Towards MIMO-Aware 802.11n Rate Adaptation

(Ioannis Pefkianakis, Suk-Bok Lee and Songwu Lu)

Advanced Computer Networks
CS577 – Fall 2013
WPI, Worcester.

Presented by Pankaj Didwania
Nov.5th, 2013

Intro…

- Study of multiple-input–multiple-output (MIMO) 802.11n rate adaptation (RA) on a programmable access point (AP) platform.
- Existing RA solutions offer much lower throughput than even a fixed-rate scheme.
- All such RA algorithms are MIMO-mode oblivious.
- They do not differentiate spatial diversity and spatial multiplexing modes.
- Show that MIMO-mode aware designs outperform MIMO-mode oblivious RAs in various settings, with goodput gains up to 73.5% in field trials.

802.11n standard

- MIMO: PHY uses multiple transmit and receive antennas to support two MIMO modes of operation.

- Spatial diversity: transmits a single data stream from each transmit antenna, leveraging the independent fading over multiple antenna links, to enhance signal diversity.

- Spatial multiplexing (SM) transmits independent and separately encoded spatial streams from each of the multiple transmit antennas to boost performance.

Experimental setting

- Programmable AP platform which uses Atheros AR5416 2.4/5 GHz MAC/BB MIMO chipset.
- AP supports SS and DS modes.
- Available rates up to 130 and 300 Mb/s for 20- and 40-MHz channel operations respectively.
- Frame aggregation with BlockAck (i.e., ACK for A-MPDU) feedback is supported as well.
- AP has three available antennas.

Experimental setting…

- 802.11n clients used:

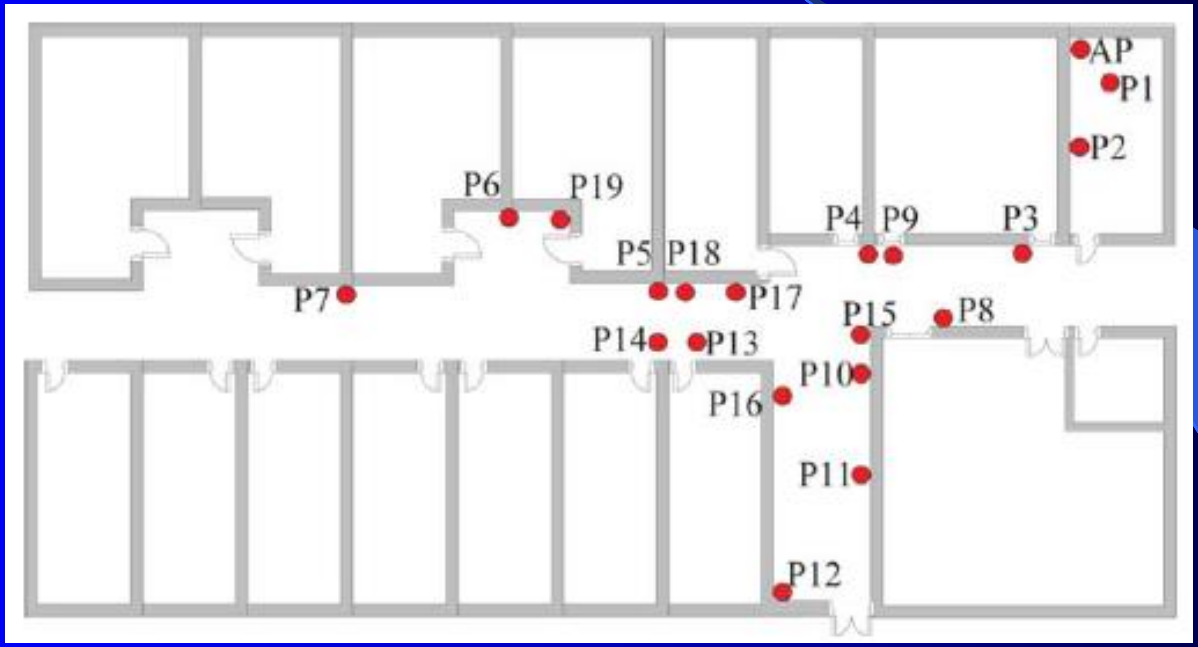
-Buffalo WLI-CB-AG300NH 802.11a/b/g/n wireless adapter based on Marvell 802.11n chipset

-Linksys WPC600N 802.11a/b/g/n

-Airport Extreme wireless adapters using Broadcom chipset

- The results presented in this paper are from the Airport Extreme adapter, which supports up to 270-Mb/s rates.

