Mobile Computing & Networking Laboratory

Extending Drive-Thru Data Access by Vehicle-to-Vehicle Relay

Jing Zhao
Todd Arnold
Yang Zhang
Guohong Cao

Pennsylvania State University
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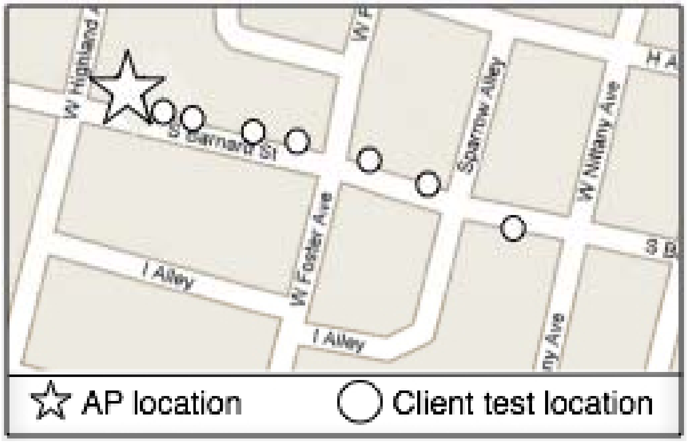
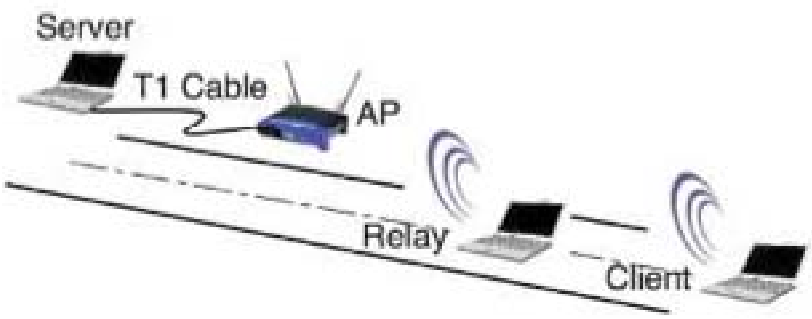
Introduction

- Focus
  - “Drive-thru access“ [Ott and Kutscher, infocom’04]
  - Drivers/passengers in vehicles to roadside access point (AP) when they are passing by the APs (drive-thru).
  - Drive-thru access obtains the best throughput for uploading/downloading data.
- Key issue
  - Short connection time.
  - Large portion of the connection time in the poor link quality area.
- Our solution
  - Use two wireless interfaces
  - Find relay vehicles to extend the connection range.

Feasibility of Relay

- Experiment
  - Move the laptop along the street and test the performance of both one-hop and two-hop relay connection with the AP.
  - 802.11b based devices
  - Metrics (at different locations)
    - Test packet delivery ratio by checking beacon message delivery.
    - Test UDP throughput.





