Using redundancy to enable interactive connectivity for moving vehicles

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Increasing demand for connectivity from moving vehicles

Commuter Internet access

Seamless access between driving and being stationary

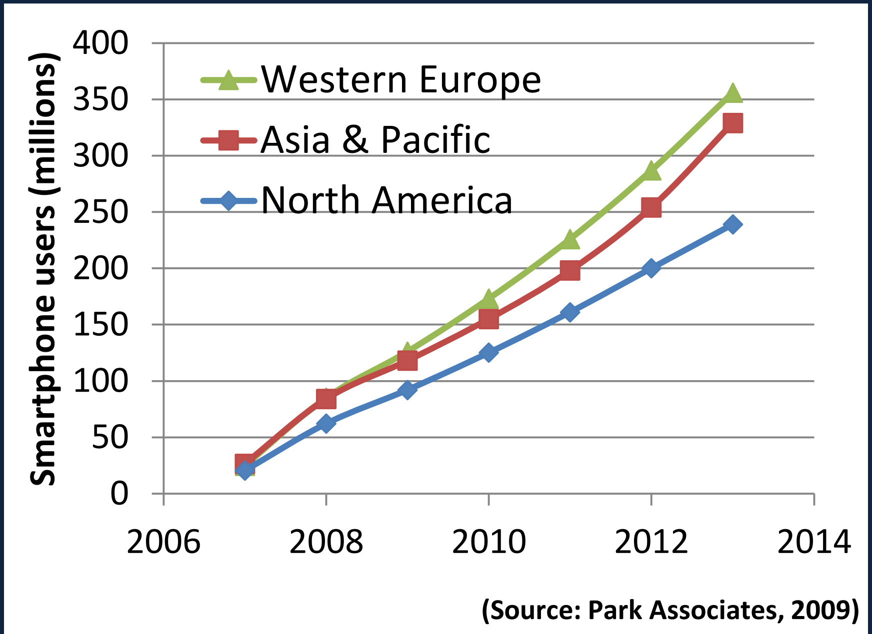
Navigation units

- E.g., current traffic conditions

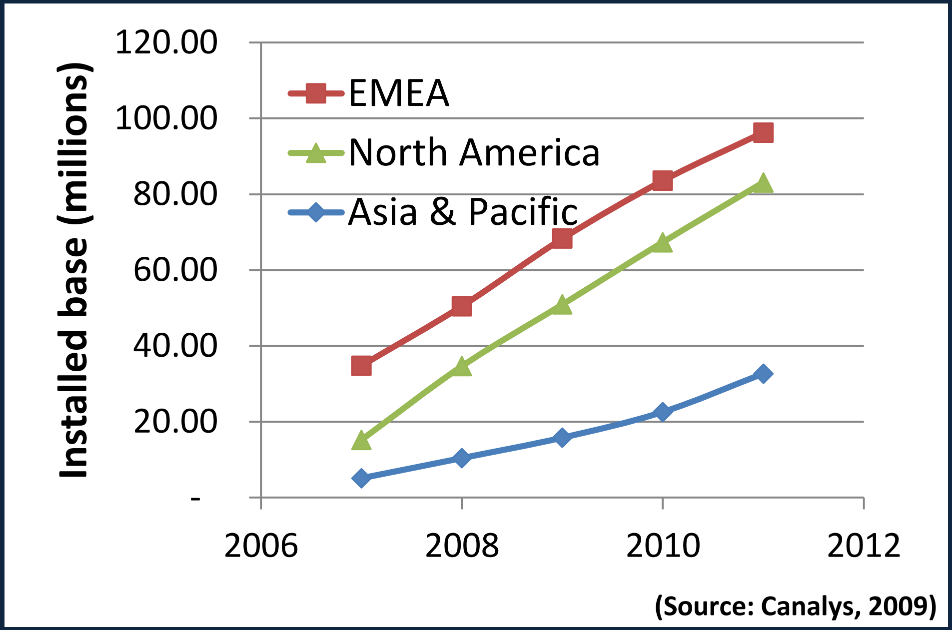
Many novel vehicular applications

- E.g., radio guides of current regions

Example devices driving the growth



Smartphones



Navigation units

How to best enable such connectivity?

	WLAN (E.g., WiFi)	WWAN (E.g., 3G, WiMax)
Cheaper	✔	
Higher peak txput	✔	
Longer range		✔
More coverage		✔

Interested in popular applications

- Web browsing, VoIP, e-mail, …

This talk

Considers each possibility and shows that challenges are similar

- Packet loss, inconsistent connectivity lead to poor performance for interactive applications
- QoS mechanisms of wired networks do not work

Advocates the use of available redundancy

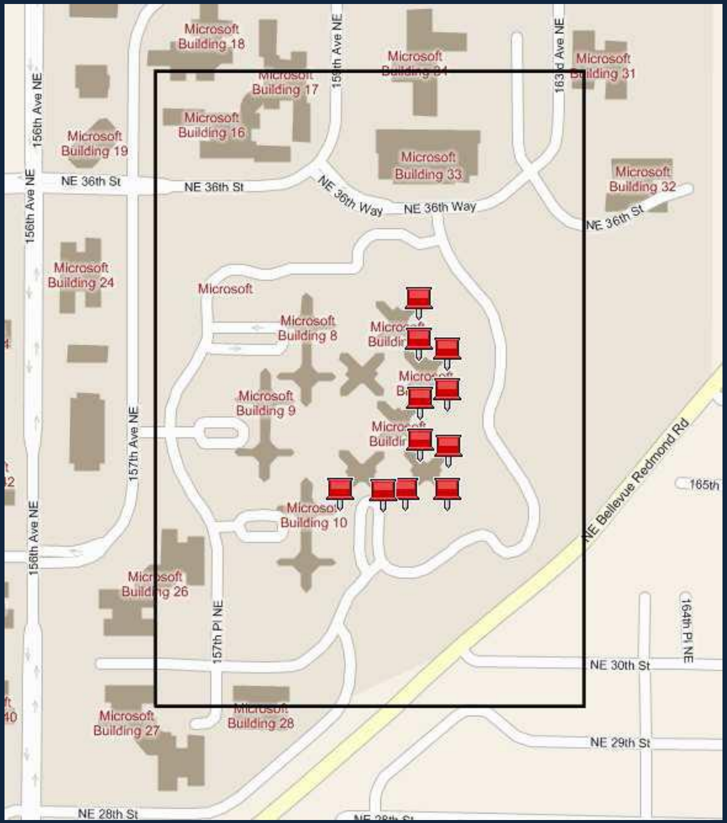
- *ViFi* uses redundant BSes for WLAN settings
- *PluriBus* uses redundant capacity for WWAN settings
- Wiffler uses redundant technology

