Overview

- Ad hoc networking concept
- Proactive versus reactive routing
- Proactive, table based routing: DSDV
- Reactive routing DSR
- Geographic routing: GPSR
- Wireless link metrics
- Ad hoc networking examples

Greedy Perimeter Stateless Routing (GPSR)

- Use positions of neighboring nodes and packet destination to forward packets
  - No connectivity or global topology is assumed – no forwarding or path information anywhere!
  - Nodes are assumed to know their location
  - Need a mechanism for address-to-location look up

- Two forwarding techniques is used
  - Greedy forwarding, if possible
  - Perimeter forwarding, otherwise

GPSR – Greedy forwarding

- A sender/forwarder x chooses to forward to a neighbor y such that \( d_{xy} + d_{yD} \) is minimum
GPSR – Perimeter forwarding

- What happens if a node does not have a neighbor that is closer to the destination?
- Right Hand Rule: you forward the packet to your first neighbor clockwise around yourself
  - Traverse an interior region in clockwise edge order
  - Guaranteed to reach a (reachable) destination for planar graph

These sequence of edges traversed is termed as PERIMETER

Many Other Variants

- Hybrid approaches mix different solutions
  - Use proactive routing for nearby nodes for reactive routing for far nodes
  - Combine source routing with distance vector (AODV)
- Hierarchical: create a hierarchy of clusters
  - Improve scalability by reducing routing overhead
  - Can use different protocols for intra and inter cluster
- Many proposals for optimizations
  - Links use different frequencies, multiple radios, etc.
  - Link metrics that consider interference level, ...
- Best solutions is highly context dependent: density, traffic load, degree of mobility, ...

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Link Metric

- Routing protocols for wired networks tend to use very simple link metrics
  - Hop count (all links have cost of 1) or simple integers
  - Performance of wired links is predictable!
- Wireless links can be very different and their performance can change unpredictably
  - Hop count is a bad idea – why?
- Some links are so bad they are not really links
- Solution: Require a minimum PDR to qualify as a link
  - PDR = Packet Delivery Rate
- Is that a sufficient solution?
Factors Influencing “Link Quality”

- Signal strength and quality: affects the bit rate used for packets
  » Bit rate affects the transmit time of packets
- Number of retransmissions needed to deliver packets
  » Retransmissions delay packets and use up more bandwidth
- Interference from nearby nodes
  » Interference limits the transmission opportunities a node has, i.e., it can take longer to get channel access
  » Some links may also face more hidden and exposed terminal problems

ETX: Minimize Number of Transmissions

- Measure each link’s packet delivery probability with broadcast probes
  » Must also measure the reverse link – ACKs must be received too for a transmission to be successful!
  \[ P(\text{delivery}) = \frac{1}{d_r \cdot d_t} \]
- The link ETX is the average number of transmissions needed to deliver a packet
  \[ \text{Link ETX} = \frac{1}{P(\text{delivery})} = d_r \cdot d_t \]
- Route ETX = sum of link ETX
  » Pessimistic: not all links interfere with each other
- ETX only considers some factors: bit rate, short probes under-estimate loss rate, traffic load, hidden terminals, …

ETX: Sanity Checks

- ETX of perfect 1-hop path: 1
- ETX of 50% delivery 1-hop path: 2
- ETX of perfect 3-hop path: 3

- So, e.g., a 50% loss path is better than a perfect 3-hop path!
  » A PDR threshold would probably fail here …
- But this ignores many real world factors!
  » Examples?

ETT: Expected Transmission Time

- The bit rate used for transmission can have a very big impact on performance
  » E.g., 802.11a rates range from 6 to 54 Mbps
  » Bit range even much larger for more recent standards (but ad hoc only standardized up to
- ETT – expected transmission time
  \[ \text{ETT} = \frac{\text{ETX}}{\text{Link rate}} \]
  \[ = \frac{1}{P(\text{delivery}) \cdot \text{Bit Rate}} \]
- Accounts for all major factors
  » Traffic load and competition for transmission time by nearby links is still not accounted for
  » Must update metric periodically
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Examples of Ad Hoc Networks

• Mesh networks, for example for last mile access to the home
  » Reduces infrastructure cost significantly (no wires!)
  » Routers are stationary, powered – simplifies routing
  » Capacity is limited by may be ok in, e.g., rural areas
  » 802.11s is a standard for WiFi mesh networking
• Vehicular networks: cars talk directly to each other, e.g., for safety applications
  » No need for infrastructure, but security is a challenge
  » Routing is very challenges (survey topic)
• Sensor networks (lecture, survey topic)
  » Emphasis on low power and low traffic volume
  » Ad hoc is an attractive solution for dense deployments

