Convergence in Ad Hoc Networking Protocols

Charles E. Perkins
Nokia Research Center
charles.perkins@nokia.com

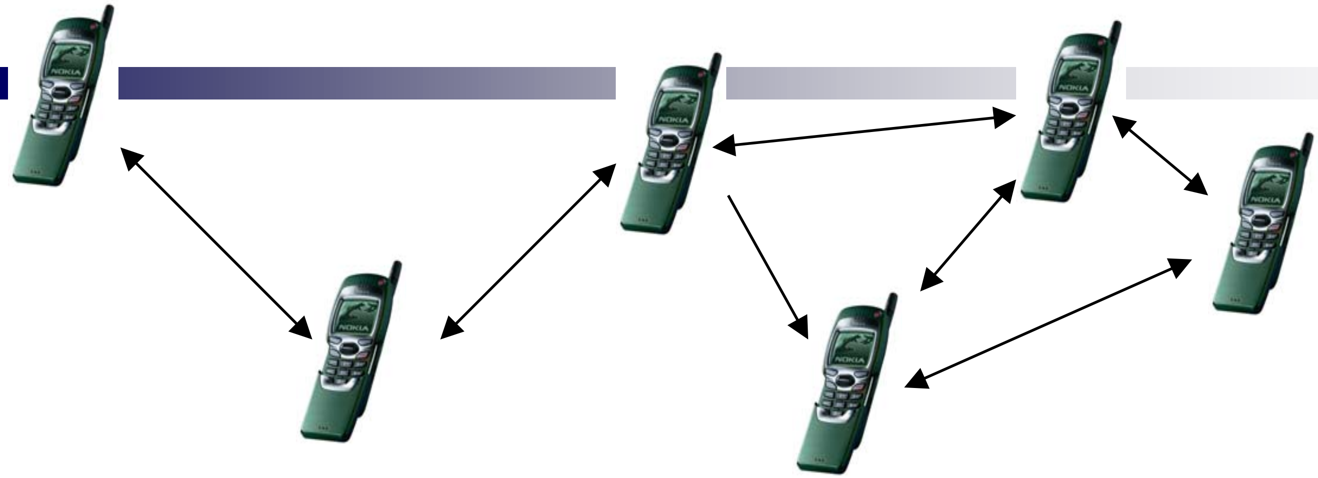
Outline of Presentation

- Why I am here
- Ad Hoc Networks in general
- Recent results from *manet*
- Performance observations
- Flooding – a potential modular component
- Convergence – by creating parameterized modular components

Why am I here???

- Because I am fascinated by the subject
- Because now is a turning point in time
- Because we need your help
  – Search for optimal parameter values
  – Search for wisest feature selection
  – Establish research collaboration?
  – Can offer an excellent simulation environment

Ad Hoc Network characteristics



- peer-to-peer
- multihop
- dynamic
- *Really* “anytime, anywhere”
- zero-administration
- low power
- autonomous
- autoconfigured

But, most of these have exceptions!

Commercial Opportunities

- Conferencing
- Home networking / Community (mesh) networking
- Emergency services
  - Ambulance, Police
  - Disasters (natural or man-made)
- Hospitals
- Embedded computing applications
  - Ubiquitous computers with short-range interactions
  - Automotive/PC interaction
  - What if wireless computers are *everywhere*?

Other Envisioned Applications

- Digital Battlefield Communications
  - Including sensor networks
- Movable base stations
  - Many military applications
- Campus wireless access from quadrangles
- Immediate, interpersonal communications
- Range extension for cellular telephones
- Enable computing where subnets do not exist

What is ***networking*** good for?

Sensor Network Characteristics

- Less dynamic than other ad hoc networks
- Large network sizes
- Battery power truly at a premium
- Congestion less of an issue
- What about latency?!
- Identity of individual nodes less important
  - Affects even concepts of addressability
  - Increases need for multicast/anycast?

Ad Hoc Research growing rapidly

- MobiHoc known as the premier ad-hoc forum
  - ~200 papers submitted for 2003 in Annapolis
  - Over 250 papers submitted for 2004 in Tokyo
- Numerous other conferences of interest
  - *Many* ad-hoc papers submitted to Mobicom
  - Globecom, Infocom, AdHoc-NOW, INSS, ...
  - Journal of Ad Hoc Networking
- Helps understand fundamentals of routing
- Major interest in sensor nets (e.g. NSF)
- Useful as a buzzword for paper acceptance
  - Increased number of NSF proposals, etc...

