Interactive WiFi Connectivity For Moving Vehicles

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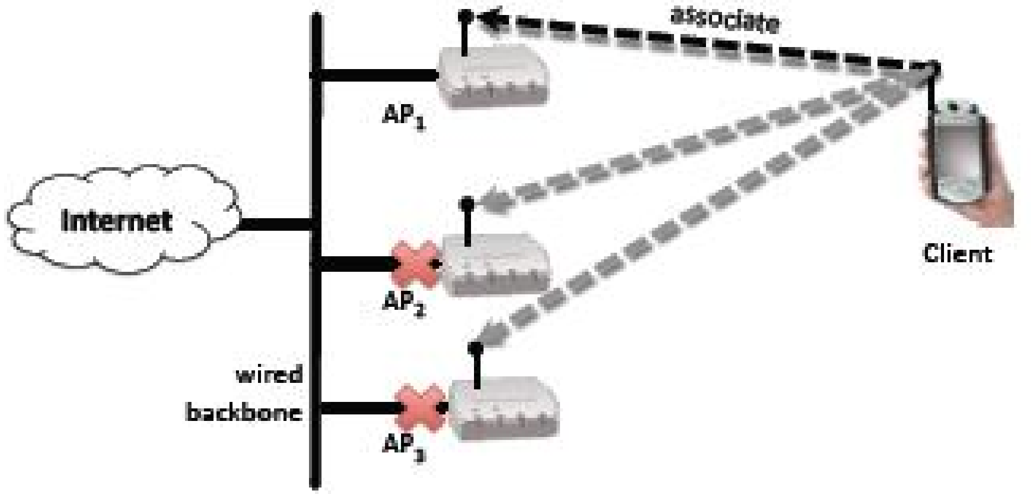
Today's Wireless LAN



- Communicates with only one basestation at a time.
- Frequent disruptions in connectivity
- Not suitable for interactive applications ex. VoIP
- Inefficient for short TCP transfers ex. Web browsing

Alternatives : Cellular networks but expensive!

Why ViFi?

- Growing need for cheap and high quality internet access from moving vehicles
- Opportunity , wide deployment in WiFi covering entire cities
- WiFi hard handoffs methods are limited by gray periods, causing user-perceived quality for interactive applications to be bad

What is ViFi ?

- Protocol that minimizes disruptions in WiFi connectivity for moving vehicles

- Uses macrodiversity by exploiting multiple BSes

- Uses a decentralized probabilistic algorithm for packet delivery

Experimental Platforms (1/2)

VanLAN

- Deployed in Microsoft campus in Redmond
- Consists of eleven basestations (BSes) and two vehicles
- Vehicles provide a shuttle service moving with a speed of 40 Km/h
- Each vehicle visits the region of BSes about ten times a day
- The BSes and vehicles have small desktops with Atheros 5213 chipset radios and omnidirectional antennae
- Vehicles are equipped with GPS unit that outputs information once every second.
- All nodes were set to the same 802.11 channel

Experimental Platforms (2/2)

DieselNet

- Deployed in Amherst in Massachusetts
- Vehicles are equipped with a computer, an 802.11 radio and a GPS unit
- One vehicle logs all beacons from nearby BSes to enable trace-driven studies
- Channels 1 and 6 were profiled for 3 days logging 100000 beacons

