Observing Home Wireless Experience through WiFi APs

Ashish Patro*

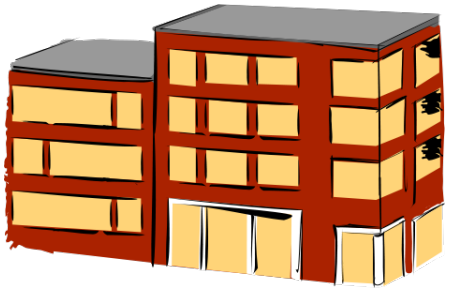
Srinivas Govindan

Prof. Suman Banerjee

University of Wisconsin Madison

*patro@cs.wisc.edu

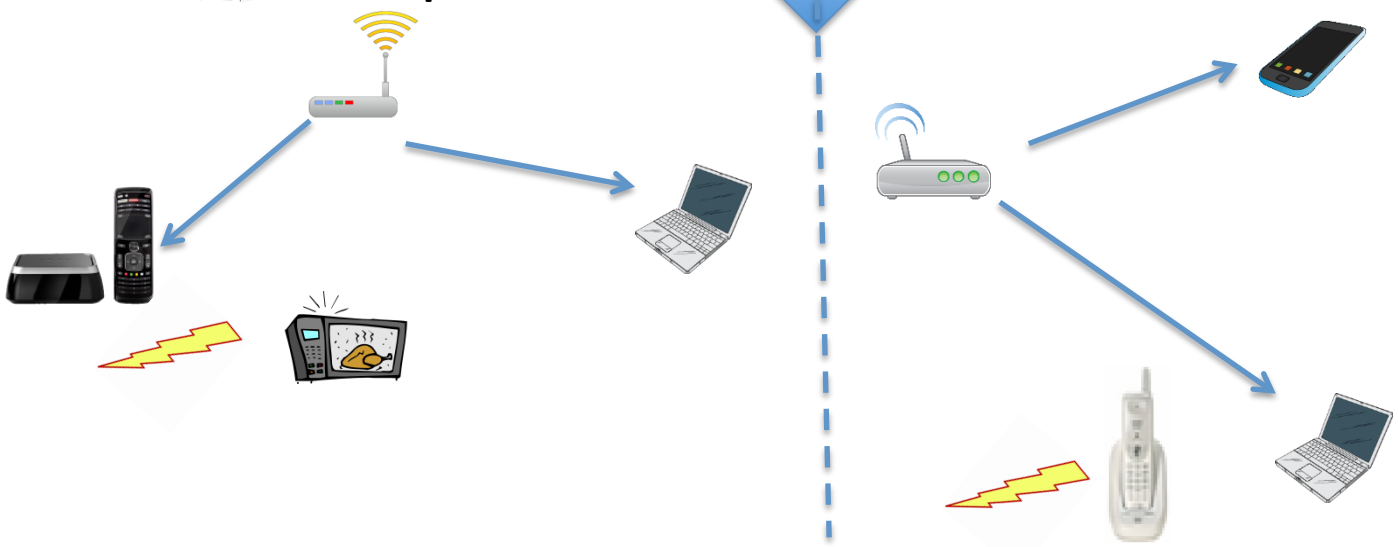
Dense residential WLANs today…



Apartment Building

Apt 201

Apt 202

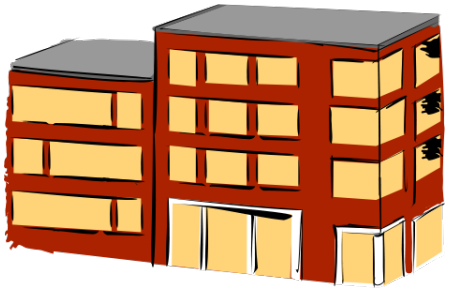


Access Points

WiFi Clients

Non-WiFi devices

Dense residential WLANs today…



Apartment Building

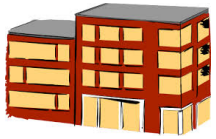
Apt 201

Apt 202

Netflix

YouTube HD

Rapidly increasing usage of WiFi devices and services (e.g., video)

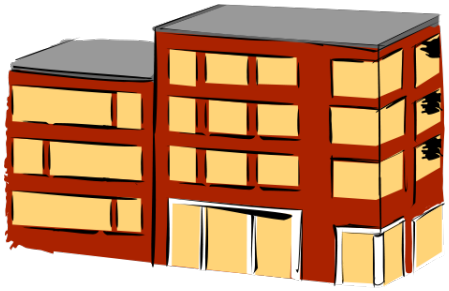


Our goal: A measurement infrastructure

How can we capture the "wireless experience" in home WLANs?

- What is the wireless performance at any instant?
- How often is wireless experience "poor"?
- What are the causes of poor performance?