Ad Hoc Routing Projects

- DSR (Dave Johnson, CMU)
- WINGs (JJ Garcia/UCSC)
- ROAM (JJ Garcia/UCSC)
- WAMIS (Gerla/UCLA)
- ODMRP (S.J. Lee/UCLA)
- TRAVLR (Kleinrock)
- Tora/IMEP (Park/UMD)
- Link Quality (Dube/UMD)
- LAR (Texas A&M)
- TBRPF/PacketHop (SRI)
- OLSR (Clausen/Jacquet)
- DSDV (Dest. Sequence #'s)
- AODV (refinement of DSDV)
- AOMDV (Multipath/Das et al.)
- LANMAR (Gerla et.al/UCLA)
- GPSR (Karp/Harvard)
- CBRP (Singapore)
- Terminodes (EPFL)
- MMWN (Steenstrup/BBN)
- ABR (C.K. Toh)
- STAR (JJ Garcia/UCSC)
- ZRP (Zygmunt Haas/Cornell)
- Fisheye/Hierarchical (UCLA)
- CEDAR (Urbana-Champaign)

More Ad Hoc Routing Projects

- FRESH (latest encounter)
- ANTS(*swarm intelligence*)
- Ariadne
- Cryptographic Threshhold
- Insignia (Columbia)
- TDR (Trigger-based Distributive Routing)
- AODV6
- FLR (UCSC)
- GPS/Geographic
- SHARP
- DREAM
- SAODV (Guerrera/Nokia)
- LDR (Mosko/Garcia …/Perkins)
- AODVjr (Caceres/Klein-Berndt)
- WRP
- Minimum-energy approaches
- Compow
- Pulse
- Face Routing
- *Many* more…

Traditional Routing Methods

Single metric: number of hops to destination

– But this isn't really appropriate, esp. for 802.11

- Advantages of using routing protocols:
  – Self-Starting
  – Multi-Hop
  – Dynamic topology
- Link-State (*Dijkstra's* shortest-path algorithm)
  – Complete topology stored
  – OSPF(RFC 1583)
- Distance-Vector protocols (*Distributed Bellman-Ford*)

On-Demand Routing Protocols

- Eliminate route table updates for routes that are not used
- Fewer control packets:
  - → Better scalability
  - → Reduced congestion
  - → More robust protocol action
- Less frequent control packets → reduced processing requirement
- Even more localization for topology changes if distance vector
- Also can be made to work for link-state

On-Demand Routing, cont.

- Downsides:
  - ICMP Unreachable only after Route Discovery attempt
  - Latency → longer application launch times
  - Route Discovery broadcasts

Mobile Ad Hoc Networking (*manet*)

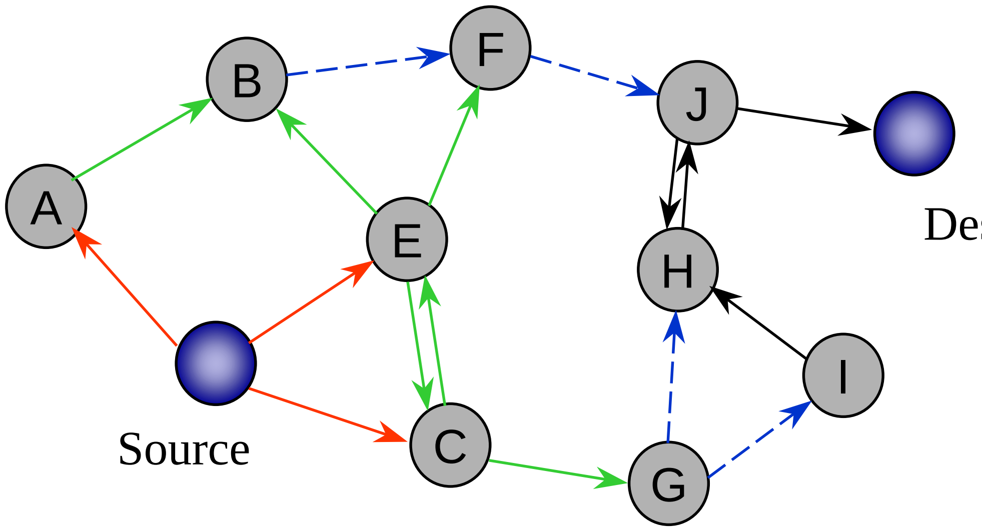
- AODV: *on-demand*, and *distance-vector*
  - Interoperability testing
  - Experimental RFC 3561
- Other *on-demand* protocol is (DSR)
- Two link-state, *table-driven / proactive* protocols
  - Optimized Link-State Routing (OLSR) is RFC 3626
  - Topology-Based Reverse Path Forwarding (TBRPF) is RFC 3684
- *Probably* DSR will be also published as Experimental
- Many other protocols have been considered!

