The COMPOW Protocol for Power Control in Ad Hoc Networks

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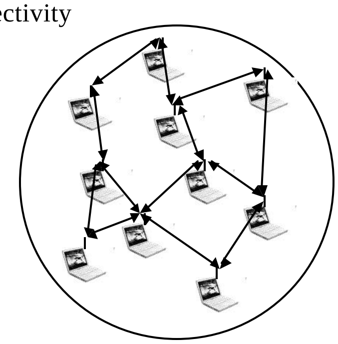
The Power Control problem

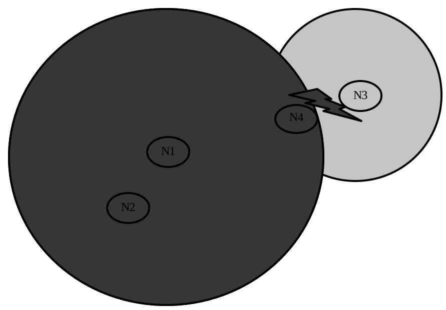
- How do we choose the right transmit power level
  - Power level influences range, hence connectivity
  - Power level determine level interference
  - Affect routes
  - Affects battery life : power management



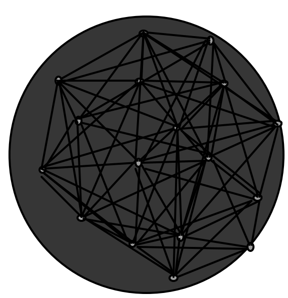
- Conceptualization : Which Layer?
  - Physical layer : Quality of reception
  - Network layer : Impact on routing
  - Transport layer : Affects congestion
- Implementation : A complete working system

The need for power control

- Affects the traffic carrying capacity of the network

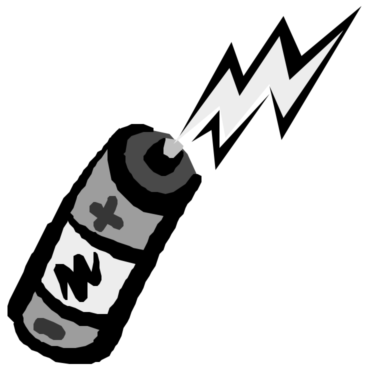


- Interference could be much worse
- Only 1 node in a neighborhood can transmit



Affects battery life

- Higher power transmission is unnecessary if the receiver is close to the transmitter



Brain damage

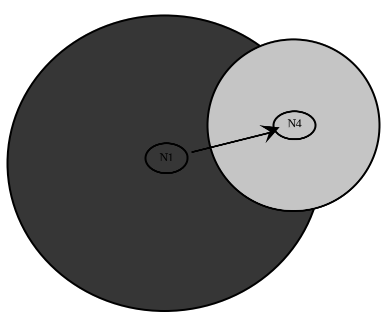
- Last and may be the least

How to choose the transmit power

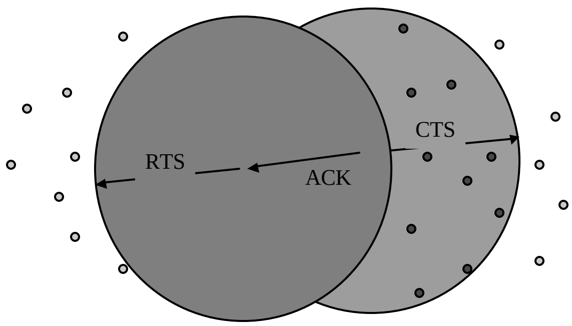
- Bidirectionality of links is critical
- Find a way to ensure bidirectionality without breaking existing protocols
- The solution should be close to optimal
- Should fit neatly in the OSI stack
- Preferably simple to implement

