AccuRate: Constellation Aware Rate Estimation in Wireless Networks

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Bit-rate in Wireless Networks

Wireless link throughput depends on transmission bit-rate

Choosing the optimal bit-rate is an important problem
Bit-rate in Wireless Networks

Optimal bit-rate selection is challenging because the wireless channel varies over:

- **Space**
  - 6 Mbps

- **Time**
  - 6 Mbps
  - 24 Mbps

![Diagram showing the variation of channel bit-rate over time and space with line graphs representing channel strength over time for different bit-rates.](image)
Recently PHY-based:

- **SoftRate [SIGCOMM ’09]**
  - Uses a BER heuristic to estimate bit rate
  - BER accurately identifies when to increase/decrease rate
  - However, may not be able to jump to optimal rate
Ideally Tx wants optimal rate for next packet
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Function of optimal rate of the previous packet
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Ideally Tx wants optimal rate for next packet

Function of optimal rate of the previous packet

In other words,

Given a transmission at rate $R$, what would have been the max rate $R^*$, at which that transmission \textit{would have been} successful
Ideally Tx wants optimal rate for next packet

Function of optimal rate of the previous packet

In other words,

Given a transmission at rate R, what would have been the max rate $R^*$, at which that transmission would have been successful

We propose AccuRate
Background:
Symbols, Modulation, Bit-rate
Physical Layer Symbols

Data = 01111001

Tx 4QAM Symbol
Physical Layer Symbols

Data = 0111001 ....

2 bits together

Tx 4QAM Symbol
Physical Layer Symbols

2 bits together

Data = 01111001 ....

Tx 4QAM Symbol

11
○

01

00
○

○
10

○
Symbols to Modulation

Data = 0111001 ....

Tx 4QAM Symbol
Symbols to Modulation

Data = 01111001 ....

2 bits together

Tx 4QAM Symbol

0 00
1 10
0 01
Symbols to Modulation

Data = 01111001 ....
2 bits together

Tx 4QAM Symbol

Rx 4QAM Symbol

Channel
Symbols to Modulation

Data = 01111001 ....

2 bits together

Tx 4QAM Symbol

Rx 4QAM Symbol

Dispersion

Channel
Symbols to Modulation

Data = 01111001 ....

2 bits together

Tx 4QAM Symbol

Dispersion

Rx 4QAM Symbol
Symbols to Modulation

Data = 01111001 ....
2 bits together

Tx 4QAM Symbol

Dispersion

Rx 4QAM Symbol
Symbols to Modulation

Data = 01111001 ....

2 bits together

Tx 4QAM Symbol

Rx 4QAM Symbol

Dispersion

Channel
Different Modulations in 802.11

Data = 01111001 ....

2 bits together

Data = 01111001 ....

4 bits together
Different Modulations in 802.11

Data $= 0111001 \ldots$

2 bits together

Tx 4QAM Symbol

Rx 4QAM Symbol

Data $= 01111001 \ldots$

6 bits together

Tx 64QAM Symbol

Rx 64QAM Symbol
Why not always transmit many bits per symbol?

e.g., 64QAM or 54Mbps
Weak Channel Induces Errors

Data = 01111001 ....

Tx 16QAM Symbol
Weak Channel Induces Errors

Data $= 01111001 \ldots$

Tx 16QAM Symbol

Weak Channel
Weak Channel Induces Errors

Data = 01111001 ....

Tx 16QAM Symbol

High Dispersion

Weak Channel
Weak Channel Induces Errors

Data $= 01111001 \ldots$

Tx 16QAM Symbol

Wrongly demodulated symbol
In General ...

- Weak Channel
- Moderate Channel
- Strong Channel

- 0
- 01
- 0111
In General...

- **Weak Channel**: 6 Mbps
- **Moderate Channel**: 24 Mbps
- **Strong Channel**: 36 Mbps
In General ...

- Weak Channel: 6 Mbps
- Moderate Channel: 24 Mbps
- Strong Channel: 36 Mbps

Smaller dispersion permits higher rate.
AccuRate
Design and Implementation
Hypothesis:
Symbol dispersion is independent of modulation
Dispersion Independent of Modulation?

Tx 4QAM

Tx 16QAM

Rx QPSK

Rx 16QAM
Dispersion Independent of Modulation?

Testbed

Fraction of symbols vs. Symbol dispersion magnitude

- BPSK
- QPSK
- 16QAM
- 64QAM
Dispersion Independent of Modulation?

