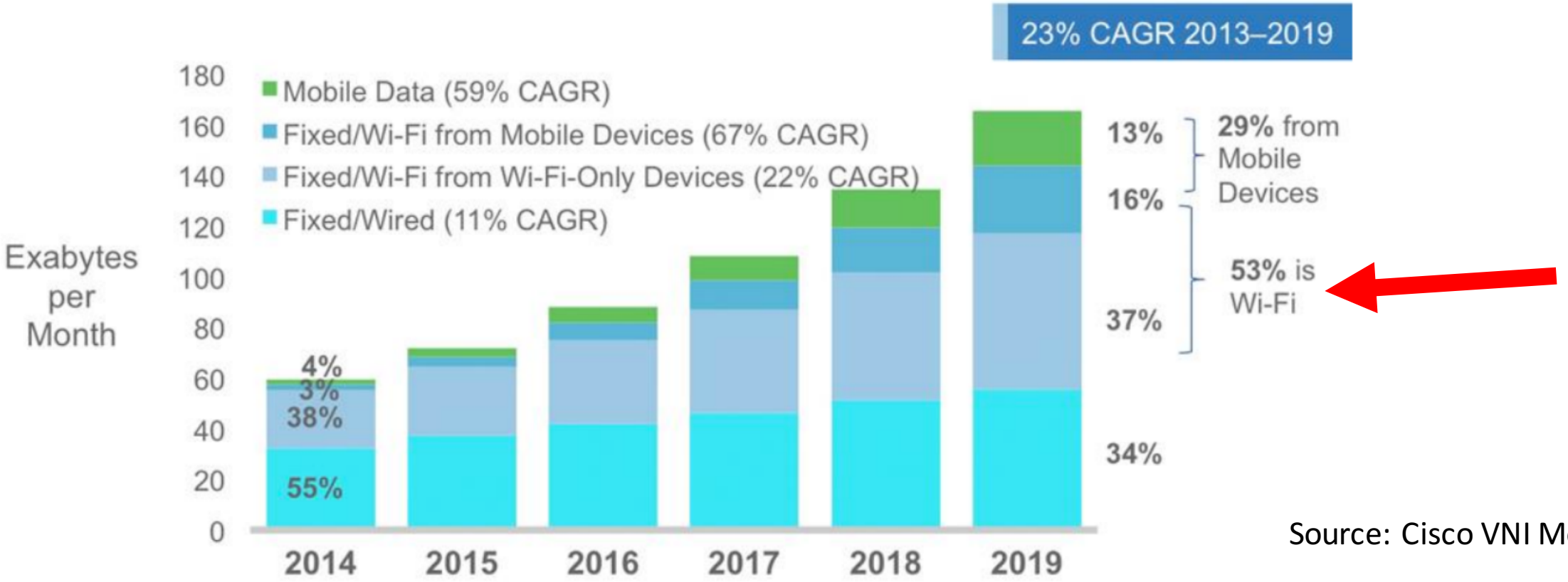
WiFi Can Be the Weakest Link of Round Trip Network Latency in the Wild

Changhua Pei†, Youjian Zhao†, Guo Chen†, Ruming Tang†, Yuan Meng†, Minghua Ma†, Ken Ling‡, Dan Pei†

†Tsinghua University ‡Carnegie Mellon University

WiFi is indispensable in our daily lives

- Overall WiFi Traffic Growth



Source: Cisco VNI Mobile, 2016

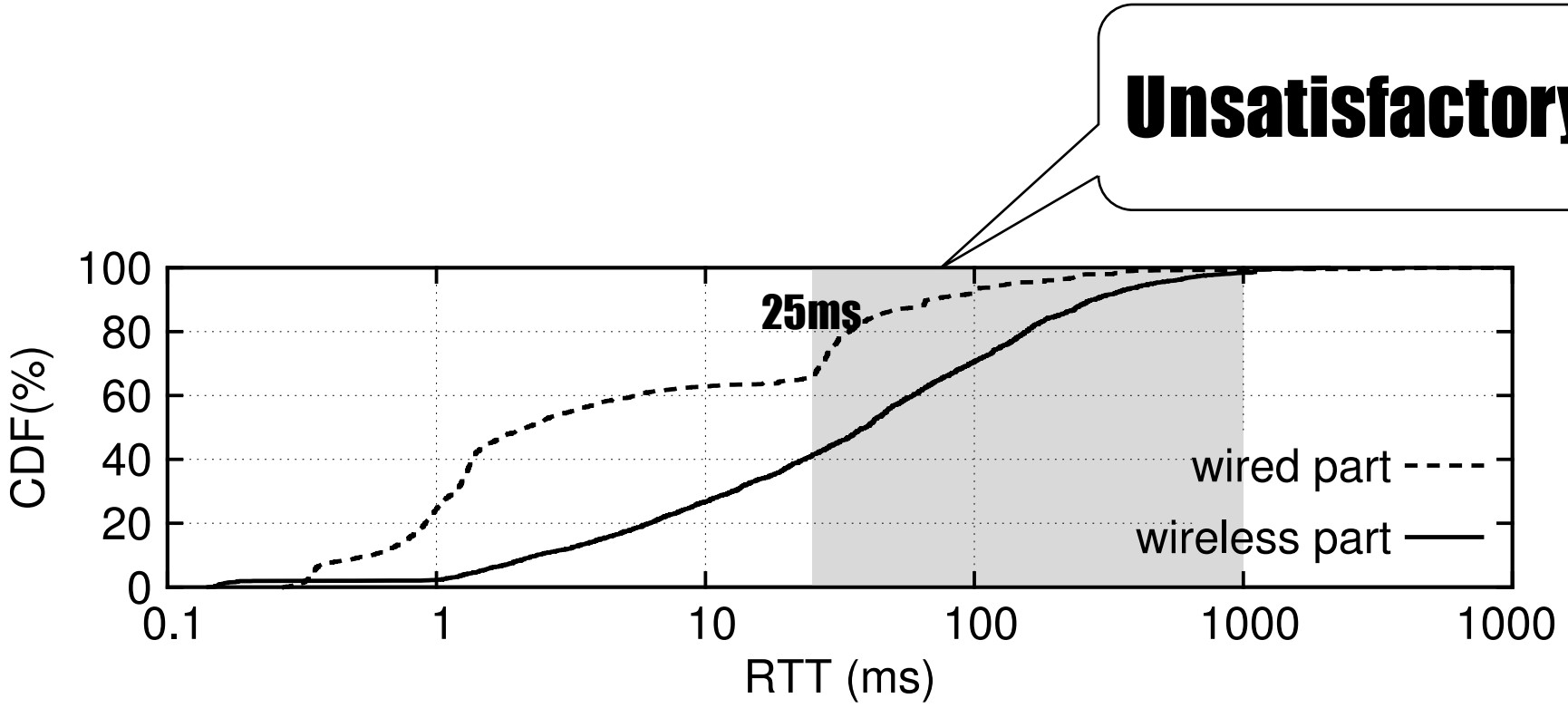
WiFi is indispensable in our daily lives!

❖ Booming of the Access Points:

Number of Access Points!

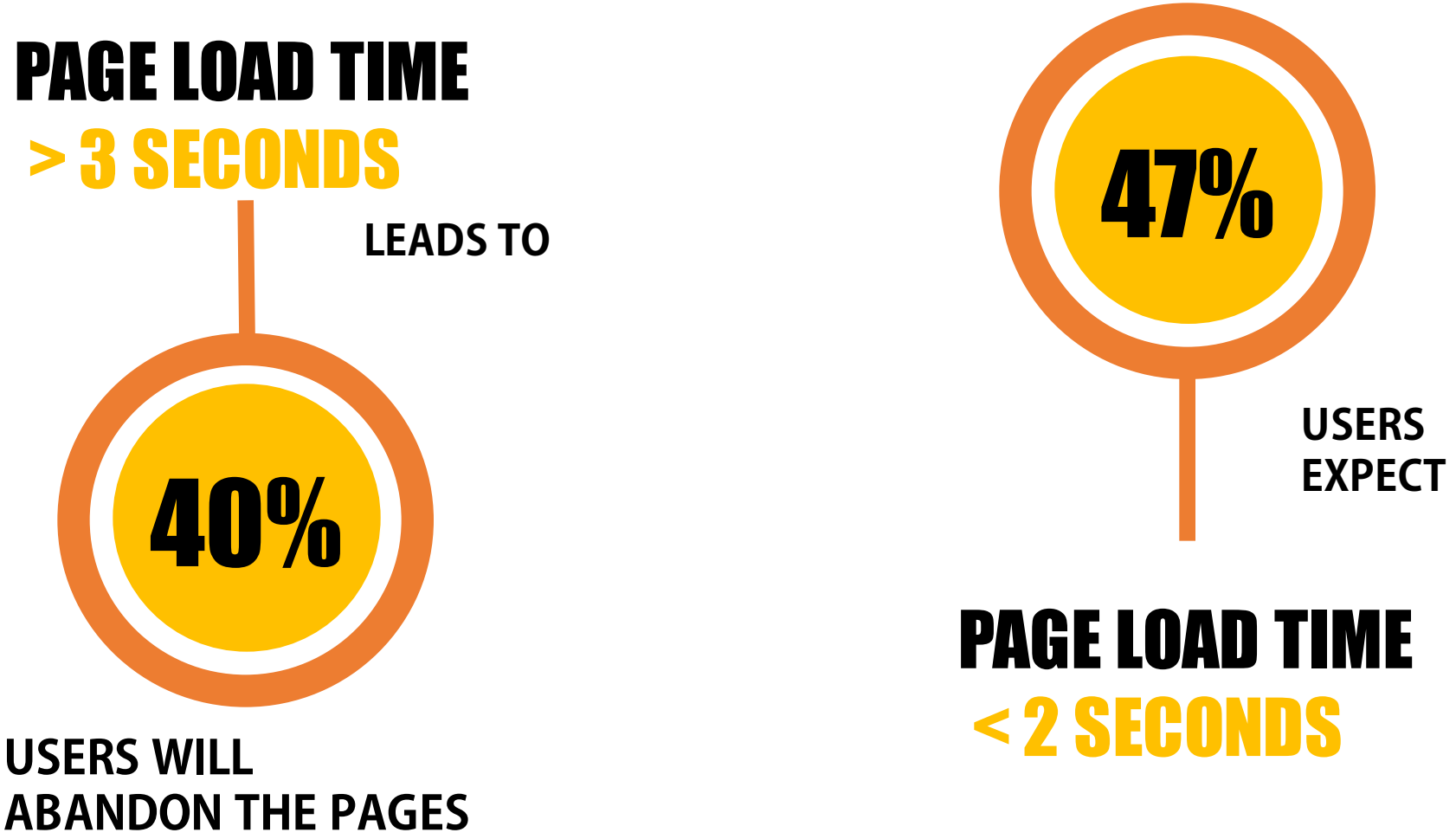
Source: Maravedis, Cisco VNI Mobile, 2016

WiFi performance is far from satisfactory



Stringent Threshold: 20~30ms

WiFi performance is far from satisfactory



Akamai study. http://goo.gl/2pwozG.

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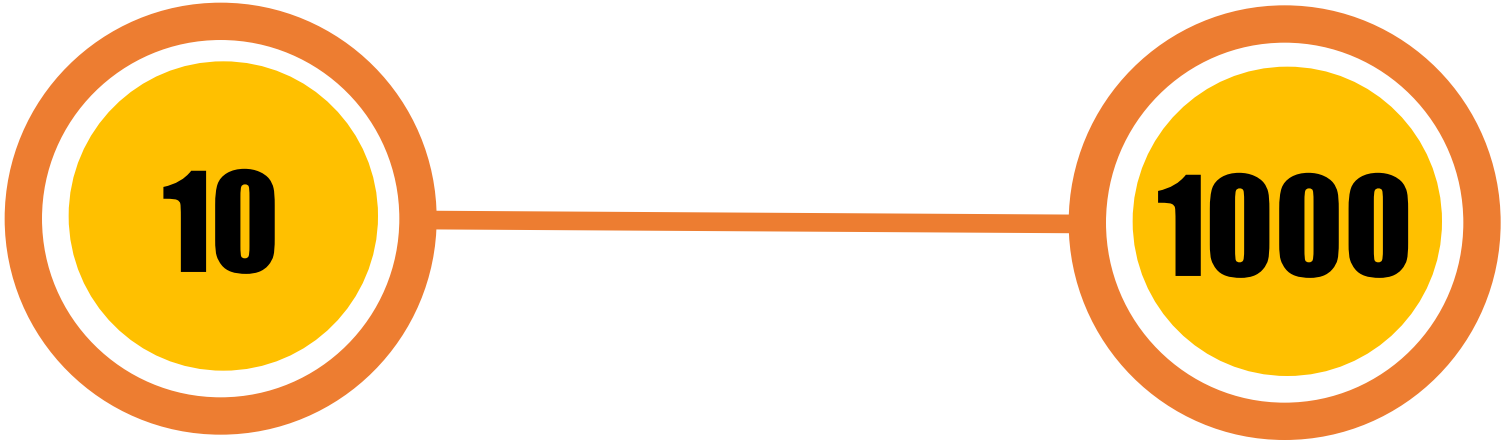
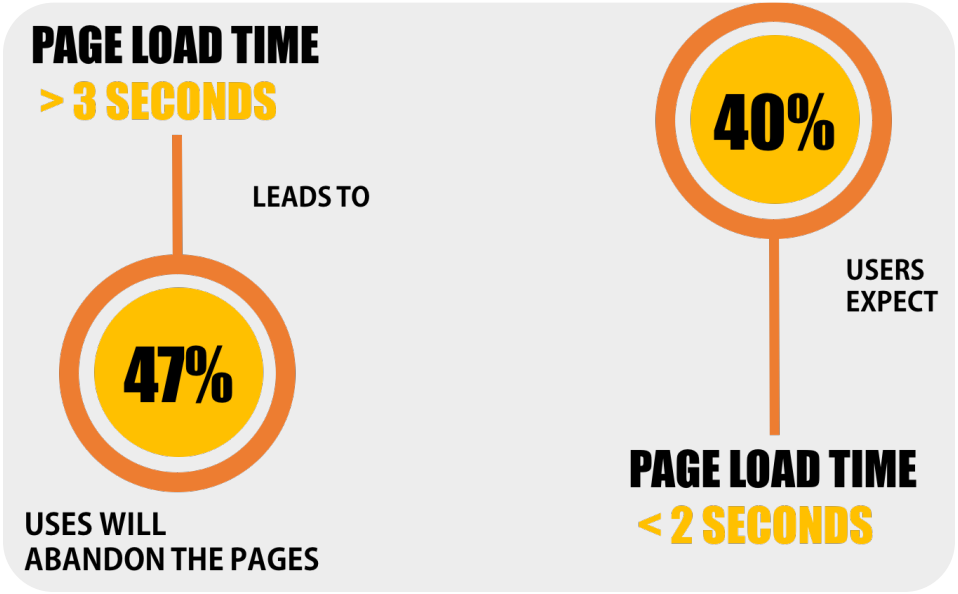
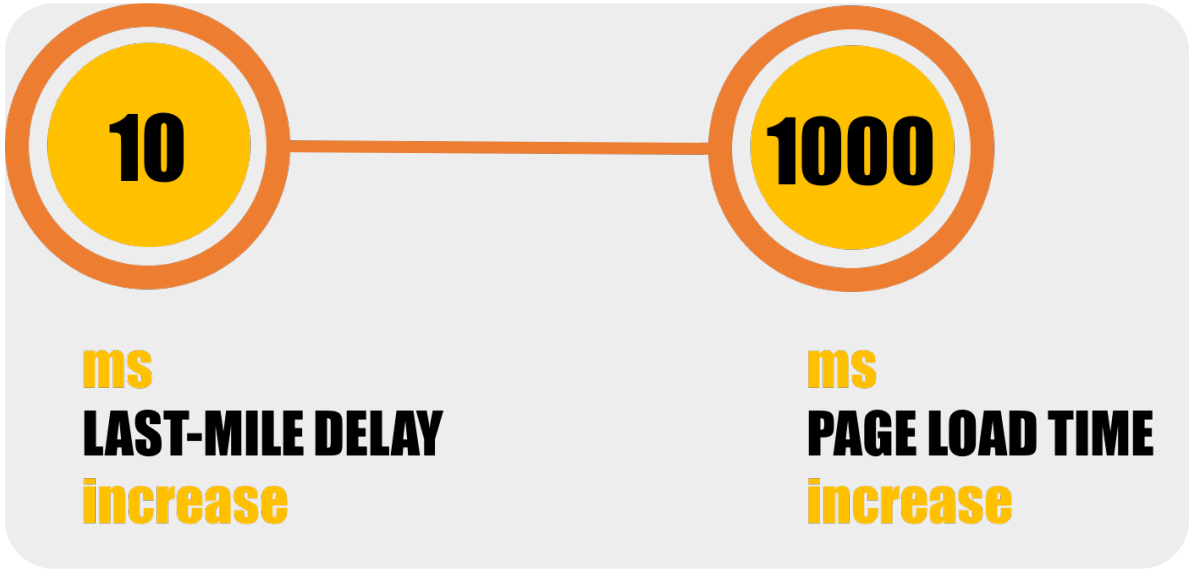


