Characterizing Wireless Pathologies in Home Networks

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Why study *Wifi* in homes?

- *Wifi* technology is the most used for connectivity to the Internet
- Home Networks are *unmanaged* and *unorganized*
- Presence of many devices that can potentially cause disruption in *Wifi* communication e.g. microwave, cordless phone, zigbee devices etc.
- How does an average home user know the causes of poor performance of *Wifi* at home?

Problems with unmanaged networks

- Nearly unusable network performance in many homes
- Connectivity problems due to proximity
- Co-channel Interference between nodes
- TCP might interact poorly because of persistent packet losses

Troubleshooting Wireless in Home Networks

- Anecdotal evidence suggest home networks are small but unpredictable
- Spectrum analyzers for detecting broadband Interference
- *NetAnalyzer* / *Speedtests* for throughput and delay measurements for short intervals

Understanding Home Networks

- There is lack of understanding of how 802.11 performs in home networks
- What does normal wireless traffic look like?
  - How many average retransmissions?
  - How stable are bitrates devices transmit at?
- How to differentiate good from bad?
- What is the ground truth? Baselines for such statistics

Research Questions?

- What is the cause of performance degradation?
  - Broadband Interference
  - Hidden Terminals
  - Contention period
- What is the most persistent/prevalent issue?
- Operating regimes for 802.11 standard
  - $a/b/g/n$ in the same environment
  - Maximum operational throughput in real deployment

Theoretical vs Practical Approach

- Model
  - Model for RF interference, signal attenuation of different devices
  - Model different kinds of construction material in homes (unlike campus/enterprise network)
  - Cannot model user behavior
- Perform simulation
  - Get results based on assumptions of the model

Theoretical vs Practical Approach

- But reality is far different from what we can infer from these simulations!
- It is hard to predict/model variable channel conditions because of multipath
- Need actual testbed!
- We need actual measurements to understand conditions of wireless medium and identify pathologies
- Many publications assume such problems and give solution

Our Approach

- Measurements from actual deployment
- Perform *passive*, *continuous* measurements from Internet gateway
  - Does not introduce traffic overhead into network
  - Scheduling regular tests from/to user devices is not required
  - Gives finegrained information for anomaly detection
- Complete control over Access Point
- No access to home users wireless devices

Rationale behind our approach

- Take advantage of a pre-existing deployment of BISMark
- Have uniformity in the measurements because of the same networking stack and hardware on all routers
- Cooperation from home users not required

Mechanism to Detect wireless pathologies

- Contention in medium
  - Measure the time difference data frame is enqueued and dequeued in the hardware queues when the queue is empty.
- Broadband Interference
  - Measure the frequency of OFDM timing errors at Physical layers
- Hidden Terminal
  - Measure the number of RTS-CTS frames in the wireless medium

Can We Do More?

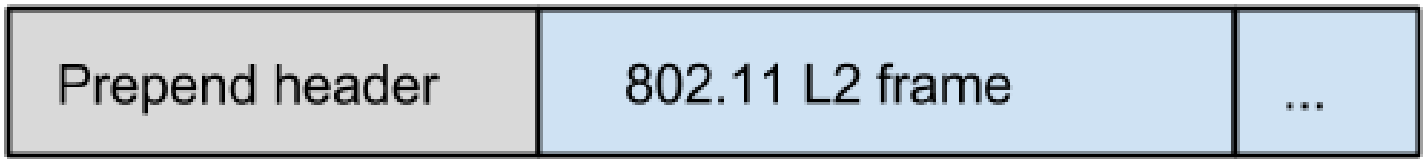
- Constrained to get access to and instrument other home devices
  - Cannot have more infrastructure in one home and get global view of the network
- Constrained by Wireless chipset (hardware)
  - *Ath9k* driver does not provide access to fine grained information of *802.11 Contention Window*, *AIFS* (Arbitration Inter-frame Spacing), *TXOP*

Our Peephole: Home Gateway

- Hardware
  - Netgear routers
  - Atheros wireless cards (b/g/n),(a/n)
  - Dual radio wireless cards
- Software
  - OpenWrt firmware
    - white russian and backfire
  - Modified ath9k driver and kernel subsystem
  - Custom written userland wireless monitoring tool: *Oculus*

Oculus: What are we Collecting?

- Prepend radiotap headers in a copy of every frame to collect
  - Physical Layer, MAC Layer information
  - Transmit and received timestamps
- Collect all data frames
- Subset of control and management frames
- Measurements data from 8 homes for over 3 months



Research Challenges

- Limited visibility into the home network
- Identification of wireless pathologies using single monitor establishing the Ground truth
- Characterizing Wireless conditions/behavior
- Building Practical and scalable measurement system
- Establishing Ground Truth
  - Hard to recreate same wireless channel conditions in controlled lab environment
  - Unlabelled devices and user behavior
- Minimal resource consumption on router
  - Measurement overhead should not effect own measurements

Engineering Challenges

- Reverse-engineering
  - Interpreting hardware descriptors from ath9k chipset (without programming manual or data sheets)
- Instrumenting wireless driver, 802.11 subsystem
  - track queue sizes
  - transmission timestamps
- Custom userland tool to perform light-weight continuous measurements
- Remote upgrade might break routers losing deployments
- Dealing with buggy Firmware

