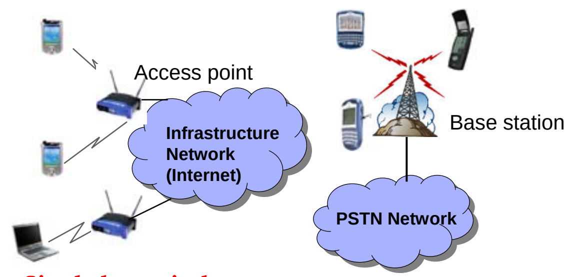
EEC173B/ECS152C, Spring 2009

Wireless Mesh Networks

- Introduction
- Flow Control Issues
- Rate Adaptation

Wireless LAN or Cellular Networks



Single hop wireless

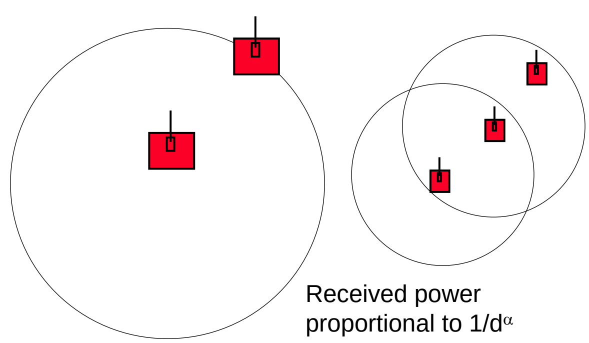
2

Driving Forces for Multihop Wireless Networks

- Battery technology has lagged behind processor/memory/radio technology.
  - Now on critical path on success of mobile and pervasive computing.
- More power needed for longer range
  - Fundamental physical limitation -- path loss.
- Use short range radios. Use multiple hops for communication.

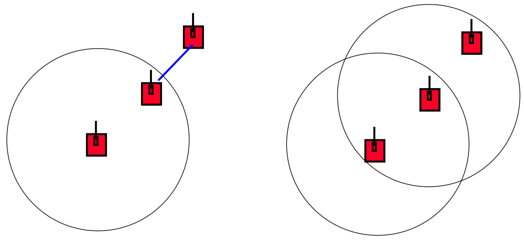
3

Multihop Saves Power over Single Hop



4

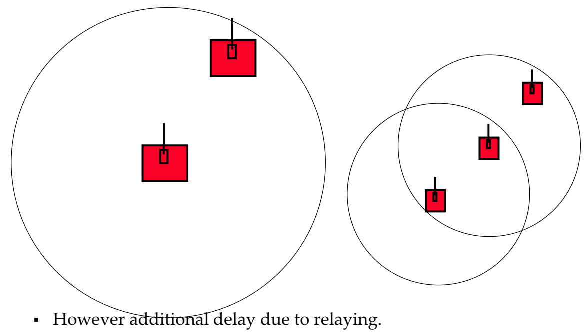
Multihop Eliminates Wires for Same Range



- It is also improves flexibility and coverage.

5

Multihop Reduces Interference over Single Hop



- However additional delay due to relaying.

6

Various Type of Multihop Wireless Networks

- Definitions:
  - Host – network node that is an end user device, also called clients.
  - Router – network node that participates in relaying.
- Ad Hoc Networks
  - Hosts are also routers. Hosts could be mobile.
- Sensor Networks
  - Ad hoc network where hosts are actually sensor devices. Hosts are not usually mobile.
- Mesh Networks
  - Hosts and routers are different entities. Usually hosts are mobile, routers are not.

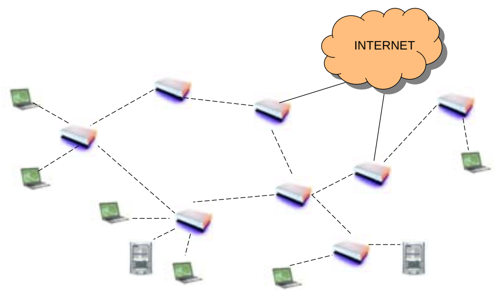
7

What are mesh networks?

- Wireless Mesh Networks are composed of wireless access points (routers) that facilitate the connectivity and intercommunication of wireless clients through multi-hop wireless paths
- The mesh may be connected to the Internet through gateway routers
- The access points are considered as the nodes of mesh; they may be heterogeneous and connected in a hierarchical fashion
- Unlike MANETs, end hosts and routing nodes are distinct. Routers are usually stationary.

8

Wireless Mesh Architecture



9

Why Wireless Mesh?

