PIE in the Sky: Online Passive Interference Estimation for Enterprise WLANs

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Enterprise WLAN setting

Functionalities implemented at controller
• Intrusion detection system
• Interference management (channel assignment, power control)
Enterprise WLAN setting

Functionalities implemented at controller
• Intrusion detection system
• Interference management (channel assignment, power control)

Clients

Access Point

Wireless controller

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Problems with wireless*

“The wireless is being flaky.”

“Flaky how?”

“Well my connection dropped earlier and now it seems to be slow”

“We will take a look.”

“Wait, now it seems fine.”

*Slide borrowed from Cheng et. al (Jigsaw, Sigcomm ’06)
Problems with wireless

Hidden terminals
Problems with wireless

Mismatch in data rates, slows down fast links

Rate anomaly

6 Mbps

54 Mbps

Mismatch in data rates, slows down fast links

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Problems with wireless

Increasing client density and mobility ....
Problems with wireless

Increasing client density and mobility…. 
Problems with wireless

.... changing interference patterns
Interference management in WLANs
Interference management in WLANs

Estimate Interference dynamically

Manage Interference (data scheduling, transmit power control, channel assignment)
Interference management in WLANs

Estimate Interference *dynamically*

Manage Interference (data scheduling, transmit power control, channel assignment)
How to estimate interference?

Use bandwidth tests
How to estimate interference?

Use bandwidth tests

AP-Client pair

Interferer
How to estimate interference?

1) Measure AP-Client delivery in isolation
How to estimate interference?

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Isolation delivery = 0.95
How to estimate interference?

1) Measure AP-Client delivery in isolation
2) Activate interferer and measure delivery
How to estimate interference?

Interference delivery = 0.66

1) Measure AP-Client delivery in isolation
2) Activate interferer and measure delivery
How to estimate interference?

1) Measure AP-Client delivery in isolation
2) Activate interferer and measure delivery

Link Interference Ratio (LIR) = \frac{\text{del Interference}}{\text{del isolation}}
How to estimate interference?

1) Measure AP-Client delivery in isolation
2) Activate interferer and measure delivery

Link Interference Ratio (LIR) = $\frac{0.66}{0.95} = 0.69$
How to estimate interference?

1) Measure AP-Client delivery in isolation
2) Activate interferer and measure delivery
But are bandwidth tests practical?

- Can we use bandwidth tests in live settings
  - Good accuracy – ✓
  - Network downtime required - X
  - Not scalable (~ 1 hr for 20 AP-Client pair network) - X
  - Not based on realistic rates and packet sizes – X
  - Inefficient in dynamic scenario (client mobility) – X
But are bandwidth tests practical?

- Can we use bandwidth tests in live settings
  - Good accuracy – ✓
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  - Not based on realistic rates and packet sizes – ×
  - Inefficient in dynamic scenario (client mobility) – ×

Can we estimate interference in a passive, real-time way?
PIE Outline

• Motivation
  • Conventional bandwidth tests not sufficient

• Passive Interference Estimation (PIE)
  • Polling period of PIE
  • Accuracy of PIE
  • Realistic trace replay with PIE

• Applications of PIE

• Summary
Estimating interference passively

Sniffer

Sniffer

Sniffer

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Estimating interference passively

- Sniffer could be a dedicated wireless radio
- Clocks synchronized using wired backplane

Sniffer Sniffer Sniffer Sniffer

Clocks synchronized using wired backplane
Estimating interference passively

Sniffer reports
Estimating interference passively

Sniffer reports

Timestamp, duration, rate, success
Estimating interference passively

Hidden terminals
Estimating interference passively

Hidden terminals

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Estimating interference passively

Hidden terminals
Estimating interference passively

Hidden terminals

1. Carrier sense
Estimating interference passively

Hidden terminals

1) Note timestamp, rate, duration

2. Channel free, transmit
Estimating interference passively

1) Note timestamp, rate, duration
2) Note if transmission is a success (ack received?)

3. Collision!
Estimating interference passively

Timestamp: T0
Rate: 6Mbps
Length: 1400 bytes
Success: False

Timestamp: T0 + δ
Rate: 12Mbps
Length: 600 bytes
Success: False
Estimating interference passively
Estimating interference passively

T₀
6Mbps
1400 bytes
False

T₀ + 𝛿
12Mbps
600 bytes
False

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Estimating interference passively
Estimating interference passively

T₀
6Mbps
1400 bytes
False

T₀ + δ
12Mbps
600 bytes
False

&
Estimating interference passively

T0
6Mbps
1400 bytes
False

T0 + δ
12Mbps
600 bytes
False

Red & Green clients interfere

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Estimating interference passively

Sniffer reports

Infer interference

Scenarios

Reception

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Estimating interference passively

Sniffer reports

Infer interference

Scenarios

Red and Green packets overlaps => both lost

Reception
Estimating interference passively

Sniffer reports

Infer interference

No overlap, no problem!
Estimating interference passively

Sniffer reports

Scenarios

Reception

Infer interference

Both way hidden terminals
Estimating interference passively

Sniffer reports

Infer interference

Scenarios

Reception

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Estimating interference passively

Sniffer reports

Infer interference

Red and Green packets overlap

=> Green is lost

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Estimating interference passively

Sniffer reports

Infer interference

Scenarios

Reception

One way hidden terminals

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Computing interference measure in PIE

- Compute Isolation loss rate
  - Fraction of non-overlapping packets lost
- Compute Interference loss rate
  - Fraction of overlapping packets lost
- Interference measure (LIR):
  \[
  \frac{1 - \text{Interference loss}}{1 - \text{Isolation loss}}
  \]
How quickly can PIE converge?