Evaluation of HandOff methods

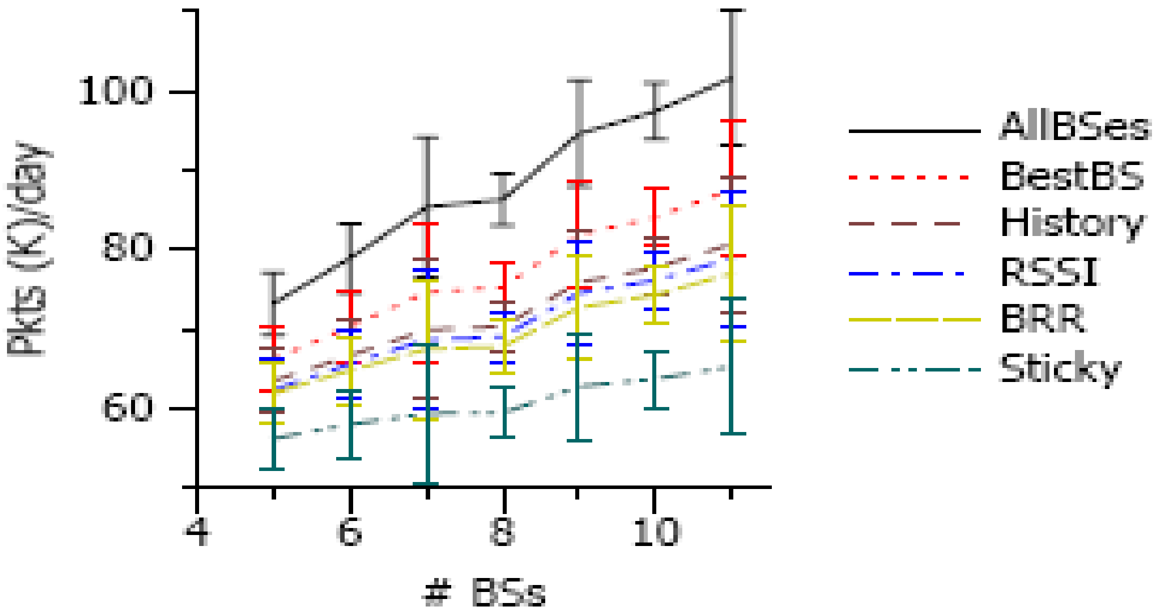
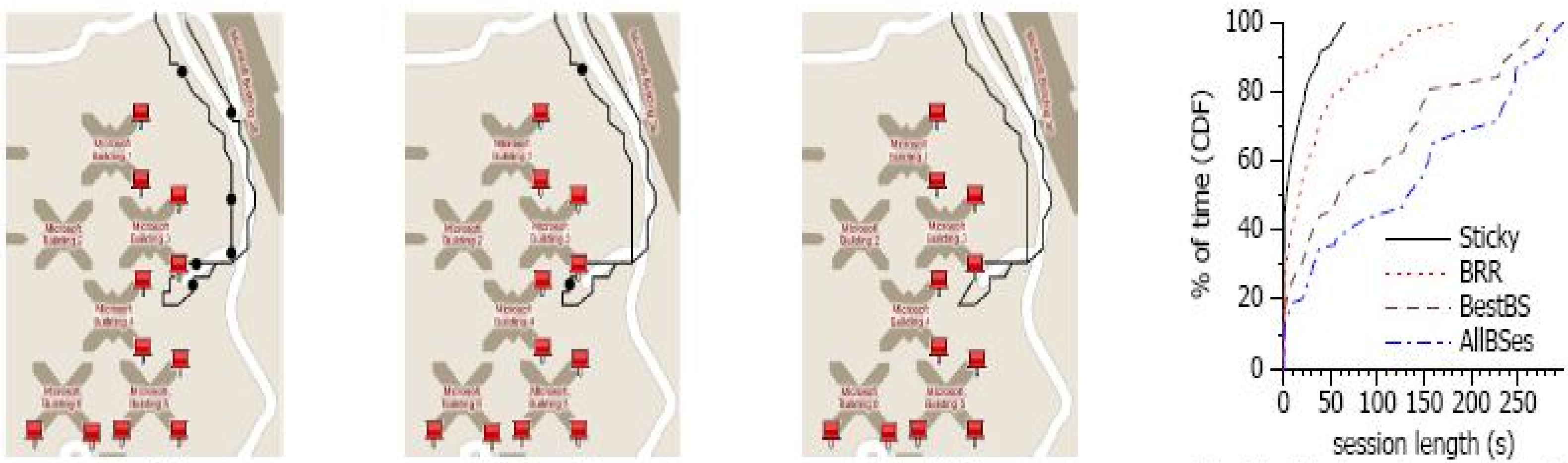


Figure 2: Average number of packets delivered per day in Van-LAN by various methods. Error bars represent 95% confidence intervals.

Connectivity with different HandOff methods



(a) *BRR* (b) *BestBS* (c) *AllBSes* (d) *Distribution of session length*

Figure 3: (a)-(c): The behavior of three handoff methods for an example path segment in VanLAN. Black lines represent regions of adequate connectivity, i.e., more than 50% reception ratio in a one-second interval. Dark circles represent interruptions in connectivity. (d): The CDF of the time the client spends in a session of a given length.