Potential causes of poor performance

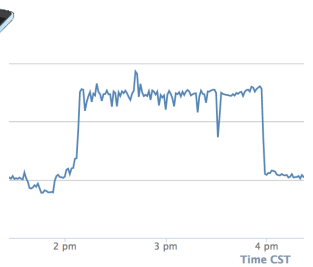


Apartment Building

Apt 201

Netflix

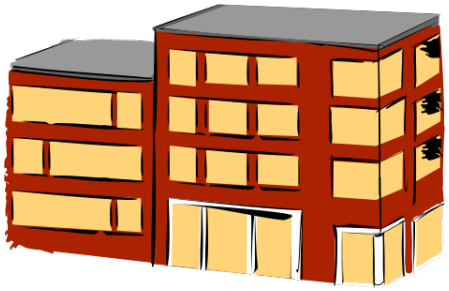
Apt 202



Busy Channel

Ad-hoc deployment of APs with no/little coordination between APs

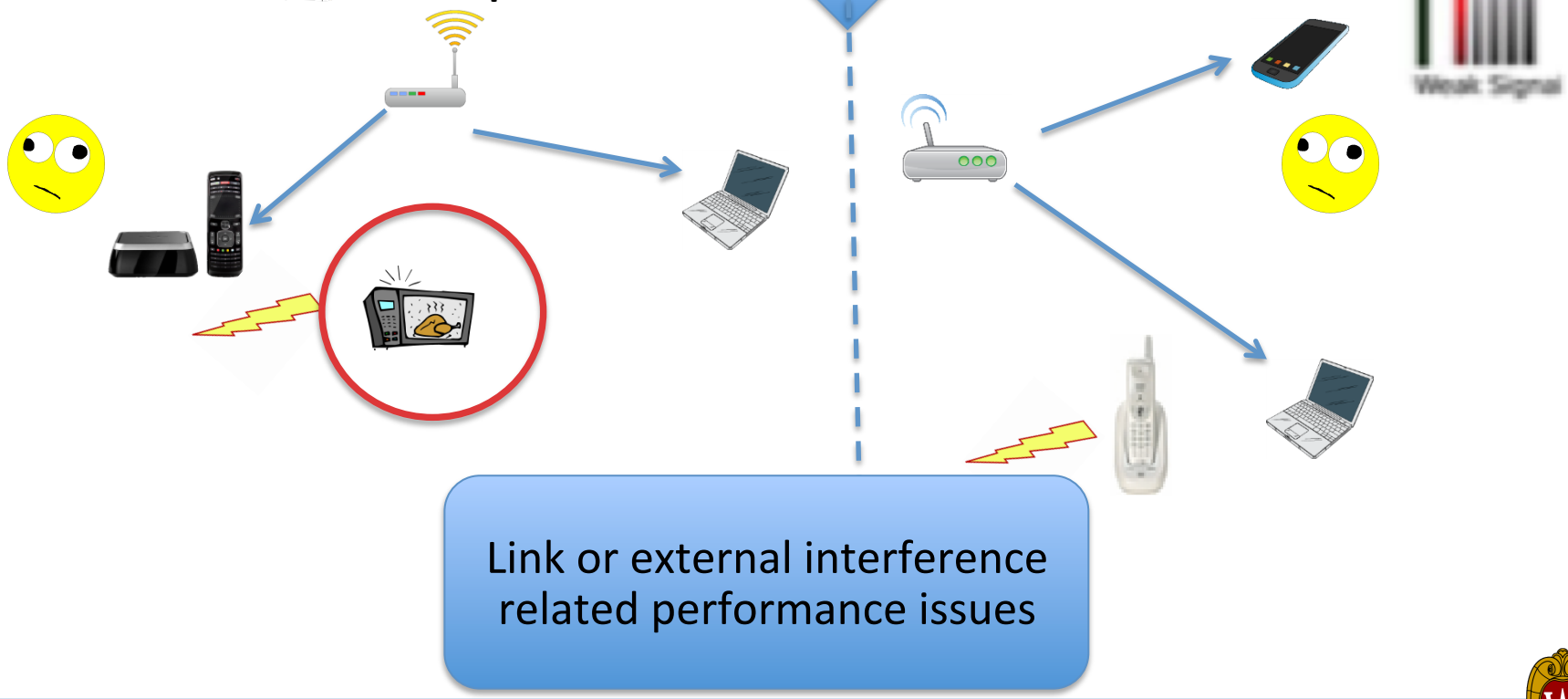
Potential causes of poor performance



Apartment Building

Apt 201

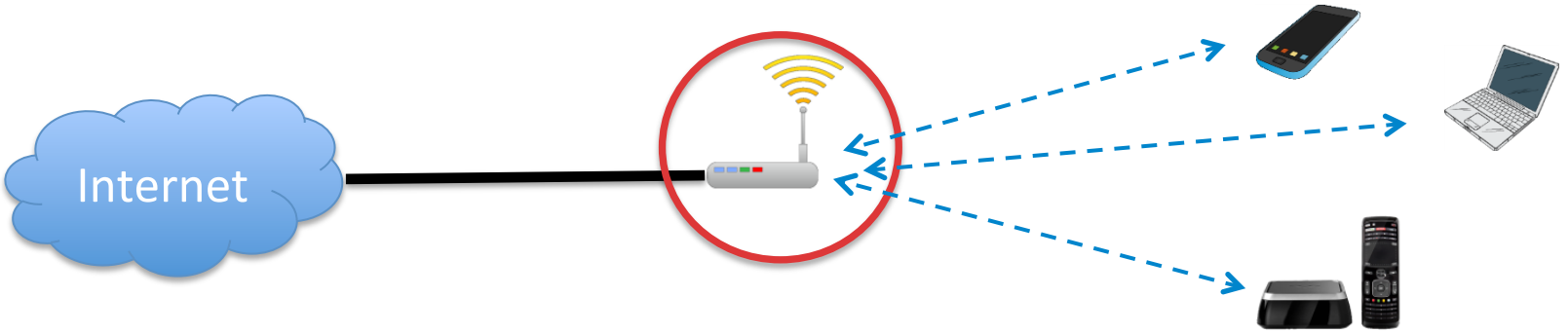
Apt 202



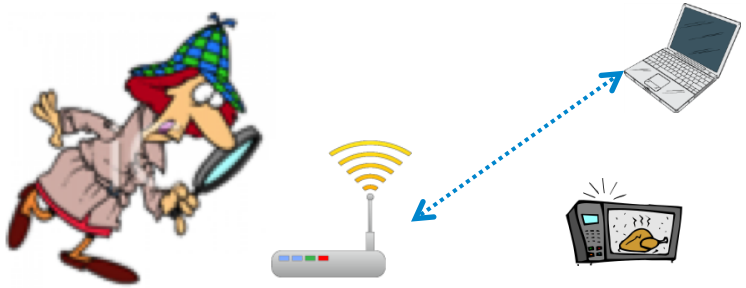
Link or external interference related performance issues

Measurement Framework: Capturing wireless experience

- Our approach: Inline measurements at home APs



Why use WiFi APs as vantage points?

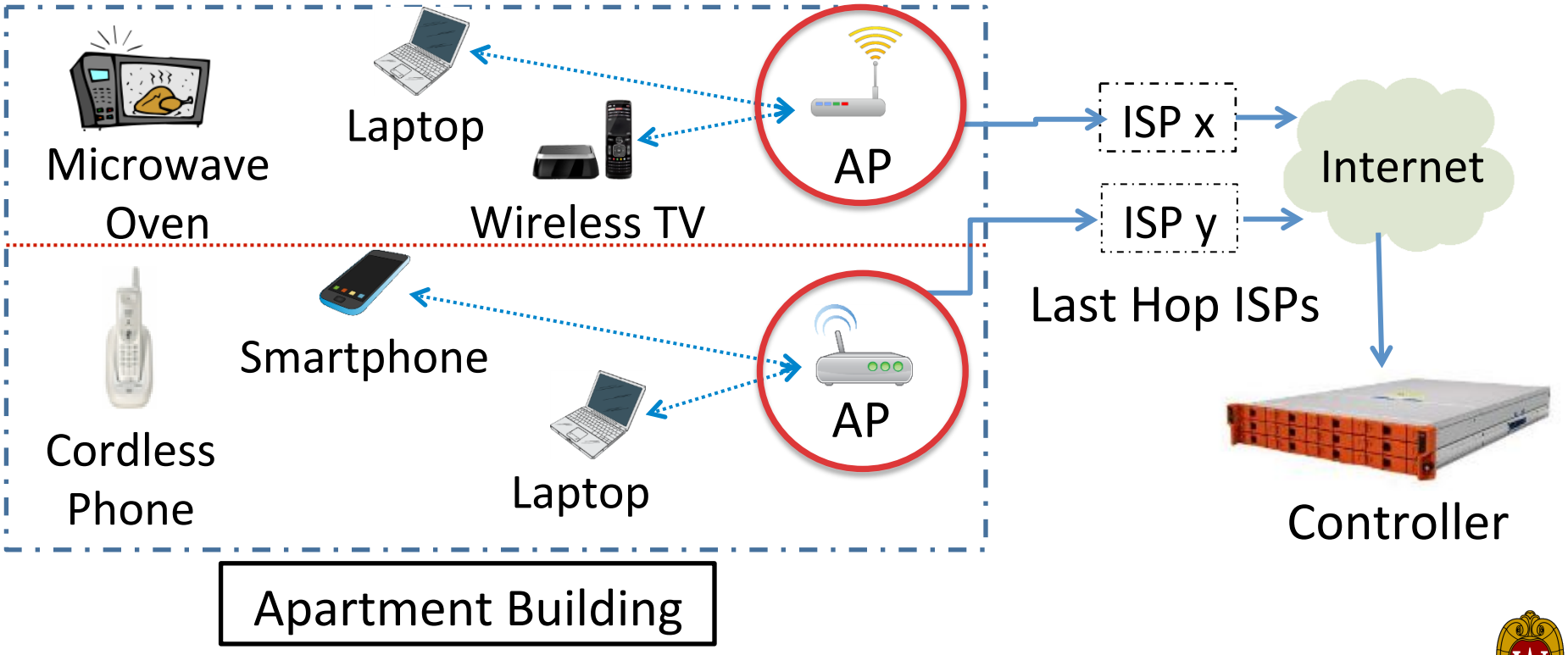


"Inline Measurements at APs"

