Humboldt Universität Informatik

Systems Architecture

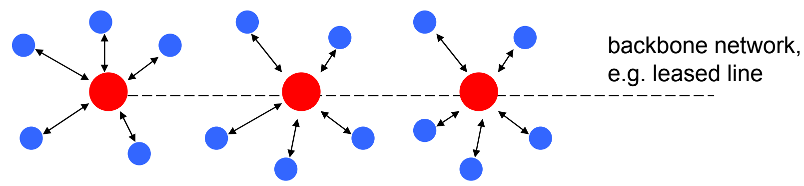
http://sar.informatik.hu-berlin.de

Ad-Hoc Networks Seminar

Introduction

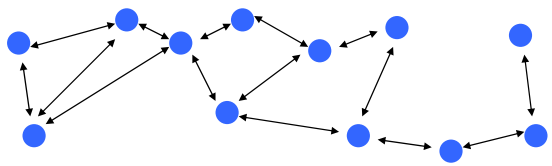
SoSe 2007

Cellular Network Topology



- Terminals communicate only with base stations.
- Association between terminal and base station.
  Handoff = process where terminal associates with another base station.
- Base station coordinates access to wireless medium.
- Base stations connected to high-capacity backbone (e.g. optical fiber), deployment is well planned.
- <u>Not</u> a true wireless network - only last hop is wireless.

(Ad-Hoc) Wireless Mesh Network Topology



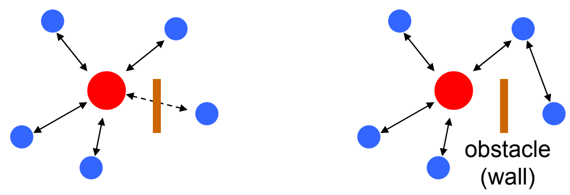
- No base stations. Terminal communicates with neighboring terminals.
- Packets forwarded from terminal to terminal (multi-hop) until final destination.
- Terminals have to “magically” coordinate access to wireless medium.
- Terminal deployment is not usually planned → Ad-Hoc deployment.
  Dynamic topology (i.e. location of terminals changes)
- True wireless network.

“ad hoc”

<u>**ad hoc**</u> [æd 'hɒk]
adjective, *adverb(ial)*

- formed or used for specific or immediate problems or needs.
  example: ad hoc solution
- fashioned from whatever is immediately available.
  example: ad hoc decision

Advantages of Wireless Mesh Networks

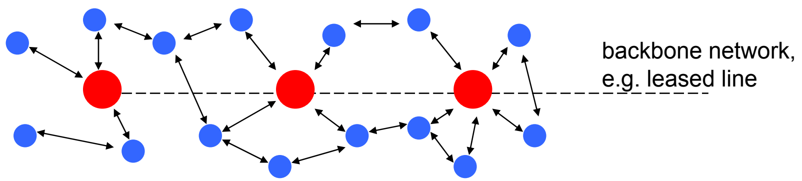


- Works around shadowing obstacles
- Potential for multiple concurrent communications
- Fast deployment (good for rescue operations)
  - Backbone is created on the fly
- Very resilient (useful in aggressive environment)
  - network still functions even if individual node fails
- Cheap
  - no base station
  - no backbone infrastructure
  - easy adaptation to changing requirements

Disadvantages of wireless ad-hoc networks

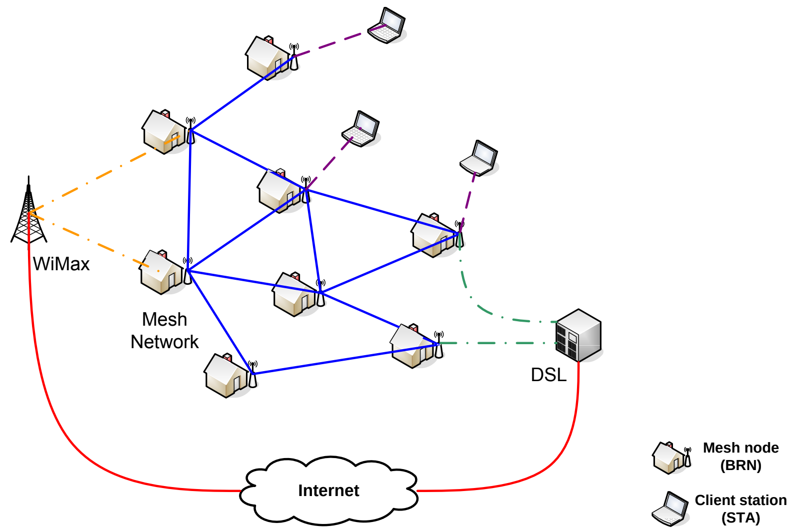
- Bandwidth limitations:
  - Professionally deployed, fiber-based backbone carries ~10 Gbits/sec
  - Wireless ad-hoc backbone has unpredictable capacity, ~10 Mbit/sec
- No capacity planning possible; no guaranties.
- How to encourage/enforce cooperation amongst terminals?
  - To preserve its battery, a terminal may shutdown if it has no own traffic.
  - A terminal may act selfish (not forward other node's traffic) or even destructive (confuse routing protocol)