MANET status update

- IETF group rechartering to focus on engineering existing techniques into a Proposed Standard
  - Two routing protocols
  - One flooding/multicast protocol
  - Internet Gateway operation
  - No "fancy" (usually, → unproven) approaches
- Recent discussion related to OSPF
  - Adjoining ad hoc domains to OSPF infrastructure?
  - Can OSPF become an ad hoc network routing protocol?
- IRTF group "Ad Hoc Network Systems" (ANS) has been formed [*needs help* : see www.irtf.org]

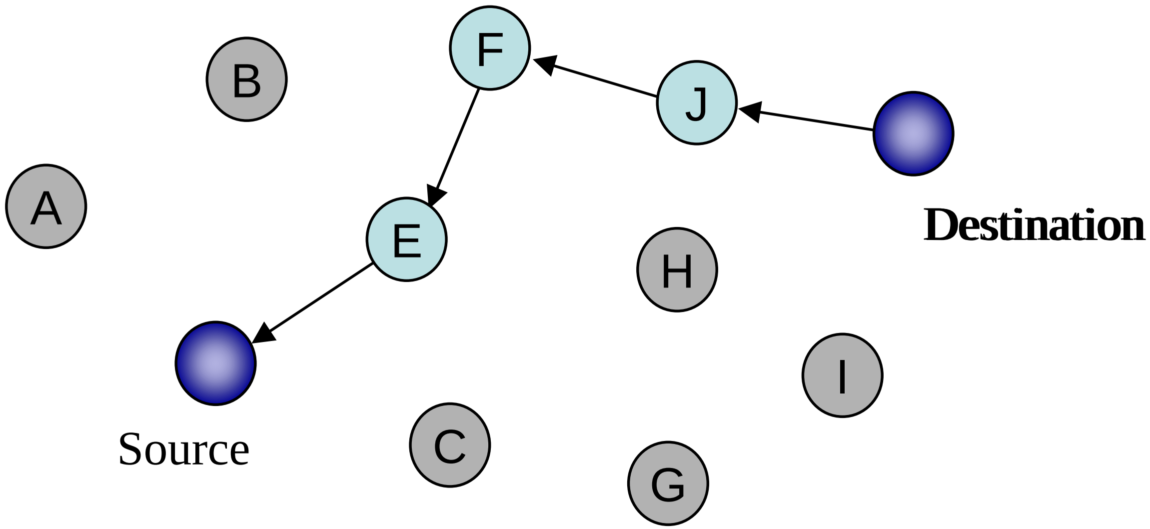
On-Demand Unicast Route Discovery Initiation

Route Request (RREQ) broadcast flood



On-Demand Unicast Route Discovery Completion

Route Reply (RREP) propagation



Some general performance observations

- When two protocols both lose almost all packets, maybe it doesn't matter which one is "better"
- Flooding → congestion, *and* flooding is unreliable
  - Problematic for creating OSPF extensions!
- At low node populations, what choices matter?
- High hop count increases fragility, latency
- NOTE: minimum hop count can be a *lousy* metric
- On-demand increases startup latency
- Table-driven tends to increase congestion
- Simulation times grow quadr. w/node population