Why multiple BSes are effective

- The vehicle is often in range of multiple BSes
- The packet losses are bursty and roughly independent across senders and receivers.

Experiments have shown that using more than 3 Bses offers no additional improvement
[Results are not shown in this paper]

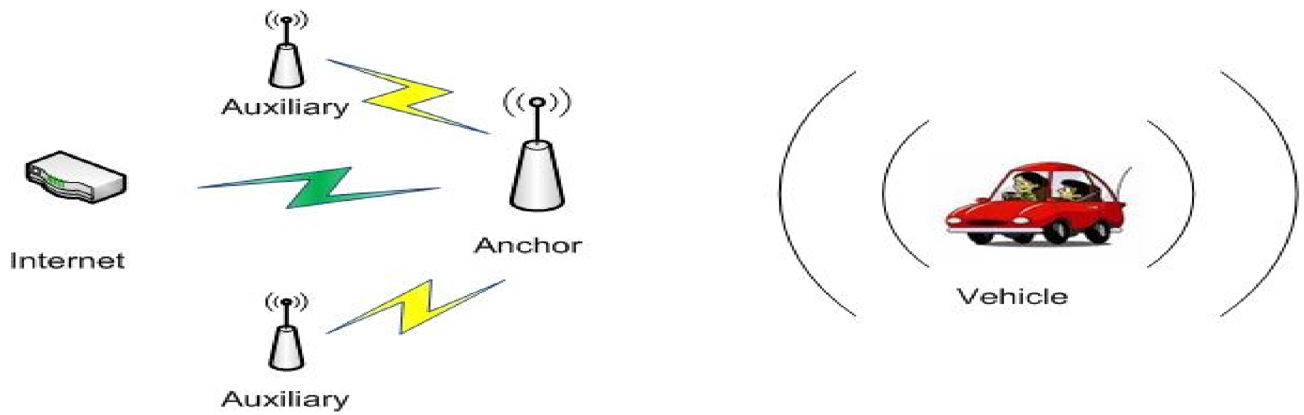
ViFi Challenges

Coordinating scheme among the BSes :

- Imposes minimal additional load on the inter-BS and vehicle-BS communication media
- Does not increase per packet latency, as that hurts interactive applications
- Can handle rapidly changing sets of BSes

ViFi Protocol Overview(1/3)

- Use one of the nearby BSes as an *anchor (gateway to the Internet) based on BRR,* other nearby nodes can be *auxiliaries (relaying BSes).*



- The vehicle broadcasts the identity of current and previous anchor and auxiliaries BSes periodically with beacons
- New anchor contacts previous anchor over the inter-BS backplane to salvage packets

ViFi Protocol Overview(2/3)

- Uses broadcast transmissions at the MAC layer
- Disables the 802.11 standard acknowledgement mechanism (automatic retransmissions/back-offs)
- Adapts it's own retransmission counter based on the observed delays in receiving acknowledgments

Collisions are not examined in the paper, the current ViFi implementation relies only in carrier sense

ViFi Protocol Overview(3/3)

ViFi uses a probabilistic **symmetric** algorithm

1. **src** transmits the packet P
2. If **dst** receives P, it broadcasts an ACK
3. If an auxiliary overhears P, but within a small window has not heard an ACK, it **probabilistically** relays P
4. If **dst** receives relayed P and has not already sent an ACK, it broadcasts an ACK
5. If **src** does not receive an ACK within a retransmission interval, it retransmits P

Why relay instead of retransmitting

- Losses are bursty. If the original is lost there is a high chance a retransmission from the source will be lost as well

- Relaying uses the inter-BS communication plane which is more reliable than the vehicle-BS channel

Computing Relaying Probability

- Prefer auxiliaries with better connectivity to the destination

  The beacons emitted by each node embed the current incoming reception probability from all nodes that they hear

- Account for relaying decisions made by other potentially relaying auxiliaries

  Each auxiliary uses their locally computed probability to decide whether to relay