- Capture local link + channel conditions
- Observe neighboring WiFi + non-WiFi transmissions
- Monitor local settings (channel, tx power)
- Easy to maintain and deploy due to no additional infrastructure overhead

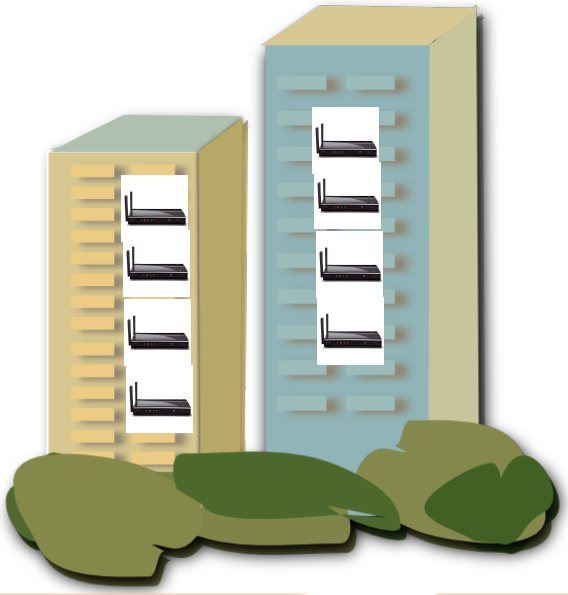
WiSe measurement infrastructure

Wireless infrastructure for **i**nline **Se**nsing (WiSe)



WiSe deployment

WiSe deployment (30 APs)



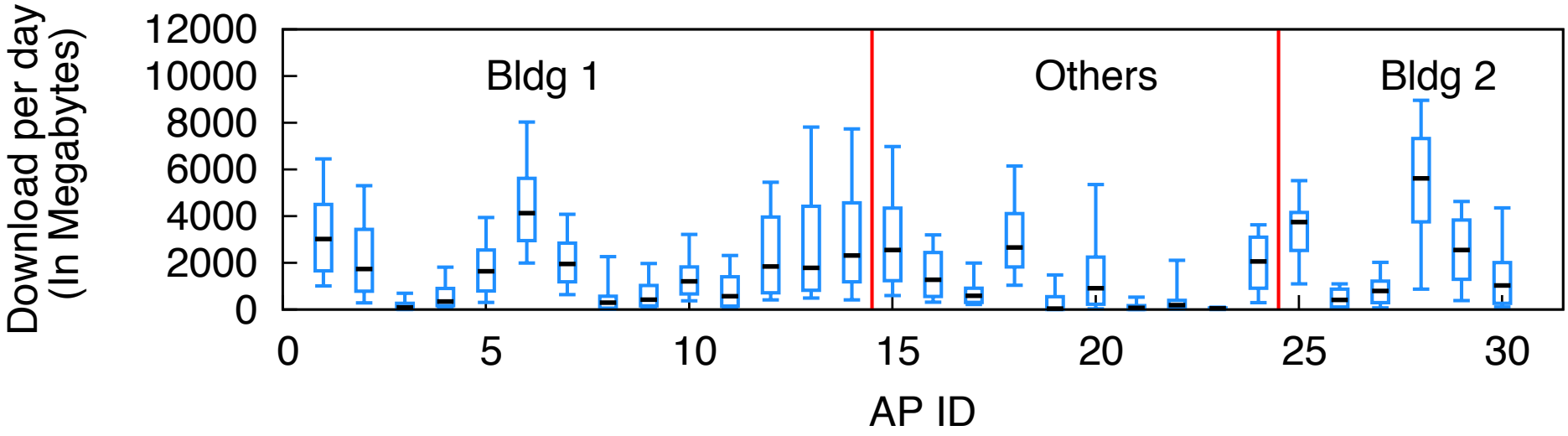
Building 1: APs 1 – 14
Individual Access Point per apartment

Building 2: APs 25 – 30
Deployment in common areas

Others: APs 15 – 24
Across different homes

Ran deployment over 8 months

Data usage across WiSe APs

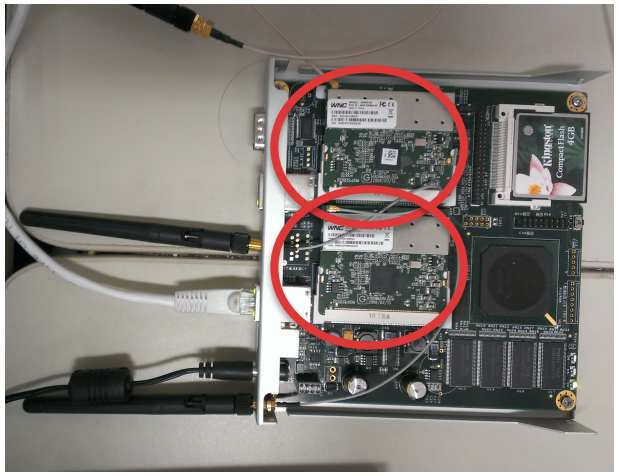


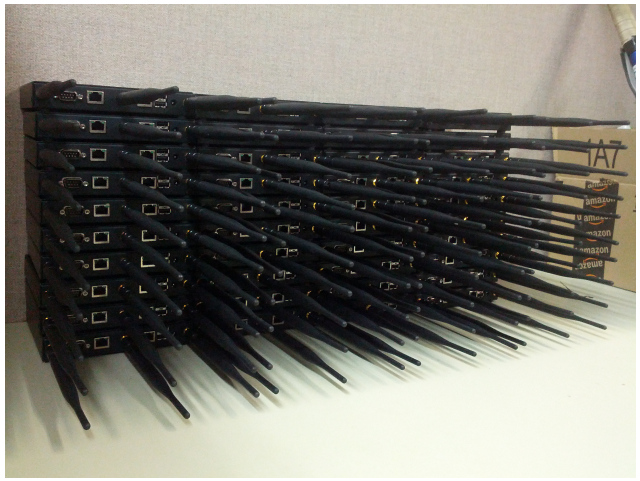
Highly variable data usage across different locations
Median of 30 MB – 5.6 GB per day

Outline

- Introduction
- **WiSe analytics toolkit**
- Quantifying wireless performance (Witt metric)
- Measurement Results
- Related Work and Summary

Hardware





- OpenWrt based APs
  - ALIX 2d2 platform: (500 MHz AMD Geocode CPU, 256 DDR RAM, flash storage)
- Two mini-PCI WiFi NICs
  - Primary NIC acts as AP
  - Secondary NIC as backup for additional measurments

What do these “WiSe APs” collect?

