Part 5

System design, prototype and experiences

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System Architecture Issues

General Theme

- We have seen clever and practical solutions to MAC, routing, discovery, position information, etc.

- But how do we put it all together into a complete *system?*
  - What is a reasonable architecture for a directional MANET?
  - How do the various mechanisms interact with each other?

- Building and testing a prototype
  - Components and assembly
  - Lessons learned

Architectural Approaches

- Start with a clean sheet
  - Directional antenna "thinking" completely woven into the design
  - Good performance
  - Time consuming
- Start with a "typical" omni-directional antenna based architecture and modify as required
  - Omni-directional MANETs fairly well understood
  - Implementations already exist
  - Many functions (e.g. forwarding table) remain unchanged
- We choose the latter

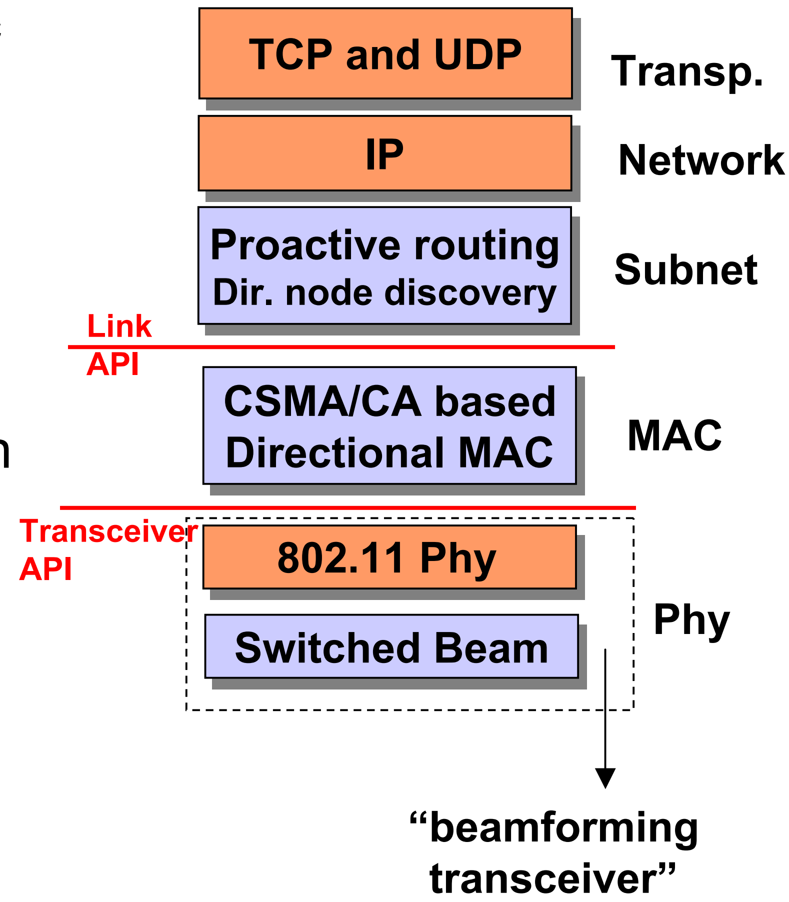
Choices at each layer

- Physical: Antenna
  - Multiple directional, switched beam, passive arrays, active arrays, optics, custom, etc.
- Physical: Radio
  - COTS chipset (e.g PRISM), custom, etc.
- MAC
  - CSMA/CA, TDMA, CDMA, hybrids, etc.
- Network
  - Proactive, Reactive, Hybrid, etc.
- Transport
  - TCP, UDP, etc.

