Design Principles for Robust Opportunistic Communication

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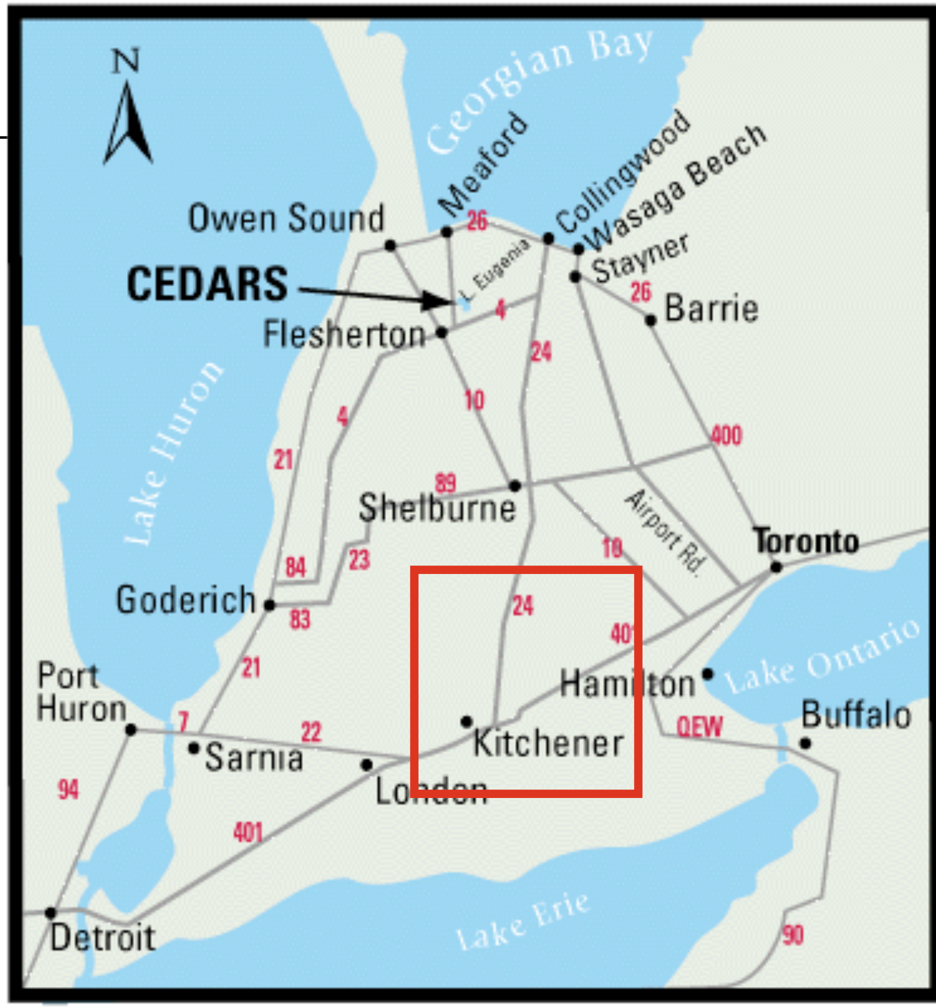
January 2009

Waterloo?

Where is that?

Canada
ARCTIC OCEAN
Ellesmere Island
GREENLAND (KALAALLIT NUNAAT) (Denmark)
ICELAND
Arctic Circle
Queen Elizabeth Islands
0 250 Miles
0 250 Kilometers
Beaufort Sea
Banks Island
Baffin Bay
Victoria Island
ALASKA (U.S.)
YUKON TERRITORY
Baffin Island
60° N
NUNAVUT
Labrador Sea
Great Bear Lake
Gulf of Alaska
Mt. Logan 19,524 ft. (5,951 m)
NORTHWEST TERRITORIES
ATLANTIC OCEAN
Great Slave Lake
Rocky Mountains
Coast Mountains
Hudson Bay
BRITISH COLUMBIA
NEWFOUNDLAND & LABRADOR
ALBERTA
MANITOBA
PACIFIC OCEAN
QUÉBEC
SASKATCHEWAN
James Bay
Laurentian Plateau
PRINCE EDWARD ISLAND
NEW BRUNSWICK
Edmonton
Vancouver I.
Calgary
NOVA SCOTIA
Vancouver
ONTARIO
Québec
Winnipeg
Halifax
Montréal
Ottawa
Bay of Fundy
40° N
Toronto
UNITED STATES
© MAPQUEST.COM
120° W
100° W
80° W
60° W


