# Mobile Communications Chapter 8: Network Protocols/Mobile IP

- Motivation
- Data transfer
- Encapsulation
- Security
- IPv6
- Problems
- Micro mobility support
- DHCP
- Ad-hoc networks
- Routing protocols



## Motivation for Mobile IP

Routing
- based on IP destination address, network prefix (e.g. 129.13.42) determines physical subnet
- change of physical subnet implies change of IP address to have a topological correct address (standard IP) or needs special entries in the routing tables

Specific routes to end-systems?
- change of all routing table entries to forward packets to the right destination
- does not scale with the number of mobile hosts and frequent changes in the location, security problems

Changing the IP-address?
- adjust the host IP address depending on the current location
- almost impossible to find a mobile system, DNS updates take to long time
- TCP connections break, security problems



## Requirements to Mobile IP (RFC 3220, was: 2002)

Transparency
- mobile end-systems keep their IP address
- continuation of communication after interruption of link possible
- point of connection to the fixed network can be changed

Compatibility
- support of the same layer 2 protocols as IP
- no changes to current end-systems and routers required
- mobile end-systems can communicate with fixed systems

Security
- authentication of all registration messages

Efficiency and scalability
- only little additional messages to the mobile system required (connection typically via a low bandwidth radio link)
- world-wide support of a large number of mobile systems in the whole Internet



## Terminology

Mobile Node (MN)
- system (node) that can change the point of connection to the network without changing its IP address

Home Agent (HA)
- system in the home network of the MN, typically a router
- registers the location of the MN, tunnels IP datagrams to the COA

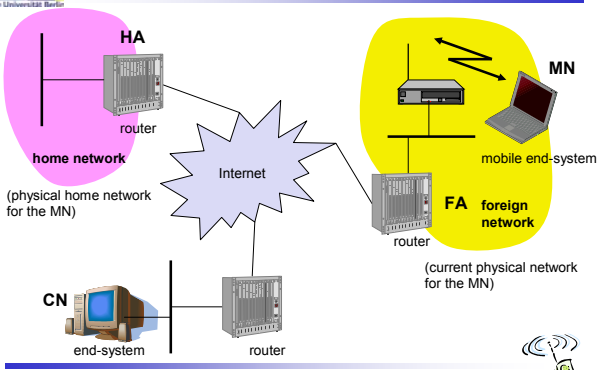
Foreign Agent (FA)
- system in the current foreign network of the MN, typically a router
- forwards the tunneled datagrams to the MN, typically also the default router for the MN

Care-of Address (COA)
- address of the current tunnel end-point for the MN (at FA or MN)
- actual location of the MN from an IP point of view
- can be chosen, e.g., via DHCP