A Complete System Solution

An Example System: Overview

- Based on the “UDAAN” system
  - “Utilizing Directional Antennas for Ad Hoc Networking” (DARPA FCS-C)
- Antenna System: Four directional elements and one omni, controllable switch
- Custom CSMA/CA MAC protocol with D-NAV and power control
- Proactive Routing
  - Hazy-sighted link state with modifications
- Transceiver and Link APIs



UDAAN Modules, Interfaces

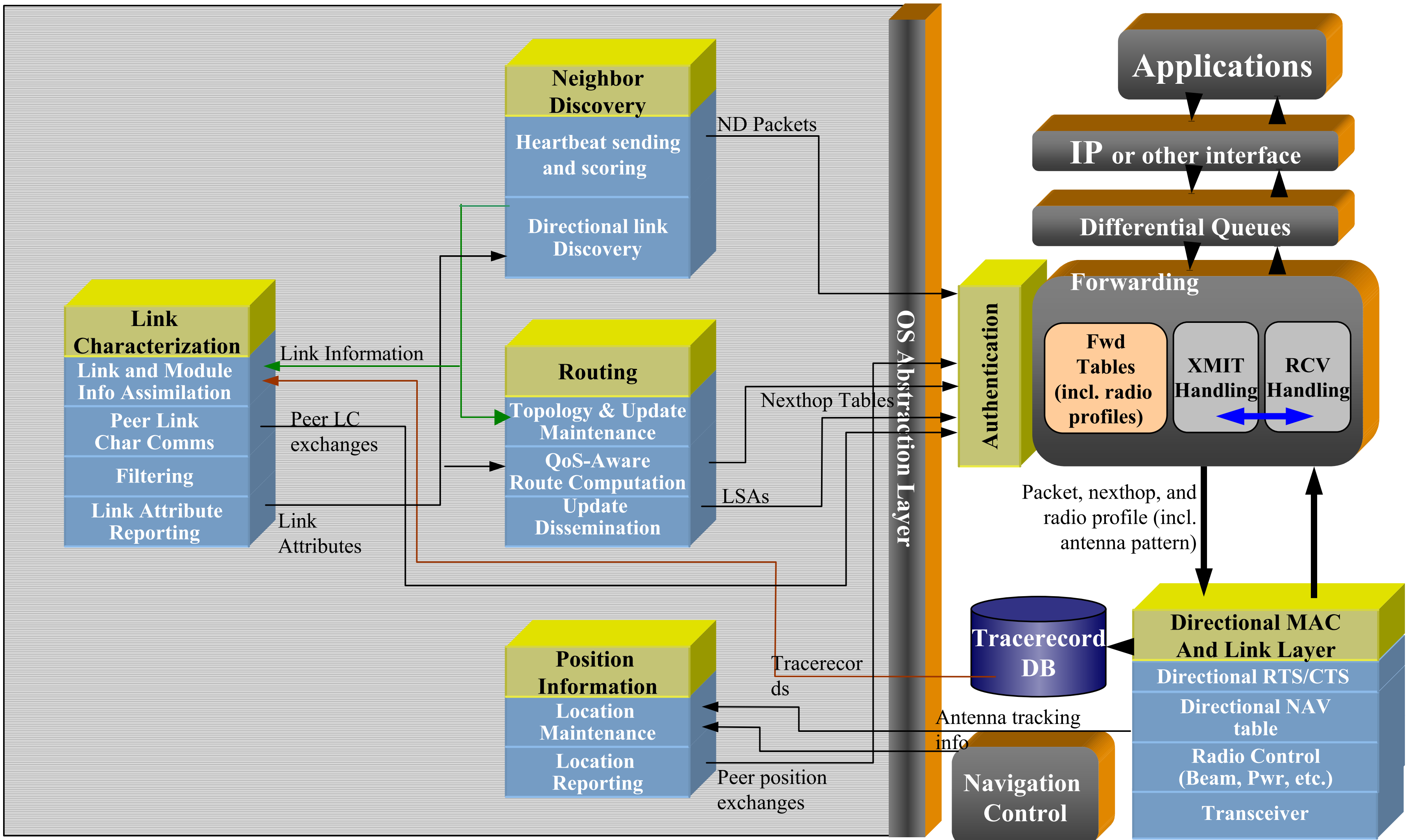


Diagram courtesy Jason Redi (BBN)