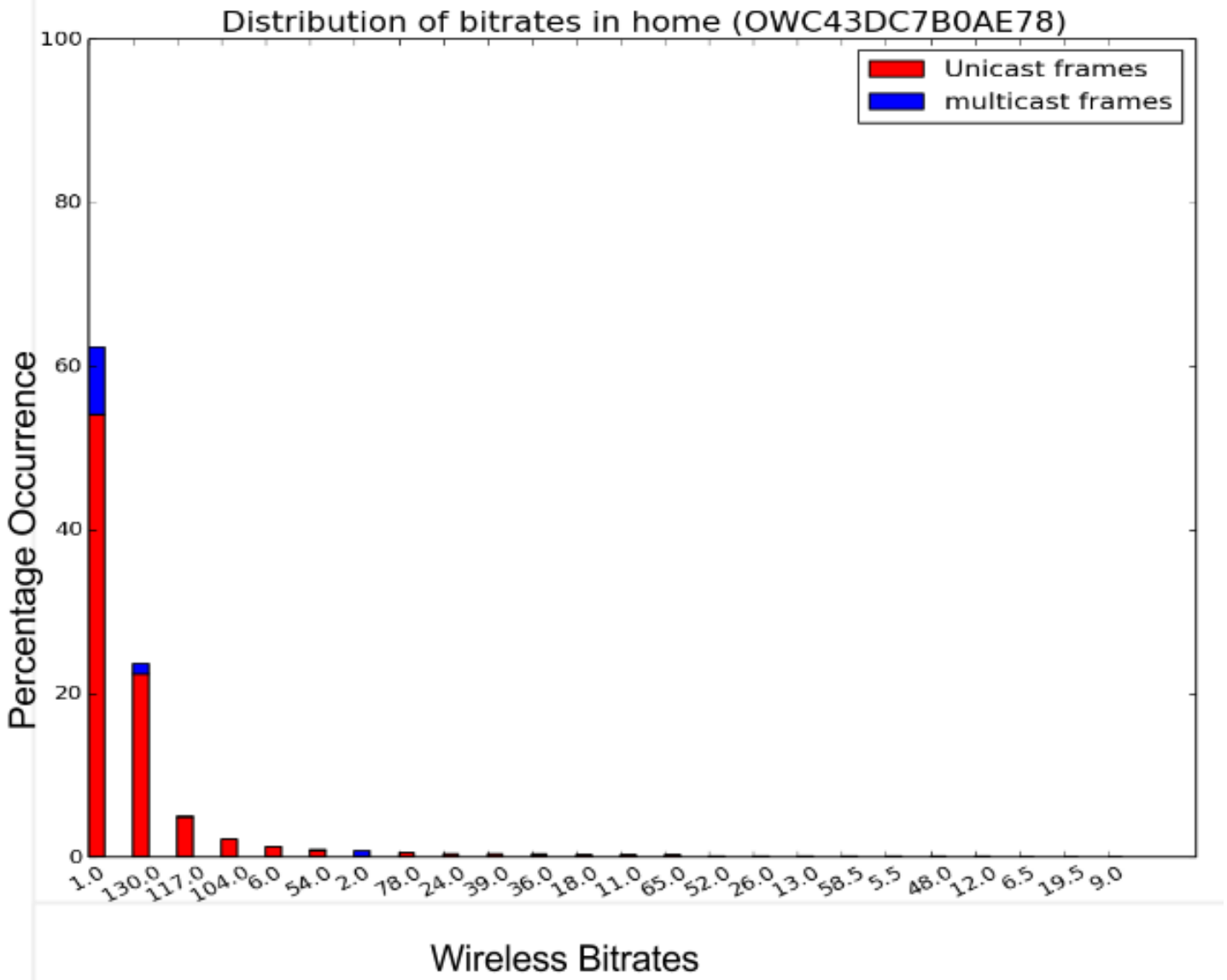
Related Studies

- Measurement study of 802.11a/b/g networks
- WLAN Enterprise Networks
  - Sufficient resources
  - Network Operators survey and design the wireless infrastructure
  - Jigsaw and Airshark
- Wireless Mesh Network
  - *Roofnet* multihop network
  - *WifiProfiler*: troubleshooting tool for DNS etc services
- Home Networks
  - Controlled experiments with multiple monitors in 3 homes
- Our study: on 2.4 GHz and 5 GHz; include 802.11 n; has more deployment