VanLAN: Our vehicular testbed

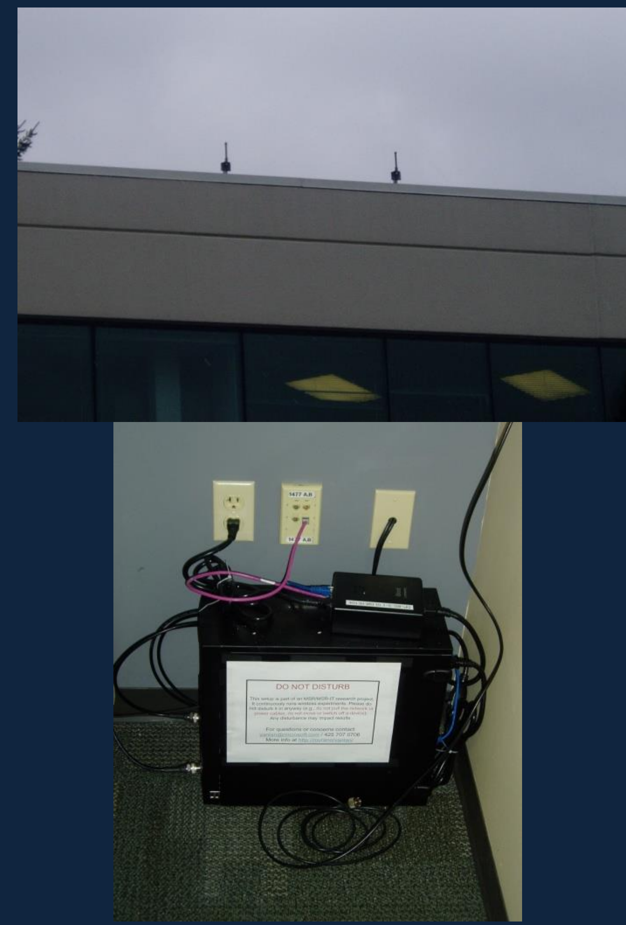
Uses MS campus shuttles as vehicular clients

- WiFi, EVDO (Sprint), WiMax (Clearwire)
- Zero driving overhead but limited control

11 WiFi basestations



Deployment of VanLAN



WiFi and moving vehicles

Motivation for using WiFi:

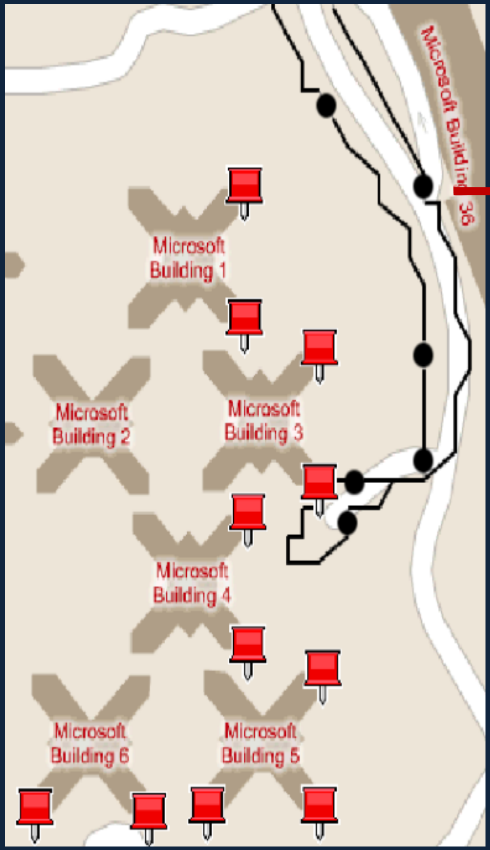
- Inexpensive, higher peak throughput
- Increasing ubiquity can make it a useful option
  - City-wide meshes, enterprise campuses, hotspots and open APs

Key question: Can popular applications be supported using WiFi today?

- E.g., VoIP, Web browsing

Our answer: Yes, by leveraging base station redundancy

Experience of a moving vehicle using WiFi



Disruptions
(high packet loss)

Disruptions have small impact on non-interactive apps
But really hurt interactive apps

How to reduce disruptions?

Traditional mechanisms have limited effectiveness

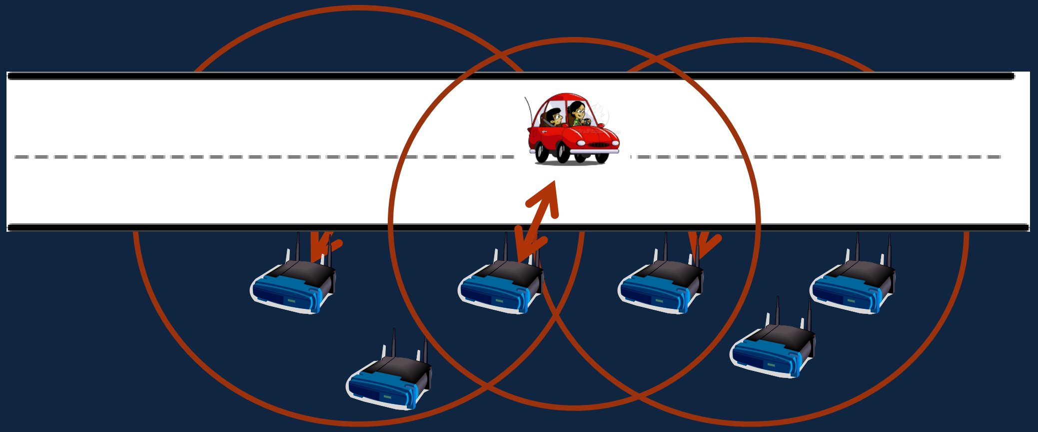
- Prioritization
- Over provisioning
- Retransmissions