Campus Building Floor plan



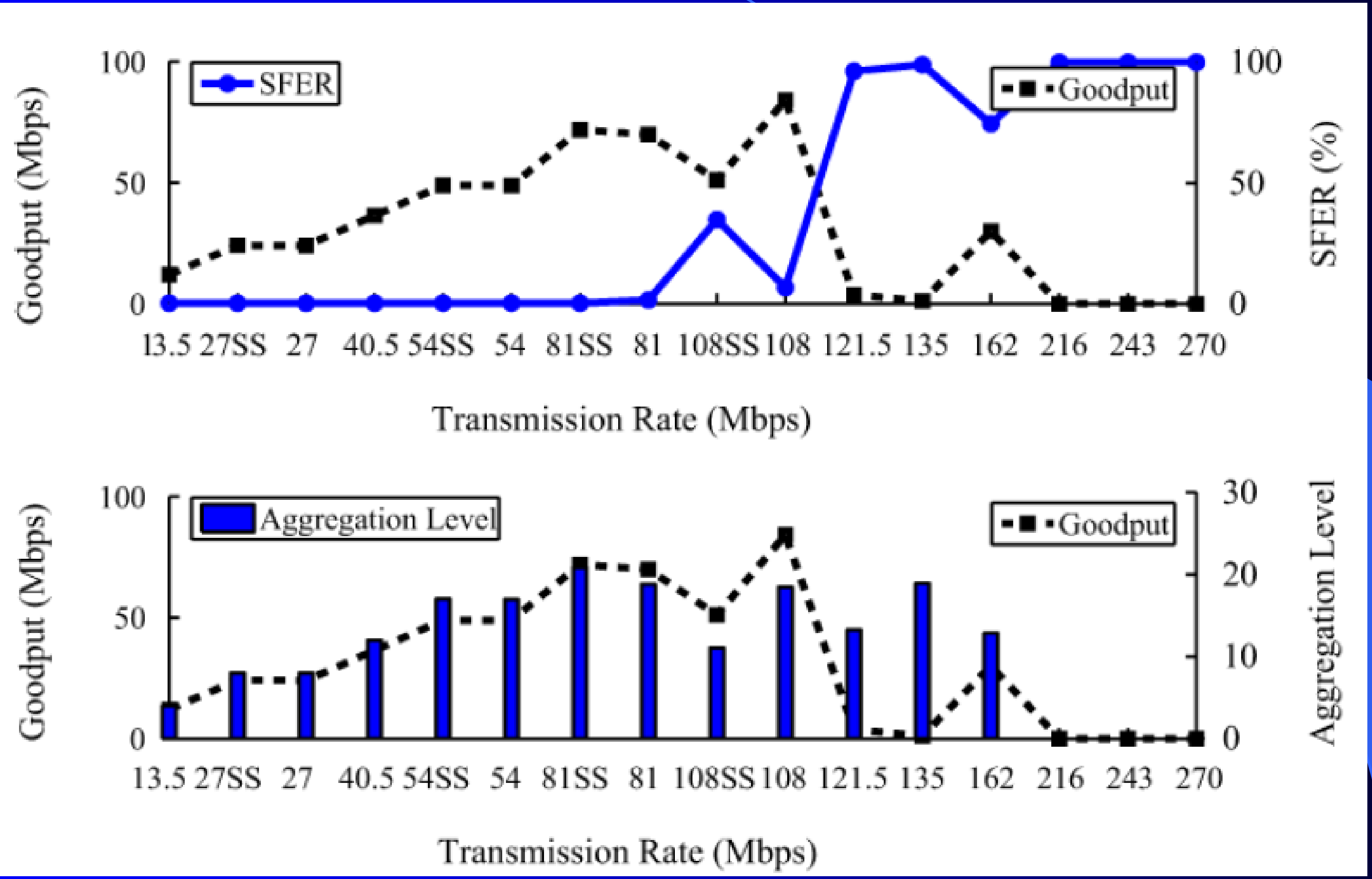
Existing Algorithms at P4

Rates (Mbps)	Atheros RA	RRAA	SampleRate	Fixed Rate Goodput (Mbps)	Fixed Rate SFER
MCS2 (40.5SS)				36.23	0.12%
MCS3 (54SS)	49%			49.08	0.20%
MCS9 (54DS)				48.87	0.12%
MCS4 (81SS)				72.94	0.07%
MCS10 (81DS)				72.64	0.06%
MCS5 (108SS)	51%			96.46	0.15%
MCS11 (108DS)		47%	89%	96.31	0.16%
MCS6 (121.5SS)		53%	4%	74.01	17.92%
MCS7 (135SS)			7%	36.56	54.61%
MCS12 (162DS)				128.46	4.31%
MCS12 (216DS)				5.71	96.73%
Goodput (Mbps)	71.40	85.36	91.95		
SFER	0.59%	13.24%	7.25%		

RATE DISTRIBUTION, GOODPUT, AND SFER OF EXISTING RA ALGORITHMS AT P4

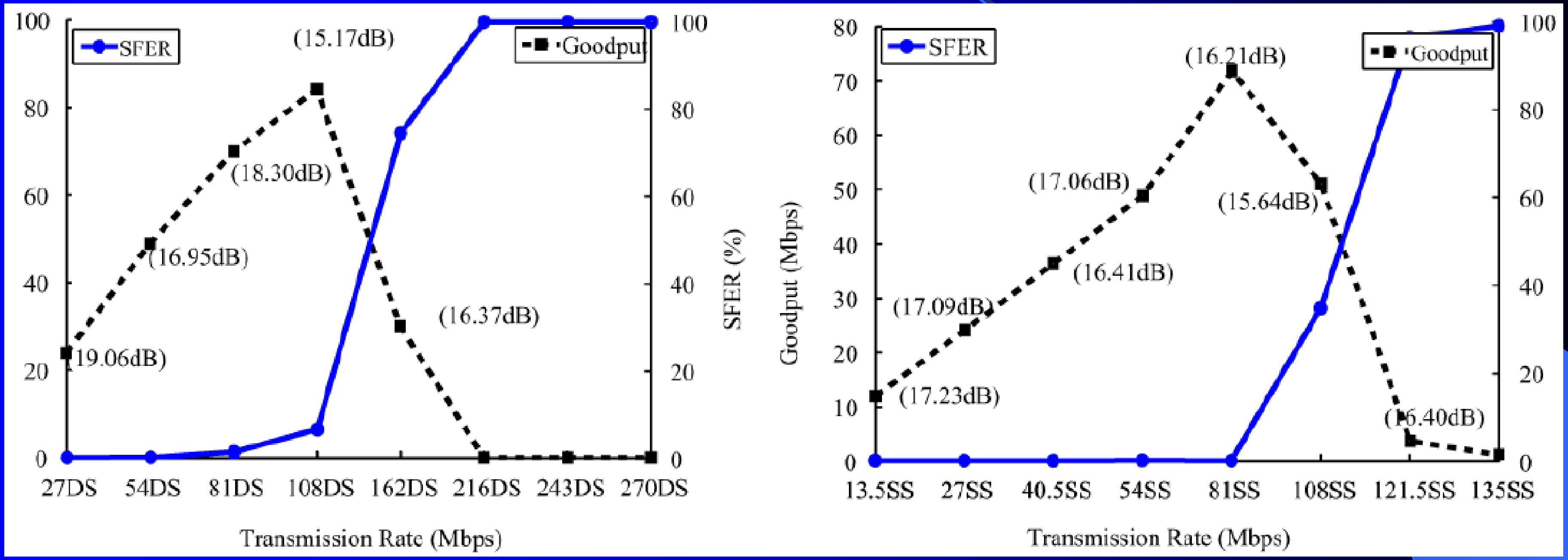
The goodput at the best fixed rate is 128.5 Mb/s, while Atheros RA gives 71.4 Mb/s, RRAA offers 85.4 Mb/s, and SampleRate gives 91.9 Mb/s. These results clearly indicate that the existing RA algorithms cannot be effectively applied in 802.11n networks.

SFER versus transmission rate in 802.11n MIMO settings @P10



SFER nonmonotonicity in same cross-mode rates.

SFER versus transmission rate in 802.11n MIMO settings @P10



SFER monotonicity in DS mode (Left). SFER monotonicity in SS mode (Right).