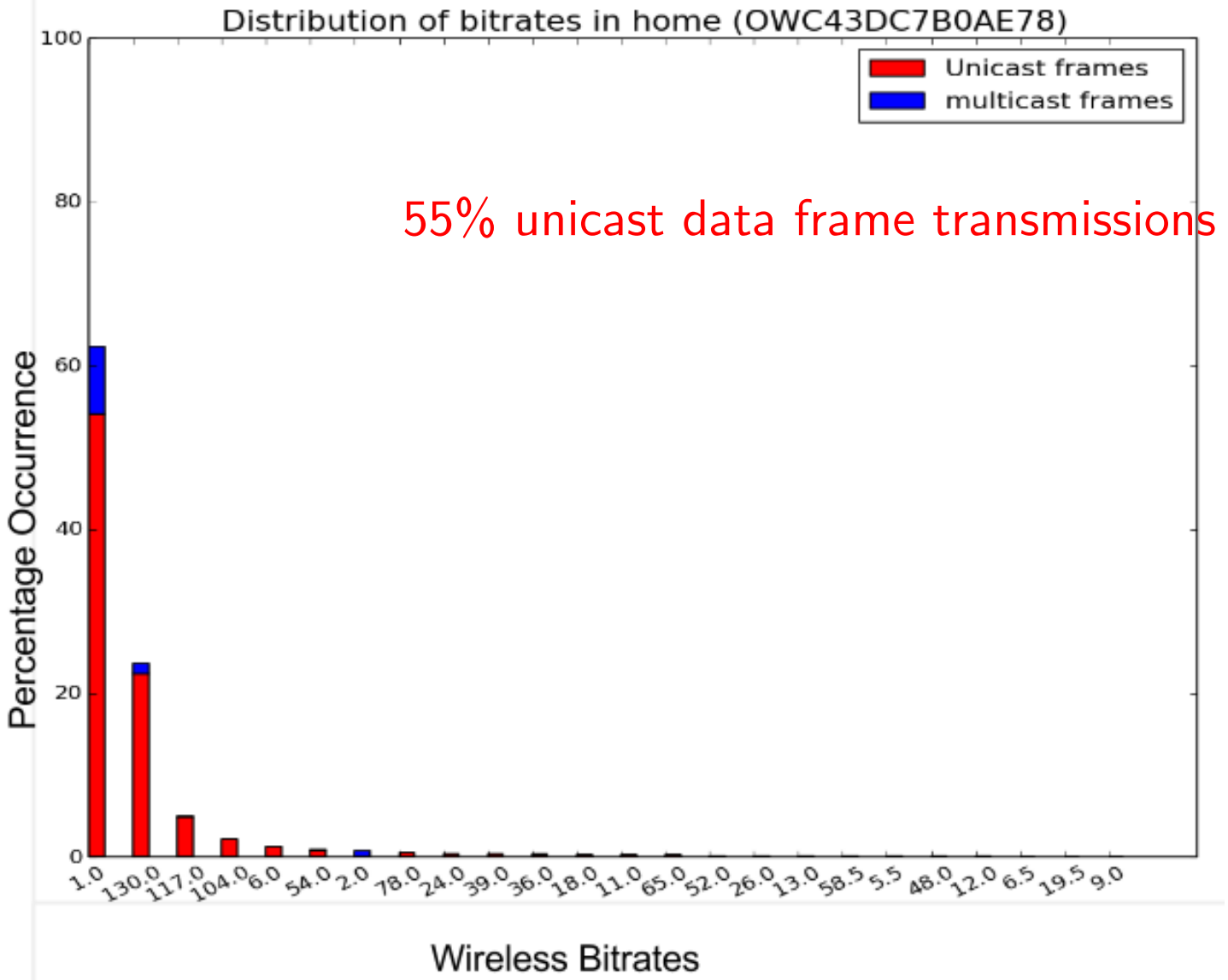
Observations

- Measurements data from 20 homes for 2 days
- Characterizing home deployment
  - Dense deployment (Apartment type)
  - Sparse deployment (Single family homes)
- Density of devices in homes
- 2.4 GHz : Maximum of over 350 wireless devices and 60 Access Points
- 5.8 GHz : Maximum of 20 wireless devices and 3 Access Points

How Poor can the Wireless perform?

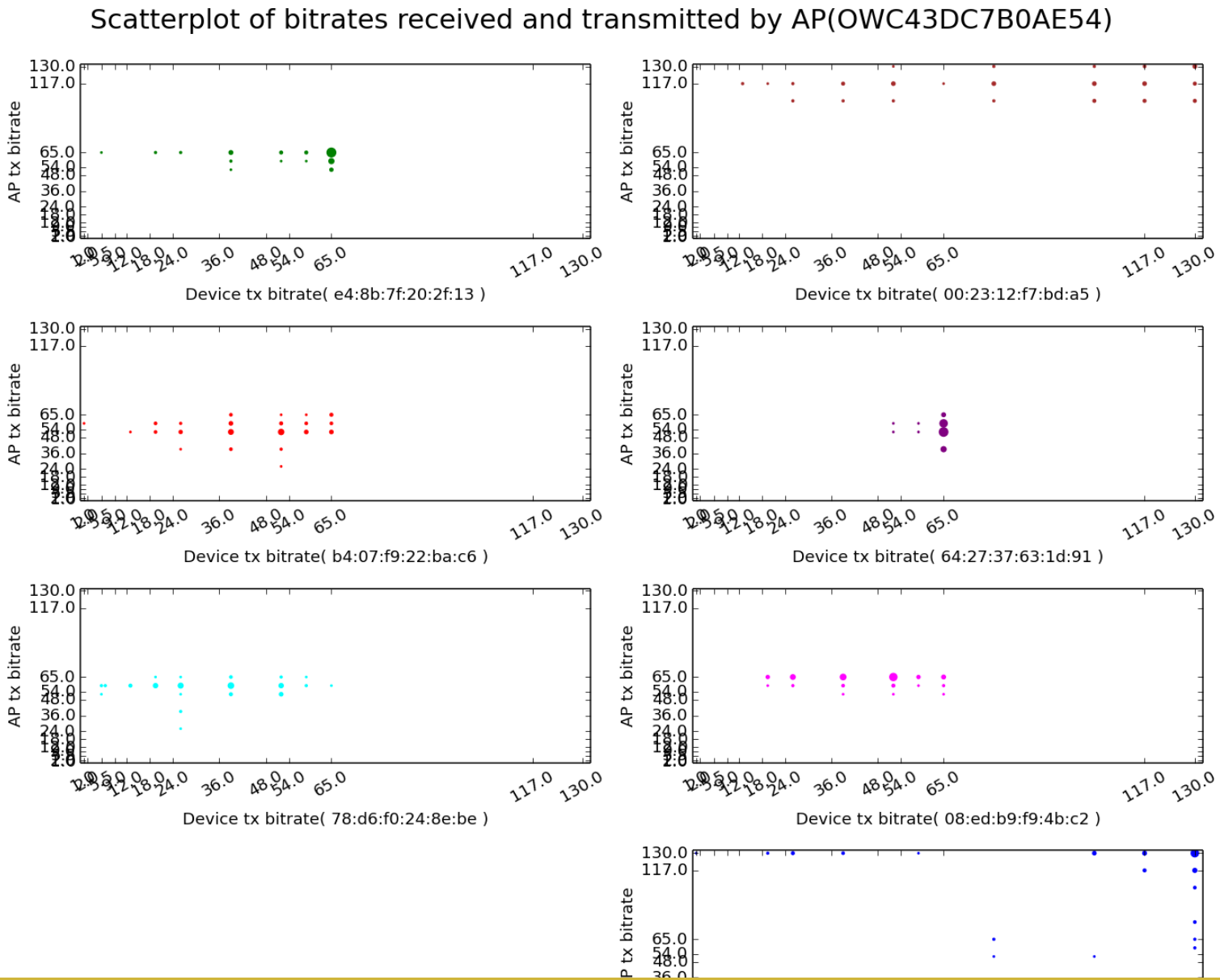


How Poor can the Wireless perform?



55% unicast data frame transmissions are at 1 Mbps!