- Leads to COMPOW : Common Power

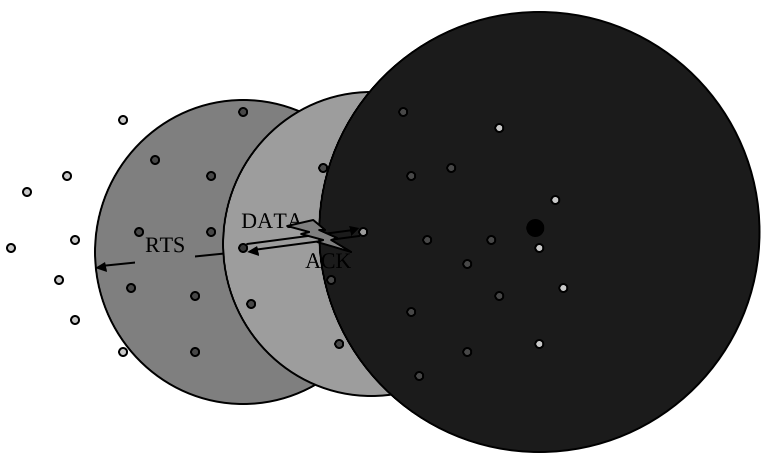
Power control could create unidirectional links



IEEE 802.11 : 4 way handshake

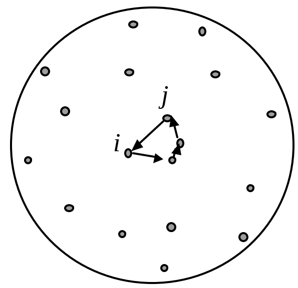


Bidirectional links needed for IEEE 802.11



Bidirectional links Distributed Bellman Ford

- $V_i = Min_j\{c_{ij} + V_j\}$
- But $c_{ij} \neq c_{ji}$
- So $c_{ji} + V_j \neq c_{ij} + V_j$
- …..
- Unidirectional routing is a difficult problem



Other protocols which need bidirectionality

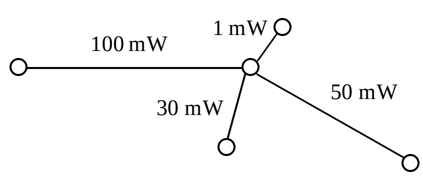
- Address Resolution protocol (ARP)
- Reverse ARP (RARP)
- Service discovery protocols (DHCP)
- …

Ensuring bidirectionality

- Simple way : A common transmit power level across the network at any given time
  - Physical paths taken by radio waves are reversible (we don't live inside anisotropic crystals)
  - Multipath, reflection does not change reversibility
  - No assumption about range being spherical

Another way to ensure bidirectionality

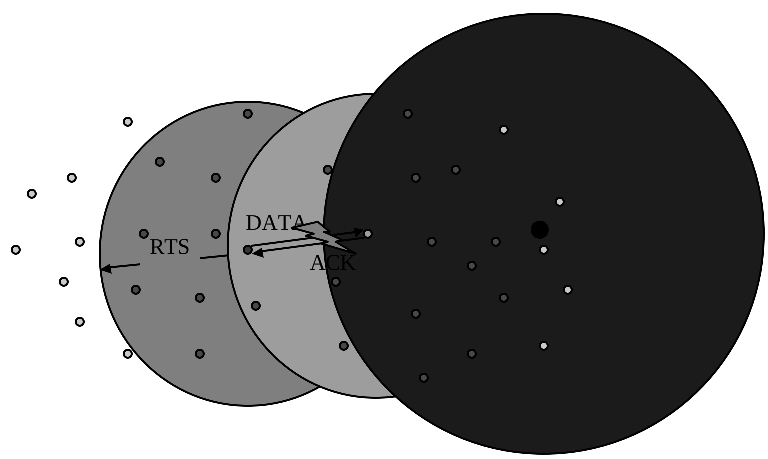
- A power level per link method
  - That is two nodes use the same power level when talking to each other.
  - Need to keep track of the power level to use for all your neighbors



Common power vs per link power

- Per neighbor power level considerably more complicated than common power method and also breaks existing protocols
  - Breaks IEEE 802.11
  - Each node has to keep track of a power level for each neighbor at the link layer, so MAC layer has to be changed
  - Not clear how routing is possible
  - Cuts across layers
  - COMPOW can be implemented very cleanly

Common range is needed for IEEE 802.11



Are we sacrificing capacity?

