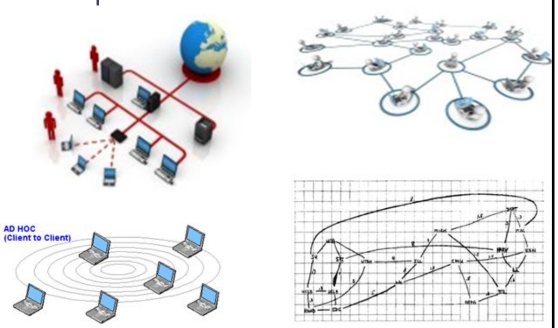
Changing Paradigms in Mobile Ad Hoc Networks : MANET

Presented By:
Dr. Shailendra Mishra
M. Abdul Rahim Khan
College of Computer & Information Sciences
Majmaah University
Saudi Arabia

Agenda

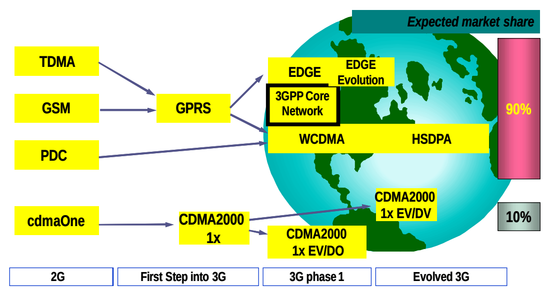
- Computer Network
  Classification, IEEE 802 project
- Ad-Hoc Networks(MANETs)
- ❖Advances in MANET
- ❖Routing
- ❖ Areas of current research
- ❖Research focus

Computer Network



Evolution

-Drivers are capacity, data speeds, lower cost of delivery for revenue growth

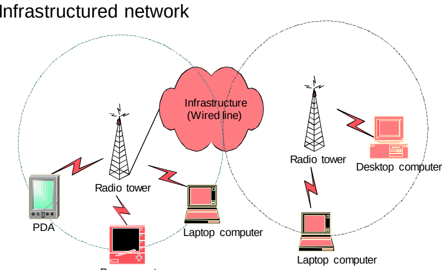


Ad-hoc Networks

- Two types of wireless network:
  - **Infrastructured**
    - the mobile node can move while communicating
    - the base stations are fixed
    - as the node goes out of the range of a base station, it gets into the range of another base station
  - **Infrastructureless or ad-hoc**
    - the mobile node can move while communicating
    - there are no fixed base stations
    - all the nodes in the network need to act as routers
  - In Latin “ad-hoc” literally means “for this purpose only”. Then an ad-hoc network can be regarded as “spontaneous network”

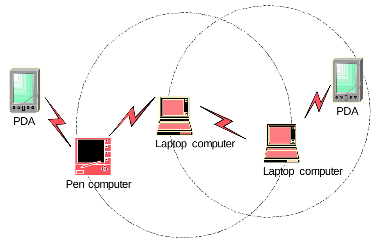
Ad-hoc Networks

- Infrastructured network



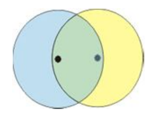
Ad-hoc Networks

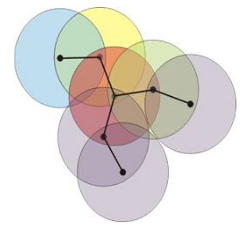
- Infrastructurless (ad-hoc) network or MANET (Mobile Ad-hoc NETwork)



Ad-hoc Networks

- Classification of ad-hoc networks
  - Single hop – nodes are in their reach area and can communicate directly
  - Multi hop – some nodes are far and cannot communicate directly. The traffic has to be forwarded by other intermediate nodes.





Fundamental Concepts

- Ad hoc networks are autonomous networks operating either in isolation or as "stub networks" connecting to a fixed network
- Do not necessarily rely on existing infrastructure
  - No "access point"
- Each node serves as a router and forwards packets for other nodes in the network
- Topology of the network continuously changes

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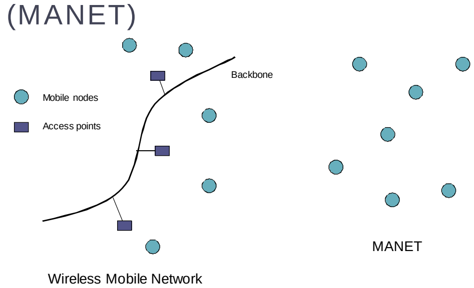
Mobile Ad Hoc Networks (MANET)



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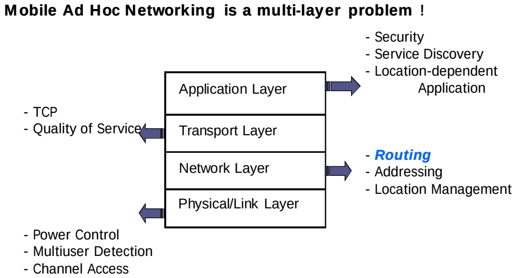
Ad-hoc Networks

Mobile Ad Hoc Networking is a multi-layer problem !