Asymmetry in Wireless Channel



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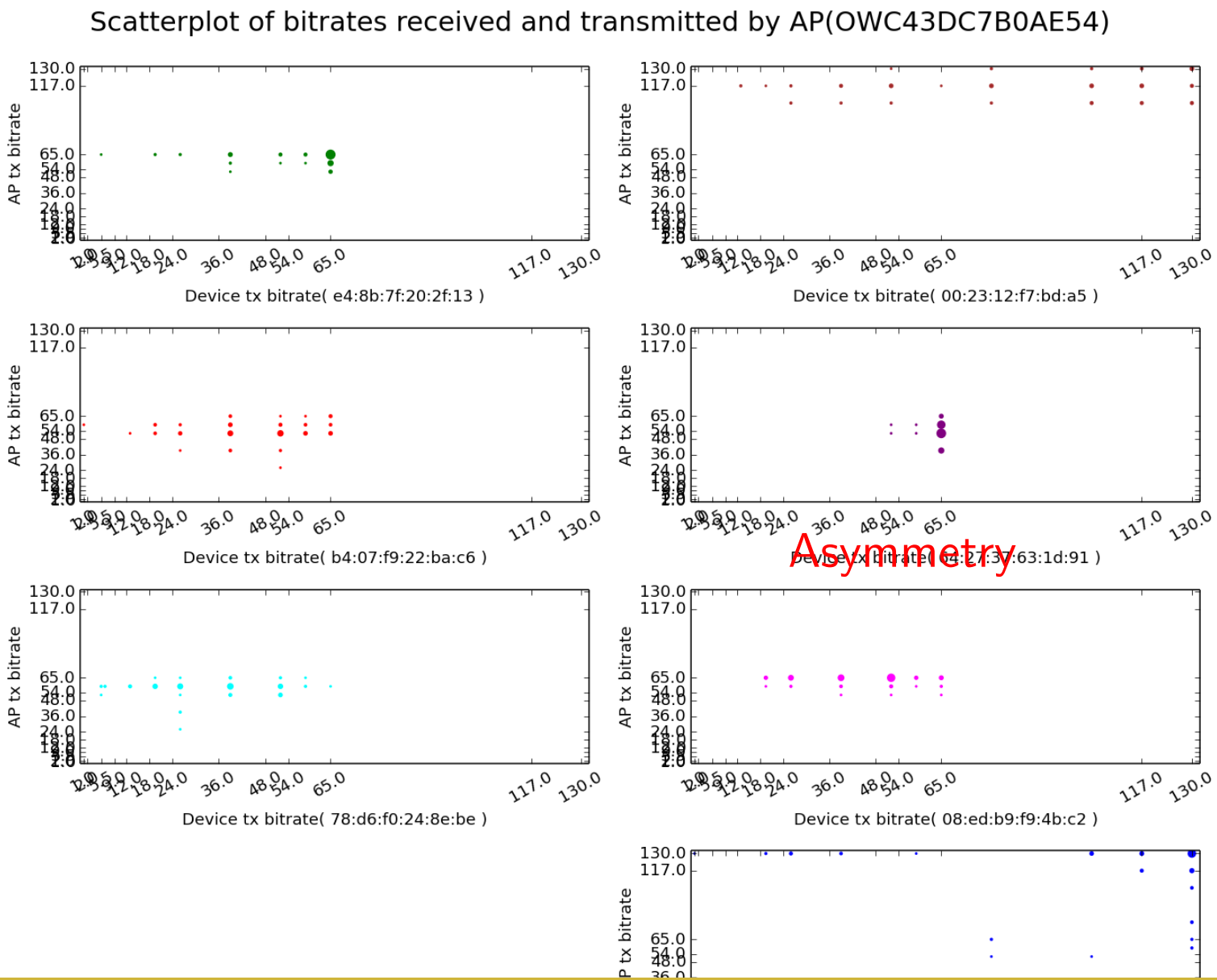