Use redundant BSes in the vicinity

Wireless handoffs

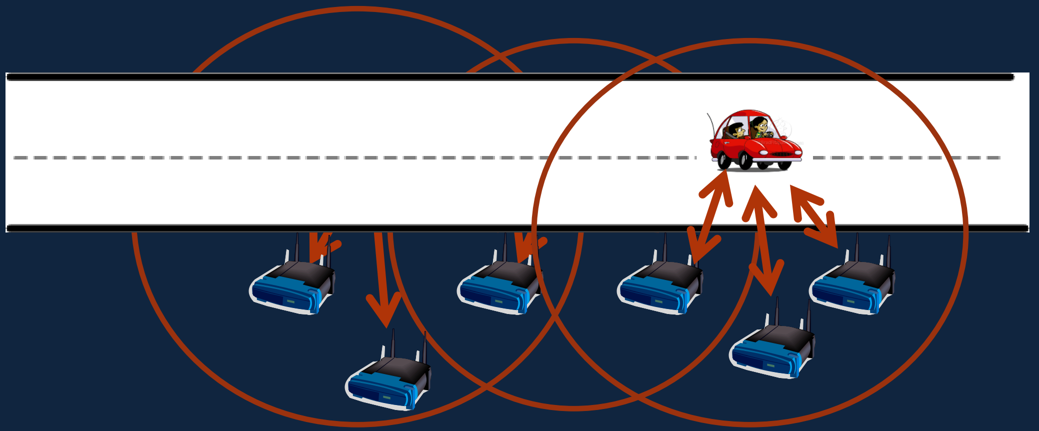
Hard handoff

- Clients talk to exactly one BS
- Current 802.11

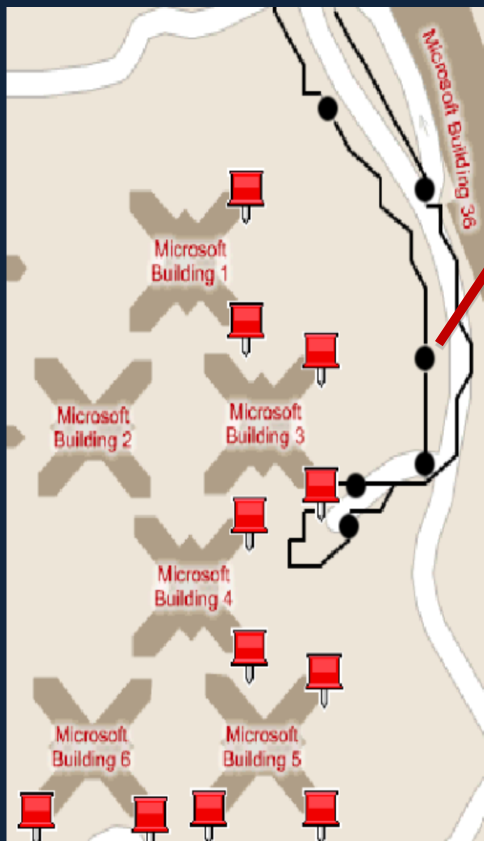


Soft handoff

- Clients talk to multiple BSes

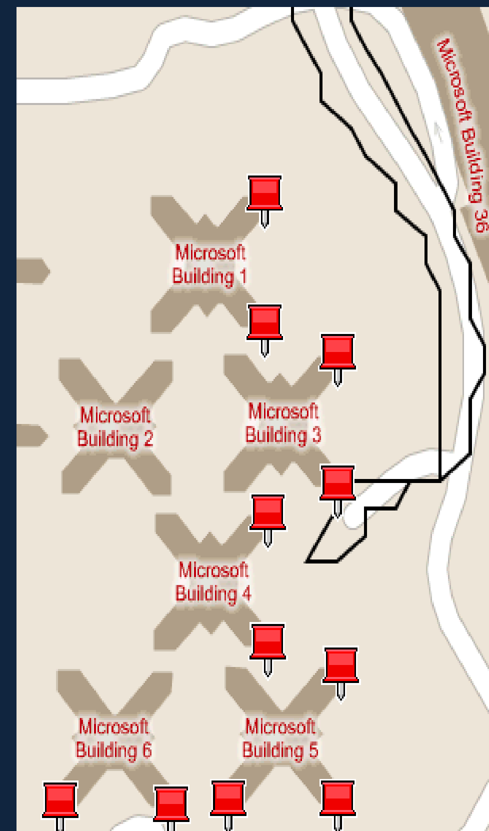


Comparing the two handoff policies



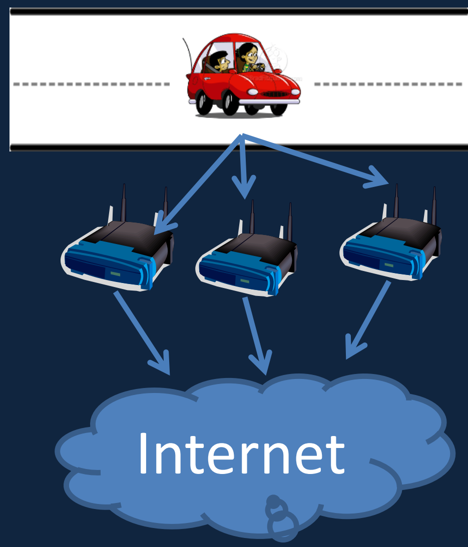
Disruption

Hard handoff



Soft handoff (ideal)

Designing a practical soft handoff policy

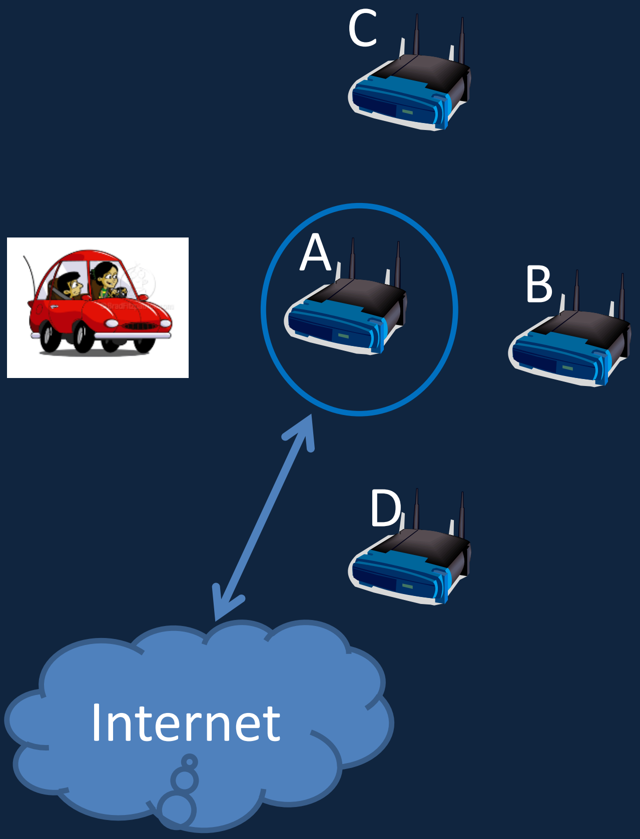


Goal: Leverage multiple BSes in range

- Inter-BS backplane is bandwidth-constrained
- Ensure timely delivery of packets
- Cannot do fine-grained scheduling of packets