Ad-hoc Networks

- Why we need ad-hoc networks?
  - **Setting up of fixed access points and backbone infrastructure is not always viable**
    - Infrastructure may not be present in a disaster area or war zone
    - Infrastructure may not be practical for short-range radios; Bluetooth (range ~ 10m)
  - Do not need backbone infrastructure support
    - Are easy to deploy
    - Useful when infrastructure is absent, destroyed or impractical

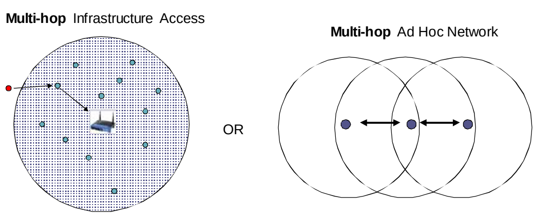
Problems

- Communication is only possible between nodes which are directly in range of each other

Problems for both Infrastructure and Ad hoc Mode

- If nodes move out of range of the access point (Infrastructure Mode)
- OR nodes are not in direct range of each other (Ad Hoc Mode)
- Then communication is not possible!!

What if ??



How can this be done?

- ROUTING!!
  - Wired Networks:
    - Hierarchical Routing
      - Network is divided into subnets
      - Nodes look at netmask and determine if the address is directly reachable. If not, just forward to the default gateway.
      - Different protocols for different levels of the hierarchy
        - RIP, OSPF, BGP

Wireless Routing

- Flat routing
  - You can't assume that since a node is in your subnet that it is directly accessible
  - Node must maintain or discover routes to the destination
  - **All nodes are routers**

Motivation

- Avoid single point of failure typical of centralized systems
- Often unable to rely on existing communications infrastructure
- Desire for a rapidly deployable, self-organizing network
- Multi-hop packet routing used to exchange messages between users

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Applications

- Military
  - Rapidly deployable battle-site networks
  - Sensor fields
  - Unmanned aerial vehicles
- Disaster management
  - Disaster relief teams that cannot rely on existing infrastructure
- Neighborhood area networks (NANs)
  - Shareable Internet access in high density urban settings
- communications among groups of people
  - Meetings/conferences
- Automobile communications (more on this later)

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Characteristics

- Dynamic topology
- Heterogeneity
- Bandwidth-constrained variable-capacity links
- Limited physical security
- Nodes with limited battery life and storage capabilities

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Standardization

- Internet Engineering Task Force (IETF) MANET working group (http://www.ietf.org/html.charters/manet-charter.html)

"The primary focus of the working group is to develop and evolve MANET routing specification(s) and introduce them to the Internet Standards track. The goal is to support networks scaling up to hundreds of routers. (…) The working group will also serve as a meeting place and forum for those developing and experimenting with MANET approaches."

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ADVANCES IN MANET

- Areas of current research
- Routing
- Cluster management

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Research focus to date

- Routing protocols
  - Reactive, proactive, hybrid
- Cluster management
  - To reduce overhead, to facilitate network management, to enable QoS, etc.
- Quality of service (QoS)
  - Differentiating among different types of applications
- Medium access
  - Closing the link, recognizing neighbors, scheduling transmission, etc.
- Other
  - TCP performance in MANETs, etc.

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Routing in MANETs

- Why is it different from routing in other types of network?
  - **Because both end nodes i.e routers are mobile**
- Rate of link failure can be high if mobility is high
- Unicast and multicast routing problems are being treated
  - No protocol has been standardized yet (but several under consideration as Internet Drafts at the IETF)
- Need new metrics to assess the effectiveness of the protocol
  - Route stability
  - Control overhead
  - Data rebroadcast overhead (for multicast)

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MANET Routing Protocols

- **Proactive**
  - **Establish routes in advance**
  - **Example: Optimized Link State Routing Protocol (OLSR)**
- **Reactive**
  - **Establish routes as needed**
  - **Example: Dynamic Source Routing (DSR)**
  - **Less routing overhead, but higher latency in establishing the path**
- **Hybrid**
  - **Proactive within a restricted geographic area, reactive if a packet must traverse several of these areas**
  - **Example: Zone Routing Protocol (ZRP)**

