Wireless Networking Projects

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[Logo images for University of Maryland and MIND lab]
Activities

- WLAN Location Determination
  - Horus Technology
  - Nuzzer Technology for passive determination of location
- Energy Efficient On-Demand Routing
- Enhancements of BEB in 802.11 in Noisy Environment
- Traffic Characterization- 802.11b MAC layer
- Z-Iteration Time-Step Simulation
Location Determination

Horus Technology

• Signal-Strength (RSSI) Based Approach

• A few commercially available, e.g. Ekahau, PanGo
  • A few research groups working on it

• Horus results significantly better than all

• Licensed by Fujitsu and deployed in a shopping center application
Comparison With Other Systems: RADAR

Average=1.38
Average=29.79
Comparison With Other Systems:

<table>
<thead>
<tr>
<th></th>
<th>Average</th>
<th>Stdev</th>
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<tbody>
<tr>
<td>Ekahau</td>
<td>10.400</td>
<td>5.692</td>
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<tr>
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<td>4.257</td>
<td>3.582</td>
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<tr>
<td>Horus New</td>
<td>2.14995</td>
<td>1.619684</td>
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Horus
- Large Open Hall 150’ by 150’
Passive Determination of Location
Nuzzer Technology

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Problem

• Can the location of a person be determined without the person carrying an active device, e.g. NIC or RFID?

• The presence of a person affects the RF field and thus the RSSI.
Results to date

• Conducted controlled experiments in a vault – no outside RF interference
• Placed two APs and two laptops with NICs at selected locations
• Initially nobody in the room
• Then a person stands at 4 locations which are 3 feet apart.
Experimental Setup and Results

Experiment 1

Experiment 2

Experiment 3

Experiment 4

Training set = SET1
- total: 4920
- correct: 4410
- err: 510
- %err: 10.36585%

Training set = SET2
- total: 4920
- correct: 4243
- err: 677
- %err: 13.76016%
Energy Efficient Routing
Energy-Efficient On-Demand Routing Protocols

• Motivation
  – Energy is a scarce resource
  – Transmissions consumes large portion of node energy
  – Noise $\rightarrow$ Error Rate $\rightarrow$ Retransmission $\rightarrow$ Energy Consumption

• To reduce energy consumption, we need reduce the number of retransmissions.
• In ad hoc networks, paths with low number of retransmissions along the hops minimize the end-to-end energy consumption.

• Develop mechanism for AODV protocol using IEEE 802.11 as MAC layer to construct energy-efficient paths.
Link Cost with 802.11 Fragmentation

- Cost of transmitting $L$ bits using fragments of $k$ bits:

$$C = v \times (o_1 + k) \times \frac{L}{k - o_2} \times \frac{1}{(1 - p)^k}$$

$v$: transmission energy per bit

$p$: bit error rate over the link

$o_1$: bits: transmitted separately with each fragment and are not considered as a part of the fragment bits (e.g., PLCP preamble bits, PLCP header, ACK frame).

$o_2$: transmitted within each fragment (e.g., frame header, frame CRC).

- Optimum fragment size is:

$$k^* = \frac{(o_2 - o_1)\beta - \sqrt{(o_2 - o_1)^2 \beta^2 - 4\beta(o_1 + o_2 - o_1 o_2 \beta)}}{2\beta}$$

where $\beta$ is $\ln(1 - p)$
Simulation Results

Grid topology, UDP flows, Fixed Noise

Mobile topology (20 m/s), UDP flows, Fixed Noise
Enhancing 802.11 for Noisy Environments
Enhancement of IEEE 802.11 DCF in Noisy Environments

- In noisy environments, large number of unsuccessful transmissions are due to noise corruption (error rates).
- IEEE 802.11 doesn’t differentiate between packet loss due to *packet collision* or *packet error*.
  -> BEB doubles CW range in the cases of packet errors -> unnecessary large idle slots -> performance degradation

- Analytically study the performance of the IEEE 802.11 performance in noise environment.
- Propose an enhanced BEB mechanism to enhance the standard 802.11 BEB mechanism (BEB$_{naive}$) to be capable of differentiating between the collision loss and the error loss
  -> BEB will double the contention window *only* for the case of the collision (BEB$_{smart}$).
**BEB\text{smart} Implementation (Basic access)**