Inferring Hidden Terminals in home Wireless Network

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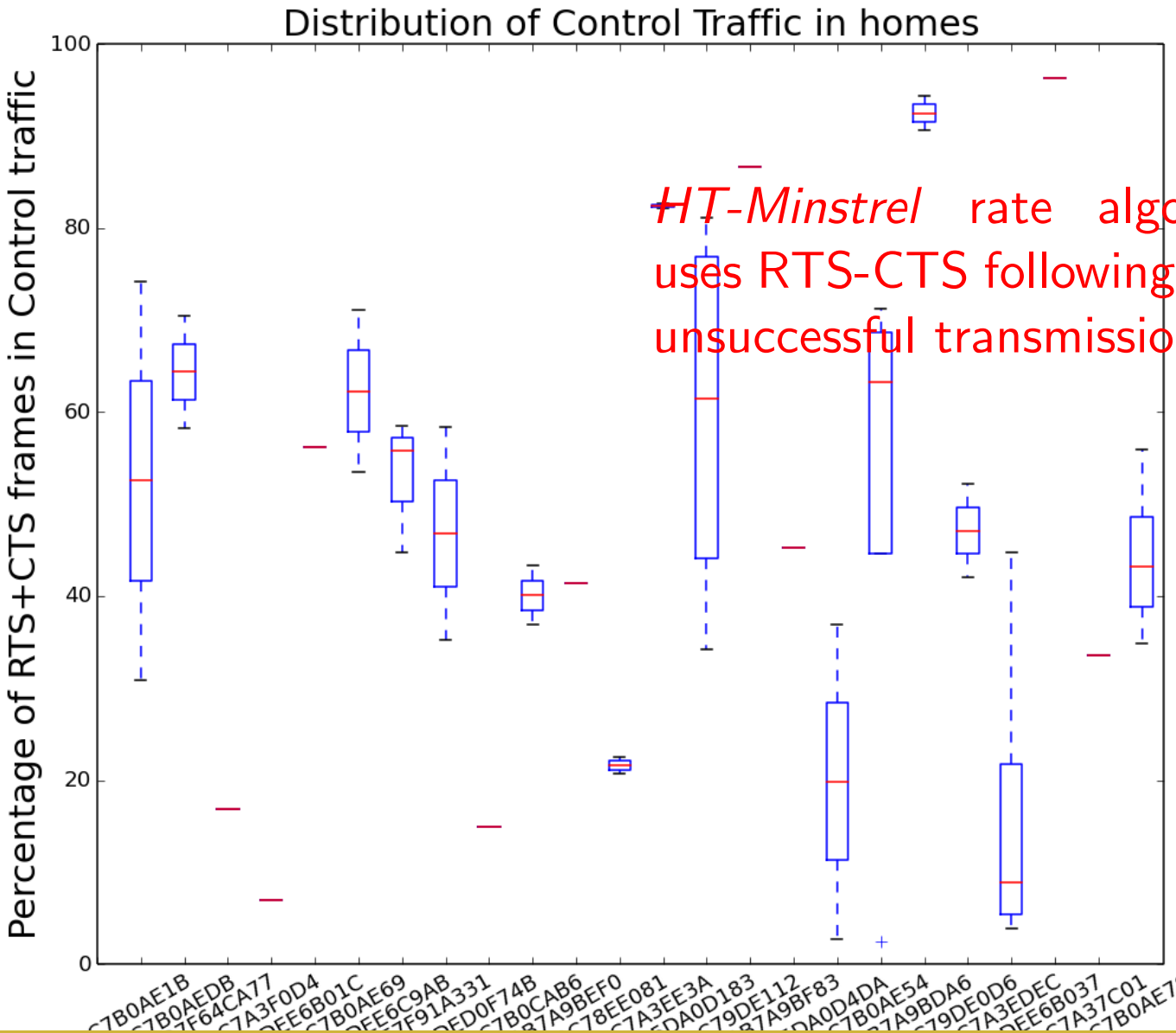
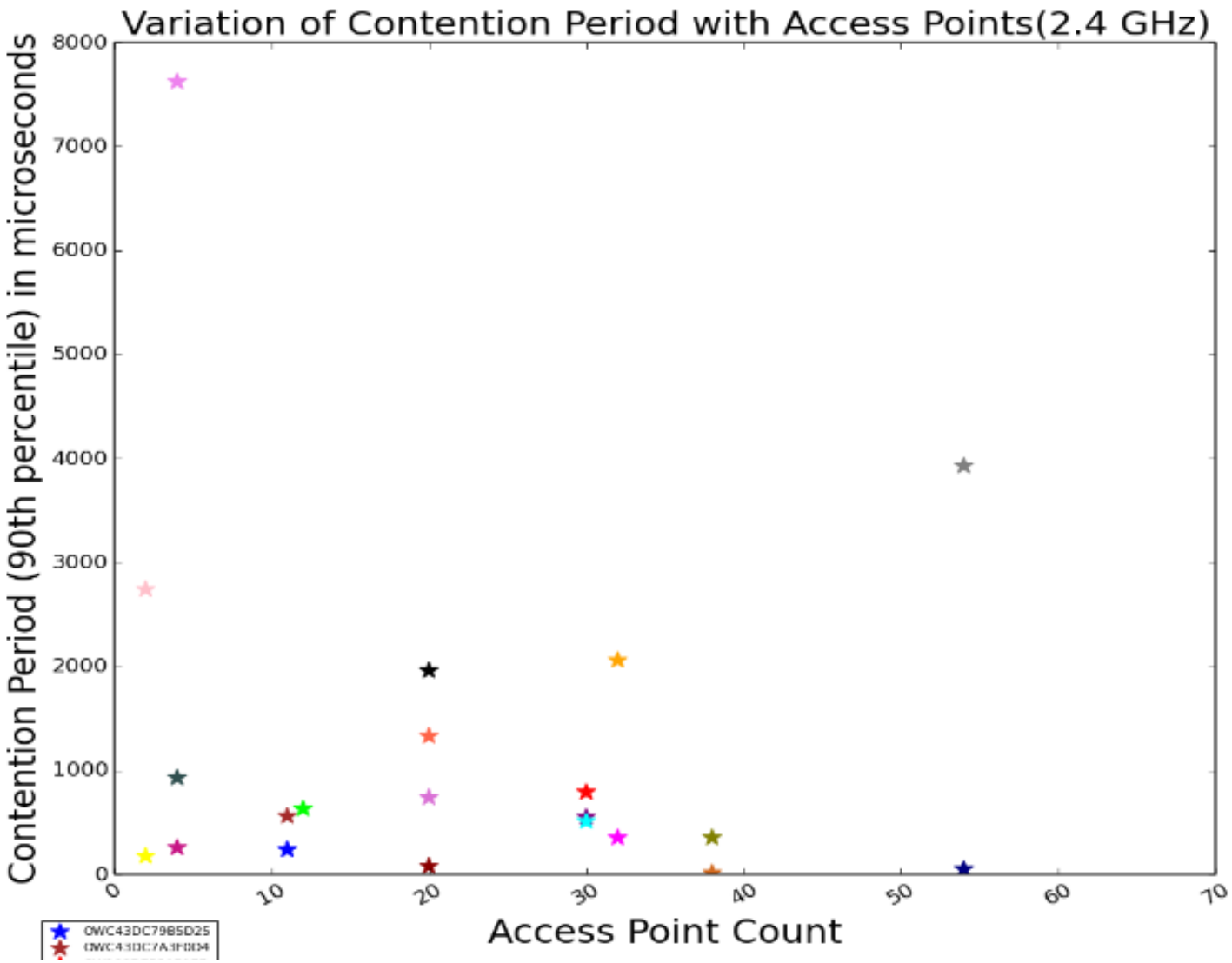


Background on Calculation of Contention Delay

- Total Transmission time = Queueing Delay + Channel Access Delay
- Empty Queue=>Queueing Delay = 0
- Total Transmission time (Contention Delay) =Channel Access Delay

- *802.11 e* Primer
- Four Access Classes: Video, Voice, Best Effort, Background Traffic
- Four hardware queues in the Wireless NIC