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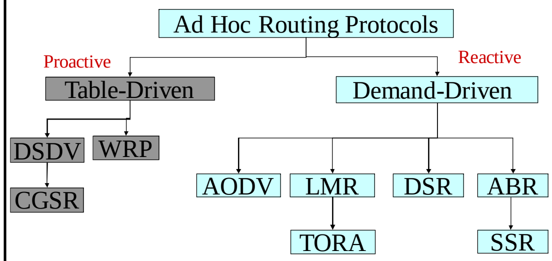
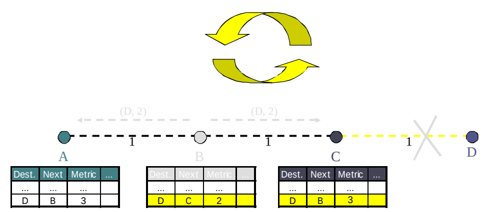
MANET Routing Protocols cont..



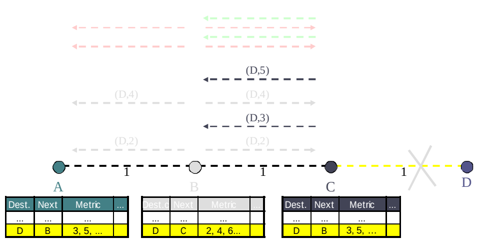
Problems with Routing

- Is it possible to use standard routing protocols?
  - **Distance-vector protocols**
    - Slow convergence due to “Count to Infinity” Problem
    - Creates loops during node failure, network partition or congestion
  - **Link state protocols**
    - Use flooding technique and create excessive traffic and control overhead
    - Require a lot of processor power and therefore high power consumption

Distance Vector (Loops)



Distance Vector (Count to Infinity)



Metric = Number of Hops to Destination

Distance Vector

- DV not suited for ad-hoc networks!
  - Loops
  - Count to Infinity
- New Solution -> DSDV Protocol

DSDV Protocol

- DSDV is Destination Based
- No global view of topology
- DSDV is Proactive (Table Driven)
  - Each node maintains routing information for all known destinations
  - Routing information must be updated periodically
  - Traffic overhead even if there is no change in network topology
  - Maintains routes which are never used

DSDV Protocol

- Guarantee Loop Freeness
  - New Table Entry for Destination Sequence Number
- Allow fast reaction to topology changes
  - Make immediate route advertisement on significant changes in routing table
  - but wait with advertising of unstable routes

DSDV (Table Entries)

Destination	Next	Metric	Seq. Nr	Install Time	Stable Data
A	A	0	A-550	001000	Ptr_A
B	B	1	B-102	001200	Ptr_B
C	B	3	C-588	001200	Ptr_C
D	B	4	D-312	001200	Ptr_D

- **Sequence number** originated from destination. Ensures loop freeness.
- **Install Time** when entry was made (used to delete stale entries from table)
- **Stable Data** Pointer to a table holding information on how stable a route is. Used to damp fluctuations in network.

DSDV (Route Advertisements)

- Advertise to each neighbor own routing information
  - Destination Address
  - Metric = Number of Hops to Destination
  - Destination Sequence Number
- Rules to set sequence number information
  - On each advertisement increase own destination sequence number (use only even numbers)
  - If a node is no more reachable (timeout) increase sequence number of this node by 1 (odd sequence number) and set metric = ∞

DSDV (Route Selection)

- Update information is compared to own routing table
  - 1. Select route with higher destination sequence number (This ensure to use always newest information from destination)
  - 2. Select the route with better metric when sequence numbers are equal.

DSDV (Tables)

A — 1 — B — 2 — C

A:

Dest.	Next	Metric	Seq
A	A	0	A-550
B	B	1	B-100
C	B	3	C-586

B:

Dest.	Next	Metric	Seq
A	A	1	A-550
B	B	0	B-100
C	C	2	C-588

C:

Dest.	Next	Metric	Seq.
A	B	1	A-550
B	B	2	B-100
C	C	0	C-588

B increases Seq.Nr from 100 -> 102
B broadcasts routing information to Neighbors A, C including destination sequence numbers

DSDV (Route Advertisement)

(A, 1, A-500)
(B, 0, B-102)
(C, 1, C-588)

(A, 1, A-500)
(B, 0, B-102)
(C, 1, C-588)

A — 1 — B — 1 — C

A:

Dest.	Next	Metric	Seq
A	A	0	A-550
B	B	1	B-102
C	B	2	C-588

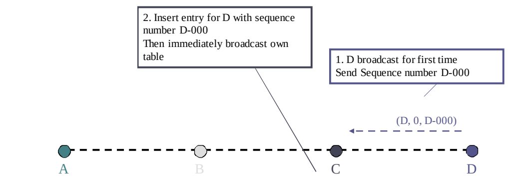
B:

Dest.	Next	Metric	Seq
A	A	1	A-550
B	B	0	B-102
C	C	1	C-588

C:

Dest.	Next	Metric	Seq.
A	B	2	A-550
B	B	1	B-102
C	C	0	C-588

DSDV (New Node)



A:

Dest.	Next	Metric	Seq.
A	A	0	A-550
B	B	1	B-104
C	B	2	C-590

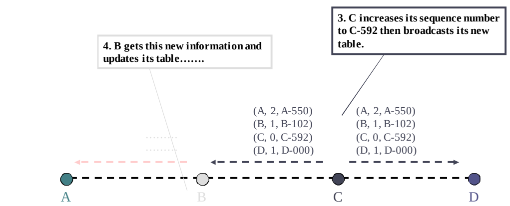
B:

Dest.	Next	Metric	Seq.
A	A	1	A-550
B	B	0	B-104
C	C	1	C-590

C:

Dest.	Next	Metric	Seq.
A	B	2	A-550
B	B	1	B-104
C	C	0	C-590
D	D	1	D-000

DSDV (New Node cont.)



A:

Dest.	Next	Metric	Seq.
A	A	0	A-550
B	B	1	B-104
C	B	2	C-590

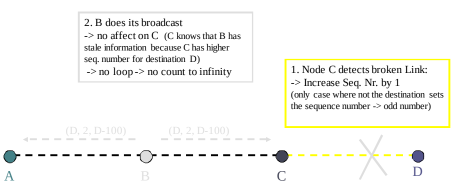
B:

Dest.	Next	Metric	Seq.
A	A	1	A-550
B	B	0	B-102
C	C	1	C-592
D	C	2	D-000

C:

Dest.	Next	Metric	Seq.
A	B	2	A-550
B	B	1	B-102
C	C	0	C-592
D	D	1	D-000

DSDV (no loops, no count to infinity)



A:

Dest.	Next	Metric	Seq.
…	…	…	
D	B	3	D-100

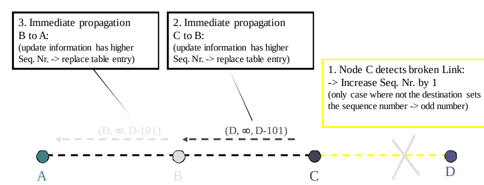
B:

Dest.c	Next	Metric	Seq.
…	…	…	
D	C	2	D-100

C:

Dest.	Next	Metric	Seq.
…	…	…	
D	D	∞	D-101

DSDV (Immediate Advertisement)



A:

Dest.	Next	Metric	Seq.
…	…	…	…
~~D~~	~~B~~	~~3~~	~~D-100~~
D	B	∞	D-101

B:

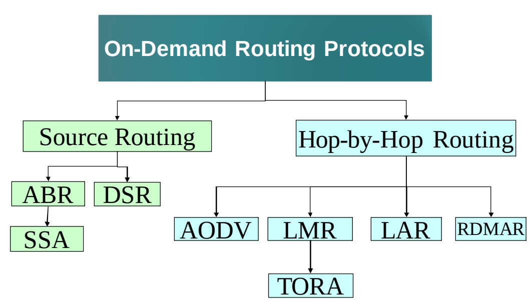
Dest.c	Next	Metric	Seq.
…	…	…	…
~~D~~	~~C~~	~~2~~	~~D-100~~
D	C	∞	D-101

C:

Dest.	Next	Metric	Seq.
…	…	…	
~~D~~	~~D~~	~~1~~	~~D-100~~
D	D	∞	D-101

DSDV

- Advantages
  - Simple (almost like Distance Vector)
  - Loop free through destination seq. numbers
  - No latency caused by route discovery
- Disadvantages
  - No sleeping nodes
  - Bi-directional links required
  - Overhead: most routing information never used
  - Scalability is a major problem



Source Routing vs Hop-by-Hop Routing

Source Routing	Hop-By-Hop Routing
Data packets carry the complete addresses from source to destination	Data packets carry the address of the destination and the next hop
No routing table in intermediate nodes	All nodes maintain localized routing tables
Not Scalable	Scalable