ONTARIO
KENORA
CANADA
WINNIPEG
122 miles
LAKE OF THE WOODS
THUNDER BAY
452 miles
INTERNATIONAL FALLS
135 miles
LAKE SUPERIOR
SAULT STE. MARIE
710 miles
GEORGIAN BAY
MINNEAPOLIS
410 miles
LAKE HURON
TORONTO
1,064 miles
U.S.A.
LAKE MICHIGAN
LAKE ERIE
CHICAGO
749 miles
MILES
KILOMETRES


N
Georgian Bay
Meaford
Collingwood
Wasaga Beach
Stayner
Owen Sound
CEDARS
L. Eugenia
Flesherton
Barrie
Lake Huron
Shelburne
Airport Rd.
Toronto
Goderich
Port Huron
Hamilton
Lake Ontario
Buffalo
Kitchener
Sarnia
London
QEW
Detroit
Lake Erie
26
4
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21
400
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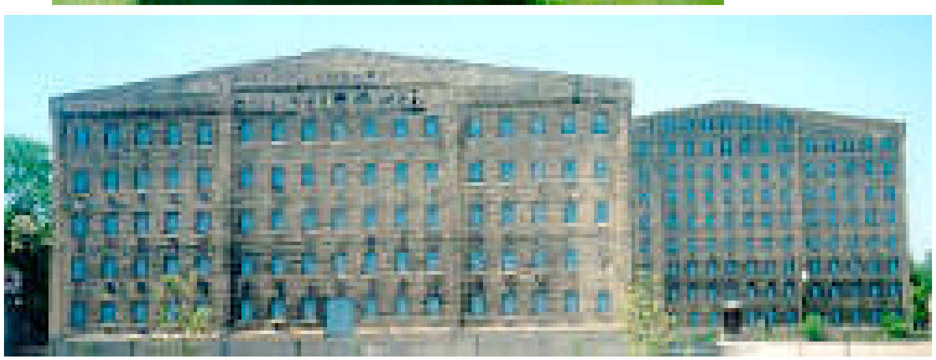
Home of:

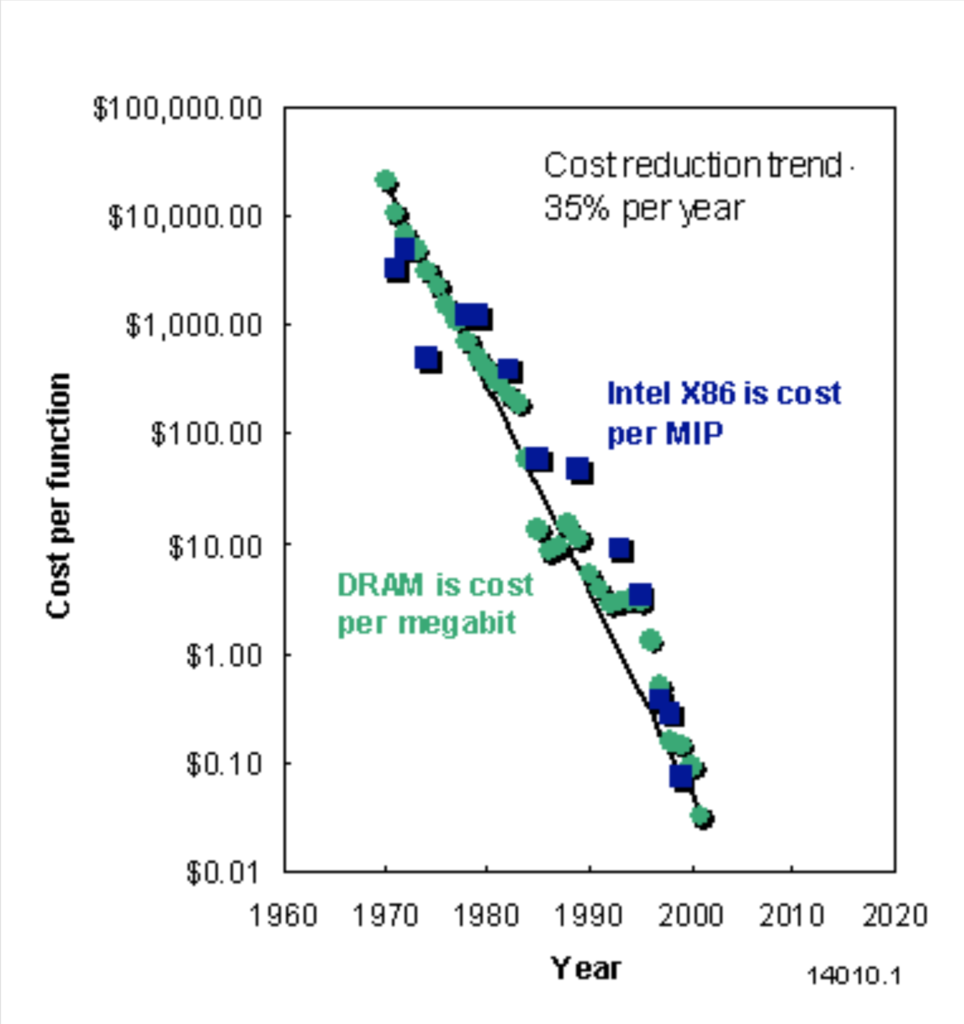
- Seagram
- RIM/Blackberry
- Maple
- OpenText
- ManuLife; SunLife



Outline

- The context for opportunistic communication
- Some opportunistic applications
- Requirements
- Architecture
- Techniques to achieve robustness
- Conclusions