Variation of Contention Delay(B.E) with Neigborhood Access Points



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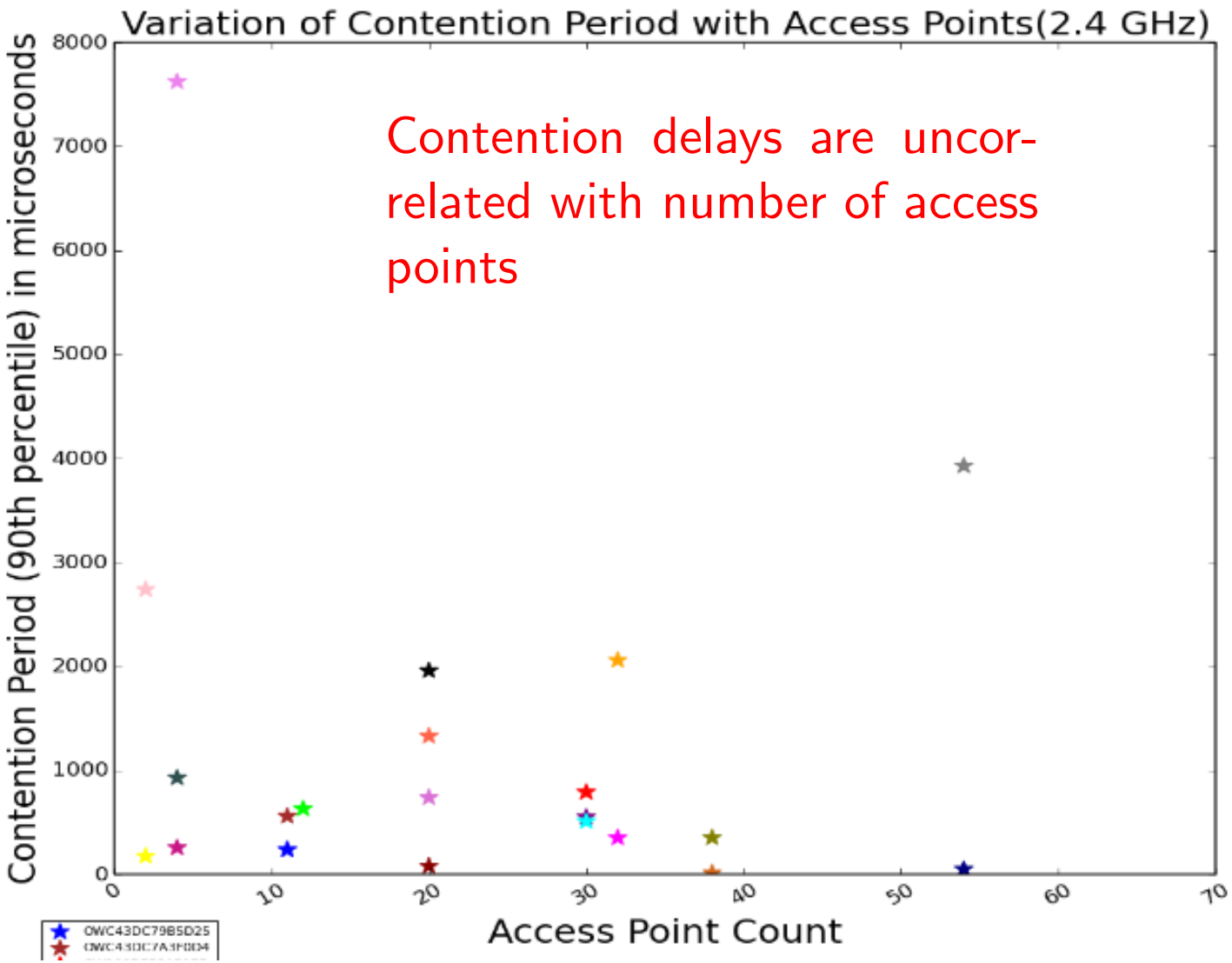
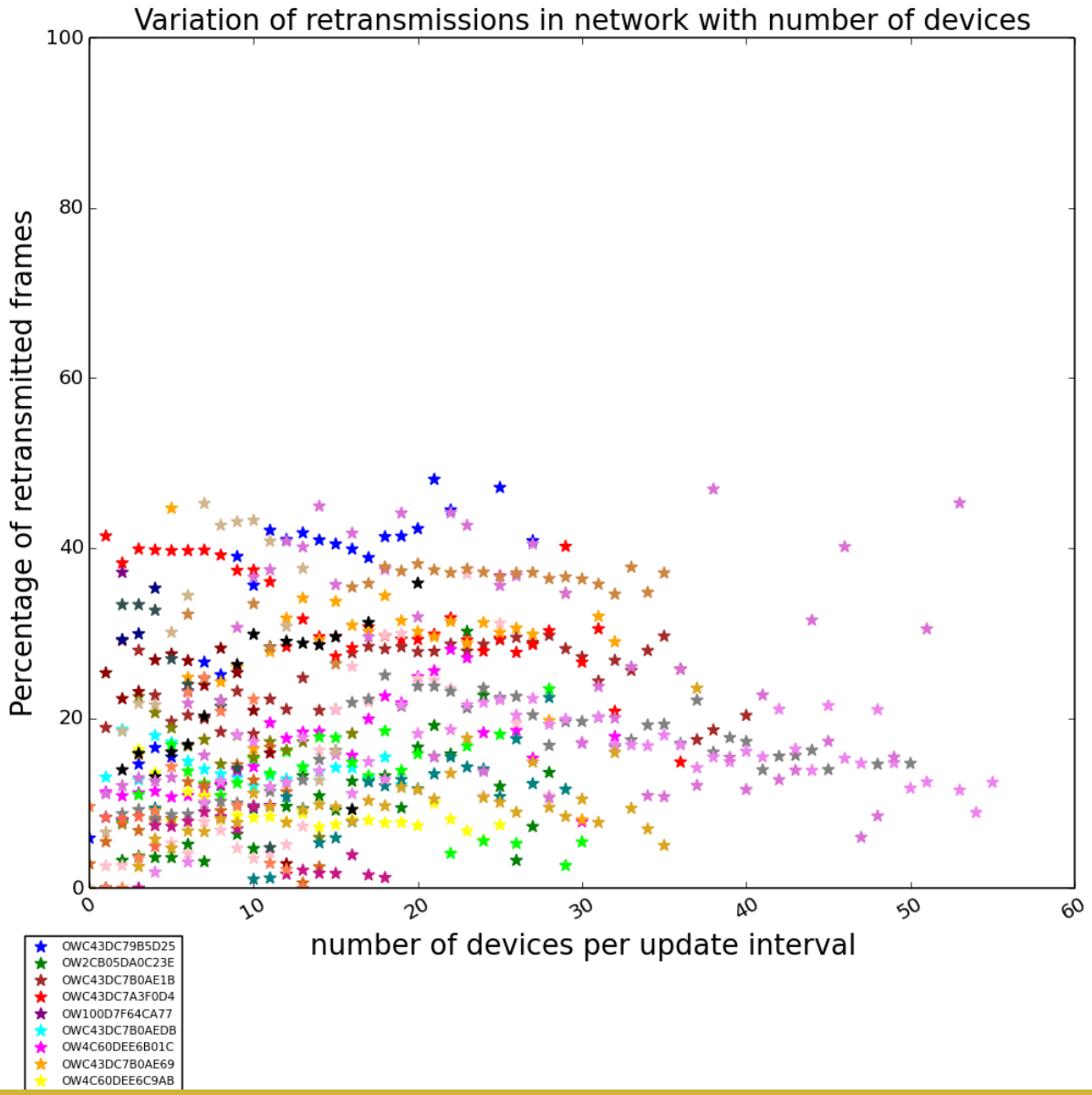