- Low up-front costs
- Ease of incremental deployment
- Ease of maintenance
- Provide NLOS coverage
- Advantages of Wireless APs (over MANETs)
  - Wireless AP backbone provides connectivity and robustness which is not always achieved with selfish and roaming users in ad-hoc networks
  - Take load off of end-users
  - Stationary APs provide consistent coverage

10

History of Research in Wireless Multihop Networks

- Some timeline

  1972: Packet Radio NETwork (PRNET)

  1980s: SURvivable Adaptive Radio Network (SURAN)

  Early 1990s: GLObal MObile Information System (& NTDR)

  Research agenda mostly set by Department of Defense in US.

  Applications military centric.

11

History of Research in Wireless Multihop Networks (contd.)

- Mid 1990s: IETF MANET (Mobile Ad Hoc Networks) Working group formed.
- Goal standardize a set of IP-based routing protocols.
- Driving force: IEEE WLAN Standard 802.11 being developed. Laptops are already common.
- Extensive research in routing. Several protocols developed and made into RFCs.

12

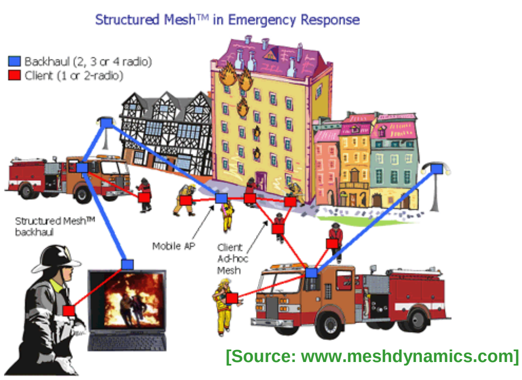
History of Research in Wireless Multihop Networks (contd.)

- Late 1990s: New focus on low-power micro sensor networks.
  - Driving force: understanding of ad hoc networks, availability of inexpensive low-power radios, microcontrollers, sensors.
- Early 2000s: Interest in Mesh networks.
  - Driving force: Availability of low-cost laptop/plamtop with WLAN interface. Need for ubiquitous broadband connectivity.

Applications

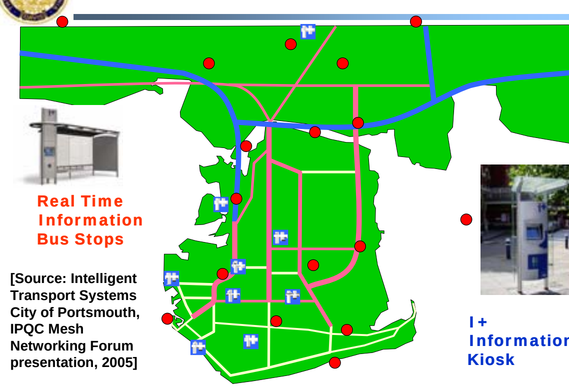
- Community Networks
- Enterprise Networks
- Home Networks
  - Coverage extension, healthcare
- Local Area Networks for Hotels, Malls, Parks, Trains, etc.
- Metropolitan Area Networks
- Ad hoc deployment of LAN
  - Public Safety, Rescue & Recovery Operation

Public Safety



[Source: www.meshdynamics.com]

Intelligent Transportation System



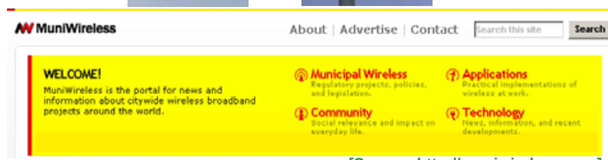
[Source: Intelligent Transport Systems City of Portsmouth, IPQC Mesh Networking Forum presentation, 2005]

Community Mesh Network

- Grass-roots wireless network for communities.
- Share Internet connections via gateway.
- Peer-to-peer neighborhood applications.
- Serious opportunities in developing countries, rural areas.