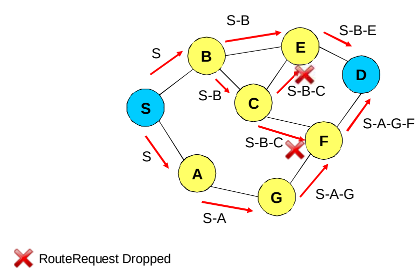
General Properties

- Loop Free Routing
- Two Operation Phases
  - Route Establishment
    - Route Request → RouteRequest Packet, flooded by the Source node
    - Route Reply → RouteReply Packet, returned to source node by Destination or Intermediate node
  - Route Maintenance
    - Route Reconstruction
    - Route Deletion

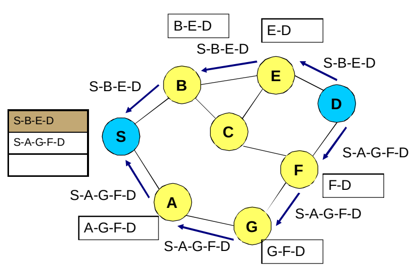
Dynamic Source Routing (DSR)

- Full source-route is aggregated in RouteRequest, and sent back in RouteReply
- Each data packet carry the full address for all nodes along the path
- Can store Multiple routes to destination
- Good for Small/ Low mobility networks

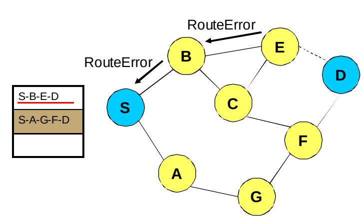
DSR - Route Request



DSR - Route Reply



DSR – Route Maintenance



When a link is broken → due to movement of nodes or any other reason

The node that discover the failure link will send RouteError to the Source

When the source gets the RouteError Packet it will delete the path from the cache

And will find another route in its cache, if it didn't find any route it will run RouteRequest again

DSR -- Concerns

- Scalability
- Large overhead in each data packet
- No Local repair of the broken link
- Stale cache information could result to inconsistence during route reconstruction
- Poor Performance as Mobility increases

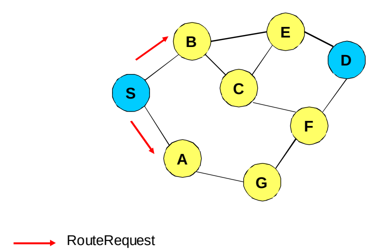
Ad Hoc On-Demand Distance Vector Routing (AODV)

- Source Routing (DSR, ABR and SSA) is good for smaller networks due to large data packet overhead
- AODV:
  - Hop by Hop basis
  - No need to include the full path in the data packet
  - Update Neighborhood information through periodic beacons

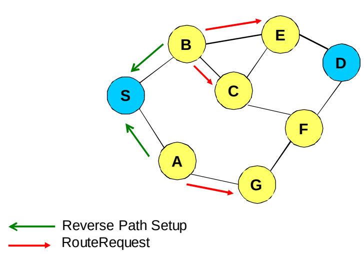
AODV– Route Discovery

- Source Node broadcast *RouteRequest* packet
- Each intermediate node gets a RouteRequest do the following steps:
  - Establish a reverse link to node it received the RouteRequest from
  - If request received before → discard
  - If route to destination is available and up-to-date → return RouteReply using the reverse link
  - Otherwise → rebroadcast the RouteRequest
- Destination node respond with RouteReply using the reverse link