- Time taken by PIE to converge depends on two key properties
  - Periodicity with which sniffer reports are collected by the controller
  - Traffic patterns for the links which dictate the number of interference events captured in a time interval
How quickly can PIE converge?

- Time taken by PIE to converge depends on two key properties
  - Periodicity with which sniffer reports are collected by the controller
    - What is the minimum polling period?
  - Traffic patterns for the links which dictate the number of interference events captured in a time interval
    - How much time does PIE take under realistic access patterns?
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What is the minimum polling period?

time interval

\[ P \ P \ P \]

\[ I_1 \ I_2 \]

Time

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What is the minimum polling period?

- **time interval**
- **P**
- **I₁**
- **I₂**
- **R(I₁)**

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What is the minimum polling period?

- Time
  - Time interval
  - $P \mid P \mid P$
  - $I_1 \mid I_2$

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What is the minimum polling period?

\[ \text{time interval} \]

\[ P \quad P \quad P \]

\[ I_1 \quad I_2 \]

\[ R(I_2) \]

\[ LIR (I_1) \]

\[ R(I_2) \]

\[ \text{Time} \]

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What is the minimum polling period?

Time intervals:
- $I_1$
- $I_2$

Polling periods:
- $P$

Network diagram:
- Devices (laptops and routers)
- Connections
- LIR ($I_1$) and LIR ($I_2$)

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What is the minimum polling period?

Stability of interference measure for saturated traffic

LIR

Polling period (ms)
What is the minimum polling period?

Measure stabilizes after ~85 ms (at least 20 overlap samples)

Stability of interference measure per polling period
What is the minimum polling period?

We use a polling period of 100ms.

Stability of interference measure per polling period.
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How accurate is PIE?
How accurate is PIE?

Mean Error in LIR estimation vs. % of link-interferer pairs

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How accurate is PIE?

95% of link-interferer pairs, LIR computed by PIE is within +/- 0.1 of the value reported by BW test.
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PIE with realistic access patterns
PIE with realistic access patterns

- Evaluate PIE using realist traffic patterns on a 15 node topology (7 AP – 8 laptops)
- Each client laptop replays the traffic patterns of an actual client from a real wireless trace
- Three activity periods: heavy (> 40% medium busy), medium (40 – 20% busy), light (< 20% busy)
PIE with realistic access patterns

Time to estimate (ms)

Traffic period

0

200

400

600

800

1000

1200

Heavy

Medium

Light
Convergence is faster for higher client activity.

Even for light activity, median time of estimate LIR is less than 650 ms.
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What is the impact on WLAN applications?
What is the impact on WLAN applications?

Evaluate usefulness of PIE for an interference mitigation mechanism (data scheduling using CENTAUR – Mobicom ‘09)
What is the impact on WLAN applications?

1. Estimate interference using PIE

AP-Client pairs
What is the impact on WLAN applications?

1. Estimate interference using PIE
2. Input estimate to a centralized data scheduler
What is the impact on WLAN applications?

1. Estimate interference using PIE
2. Input estimate to a centralized data scheduler
3. Evaluate performance under dynamic scenarios
What is the impact on end users?

System Throughput (Mbps)

- Distributed
- Cent. Sched (BW)
- Cent. Sched (PIE)

Static scenario

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What is the impact on end users?

Static scenario
What is the impact on end users?

Static scenarios, PIE is comparable to BW test

System Throughput (Mbps)

- Distributed
- Cent. Sched (BW)
- Cent. Sched (PIE)

Static scenario
What is the impact on end users?

![Bar chart showing system throughput (Mbps) for different scenarios.](image)

- Distributed
- Cent. Sched. (BW)
- Cent. Sched. (PIE)

**Mobile scenario**
What is the impact on end users?

System Throughput (Mbps)

- Distributed
- Cent. Sched. (BW)
- Cent. Sched. (PIE)

Mobile scenario
What is the impact on end users?

Mobile scenarios, PIE outperforms BW test

Distributed  Cent. Sched. (BW)  Cent. Sched. (PIE)

Mobile scenario
What is the impact on end users?

- PIE can also be used to monitor production systems (like Jigsaw)
- We monitored two production WLANs
- Use testbed nodes in proximity of production APs as sniffers
- Identify hidden terminals and rate anomaly problems
What is the impact on end users?

<table>
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<th>WLANs</th>
<th>Hidden terminal cases (LIR &lt; 0.7)</th>
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- Hidden terminals are rare, but can become pain points for clients.
- Rate anomaly is more frequent, but do not cause drastic performance issues.
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Related Work

• PIE leverages techniques from Jigsaw, WIT (Sigcomm 2006) and builds on their ideas

• Focus of Jigsaw, WIT was to understand interference, ours is to compute it in real-time

• CMAP also infers interference to harness exposed terminals, but requires physical layer change

• Active techniques like Microprobing (CoNext 2008) still require downtime and do not use realistic traffic
PIE Limitations

• Does not handle non-WiFi interferer like microwaves.
• Can miss external interferers if none of the enterprise APs can listen to the interferer
• May miss client conflicts, can use client participation in PIE to enhance the system
• Interference detection techniques at the physical layer may be more accurate in some scenarios where diversity is too low for PIE to function
PIE Summary

• Online interference estimation important for interference mitigation
  • BW test incurs high overhead, requires downtime
• PIE is a passive mechanism, generates interference estimates in real time
  • Leverages centralized infrastructure to collect real time reports from APs
  • Non-intrusive with good accuracy
Thank you!

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