Comparison between SS and DS modes

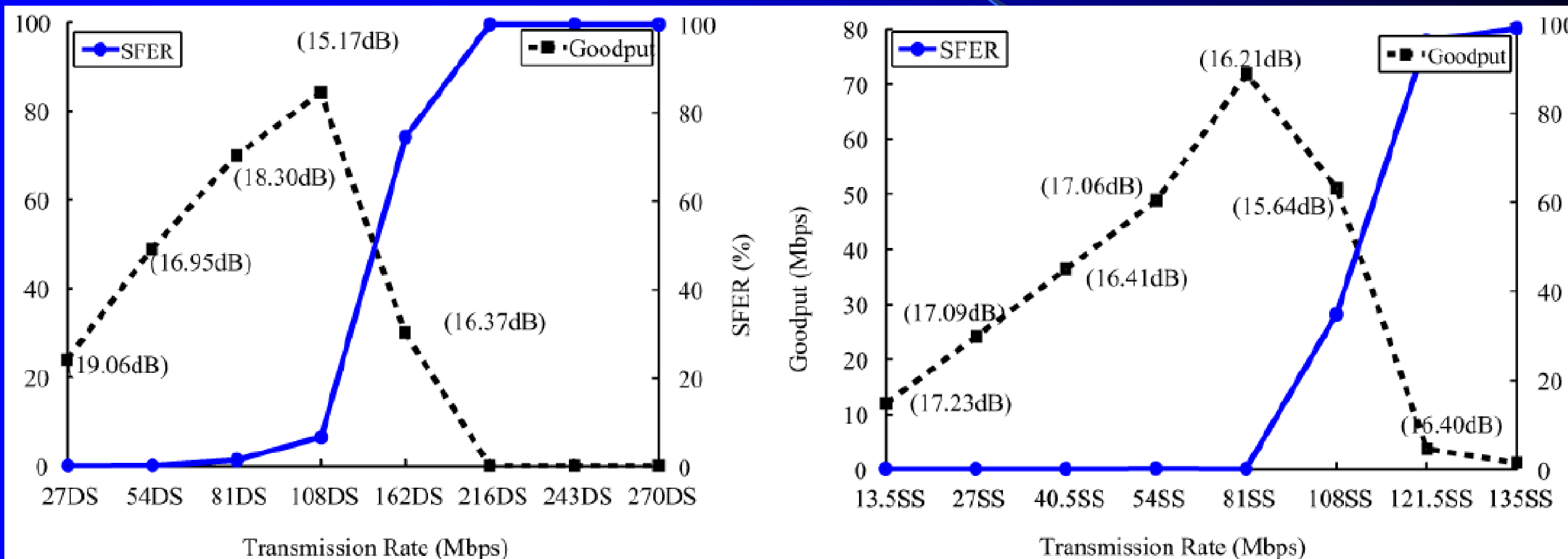
SFER NONMONOTONICITY W.R.T. RATE IN CROSS MODES

Location	$SFER_{121.5SS}$ (%) SNR (dB)	$SFER_{135SS}$ (%) SNR (dB)	$SFER_{162DS}$ (%) SNR (dB)
P3	0.39% 42.97 (dB)	7.99% 40.64 (dB)	0.33% 41.53 (dB)
P8	0.27% 29.69 (dB)	11.90% 30.80 (dB)	0.39% 31.22 (dB)
P4	17.92% 21.67 (dB)	54.61% 22.41 (dB)	4.31% 22.15 (dB)
P10	96.29% 17.38 (dB)	98.99% 16.75 (dB)	74.50% 17.79 (dB)

SFER W.R.T. DIFFERENT CROSS-MODE RATE PAIRS

Location	P10 SFER(%) SNR(dB)	P13 SFER(%) SNR(dB)	P14 SFER(%) SNR(dB)	P11 SFER(%) SNR(dB)	P7 SFER(%) SNR(dB)
MCS1 (27SS)	0.19% 17.10(dB)	0.30% 14.93(dB)	0.61% 12.96(dB)	4.95% 12.34(dB)	10.95% 7.03(dB)
MCS8 (27DS)	0.23% 13.40(dB)	0.31% 14.09(dB)	0.52% 12.51(dB)	17.79% 14.09(dB)	25.143% 7.10(dB)
MCS3 (54SS)	0.25% 16.1(dB)	1.41% 12.34(dB)	1.19% 12.87(dB)	7.44% 10.60(dB)	100% -
MCS9 (54DS)	0.25% 14.82(dB)	0.72% 12.16(dB)	9.23% 12.19(dB)	16.73% 12.16(dB)	100% -
MCS4 (81SS)	0.19% 17.05(dB)	10.14% 11.95(dB)	25.60% 11.58(dB)	27.88% 11.95(dB)	100% -
MCS10 (81DS)	1.54% 16.59(dB)	10.03% 12.17(dB)	37.04% 13.29(dB)	37.15% 11.79(dB)	100% -
MCS5 (108SS)	34.83% 16.13(dB)	99.09% 11.64 (dB)	97.69% 13.15(dB)	97.85% 11.64(dB)	100% -
MCS11 (108DS)	6.68% 15.02 (dB)	82.88% 11.71(dB)	93.60% 13.47(dB)	98.24% 11.71(dB)	100% -

SFER versus transmission rate in 802.11n MIMO settings @P10



SFER monotonicity in DS mode (Left). SFER monotonicity in SS mode (Right).

STUDYING MIMO CHARACTERISTICS IN 802.11n SYSTEMS

- SFER (Subframe Error Rate) Nonmonotonicity in SS and DS
- SS/DS Mode Selection
- On Frame Aggregation

DESIGN

- Zigzag RA: Intra- and Intermode RA

  - How to decide which rates, in the same mode or across the mode, to probe.

  - How to estimate the goodput based on the probing results while taking into account the effect of aggregation.

- Handling Hidden Terminals

  - Collision Detection

  - Cost-Effective Collision Reaction

ALTERNATIVE DESIGNS FOR MIMO 802.11n RATE ADAPTATION

- Window-Based 802.11n RA
  - Sliding Window Best Rate Selection
  - Best-Throughput Rate Selection
  - Triggers for Window Movement
  - Length of Window Movement
  - Impact of Window Size:
  - Adaptability Versus Probing Overhead
- Other Design Options for MIMO RA

IMPLEMENTATION AND EVALUATION

- Implementation

  - Implemented MiRA in the firmware of a programmable AP platform (about 900 lines of C code)

- Performance Evaluation

  - With BlockAck (i.e., ACK for A-MPDU) feedback is supported as well.

IMPLEMENTATION AND EVALUATION contd….

- 1) Static Clients:
  - UDP/3 3 Antennas/5-GHz Case:
  - UDP/2 2 Antennas/5-GHz Case:
  - TCP/3 3 Antennas/5-GHz Case:
  - UDP/3 3 Antennas/2.4-GHz/40-MHz Case:
  - UDP/3 3 Antennas/2.4-GHz/20-MHz Case:
  - Effective Probing:
  - Handling SFER NonMonotonicity:
- 2) Mobile Clients:
- 3) Setting With Hidden Terminals:
- 4) Field Trials:

IMPLEMENTATION AND EVALUATION contd….