Contention delays are uncorrelated with number of access points

Percentage Retransmissions with Number of Devices



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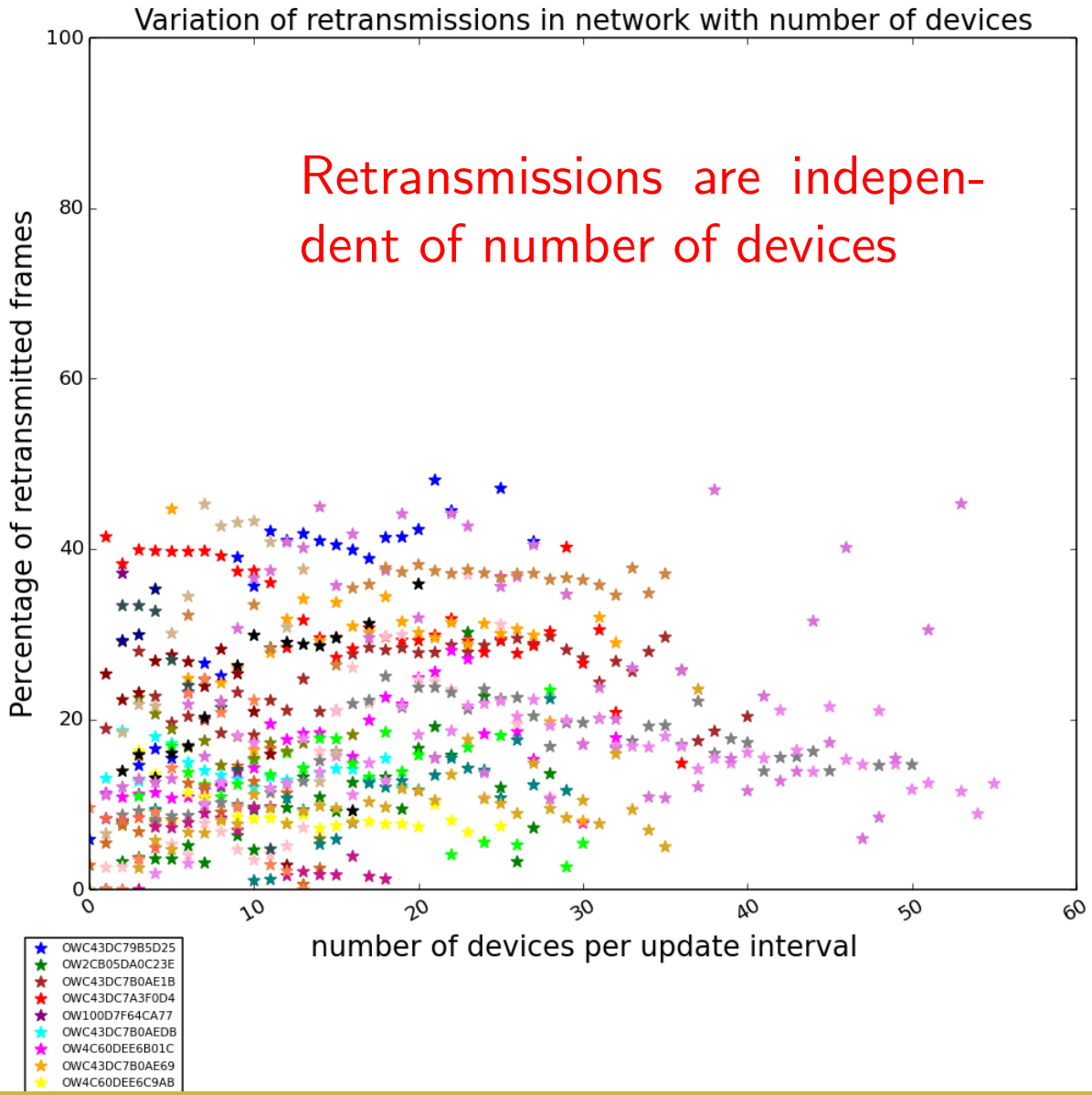
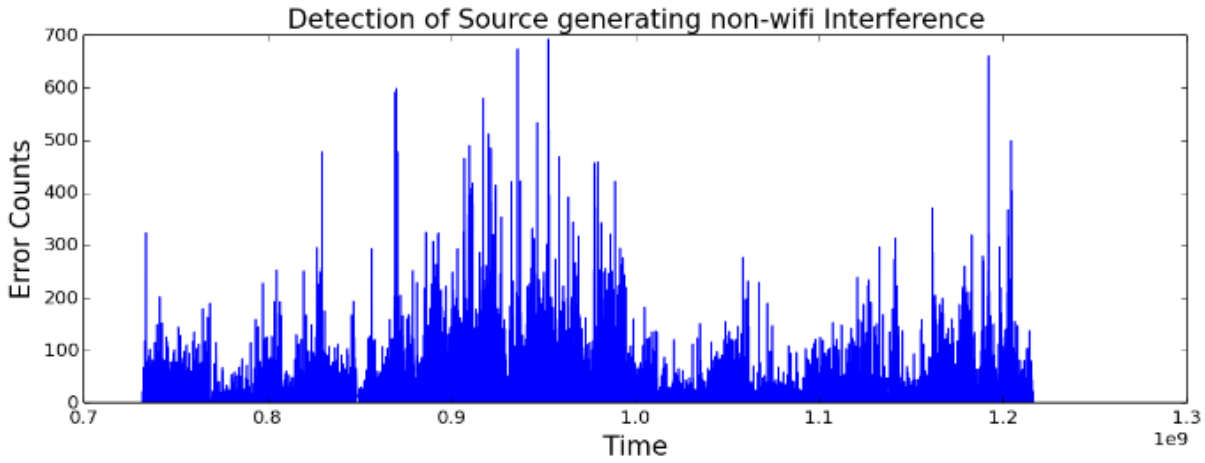
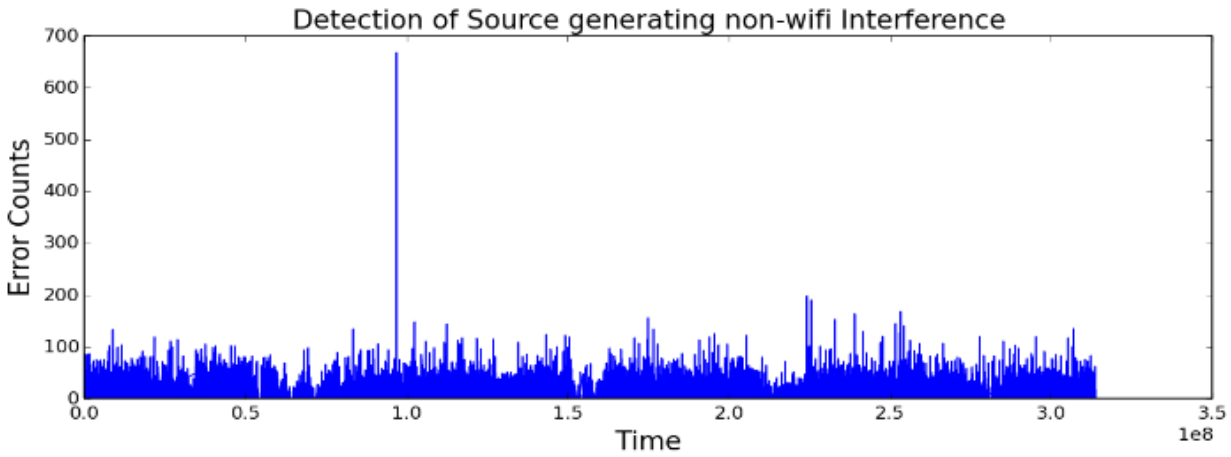