1. Computing costs are plummeting



Processor costs have come down by six orders of magnitude in three decades

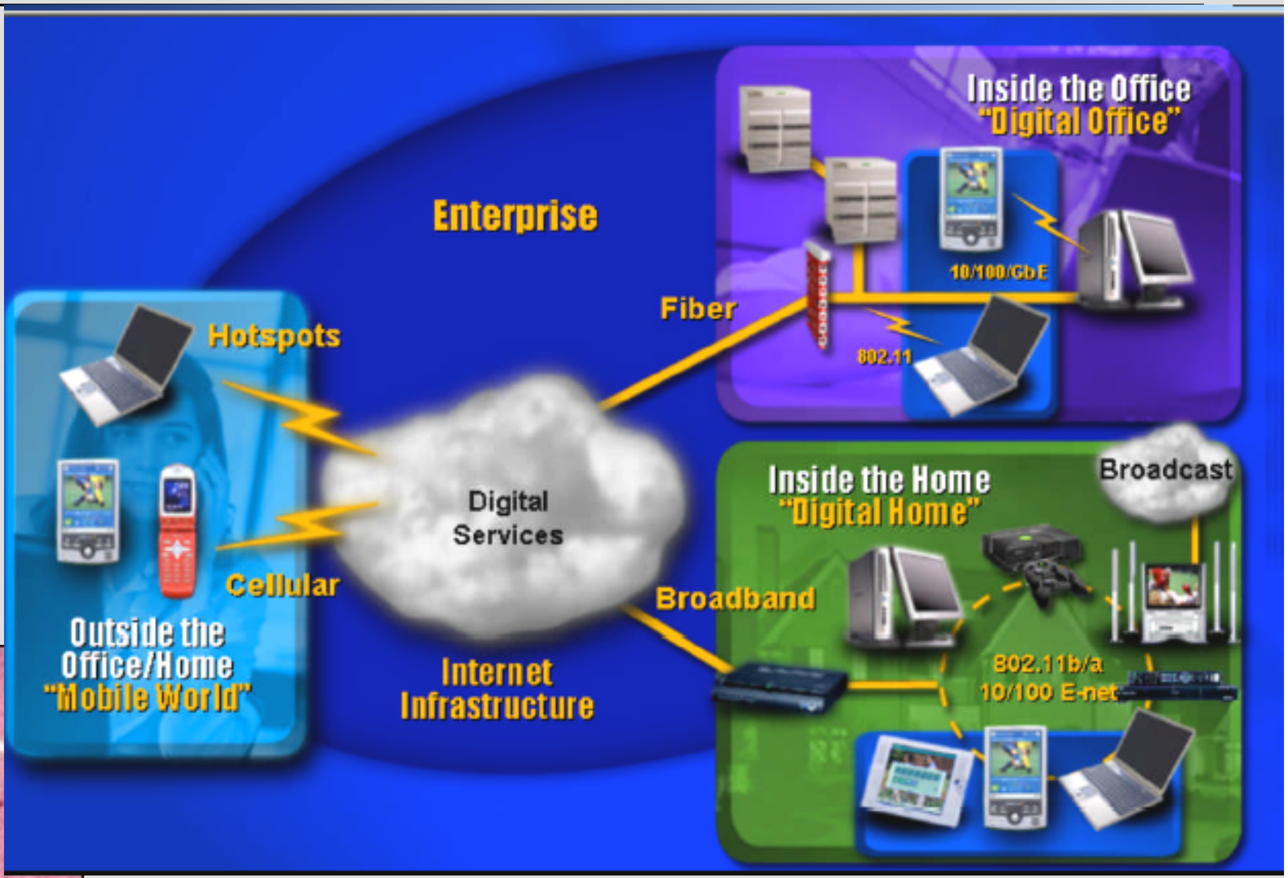
CMOS allows on-chip logic, memory, imaging and RF components

Devices will merge computing, audio, and video

- Processor
- RAM
- Flash memory
- Cell phone modem
- Still camera
- Video camera
- MP3 player