- Aggregate Statistics
- Non-WiFi activity
- Interference analysis

WiSe analytics toolkit

Aggregate Statistics

Non-WiFi activity

Interference analysis

Airtime Utilization
Observed beacons
CRC errors

AP Statistics

Client Signal Strength
Packets sent + retried
PHY rates statistics

Client Statistics

WiSe analytics toolkit

Aggregate Statistics

Non-WiFi activity

Interference analysis

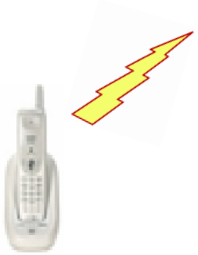
WiSe AP

Generate signature

Identify device

Device Type,
Start time + duration
Signal strength

Non-WiFi Statistics



Airshark (IMC 2011)

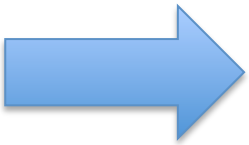
WiSe analytics toolkit

Aggregate Statistics

Non-WiFi activity

Interference Analysis

WiSe AP



MAC timestamp (in microseconds)
Packet length
PHY rates + RSSI
Success/Loss

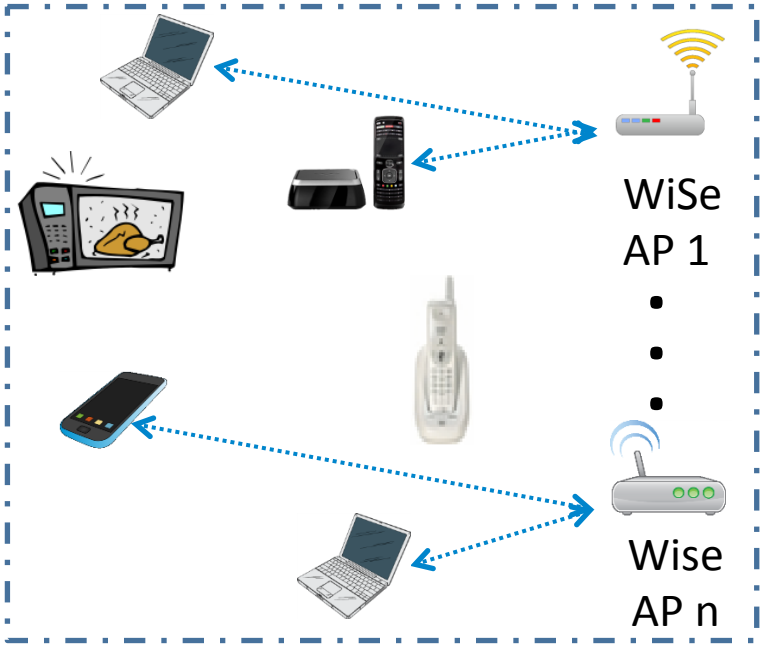
Per-Link WiFi Header Summaries

WiSe analytics toolkit

Aggregate Statistics

Non-WiFi activity

Interference Analysis



Apartment Building

PIE (NSDI 2011)

WiFiNet (NSDI 2012)

WiFi Packet Transmission Reports

Co-relate transmissions (timing overlaps)

Non-WiFi activity information

Controller

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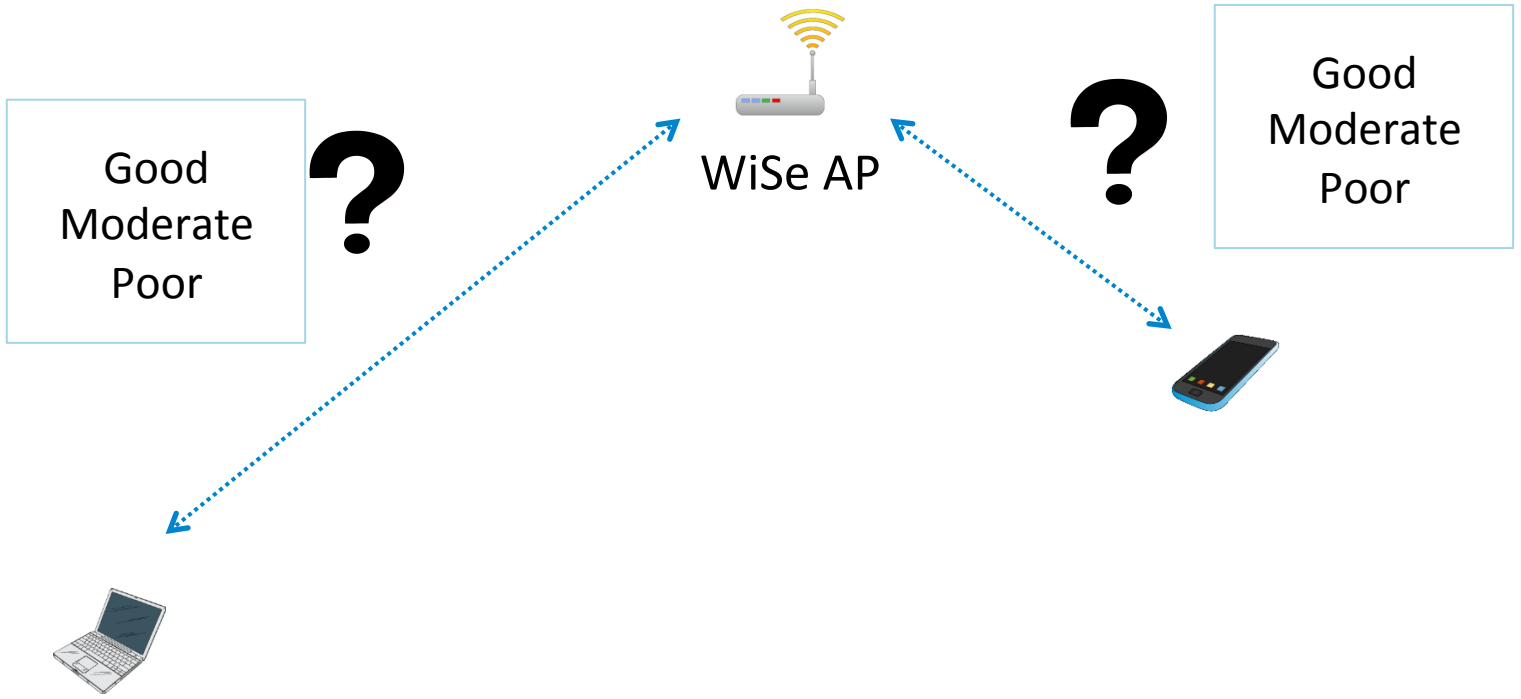
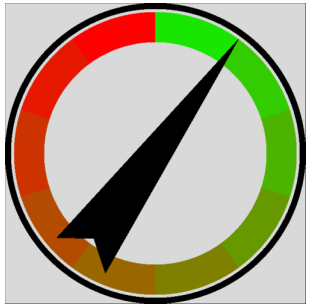
Characterizing wireless performance

At a given time instant, what is the expected wireless throughput of my different wireless links?