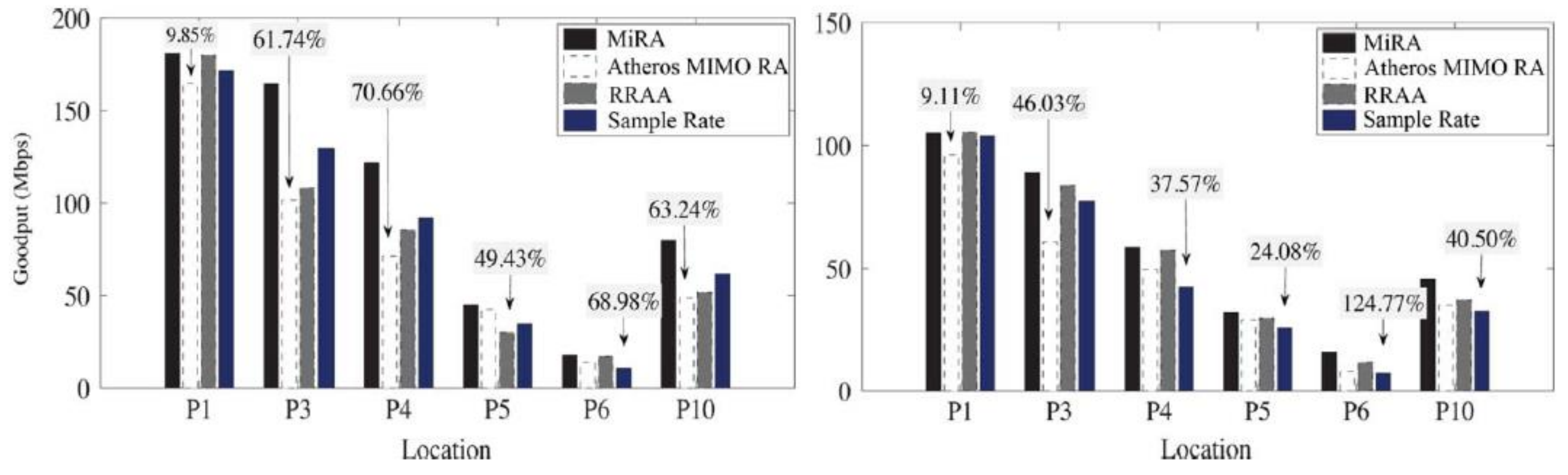
- Assessing MIMO RA Alternatives
  - Window-Based RA Algorithm:
  - Tuned Sample rate Algorithm:
  - SNR-Based Mode Selection RA:
  - RA Based on Fast MCS Feedback:

IMPLEMENTATION AND EVALUATION contd….

GOODPUT GAINS OF MIRA OVER EXISTING RAS

	Atheros RA	RRAA	SampleRate
Static UDP	(3.4-82.3)%	(2.9-71)%	(1.1-104.5)%
Static TCP	(9.1-107.9)%	(5.9-37.5)%	(14.7-124.8)%
Mobility UDP	116.1%	30.2%	182.2%
Mobility TCP	72.5%	4.9%	94%
Hidden Terminal	(79.4-1094)%	up to 6.5%	(33.8-983)%
Field Trial	(46.35-67.4)%	(16-28.9)%	(19.4-73.5)%

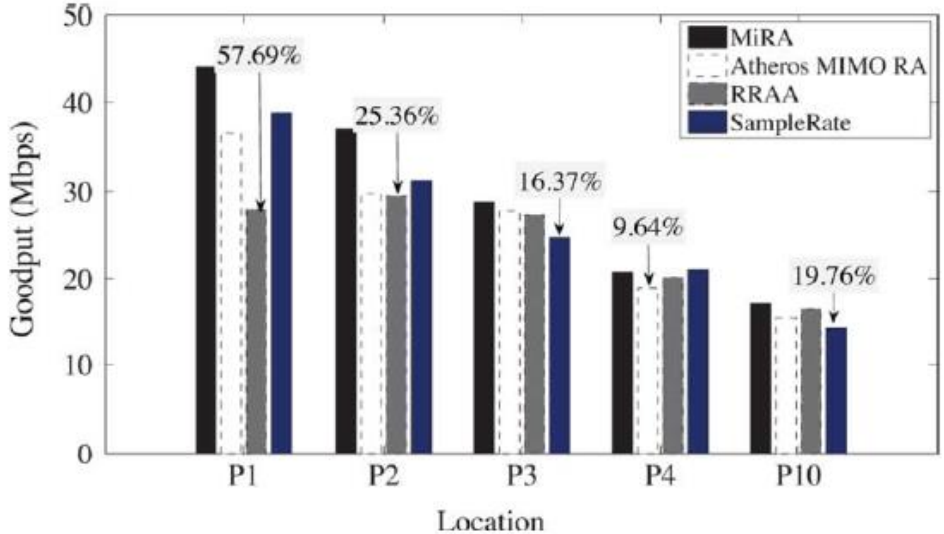
IMPLEMENTATION AND EVALUATION contd....



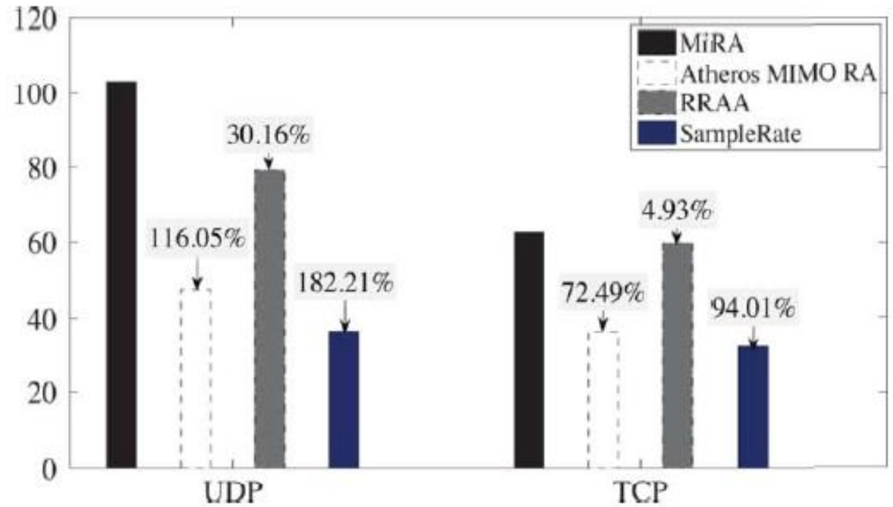
3 × 3/5-GHz/UDP static setting.