*From www.icknowledge.com

2. Wireless networks are proliferating

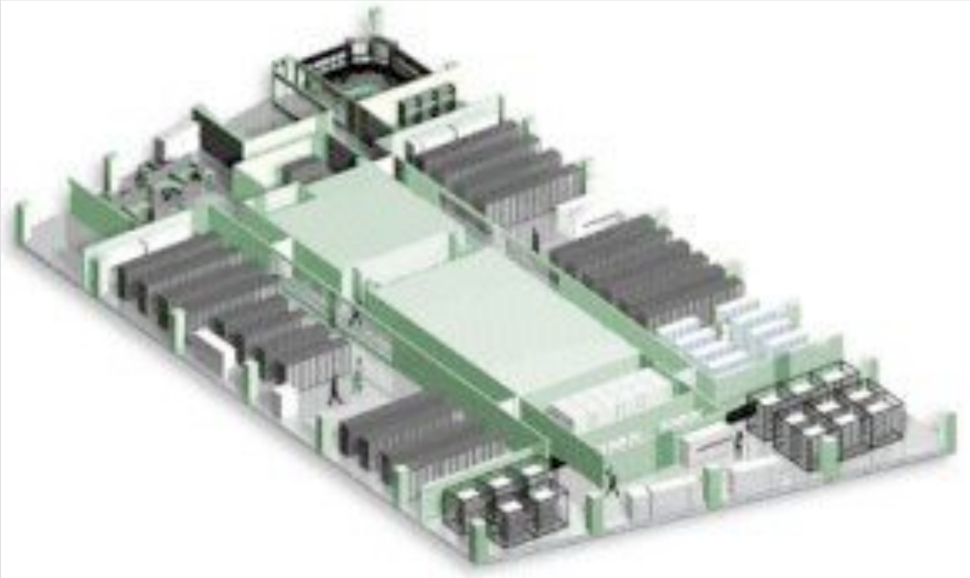


© Intel

3. Data Centers aggregate resources

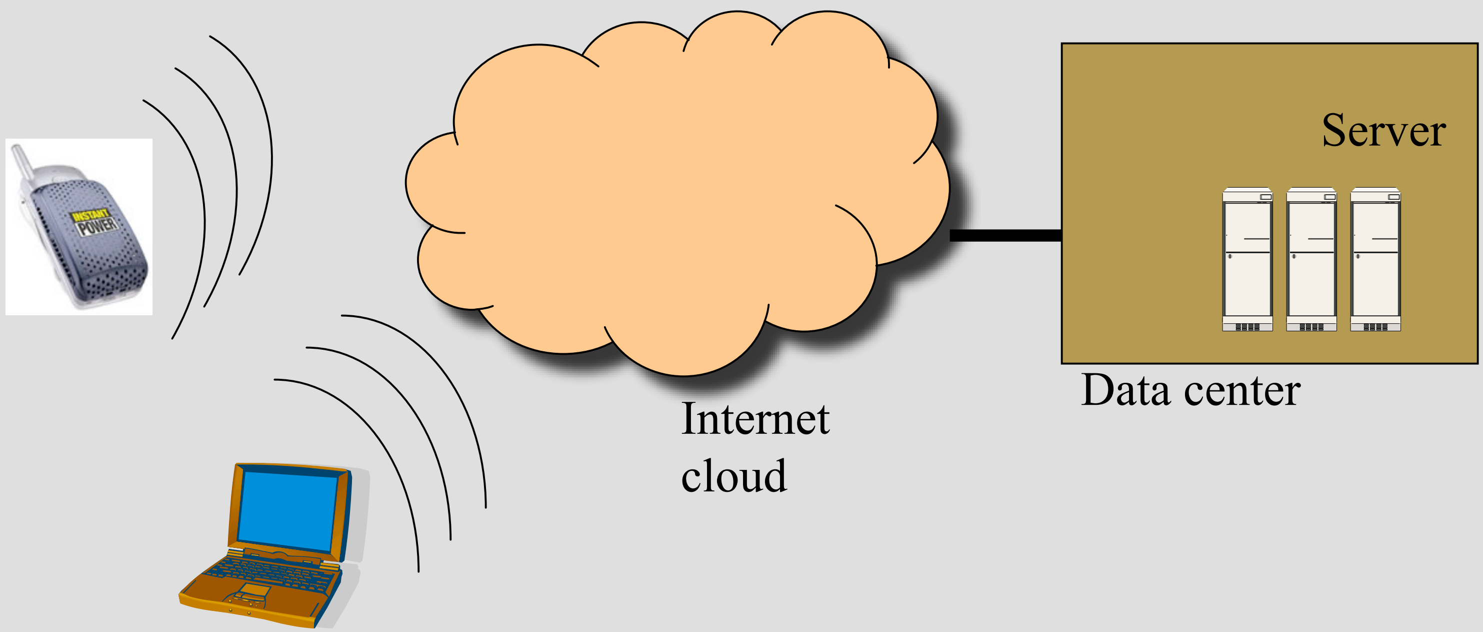






Where will this lead?