Metro-Scale Mesh Network

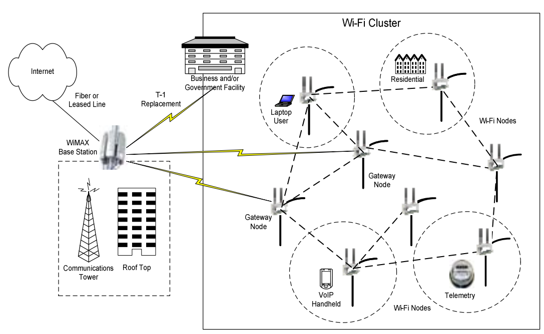

Photo Credit:
Mesh Dynamics



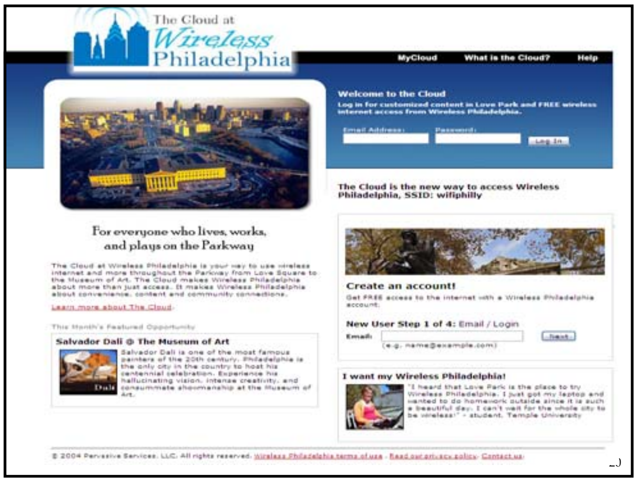
[Source: http://muniwireless.com]

- Covers an entire metropolitan area.

Wireless Philadelphia



[Source: City of Philadelphia, Mayor's Office of Information Services www.wirelessphiladelphia.org]



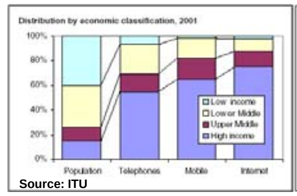
Digital Gangetic Plane Project (India)

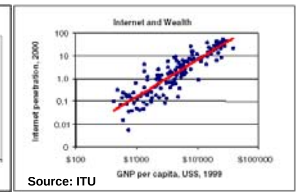

- Long range wifi links (several Km).
- Range extension using directional antennas.

[Courtesy: Vishnu Pradha, Media Lab, Asia]

21

Addressing the Digital Divide





- Internet penetration positively correlated with per capita GNP.
- Need affordable and fast last mile connectivity.
- Tremendous opportunities in developing countries.

22

Many Service Models for Outdoor Mesh

- Private ISP (paid service)
- City/county/municipality efforts
- Grassroots community efforts

- May be shared infrastructure for multiple uses
  - Internet access
  - Government, public safety, law enforcement
  - Education, community peer-to-peer

23

EEC173B/ECS152C, Spring 2009

Wireless Mesh Networks
- Introduction
- Flow Control Issues
- Rate Adaptation

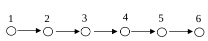
Motivation

- "Exposed Terminal Interference" is known to cause constant route breakages, which leads to reduction in the throughput of ad hoc and sensor networks based on CSMA/CA MAC
- Another problem that causes severe throughput and energy degradation is due to CONGESTION!
- The current state of the art:
  - Packet transmission are regulated at higher layers (e.g. transport layer)
  - MAC only regulates the transmission based on probability of medium contention
  - MAC is isolated from the upper layers and just performs its function (it is unaware of the states in the upper layer); buffer overflow is transparent to MAC !!

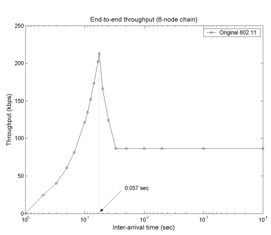
Metrics considered in this work..

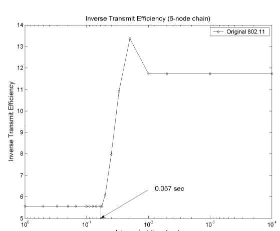
- End-to-end Throughput
- Transmission Cost
  - measures the amount of bits expended by the nodes in the system to transmit a single data bit from the source to the destination

Chain setup



- Single flow



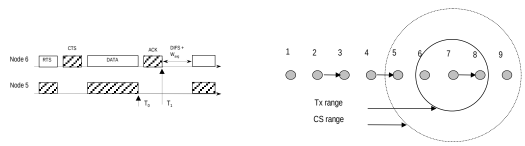


Single TCP flow

- Distance between link = 200m;
- Simulation time - 40 seconds
- Packet inter-arrival time for CBR = 0.001sec
- Packet size – 1500 bytes
- TCP Reno

Throughput (S) in Kbps	Normal 802.11; With NAV;	
	S	
TCP - 10 nodes	91.104	
TCP - 8 nodes	107.016	
TCP – 5 nodes	128.232	
TCP – 3 nodes	384.072	

Why Congestion Happens?