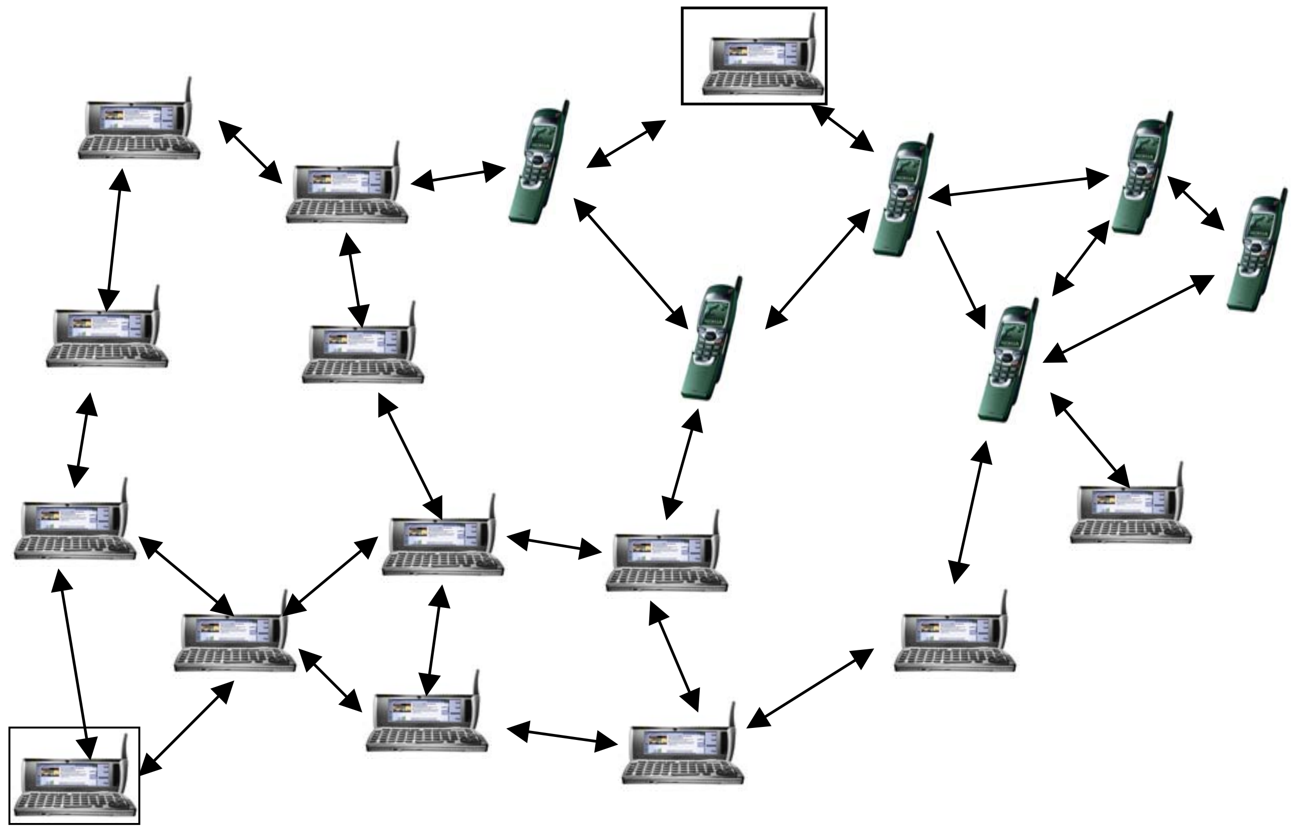
Simulation performance results

- Old AODV at 10,000 nodes performs poorly
  - 25% packet deliveries in the best of circumstances
  - Even worse without local repair and expanding-ring
- AODV vs. DSR with limited node populations
  - DSR works better under conditions of low mobility
  - Node movement favors AODV's route management
- MAODV has been tested under ns-2, and shows performance difficulties even at low populations
- Gun Shirer at Cornell offers the *Staged Network Simulator* (SNS) using ns-2 for big simulations

More performance results

- # RREQs ~ linearly with the node population
- Line’s slope changes depending on strategy
- At 10,000 nodes, most packets are control traffic (in one case, ratio was 5000 to 1)
- End-to-end delay wasn’t outrageously terrible (150ms) even at high node populations
- AODV w/expanding ring has the longest latency
- Query localization seems not to work (?why?)
- Should be similar for other on-demand protocols

Is Distance Vector *better* than Link-State?