Link Profiles: The system "glue"

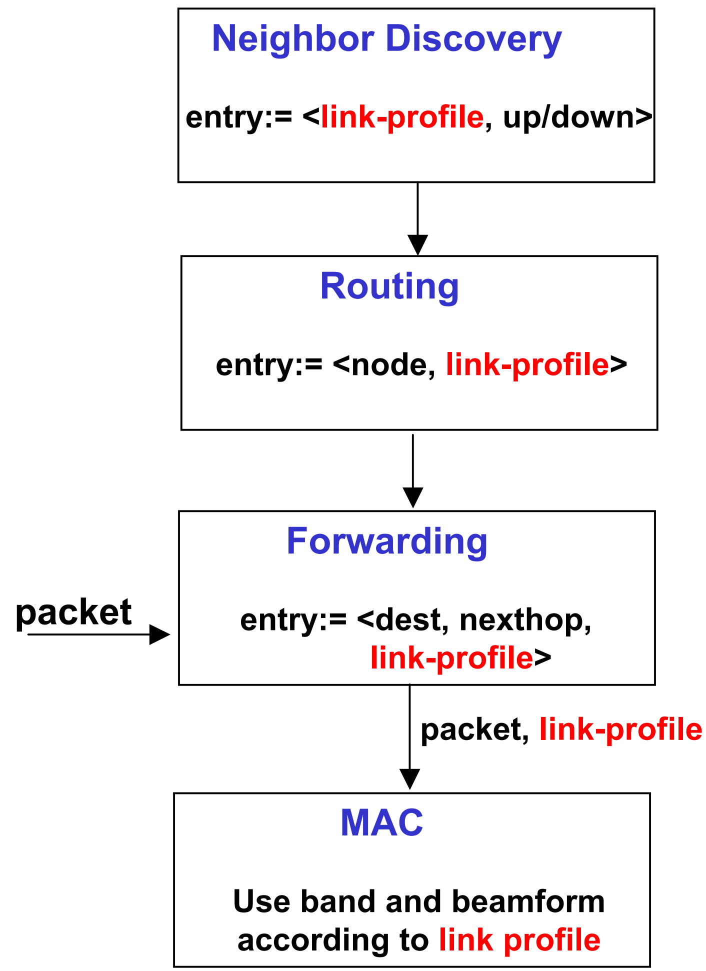
- With directional antenna systems, an important piece of information is *how* to communicate with neighbor
  - Whether both or one of xmitter/receiver should point, what power, which band (in multi-band systems) etc.

- Generalized *Link Profile* = [P1, P2, ... , Pm] where Pi is a transceiver parameter
  - Each link profile indicates a different combination of parameters sufficient for activating the link