3 × 3/5-GHz/TCP static setting.

IMPLEMENTATION AND EVALUATION contd….

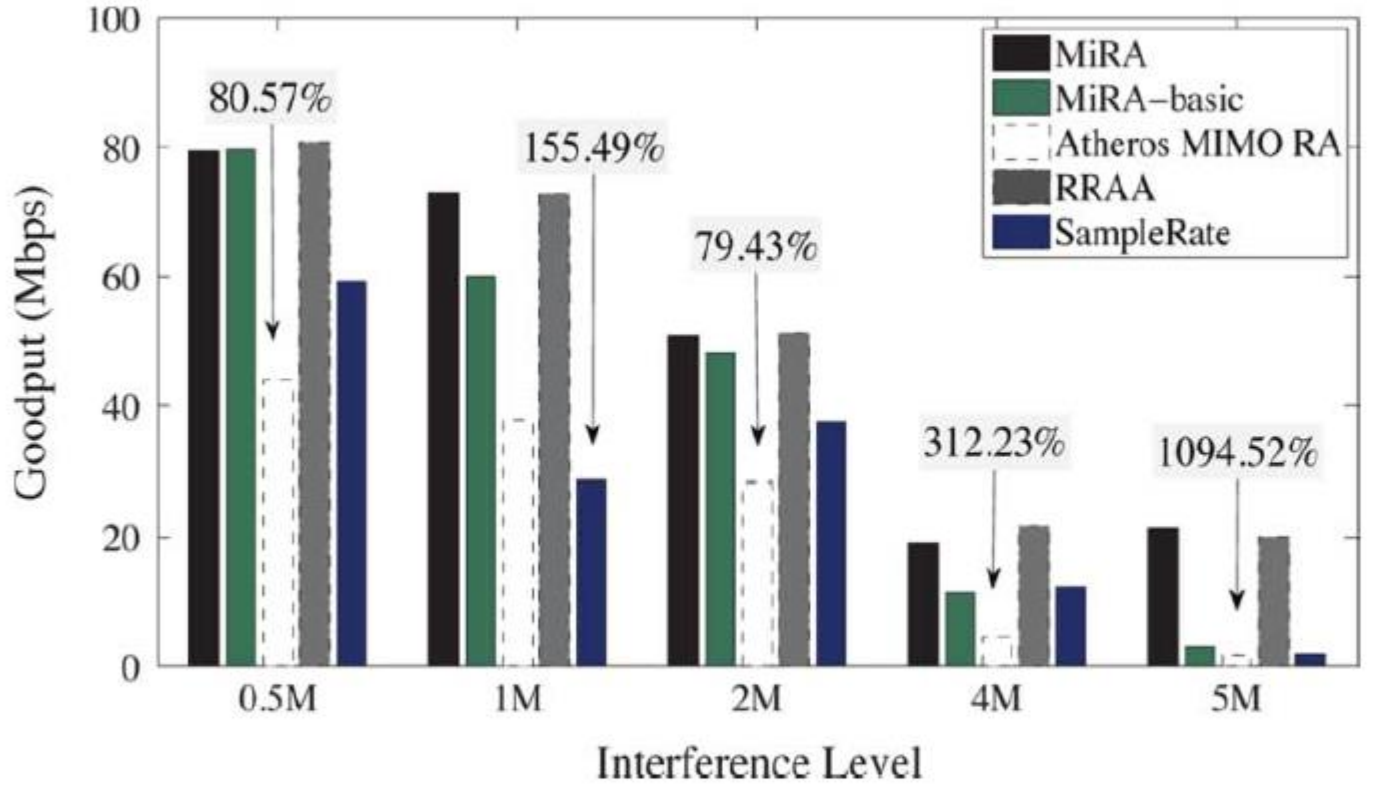


3 × 3/2.4-GHz/40-MHz/UDP static setting.



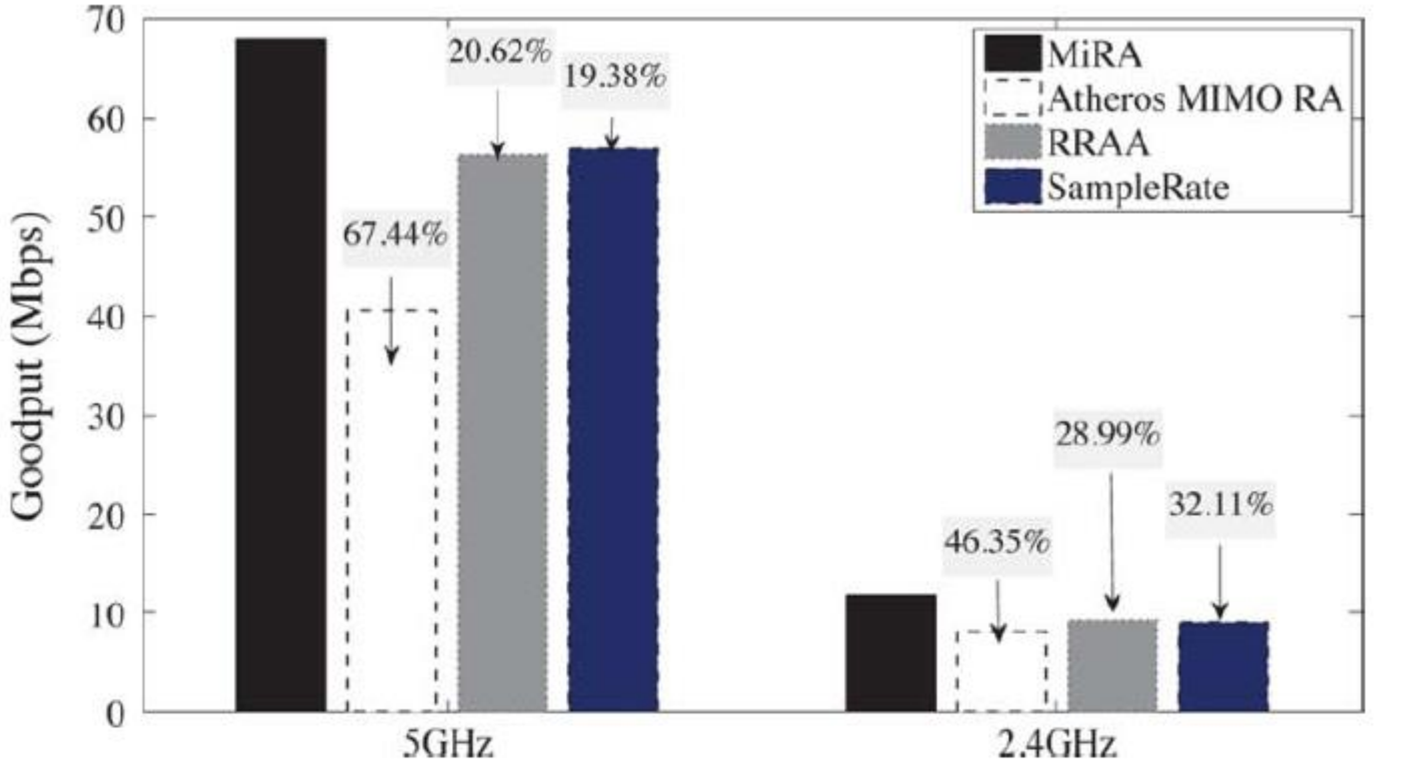
Goodput in mobility setting.