- Per link power method is seemingly more optimal
- There are pessimistic scenarios where COMPOW is not as good
- How much are we loosing ?

Common power level: Impact on capacity

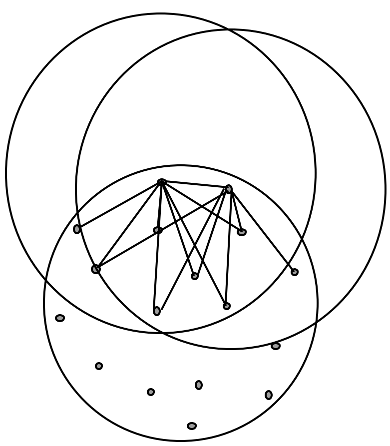
- Theorem: Best case capacity
  - Optimally located nodes,destinations, demands for OD-pairs
  - Optimal spatio-temporal scheduling, routes, ranges for each transmission
  - Each node obtains $\Theta\left(\frac{1}{\sqrt{n}}\right)$ bits/sec
- Theorem: Random networks
  - Randomly located nodes and destinations
  - Each node chooses same range *r*
  - Each node obtains $\Theta\left(\frac{1}{\sqrt{n \log n}}\right)$ bits/sec

◆ Only $\sqrt{\log n}$ factor difference between common and different power levels

◆ **Low common power is asymptotically nearly capacity optimal**

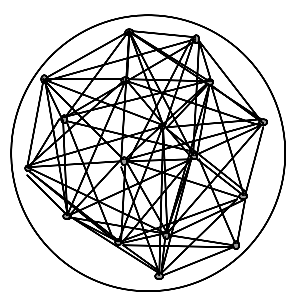
What should the common power level be ?

When the range is too large: Too much interference

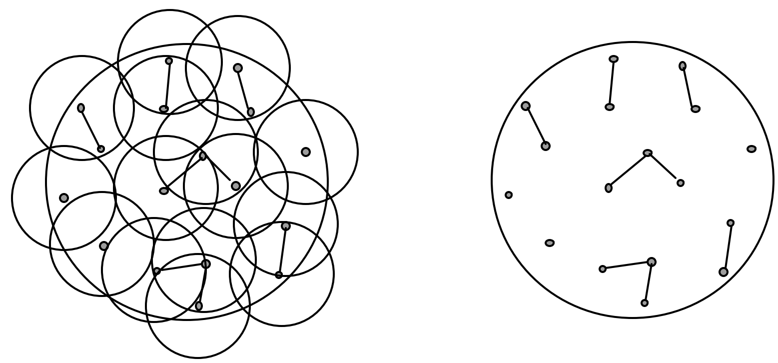


-Node can receive only when none of its neighbors is transmitting

- Capacity of network is reduced
- Capacity = $1/n$

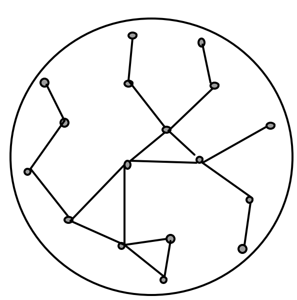


When common range is too small: Network gets disconnected



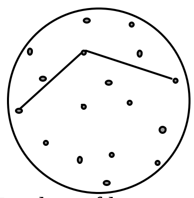
Just right…

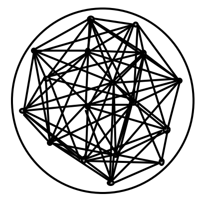
Lowest common range to ensure connectivity



The optimal range for maximum capacity

- Tradeoff between long hops and short hops
  - Long hops reduce number of hops and thus the relaying required
  - But they also increase interference