Correspondent Node (CN)
- communication partner

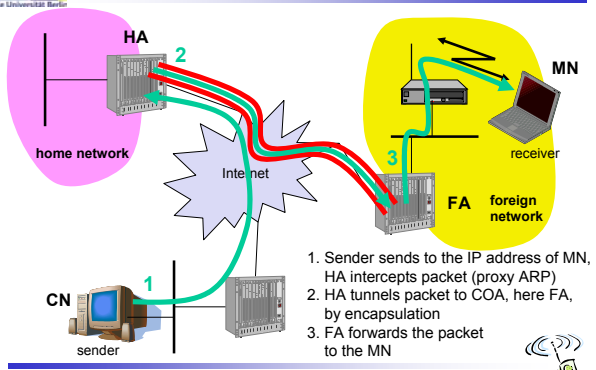


## Example network



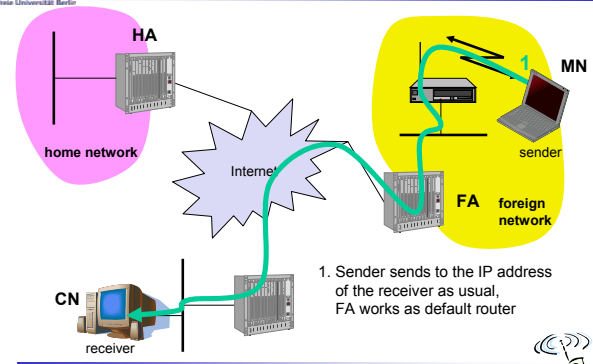



## Data transfer to the mobile system



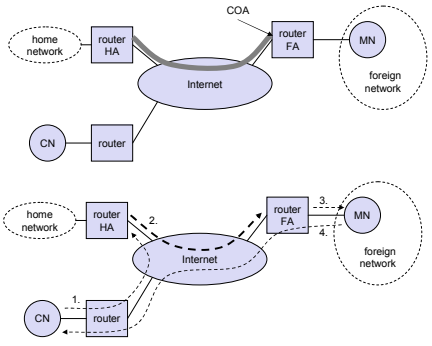

1. Sender sends to the IP address of MN, HA intercepts packet (proxy ARP)
2. HA tunnels packet to COA, here FA, by encapsulation
3. FA forwards the packet to the MN

## Data transfer from the mobile system






## Overview






## Network integration

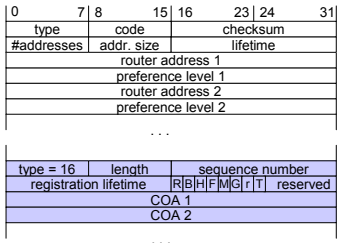
Agent Advertisement
- HA and FA periodically send advertisement messages into their physical subnets
- MN listens to these messages and detects, if it is in the home or a foreign network (standard case for home network)
- MN reads a COA from the FA advertisement messages

Registration (always limited lifetime!)
- MN signals COA to the HA via the FA, HA acknowledges via FA to MN
- these actions have to be secured by authentication

Advertisement
- HA advertises the IP address of the MN (as for fixed systems), i.e. standard routing information
- routers adjust their entries, these are stable for a longer time (HA responsible for a MN over a longer period of time)
- packets to the MN are sent to the HA,
- independent of changes in COA/FA



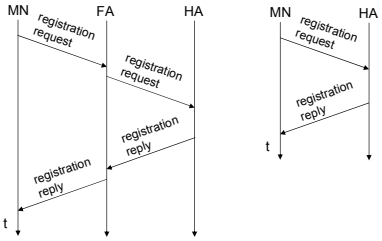
## Agent advertisement




type = 16
length = 6 + 4 * #COAs
R: registration required
B: busy, no more registrations
H: home agent
F: foreign agent
M: minimal encapsulation
G: GRW encapsulation
r: =0, ignored (former Van Jacobson compression)
T: FA supports reverse tunneling
reserved: =0, ignored

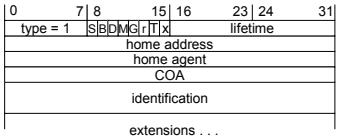


## Registration



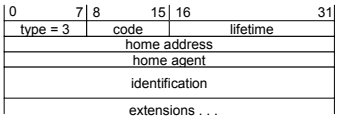



## Mobile IP registration request




S: simultaneous bindings
B: broadcast datagrams
D: decapsulation by MN
M mininal encapsulation
G: GRE encapsulation
r: =0, ignored
T: reverse tunneling requested
x: =0, ignored

## Mobile IP registration reply



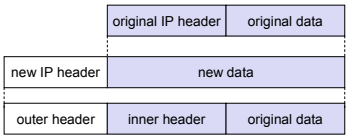

**Example codes:**
registration successful
- 0 registration accepted
- 1 registration accepted, but simultaneous mobility bindings unsupported

registration denied by FA
- 65 administratively prohibited
- 66 insufficient resources
- 67 mobile node failed authentication
- 68 home agent failed authentication
- 69 requested Lifetime too long

registration denied by HA
- 129 administratively prohibited
- 131 mobile node failed authentication
- 133 registration Identification mismatch
- 135 too many simultaneous mobility bindings