- Using a Markov chain model to model BEB, we calculate the probability a node transmits in a randomly chosen time slot, $\tau$.
- **Mechanism:**
  - Each node case calculate $\tau_{\text{ideal}}$
  - Each node maintains a parameter $p$, initially set to zero.
  - When ACK is missing, nodes doubles the contention window with probability $(1 - p)$ and resets its $CW$ to $W_0$ with probability $p$.
  - Each node measures its $\tau$ every $T$ time slots.
  - If $\tau > \tau_{\text{ideal}}$ → too frequent transmissions → few idle slots → Decrease $p$ by $\delta$
  - If $\tau < \tau_{\text{ideal}}$ → too few transmissions → large idle slots → Increase $p$ by $\delta$
Simulation Results

- 10 nodes transmitting data packets of size 500 bytes at data rate 22Mbps where $\delta = 0.01$.

- $p$ is the percentage of the dropped packet assigned to the noise corruptions only.

\[
p = \frac{(1 - p_c)p_e}{p_c + p_e - p_c p_e}
\]

- From the maintained parameter $p$, a node can estimate its packet error rate $p_e$
802.11 DCF Location Aware

- Problem Statement:
  - Contention based MAC protocols are based on CSMA.
  - A node transmits a packet if and only if the medium is sensed to be free.
  - A node *should not block* its transmission when the medium is *busy*, but it *has to block* its transmission only when *its transmission corrupts* the ongoing transmission(s).

- Capture phenomena:
  - Successful reception of the stronger frame in a collision
  - A frame is captured if its detected power $P_r$ exceeds the joint interfering power $P_i$ of $I$ interfering powers by a minimum capture ratio $\alpha$

$$P_r > \alpha \sum_{i=1, i \neq r}^{N} P_i$$
Analysis of Capture Effect

- We analytically studied the probability a node, detecting ongoing transmissions, can transmit without corrupting any of these ongoing transmissions.

\[
P = \left[ 1 - \frac{\tau}{T} + \frac{\tau}{T} \int_0^1 \frac{A(x)}{\pi R^2} \frac{2x}{I^2} \, dx \right] \delta \pi I^2 - \left[ 1 - \frac{\tau}{T} \right] \delta \pi I^2
\]

\[
A(x) = \int_0^{\min(R, \frac{x}{\sqrt{\alpha}})} 2(\pi - \arccos \left( \frac{x - x^2 - m^2 + (\sqrt{\alpha}m)^2}{2x} \right)) \, m \, dm
\]

![Graph showing the probability analysis with different assumptions for \( \tau/T \).](image)
802.11 MAC Traffic Characterization

MacTC
Measurement Setup

• Location: 4th floor, A.V. Williams Bldg
• Duration: Feb 9 (Monday) 0 am – Feb 22 (Sunday) 12 pm (2 weeks)
• Target traffic: Wireless LAN traffic of one umd AP (at Rm. 4149) on channel 6
• Methodology:
  – Three wireless sniffers at Rm. 4140 (closest to the AP), Rm. 4166, and Rm. 4132
  – Wireless sniffers capture MAC traffics
  – Merging three sniffers to reduce the measurement losses
MacTC

MAC Traffic Characterization

1. MAC Traffic
   - Number of frames, Bytes
2. MAC Transmission Errors
   - Retransmissions / number of frames
3. MAC Frame Types
4. MAC Frame Size Distribution
5. PHY Layer
   - Data rate and signal strength
- From-AP and To-AP traffics have the same shape.
- From-AP has 5 (12) times larger than To-AP in number of frames (in bytes)
- Maximum throughput within 1.5 Mbps (because channel 6 is shared with two other APs)
Transmission Errors

- TX-Error = Number of Retransmissions / Number of Frames
- Retransmissions examined using MAC Retry field in MAC header at each frame
- More TX-errors in To-AP traffic than From-AP traffic. Why?
  - AP has better H/W than STA.
  - STAs do not adapt sending data rate (possibly an anomaly).
- Higher variability of TX-error in To-AP traffic than From-AP traffic
MAC Frame Types

