if it has a lower hop count than the advertised hop count for that destination
- Link-disjointness of multiple paths is achieved by using a particular property of flooding
- Performance comparison of AOMDV with AODV shows that
  - AOMDV improves the end-to-end delay, often more than a factor of two
  - AOMDV reduces routing overheads by about 20%

Basic AODV Route Discovery



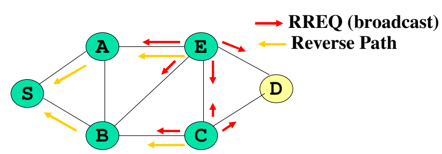
- When a route is needed, source floods a route request for the destination.

Basic AODV Route Discovery



- Reverse path is formed when a node hears a non-duplicate route request.
- Each node forwards the request at most once (pure flooding).

Basic AODV Route Discovery



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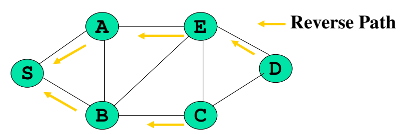
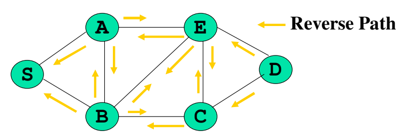
Basic AODV Route Discovery



- Observation: Duplicate RREQ copies completely ignored. Therefore, potentially useful alternate reverse path info lost.

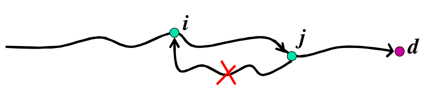
Use of duplicate RREQ: the wrong way



- Form reverse paths using all duplicate RREQ copies causes routing loops
- alternate "loop-free" reverse paths are build in AOMDV using some selected duplicate RREQ copies?

Loop Freedom

- Impose ordering among nodes in every path.
- Notion of upstream/downstream nodes
- Never form a route at a downstream node via an upstream node
- Prune portions of paths that are longer
- Surviving s-d path will be disjoint and loop-free



AOMDV Loop Freedom

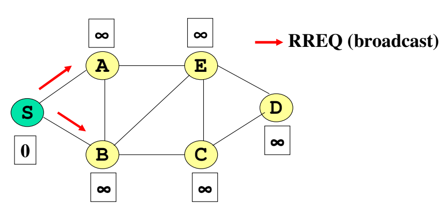
- Sequence number rule: Keep only routes for the highest dest seqno (like in AODV).
- For the same dest seqno,
  - Route advertisement rule: Keep multiple routes but always *advertise* only one of them to others. Hop count of that path is the "advertised hop count"
  - Which one? Longest path at the time of first advertisement
  - Why? Maximize chances of forming more paths

  Route acceptance rule: Accept a route from a neighbor only if it has a smaller or equal advertised hop count. Break ties using node ids.
  - No need for coordination with upstream nodes

AOMDV Routing Table Entry

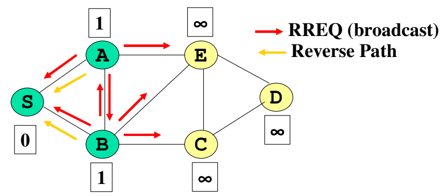
Dest	Seqno	Advertised hop count	Hop count 1	Next hop 1
			Hop count 2	Next hop 2
			…	…

Multiple Loop-free Reverse Paths

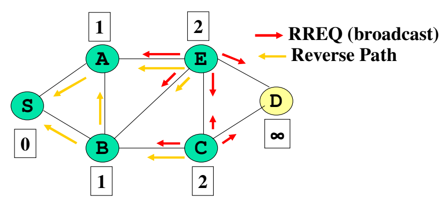


- Suppose RREQ from S includes highest seqno for itself.

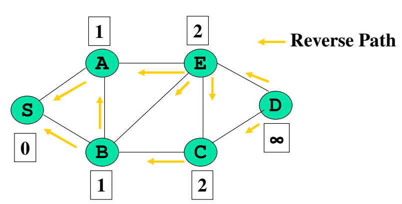
Multiple Loop-free Reverse Paths



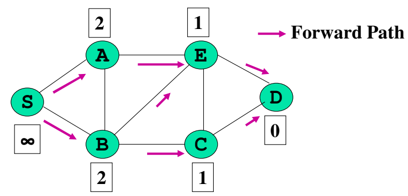
Multiple Loop-free Reverse Paths



Multiple Loop-free Reverse Paths



Multiple Loop-free Forward Paths



- Another modification to basic AODV route discovery: multiple replies from destination.