Bismark Paper: S. Sundaresan, N. Feamster, R. Teixeira, N. Magharei, et al. Measuring and mitigating web performance bottlenecks in broadband access networks. In ***ACM Internet Measurement Conference***, 2013.

WiFi performance is far from satisfactory

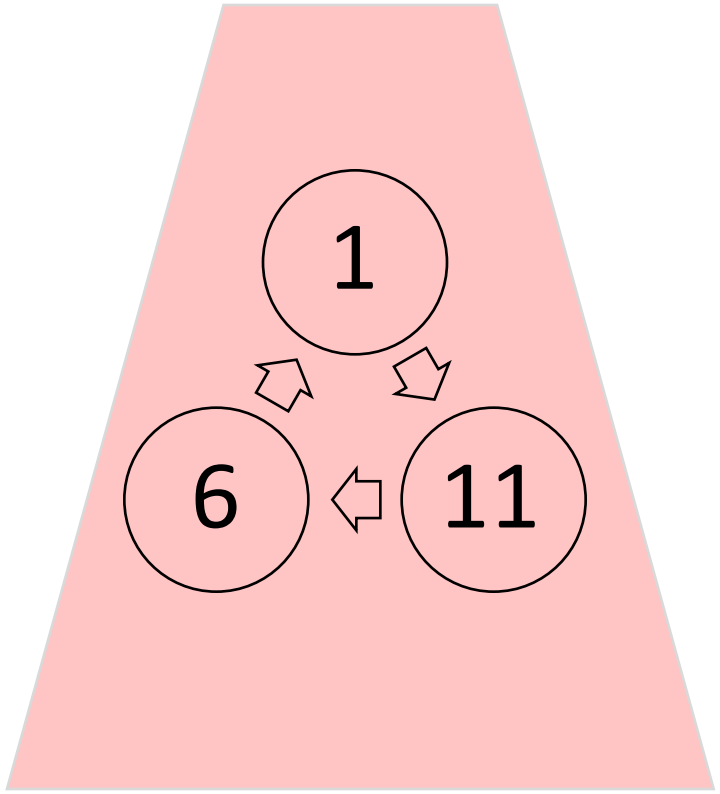




Stringent Threshold: 20~30ms

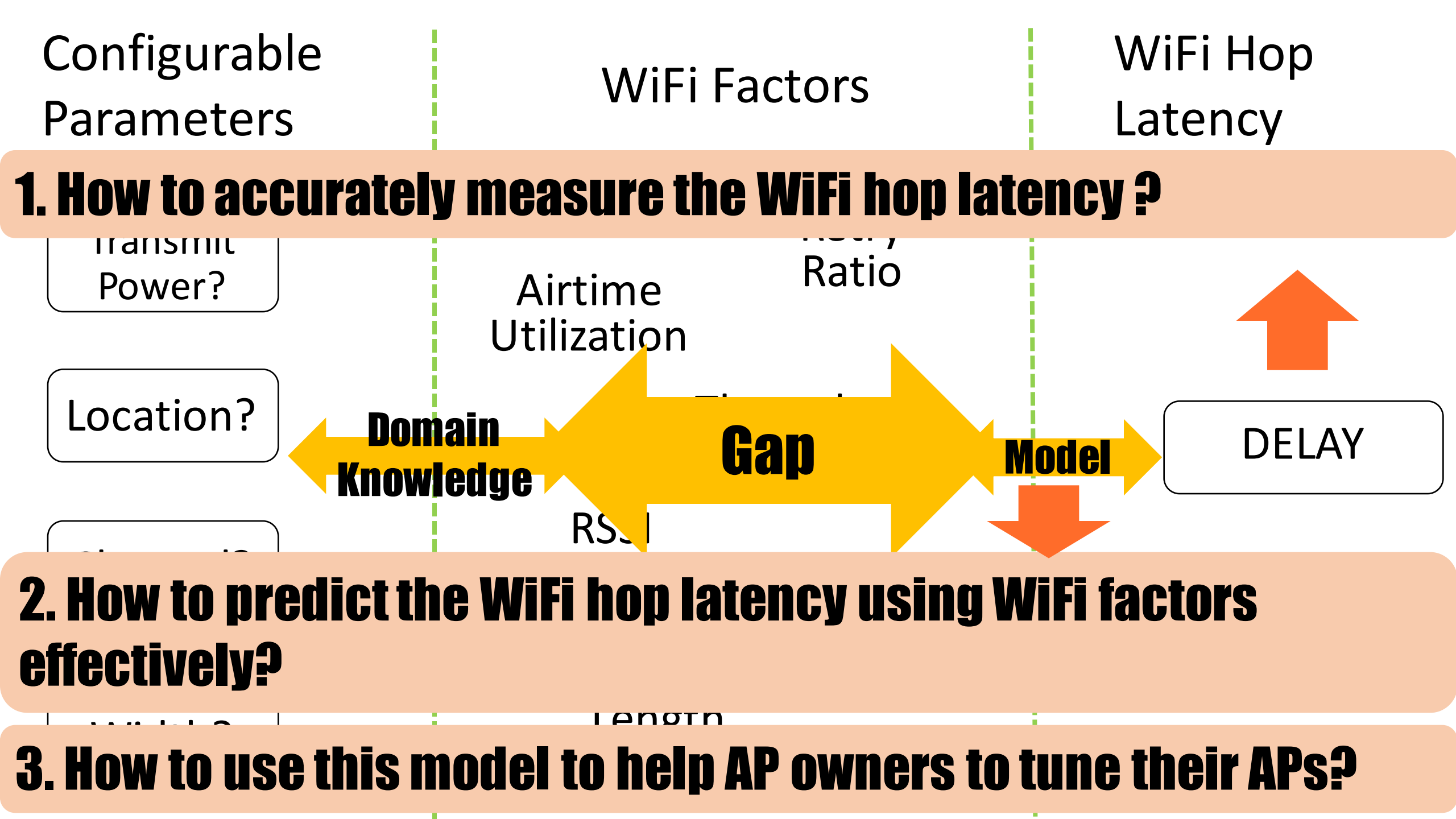
Challenge: Large Search Space of AP parameters

Transmit Power? ✕ Channel? ✕ Location? ✕ Channel Width? =



BLIND SEARCH among all re-configuration possibilities

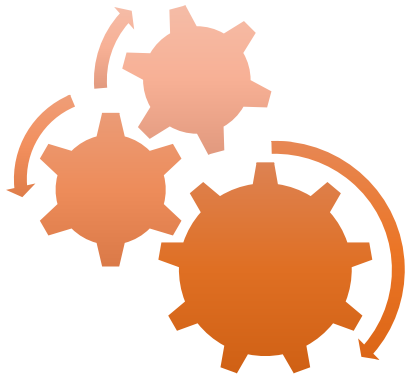
Don't know the effect before the re-configuration


Configurable Parameters
WiFi Factors
WiFi Hop Latency
1. How to accurately measure the WiFi hop latency ?
Transmit Power?
Location?
Airtime Utilization
Ratio
Domain Knowledge
Gap
Model
DELAY
2. How to predict the WiFi hop latency using WiFi factors effectively?
3. How to use this model to help AP owners to tune their APs?

Measurement

Trace

Training

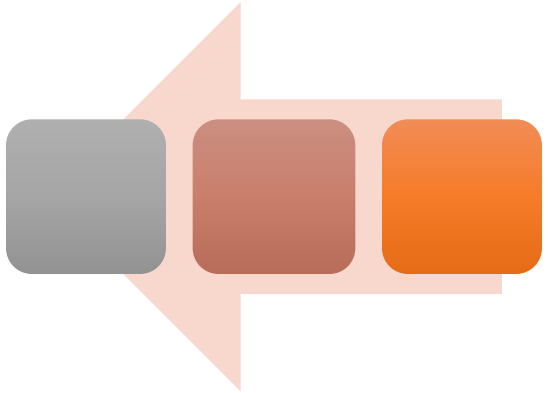


ML Model

Problematic AP

WiFi Factors for this AP

Optimization



Reconfigure which ?

- Transmit Power?
- Location?
- Channel?
- Channel Width?

Measurement

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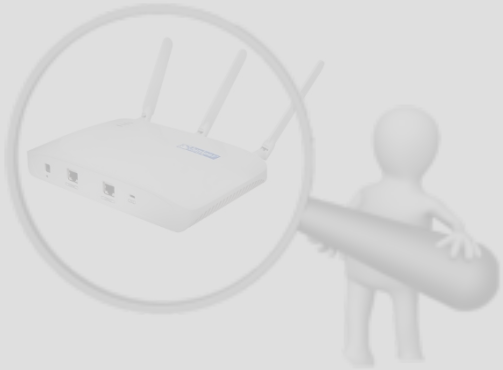