These constraints rule out known diversity solutions

ViFi overview



Vehicle chooses *anchor* BS

- Anchor responsible for vehicle's packets

Vehicle chooses a set of BSes in range to be *auxiliaries*

- Leverage packets overheard by auxiliaries

ViFi protocol

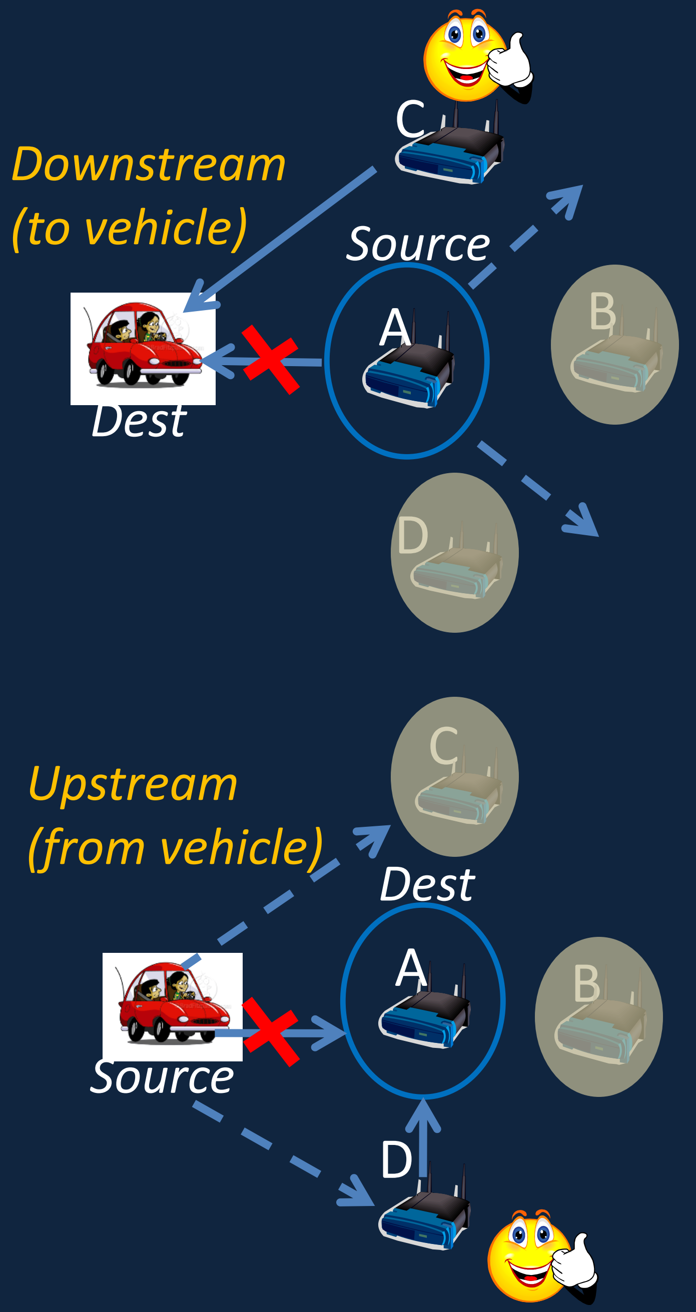
(1) Source transmits a packet

(2) If destination receives, it transmits an ack

(3) If auxiliary overhears packet but not ack, it *probabilistically* relays to destination

(4) If destination received relay, it transmits an ack

(5) If no ack within retransmission interval, source retransmits

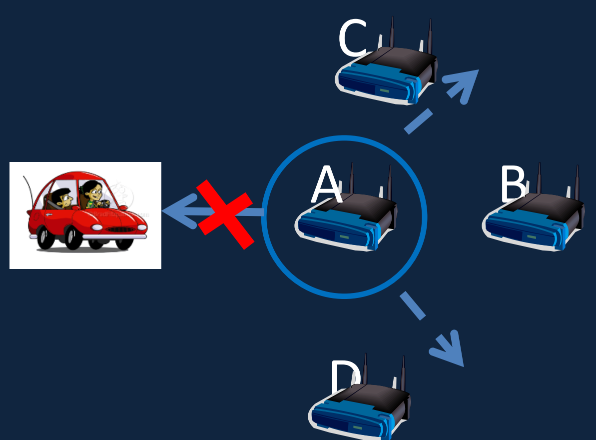


Why is relaying effective?

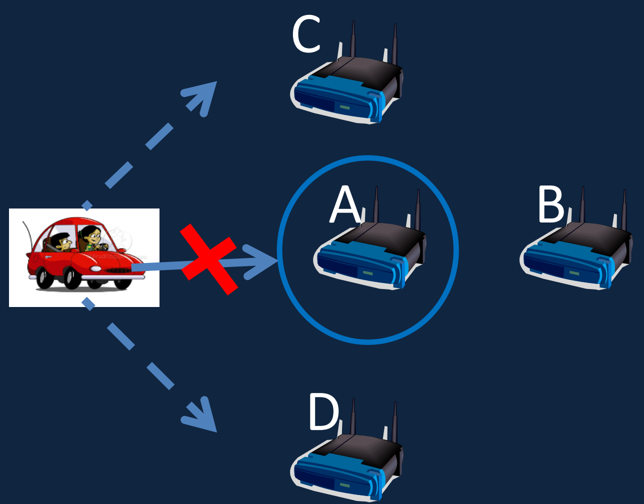
Losses are bursty

Losses are independent

- Different senders → receiver
- Sender → different receivers



Downstream: To vehicle



Upstream: From vehicle

Probability computation

Based on the knowledge of available auxiliaries and their connectivity to the destination

1. Makes a collective decision and limit the total number of relays
2. Prefers auxiliaries with better connectivity to destination
3. No per-packet coordination

ViFi implementation and evaluation

Implementation requires only software changes

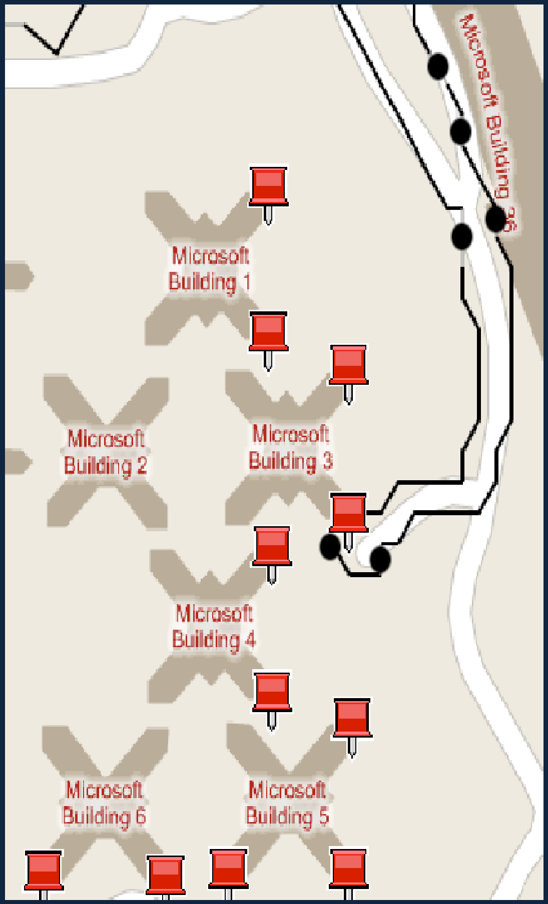
- Built on top of ad hoc mode
- Uses broadcast mode transmissions