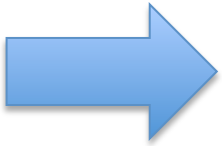


Goal: Metric for wireless performance

Capture impact of link and external wireless properties on performance



Only Passive + Coarse local measurements
(10 sec local measurements at APs)



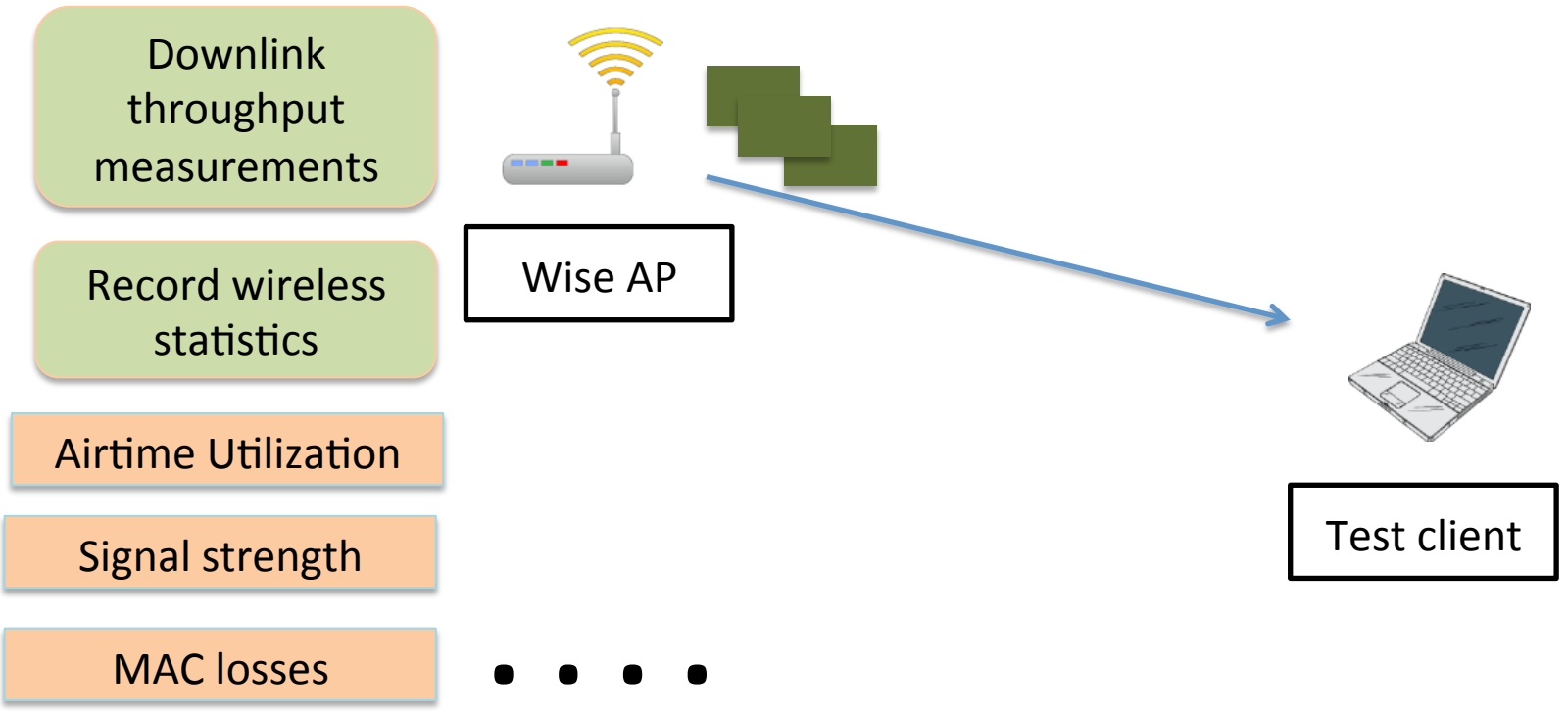
Witt
(WiFi based estimated TCP throughput)

Computed per AP – Client pair

Application agnostic

Building the Witt metric

- Ground Truth: Active TCP throughput measurements (wireless downlink) under different conditions



Determining candidates for Witt metric

- Correlated wireless statistics with actual TCP throughput

Feature	Correlation Coefficient (Absolute value)
Busy airtime	0.321
CRC Errors	0.345
Local contention	0.463
Signal strength	0.536
Effective rate	**0.882**
"Link_exp" model (Preferred)	**0.958**

Best overall

Determining candidates for Witt metric

- Correlated wireless statistics with actual TCP throughput

Feature	Correlation Coefficient (Absolute value)
Busy airtime	0.321
Signal strength	0.536
Effective rate	**0.882**
"Link_exp" model (Preferred)	**0.958**

Use "Link experience" model as candidate for Witt metric

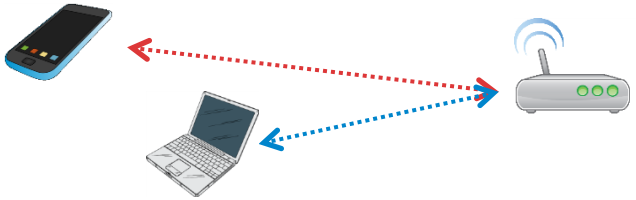
Best overall

Inputs for the Witt metric (using link experience)

Airtime Utilization (a)

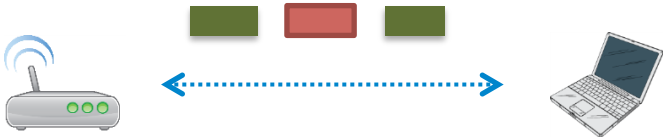
Busy airtime due to external sources

Local contention (c)



Cross-traffic from other clients

Effective rate (r)



$$r = \frac{1}{\sum_i p_i} \sum_i s_i \cdot r_i, \quad 1 \le i \le n$$

Capture impact of successful packet (s_i) over total packets (p_i) sent at each PHY rate (r_i)

Creating the Witt metric

- Estimating per-link performance ("Link Experience")
  - Using busy airtime (a), local contention (c), effective rate (r)

$$\text{link\_exp} = (1-a) * (1-c) * r,\ 0 \le a \le 1,\ 0 \le c \le 1$$

- Use linear regression to obtain coefficients (β_0, β_1) from ground truth TCP throughput values

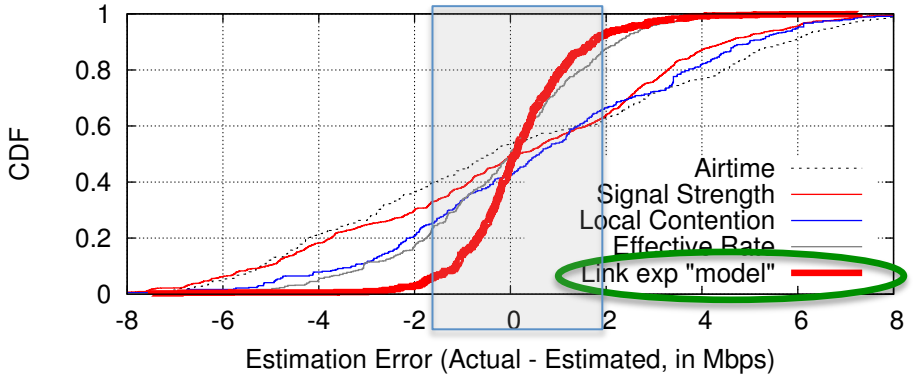
$$Witt = \beta_1 * \text{link\_exp} + \beta_0$$

Use "Witt" as a passive estimate of TCP throughput (per link)