## Encapsulation

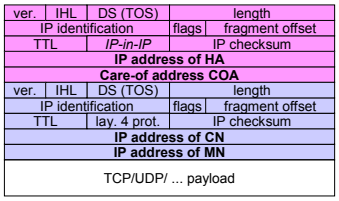





## Encapsulation I

Encapsulation of one packet into another as payload
- e.g. IPv6 in IPv4 (6Bone), Multicast in Unicast (Mbone)
- here: e.g. IP-in-IP-encapsulation, minimal encapsulation or GRE (Generic Record Encapsulation)

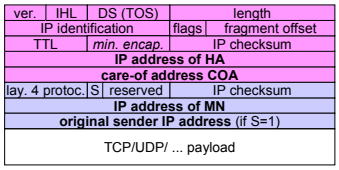
IP-in-IP-encapsulation (mandatory, RFC 2003)
- tunnel between HA and COA





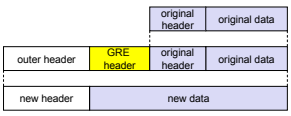

## Encapsulation II

Minimal encapsulation (optional)
- avoids repetition of identical fields
- e.g. TTL, IHL, version, DS (RFC 2474, old: TOS)
- only applicable for unfragmented packets, no space left for fragment identification

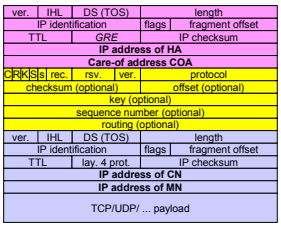




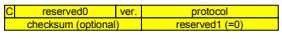

## Generic Routing Encapsulation




RFC 1701




RFC 2784





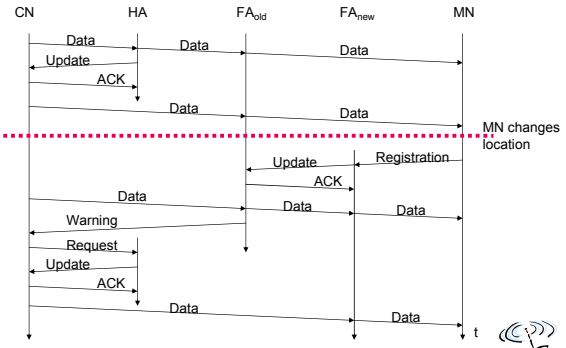

## Optimization of packet forwarding

Triangular Routing
- sender sends all packets via HA to MN
- higher latency and network load

"Solutions"
- sender learns the current location of MN
- direct tunneling to this location
- HA informs a sender about the location of MN
- big security problems!

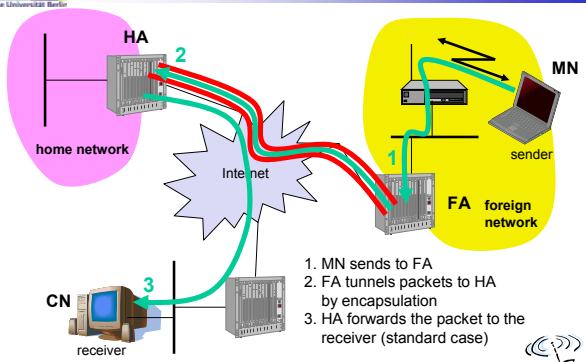
Change of FA
- packets on-the-fly during the change can be lost
- new FA informs old FA to avoid packet loss, old FA now forwards remaining packets to new FA
- this information also enables the old FA to release resources for the MN

## Change of foreign agent






## Reverse tunneling (RFC 3024, was: 2344)






## Mobile IP with reverse tunneling

Router accept often only “topological correct“ addresses (firewall!)
- a packet from the MN encapsulated by the FA is now topological correct
- furthermore multicast and TTL problems solved (TTL in the home network correct, but MN is to far away from the receiver)