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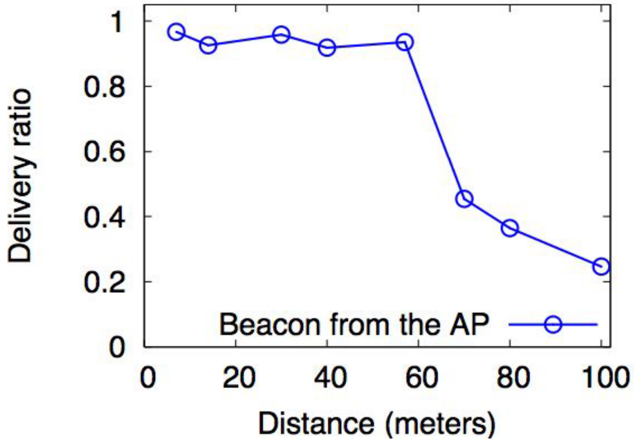
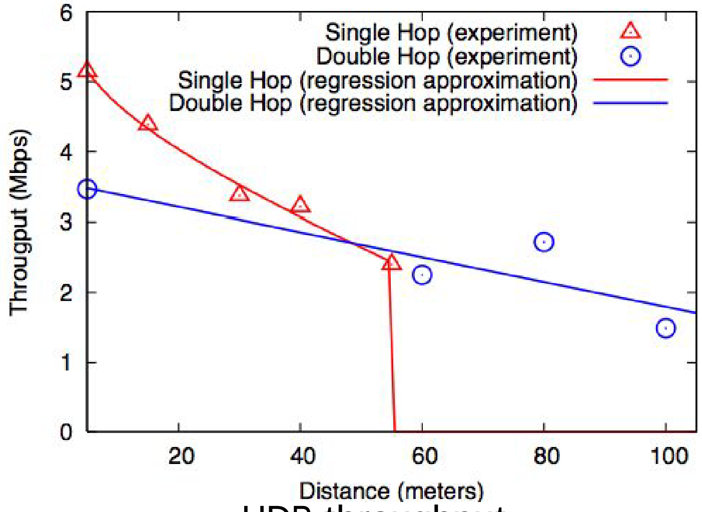
Observations

- Delivery ratio
  - Short distance from AP (e.g. within 57m)
    - Packet loss low
  - Fairly long distance from AP (e.g. outside 57m)
    - Vehicle can establish connectivity with AP
    - Packet loss is very high
- Throughput
  - One hop
    - High and stable throughput within 57m
    - Link outside 57m is not useful for data transmission
  - Relay
    - Able to obtain high and stable throughput when one hop link failed for data transmission
- Useful discoveries
  - Existence of a critical range
  - Relay is effective when vehicles are outside the critical range



Beacon delivery ratio



UDP throughput

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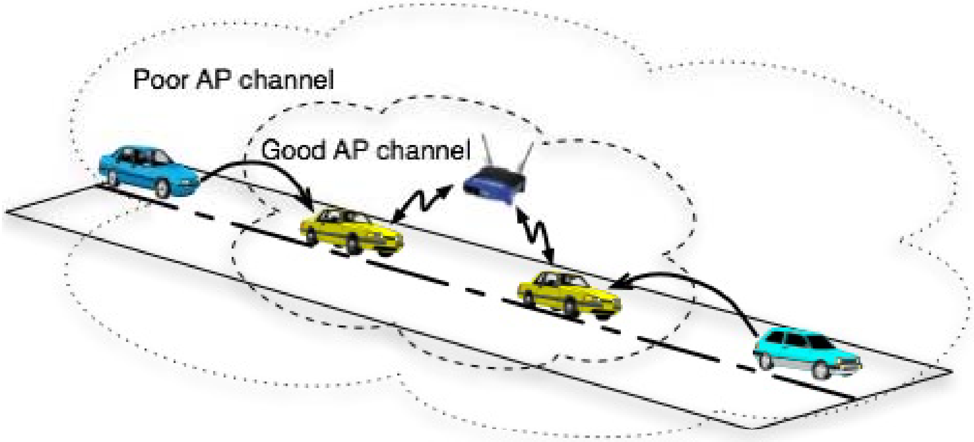
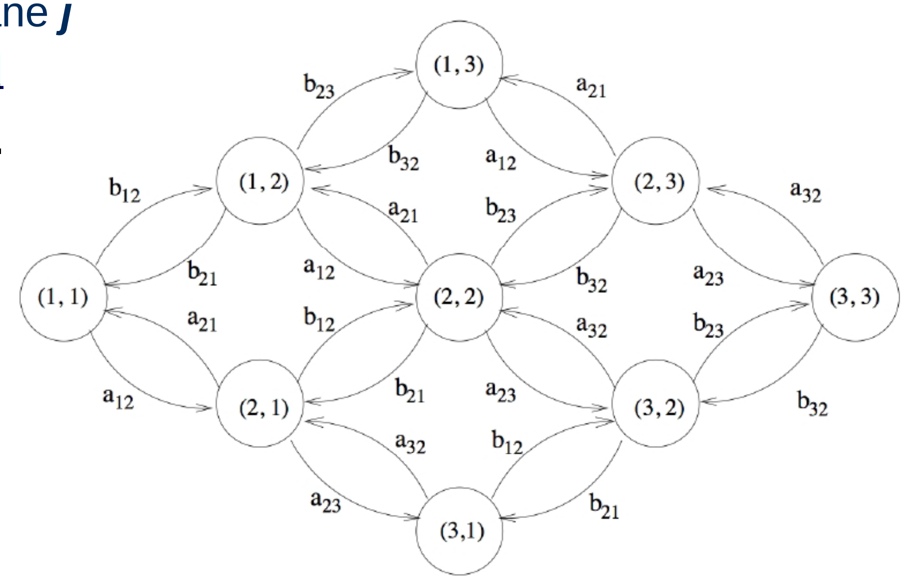
Vehicle to Vehicle Relay (V2VR)