Hybrid Networks



- Network contains both, ad-hoc and cellular parts.
- 4-G Networks will likely have this topology.
- Our understanding of these networks is still limited.
  e.g. coordination of access to wireless medium seems difficult.

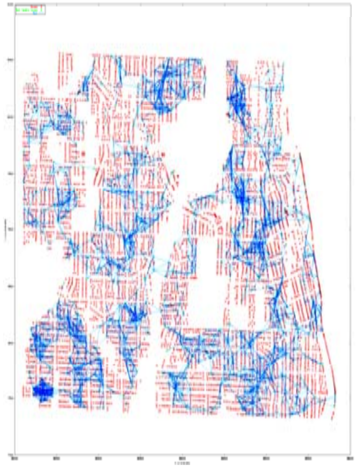
Community Mesh Networks



Wireless mesh networks have the potential to extend broadband connectivity

Community Network Formation

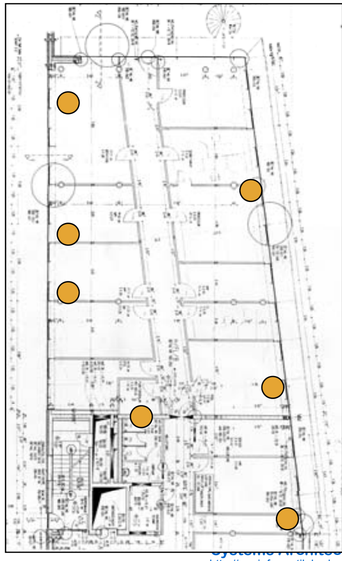
- Q.: How many homes in the neighborhood have to sign up before a viable mesh forms?
- Answer depends on
  - Definition of “viable”
  - Wireless range (50, 100, 200 and 1000m)
  - Neighborhood topology (North Seattle, 4km x 4km)
  - Probability of participation by a given household



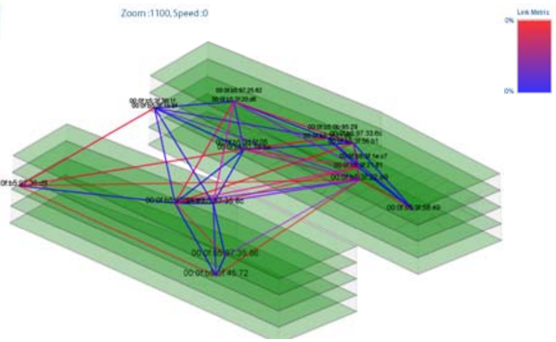
P. Bahl, **Opportunities and Challenges of Community Mesh Networking**, Keynote @ MICS Workshop ETH Zurich, July 6, 2004

Indoor Testbed

- 40 to 50 nodes
- Netgear WGT634u router
- Purpose: Test of new technology (after NS2/Jist simulation)
  - Link quality (measurement, prediction)
  - Topology creation
  - New routing protocols
  - Software distribution
  - Security issues
  - Stress tests (TCP with iperf)
  - Distributed Configuration