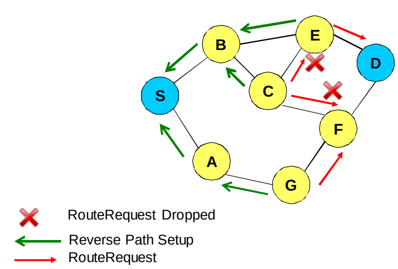
AODV - Route Discovery



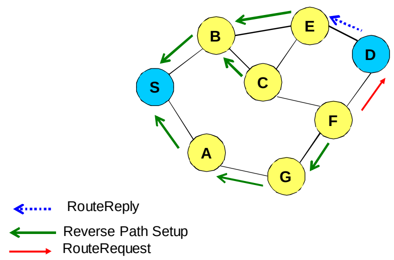
AODV - Route Discovery



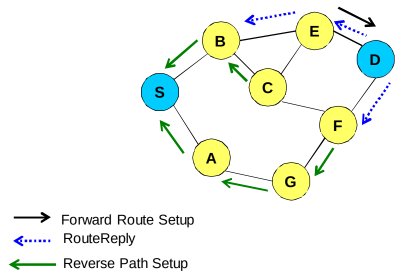
AODV - Route Discovery



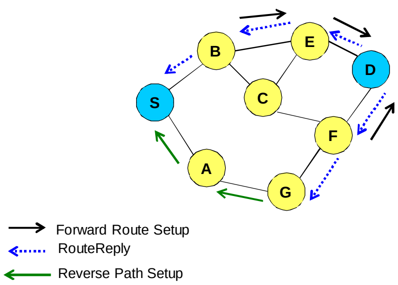
AODV - Route Discovery



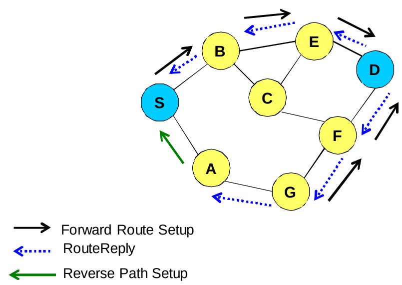
AODV - Route Discovery



AODV - Route Discovery



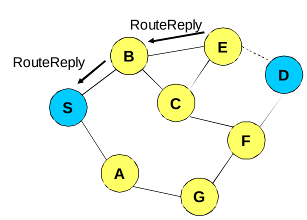
AODV - Route Discovery



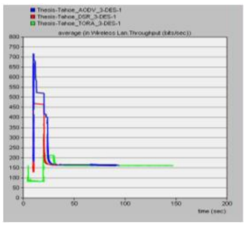
AODV – Route Maintenance

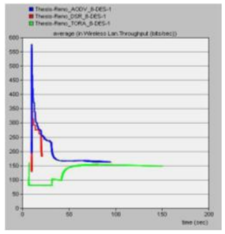
- When a node detects a link failure, it sends special RouteReply with infinity distance
- RouteReply is propagated to source node
- Source node initiates a new RouteRequest

AODV – Route Maintenance



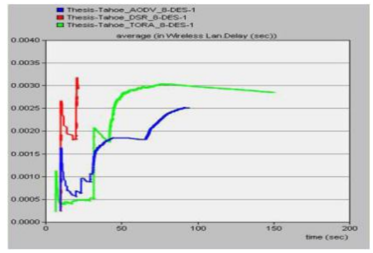
THROUGHPUT ANALYSIS FOR EIGHT NODES SCENARIO





AODV have the higher throughput in the start as compared to the DSR and TORA. A small change has been observed in the number of data packets when nodes are increased to 8 The highest number of data packets are reduces from approximately 750 to 575, which means that if more and more nodes are added in MANET, throughput will reduce. Similarly TORA takes more time when the numbers of nodes are increased to 8, as compared to 3 nodes and 5 nodes

Delay comparisons in eight nodes scenario



Comparison

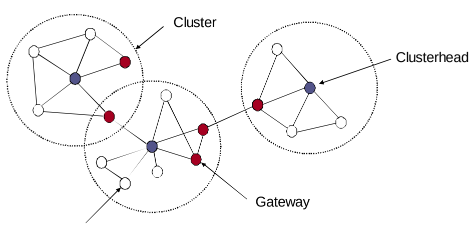
- DSR: Dynamic Source Routing
- ABR: Associativity-Based Routing
- SSA: Signal Stability-Based Adaptive Routing Algorithm
- AODV: Ad Hoc On-Demand Distance Vector
- LAR : Location Aided Routing Protocol
- RDMAR: Relative Distance Micro-Discovery Ad Hoc Routing
- LMR: Light-weight Mobile Routing
- TORA: Temporally Ordered Routing Algorithm
- ARA: Ant-colony-based Routing AlgorithmUsed
- *BEACON* ---directional signal for navigational purposes

Protocol	Routes	Route Selection	Beacon
DSR	Multiple	Shortest Path	No
ABR	Single	Link Stability	Yes
SSA	Single	Signal Strength	Yes
AODV	Single	Shortest Path, Freshness	Yes
LAR	Multiple	Shortest Path	No
RDMAR	Single	Shortest Path	No
LMR-TORA	Multiple	Link reversal	No
ARA	Multiple	Shortest Path	No

Research on MANET

- Cluster Management
- Smart antennas in ad hoc networks
- Policy-based management for ad hoc mobile networks
- Game Theory
- Adaptive MACs

Link-Clustered Architecture



Since clusterheads decide network topology, *election* of clusterheads optimally is critical

Previous Work

Highest-Degree Heuristic [Gerla+ 1995, Parekh 1994]

- Computes the degree of a node based on the distance (transmission range) between the node and the other nodes
- The node with the maximum number of neighbors (maximum degree) is chosen to be a clusterhead and any tie is broken by the node ids

Drawbacks:

- A clusterhead cannot handle a large number of nodes due to resource limitations
- Load handling capacity of the clusterhead puts an upper bound on the node-degree
- The throughput of the system drops as the number of nodes in cluster increases