- Out of Data/Management frames, Data frames (50.7%) and Beacons (46.5%) dominate.
- From-AP traffic has larger avg. frame size (410 Bytes) than To-AP traffic (165 Bytes).
- (Re-)Association Request is sent at 1 Mbps but (Re-) Association Response is sent at 11 Mbps.
- Some Management frames experience severe retransmissions (up to 65%)
  - Probe Response, Re-Association Request, and Power-Save.
Anomalies of 802.11 Protocol
Severe ReTX of Management Frames

• Reasons
  – Probe Response: STA sent Probe Request and quickly switched to other APs on other channels.
  – Re-Association Request: mismatch of STA’s data rate (1Mbps) and AP’s (11Mbps).
  – Power-Save Poll: STA in sleep mode cannot synchronize with AP.
PHY Layer

- Examine Data rate and Signal Strength, which we can obtain in Prism2 header in each frame.
- In From-AP traffic, AP sends most frames at low data rate.
- In To-AP traffic, each STA sends most frames at high data rate.
- Observe no correlation between STA’s sending data rate and signal strength received by the AP.
- (Anomaly) Client STAs do not adapt data rate according to the signal condition.
No Correlation between STA’s Data Rate and Signal Strength Received by AP
Time-Step Network Simulation

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Introduction

• Goal: Fast accurate performance evaluation tool for computer networks
  – Handles general control schemes (time- and state-dependent)

• Packet-level simulation:
  – Handles general control scheme precisely but prohibitively expensive

• Steady-state exact queuing models
  – Handles only simple models; no transient metrics

• Time-dependent exact queuing model
  – Only very simple systems; no state-dependent control

• Time-dependent stochastic model (fluid and diffusion approximations)
  – Handles time-dependent, but not state-dependent control

• Approach: Combine discrete-event simulation with diffusion approximation
  – Accurate, inexpensive, handles time- and state-dependent control
Hybrid time-step simulation

- Consider a single communication link
- Want to generate sample paths efficiently

$N(t)$

Sample path
Hybrid time-step simulation

- Divide time axis into small intervals $\Delta$
- For interval $[t_0, t_0 + \Delta]$ choose $N(t_0 + \Delta)$ randomly based on $N(t_0)$ and arrival and service processes
- Repeat for successive time intervals
Hybrid time-step simulation

- Time/state dependent sources undergo state changes at every $\Delta$ ($\Delta \approx$ time scale of upper-layer control, e.g., RTT for TCP)
- Discrete events are not packet transmissions but time steps
- Captures state-dependent control because sample-path is explicit
- Diffusion approximation [Kolomogorov] to obtain $\text{Prob}[N(t+\Delta) \mid N(t)]$
  - Arrival and service processes defined by time-varying mean and variance
Extension to network of queues

- For each interval \([ t, t + \Delta ]\)
  - Approximate queue departure and internal flows by renewal processes characterized by the first two moments
  - Routing probabilities determined by queue occupancy
- Formulate equations for merging and splitting flows
Example: Queue size prob density

- GI/D/1/40 queue, $\lambda=800$, $c_A=1$, and $\mu=810$, $N(t) = 2$, $\Delta=0.05$
Example: TSS vs. packet-level simulation

- GI(t)/D/1/300 queue, uniform arrival dist, \( \mu = 1900 \)
- Computation time of one run:
  - 10 Mbps link - simulation 1.5 sec., hybrid 0.1 sec.
  - 100 Mbps link - simulation 15 sec., hybrid 0.1 sec.
- Time-step simulator converges faster due to smaller probability space
Time-step simulation - Conclusions

- Time-stepped simulation using diffusion approximation
- Fast and accurate alternative to packet-level (discrete-event) simulation
- Computational complexity not affected by increasing link bandwidth
- Handles state-dependent control schemes
- Yields time-dependent evolution of performance metrics

Future research plans
- Extend queue model to handle wireless links (802.11)
- Extend to other router disciplines (RED, AQM, CBQ)
- Optimize numerical computation
- Detailed comparisons with simulation for large networks