- Forward Relay
  - Find a vehicle in front of itself to access AP before entering the AP coverage or at the fringe of the AP coverage area.
- Backward Relay
  - Find a vehicle behind to relay traffic when leaving the AP coverage area and the connection with the AP becomes poor.
- Select the relay before entering AP coverage
- Issues
  - How to find a relay among highly mobile vehicles?
  - How to enable the relay process on the fly?



Finding a Proper Relay

- Considerations
  - Link quality, location, relative movement
- Explore "platoon pattern" and car following model
- Markov Chain model
  - State ***(p,q)***
    - ***p*** is the lane number of the client vehicle, ***q*** is the lane number of the relay vehicle
  - $a_{i,j}$ - Lane changing rate of the client.
    - lane changing rate from Lane ***i*** to Lane ***j***
    - $a_{i,j} = 0, \forall 0 \leq i, j \leq n, |i - j| > 1$
  - $b_{i,j}$ - Lane changing rate of the relay.
- A 3-lane Markov Chain example



Finding a Proper Relay (cont.)

- $\boldsymbol{P_{(i,j) \to (p,q)}}$ - State transition probability, e.g. from State (i,j) to State (p,q)

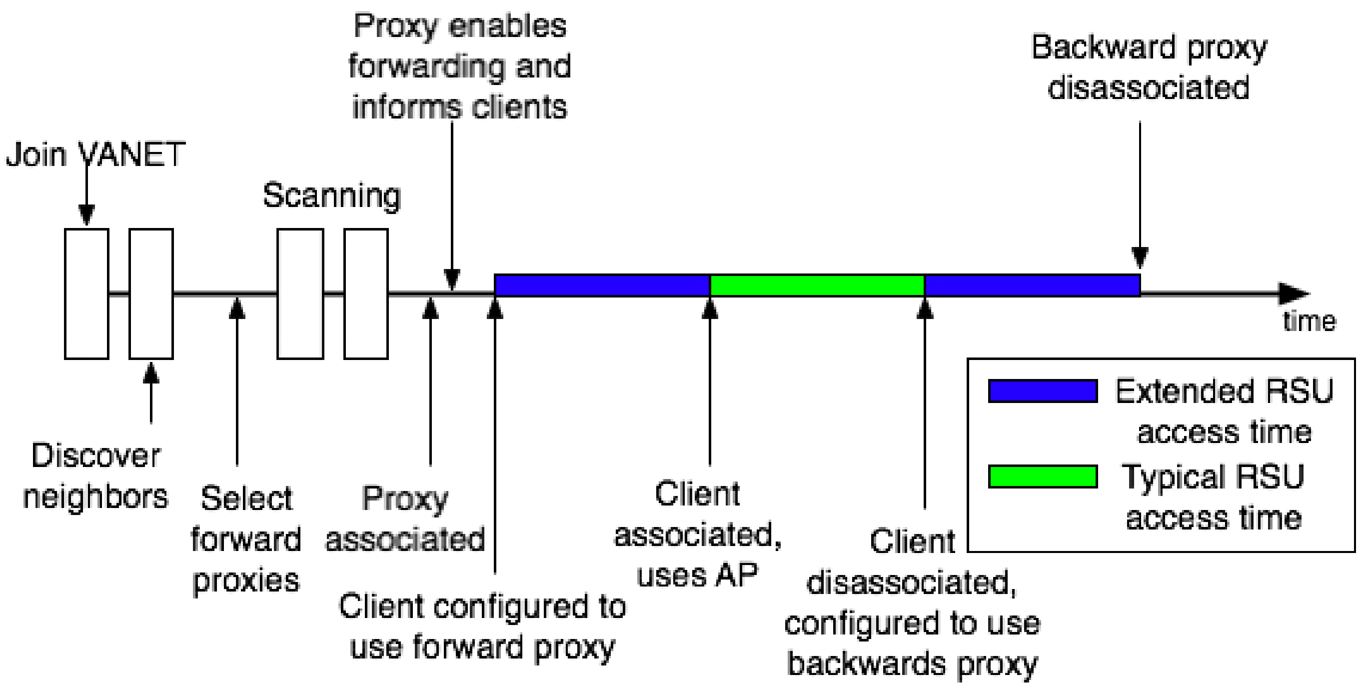
$$P_{(i,j)\to(p,q)} = \begin{cases} \frac{a_{ip}}{u_{(i,j)}}, & |i-p| = 1, j = q \\ \frac{b_{jq}}{u_{(i,j)}}, & |j-q| = 1, i = p \\ 0, & \text{else} \end{cases}$$ where $u_{(i,j)} = a_{i,i-1} + a_{i,i-1} + b_{j,j-1} + b_{j,j+1}$

- ***P(i,j)*** - The proportion of time spent in any state *(i, j).*
  - Can be calculated by solving the Markov Chain model.