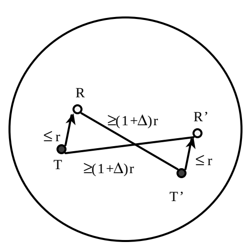


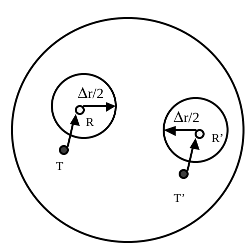


  - Number of hops = Relaying burden = $1/r$
  - Interference $\propto r^2$
  - *So, net burden is proportional to r*

A little bit formally…

- There are n nodes
- Area of domain = 1
- Each wireless transmissions consume area of πÄr^2/4 : A wireless footprint
- At least 1/4th is inside the domain





Sketch continued…

- Each OD pair carries λ bits/sec
- Suppose common range = r meters

- Number of hops per OD pair = 1/r hops
- Traffic for each node = λ/r bits/sec
- Total rate to be carried over all nodes = nλ/r bits/sec

- Area consumed by each transmission = πÄr^2/16
- Number of simultaneous transmissions = 16/(πÄr^2)
- Each transmission = W bits/sec
- Total traffic capability over all nodes = 16W/(πÄr^2)
- Capacity λ is feasible only if: nλ/r 16W/(πÄr^2)

Gist

- Overall network throughput is inversely proportional to the range r
- To optimize capacity select the lowest possible range
- Thus COMPOW chooses the lowest common range such that the network is connected

Impact on MAC efficiency

- Low common power level also enhances efficiency of MAC layer
  - Contention within range = # nodes within range × # hops × Throughput

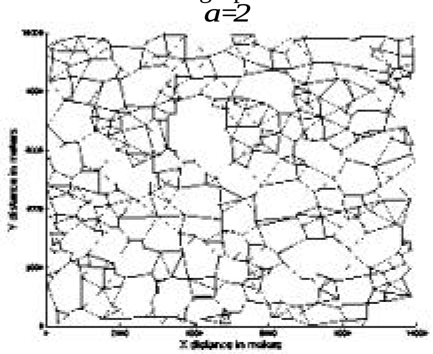
$$= \left(\frac{pr^2 n}{A}\right)\times\left(\frac{L}{r}\right)\times W = cr$$

  - Minimized when r is small

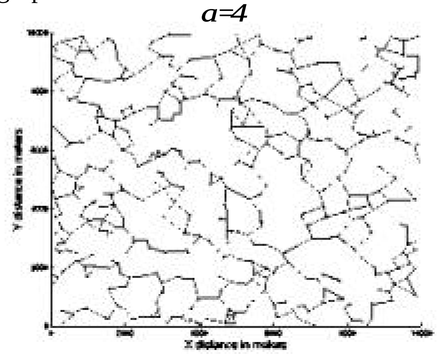
Low common power level also yields power optimal routes

- Theorem
  - For propagation path loss $1/r^{a}$ with a ³$2$ the minimum power routes give a planar graph with straight line edges that do not cross.
  - The graph for $a>2$ is a subgraph of that for $a=2$.

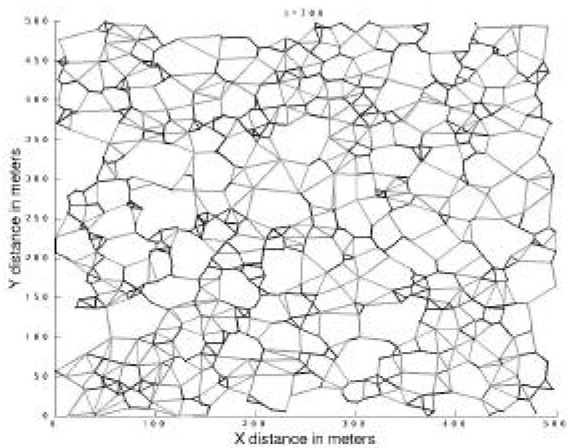
$a=2$



$a=4$



COMPOW obviates need for power optimal routing



Where to place power control in the OSI hierarchy

- Physical layer
  - Affects link quality and SNR
- MAC layer
  - Affects correct functioning
- Network layer
  - Affects the routes discovered
- Transport layer
  - Affects congestion
- Everywhere : Bad idea