Evaluation based on deployment on VanLAN

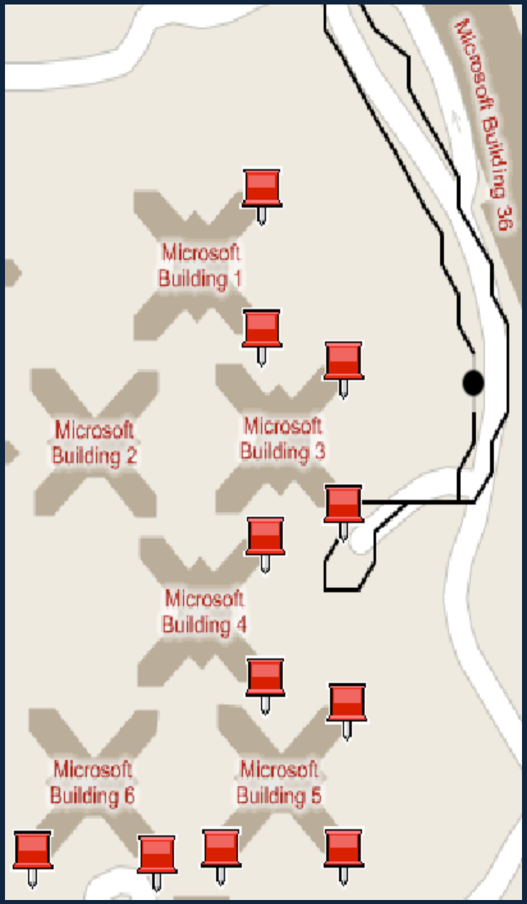
- Results verified on another testbed

ViFi reduces disruptions

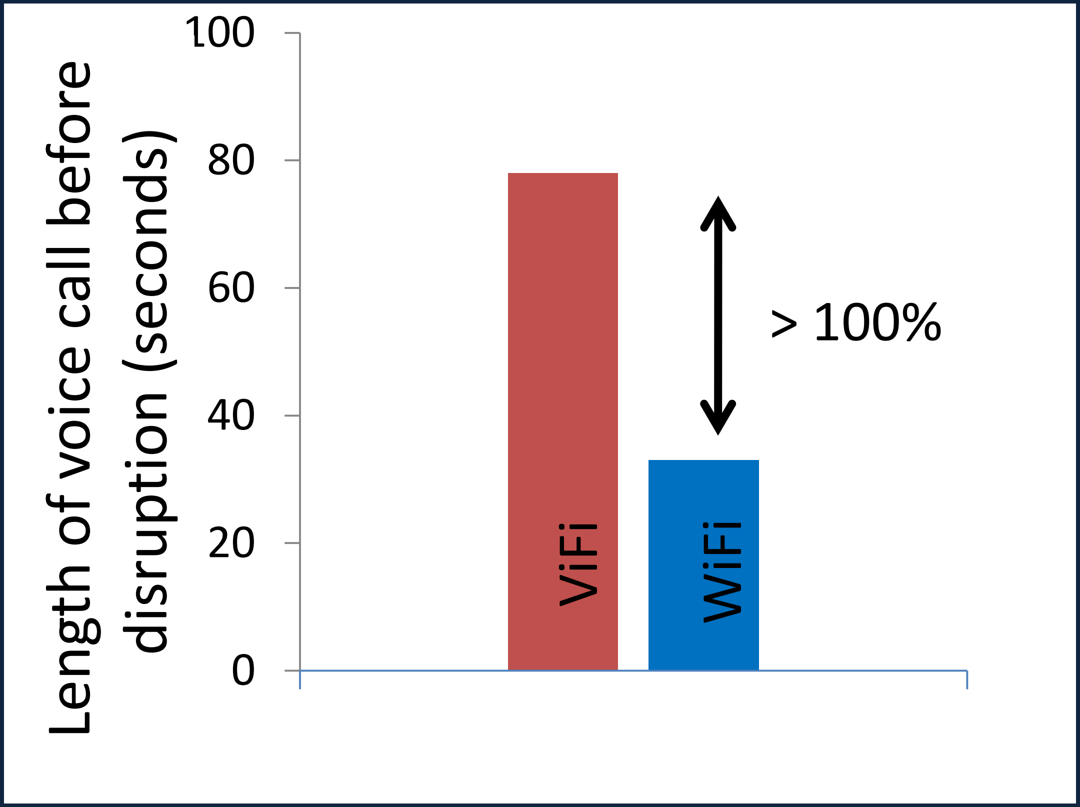
WiFi



ViFi

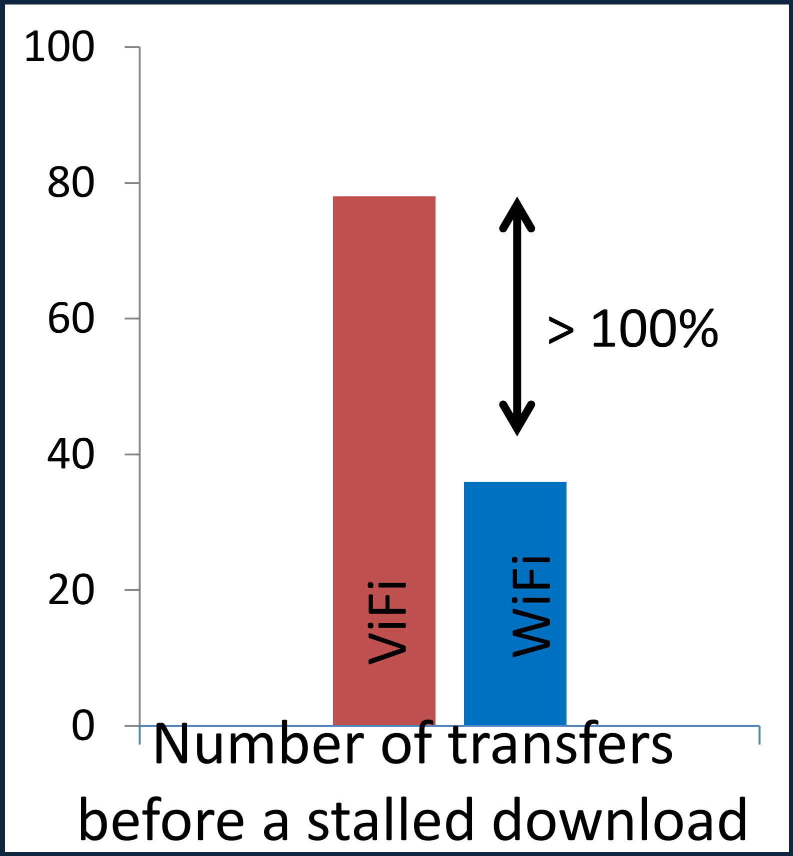


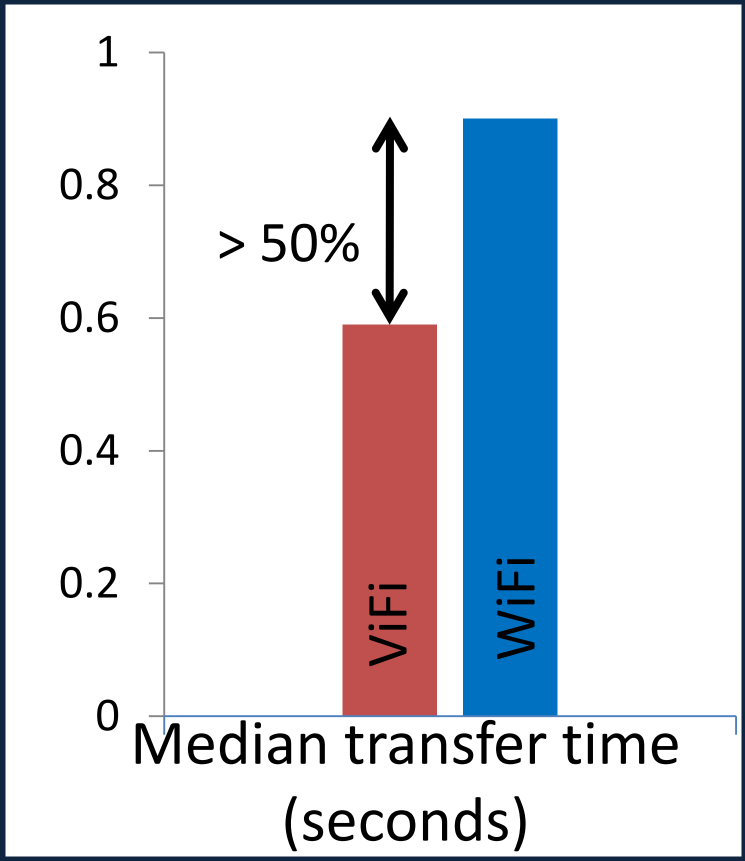
ViFi improves VoIP performance



Traffic generated per G.729 codec
Disruption: when MoS < 2