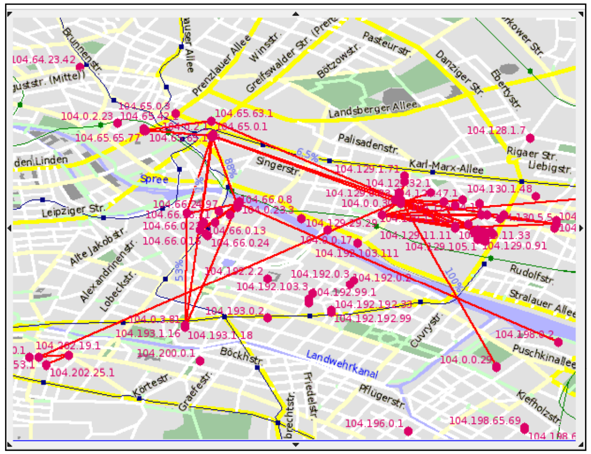


Visualization Tools



Outdoor Testbed

- Community network (http://www.olsrexperiment.de)
- > 500 nodes
- Linksys router, Mesh-cube
- Purpose
  - Test of new routing protocols/services in real world
  - Permanent use

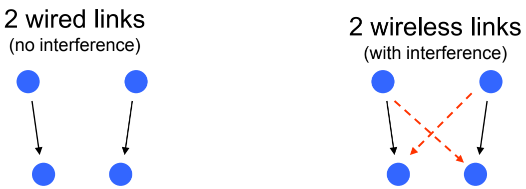


History

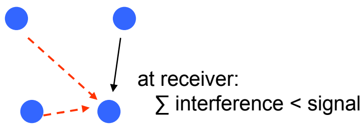
- Research started in 70's.
  - ARPA project initiated at Stanford University in 1972.
  - Called 'packet radio networks'
- Interest cooled off in the 80's.
  - Called 'multihop wireless networks'
- Renewed interest in the 90's.
  - Called 'wireless ad-hoc networks'
- Discovery of fundamental capacity limitations in 2000's.
- Booming interest in sensor networks in 2000's.

- Amateur packet radio network (1970's)
- Bluetooth (1990's)

Interference
fundamental difference between wired and wireless



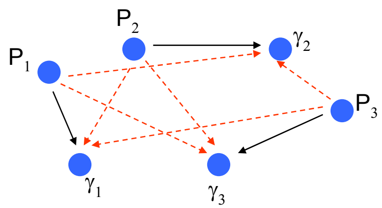
- In wired networks links are independent.
- In wireless networks, links are coupled by interference.
- Wired networks are modeled with graphs.
- Wireless networks are modeled in terms of `n(n-1)` power gains.



Interesting questions

- Power control
  - Transmitter power
- Medium access control
  - Who can send when – to avoid collisions
- Routing
  - Finding path to distant destination
- Capacity
  - How much information can the network carry?
- Security
  - What is a node malfunctions / is malicious?

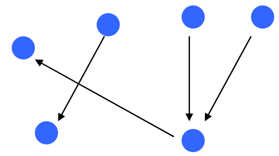
Power Control



3 simultaneous transmissions at powers $P_1 \ldots P_3$

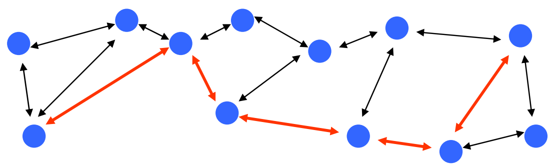
- Each node receives noise, resulting from transmissions of other nodes and general background noise.
- Signal / Noise ratio (SNR) decides if a node can recover a received signal.
- Each node has a SNR requirement γ_i
- To enable simultaneous transmission:
  - Are there powers P_i that achieve γ_i?
  - Can they be found in a distributed manner?

Power Control



- Each node makes its own decision when to send.
- If a node receives two signals of similar strength, it will not be able to recover either one.
- Two transmissions may start at same time (collision)
- There is no fixed duration of a transmission.

Routing



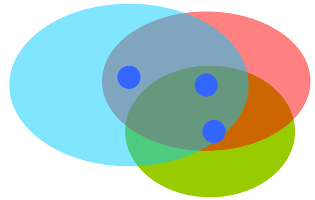
- Each node must find a route to every destination
- Nobody has clear picture of network's topology
- Topology may change, even as a packet is forwarded (nodes are moving)
- How to avoid loops in forwarding path?
- Traffic aggregation is bad idea
  - Depletes energy of involved nodes
  - Causes massive interference at involved nodes

Capacity

- The capacity is the theoretical limit on the performance of the wireless network.
- There are `n` users, each with `n-1` potential destinations.
- Capacity is not a number, but a `n(n-1)` dimensional region.
- Calculating is a very hard, not completely solved problem.