Summary

• Ad hoc networks face many challenges
  » Bad links, interference, mobility, …
  » Makes routing very challenging
  » Limited support: hardware and driver limitations
• Many proposals!
  » Proactive routing: variants of “wired” routing protocols
  » Reactive routing: only establish a path when it is needed
  » Geographic routing: use destination location info only
  » Many variants and extensions
• Specific challenges depend on the application domains
  » Mesh versus vehicular
  » Active area of research

Outline

• Brief history
• 802 protocol overview
• Wireless LANs – 802.11 – overview
• 802.11 MAC, frame format, operations
• 802.11 management
• 802.11 security
• 802.11 power control
• 802.11*”
• 802.11 QoS
Power Management

- Goal is to enhance battery life of the stations
- Idle receive state dominates LAN adapter power consumption over time
- Allow stations to power off their NIC while still maintaining an active session
- Different protocols are used for infrastructure and independent BSS
  » Our focus is on infrastructure mode

Power Management Approach

- Idle station to go to sleep
- AP keeps track of stations in Power Savings mode and buffers their packets
  » Traffic Indication Map (TIM) is included in beacons to inform which power-save stations have packets waiting at the AP
- Power Saving stations wake up periodically and listen for beacons
  » If they have data waiting, they can send a PS-Poll to request that the AP sends their packets
- TSF assures AP and stations are synchronized
  » Synchronizes clocks of the nodes in the BSS
- Broadcast/multicast frames are also buffered at AP
  » Sent after beacons that includes Delivery Traffic Indication Map (DTIM)
  » AP controls DTIM interval

Infrastructure Power Management Operation

Some IEEE 802.11 Standards

- IEEE 802.11a
  » PHY Standard: 8 channels: up to 54 Mbps: some deployment
- IEEE 802.11b
  » PHY Standard: 3 channels: up to 11 Mbps: widely deployed.
- IEEE 802.11d
  » MAC Standard: support for multiple regulatory domains (countries)
- IEEE 802.11e
  » MAC Standard: QoS support: supported by many vendors
- IEEE 802.11f
  » Inter-Access Point Protocol: deployed
- IEEE 802.11g
  » PHY Standard: 3 channels: OFDM and PBCC: widely deployed (as b/g)
- IEEE 802.11n
  » Suppl. MAC Standard: spectrum managed 802.11a (TPC, DFS): standard
  » IEEE 802.11i
  » Suppl. MAC Standard: Alternative WEP: standard
  » IEEE 802.11n
  » MAC Standard: MIMO: standardization expected late 2008
**IEEE 802.11 Family**

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Release Data</th>
<th>Freq.</th>
<th>Rate (typical)</th>
<th>Rate (max)</th>
<th>Range (indoor)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legacy</td>
<td>1997</td>
<td>2.4 GHz</td>
<td>1 Mbps</td>
<td>2Mbps</td>
<td>?</td>
</tr>
<tr>
<td>802.11a</td>
<td>1999</td>
<td>5 GHz</td>
<td>25 Mbps</td>
<td>54 Mbps</td>
<td>~30 m</td>
</tr>
<tr>
<td>802.11b</td>
<td>1999</td>
<td>2.4 GHz</td>
<td>6.5 Mbps</td>
<td>11 Mbps</td>
<td>~30 m</td>
</tr>
<tr>
<td>802.11g</td>
<td>2003</td>
<td>2.4 GHz</td>
<td>25 Mbps</td>
<td>54 Mbps</td>
<td>~30 m</td>
</tr>
<tr>
<td>802.11n</td>
<td>2008</td>
<td>2.4/5 GHz</td>
<td>200 Mbps</td>
<td>600 Mbps</td>
<td>~50 m</td>
</tr>
</tbody>
</table>

**802.11b Channels**

- In the UK and most of EU: 13 channels, 5MHz apart, 2.412 – 2.472 GHz
- In the US: only 11 channels
- Each channel is 22MHz
- Significant overlap
- Non-overlapping channels are 1, 6 and 11

**802.11b Physical Layer**

- FHSS (legacy)
  - 2 & 4 GFSK
  - Using one of 78 hop sequences, hop to a new 1MHz channel (out of the total of 79 channels) at least every 400milliseconds
- DSSS (802.11b)
  - DBPSK & DQPSK
  - Uses one of 11 overlapping channels (22 MHz)
  - 1 and 2 Mbps: multiply the data by an 11-chip spreading code (Barker sequence)
  - 5.5 and 11 Mbps: uses Complementary Code Keying (CKK) to generate spreading sequences that support the higher data rates
    - Spreading code is calculated based on the data bits