ViFi improves Web browsing performance



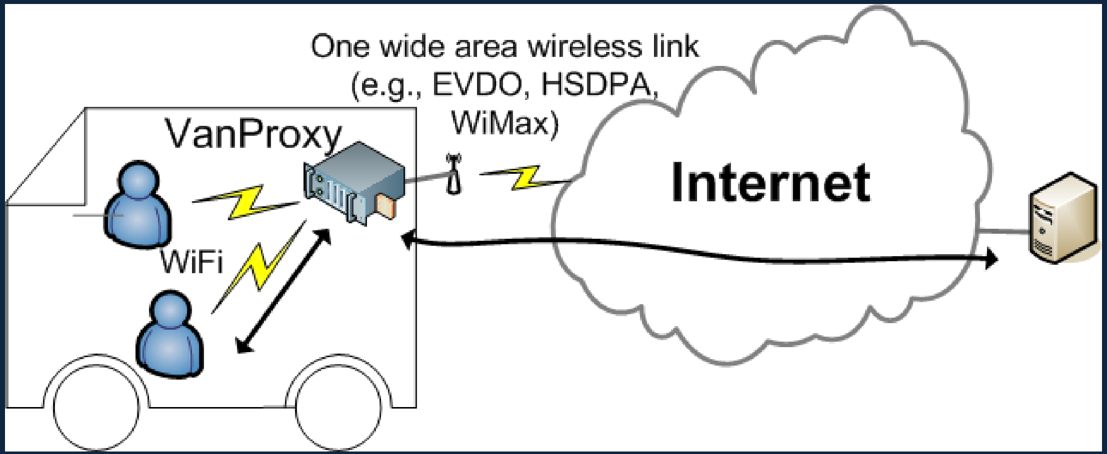


Workload: Repeated downloads of a 10 KB file

WWAN and moving vehicles

Motivation for using WWAN:

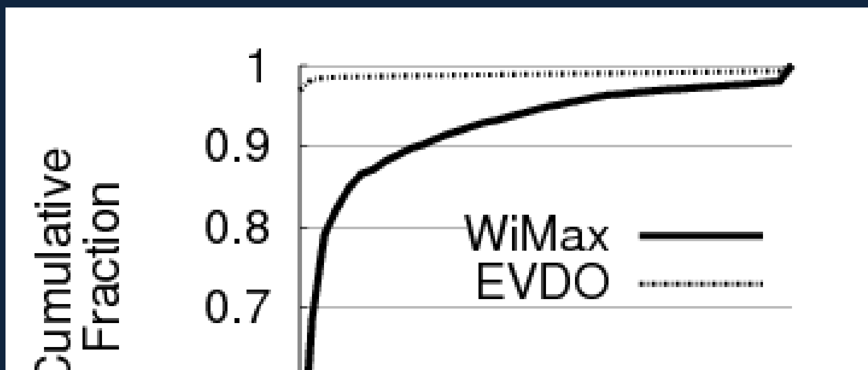
- Almost ubiquitous
- All-you-can-eat plans

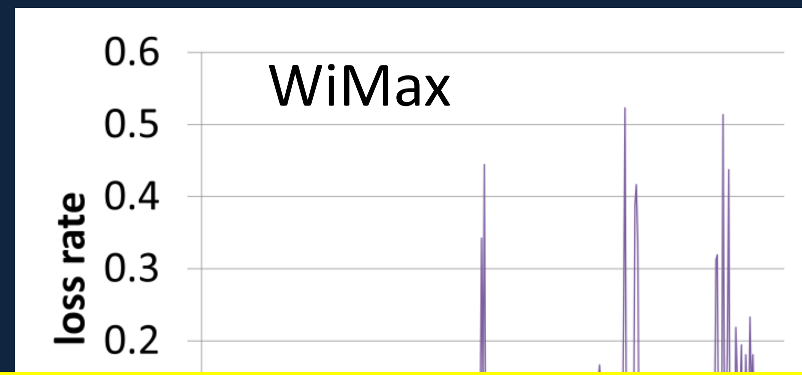


Key question: Can applications that need a high degree of reliability be supported?