IMPLEMENTATION AND EVALUATION contd....



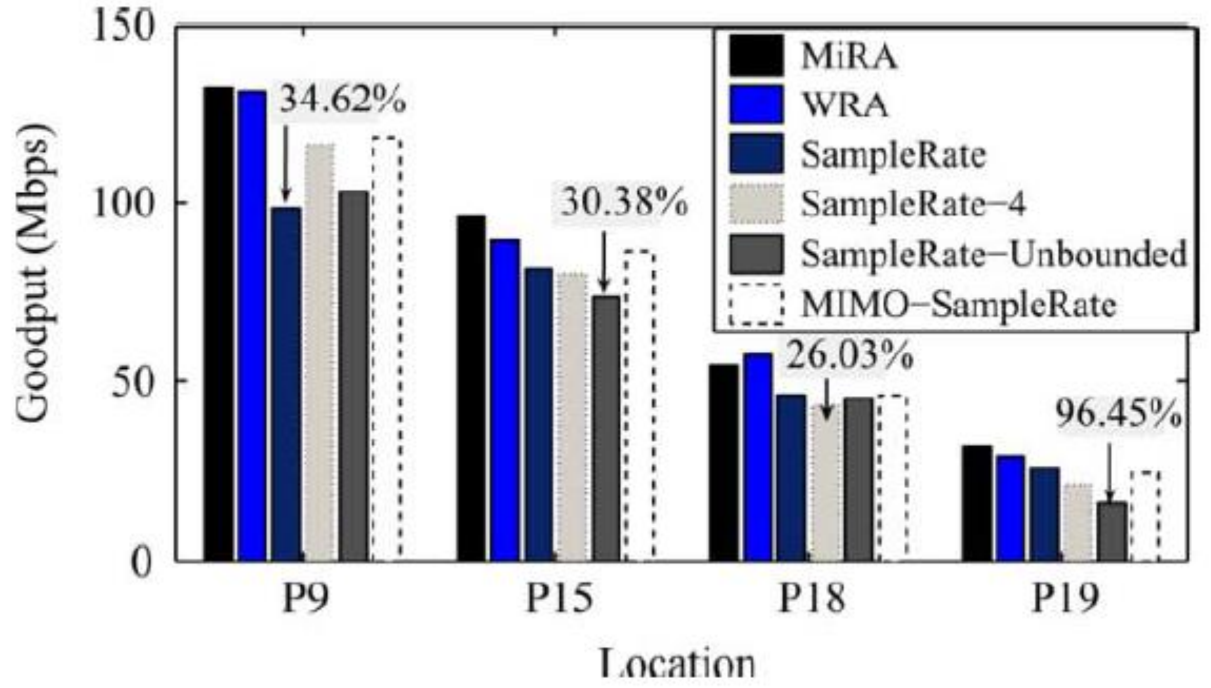
Goodput in hidden terminal.

IMPLEMENTATION AND EVALUATION contd….



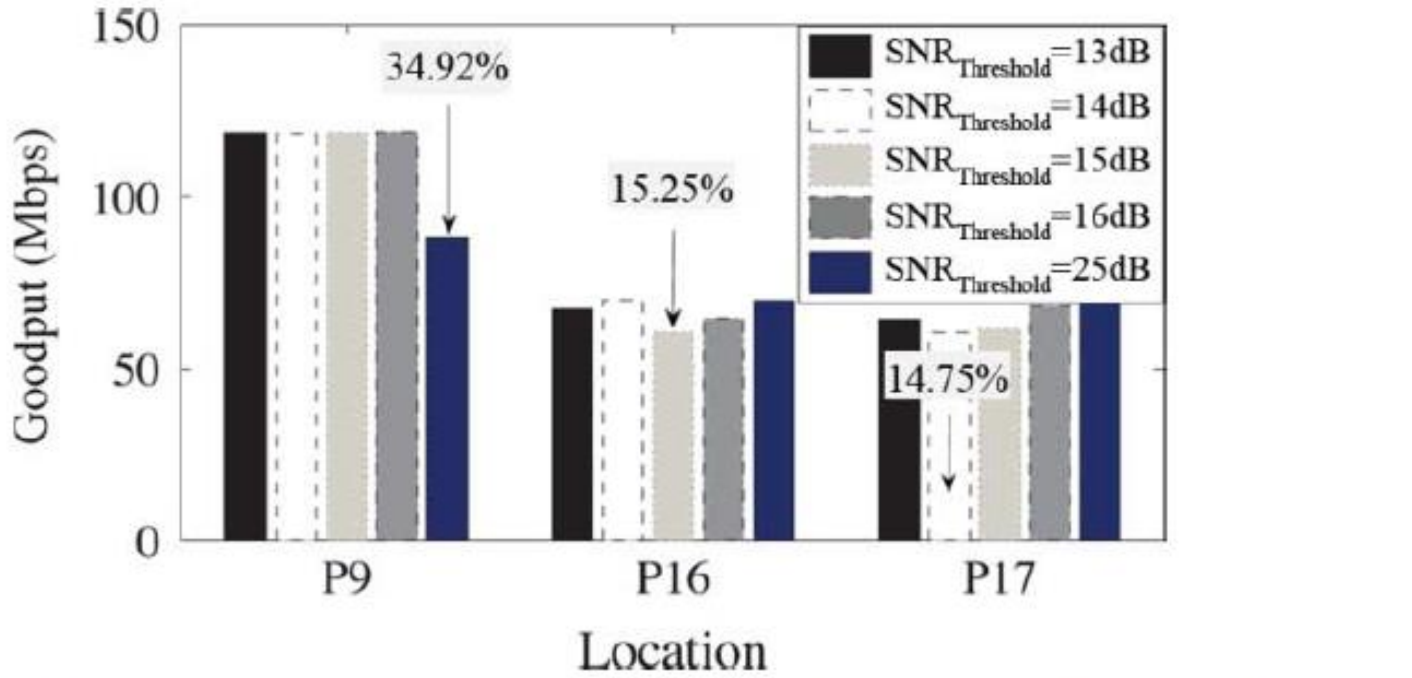
MiRA performance in field trials.