Weighted Clustering Algorithm (WCA)

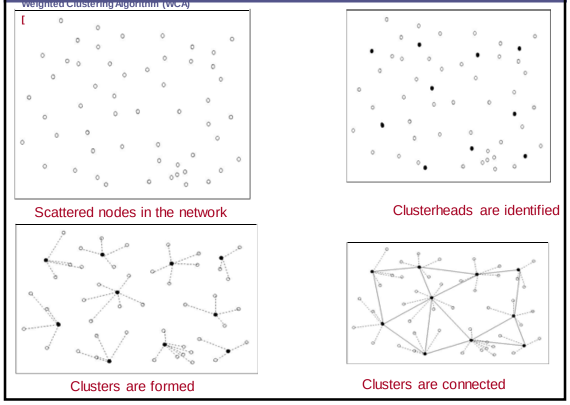
[Chatterjee+ 2000, 2002]

- A clusterhead can *ideally* support nodes
  - Ensures efficient MAC functioning
  - Minimizes delay and maximizes throughput
- A clusterhead uses more battery power
  - Does extra work due to packet forwarding
  - Communicates with more number of nodes
- A clusterhead should be less mobile
  - Helps to maintain same configuration
  - Avoids frequent WCA invocation
- A better power usage with physically closer nodes
  - More power for distant nodes due to signal attenuation

Invocation of WCA is *on-demand*
- Reduces information exchange by less system updates
- Reduces computation/communication costs
- Manages mobility by *reaffiliations*
- Delays (avoids) invocation of clustering as far as possible

WCA is *distributive*
- No clusterhead is over loaded
- Balances load by limiting the cluster size

Weighted Clustering Algorithm (WCA)



Smart antennas in ad hoc networks

- Potential benefits in closing the link, reaching distant nodes through a direct link, directional multicasting, etc.
- Simulation of smart antenna controller, with dynamic beam forming and null steering
  - Development of an integrated Matlab™/OPNET Modeler™ simulation including layers 1 (signal degradation and attenuation, optimum assignment of antenna weights), 2 (medium access) and 3 (routing) considerations
- Application of directed beams to increase the efficiency of medium access algorithms in ad-hoc environments
  - Multi-hop request-to-send/request-to-orient

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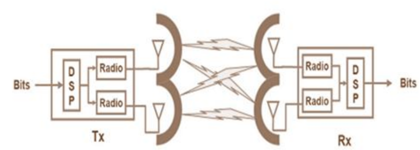
MIMO (Multiple-Input Multiple-Output) Systems

- Multiple antennas
  - Consists of M transmit antennas and N receiving antennas
  - MIMO transmits different information streams on each transmit antenna in the same band.
  - The receiver receives a linear combination of N transmitted signal.



MIMO (cont..)

- The received signals r1(t), r2(t), r3(t) at each of the three received antennas are a linear combination of x(t), y(t), z(t).
- R = A [x y z]'

A-Channel coefficents

Aim of MIMO

- Provide reliable communication.
- Enhance mobile ad-hoc network throughput rate by 10 times.
- Significantly extend the reach of conventional single antenna systems.
- The IEEE 802.11n uses MIMO technology.
- The proposed theoretically data rate supported by 802.11n is 600 Mbps at a frequency of 2.4GHz.

SNR & Channel Capacity

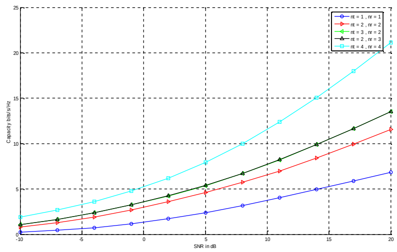
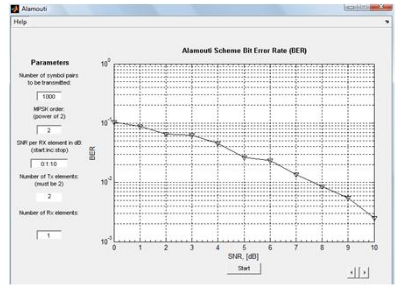
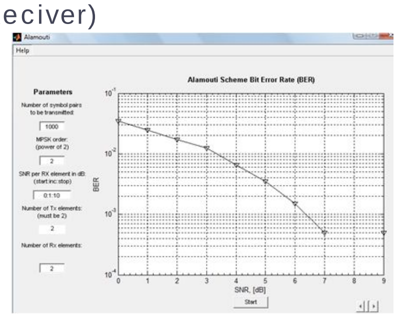


Figure 1: SNR & Channel Capacity

BER Vs SNR(2 Transmitter &1Reciver)



BER Vs SNR(2 Transmitter &2Reciver)



Smart antennas in ad hoc networks

- Node 1 & Node 3 transmit packets to Node 0 using circular array antenna containing 8 elements.
- Node 2 orients the receive antenna towards the Node 1.
- Node 0 uses null forming algorithm to receive packets only from Node 1.