Detection of Broadband Interference





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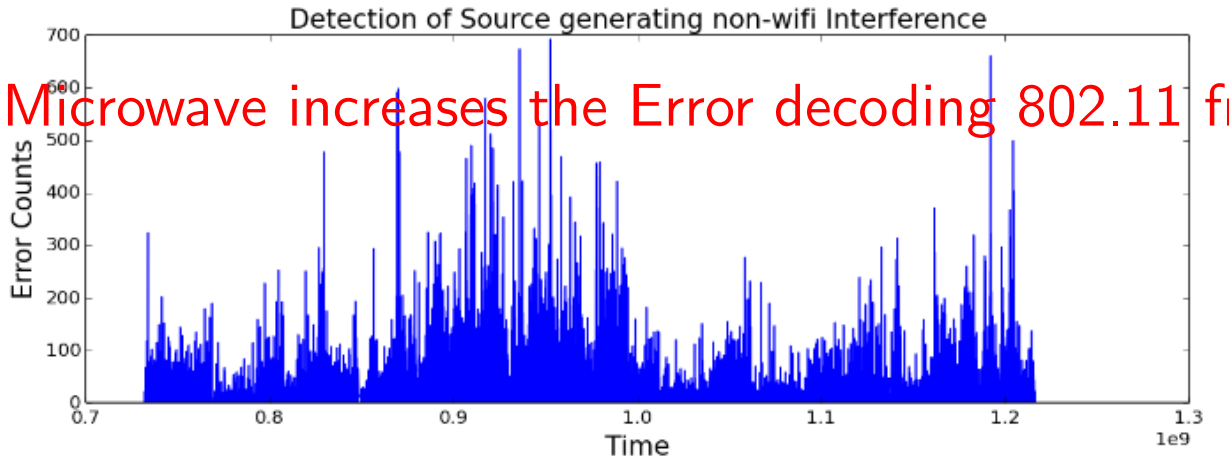
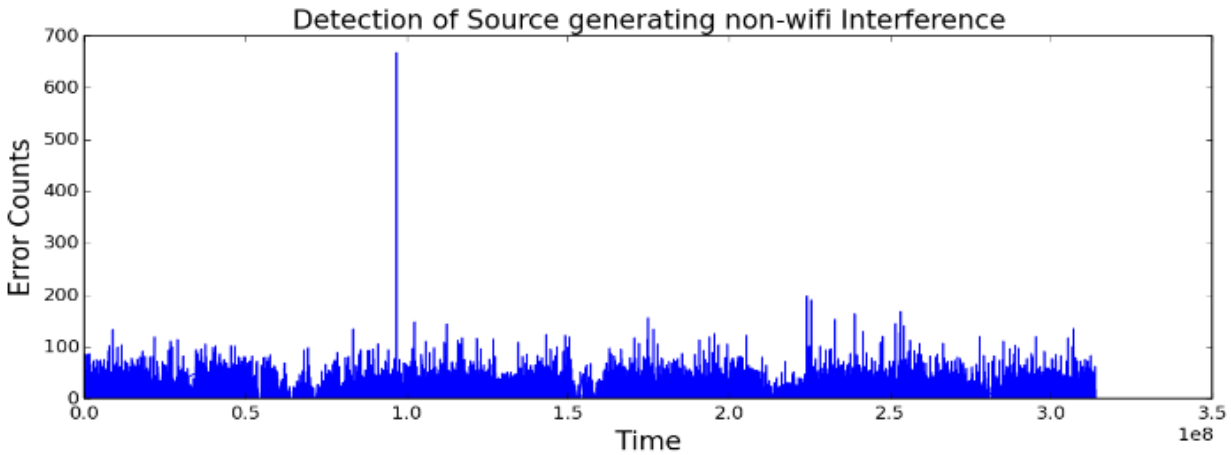


Microwave increases the Error decoding 802.11 frames



Conclusion and Future Work

- Designed, Implemented measurement system for home networks
- Analysis of collected data of BISMark deployment
- Deviced mechanism to measure broadband Interference using commodity hardware
- Collect transport layer traces to correlate poor performance across layers
- Design in-kernel aggregiate data structures for accurate broadband Interfering source identification

Publication/Poster/Talks

- Talk at IS4CWN (International Summit for Community Wireless Networks), Berlin. Oct, 2013