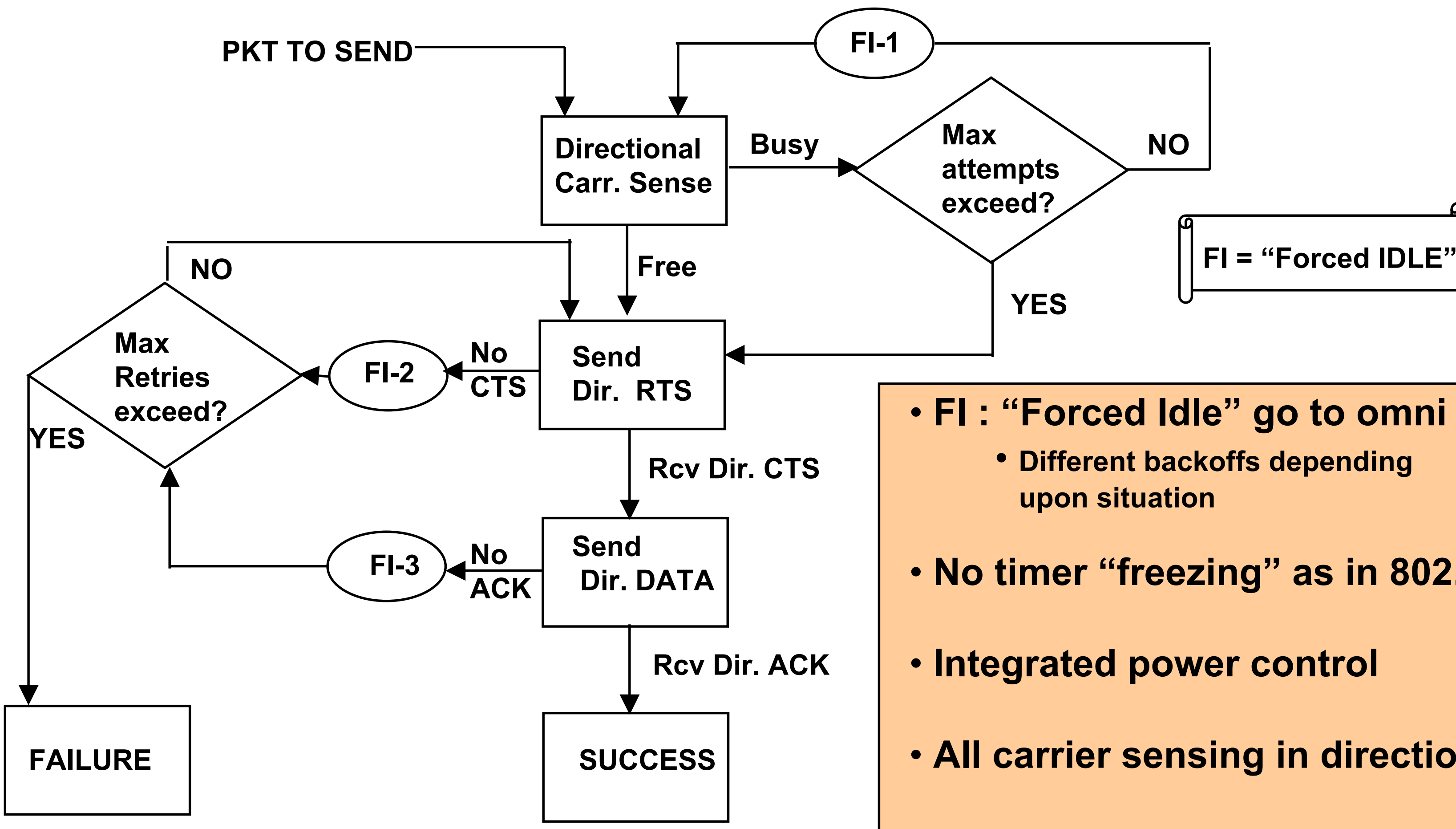
- UDAAN link profile = [Beamforming mode, Band]
  - Band = {band-1, band-2}
  - Beamforming mode = {No Beamform (N-BF), Transmit-BeamForm (T-BF), TransmitReceive-Beamform (TR-BF)}

Link Profiles (Continued)

- Example:
  - linkprofile(n1) = (n2, band-2, T-BF)
- Multiple link profiles may exist between two nodes
- Link profile information is circulated between modules to identify antenna (and other) parameters to use



UDAAN Directional MAC (D-MAC)



- FI : "Forced Idle" go to omni
  - Different backoffs depending upon situation
- No timer "freezing" as in 802.11
- Integrated power control
- All carrier sensing in directional
- Key "knobs" pushed to config

Neighbor Discovery Operation

- Each node sends periodic “Hellos” or “Beacons”
  - Sent without beamforming for N-BF
  - Sent with beamforming toward target for T-BF and TR-BF