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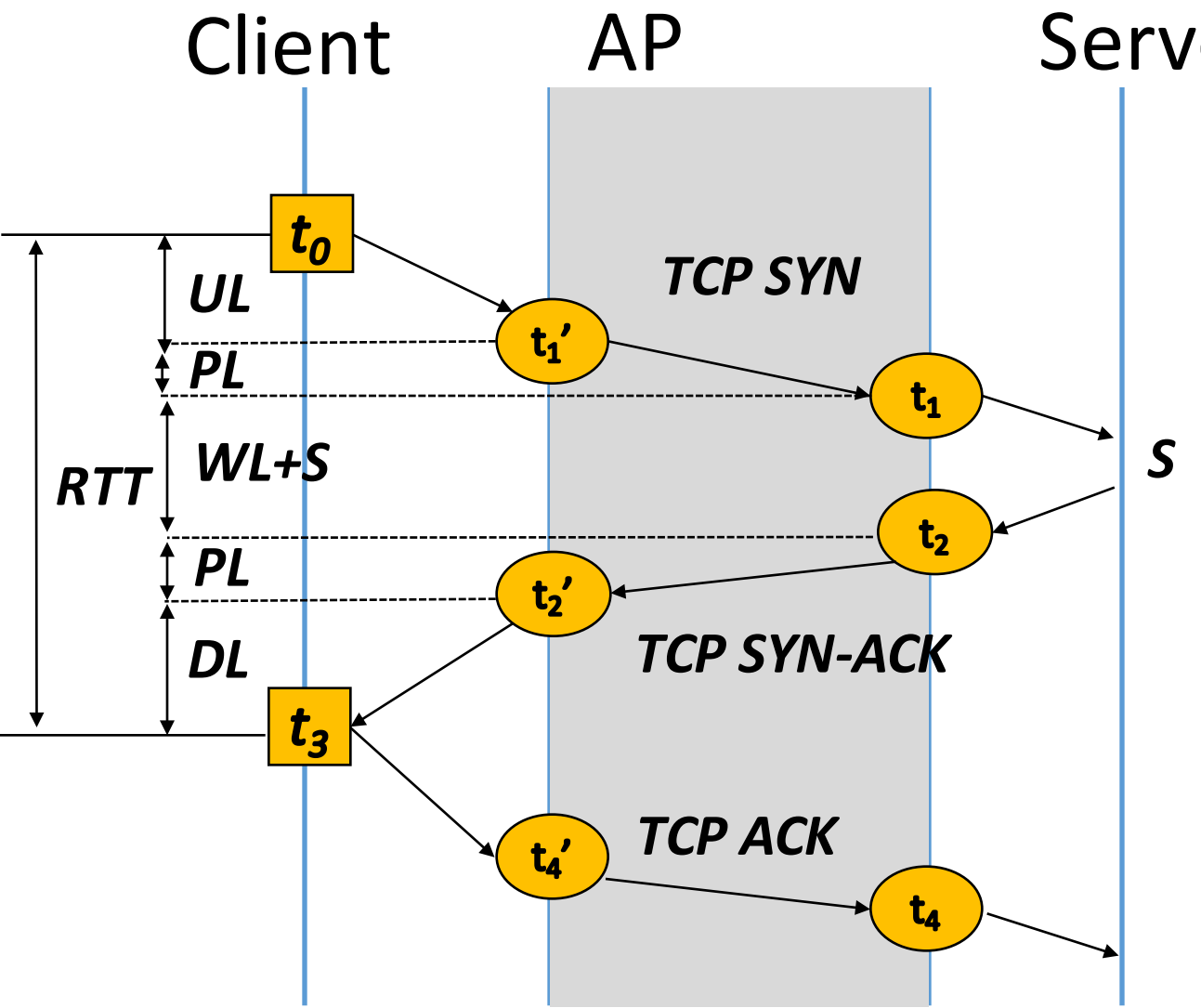
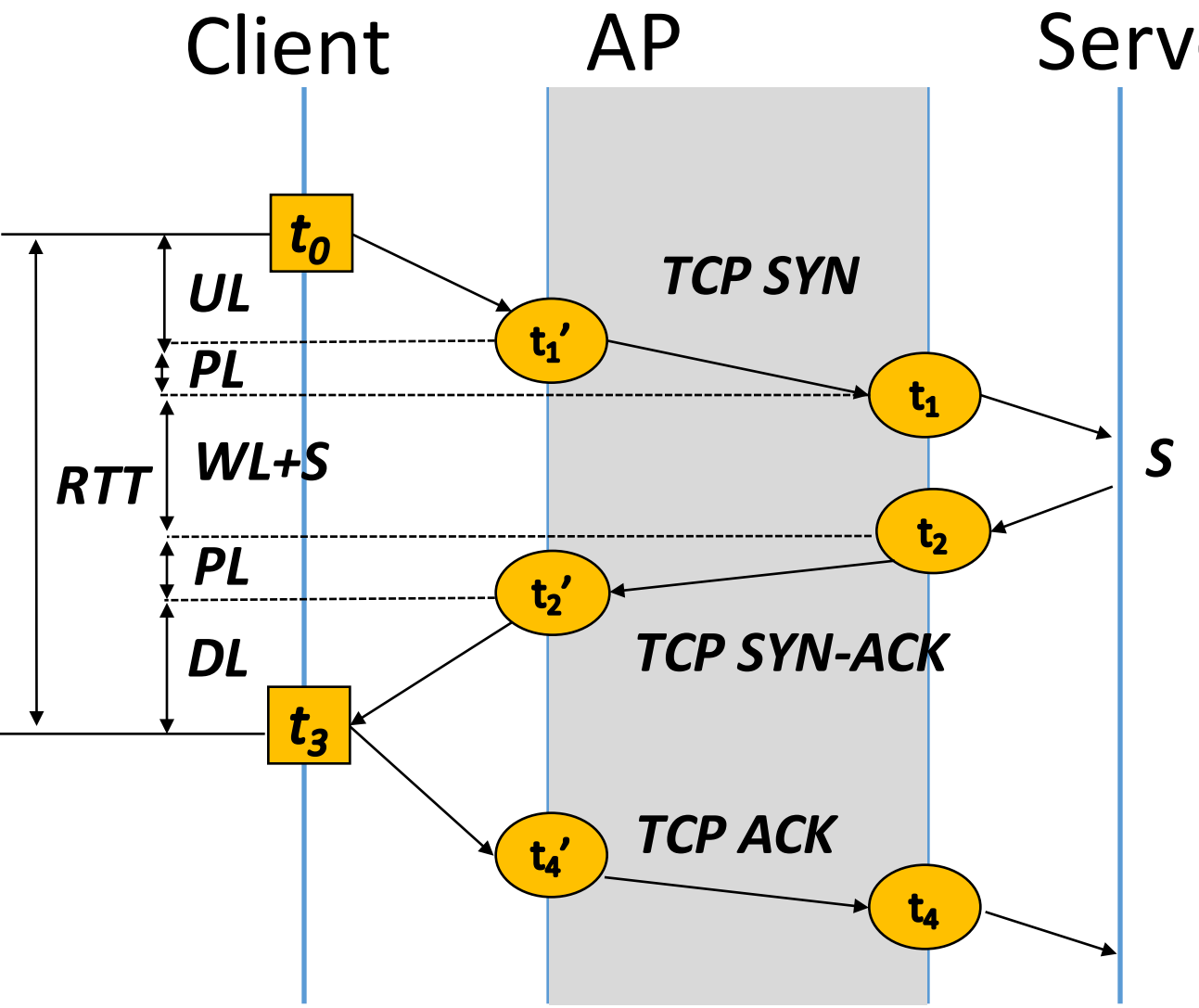
Measuring WiFi Hop Latency: Background



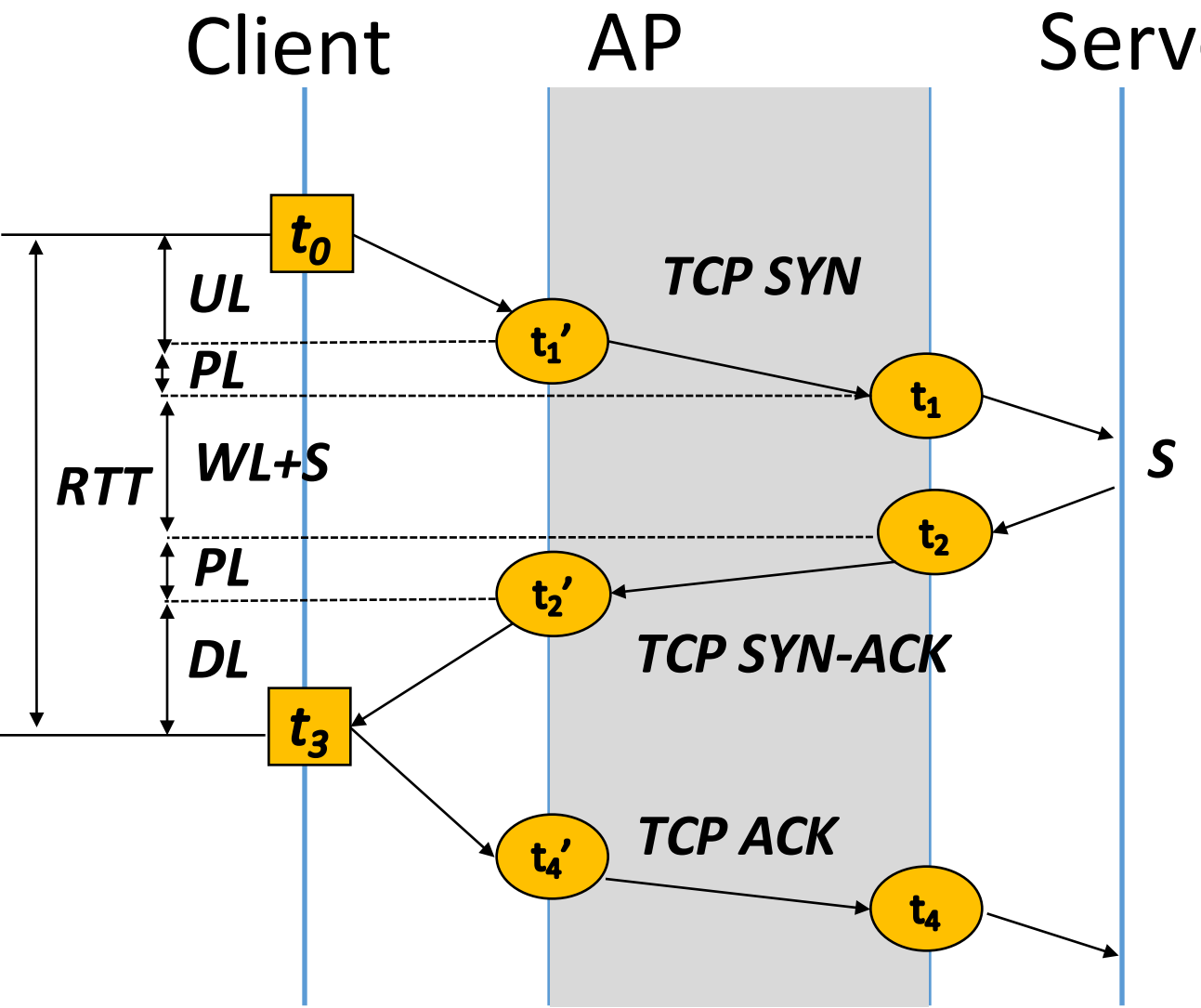
Measuring WiFi Hop Latency: existing approaches need client-side involvement



- **RTT**: Using PING at client side: RTT = t_3-t_0 ☹

client-side assistance

Measuring WiFi Hop Latency: existing approaches need client-side involvement



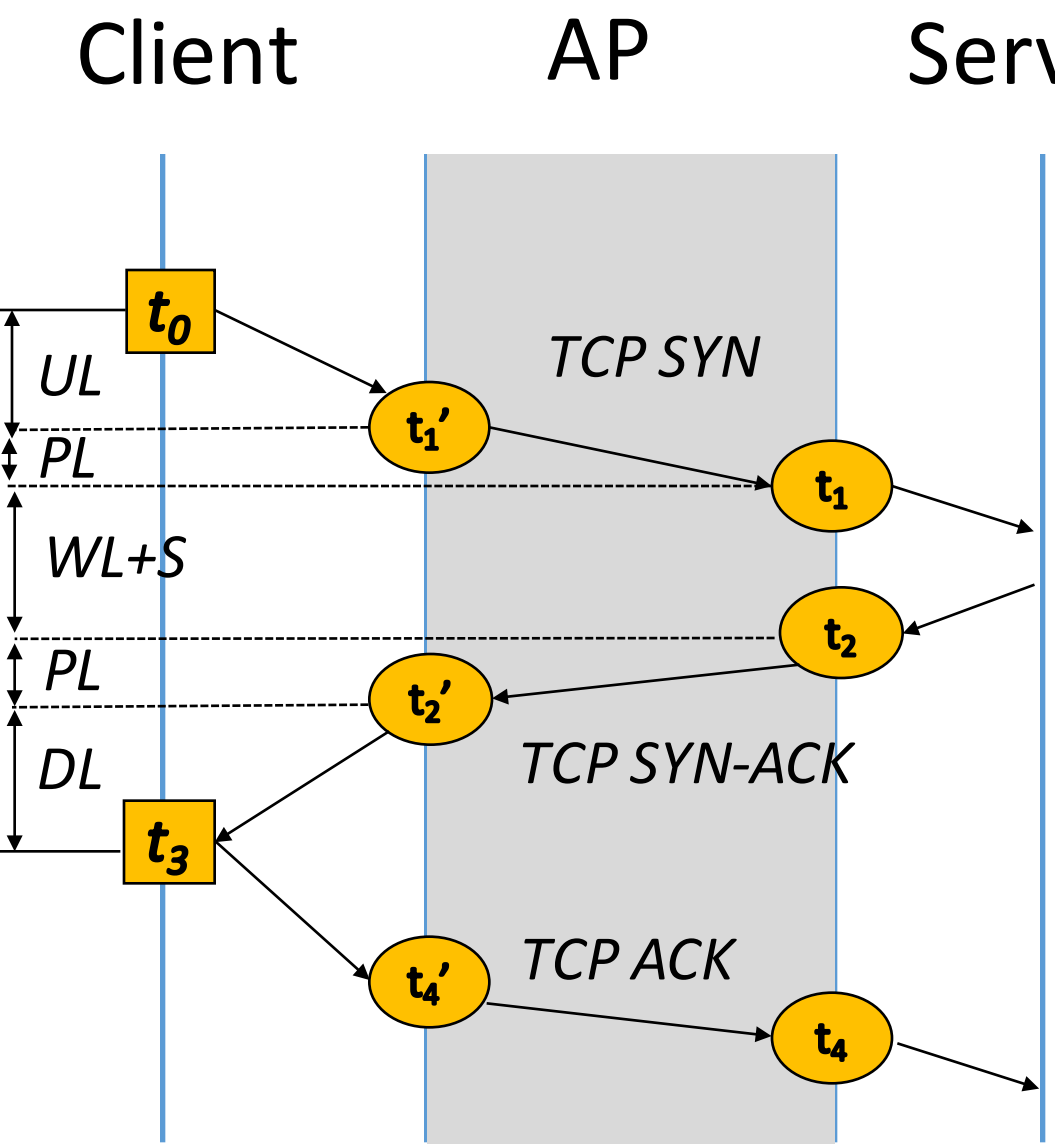
- **RTT**: Using PING at client side: RTT = t_3-t_0 ☹

