DIRAC: A Software-based Wireless Router System

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Overview

• Background
• Issues
• Motivation
• Design
• Implementation
• System Evaluation
• Conclusions
Background – Topology

- Typical 802.3/802.11 mixed network
  - Wireless “last hop”
- Multiple mobile hosts/AP, multiple APs/AR
- Hosts roam between APs
- Moderate Load/Traffic
- Wireless link is the bottleneck
Issues

• New Internet services, such as packet filtering, intrusion detection, level-$n$ switching, and packet tagging
  – But current routers do not work well in a wireless network
• Protocols have been proposed to achieve above goals
  – Use link-layer information feedback, such as channel errors and link handoff events
  – Work in simulation, not in practice
  – Why? System framework missing
Motivation

• Significant increase in demand for wireless services
  – Carrier-grade data delivery, security, QoS, VoIP, interactive multiplayer gaming, multimedia IM

• Protocol solutions devised, but a system support framework is needed
Motivation (cont.)

• Some services require inter-cell coordination across multiple APs
  – Roaming users use resources in both the time and spatial domains
  – Wireless resource management schemes must coordinate decisions among neighboring cells

• DIRAC seeks to enable inter-cell coordination, to enable seamless services and minimize inter-cell channel interferences
Motivation (cont.)

• Typical wireless network has a large number of APs, posing the challenge of minimizing software and hardware costs and configuration management

• Must intelligently partition software between APs and AR, with most complexity at centralized router

• Software-based frameworks provide extensibility and flexibility, accelerates implementation, experimentation, and deployment
Design – Alts

• Alternative Architectures
  – AP delivers 802.11 MAC functionality only (current practice)
  – Intelligent AP: adaptive link-layer services implemented at each network-layer oblivious access point
  – Ubiquitous router: turns each AP into a router
Design – DIRAC

Distributed Router Architecture

Oblivious Approach
- Current practice
- No interaction between AR ↔ APs
- Difficult to implement wireless router services

Integrated Approach
- Convert every AP to AR
- Collapse L2 and L3 layers
- Increased Cost
- Complicated Management
Design – RC & RAs

- Central Router Core (RC)
- Multiple Router Agents (RAs)
- Interaction constrained:
  - Events
  - Statistics
  - Actions
Design – RA

• RA is link-layer specific and light-weight
  – Serves as a messenger between the RC and the link-layer device driver
  – Communication between RC and RA via standard UDP sockets
Design – RC

- RC carries out regular router operations for each wireless subnet
- Forwarding engine addresses wireless link issues
  - Accepts link-layer info and performs adaptive forwarding operations
  - Can request *actions* of RAs
  - Accepts *events* from RAs
- RC contains a DIRAC control engine
Design – RC/RA Interaction

• *Events* denote occurrences of asynchronous link-layer activity
  – Use: mobility-aware decisions

• *Statistics* report latest channel quality information
  – Use: channel-adaptive packet delivery

• *Actions* enforce RC policies
Design – Router Core

Adapted control-plane management protocols and data-plane forwarding engine to be wireless and mobility aware
Design – RC Ctrl Plane

• Routing and management protocols
• Control engine
  – OS support to enable cross-layer interactions
  – Four components: EventProcessor, StatisticsMonitor, ActionProcessor, and RegistrationDB
Design – RC Data Plane

• Allows components to implement channel-adaptive protocols, based on link-layer feedback
  – DIRAC does not stipulate the specific choice of protocol

• Forwarding engine provides asymmetric operations for uplink and downlink
  – Downlink proactive, uplink reactive
Design – Router Agent

• Bridges interaction between RC and wireless link layer, a light-weight messenger between layer-2 of the AP and layer-3 of the RC
  – Monitors state and channel quality
  – Sends event messages to RC
  – Intercepts action commands from RC
Implementation – Router Core

• IPv6
• Set of *Click Elements* within the *Click Router* framework under Linux
  – Developed 13 new Click elements
Implementation – Router Agent

• OpenAP platform

• WL11000 SA-N board
  – Wired Ethernet controller (NE2000)
  – AMD ELAN SC400 @ 33MHz
  – 1MB of Flash RAM
  – RS-232 serial interface

• Wireless PCMCIA 802.11b

• Embedded Linux 2.4.17
Implementation – RA (cont)

- Wireless Linux Extensions for monitoring
- 802.11 frame snooping for events
- Customized 802.11 management frames to enforce actions
Implementation – RC/RA Comm