Wireless
Medium Access Control
(Wireless MAC)

Shared Channel Access



Overlapping areas indicate shared communication channel

- Access to communication channel is shared.
- Any node can transmit at any time.
- Collisions result from simultaneous transmission in shared channel.
- Random access leads to many collisions at high load → poor throughput.
- No central controller to coordinate access in ad-hoc networks.
- MAC protocol enables efficient, coordinated use of medium.
  MAC is concerned with per-link communication, not end-to-end.

Timing in MAC Protocols

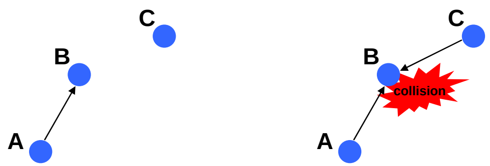
Synchronous MAC Protocols:

- Timer master broadcasts beacon (e.g. from GPS satellite)
- All nodes synchronize to same time
- Time slots may be defined
- Contention-free channel access possible

Asynchronous MAC Protocols:

- Time intervals have different offsets at each node.
  Offsets may drift over time.
- Contention based channel access
  (two nodes race for access to channel)

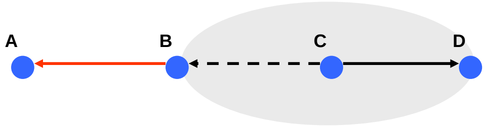
Hidden Terminal Problem



1. A transmits to B;
   C does not hear this.
2. C decides to transmit to B → Collision at B
   (A and C may not even notice the collision at B)

Two nodes are hidden from each other (out of signal range) when both perceive radio silence and send data to the same receiving node, resulting in a collision at the receiver.

Exposed Terminal Problem



C transmits to D – okay.
B overhears transmission from C to D.
B wants to transmit to A
B does not know where C and A are located – could be close together;
→ B can not know that A would not be intimidated by the transmission from C.
→ B will not transmit to A (even though it would work)

An **exposed node** is a node in range of the transmitter, but out of range of the receiver.
Overhearing a transmission from a neighbor inhibits a node from transmitting to other nodes.
Impact: Nodes are unnecessarily blocked, reducing the system's total throughput.
Solution: (1) Use directional antennas (so B does not hear when C transmits to D).
(2) Use different channels for data and control messages (so B can use RTS-CTS to figure out if it can transmit to A without interfering with C and D).

Sender-Initiated MAC

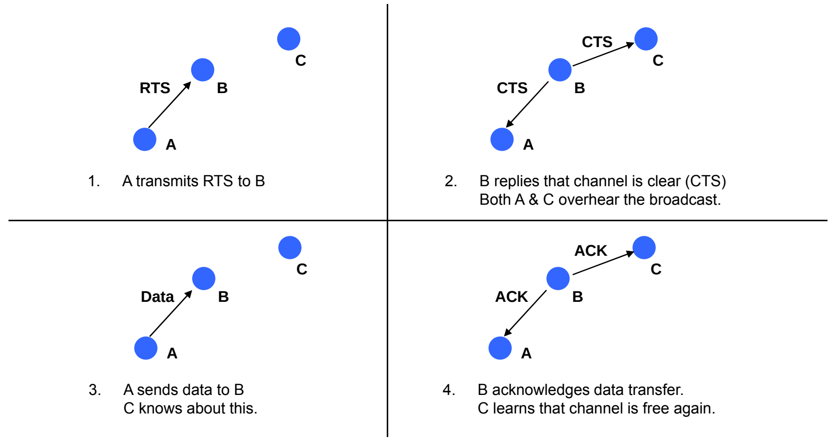
- Sender informs receiver that it has data (RTS).
- Receiver immediately 'polls' sender for data (CTS) - same as receiver-initiated MAC.
- Receiver may choose to issue CTS at later time.
- Examples:
  - MACA - Multiple Access with Collision Avoidance
  - MACAW - MACA with Acknowledgement
  - FAMA - Floor Acquisition Multiple Access