client-side assistance

- **DL**: Packet Capture: DL = $t_3 - t_2'$ ☹

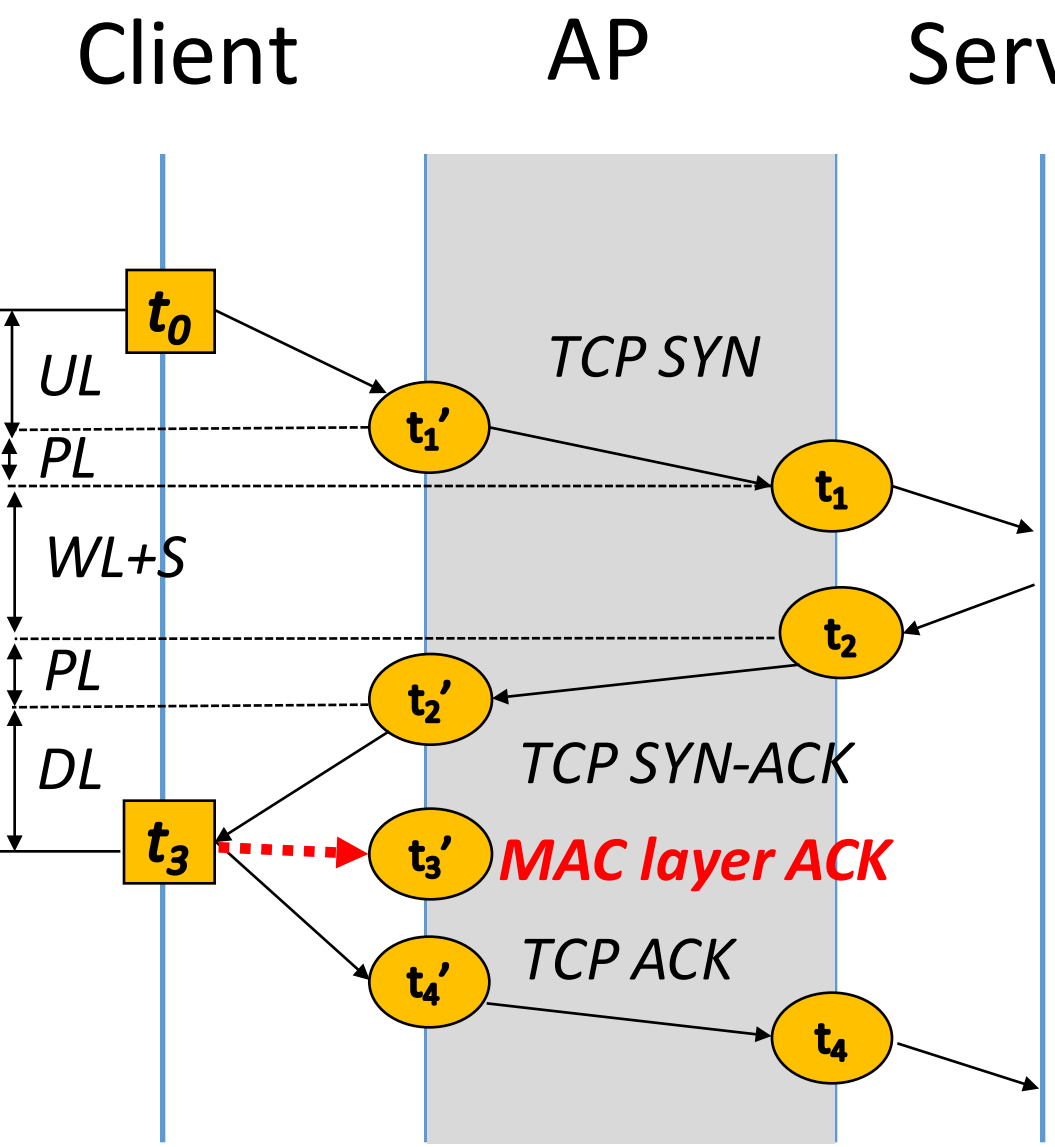
Time synchronization

Measuring WiFi Hop Latency: all measurements on APs



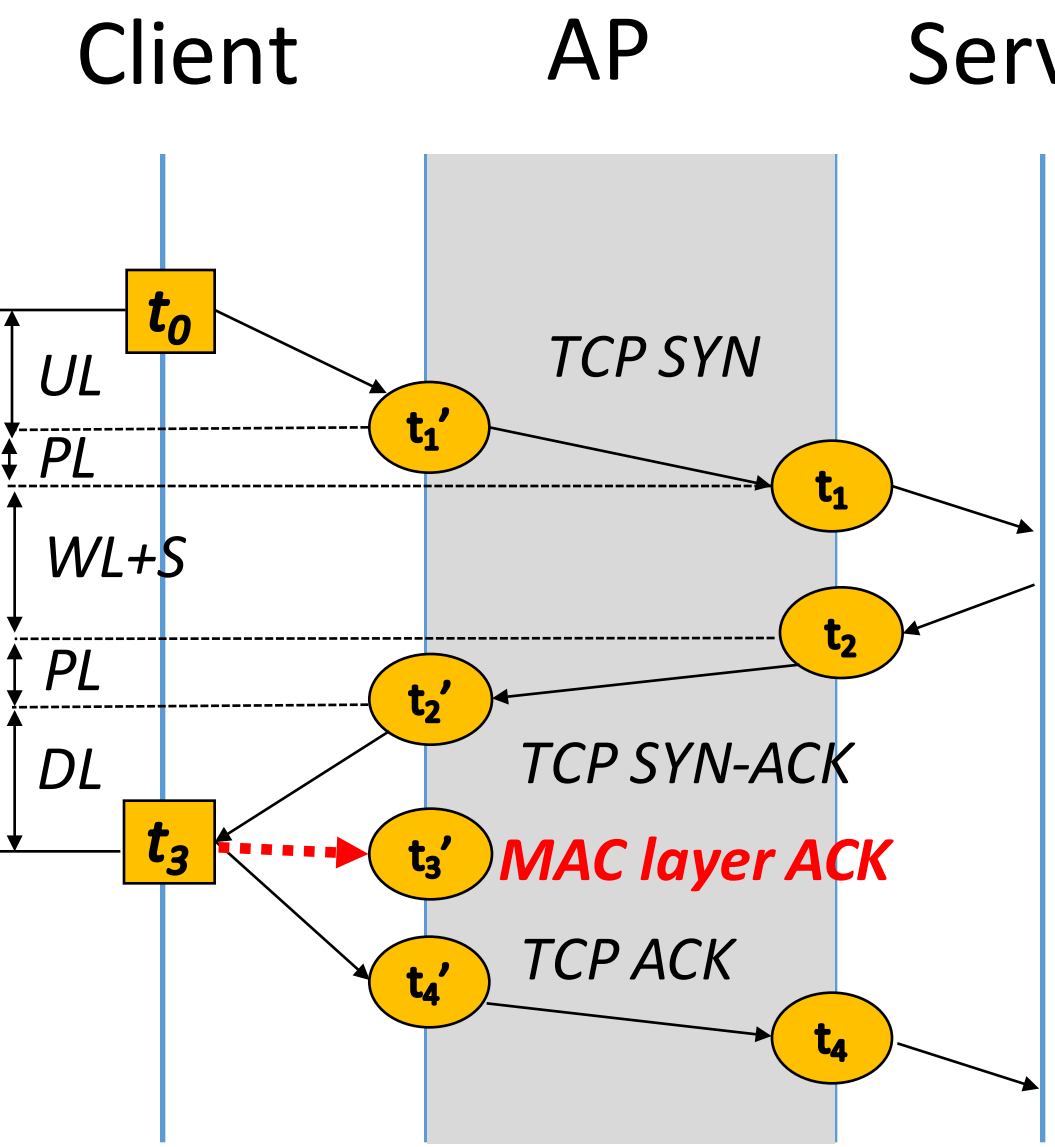
	Delay Type	Description	
3-way handshake packets	WL	t_2'-t_1'	√

Measuring WiFi Hop Latency: all measurements on APs



	Delay Type	Description	
3-way handshake packets	WL	t_2'-t_1'	√
	DL		

Measuring WiFi Hop Latency: all measurements on APs



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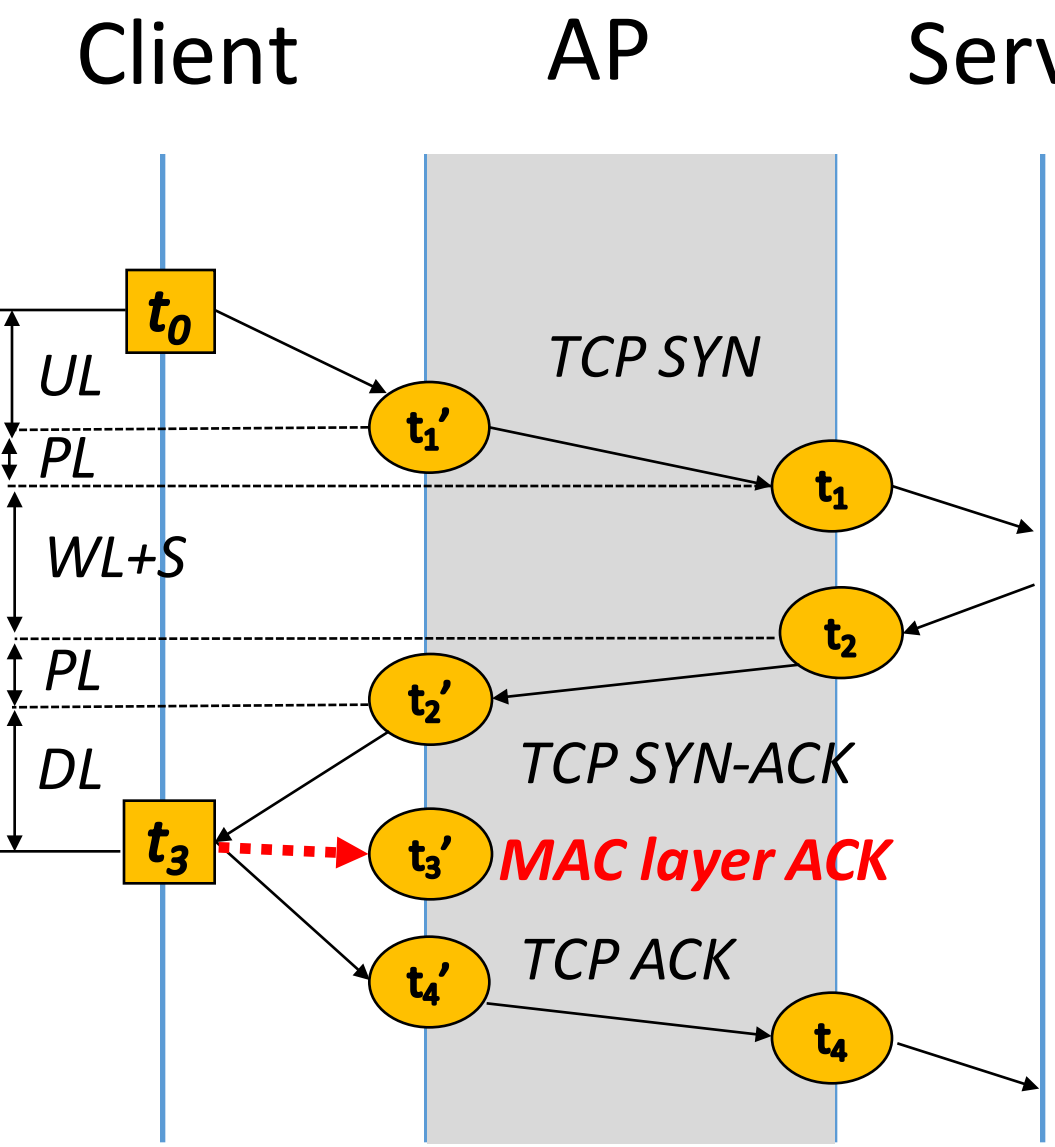
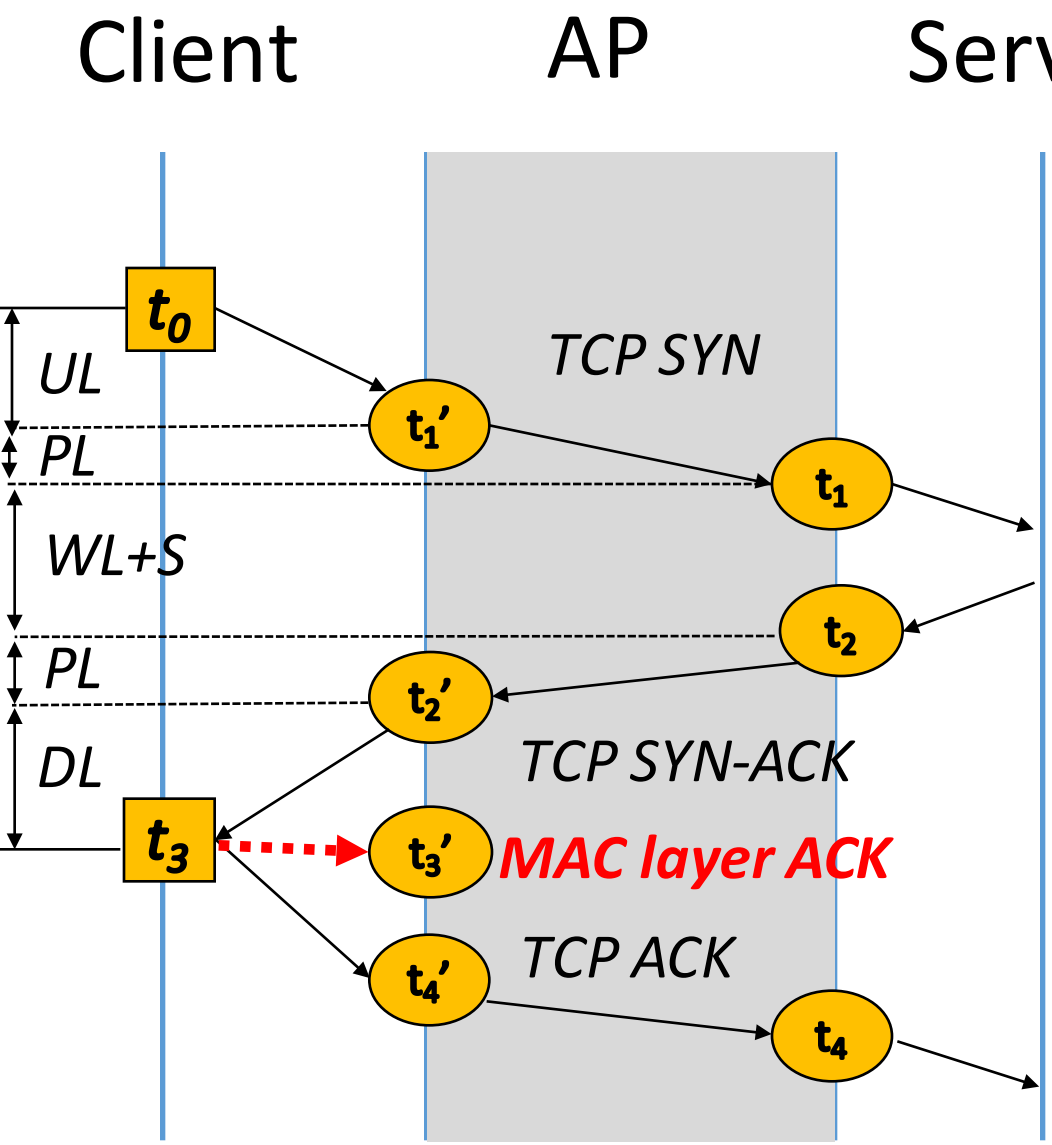