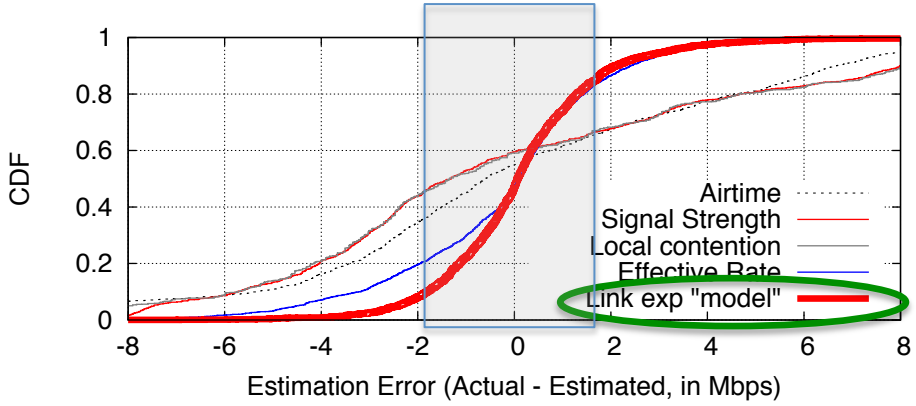
Prediction Errors

Compare Ground truth TCP throughput with predicted values

802.11g
(Max. tput ~ 19 Mbps)



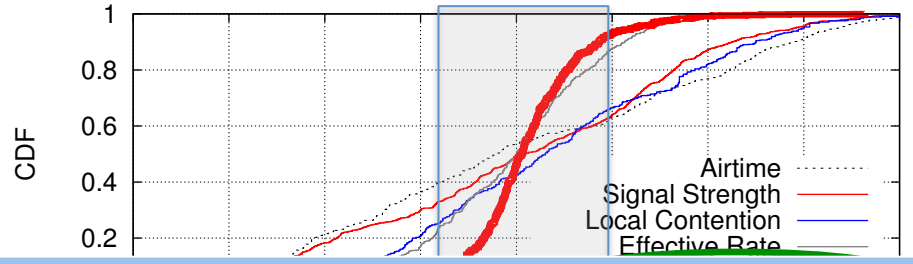
802.11n
(Max. tput ~ 34 Mbps)



Prediction Errors

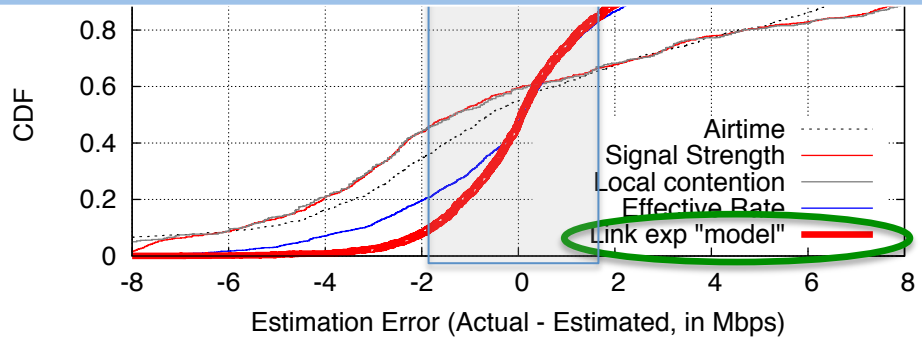
Compare Ground truth TCP throughput with predicted values

802.11g
(Max. tput ~ 19 Mbps)



80% of errors within 1.5 Mbps and 3Mbps for 802.11g and 802.11n respectively

802.11n
(Max. tput ~ 34 Mbps)



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- **Measurement Results**
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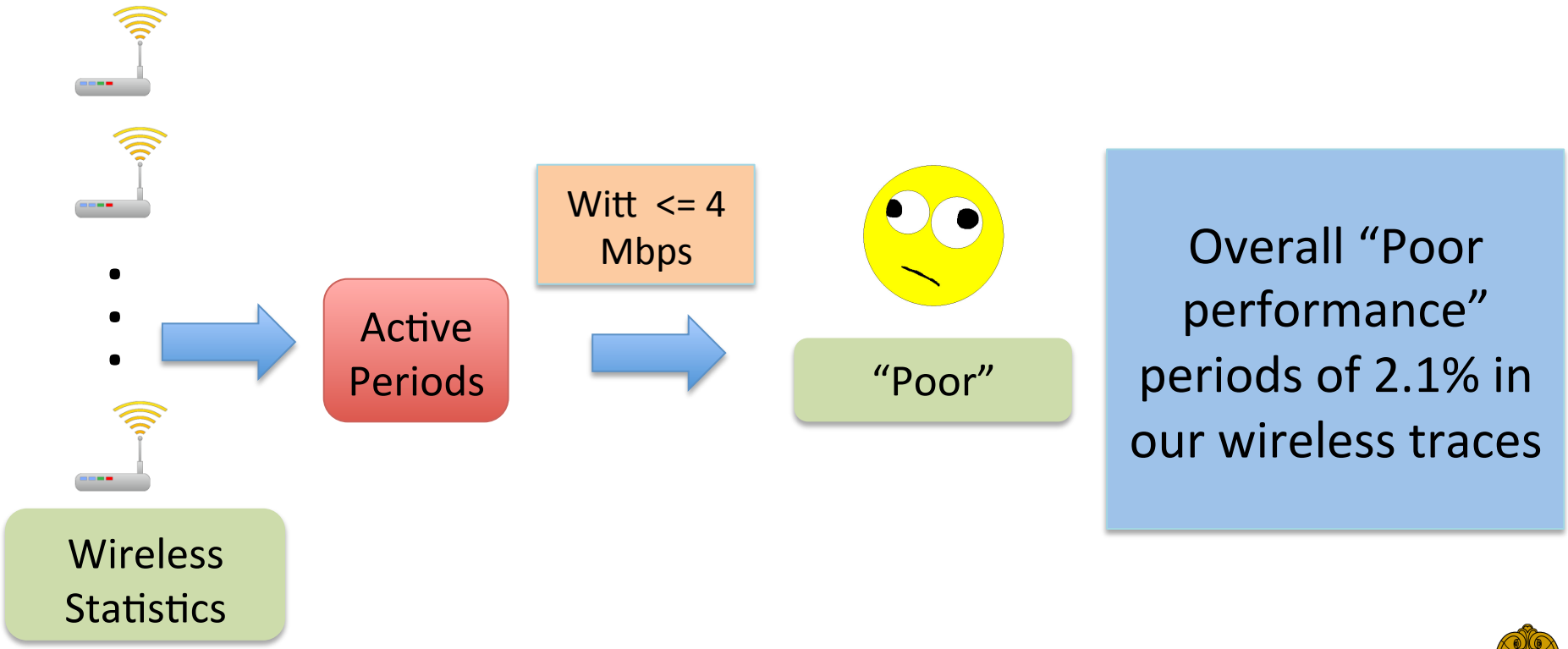
How often was performance “poor”?