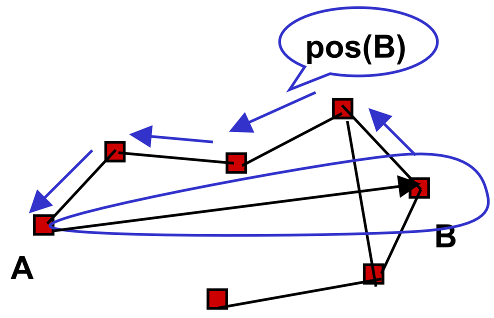
- Soon after activation, a node first discovers N-BF neighbors

- Then the node finds out about other nodes in the network
  - Through a different directly reachable method (e.g. lower band)
  - Through routing (e.g. link-state) updates
  - Through different media

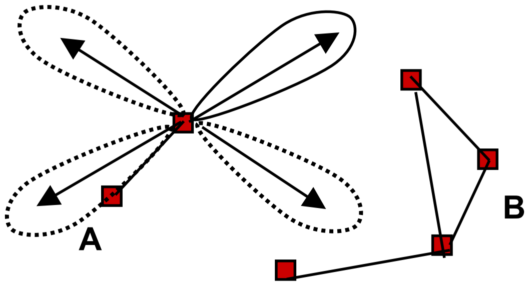
- The node then sends directional Hellos to each target
  - TR-BF links require special handling

T-BF (D+O) Neighbor Discovery

- Transmitter sends directional Hello to receiver
  - "Informed":
    - Relayed position information (e.g. piggy backed on routing updates)
    - Angle-of-arrival
  - "Blind"
    - Searching/Scanning
    - Omni with spreading



- Transmitter includes own position in Hello

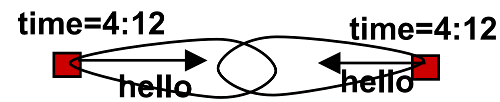


- Receiver uses the position info to point back and send Hello

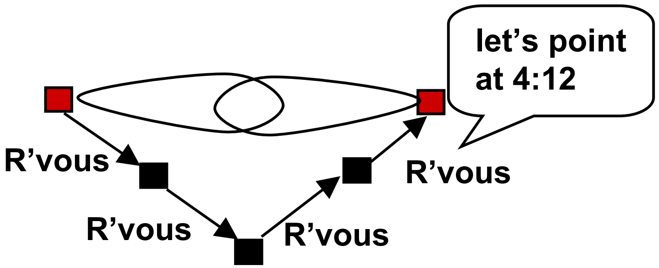
- Transmitter receives in omni

TR-BF (D+D) neighbor discovery

- Key issue: Receiver has to be pointing toward the transmitter at the exact time the transmitter points and sends Hello
  - How do they synchronize the pointing?

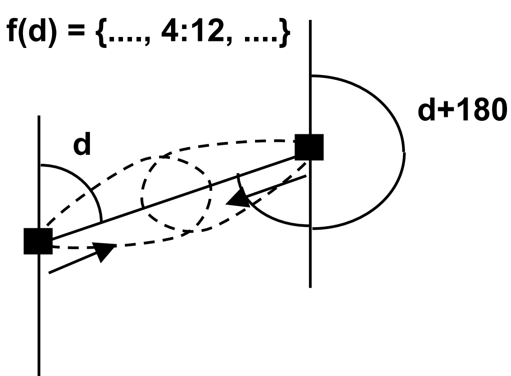


- Rendezvous packet
  - Works for D+O connected networks
  - Similar to MH-RTS



- Random searching

- Timetable based
  - At 2 O'clock, transmit toward "2" and receive toward "8"