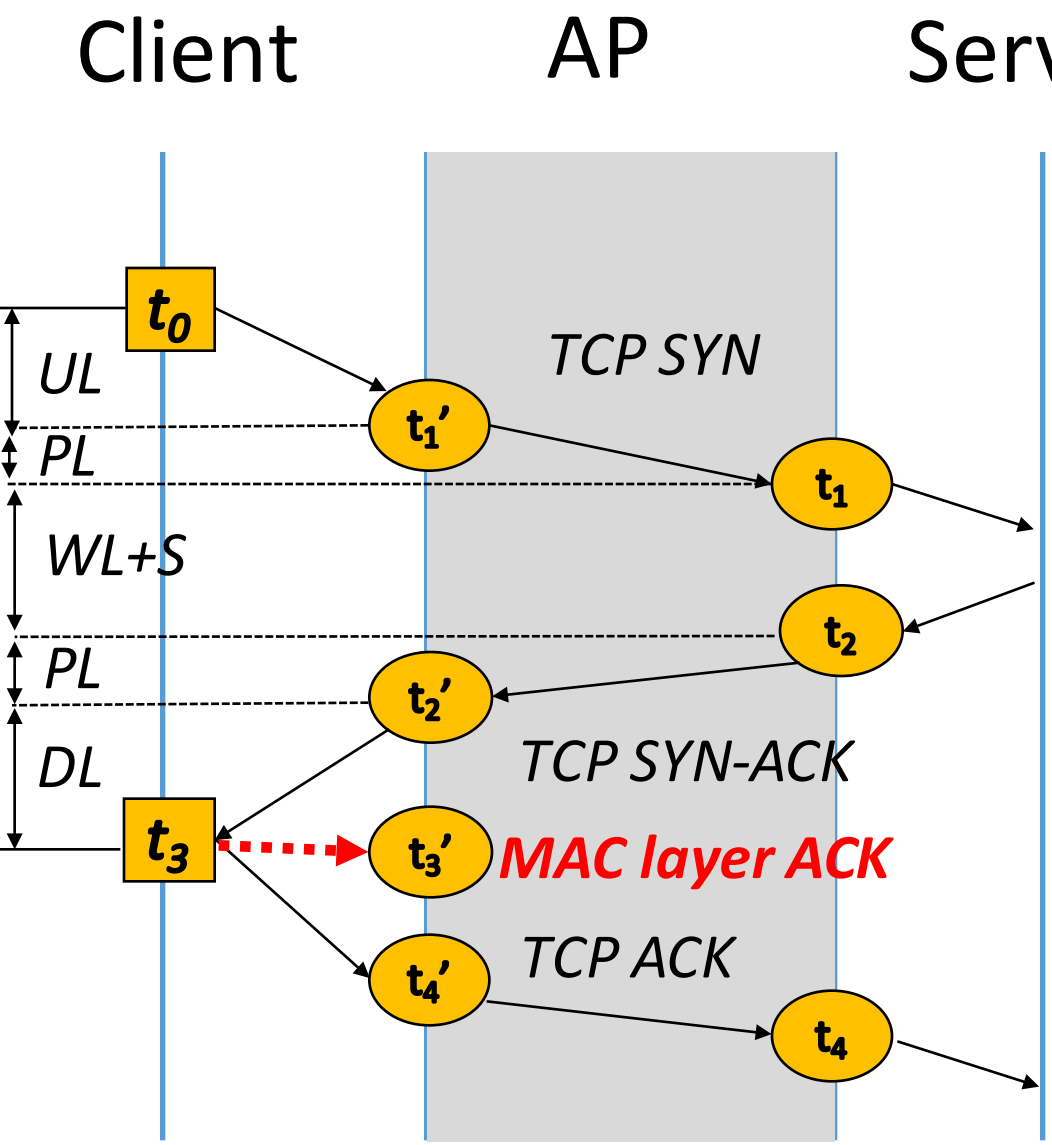
	Delay Type	Description	
3-way handshake packets	WL	t_2'-t_1'	√
	DL	t_3'-t_2'	√
	UL	t_4'-t_3'	√

Measuring WiFi Hop Latency: all measurements on APs



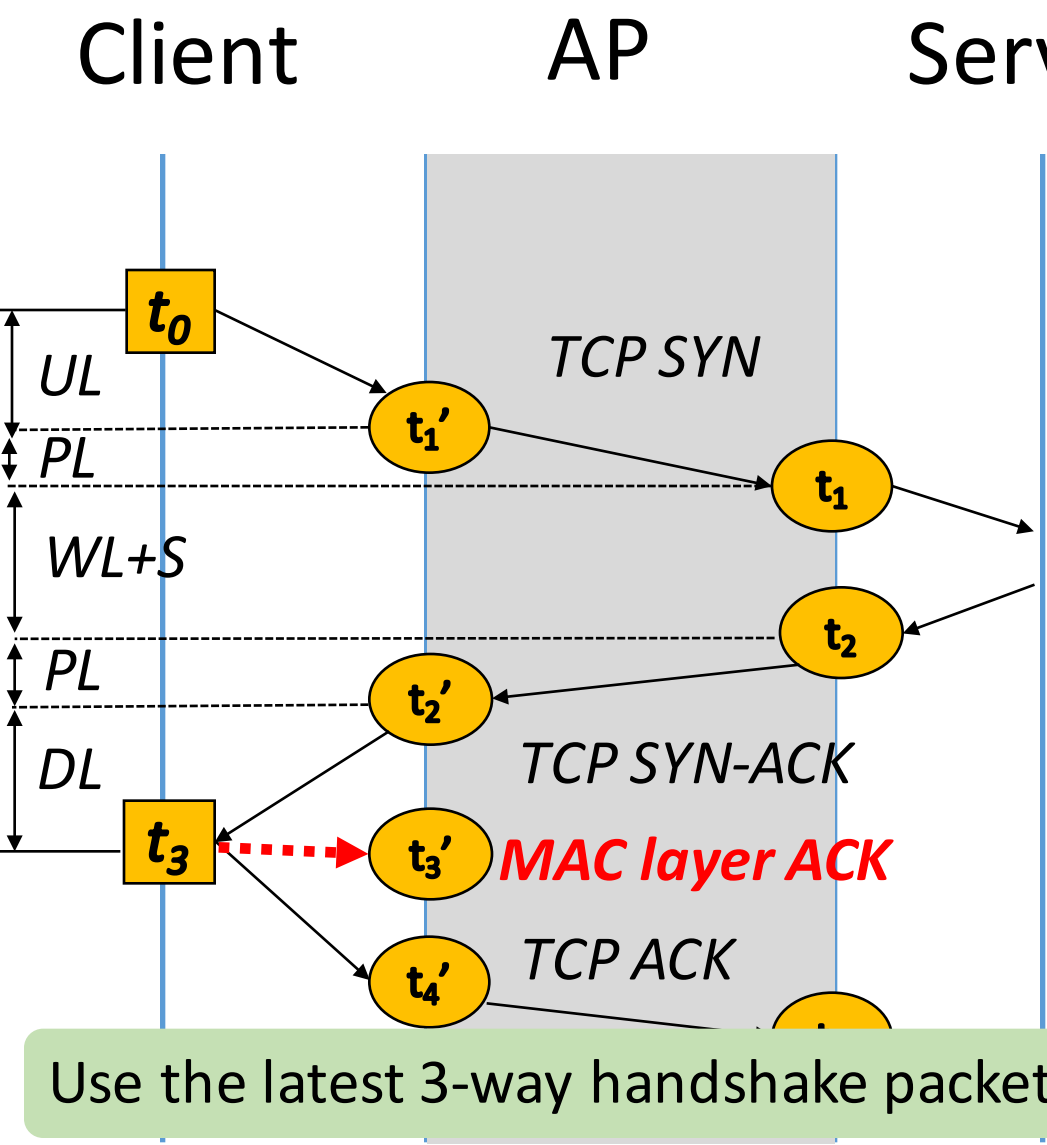
	Delay Type	Description	
3-way handshake packets	WL	t_2'-t_1'	√
	DL	t_3'-t_2'	√
	UL	t_4'-t_3'	√
Data packets			
	DL	t_3'-t_2'	√

Measuring WiFi Hop Latency: all measurements on APs



	Delay Type	Description	
3-way handshake packets	WL	t_2'-t_1'	√
	DL	t_3'-t_2'	√
	UL	t_4'-t_3'	√
Data packets			
	DL	t_3'-t_2'	√
	UL	**delay-ACK**	×

Measuring WiFi Hop Latency: all measurements on APs



	Delay Type	Description	
3-way handshake packets	WL	t_2'-t_1'	√
	DL	t_3'-t_2'	√
	UL	t_4'-t_3'	√
Data packets	WL	***S***	×
	DL	t_3'-t_2'	√
	UL	**delay-ACK**	×

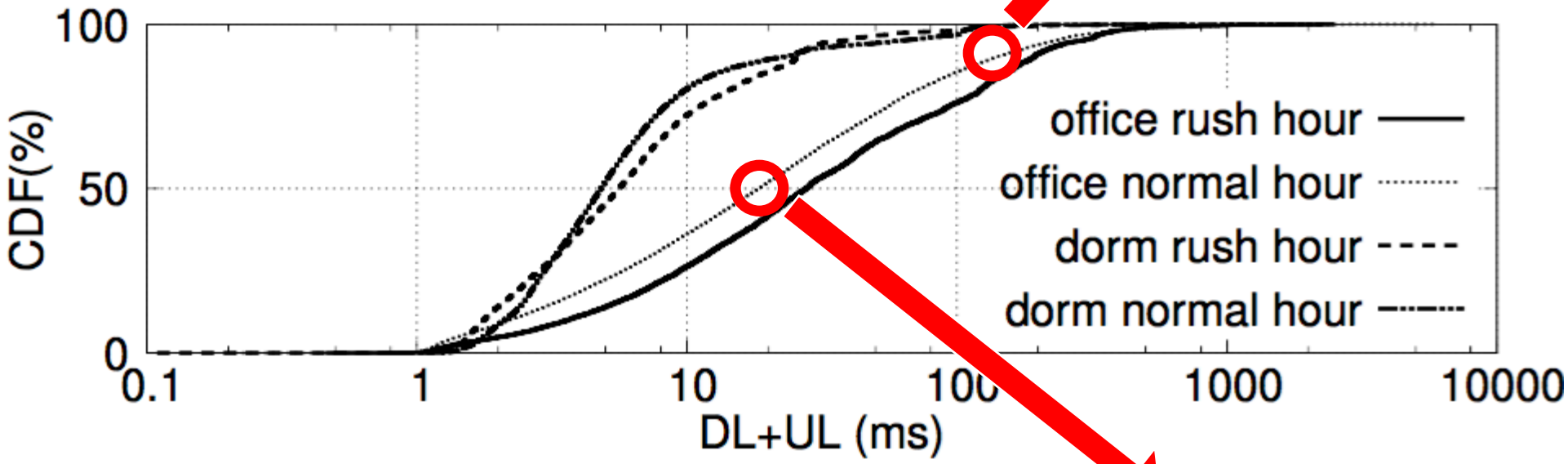
Use the latest 3-way handshake packet to approximate data packets' WL and UL!

Data collection

- Real deployment in Tsinghua University in China.
- 47 free Netgear WNDR4300 router equipped with Openwrt
- 44 in dormitory, 3 in department of computer science
- Continuously collected from May 20th to July 20th
- Collected about 2 terabytes raw data trace

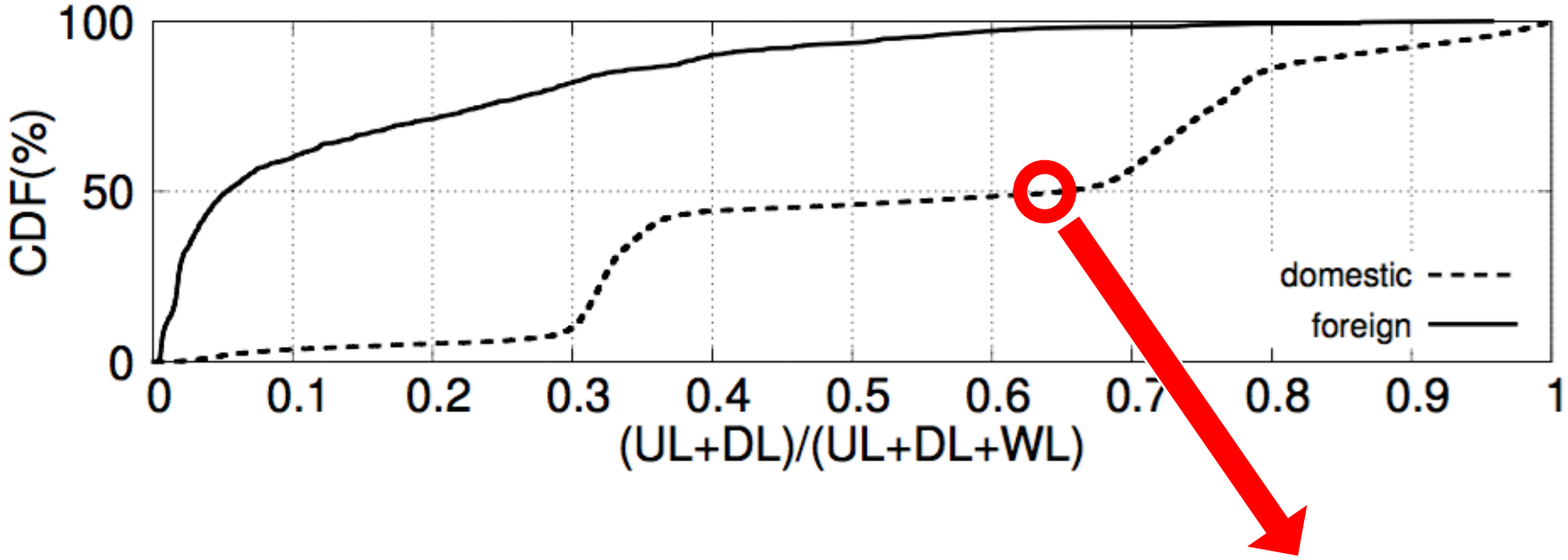
Measurement Result

10% packets'
WiFi hop latency **> 100ms**



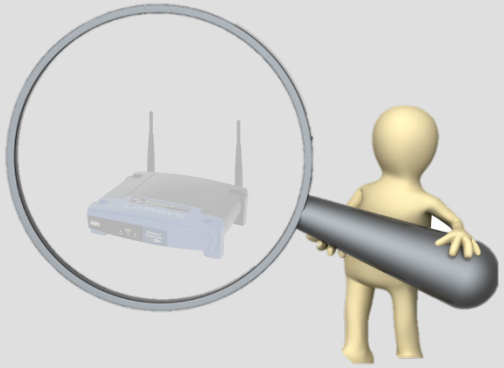
50% packets'
WiFi hop latency **> 20ms**

Measurement Result



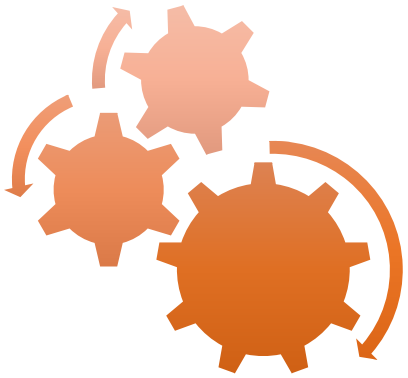
For nearly 50% of the domestic packet, over 60% of the time is occupied by WiFi hop delay.