Our verdict : Network layer

- COMPOW needs to find the smallest common power at which the network is connected
- Only the network layer has a picture of the whole network
- In fact power control and routing affect each other.
- Joint solution for power control and routing

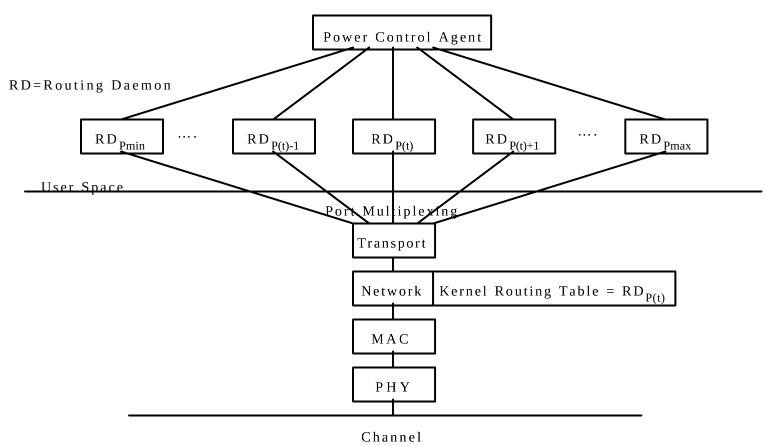
The Architecture

- Desired features
  - Distributed
  - Asynchronous
  - Modular
  - Should integrate seamlessly into the OSI stack
  - Nicely implementable

The algorithm

- Run multiple routing daemons : One at each power level available
  - Each maintains a separate routing table
- Number of entries in the routing table give the number of reachable nodes as that power level
- Set the node power level to be the power level at which the number of reachable nodes is the same as that of the max power level
  - Set the kernel routing table to be the routing table corresponding to this power level

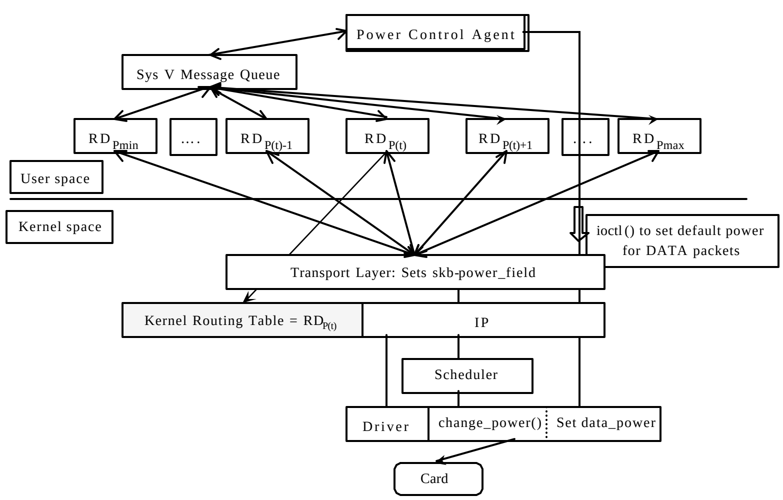
Parallel Modularity



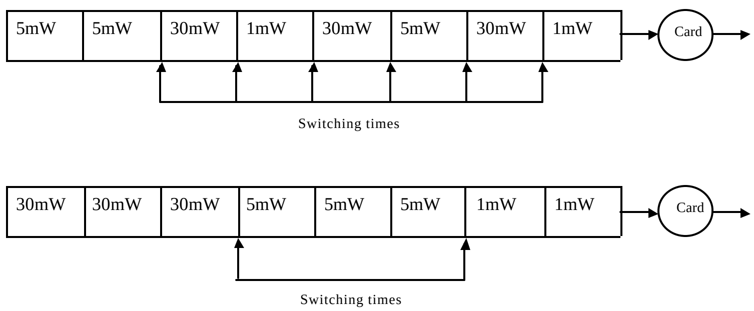
Assumptions

- Transmit power level are discrete and few in number
  - – Cisco Aironet 350 wireless cards
    - 6 discrete power levels : 1,5,20,30,50,100 mW s
- Hardware allows setting the power level of each packet without significant latency
- Proactive routing protocols only