How Many Paths?

- Too many paths are not useful
  - Overhead proportional to # paths.
  - Diminishing utility with larger # paths. Analytical study in
- **Solution: Disjoint paths**
  - Automatically fewer paths
  - Paths fail independently, more robust
  - Node or link disjoint?
  - Too few node disjoint paths in dense networks using flooding → link disjoint

Finding Link-disjoint Paths

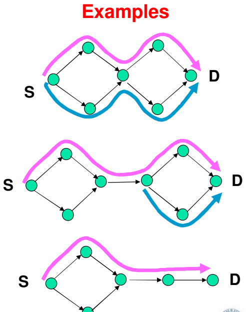
How?

- Maintain last hop info in routing table
- Ensure that next hops and last hops before destination are unique

dest	seq. no	next hop	last hop	hop count
D	...	N1	L1	...
D	...	N2	L2	...

- This requires route request and replies to carry first hop info

Examples



Mesh – Ad-Hoc: OLSR

Optimized Link-State Routing Protocol (rfc3626)

- Proactive, link-state routing protocol
- Based on the notion of MultiPoint Relay (MPR)
- Three main components:
  - Neighbor Sensing mechanism
  - MPR Flooding mechanism
  - topology Discovery (diffusion) mechanism.
- Auxilary features of OLSR:
  - network association - connecting OLSR to other networks

Mesh – Ad-Hoc: OLSR

Basic neighbor sensing:

- periodic exchange of HELLO messages;
- HELLO messages list neighbors + "neighbor quality"
  - HEARD - link may be asymmetric
  - SYM - link is confirmed to be symmetric
  - MPR - link is confirmed to be symmetric AND neighbor selected as MPR
- Providing:
  - topology information up to two hops
  - MPR selector information notification

Mesh – Ad-Hoc: OLSR

- Each node selects from among its neighbors an MPR set such that
  - an emitted flooding message, relayed by the MPR nodes, can be received by all nodes in the 2-hop neighborhood
- Goals:
  - reduce flooding overhead (select minimal sets)
  - provide optimal flooding distances

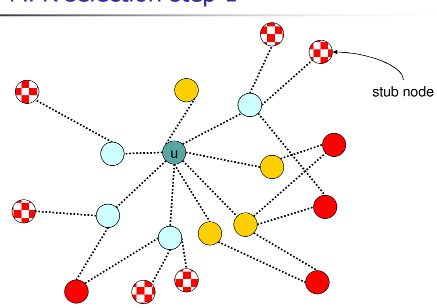
Mesh – Ad-Hoc: OLSR

- Exchanges topology information with other nodes of the network regularly
- MPRs announce their status periodically in control messages
- In route calculation, the MPRs are used to form the route from a given node to any destination in the network
- Uses MPRs to facilitate efficient flooding of control messages
- The presence of a 2-tiear topology (MPRs are sort of supernodes) makes it complex and prone to failures

MPR selection algorithm

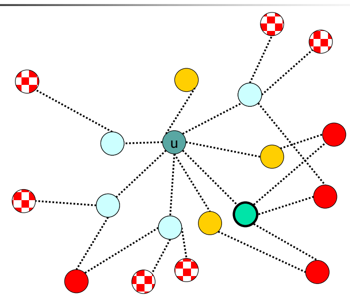
- Each point u has to select its set of MPR.
- Goal : select in the 1-neighborhood of u –N1(u)– a set of nodes as small as possible which covers the whole 2-neighborhood of u –N2(u)–
- Done in two steps:
  - Step 1: Select nodes of N1(u) which cover stub nodes of N2(u)
    - stub nodes are those that are connected to one N1(u) node only
  - Step 2: Select among the nodes of N1(u) not selected at the first step, the node which covers the highest number of nodes in N2(u) not yet connected
    - Repeat Step 2 until all N2(u) is reached

MPR selection step 1



Select nodes (light blue) in N1(u) which cover stub nodes of N2(u)

MPR selection step 2



Select the node in N1(u) which cover the largest number of non-stub nodes in N2(u)