Testbed

Fraction of symbols

Symbol dispersion magnitude

BPSK
QPSK
16QAM
64QAM

McKinley et. al., 2004, “EVM calculation for broadband modulated signals”
Hypothesis:
Symbol dispersion is independent of modulation

Selection of optimal modulation
Data

BPSK

4QAM

16QAM
Data

BPSK

4QAM

16QAM
Data
We call it Virtual Channel Replay
AccuRate records dispersion for every symbol in a packet

Creates a vector: **Channel Replay Vector** ($V$)

$$V = \{d_1, d_2, \ldots, d_n\}$$
AccuRate records dispersion for every symbol in a packet

- Creates a vector: **Channel Replay Vector (V)**

\[ V = \{d_1, d_2, \ldots, d_n\} \]

- When packet succeeds
  - All dispersions are known

- When packet fails
  - Approximates V from (known) preamble/postamble
Optimal modulation $\neq$ Optimal rate
Optimal modulation $\neq$ Optimal rate

Bit-rate is a function of both modulation and coding
Can we find the optimal \textless \text{modulation, coding} \textgreater for a received packet?
Performance Evaluation

✦ Used 802.11 like Tx and Rx design on USRP/GnuRadio
  ✦ Modulation: BPSK, QPSK, 16QAM, 64QAM
  ✦ Coding: Convolution coding with puncturing with rate 1/2, 3/4
  ✦ Compare with Softrate, SNR-based

✦ Testbed
  ✦ 10 traces at walking speed
  ✦ Trace based evaluation

✦ Simulation
  ✦ Characterize AccuRate’s performance under high mobility
  ✦ Raleigh fading channel simulator ported to GnuRadio
What is the True Optimal Rate?

- Testbed
  - Using train of packets (Virtual Packet)
  - Each Virtual Packet consists of data packets at all bit-rates
  - Similar method as Softrate

![Virtual Packet flow](6Mbps, 9Mbps, 12Mbps, 18Mbps, 24Mbps, 36Mbps, 54Mbps)
What is the True Optimal Rate?

❖ Testbed
❖ Using train of packets (Virtual Packet)
❖ Each Virtual Packet consists of data packets at all bit-rates
❖ Similar method as Softrate

Virtual Packet

6Mbps 9Mbps 12Mbps 18Mbps 24Mbps 36Mbps 54Mbps
What is the True Optimal Rate?

- **Testbed**
  - Using train of packets (Virtual Packet)
  - Each Virtual Packet consists of data packets at all bit-rates
  - Similar method as Softrate

![Diagram showing virtual packets at different bit-rates and optimal rates marked with green check marks and red X marks.]

- Virtual Packet
- Optimal-1
- Optimal
- Optimal+1
Can we estimate the optimal rate?

For correctly received packets,
100% in Simulation,
95% in Testbed
AccuRate needs to detect Interference
AccuRate needs to detect Interference

Rate selection needs to be independent of interference
How to Detect Interference?

- Interference causes substantial symbol dispersion
How to Detect Interference?

✦ Interference starts first: Preamble with high dispersion

✦ Interference starts second: Postamble with high dispersion
How to Detect Interference?

✦ Interference starts first: Preamble with high dispersion

✦ Interference starts second: Postamble with high dispersion

Compare preamble with postamble dispersion
Detection Accuracy is better at higher rates (95%)
Estimation Performance with Interference

Testbed

Fraction of Lost Packets

Overselect
Accurate
Underselect

Over select
Correct

Under select

BPSK 1/2
BPSK 3/4
QPSK 1/2
QPSK 3/4
QAM16 1/2
QAM16 3/4

Bit Rate
Estimation Performance with Interference

91% accuracy in Optimal rate selection
AccuRate estimates the optimal rate for an already received packet

What is the performance if the next transmission uses this rate?
Throughput at Walking Speeds

![Graph showing normalized throughput at walking speeds for different testbeds and methods: AccuRate, SoftRate, SNR based.](image-url)
AccuRate achieves 87% of the optimal throughput
Throughput under Mobility

AccuRate performs well even under high mobility.

AccuRate performs well even under high mobility.
Limitations

✧ **Hardware Complexity**
  ✧ AccuRate targets optimal rate estimation
  ✧ Does not consider implementation cost

✧ **Rate estimation sub-optimal under packet failure**
  ✧ Pre/Post amble based estimation achieves 93% accuracy
  ✧ Improvements possible with midamble

✧ **Interfering packet may engulf or be engulfed by data**
  ✧ AccuRate unable to detect such cases
Summary

- AccuRate uses symbol dispersion to estimate bit-rate
  - Symbol dispersion is a measure of channel behavior

- AccuRate replays this channel on different bit-rates
  - The max rate that “passes” this replay is declared optimal

- The optimal rate is prescribed for subsequent transmissions
  - USRP testbed results show 87% of optimal throughput

- SoftRate capable of choosing very good bit-rates
  - AccuRate pushes rate estimation towards optimality
Questions, Comments?

Thank You

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