Implementation details



Scheduling packets to minimize power change latency



Implementation

- int sendto (int s, const void *msg, size_t len, int flags, const struct sockaddr *to, socklen_t tolen);
- int ioctl(int d, int request, …);

- New power_field in the sk_buff structure
- Aironet iwreq structure stores data power set by ioctl (SIOCDATAPOWER)
- Modified dev_queue_xmit() for scheduling

Salient features of the implementation

- A minimalist approach
- Minimal changes in the kernel and the driver
  - Most of them are to make them aware of the concept of transmit power of a packet
- Code reuse
- Extremely modular
  - Can plug in any proactive routing protocol

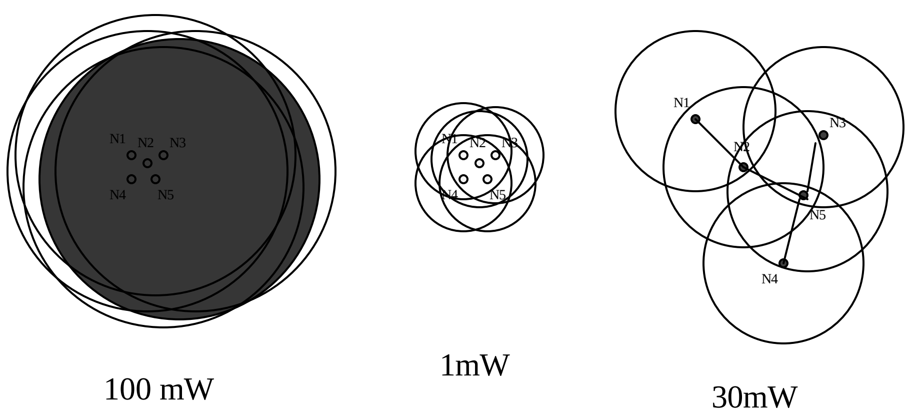
Routing protocol overhead

- We used DSDV
- Assume transmits 1 hello packet of 1000 bytes every 5 seconds
  - This provides for 10 incremental updates per hello packet, assuming 100 bytes per entry
- 6 Routing daemons implies 1200 bytes/sec
- Assume 8 neighbors
  - Average case for connectivity
- Total overhead ~ 10Kbytes/sec = 80Kbits/sec
- Less than 1% of 11Mbps, the link bandwidth

System details

- Linux 2.2.16 kernel, now 2.4.18
- Cisco Aironet 350 wireless cards
  - – 6 discrete power levels
    - 1,5,20,30,50,100 mW
  - – airo driver by Ben Reed et. al
- 30 laptops : Compaq

Testing : a simple scenario



Issues with experimentation

- Lack of robust hardware
  - Power change requires card reset
  - Latency of power change
    - > 6ms in driver , ~100ms in IP stack
- Carrier-sensing in 802.11
  - Interference range higher than transmit power range
- Unstable power ranges
  - 1 mW very sensitive

Conclusions

- Conceptualization and a complete protocol for power control in Ad Hoc networks
  - Is asymptotically capacity optimal
  - Reduces MAC contention
  - Provides power optimal routes
  - Has been completely implemented and tested on a real testbed

Future work

- CLUSTERPOW
  - Joint power control, routing and clustering
  - Clustering based on power control
- Better hardware will allow complete testing and performance analysis

- http://www.uiuc.edu/~kawadia/papers/compow.pdf