- Active periods: 10 sec intervals with > 500 downlink packets per AP-Client pair



Diagnosing "Poor" Performance

Poor: Witt < 4 Mbps

Indicators				Bldg 1		Bldg 2	
$A \uparrow$	$S \downarrow$	$L \uparrow$	$R \downarrow$	V. Poor	Poor	V. Poor	Poor
✓	×	×	×				
×	×	✓	×				
✓	×		×				
×	✓						
×	✓						
	O						

High airtime usage (> 60%)

Diagnosing "Poor" Performance

Poor: Witt < 4 Mbps

Indicators				Bldg 1		Bldg 2	
$A \uparrow$	$S \downarrow$	$L \uparrow$	$R \downarrow$	V. Poor	Poor	V. Poor	Poor
✓	×	×	×				
×	×	✓	×				
✓	×	✓	×				
×	✓						
×	✓						
		O					

Poor signal strength
(< -70 dBm)

Diagnosing "Poor" Performance

Poor: Witt < 4 Mbps

Indicators				Bldg 1		Bldg 2	
$A \uparrow$	$S \downarrow$	$L \uparrow$	$R \downarrow$	V. Poor	Poor	V. Poor	Poor
✓	×	×	×				
×	×	✓	×				
✓	×	✓	×				
×	✓						
×	✓						
		O					

High MAC losses
(> 50%)

Diagnosing "Poor" Performance

Poor: Witt < 4 Mbps

Indicators				Bldg 1		Bldg 2	
$A \uparrow$	$S \downarrow$	$L \uparrow$	$R \downarrow$	V. Poor	Poor	V. Poor	Poor
✓	×	×	×				
×	×	✓	×				
✓	×	✓	×				
×	✓						
×	✓						
		O					

Low PHY rates
(< 12 Mbps)

Diagnosing "Poor" Performance

Poor: Witt < 4 Mbps

Indicators				Bldg 1		Bldg 2	
$A \uparrow$	$S \downarrow$	$L \uparrow$	$R \downarrow$	V. Poor	Poor	V. Poor	Poor
✓	×	×	×				
×	×	✓	×				
✓	×	✓	×				
×	✓	✓	×				
×	✓	✓	✓				
Others							

Diagnosing "Poor" Performance

Poor: Witt < 4 Mbps

Indicators				Bldg 1		Bldg 2	
$A \uparrow$	$S \downarrow$	$L \uparrow$	$R \downarrow$	V. Poor	Poor	V. Poor	Poor
✓	×	×	×		18.4%		1%
×	×	✓	×		**49.5%**		**78.1%**
✓	×	✓	×		26.7%		1.4%
×	✓	✓	×		1.1%		15.8%
×	✓	✓	✓		0%		3.4%
					4		%

High MAC losses but, good signal strengths

Client-side reception issues, Interference

Diagnosing "Very Poor" Performance

Very Poor: Witt < 1 Mbps

Indicators				Bldg 1		Bldg 2	
$A \uparrow$	$S \downarrow$	$L \uparrow$	$R \downarrow$	V. Poor	Poor	V. Poor	Poor
✓	×	×	×				
×	×	✓	×				
✓	×	✓	×				
×	✓	✓	×				
×	✓	✓	✓				
		Others					

Diagnosing "Very Poor" Performance

Very Poor: Witt < 1 Mbps

Indicators				Bldg 1		Bldg 2	
$A \uparrow$	$S \downarrow$	$L \uparrow$	$R \downarrow$	V. Poor	Poor	V. Poor	Poor
✓	×	×	×	0%			
×	×	✓	×	24.2%			
✓	×	✓	×	**61.8%**			
×	✓	✓	×	2.3%			
×	✓	✓	✓	9.4%			
				2.3%			

Dense AP deployments
In Building 1
Channel congestion main cause of poor performance

High Airtime +
Packet Losses

Diagnosing "Very Poor" Performance

Very Poor: Witt < 1 Mbps

Indicators				Bldg 1		Bldg 2	
$A \uparrow$	$S \downarrow$	$L \uparrow$	$R \downarrow$	**V. Poor**	**Poor**	**V. Poor**	**Poor**
✓	×	×	×	0%			
×	×	✓	×	24.2%			
✓	×	✓	×	**61.8%**			
×	✓	✓	×	2.3%			
×	✓	✓	✓	9.4%			
Others				2.3%			

Diagnosing "Very Poor" Performance

Very Poor: Witt < 1 Mbps

Indicators				Bldg 1		Bldg 2	
$A \uparrow$	$S \downarrow$	$L \uparrow$	$R \downarrow$	V. Poor	Poor	V. Poor	Poor
				0%		0%	
				24.2%		25.2%	
✓	✓	✓	×	**61.8%**		2.1%	
×	✓	✓	×	2.3%		20%	
×	✓	✓	✓	9.4%		**51.6%**	
Others				2.3%		1.1%	

Weak Signal + High Losses + Low PHY Rates

Centralized AP deployments in Building 2
Weak signal main cause of poor performance