- Limit the expected number of relayed transmissions

  Compute relaying probabilities so that the expected number of packets relayed across all auxiliary BSes is equal to 1 (less overhead for the network)

$$\sum_{i=1}^{K} c_i r_i = 1$$

ci = probability that auxiliary BSi is contending on this packet

ri = BSi relay probability

Evaluation Methodology

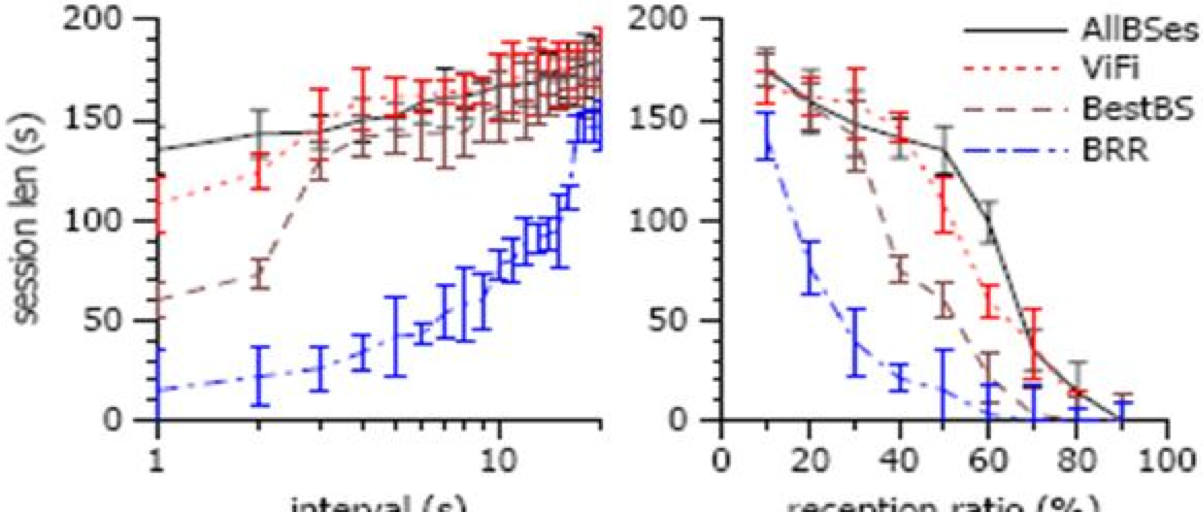
- The evaluations use the deployment of ViFi on **VanLan** and a trace-driven simulation based on measurements from **DieselNet**

- The experiments are based on a fixed 802.11b transmission rate of 1 Mbps to maximize range

- Results for VanLan are based on at least three days of data for each protocol and workload configuration