- ***Δd*** - Relative displacement between the client and the proxy after a period of time *t*.
  - $$\Delta d = \sum_{1 \le i,j \le n} P(i,j) \cdot (v_j - v_i) \cdot t$$

    v_i denote the speed of vehicles in Lane *I*
  - The metric for determine the reliability of a relay vehicle
    - In combined with SNR and position of the relay vehicle to make the final decision

Relay Implementation

- Backwards compatible solution with existing infrastructure
  - No change required at the AP side.
  - Client side follows basic 802.11 protocols.
- Steps for accessing a AP through a relay vehicle



Implementation Setup

- AP
  - Linksys WRT54GL router / access point
  - OS: DD-WRTv23 SP3
- Nodes:
  - Compaq laptops
  - Redhat Linux, kernel v2.4.5
  - Two NICs on each node
  - PCAP Library
- Monitor: Powerbook G4 using ethereal 0.10.12-1011

Implementation: Key components

- Masquerading at relay node
  - Ability to forward packets from the VANET interface to the infrastructure interface.
  - Use IP table to manipulate packet headers.
  - Use IP table provides the rules for forwarding packets and can be enabled or disabled on the fly.
- Configure default route at client
  - Relay vehicles' IP address for install default route.
  - Relay vehicles' MAC address to eliminate the need for ARP requests.
  - DNS address if internet access is desired.
- Sending control messages
  - Use MAC broadcasts
- Capturing control packets
  - PCAP library

Results

802.11 association for relay vehicle (packets 1–14)

Forwarding enabled on the relay (packets 15–16)