Diagnosing “Very Poor” Performance

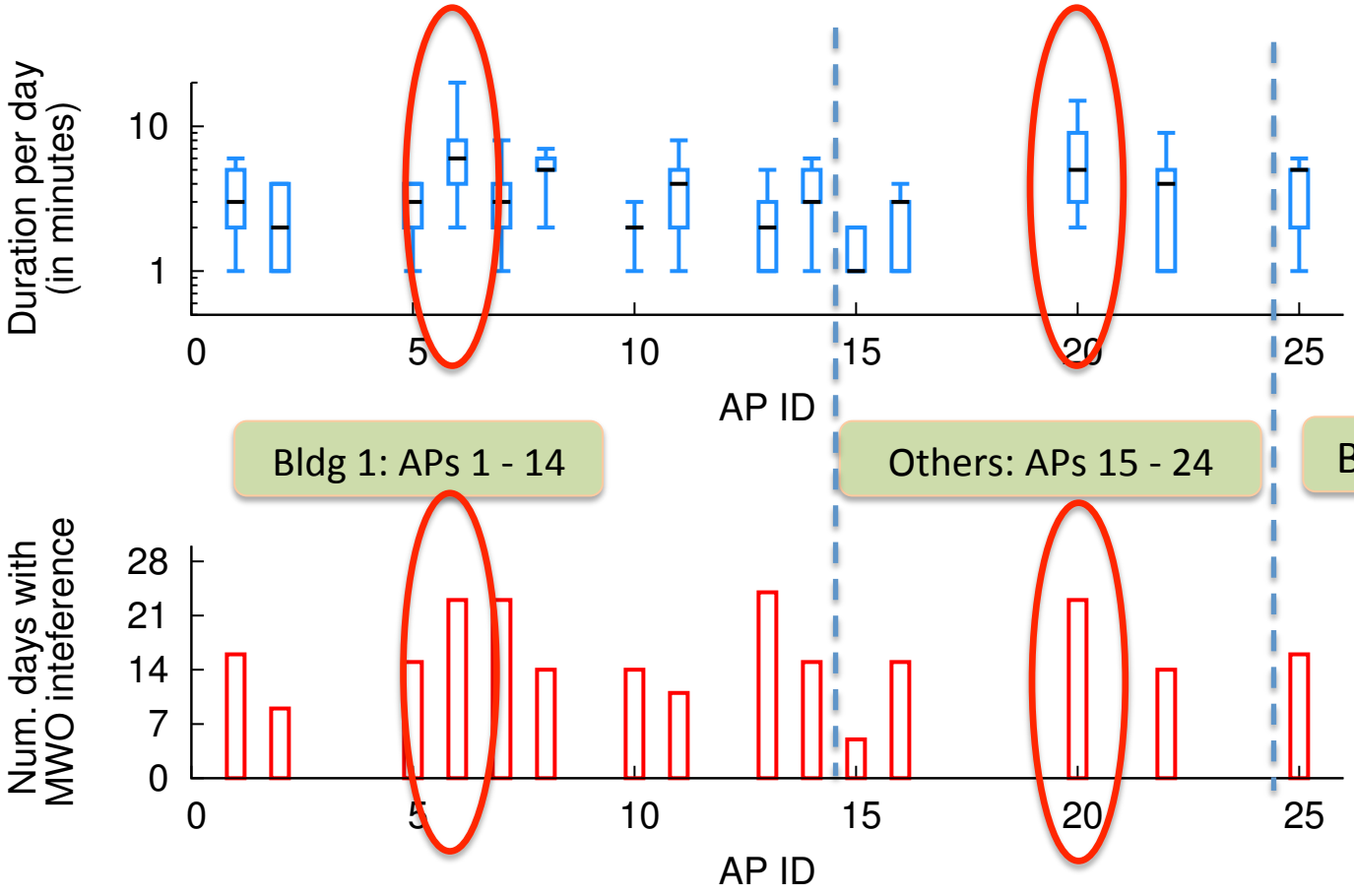
Very Poor: Witt < 1 Mbps

Indicators				Bldg 1		Bldg 2	
$A\uparrow$	$S\downarrow$	$L\uparrow$	$R\downarrow$	V. Poor	Poor	V. Poor	Poor
				0%			
				2.3 %			
×	✓	✓	✓	9.4%			
Others				2.3%			

The nature of the wireless deployment impacted the causes of the degraded wireless performance

Centralized AP deployments in Building 2
Weak signal main cause of poor performance

Results 2: Microwave oven interference (30 day period)



Bldg 1: APs 1 - 14

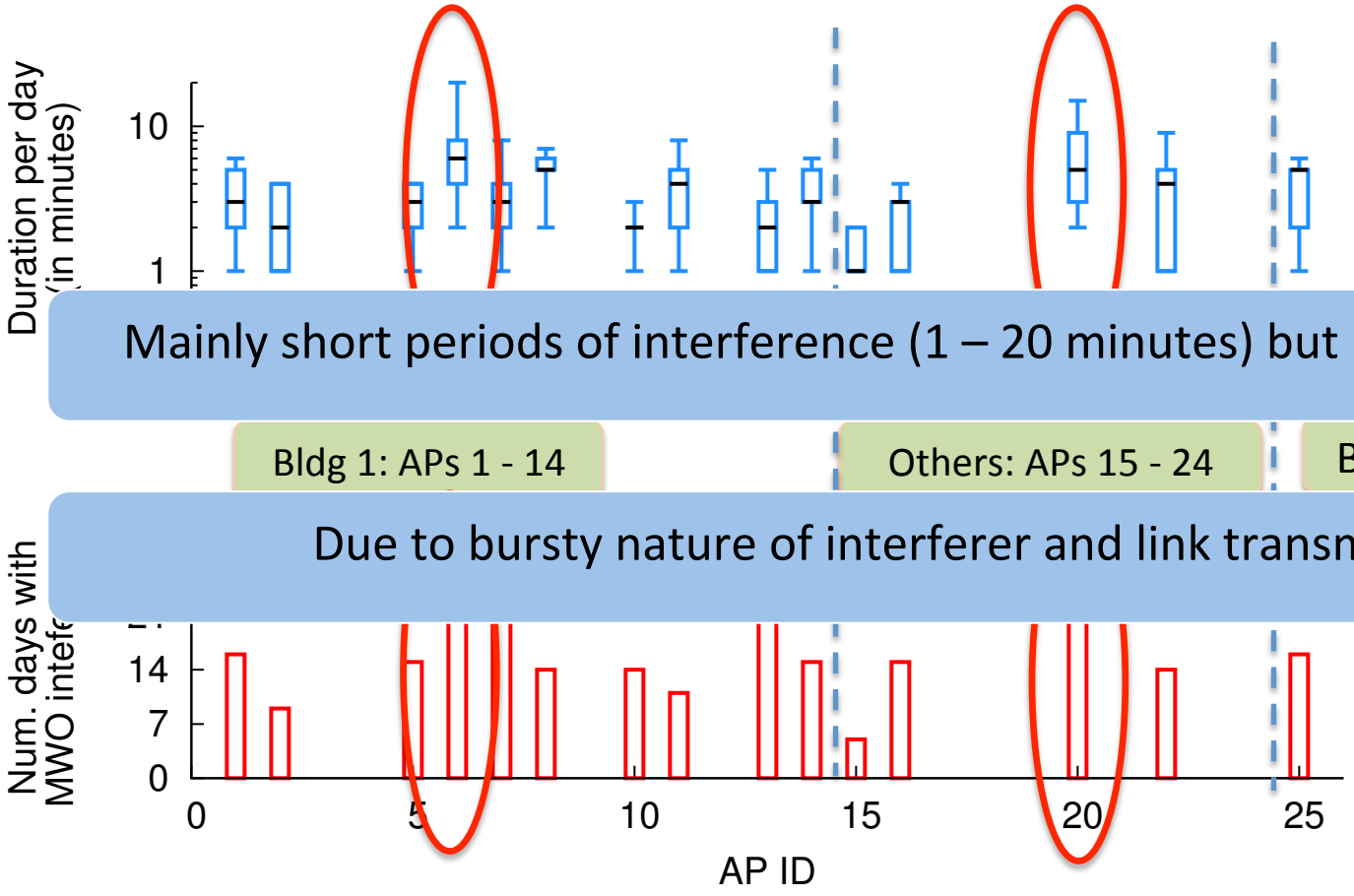
Others: APs 15 - 24

Bldg 2: APs 25 - 30

Interference periods per day 1 – 20 minutes

But, prevalent at many locations

Results 2: Microwave oven interference (30 day period)



Interference periods per day 1 – 20 minutes

Mainly short periods of interference (1 – 20 minutes) but recurring impact

Bldg 1: APs 1 - 14

Others: APs 15 - 24

Bldg 2: APs 25 - 30

Due to bursty nature of interferer and link transmissions

But, prevalent at many locations

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- **Related Work and Summary**

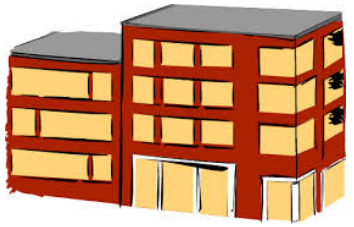
Related Work

- Measuring home broadband performance
  - BISMark (SIGCOMM'11)
- Enterprise sniffer deployments
  - Kotz et al. (MobiCom'02)
  - Jigsaw (SIGCOMM'06)
- Urban scale WiFi deployments
  - TFA-Rice Mesh networks (MobiCom'08)

Summary

- Deployed an infrastructure that uses APs to study home WLANs
- Presented a simple wireless performance metric
- Overall poor performance periods of 2.1% in our deployment
  - Wireless problems dependent on the nature of deployment
- Observed short (1 – 20 minutes) but recurring instances of interference
  - Bursty nature of link and interferer activity





Thanks!