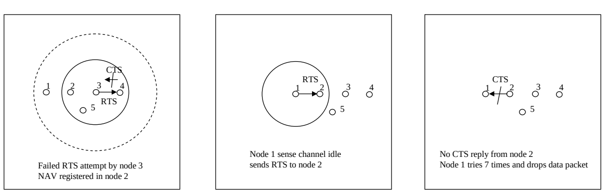
- This problem occurs even if the CS range = Tx range
- Congestion will still occur even if we use 2-way handshake
- Intra-flow interference!

Causes of Performance Degradation

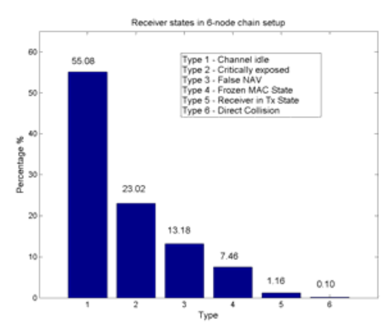
- Channel idling
- Exposed terminal
- False NAV
- Frozen MAC
- Receiver in Tx state
- Direct collision

False NAV problem

- In the original 802.11, a node in the Tx range, that receives a NAV from a RTS frame keeps silent for the entire duration of the NAV..
- This happens irrespective of whether the node that sent out the RTS receives a valid CTS.
- This is detrimental to the throughput because nodes that can receive a valid packet will ignore the packet
- This causes some senders to experience the maximum retry limit even when the channel is idle.



Breakdown of Performance Degrading Factors



EEC173B/ECS152C, Spring 2009

Wireless Mesh Networks

- Introduction
- Flow Control Issues
- Rate Adaptation

Multiple Transmission Rates

- IEEE 802.11 specifications mandate multiple transmission rates at the PHY layer that use different modulation and coding schemes
  - 802.11b : 1, 2, 5.5, 11 Mbps
  - 802.11a : 6, 9, 12, 18, 24, 36, 48, 54 Mbps
  - 802.11g: 1, 2, 5.5, 6, 9, 11, 12, 18, 24, 36, 48, 54 Mbps

Rate Adaptation

- Exploits the multi-rate capability
- A sender must select the best transmission rate and dynamically adapt its decision to the time-varying and location-dependent channel quality
- Plays a critical role in the overall performance in 802.11-based mesh networks
- Goal: Select the rate that will give the optimum throughput for given channel conditions
- Unspecified by the standards

Two Aspects

- Channel quality estimation
  - Measure the time-varying state of the wireless channel and generate predictions for future
  - Metrics: SNR, signal strength, symbol error rate, bit error rate, short-term and long-term predictors
- Rate selection
  - Select an appropriate rate based on the prediction
  - Common approach – threshold selection
  - Effectiveness depends on accuracy of estimation

Auto Rate Fallback (ARF)

- Each sender attempts to use a higher transmission rate after a fixed number of successful transmission at a given rate and switches back to a lower rate after 1 or 2 consecutive failures
- Drawbacks:
  - Cannot adapt effectively for fast varying channel conditions
  - For very slow varying channel conditions, the number of retransmissions attempts would decrease the application throughput

37

Receiver-Based Auto Rate (RBAR)

- Mandates an RTS/CTS exchange; the receiver compares the SNR of the received RTS frame to threshold values calculated a priori and selects a rate for the upcoming transmission
- The transmission rate is sent back through CTS packet
- The RTS, CTS, and data frames are modified, and the NAV is updated accordingly
- Drawbacks:
  - Needs changes in the 802.11 standards
  - SNR variations make the rate estimations inaccurate
  - Requires RTS/CTS exchange – performance hit!

38

Adaptive ARF (AARF)

- Exploits the inability of ARF to stabilize for long periods
- AARF continuously changes the threshold at runtime to better reflect the channel conditions
- Uses the concept of binary exponential backoff (BEB)
  - When the transmission of a probing packet fails, the number of required successful transmission is doubled.

39

Robust Rate Adaptation Algorithm (RRAA)

- Goals:
  - Should maintain stable rate behavior and throughput performance in the presence of mild, random channel variations
  - Should respond quickly to significant channel changes
- Ideas:
  - Uses *short-term loss ratio* to assess the channel and opportunistically adapt the transmission rate to dynamic channel variations
  - Leverages the RTS option in an adaptive manner to filter out collision losses with small overhead

40

RRAA Modules

- Loss Estimation
  - Assess channel condition by keeping track of frame loss ratio within a short time window
- Rate Change
  - Achieved through the use of estimation window size, maximum tolerable loss threshold, opportunistic rate increase threshold
- Adaptive RTS Filter
  - Turn RTS on or off based on the previous successful or unsuccessful frame transmission
  - Suppresses collision losses when it estimates the loss ration

41