Reverse tunneling does not solve
- problems with *firewalls*, the reverse tunnel can be abused to circumvent security mechanisms (tunnel hijacking)
- optimization of data paths, i.e. packets will be forwarded through the tunnel via the HA to a sender (double triangular routing)

The standard is backwards compatible
- the extensions can be implemented easily and cooperate with current implementations without these extensions
- Agent Advertisements can carry requests for reverse tunneling



## Mobile IP and IPv6

Mobile IP was developed for IPv4, but IPv6 simplifies the protocols
- security is integrated and not an add-on, authentication of registration is included
- COA can be assigned via auto-configuration (DHCPv6 is one candidate), every node has address autoconfiguration
- no need for a separate FA, **all** routers perform router advertisement which can be used instead of the special agent advertisement; addresses are always co-located
- MN can signal a sender directly the COA, sending via HA not needed in this case (automatic path optimization)
- „soft“ hand-over, i.e. without packet loss, between two subnets is supported
  - MN sends the new COA to its old router
  - the old router encapsulates all incoming packets for the MN and forwards them to the new COA
  - authentication is always granted



## Problems with mobile IP

Security
- authentication with FA problematic, for the FA typically belongs to another organization
- no protocol for key management and key distribution has been standardized in the Internet
- patent and export restrictions

Firewalls
- typically mobile IP cannot be used together with firewalls, special set-ups are needed (such as reverse tunneling)

QoS
- many new reservations in case of RSVP
- tunneling makes it hard to give a flow of packets a special treatment needed for the QoS

Security, firewalls, QoS etc. are topics of current research and discussions!

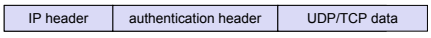


## Security in Mobile IP

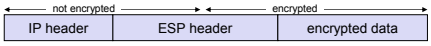
Security requirements (Security Architecture for the Internet Protocol, RFC 1825)
- Integrity
  any changes to data between sender and receiver can be detected by the receiver
- Authentication
  sender address is really the address of the sender and all data received is really data sent by this sender
- Confidentiality
  only sender and receiver can read the data
- Non-Repudiation
  sender cannot deny sending of data
- Traffic Analysis
  creation of traffic and user profiles should not be possible
- Replay Protection
  receivers can detect replay of messages

## IP security architecture I

- Two or more partners have to negotiate security mechanisms to setup a security association
  - typically, all partners choose the same parameters and mechanisms
- Two headers have been defined for securing IP packets:
  - Authentication-Header
    - guarantees integrity and authenticity of IP packets
    - if asymmetric encryption schemes are used, non-repudiation can also be guaranteed



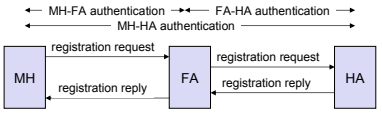

  - Encapsulation Security Payload
    - protects confidentiality between communication partners






## IP security architecture II

- Mobile Security Association for registrations
  - parameters for the mobile host (MH), home agent (HA), and foreign agent (FA)
- Extensions of the IP security architecture
  - extended authentication of registration

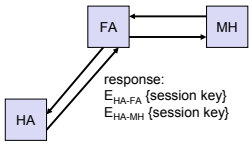



  - prevention of replays of registrations
    - time stamps: 32 bit time stamps + 32 bit random number
    - nonces: 32 bit random number (MH) + 32 bit random number (HA)



## Key distribution

Home agent distributes session keys




- foreign agent has a security association with the home agent
- mobile host registers a new binding at the home agent
- home agent answers with a new session key for foreign agent and mobile node



## IP Micro-mobility support

Micro-mobility support:
- Efficient local handover inside a foreign domain without involving a home agent
- Reduces control traffic on backbone
- Especially needed in case of route optimization

Example approaches:
- Cellular IP
- HAWAII
- Hierarchical Mobile IP (HMIP)

Important criteria:
Security Efficiency, Scalability, Transparency, Manageability