Our answer: Yes, by leveraging redundant capacity

Packet loss in the WWAN environment





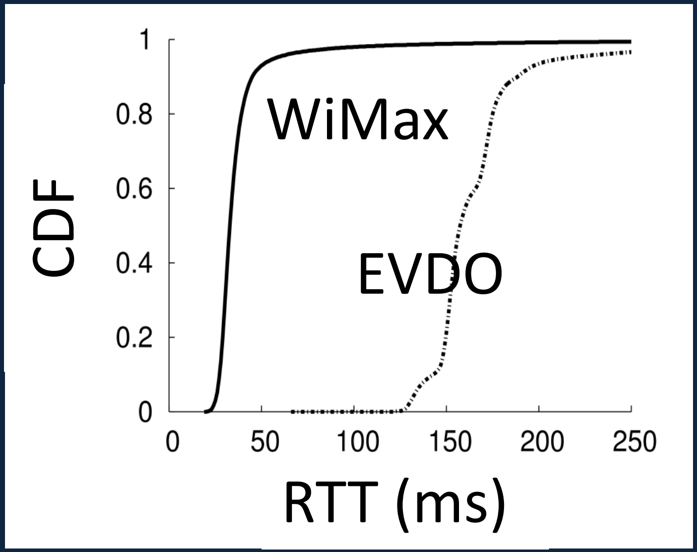
Expectation setting by network operators:

- “there can be lapses in the backhaul coverage or system congestion”
- “cancel a failed download and re-try in approximately 5 minutes”

How to combat packet loss?

Traditional mechanisms have limited effectiveness

- Prioritization
- Over provisioning
- Retransmissions
- No control over BSes

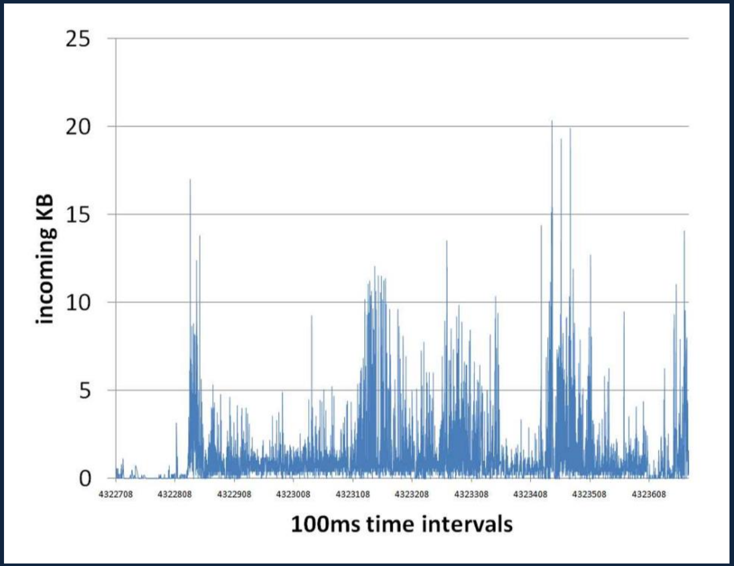


Uses redundant path capacity through erasure coding

Existing erasure coding systems

1. Amount of overhead independent of load
   - Redundant packets can steal capacity from data packets
   - Under-protect even where additional capacity is available

2. Rely on receiving a threshold number of packets
   - Hard to guarantee when losses and data rate are bursty



Opportunistic erasure coding

Send coded packets when and only when there is instantaneous spare capacity in the system → Minimal interference and maximal protection for data

Evolution codes greedily maximize the amount of data recovered by each coded packet → No reliance on receiving a threshold number of packets

Evolution codes (1/2)

Encode over a window of packets sent in the last round trip time

- Aim for greedy, partial recovery of packets

Let W = window of packets; and
r = fraction of packets at the receiver

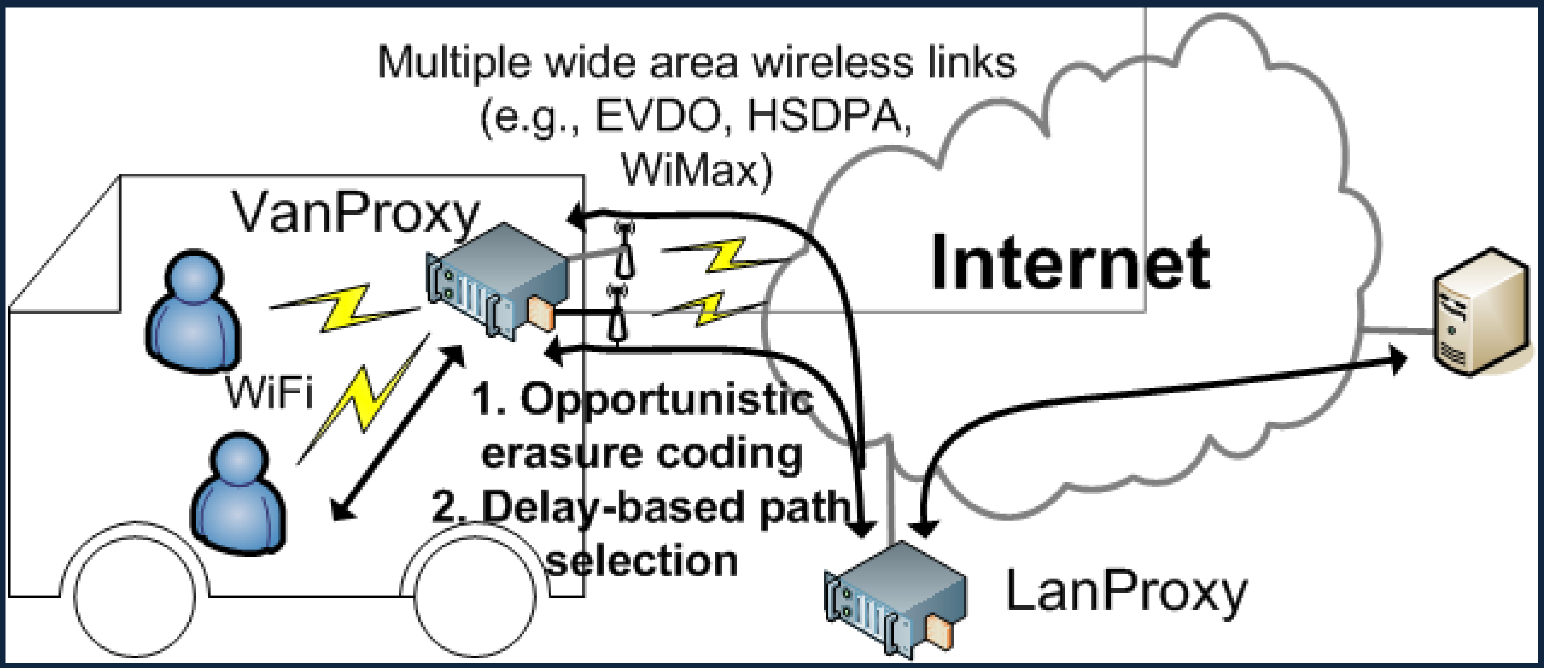
- Assume all packets have the same probability
- Use the XOR operator for encoding packets