• Simple UDP protocol for exchanging information
  – Packet format: Type, Subtype, Len, Data
    • Type: Statistic, Event, Action, Registration
    • Subtype: Specific instance of type
    • Length: in bytes of Data field
    • Data: “Value” - actual information
Implementation – Prototype Wireless Services

• Link-Layer Informed Fast Handover
  – Reduced latency and minimized loss when roaming between subnets

• Channel-Adaptive FEC-Based Downlink Forwarder
  – Addresses wireless Head-of-Line blocking problem

• Link-Layer Assisted Uplink Policing
  – Temporarily squelches aggressive uplink flows
System Evaluation – Overhead

RC:

- Intel Pentium III @ 900MHz
- 256 MB RAM
- Intel Ethernet Express 10/100

- Performance scaled linearly based on # of APs and # of mobile clients

<table>
<thead>
<tr>
<th>Operation</th>
<th>Time (ns)</th>
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<tbody>
<tr>
<td>Action</td>
<td>498</td>
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<tr>
<td>Event</td>
<td>1712</td>
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<tr>
<td>Statistics Report</td>
<td>32</td>
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<tr>
<td>Basic Forwarding</td>
<td>1299</td>
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</table>
System Eval – Fast Handover

- Mobile node-initiated
- No movement prediction
- 802.11 ReAssociation event as “trigger”

1. ReAssoc
2. Roam. Host!
3. Tunnel Req
4. Tunnel Est.
5. Accept!
6. ReAssoc Reply
7. Change IP/GW
## System Eval – Fast Handover Performance

<table>
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<th>Mean</th>
<th>Median</th>
<th>stdv</th>
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<tr>
<td>Tunnel Establishment</td>
<td>4.2</td>
<td>3.6</td>
<td>1.5</td>
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<tr>
<td>Additional latency to complete L2 assoc.</td>
<td>7.9</td>
<td>7.4</td>
<td>1.8</td>
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<tr>
<td>Time to send new IP/GW</td>
<td>18.6</td>
<td>18.8</td>
<td>3</td>
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<tr>
<td>Time for MN to change IP/GW</td>
<td>8.1</td>
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</table>

Latencies are in milliseconds
System Eval – FEC-based Downlink Forwarding

• RA reports channel quality to RC
  – RC determines that channel quality is not acceptable; requests disabling of retransmissions

• FEC implemented on RC
  – FEC compensates for unreliability
  – Strength of FEC adaptive to transmission rate and quality of the channel

• Nodes with a good channel do not experience packet loss
System Eval – DL Forwarding Results

<table>
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<tr>
<th>Ave. Quality</th>
<th>Stdv</th>
<th>MN1</th>
<th>MN1</th>
<th>MN3</th>
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<td>15.02</td>
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<td>9980</td>
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<td>20.17</td>
<td>1.54</td>
<td>9943</td>
<td>9903</td>
<td>9985</td>
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</table>

<table>
<thead>
<tr>
<th>Ave. Quality</th>
<th>Stdv</th>
<th>MN1</th>
<th>MN2</th>
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**FEC-Based Approach**

**Link-Layer Retransmissions**

#packets received by each node, out of the 10,000 sent
System Eval – Policing

- Two mobile nodes, MN1 and MN2, competing for wireless channel
  - MN1 running a 128kbp streaming MP3 server over TCP
  - MN2 sourcing 3.6Mbps of UDP traffic
- Without policing, MN2 occupies the majority of the channel
  - So much so that TCP cannot maintain connection
System Eval – Policing

• With policing MN1 is protected from MN2
  – RC can instruct the AP to limit MN2’s access
  – MN2 is constantly being limited, but MN1 is now able to run to completion
Conclusions – RC

• Scales well
  – Consumes processing power less than 2.5% of standard packet forwarding cost
  – Takes less than 1us to process channel states for 50 clients per AP
  – Supports a large number of APs
    • Less than 140us required to process statistics from 50 APs, each which transmits 20 reports per second
Conclusions – Services

• Enables deploying of critical wireless network services
  – Fast handover service creates a tunnel for packet forwarding in under 10ms
  – FEC-based forwarding solves HoL blocking problem
  – Policing service protects flows
Conclusions – Summary

- Motivated by wireless-adaptive and mobility-aware service
- Two-way interaction between Access Routers & Access Points
- Enable implementation of wireless router services
- Low cost of deployment/management