Measurement



Trace

Training



ML Model

Optimization

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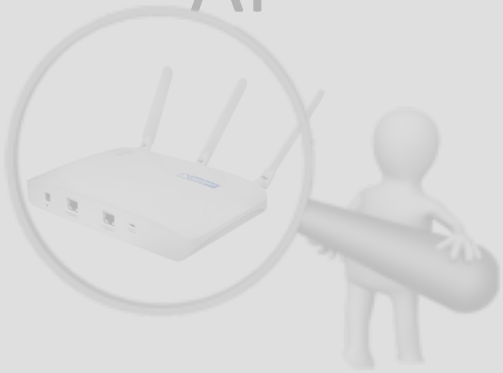

WiFi Factors for this AP

Reconfigure which ?

- Transmit Power?
- Location?
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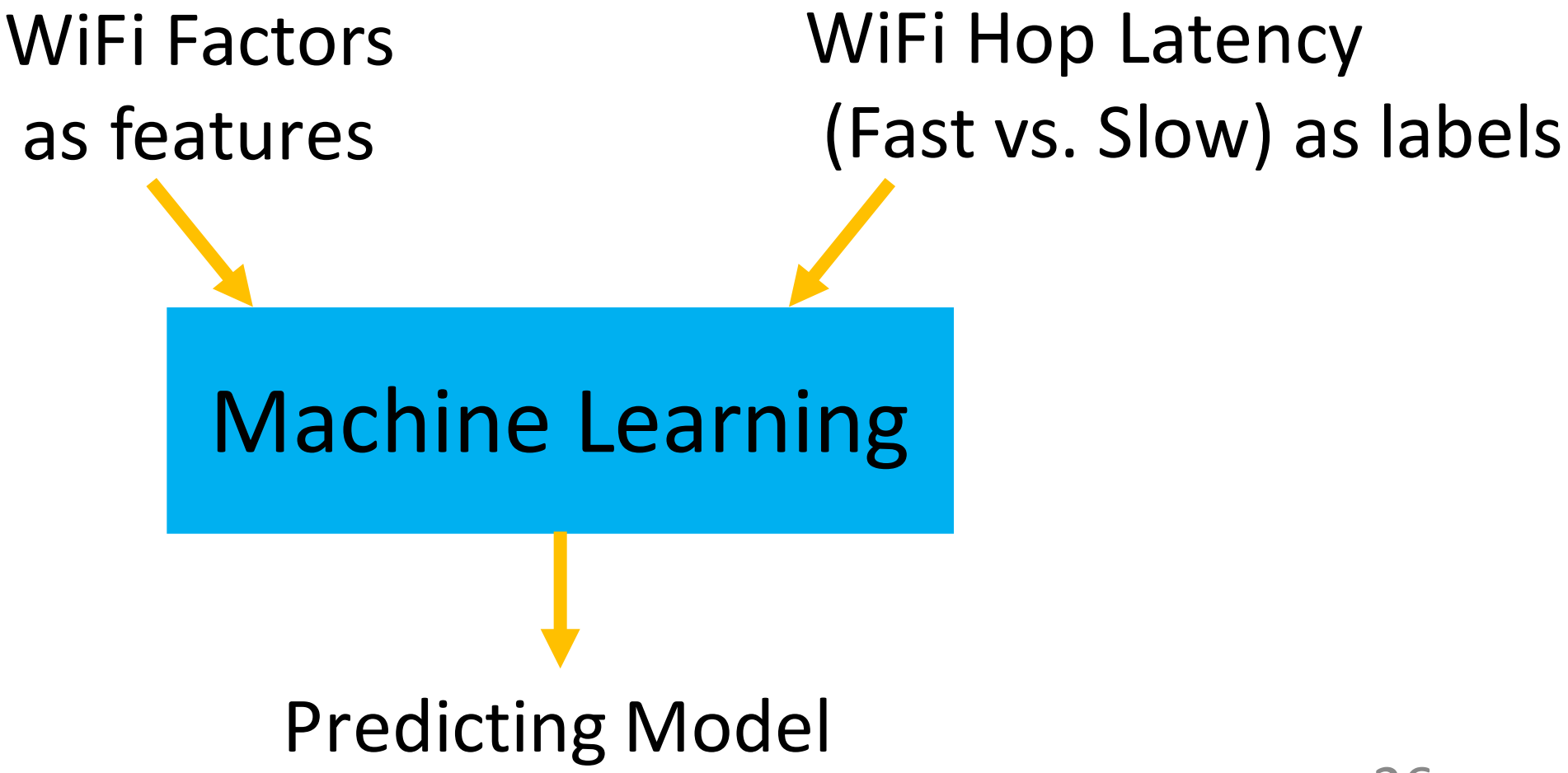
- Channel Width?

Predicting the Latency using WiFi factors



Abbr.	WiFi factors	Description	Generated By
AU	airtime utilization	% of channel time used by all the traffic	iw info
Q	queue length snapshot	Number of packets queued in hardware queue.	debugfs
RR	retry ratio	%packets retried in IEEE 802.11 MAC-layer.	iw info
RSSI	RSSI	Received signal strength of UE associated on AP.	iw info
T_{tx}	transmitting throughput	Bytes sent to UE every 10s.	ifconfig info
T_{rx}	receiving throughput	Bytes received from UE every 10s.	ifconfig info
RPR	receiving physical rate	Snapshot of physical rate for receiving packets from UE.	iw info
TPR	transmitting physical rate	Snapshot of physical rate for sending packets to UE.	iw info

Visualization and Correlation analysis

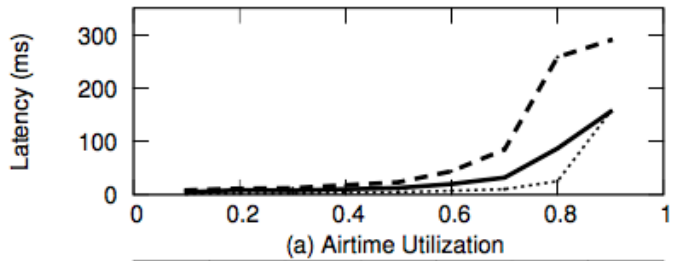
Purposes:

- Intermediate results to gain some intuitions
- Help explain the ML results.

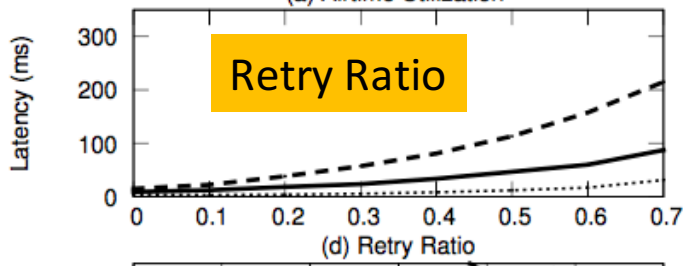
Visualization of the correlation

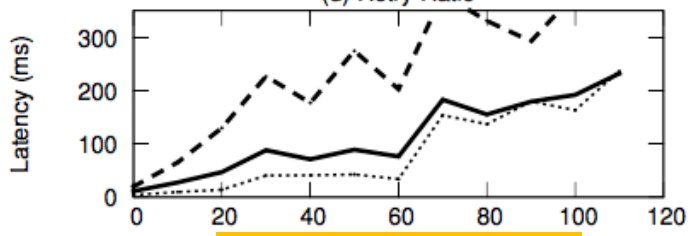
Positive Trends

Airtime Utilization



Retry Ratio

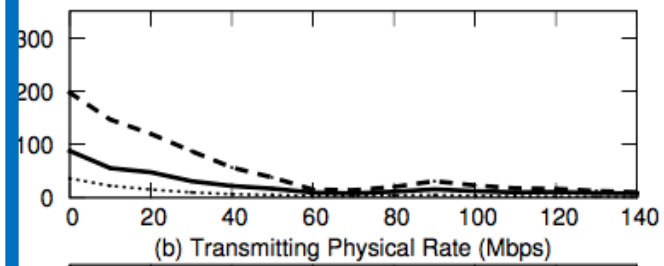




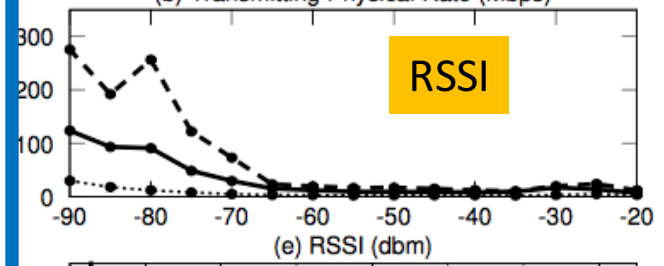
Queue Snapshot

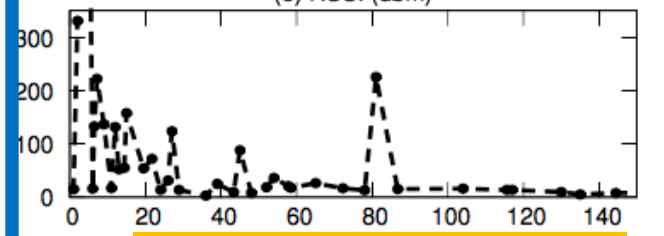
Negative Trends

Transmitting Physical Rate



RSSI

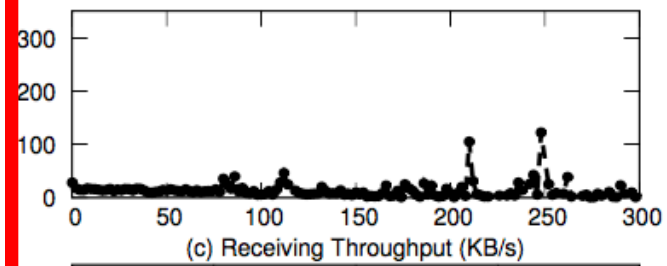




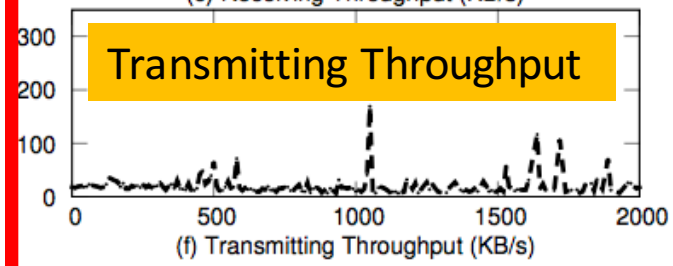
Receiving Physical Rate

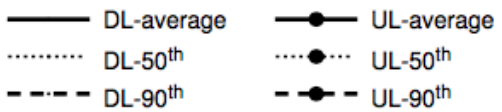
No Clear Trends

Receiving Throughput



Transmitting Throughput





Visualization of the correlation

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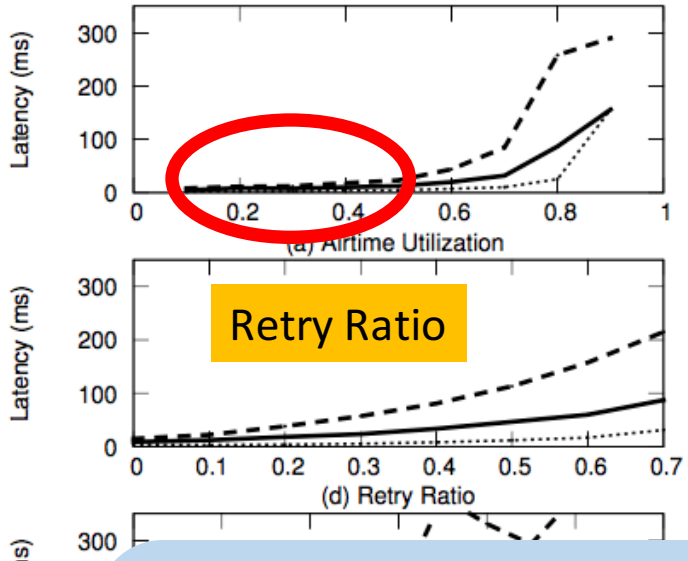
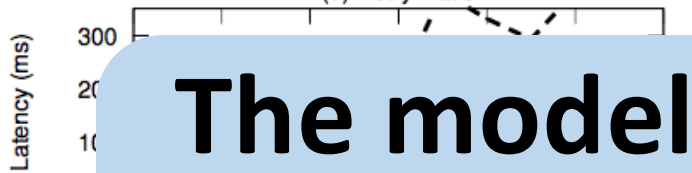
Airtime Utilization

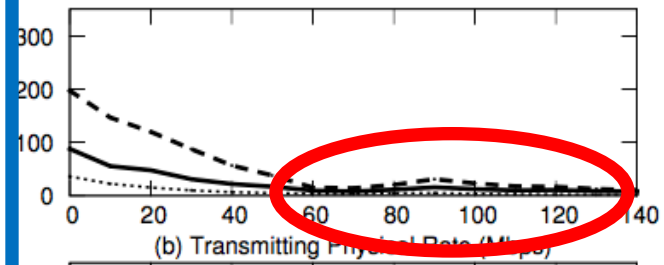


Retry Ratio

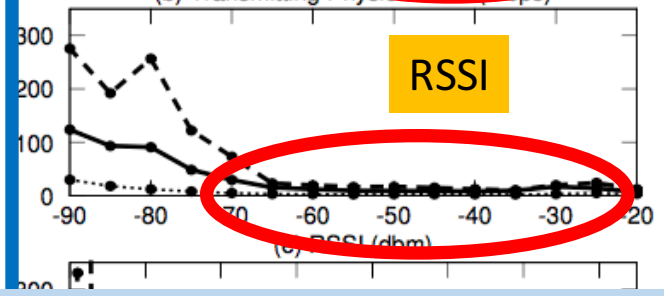


Negative Trends

Transmitting Physical Rate

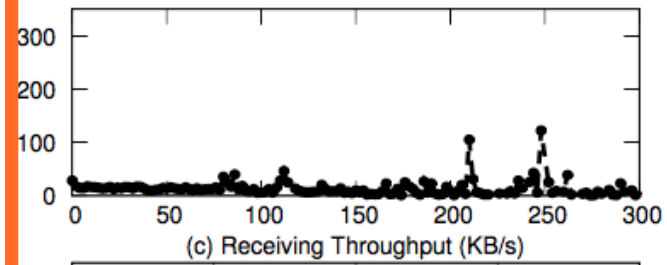


RSSI

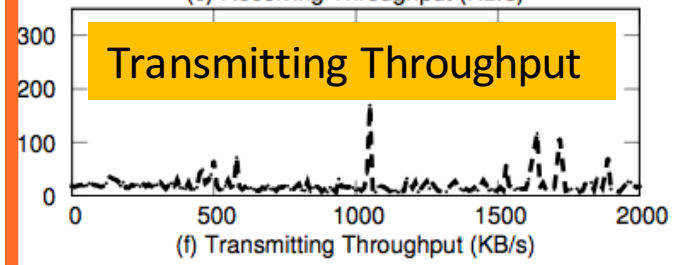


No Clear Trends

Receiving Throughput



Transmitting Throughput



The model is general because almost all parameter spaces are covered thanks to the variety of the data.