- All error bars in the graphs represent 95% confidence intervals

Session length

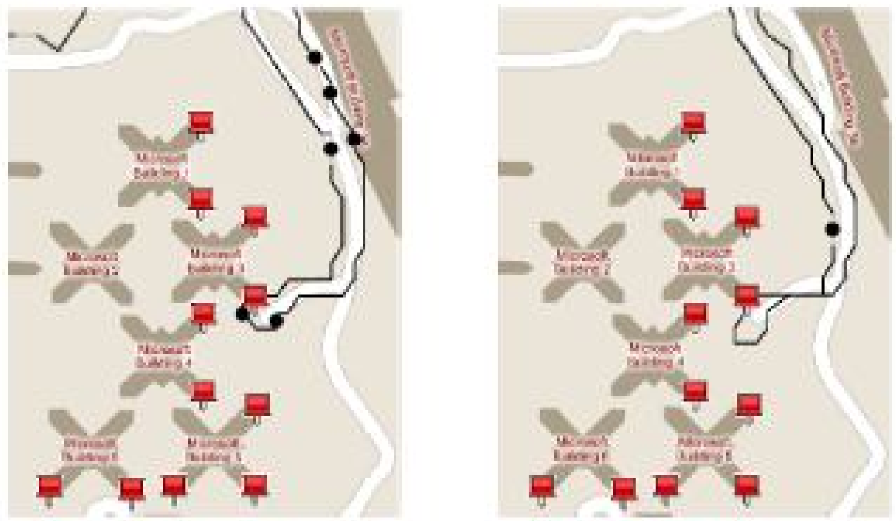


(a) *Reception ratio=50%* (b) *Interval=1 sec*

The link-layer performance of ViFi is close to ideal

They don't justify why ViFi outperforms AllBSes in some cases

Connectivity

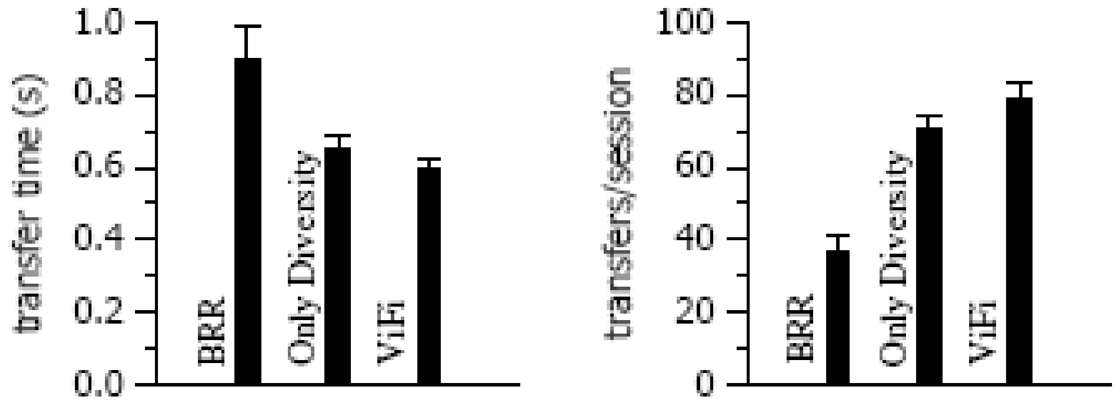


(a) *BRR* (b) ViFi

Figure 8: The behavior of *BRR* and ViFi along a path segment in VanLAN. Black lines represent regions where the reception ratio was more than 50% in 1-second intervals. Dark circles represent interruptions.

The paths are similar but not identical as they represent different days!

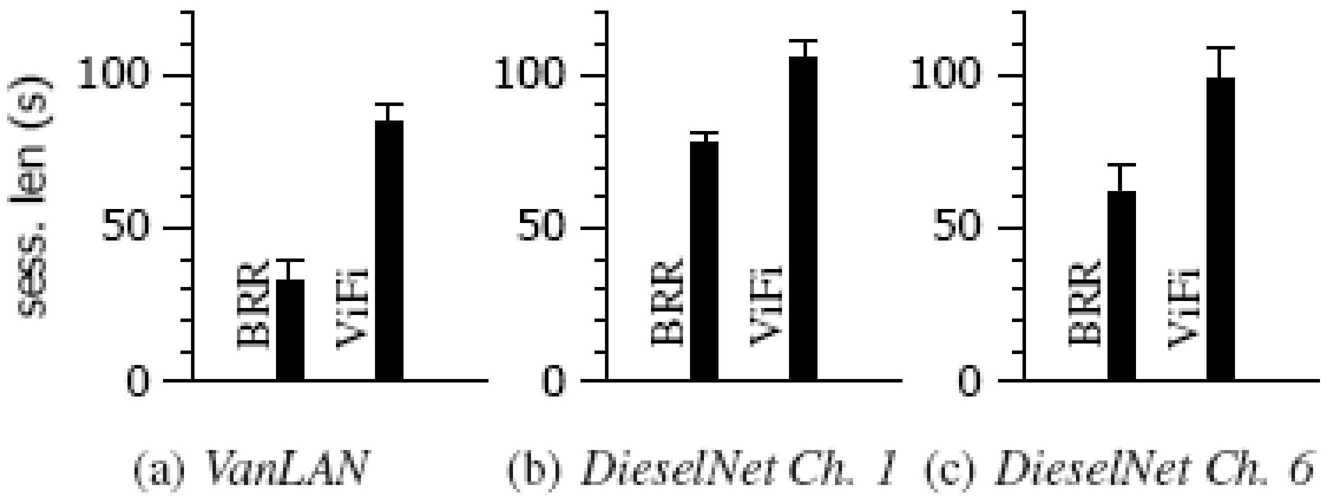
TCP Performance in VanLAN



(a) *Median transfer time* (b) *Transfers per session*

- ViFi median transfer time is about 0.6 seconds, which represents a 50% improvement over BRR
- Salvaging provides a noticeable gain of about 10%, even though only 1.2% of the packets are salvaged