- RTS: Ready To Send
- CTS: Clear To Send

MACA

- MACA = Multiple Access with Collision Avoidance
- Suggested by Phil Karn
  for amateur packet radio networks
- single-frequency ad-hoc networks
- RTS-CTS-DATA three-way handshake
- Supposed to solve hidden & exposed terminal problem
- Allows for per-packet transmitter power control (improves network capacity)

MACA (RTS-CTS-DATA Handshake with ACK)



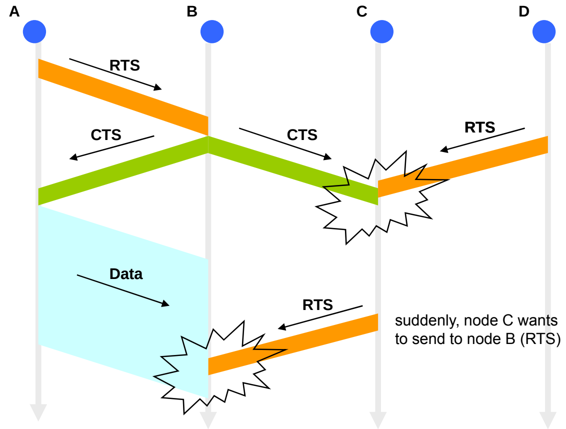
RTS-CTS handshake is used to resolve hidden terminal problem.

- RTS = Ready to Send; transmitted by sender to inform receiver of available data
- CTS = Clear to Send; broadcasted by receiver to inform all neighbors that channel will be occupied
- ACK = Acknowledgement; broadcasted by receiver to inform all neighbors that channel is free again

Shortcomings of RTS-CTS

What happens if a neighbor of the receiver does not hear the CTS?

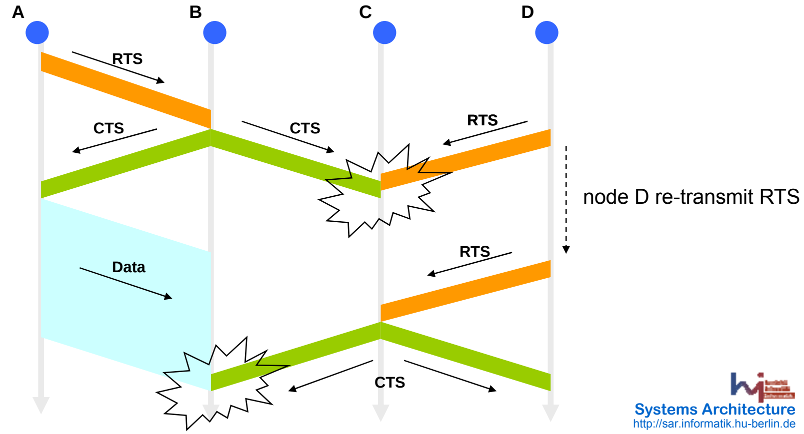
A is sender, B the receiver, C the receiver's neighbor that does not hear the CTS.
Possible reason: CTS from B and RTS from D collide at C. (D can not hear A or B).
Result: C does not hear CTS → not aware of data transmission between A and B.



Shortcomings of RTS-CTS (2)

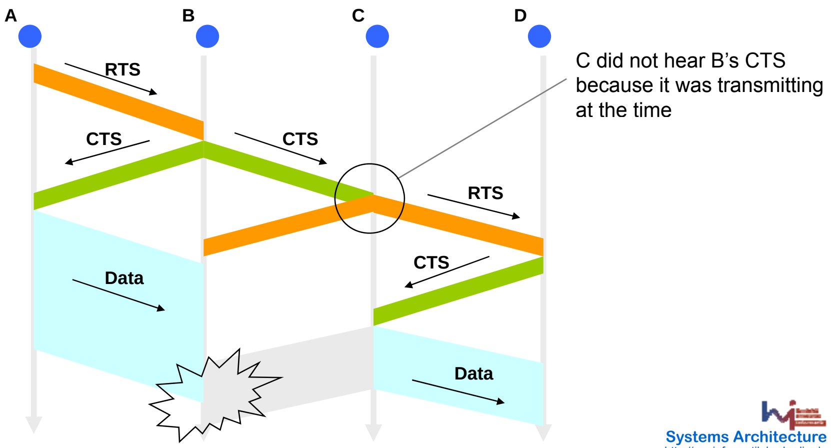
More common example where RTS-CTS problem materializes:

D can't hear A or B. D wants to send data to C → transmits RTS.
RTS from D and CTS from B collide at C → C hears no RTS or CTS.
D re-transmits RTS to C → C broadcasts CTS → collision at B



Shortcomings of RTS-CTS (3)

A node may not hear a CTS because it is transmitting (i.e. cannot receive)



Receiver-Initiated MAC

- Why have RTS at all? Let receiver start with CTS.
- How does receiver know that sender has data?
- **Polling**: Receiver periodically checks if sender has data for it.
- Received data packet piggybacks number of packets still available at sender
  - If more packets are available, receiver issues new poll/CTS immediately after receiving of current packet is complete.
- Performs well under high load, streaming data (audio).
- Increased delay under light load (packets have to wait for next poll).
- Examples:
  - MACA-BI

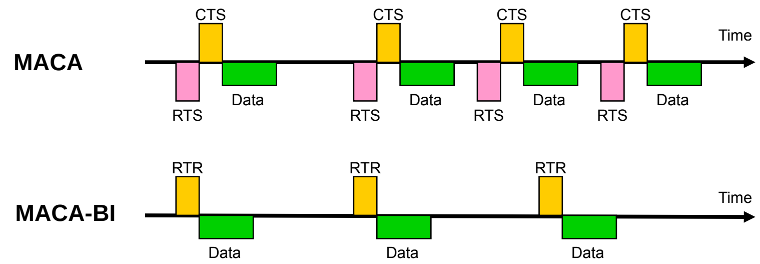
MACA-BI (By Invitation)

1. A transmits RTR to B.
   Blocks A's neighbors from transmitting.
2. B transmits Data to A.
   Blocks B's neighbors from transmitting.

- Proposed by Fabrizio Talucci
- 2-way handshake: RTR-DATA
  - no RTS
  - CTS→RTR renamed (Ready To Receive)
- Node cannot transmit data unless receiver announces invitation (RTR)
- Sender's queue length, arrival rate regulate receiver's transmission of invitations.

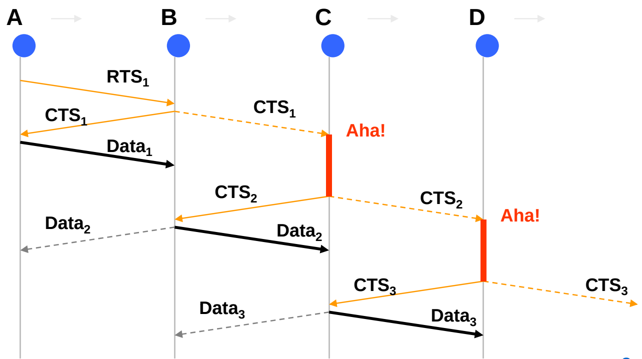
MACA *vs.* MACA-BI

- Constant Bit Rate
  - High efficiency of MACA-BI (less control traffic)
- Bursty traffic
  - MACA initiates data-forwarding as soon as data available.
  - Sender's queue fills up in MACA-BI when packets arrive but receiver extends no invitation.
- Hybrid approach:
  - MACA-BI with RTS.
  - RTS only used in rare event where sender's queue too full.

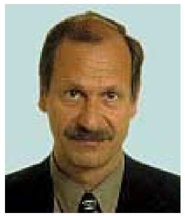


Media Access with Reduced Handshake

- Receiver/sender initiation hybrid
  - Tries to work receiver-initiated most of the time
- Omni-directional antennas
  - Node can overhear neighbors control traffic
- Upstream node initiates CTS based on downstream-node's activity.
- CTS includes Route-ID. Upstream-Node knows if it will be next.



PAMAS – Busy Tone



- PAMAS = Power-Aware Multi-Access with Signaling
- RTS-CTS over separate signaling channel
  1. Sender transmits RTS to receiver
  2. Receiver replies with CTS
  3. Sender transmits data; Receiver transmits busy tone on signaling channel while receiving data
- Busy tone introduced by Fouad Tobagi (Stanford Univ.) for BTMA – Busy Tone Multiple Access.
  - solves hidden terminal problem
- Energy conservation:
  - Nodes power off data channel if they hear busy tone and are not sender or receiver of this transmission.