IMPLEMENTATION AND EVALUATION contd….



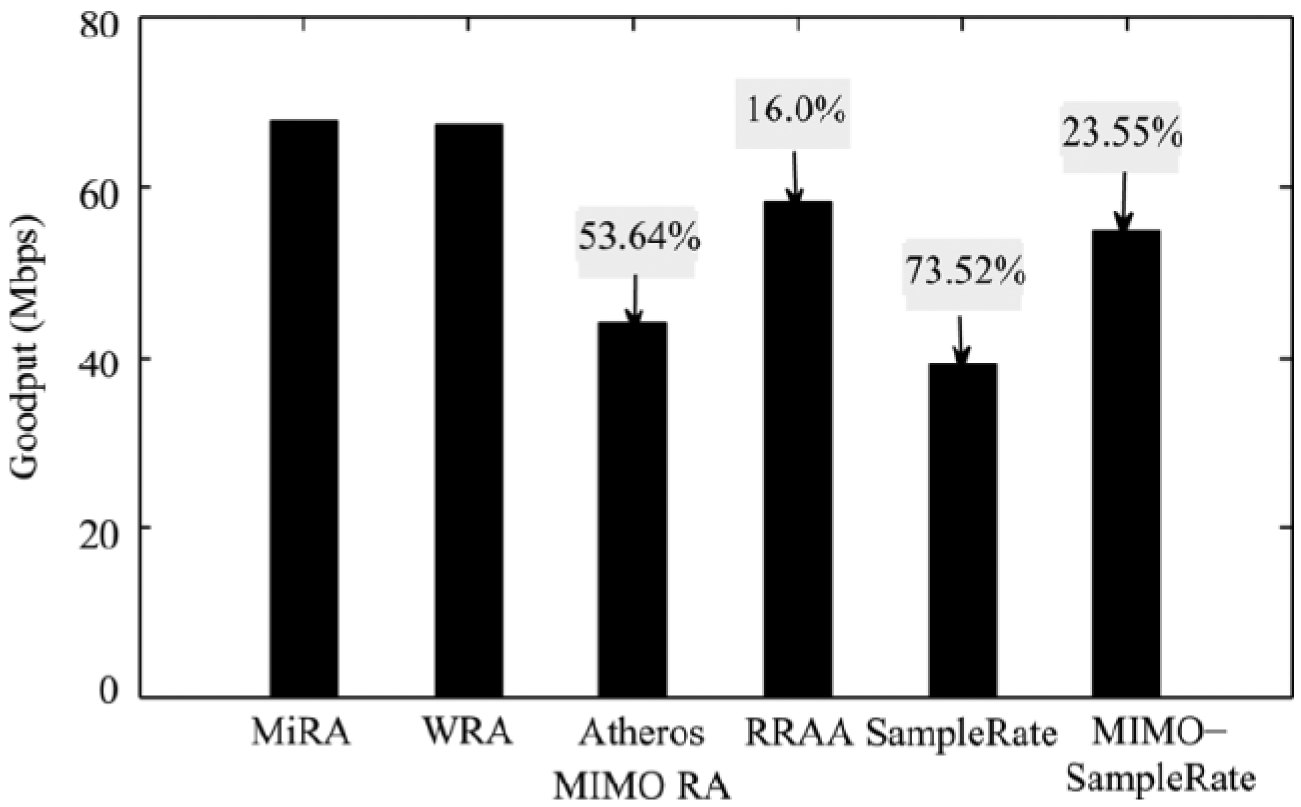
MIMO RA alternatives in static settings.

IMPLEMENTATION AND EVALUATION contd….



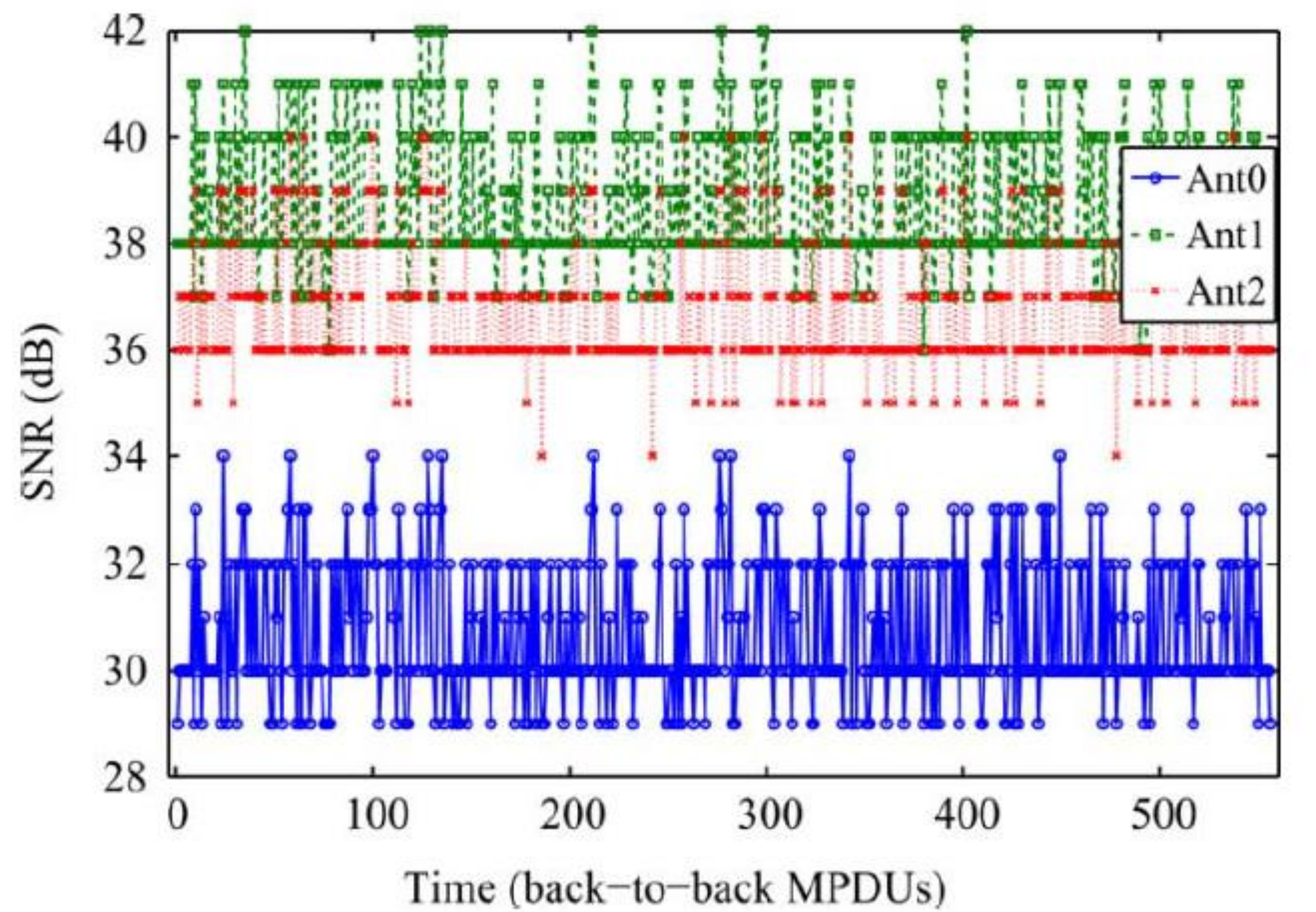
MIMO-SampleRate versus different SNR thresholds.