Evolution codes (2/2)

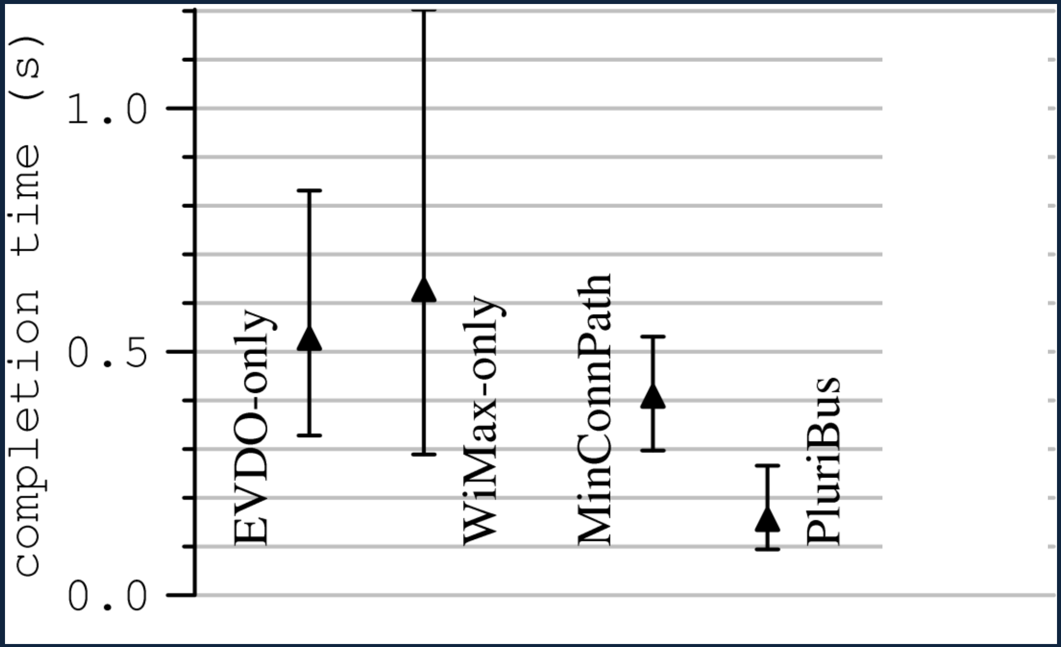
What should be the degree of a coded packet?

- Expected yield with degree x $Y(x) = x \cdot (1 - r) \cdot r^{x-1}$
- The yield is maximized for $x = -1 / \log(r)$
- Higher *r* => higher degree

Implementation of PluriBus

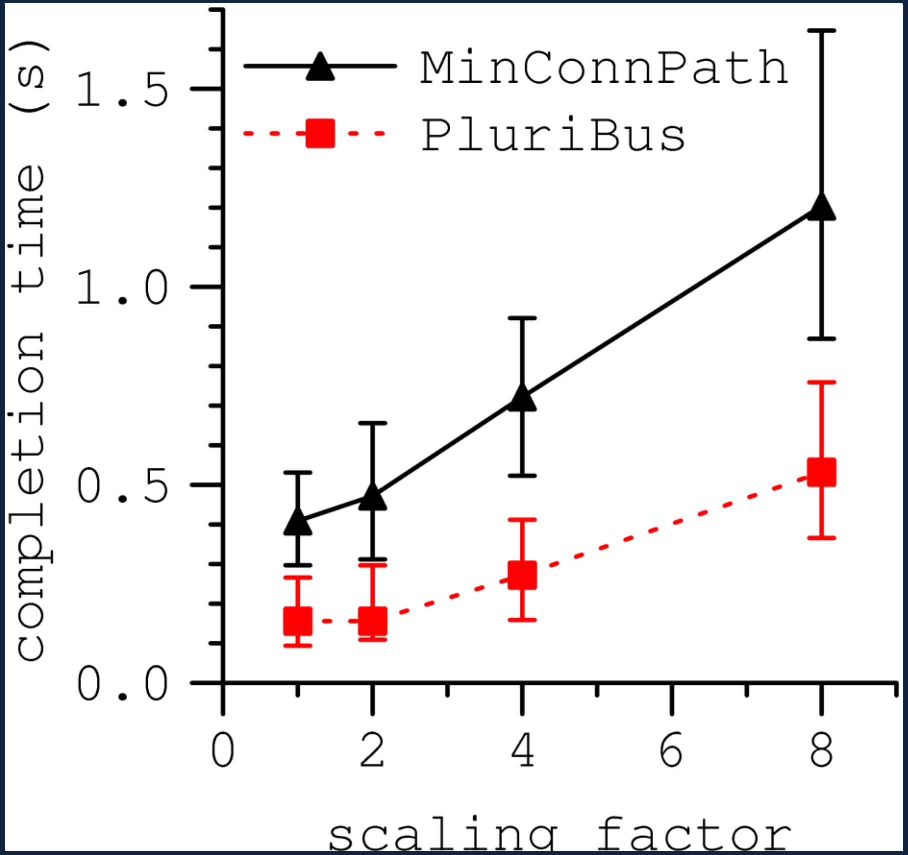


Performance of PluriBus



Workload mimics that observed on the MS Connector

Performance as a function of load



WiFi or 3G?

The two have disparate features

	WiFi	3G
Cheap	✔	
Coverage		✔

Why not use both?

- WiFi where available, 3G as backup
- Use of redundancy in technology

	WiFi + 3G
Cheap	✔
Coverage	✔

Early results on *Wiffler*

- Negative correlation between WiFi and 3G availability
- Application patience helps immensely

Conclusions

Providing high performance connectivity aboard moving vehicles is particularly challenging for interactive apps

- Traditional mechanisms to counter packet losses are not effective

Using available redundancy is a promising approach

- ViFi uses redundant base stations
- PluriBus uses redundant capacity
- Both systems deployed and tested on a real vehicular testbed

More details at *http://research.microsoft.com/vanlan/*