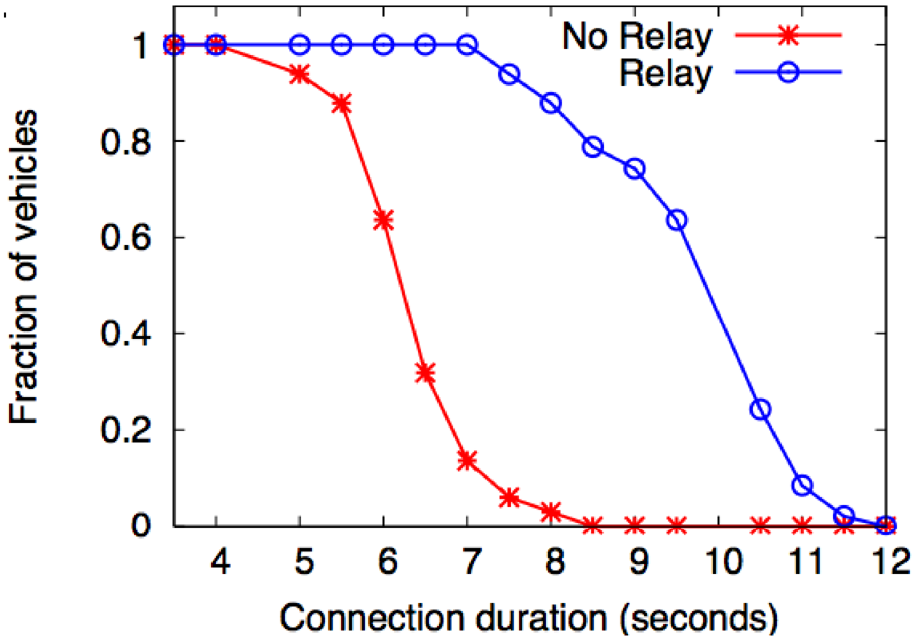
Client starts data session (packets 17–22)

Packet #	Elapsed Time	Source	Destination	Protocol	Bytes	Information
1	0.000000	00:1a:73:37:8a:d1	ff:ff:ff:ff:ff:ff	IEEE 802.3	130	Hello packet
2	0.105106	00:1b:2f:3e:3d:b9	00:18:39:ea:5f:04	IEEE 802.11	98	Authentication[Malformed Packet]
3	0.105987	00:18:39:ea:5f:04	00:1b:2f:3e:3d:b9	IEEE 802.11	106	Authentication[Malformed Packet]
4	0.107098	00:1b:2f:3e:3d:b9	00:18:39:ea:5f:04	IEEE 802.11	118	Association Request
5	0.108577	00:18:39:ea:5f:04	00:1b:2f:3e:3d:b9	IEEE 802.11	122	Association Response[Malformed Packet]
6	0.110374	00:1b:2f:3e:3d:b9	00:18:39:ea:5f:04	IEEE 802.11	110	Probe Request
7	0.111642	00:18:39:ea:5f:04	00:1b:2f:3e:3d:b9	IEEE 802.11	143	Probe Response
8	0.219166	0.0.0.0	255.255.255.255	DHCP	428	DHCP Discover - Transaction ID 0x20f19200
9	0.278245	00:18:39:ea:5f:04	Broadcast	ARP	128	Who has 192.168.1.106? Tell 192.168.1.1
10	1.297803	00:18:39:ea:5f:04	Broadcast	ARP	128	Who has 192.168.1.106? Tell 192.168.1.1
11	2.218863	00:18:39:ea:5f:04	Broadcast	ARP	128	Who has 192.168.1.106? Tell 192.168.1.1
12	2.714642	192.168.1.1	192.168.1.106	DHCP	428	DHCP Offer - Transaction ID 0x20f19200
13	2.716917	0.0.0.0	255.255.255.255	DHCP	428	DHCP Request - Transaction ID 0x20f19200
14	2.720883	192.168.1.1	192.168.1.106	DHCP	428	DHCP ACK - Transaction ID 0x20f19200
15	2.995471	00:1a:73:37:8a:d1	ff:ff:ff:ff:ff:ff	IEEE 802.3	130	Hello packet
16	3.094725	00:1a:73:37:8a:d1	ff:ff:ff:ff:ff:ff	IEEE 802.3	134	Hello packet
17	3.460062	10.0.2.3	192.168.1.121	ICMP	184	Echo (ping) request
18	3.674821	00:1b:2f:3e:3d:b9	ff:ff:ff:ff:ff:ff	ARP	128	Who has 192.168.1.121? Tell 192.168.1.106
19	3.680323	00:0d:9d:85:b9:09	00:1b:2f:3e:3d:b9	ARP	146	192.168.1.121 is at 00:0d:9d:85:b9:09
20	3.680698	192.168.1.106	192.168.1.121	ICMP	184	Echo (ping) request
21	3.681044	192.168.1.121	192.168.1.106	ICMP	184	Echo (ping) reply
22	3.681346	192.168.1.121	10.0.2.3	ICMP	184	Echo (ping) reply