IMPLEMENTATION AND EVALUATION contd….



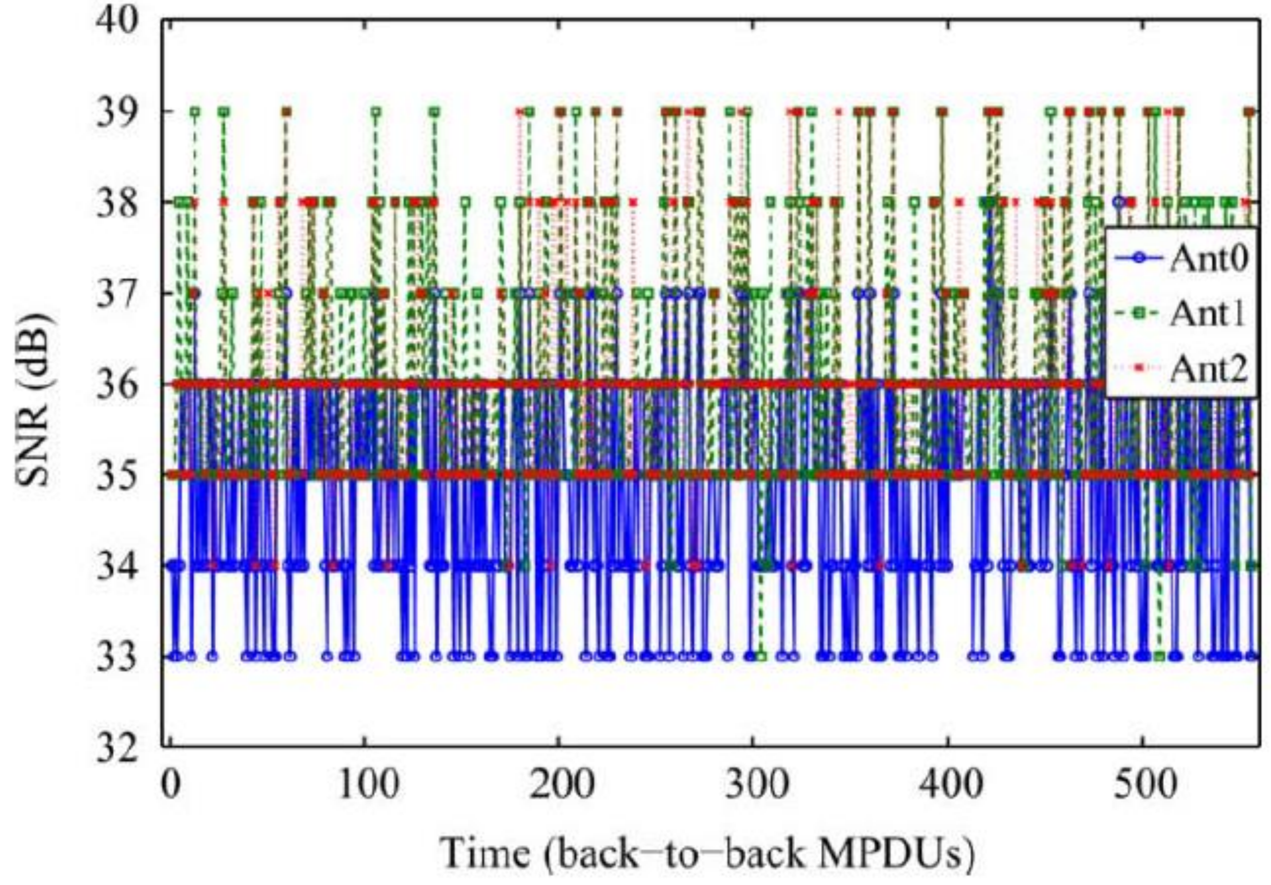
MIMO RA alternatives in field trials.

EVALUATION contd….



Per-antenna SNR of control channel
in a static RF-chamber setting.

EVALUATION contd….



Per-antenna SNR of extension channel
in a static RF-chamber setting.

RELATED WORK

- Many of the prior rate adaptation proposals target the legacy 802.11a/b/g networks or take a cross-layer approach by using PHY-layer feedback to select the best-goodput rate.
- These algorithms are not designed for MIMO systems, and they do not consider MIMO modes and 802.11n frame aggregation.

Conclusion

- Authors empirically study MIMO rate adaptation,using an IEEE 802.11n compliant, programmable AP platform.
- Show that diversity-oriented SS mode and spatial multiplexing-driven DS mode exhibit different features and cannot be managed indistinctly.
- Existing RA solutions do not properly consider characteristics of SS and DS, thus suffer severe performance degradation.
- first propose MiRA, a new zigzag RA algorithm that explicitly adapts to the SS and DS modes in 802.11n MIMO systems.
- Design and evaluate window-based and SNR-based MIMO RA solutions, experiments show clear gains of MIMO-mode-aware RAs.

References

- Towards MIMO-Aware 802.11n Rate Adaptation by Ioannis Pefkianakis, Suk-Bok Lee, Songwu Lu.
- Prof. Kinicki's presentation from previous year at WPI.

Questions