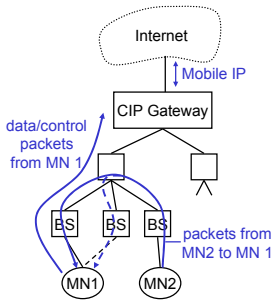


## Cellular IP

Operation:
- „CIP Nodes“ maintain routing entries (soft state) for MNs
- Multiple entries possible
- Routing entries updated based on packets sent by MN

CIP Gateway:
- Mobile IP tunnel endpoint
- Initial registration processing

Security provisions:
- all CIP Nodes share „network key“
- MN key: MD5(net key, IP addr)
- MN gets key upon registration






## Cellular IP: Security

Advantages:
- Initial registration involves authentication of MNs and is processed centrally by CIP Gateway
- All control messages by MNs are authenticated
- Replay-protection (using timestamps)

Potential problems:
- MNs can directly influence routing entries
- Network key known to many entities (increases risk of compromise)
- No re-keying mechanisms for network key
- No choice of algorithm (always MD5, prefix+suffix mode)
- Proprietary mechanisms (not, e.g., IPSec AH)

## Cellular IP: Other issues

Advantages:

- Simple and elegant architecture
- Mostly self-configuring (little management needed)
- Integration with firewalls / private address support possible

Potential problems:

- Not transparent to MNs (additional control messages)
- Public-key encryption of MN keys may be a problem for resource-constrained MNs
- Multiple-path forwarding may cause inefficient use of available bandwidth



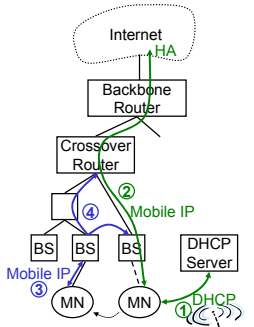
## HAWAII

Operation:

- MN obtains co-located COA ① and registers with HA ②
- Handover: MN keeps COA, new BS answers Reg. Request ③ and updates routers ④
- MN views BS as foreign agent

Security provisions:

- MN-FA authentication mandatory
- Challenge/Response Extensions mandatory






## HAWAII: Security

Advantages:

- Mutual authentication and C/R extensions mandatory
- Only infrastructure components can influence routing entries

Potential problems:

- Co-located COA raises DHCP security issues (DHCP has no strong authentication)
- Decentralized security-critical functionality (Mobile IP registration processing during handover) in base stations
- Authentication of HAWAII protocol messages unspecified (potential attackers: stationary nodes in foreign network)
- MN authentication requires PKI or AAA infrastructure



## HAWAII: Other issues

Advantages:

- Mostly transparent to MNs (MN sends/receives standard Mobile IP messages)
- Explicit support for dynamically assigned home addresses

Potential problems:

- Mixture of co-located COA and FA concepts may not be supported by some MN implementations
- No private address support possible because of co-located COA



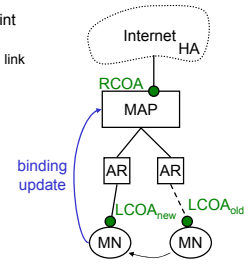
## Hierarchical Mobile IPv6 (HMIPv6)

Operation:

- Network contains mobility anchor point (MAP)
  - mapping of regional COA (RCOA) to link COA (LCOA)
- Upon handover, MN informs MAP only
  - gets new LCOA, keeps RCOA
- HA is only contacted if MAP changes

Security provisions:

- no HMIP-specific security provisions
- binding updates should be authenticated






## Hierarchical Mobile IP: Security

Advantages:

- Local COAs can be hidden, which provides some location privacy
- Direct routing between CNs sharing the same link is possible (but might be dangerous)

Potential problems:

- Decentralized security-critical functionality (handover processing) in mobility anchor points
- MNs can (must!) directly influence routing entries via binding updates (authentication necessary)

## Hierarchical Mobile IP: Other issues

Advantages:

- Handover requires minimum number of overall changes to routing tables
- Integration with firewalls / private address support possible

Potential problems:

- Not transparent to MNs
- Handover efficiency in wireless mobile scenarios:
  - Complex MN operations
  - All routing reconfiguration messages sent over wireless link



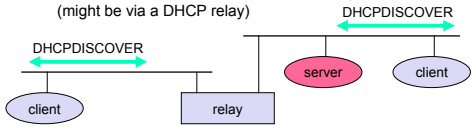
## DHCP: Dynamic Host Configuration Protocol

Application

- simplification of installation and maintenance of networked computers
- supplies systems with all necessary information, such as IP address, DNS server address, domain name, subnet mask, default router etc.
- enables automatic integration of systems into an Intranet or the Internet, can be used to acquire a COA for Mobile IP

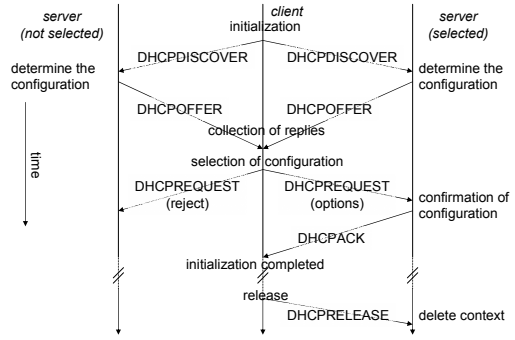
Client/Server-Model

- the client sends via a MAC broadcast a request to the DHCP server (might be via a DHCP relay)






## DHCP - protocol mechanisms






## DHCP characteristics

Server

- several servers can be configured for DHCP, coordination not yet standardized (i.e., manual configuration)

Renewal of configurations

- IP addresses have to be requested periodically, simplified protocol

Options

- available for routers, subnet mask, NTP (network time protocol) timeserver, SLP (service location protocol) directory, DNS (domain name system)

Big security problems!

- no authentication of DHCP information specified



## Mobile ad hoc networks

Standard Mobile IP needs an infrastructure

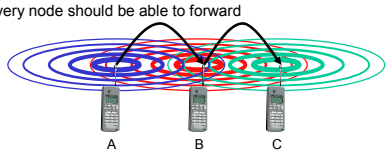
- Home Agent/Foreign Agent in the fixed network
- DNS, routing etc. are not designed for mobility

Sometimes there is no infrastructure!

- remote areas, ad-hoc meetings, disaster areas
- cost can also be an argument against an infrastructure!

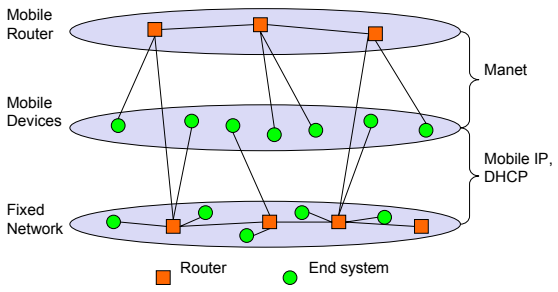
Main topic: routing

- no default router available
- every node should be able to forward

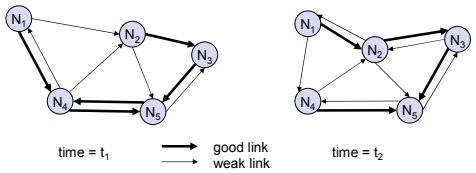





## Manet: Mobile Ad-hoc Networking



## Routing examples for an ad-hoc network






## Traditional routing algorithms

Distance Vector
- periodic exchange of messages with all physical neighbors that contain information about who can be reached at what distance
- selection of the shortest path if several paths available

Link State
- periodic notification of all routers about the current state of all physical links
- router get a complete picture of the network

Example
- ARPA packet radio network (1973), DV-Routing
- every 7.5s exchange of routing tables including link quality
- updating of tables also by reception of packets
- routing problems solved with limited flooding