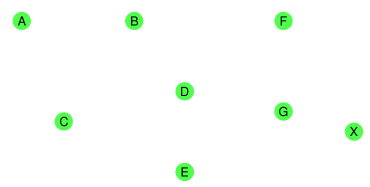
BATMAN

- Better Approach To Mesh Ad-hoc Networking
- A DV protocol using Link Qualities
- Based on periodic Broadcast of "Originator Messages" –OGM
  - Link Quality metric is the number of received OGMs
  - Path Metric is the product of link metric
  - Broadcast is always at minimum PHY rate ... difficult to distinguish high speed paths
- OGM have TTL fields to avoid too long paths
  - TTL must be tailored to the MESH dimension

BATMAN

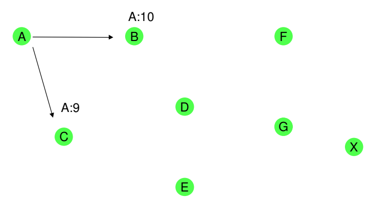
- BATMAN is a level 2.5 routing solution
- Uses MAC addresses to identify stations, avoiding the problem of changing IP addresses to deliver frames
- Not pure layer 2 since it runs in the kernel and is not integrated in NIC cards or drivers
- Relies on Layer 2 info, like link quality
- Send UDP packets and not Layer 2 frames for routing purposes
- BATMAN does not have handover enhancement support
  - Slow convergence makes connection fail
  - We are proposing one (already in the distribution) with a colleague of yours from last year ☺

BATMAN



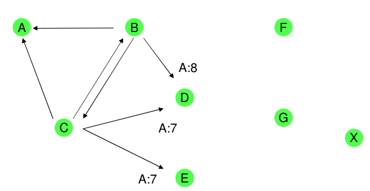
A wants to reach X

BATMAN



- Nodes broadcast originator messages (OGM's) every second
- OGM's are rebroadcast
- Other nodes measure how many OGM's are received in a fixed time window

BATMAN



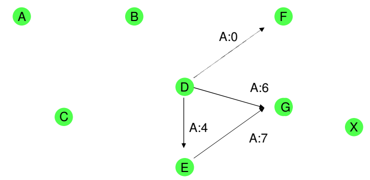
D BATMAN routing table

TO	VIA	Q
A	B	8
A	C	7

D Final routing table

TO	VIA
A	B

BATMAN



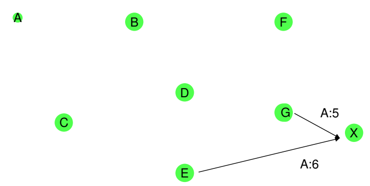
G BATMAN routing table

TO	VIA	Q
A	D	6
A	E	7

G Final routing table

TO	VIA
A	E

BATMAN



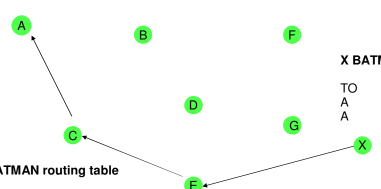
X BATMAN routing table

TO	VIA	Q
A	G	5
A	E	6

X Final routing table

TO	VIA
A	E

BATMAN



X BATMAN routing table

TO	VIA	Q
A	G	5
A	E	6

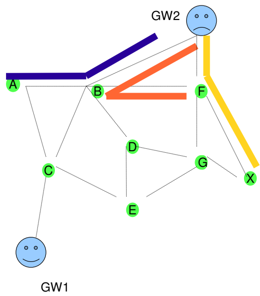
C BATMAN routing table

TO	VIA	Q
A	A	9

E BATMAN routing table

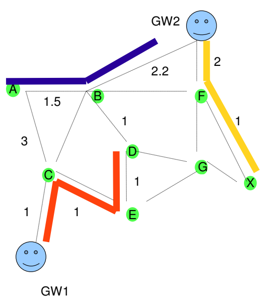
TO	VIA	Q
A	C	7
A	D	4

Current GW selection techniques



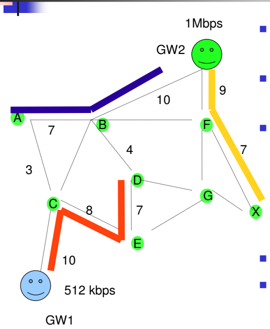
- Minimum hop count to gateways
- Used by routing protocols like AODV
- Creates single over congested gateways

Current GW selection techniques



- Best link quality to GW
- Used by
  - source routing protocols like MIT Srcr
  - Link state protocols like OLSR
- Prevents congested links to GW
- Not global optimum of GW BW usage