Correlation Analysis

- Kendall correlation: (Kendall)

$$tau = \frac{|concordant\ pairs| - |discordant\ pairs|}{n(n-1)/2}$$

- Relative Information Gain: (RIG)

how much a factor helps to predict the final latency

Quality Metric	Kendall	RIG
AU	0.86	0.05
RSSI	-0.5	0.06
RR	0.4	0.08
TPR	-0.3	0.11
RPR	-0.2	0.09
T_{rx}	-0.17	0.01
Q	0.15	0.007
T_{tx}	-0.006	0.02

Correlation Analysis

- TPR is the best choice to present the latency. This is because of the rate adaption algorithm.

Quality Metric	Kendall	RIG
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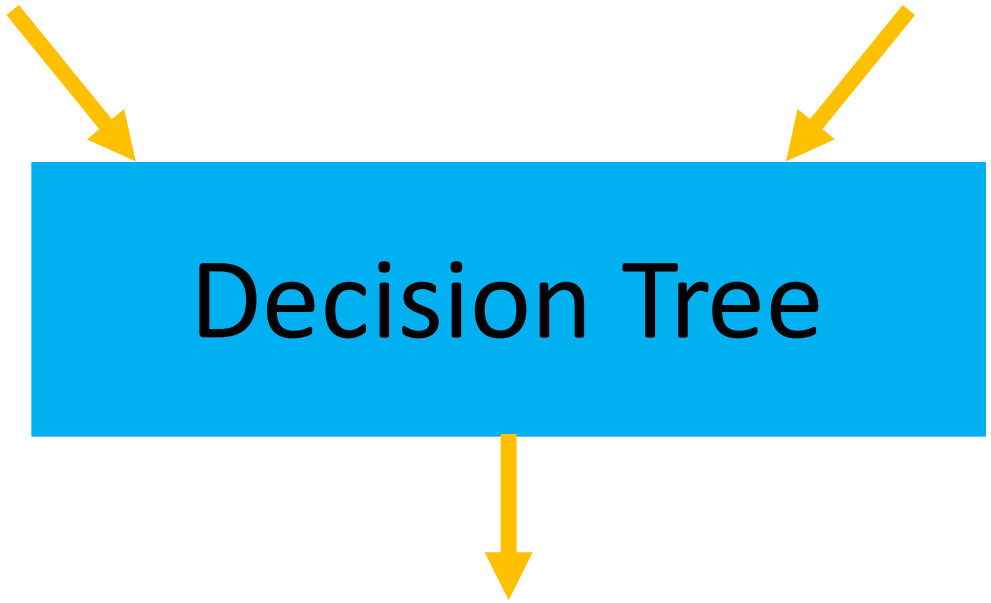
Decision Tree

(AU, RR, RSSI, T_{rx}, T_{tx}, TPR, RPR) **SLOW/FAST**



Decision Tree

- $\begin{cases} \text{FAST}: & DL, UL < 12.5\ ms,\ \ DL + UL < 25\ ms \\ \text{SLOW}: & DL, UL \geq 12.5\ ms,\ \ DL + UL \geq 25\ ms \end{cases}$
- Package: scikit learn package
- Evaluation: 10-fold validation

Decision Tree

Method	Latency Type	Accuracy	Truth Positive Rate	False Positive Rate
Decision Tree	DL	0.78	0.76	0.24
	UL	0.68	0.67	0.27
	DL+UL	0.77	0.79	0.31

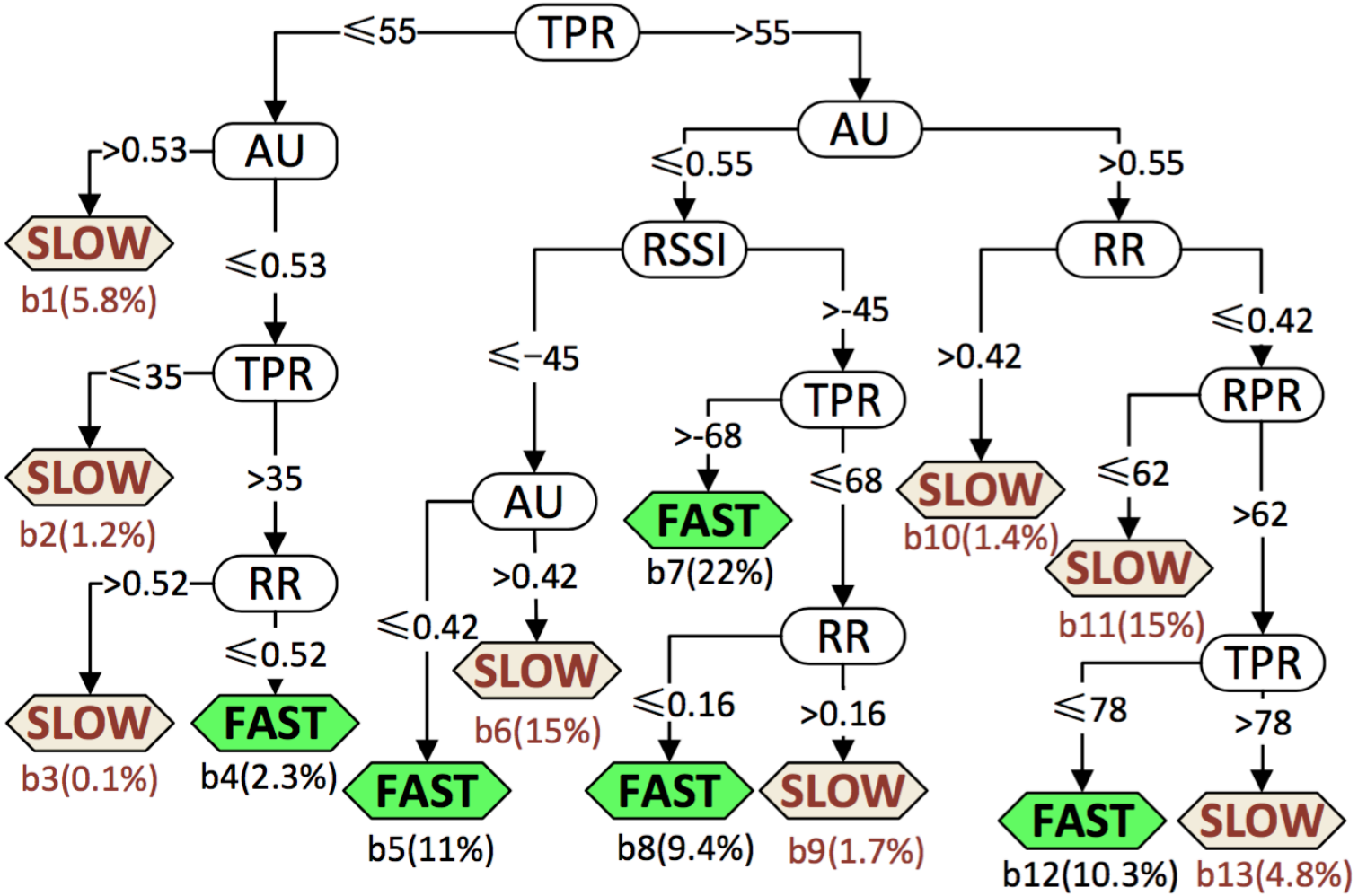
Decision Tree

Method	Latency Type	Accuracy	Truth Positive Rate	False Positive Rate
Decision Tree	DL	0.78	0.76	0.24
	UL	0.68	0.67	0.27
	DL+UL	0.77	0.79	0.31

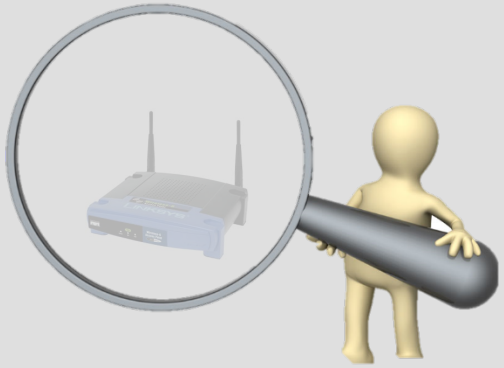
- The Random Forest, (tree number = 200, tree depth = 100), Accuracy > **0.8** with 0.21 False Positive Rate for DL.
- Why Decision Tree instead of Random Forest?

  interpretability + usability

Decision Tree



Measurement



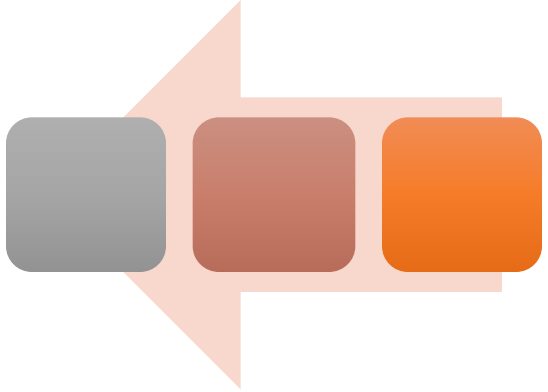
Trace

Training

ML Model

Problematic AP

Optimization



WiFi Factors for this AP

Reconfigure which ?

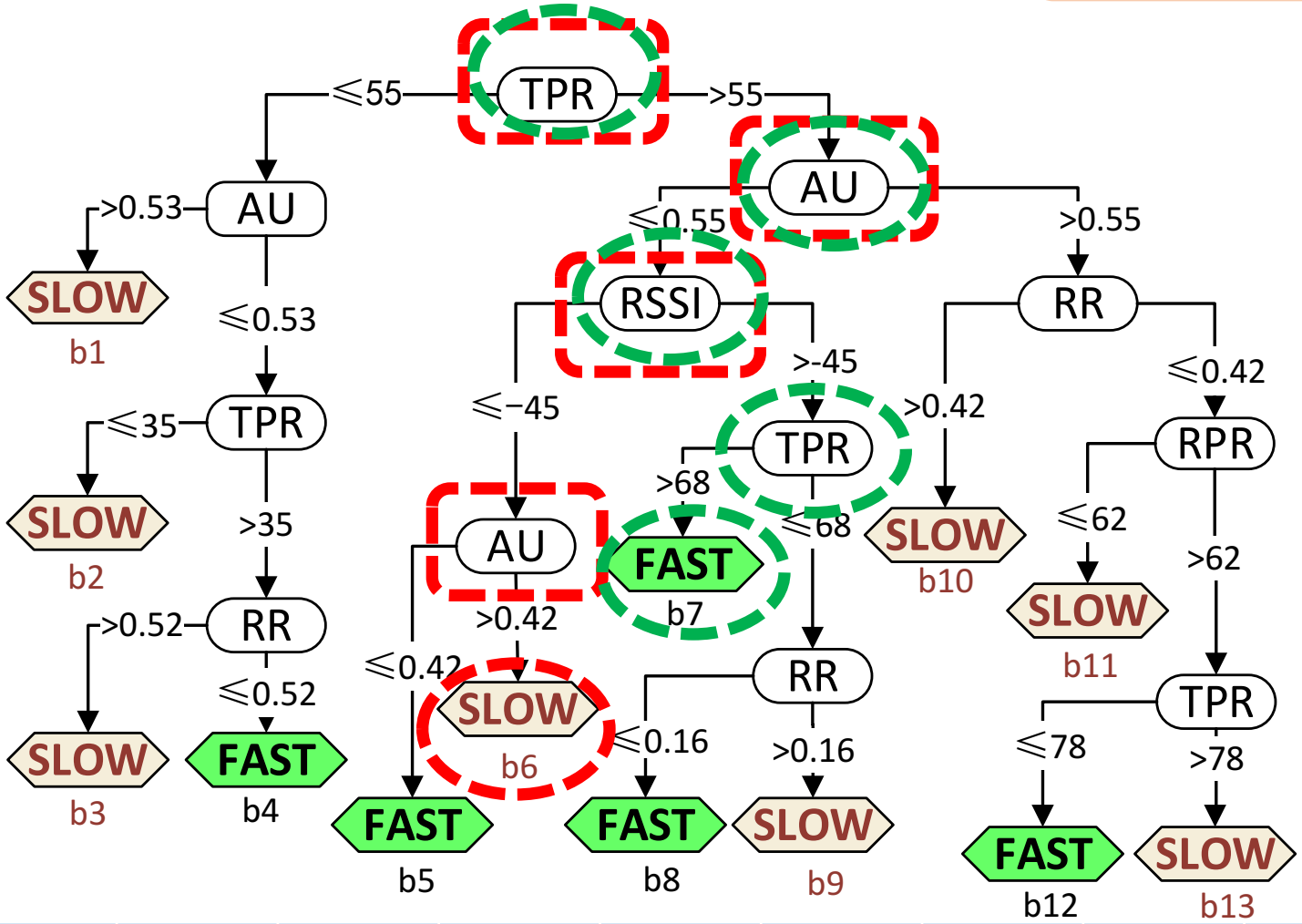
- Transmit Power?
- Location?
- Channel?
- Channel Width?