Distance Vector Characteristics

- Very suitable for *on-demand* operation
- Remote movement less likely to propagate
  - i.e., mobility has more localized effects
- Natural fit for IP route table operation
  - e.g., OLSR and TBRPF use a shortest-path algorithm to fill route table with distance-vector entries
- To handle multipath, sort by metric

Ways to produce convergence

- Try to apply each new advance to various routing protocols...
- Eventually, common part may dominate!
- Modularize features, new and old (easier said than done!)
  - Flooding – example given, MPRF
  - Expanding rings search
  - QoS routing
  - Internet Gateway operation
  - more examples

Flooding: Needed for *discovery*

- “Application” flooding vs. “IP-level” flooding
  - TTL = 1 vs. TTL = network-diameter
- Multicast vs. Broadcast vs. ???
  - No multicast tree needed
  - 255.255.255.255 isn’t right
  - No subnet broadcast
  - Wanted: *manet-local* flooding
- Our goal: *Many* fewer packet retransmissions
- Technique: Fewer nodes retransmitting
  - E.g., by picking a set of multipoint relays
- Needed: unique identification for flooded packets

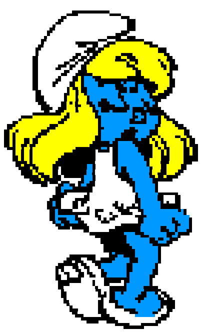
Multipoint Relay Flooding (MPRF)

- Taken from OLSR by Thomas Clausen, Pascale Minet, Charles E. Perkins, with much advice from Philippe Jacquet.
- Module meant for use by any flooding application (e.g., all four of the current experimental protocols)
- Closely related to *dominating sets*
- New release imminent, easier to deploy

Current MPRF Issues

- Use of *all-manet-nodes* multicast address
- *Bundling* for multiple simultaneous messages?
- Need to remove MPR dependence on last hop
  - Else, how do receivers detect sender's identity?
- ICMP vs. UDP vs. IP vs. ??
- Redundant coverage (> 1 seems advisable)
  - Broadcast minimized → process is *fragile*
- Only MPRs can be relays → non-optimal routing!
- MPR nodes in all routes → reduced MPR life!
- Unneeded for uncongested or transient networks

Simplified Manet Multicast Routing/Forwarding (SMURF)



Concerned Citizens Against Wasteful Flooding

Brian Adamson, Thomas Clausen, Joe Macker, Christopher Dearlove, Emmanuel Baccelli, Li Li, Maoyu Wang, Simone Ruffino, Charles E. Perkins

Stanford University
November 18, 2004

NOKIA

Design Requirements

- No group-specific tree maintenance
- Can be used for generic multicast delivery
- IANA allocation(s) for MANET_FORWARDING
  - Duplicate suppression mandated (aware or not)
- Native IPv4 or IPv6 forwarding
- Work with unaware nodes
- Insure bidirectional links between relay nodes
- Useful with (most?) applications, route discovery
- Compatible with various/advanced algorithms
  - However, baseline algorithm needed for aware nodes

Requirements - ?Requirements?

- Design requirements in document
- Experimental publication
- ???Extension for dynamic membership???
- ???Multiple relay-selection algorithms???

MPRF comparisons (initial results)

- We can show nice pictures for the nodes that become part of the broadcast skeleton
- Minimal broadcast *does* reduce PDR
- At 1,000 nodes, TBRPF took all weekend to simulate 3 seconds
- At 1,000 nodes, AODV plus MPRF took 30 minutes to simulate 900 seconds
- We also have ideas for further improving the simulator (SNS)
- MUCH work needs to be done!!

Convergence ideas

- AODV with DSR; OLSR with TBRPF
  - All *could* use the same flooding protocol
- Distance Vector with Link State
- On Demand with Proactive
- Modular, Constructible approach
- Adaptive/Hybrid approach
- Simulation Results
  - http://lsewww.epfl.ch/Documents/acrobat/CSA02b.pdf
  - "Simplified Simulation Models for Indoor MANET Evaluation Are Not Robust" (Secon 2004)

AODV converged with DSR

- Looks simple to do (we've done some of it)
- AODVbis takes a major step for this, namely path accumulation during route discovery
- DSR source routes are not always beneficial
  - Distance-vector more robustly enables route repair
- AODV route caching is beneficial
  - Inverse dependence on *relative* mobility
- AODV and DSR can use the same tricks
  - And offer the same extensions
- Multipath: DSR vs. AOMDV