Current GW selection techniques



- BATMAN has advanced a little further
- GW can advertise downlink speed
- User can choose GW selection based on
  - GW with best BW
  - Stable GW (need history)
  - GW_{BW} x LQ
- Can't trust advertised GW BW
- Doesn't achieve fairness

BABEL

- Experimental RFC 6126
- Found in many Linux releases
- DV based on IP addresses
  - problems with handovers and mobility
- Loop free, based on ideas similar to BATMAN, AODV, DSDV (Destination Sequenced Distance Vector)
  - Destination Sequenced

DSDV Protocol

- Keep the simplicity of Distance Vector
- Guarantee Loop Freeness
  - New Table Entry for Destination Sequence Number
- Allow fast reaction to topology changes
  - Make immediate route advertisement on significant changes in routing table
  - but wait with advertising of unstable routes (damping fluctuations)

DSDV (Table Entries)

Destination	Next	Metric	Seq. Nr	Install Time	Stable Data
A	A	0	A-550	001000	Ptr_A
B	B	1	B-102	001200	Ptr_B
C	B	3	C-588	001200	Ptr_C
D	B	4	D-312	001200	Ptr_D

- **Sequence number** originated from destination. Ensures loop freeness.
- **Install Time** when entry was made (used to delete stale entries from table)
- **Stable Data** Pointer to a table holding information on how stable a route is. Used to damp fluctuations in network.

DSDV (Route Selection)

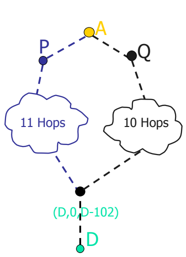
- Update information is compared to own routing table
  - 1. Select route with higher destination sequence number (This ensure to use always newest information from destination)
  - 2. Select the route with better metric when sequence numbers are equal

DSDV (Respond to Topology Changes)

- Immediate advertisements
  - Information on new Routes, broken Links, metric change is immediately propagated to neighbors.
- Full/Incremental Update:
  - Full Update: Send all routing information from own table.
  - Incremental Update: Send only entries that has changed. (Make it fit into one single packet)

Fluctuations

What are Fluctuations

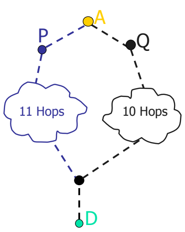


- Entry for D in A: [D, Q, 14, D-100]
- D makes Broadcast with Seq. Nr. D-102
- A receives Update from P (D, 15, D-102)
  -> Entry for D in A: [D, P, 15, D-102]
  A must propagate this route immediately.
- A receives Update from Q (D, 14, D-102)
  -> Entry for D in A: [D, Q, 14, D-102]
  A must propagate this route immediately.

This can happen every time D or any other node does its broadcast and lead to unnecessary route advertisements in the network, so called fluctuations

Damping Fluctuations

How to damp fluctuations



- Record last and avg. Settling Time of every Route in a separate table. (Stable Data)
- Deleting Time = Time between arrival of first route and the best route with a given seq. nr.
- A still must update his routing table on the first arrival of a route with a newer seq. nr., but he can wait to advertising it. Time to wait is proposed to be 2*(avg. Settling Time).

Mesh Networks: 802.11s

- Working group to deliver a standard for 802.11 (& around) base Mesh Networks
- There are drafts and early releases, but not yet a definitely released standard (as of 2010)
- Tries to define a framework to support a Mesh network as a standard extended WLAN with routing that goes beyond the standard minimum spanning tree of 802.1 interconnection

Device Classes in 802.11s

- Mesh Point (MP)
  - a point able to relay messages
- Mesh AP (MAP)
  - a MP able to provide services to STAs
- Mesh Portal (MPP)
  - a MAP connected to a wired LAN
  - normally called a gateway and assumed to access the internet

Routing in 802.11s

- Hybrid Wireless Mesh Protocol (HWMP) - Mandatory
  - AODV derived link-state protocol
  - Based on trees for proaction and efficiency
  - Add on-demand features (like AODV)
- Radio Aware OLSR (RA-OLSR) – Optional
  - Radio aware metrics added to MPRs in OLSR
  - optional fish-eye routing capabilities
  - association and discovery protocols for topology discovery and buildup

Routing in 802.11s

- BATMAN probably supported
- Features for multi-gateway management
- Support for Vehicular networks, where some specialized features are needed
- Use only MAC addresses for routing
- Run directly in the diverse/NIC cards

- Integration with the other 802.11 protocols ... which is the real strength!