Case Study 1: Relocate the AP

1. Classifying WiFi factor traces

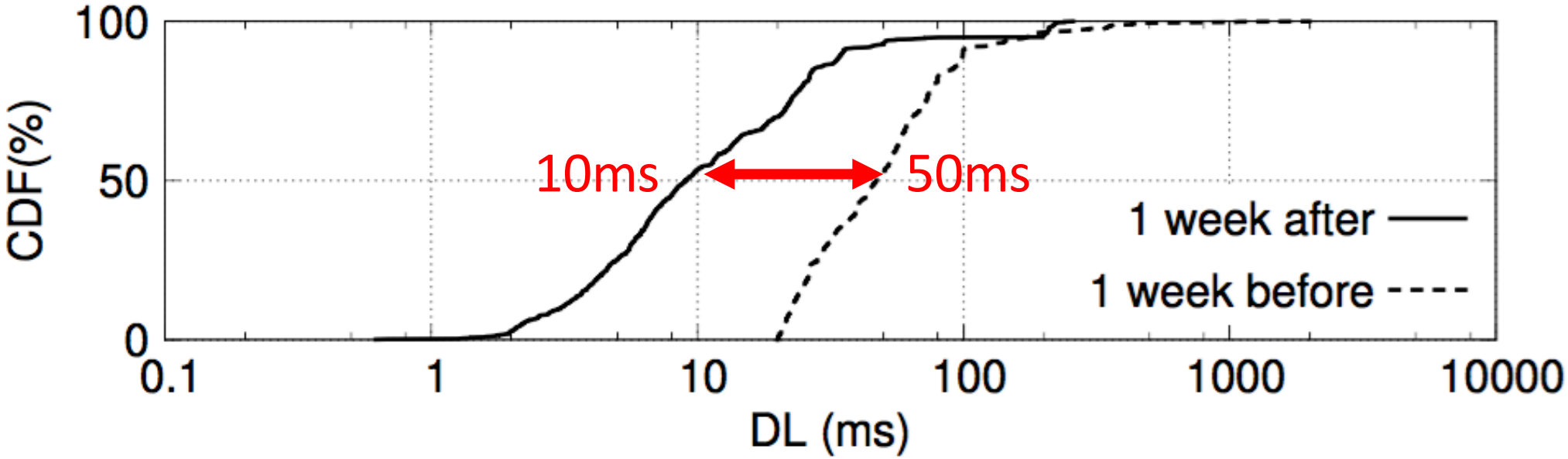
2. Locate the worst branch

3. Reconfigure the AP



branch	B1	B2	B5	B6	B7	B10	B11	B12	b13
before	0.1%	0.8%	3%	58%	0	6.7%	13.4%	4.2%	13.8%
after	0%	0%	0	0.5%	61.2	0.4%	3.5%	0.4%	34%

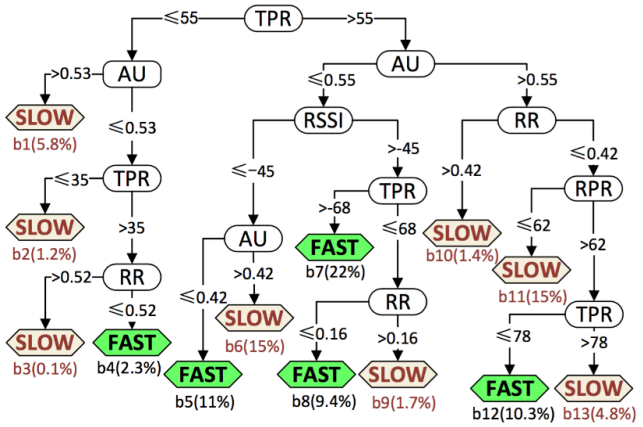
Case Study 1: Relocate the AP



CDF of OAP DL one week before and one week after optimization under the guidance of decision tree.

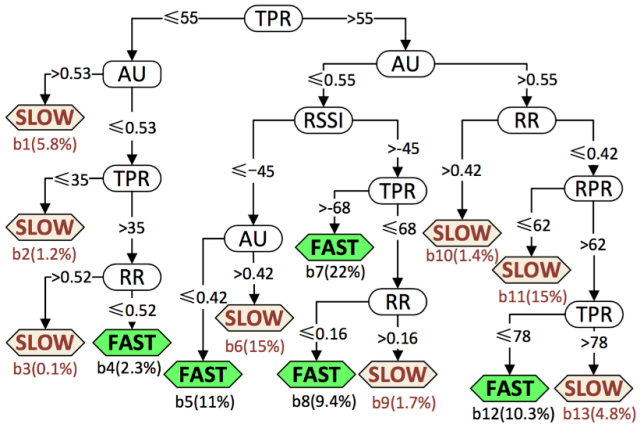
5X improvement!

Three Steps for Optimization



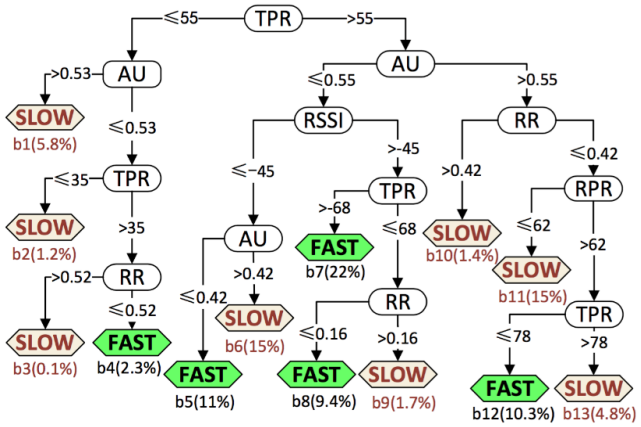
- Collect raw WiFi factor traces from the AP we want to diagnose and use the decision tree to classify these samples.

Three Steps for Optimization



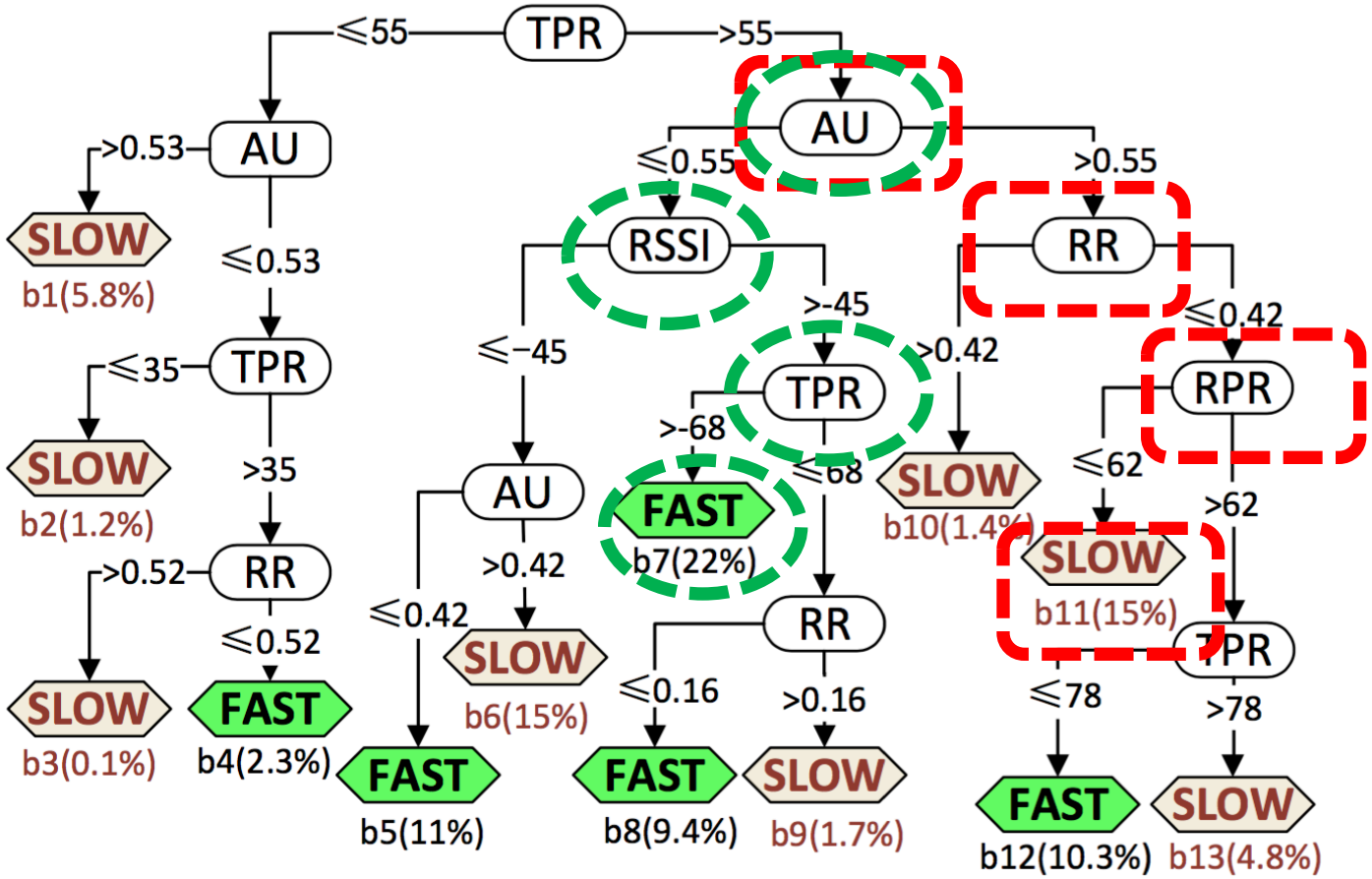
- Collect raw WiFi factor traces from the AP we want to diagnose and use the decision tree to classify these samples.
- Find the worst branch and locate the candidate factors for optimization.

Three Steps for Optimization



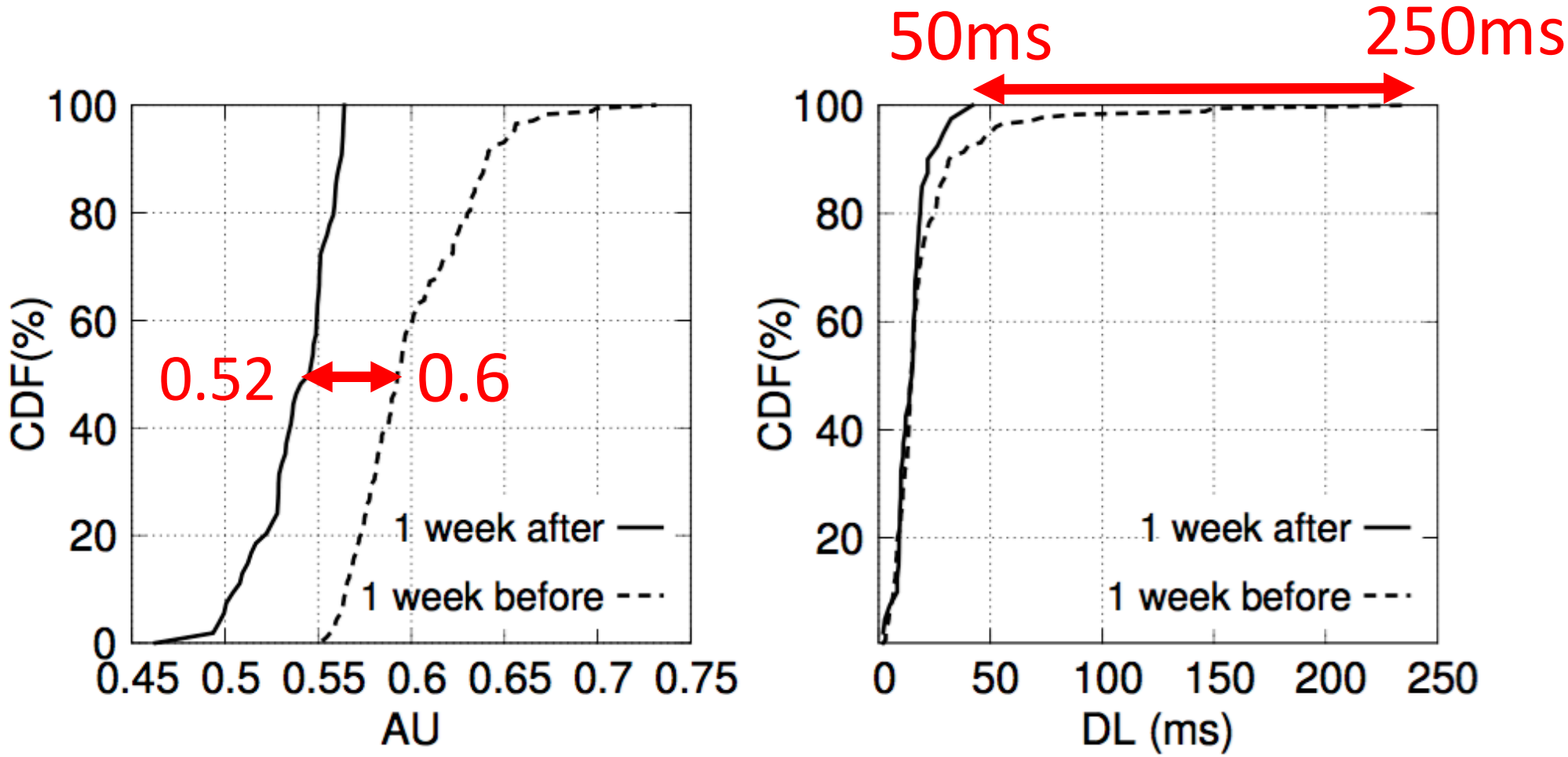
- Collect raw WiFi factor traces from the AP we want to diagnose and use the decision tree to classify these samples.
- Find the worst branch and locate the candidate factors for optimization.
- Reconfigure the AP to change the value of certain split criterion.

Case Study 2: Channel Switching



branch	b1	b6	b7	b10	b11	b12
fraction of packets before optimization	3	0	0	0	**82**	15
fraction of packets after optimization	0	12.6	**82**	0.9	4.5	0

Case Study 2: Channel Switching

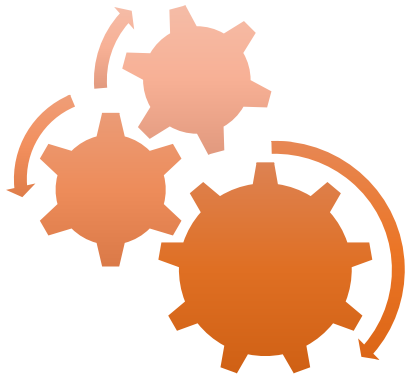


CDF of AU and DL one week before and one week after the channel selection.

Measurement

Trace

Training

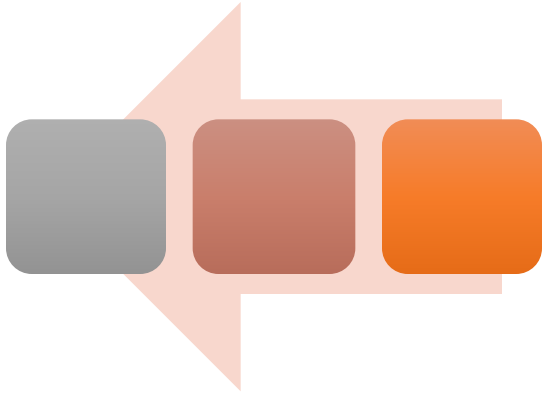


ML Model

Problematic AP

WiFi Factors for this AP

Optimization



Reconfigure which ?

- Transmit Power?
- Location?
- Channel?
- Channel Width?

Conclusion & Future Work

- Effectively measuring the Round Trip Network Latency.
- Comprehensive measurement on 47 APs in the wild.
- Train a decision tree based model which shows good optimization results in the wild.
- This work can be further extended by: Delay ACK packets filtering
- This work can be applied to other applications such as : dynamic channel selection.

Thank you!

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