- The lead vehicle spends less than 100 milliseconds (between two hello packets 15 and 16) to configure itself and get ready to forward traffic.
- The client vehicle spends less than 0.4 seconds to finish the configuration and start to use the relay

Connection Duration (Complementary CDF)

- No Relay:
  - Average connection time: 6.06 seconds
  - Clustered around 6-7 seconds. Implies that even if vehicles can receive the beacon fairly far away from AP , they can hardly make use of the direct link with the AP.
- Relay
  - Average connection time: 9.68 seconds, 60% longer
  - More evenly distributed, since vehicles rely on the opportunistic connection with the proxy vehicles.



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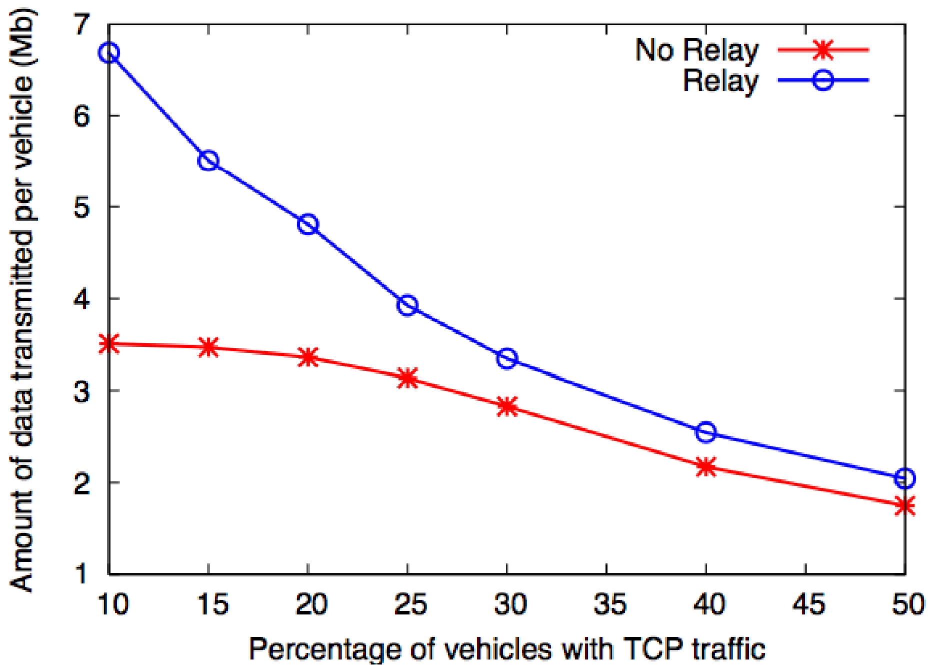
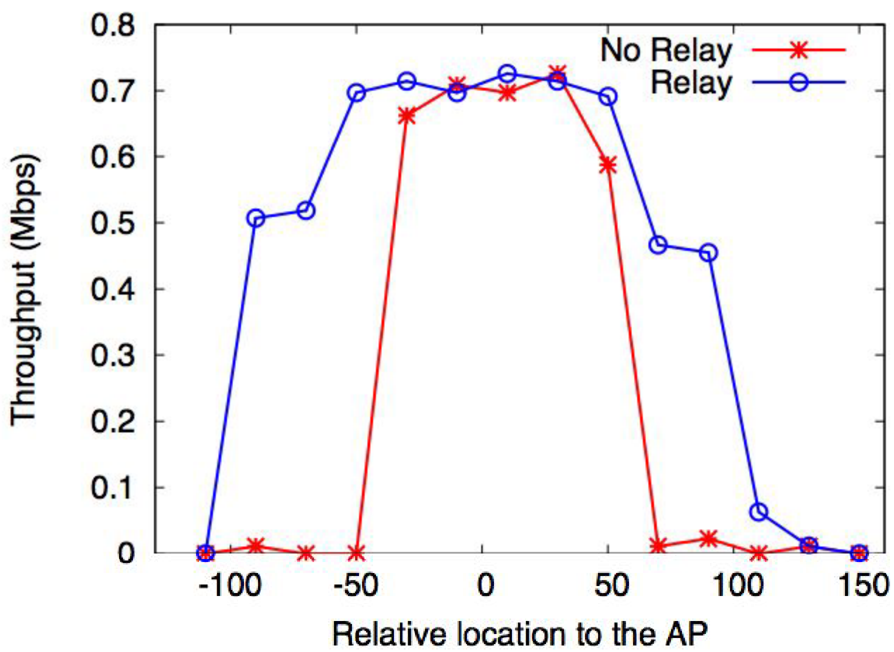
Amount of Data Delivered