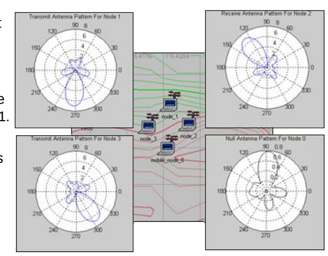
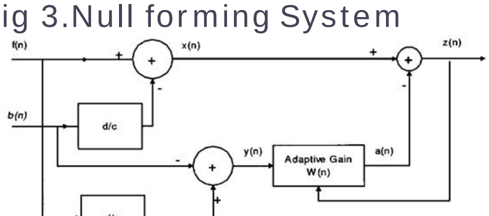


Fig 3.Null forming System



The proposed scheme is shown in Fig. 3, where the received signals at the front microphone and the rear microphone are $f(n)$ and $b(n)$, respectively.

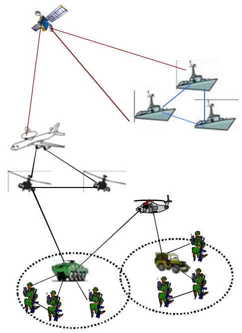
d/c delay unit in two channels;
$z(n)$ output of the system;
$W(n)$ adaptive gain;
$a(n)$ output of the adaptive gain processing unit.

Policy-based Management

- Policy-based Networking (PBN)
  - Automating network management
  - Abstraction of complex low-level policies to simple high-level policies
  - Multiple policy disciplines
    - QoS, network security, IP address allocation etc.
- QoS policy
  - QoS means incentive to steal resources?!
    - Need for Authentication, Authorization, Accounting
  - Policy-based Admission Control (PAC)
    - Not just based on available resources (bandwidth)

Management of Ad Hoc Networks

- Autonomous networks operating in isolation or as 'stub networks'
- Extremely challenging
  - Severe bandwidth constraints
  - Limited battery life
  - Dynamic topology
  - Heterogeneity
  - Limited survivability
- Need a robust, adaptive, and efficient management framework
- Are wireless mobile networks another venue for policy-based management?



Framework

- Policy-based Networking (PBN)
  - Automating network management
  - Abstraction of complex low-level policies to simple high-level policies
  - Multiple policy disciplines
    - QoS, network security, IP address allocation etc.
- QoS policy
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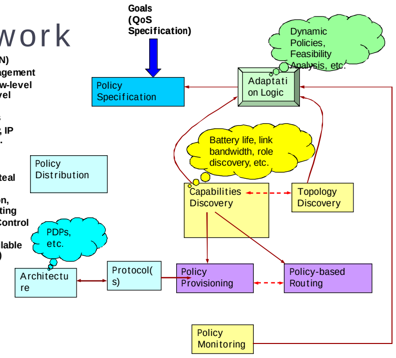

Applications

- Weather and hazard alerts
- Safety and security
- Travel information and m-commerce (car is your credit card)
- Interactive navigation
- Diagnostic data
- Maintenance support
- Instant messaging
- Data mining
- General Internet access

Benefits of this on going Research

- Clear understanding of feasibility of vehicular ad-hoc network and performance of such a network
- Fill a gap in vehicular communications research on external networking and communications
- Future research to provide more detailed descriptions of realizing the network on a broad scale
- Future work could include prototypes to be demonstrated

Readings and References (1)

- Books on MANET
  - C. K. Toh, *Ad Hoc Mobile Wireless Networks: Protocols and Systems,* Prentice Hall, 2001.
  - C. E. Perkins, *Ad Hoc Networking*, Addison Wesley, 2000.
- IETF MANET working group for RFCs with details of proposed routing protocols
  - http://www.ietf.org/html.charters/manet-charter.html

Further Readings

Survey Papers

- Imrich Chlamtac, Marco Conti ,Jennifer J.-N. Liu c,Mobile ad hoc networking: imperatives and challenges, Ad Hoc Networks 1 (2003) 13–6420, Elsevier
- Hui Xu,, Xianren Wu, Hamid R. Sadjadpour, ACMA Unified Analysis of Routing Protocols in MANETs, IEEE TRANSACTIONS ON COMMUNICATIONS, VOL. 58, NO. 3, MARCH 2010
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