Field Experimentation and Experiences

UDAAN Prototype Node Architecture

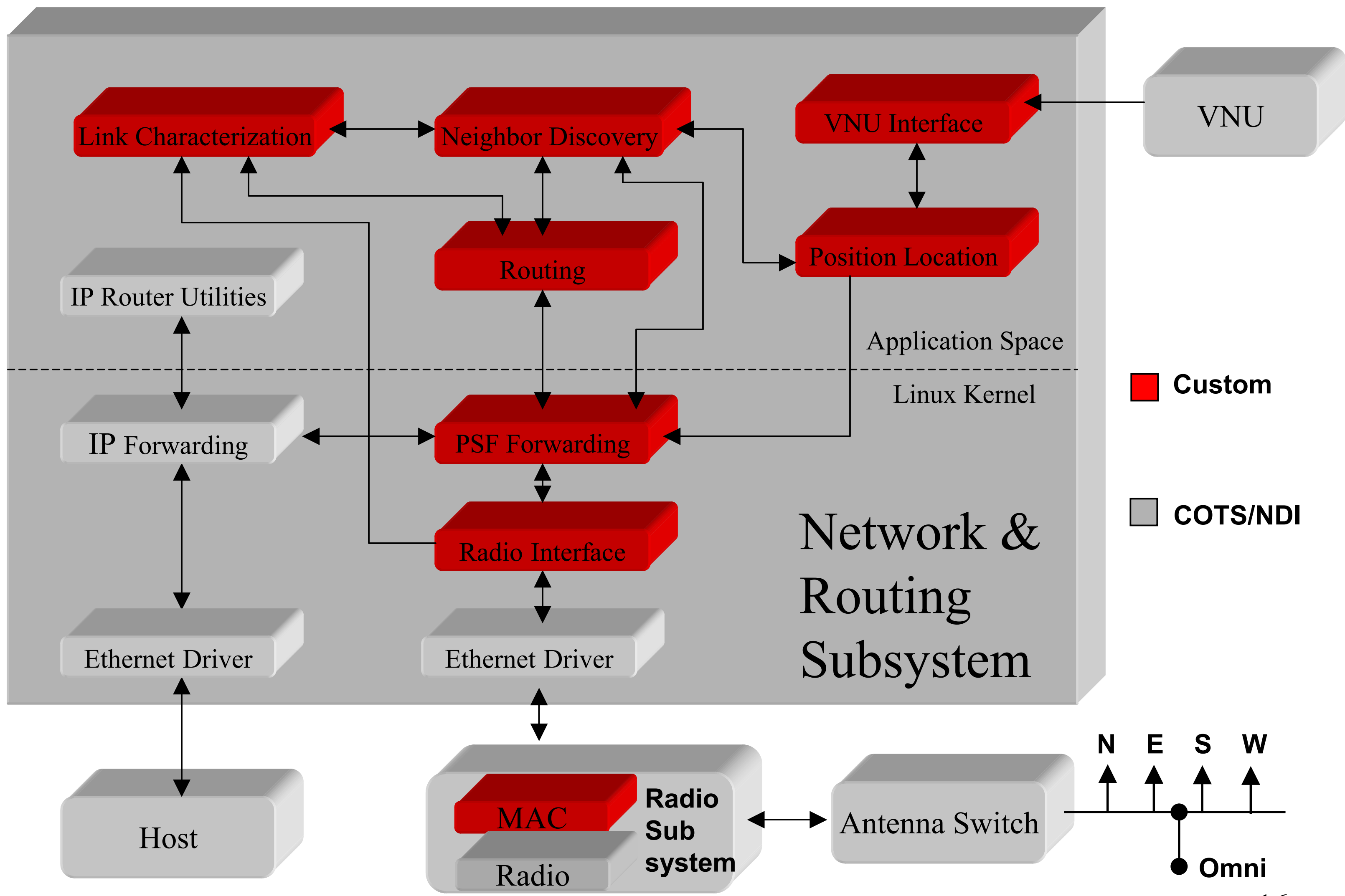
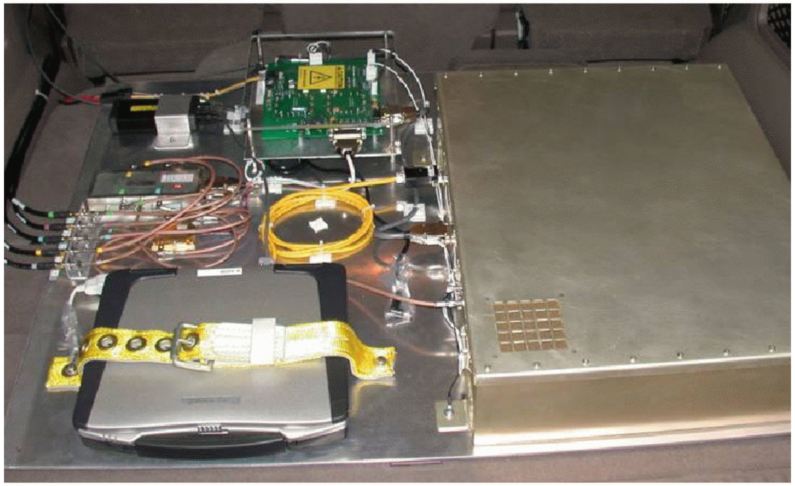