- The relay scheme can delivery significant more data when the network traffic are light.
    - Transmitted 90% more data when 10% vehicles are sending TCP traffic
- When more vehicles are sending data, less amount of data can be delivered by each vehicle in both schemes

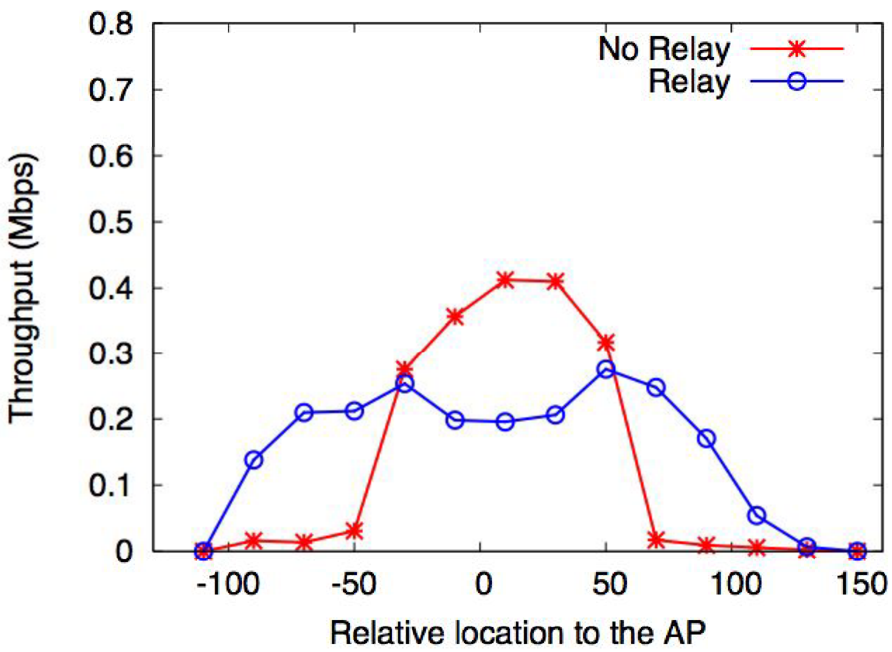


Data Transmission Throughput

- Relay can extend the connection to the AP regardless of the density.
- More effective when the density is low.



10% client sending TCP traffic



50% client sending TCP traffic

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Thank You

Jing Zhao
Todd Arnold
Yang Zhang
Guohong Cao

www.cse.psu.edu/~jizhao

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