## Problems of traditional routing algorithms

Dynamic of the topology
- frequent changes of connections, connection quality, participants

Limited performance of mobile systems
- periodic updates of routing tables need energy without contributing to the transmission of user data, sleep modes difficult to realize
- limited bandwidth of the system is reduced even more due to the exchange of routing information
- links can be asymmetric, i.e., they can have a direction dependent transmission quality

Problem
- protocols have been designed for fixed networks with infrequent changes and typically assume symmetric links



## DSDV (Destination Sequenced Distance Vector)

Early work
- on demand version: AODV

Expansion of distance vector routing

Sequence numbers for all routing updates
- assures in-order execution of all updates
- avoids loops and inconsistencies

Decrease of update frequency
- store time between first and best announcement of a path
- inhibit update if it seems to be unstable (based on the stored time values)



## Dynamic source routing I

Split routing into discovering a path and maintaining a path

Discover a path
- only if a path for sending packets to a certain destination is needed and no path is currently available

Maintaining a path
- only while the path is in use one has to make sure that it can be used continuously

No periodic updates needed!



## Dynamic source routing II

Path discovery
- broadcast a packet with destination address and unique ID
- if a station receives a broadcast packet
  - if the station is the receiver (i.e., has the correct destination address) then return the packet to the sender (path was collected in the packet)
  - if the packet has already been received earlier (identified via ID) then discard the packet
  - otherwise, append own address and broadcast packet
- sender receives packet with the current path (address list)

Optimizations
- limit broadcasting if maximum diameter of the network is known
- caching of address lists (i.e. paths) with help of passing packets
  - stations can use the cached information for path discovery (own paths or paths for other hosts)

## Dynamic Source Routing III

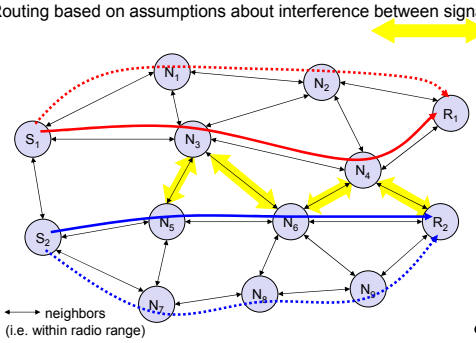
Maintaining paths

- after sending a packet
  - wait for a layer 2 acknowledgement (if applicable)
  - listen into the medium to detect if other stations forward the packet (if possible)
  - request an explicit acknowledgement
- if a station encounters problems it can inform the sender of a packet or look-up a new path locally



## Interference-based routing

Routing based on assumptions about interference between signals






## Examples for interference based routing

Least Interference Routing (LIR)

- calculate the cost of a path based on the number of stations that can receive a transmission

Max-Min Residual Capacity Routing (MMRCR)

- calculate the cost of a path based on a probability function of successful transmissions and interference

Least Resistance Routing (LRR)

- calculate the cost of a path based on interference, jamming and other transmissions

LIR is very simple to implement, only information from direct neighbors is necessary



## A plethora of ad hoc routing protocols

Flat

- proactive
  - FSLS – Fuzzy Sighted Link State
  - FSR – Fisheye State Routing
  - OLSR – Optimised Link State Routing Protocol
  - TBRPF – Topology Broadcast Based on Reverse Path Forwarding
- reactive
  - AODV – Ad hoc On demand Distance Vector
  - DSR – Dynamic Source Routing

Hierarchical

- CGSR – Clusterhead-Gateway Switch Routing
- HSR – Hierarchical State Routing
- LANMAR – Landmark Ad Hoc Routing
- ZRP – Zone Routing Protocol

Geographic position assisted

- DREAM – Distance Routing Effect Algorithm for Mobility
- GeoCast – Geographic Addressing and Routing
- GPSR – Greedy Perimeter Stateless Routing
- LAR – Location-Aided Routing



## Clustering of ad-hoc networks