Diagram courtesy Jason Redi, BBN

Field Testing

- Prototype assembled with COTS hardware
  - Linux laptop for network layer and above
- COTS directional antennas about 10 dBi
- Twenty SUVs, scripted mobility model
- A mix of real-time and non-real-time traffic.



Pictures courtesy Jason Redi, BBN

Lessons Learned

- Real antenna patterns are far more complex than “pie slices” or “cone-plus-ball”
- Gain alone is no guarantee of good performance – need good “front-to-back” and “front-to-side” ratios
- Modeling should use “real-life” patterns as much as possible
- Vehicular metal (e.g. hood) can change the “effective” antenna pattern

Lessons Learned(2)

- Obtaining accurate position and orientation information is easier said than done
  - Inertial management unit accuracy varied by cost and gets affected due to accelaration and deceleration
- With switched beam systems, omni gain might be higher in some directions
  - Need to be careful if omni is used to discover neighbors
- Using position information to select the right beam mostly works, but not always
  - Multipath may result in a different beam being better

Lessons Learned(3)

- Vehicle role, pitch, yaw etc. can significantly affect the direction, or the choice of antenna

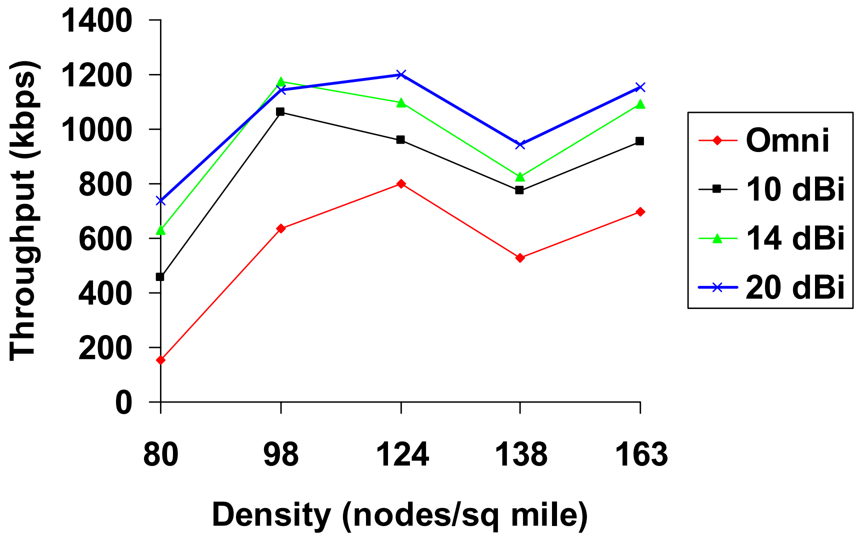
- Big difference between 3-D and 2-D complexity