OLSR converged with TBRPF

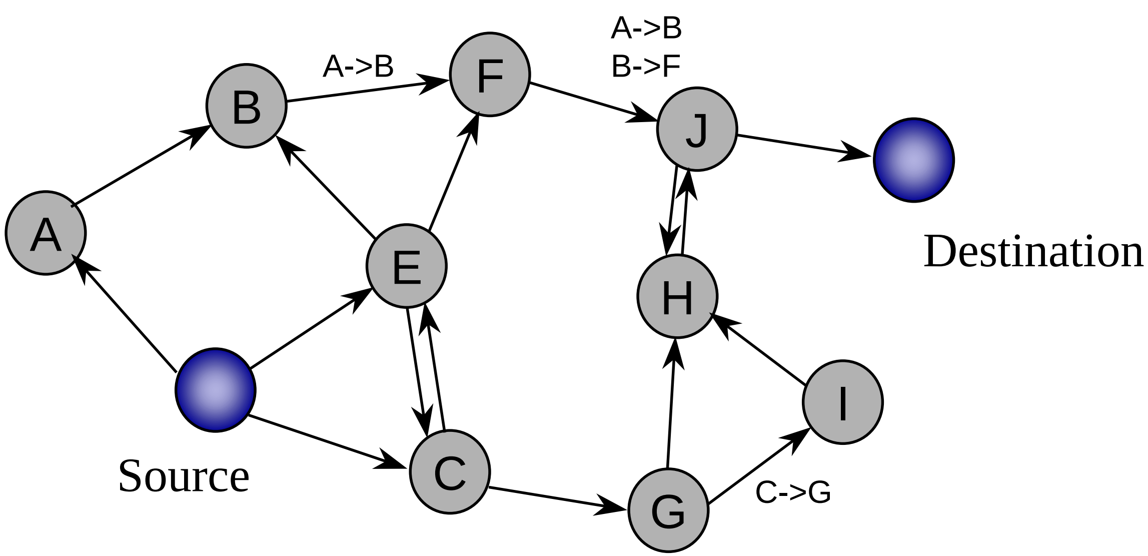
- Protocols are both link-state routing protocols
- Both report only restricted topology information
- Story about the role of patents
- OLSR uses “Multi-Point Relays”, as described
- A TBRPF node relays broadcasts from a neighbor *j* only if it belongs to *j*'s *reported nodes* set.
  - *Reported nodes* are those which are next hops towards farther destinations (i.e., not leaf nodes in the *source tree*)

Use Route Discovery for Topology

- Why *waste* all that capacity?
- AODVbis now specifies *path accumulation* on RREQ and RREP
  - Other features → fewer mandates (AODVjr)
- One step along the way towards link-state approach (but must avoid stale link info...)
- Only relevant for *on-demand*

Added-value Signaling

- Route Request (RREQ) broadcast flood
  - Each retransmission carries more link info



Merging Proactive and On-Demand

- Key parameter: *ACTIVE_ROUTE_TIMEOUT*
- If *ACTIVE_ROUTE_TIMEOUT* >> 0, route repair will maintain routes
  - Example: Internet Gateways
- Special case solution: multi-hop Route Advertisement
- Helpful: frequent topology updates
  - potentially via "rich" Route Discovery

Service Discovery

- Needs same sort of “flooding” operation
- But, instead of an “IP address”, a service is needed which meets some desired service criteria (name & attributes)
- Allow a service to be identified by the application *port number*
- Alternatively, use SLP *service descriptors*
  - Others exist

Ad Hoc Quality of Service

- Add QoS constraint to link descriptor
  - RREQ for on-demand
  - Topology updates for proactive
- Nodes only forward RREQ if they can possibly meet constraint
- Need ICMP for links that “fail”
- NP complete problems abound, due to congestion management, scheduling

Challenges for the Future

- Getting to Standard!
- Multicast/Anycast/Geocast/Mobicast
- Security (e.g., route repair!)
- Scalability: the 1/sqrt(N) capacity limit
  - Backbone formation and maintenance
- QoS – and don't forget layer 2!
- Multipath routing "vs." route caching
- Route Repair vs. multihop context transfer
- Re-examine the "client-server" paradigm
- Using positional hints (for sensors, worth it!)

Summary and Conclusions

- Ad Hoc Networking is a great research area
  - Can be applied whenever *infrastructureless*
  - Related fields: sensor networks, graph theory, ...
- IETF *manet* working group working to converge
- Distance Vector can be made loop free, and localizes the effect of topology changes
- On-demand protocols offer many advantages
- Creating modular components aids convergence
- Convergence aids getting to standard