**802.11a Physical Channels**
802.11a Modulation

- Use OFDM to divide each physical channel (20 MHz) into 52 subcarriers (20M/64=312.5 KHz each)
  - 48 data, 4 pilot

- Adaptive modulation
  - BPSK: 6, 9 Mbps
  - QPSK: 12, 18 Mbps
  - 16-QAM: 24, 36 Mbps
  - 64-QAM: 48, 54 Mbps

802.11a Discussion

- Uses OFDM in the 5 GHz band
  - Also used by 802.11g in 2.4 GHz (next slides)
- What are the benefits of 802.11a compared with 802.11b/g?
  - Greater bandwidth (up to 54Mb)
    - 54, 48, 36, 24, 18, 12, 9 and 6 Mbs
    - 802.11g (next slide) offers same benefit
  - Less potential interference (5GHz)
  - More non-overlapping channels
- But it does not provide interoperability with 802.11b, as 802.11g does
  - Cannot fall back to lower rates (not an issue in practice)
  - Cards typically support a and g

Going Faster: 802.11g

- 802.11g is the same as 802.11a, but in 2.4GHz band
  - Falls back to 802.11b for the lower rates (1, 2, 5.5, 11 MHz)
  - Uses 802.11a OFDM technology for new rates (6 Mbs and up)
- Creates an interoperability problem since 802.11b cards cannot interpret OFDM signals
  - Interoperability mode: protection mechanism in hybrid environment: Send CCK CTS before OFDM packets or use(optional) hybrid packet
  - Can also run an 802.11n only network – reduces overhead

Spectrum and Transmit Power Management Extensions (802.11h)

- Support 802.11 operation in 5 GHz band in Europe: coexistence with primary users
  - Radar: cannot use bands if a radar is nearby
    - Allows opening up 11 more bands in 5 GHz band
  - Satellite: limit power to 3dB below regulatory limit
- Dynamic Frequency Selection (DFS)
  - Detect primary users and adapt
  - AP notifies stations to switch channel at some point in time
- Transmit Power Control (TPC)
  - Goal is to limit interference – also controlled by AP
- DFS and TPC have broader uses such as range and interference control, reduced energy consumption, automatic frequency planning, load balancing, ..
IEEE 802.11e

- Original intent was that 802.11 PCF could be used to provide QoS guarantees
  - Scheduler in the PCF priorities urgent traffic
  - But: overhead, "guarantees" are very soft
- 802.11e Enhanced Distributed Coordination Function (EDCF) is supposed to fix this.
  - Provides Hybrid Coordination Function (HCF) that combines aspects of PCF and DCF
- EDCF supports 4 Access Categories
  - AC_BK (or AC0) for Back-ground traffic
  - AC_BE (or AC1) for Best-Effort traffic
  - AC_VI (or AC2) for Video traffic
  - AC_VO (or AC3) for Voice traffic

Service Differentiation Mechanisms in EDCF

- The two types of service differentiation mechanisms proposed in EDCF are:
  - Arbitrate Inter-frame Space (AIFS) Differentiation
    - Different AIFSs instead of the constant distributed IFS (DIFS) used in DCF.
    - Back-off counter is selected from \([1, \text{CW[AC]}+1]\) instead of \([0,\text{CW}]\) as in DCF.
  - Contention Window (CWmin) Differentiation
    - Different values for the minimum/maximum CWs to be used for the back-off time extraction.

Mapping different priority frames to different AC

- Each frame arriving at the MAC with a priority is mapped into an AC as shown in figure below.

![Mapping different priority frames to different AC](image-url)
Other 802.11 MAC Improvements

- **TXOP** - Transmission opportunity (TXOP) is an interval of time during which a back-off entity has the right to deliver multiple MSDUs.
  - A TXOP is defined by its starting time and duration
  - Announced using a traffic specification (length, period)
  - Can give more transmission opportunities to a station
  - Can also limit transmission time (e.g. for low rate stations)

- **CFB** - In a single TXOP, multiple MSDUs can be transmitted.
  - “Contention Free Burst” (CFB)
  - Can use a block acknowledgement

802.11p: Vehicular Networking

- **Basis for Dedicated Short Range Communication (DSRC)**
  - Connecting vehicles and road side units
  - Dedicated band at 5.9 GHz
  - Higher layers of protocol stack defined by WAVE
  - Primary driver is vehicular safety such as reporting accidents, ...

- **Differences with 802.11a**
  - Channels are 10 MHz wide; this means that symbol times are twice as long (more robust to ISI)
  - Communication is between stations that are not associated or authenticated (no BSS ID)