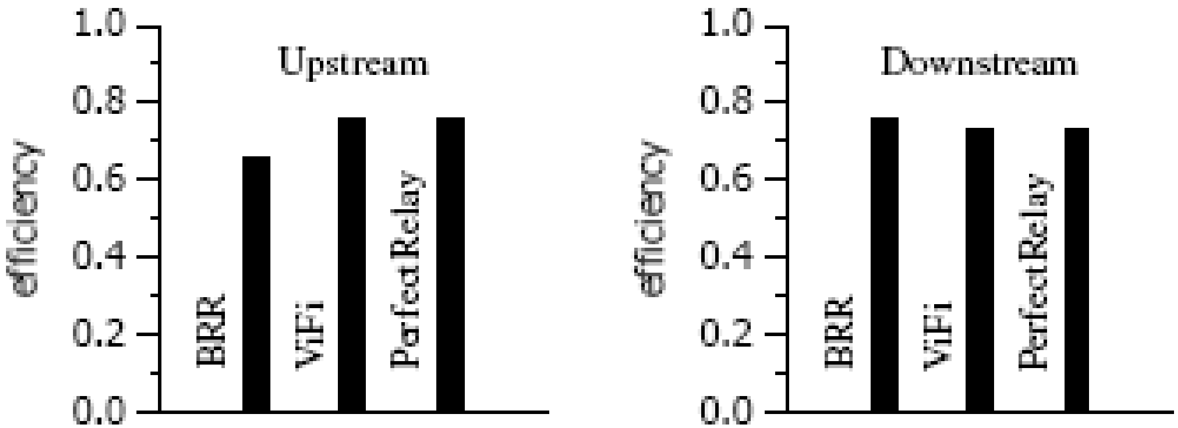
Median length of uninterrupted VoIP sessions



ViFi improves application performance two-fold compared to current handoff methods

The VoIP packets are **simulated** and use only **constant values**!
Coding Delay 20 ms, Jitter Buffer 60ms ,End-end wireless paths 40 ms

Efficiency of medium usage



- ViFi is slightly more efficient in using the medium in the upstream direction
- For downstream BRR has a slightly better efficiency because in ViFi the BS chosen to relay a packet may be distant

Detail statistics on the behaviour of ViFi in VanLan

		Upstream	Downstream
A1	Median number of auxiliary BSes	5	5
A2	Average number of auxiliary BSes that hear a source transmission	1.7	3.6
A3	Average number of auxiliary BSes that hear a source transmission but not the acknowledgment	0.6	2.5
B1	Source transmissions that reach the destination	67%	74%
B2	Relayed transmissions corresponding to successful source transmissions (i.e., false positives)	25%	33%
B3	Average number of auxiliary BSes that relay when a false positive relay occurs	1.5	1.5
C1	Source transmissions that do not reach the destination	33%	26%
C2	Cases where at least one auxiliary BS overhears a failed source transmission	66%	98%
C3	Cases where zero auxiliary BSes relay a failed source transmission (i.e., false negatives)	10%	34%
C4	Relayed packets that reach the destination	100%	50%

Limitations

Higher false positives and false negatives caused by increase in the number of relays per packet:

- When the number of auxiliary BSes is high (e.x greater than 15), especially in dense networks
- When all auxiliary Bses are equidistant from both the source and the destination

ViFi requires changes to BSes and clients that may create an initial barrier to adoption

ViFi is beneficial only if clients often hear multiple Bses on the same channel

Lack of WiFi coverage between cities would render this technology unusable

Related Work (1/2)

- **Using multiple BSes**

Cellular Networks

Provide macrodiversity and wider coverage

Expensive, tight integration with physical layer, strict timing across Bses

MRD

Less retransmissions, higher throughput

High capacity LAN required

MultiNet, FatVAP, PERM

Increases throughput for client and BS communication by associating with multiple BSes

Related Work (2/2)

- **Opportunistic routing in static mesh networks**

  ExOR

    Low coordination overhead, high throughput

    Delay caused by batch packets not suitable for interactive applications

- **Network access from moving vehicles**

  MobiSteer

    Significantly improves performance

    Use of expensive directional antennas

- **Fast Handoffs**

  Minimize the delay associated with handoffs

Conclusions

- Improves WiFi performance for interactive applications and TCP throughput
- ViFi leverages basestation diversity and improves link-layer performance
- Minimizes disruptions for clients by exploiting opportunistic receptions

The key to it's effectiveness is a **decentralized probabilistic algorithm** which efficiently coordinates packet delivery

Thank You