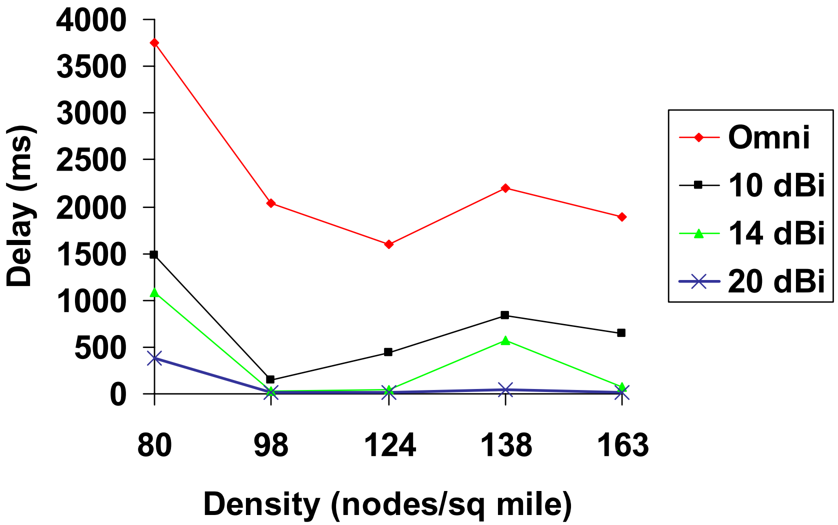
Performance: Network Capacity

OPNET Simulation of UDAAN to assess throughput/delay

<u>Throughput is 70% - 370% better, and delay is down by a factor of 10 - 150</u> in a highly loaded 20 node ad hoc network running UDAAN protocols when using steerable antennas with transmit and receive beamforming.

Data Rate 2 Mbps, 1:1 FEC, power control, stationary networks, random traffic of 10 unicast streams, 30 pps, 50 packet buffer, stochastic (r4) propagation, *N-BF neighbors only (thus, only the benefits of spatial reuse captured)*





Acknowledgements

- Part 5 based on work jointly with Jason Redi, David Wiggins, Cesar Santivanez, Keith Manning, Steve Polit (all from BBN)

Summary and Open Issues

Summary

- Directional Antenna Systems offer tremendous potential for improving MANET performance

- There are many different kinds of directional antenna systems, and understanding them is crucial to research into their exploitation for MANETs

- Recent years have seen a surge in MAC- and network-layer protocols for directional antennas
  - But much work remains to be done

Summary(2)

- Modeling and simulation with directional antennas is far more complex than with omni-directional antennas, but tools exist
  - It is very important to have realistic models (sidelobes, etc.)

- Building a directional antenna based prototype offers unique challenges at each layer of the stack
  - Experience with a testbed is very valuable in gaining insight into the real-life performance of directional MANET systems

Some Research Areas

- MAC for directional antennas
  - TDMA and hybrid schemes, multiple channels, power control, etc.
- Neighbor discovery (proactive) and flooding (reactive) schemes that exploit the longer range of directional antennas
  - Discovery of DD (TR-BF) links
- New analytical and simulation work that do not assume the pattern is a “circle” (aka “unit disks”)
- Location information dissemination that balances use of directional and broadcast

Research Areas (continued)

- Tradeoff between switched beam gain and coverage
  - Longer range versus “gaps” in azimuthal coverage
- Link level multicast by selecting beams that only cover the target node
  - Use of beamwidth control in the above context
- Theoretical work on ad hoc network capacity limitations when directional antennas are used
- Study of beam control in conjunction with other physical layer parameters (e.g. spreading, modulation, etc.)

Latest version of these slides and a list of references will be made available on the web page below:

http://www.crhc.uiuc.edu/~nhv/presentations.html

That's all folks!