- Ubiquitous mobile devices will communicate with resource-rich data centers over wireless and wireline networks



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Assume

- … that any mobile node can opportunistically communicate with any other node, fixed or mobile

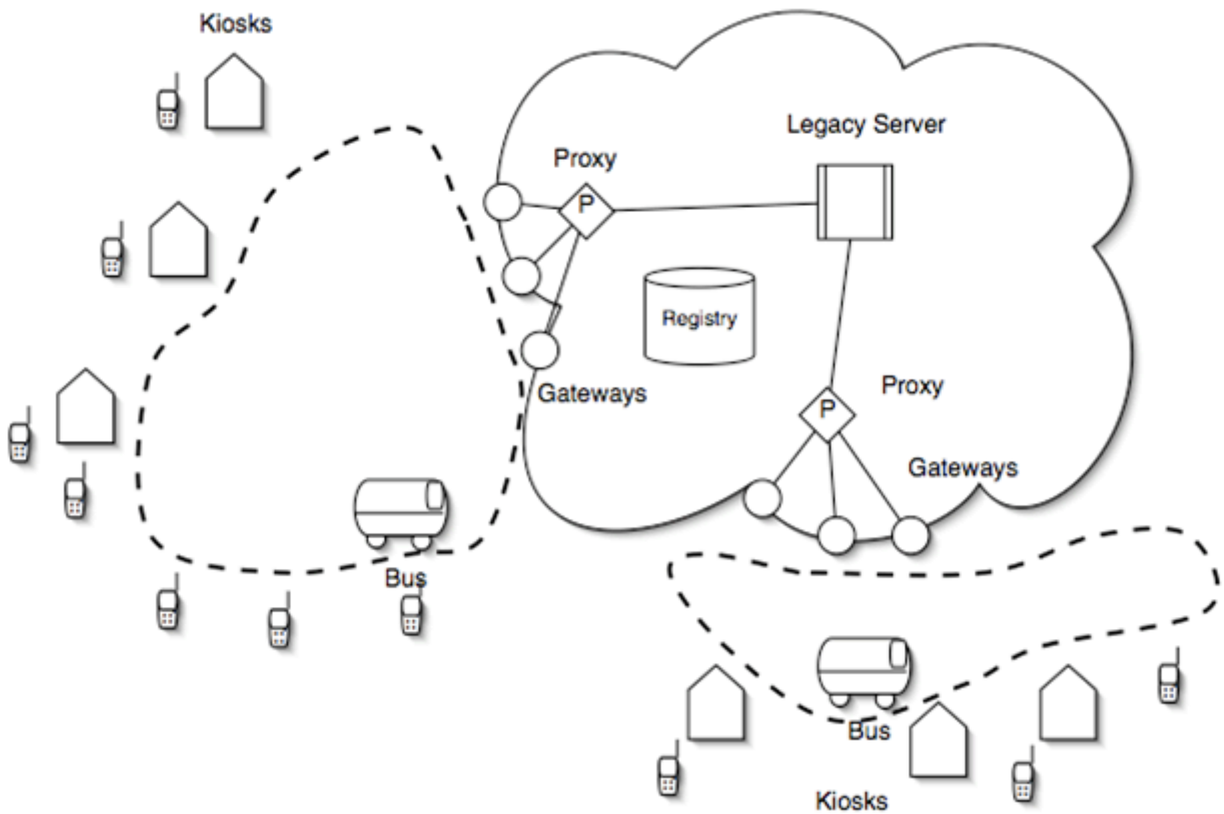
Application 1:Wireless P2P video

- Shoot
- Create metadata (‘tag’)
- Segment
- Flood ‘want’ and ‘have’ metadata
- Route data
- Re-assemble
- Enjoy!

Application 2: Drive through Internet

- Roadside WiFi APs can upload and download data
  - up to 50 MB at 110 kmph
- Upload pictures and videos
  - potholes
  - construction sites
- Download pictures and videos
  - real estate

Application 3: KioskNet



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Requirements

Assume applications are tolerant to both delay and delay variance

- Should not require human intervention
- Should recover from disconnections
- Should support bulk data transfer
- Should be low cost
- Should be legacy compatible
  - minimal change to clients and servers
  - no change to TCP or IP

Additional requirements

- Should minimize device power usage
- Should maximize use of communication opportunity
- Should support both single and multi-hop communication
- Should provide over-the-air security

What makes this hard?

- Disconnection is first class
  - what does routing mean on a temporal graph?
- Affects every layer of the protocol stack

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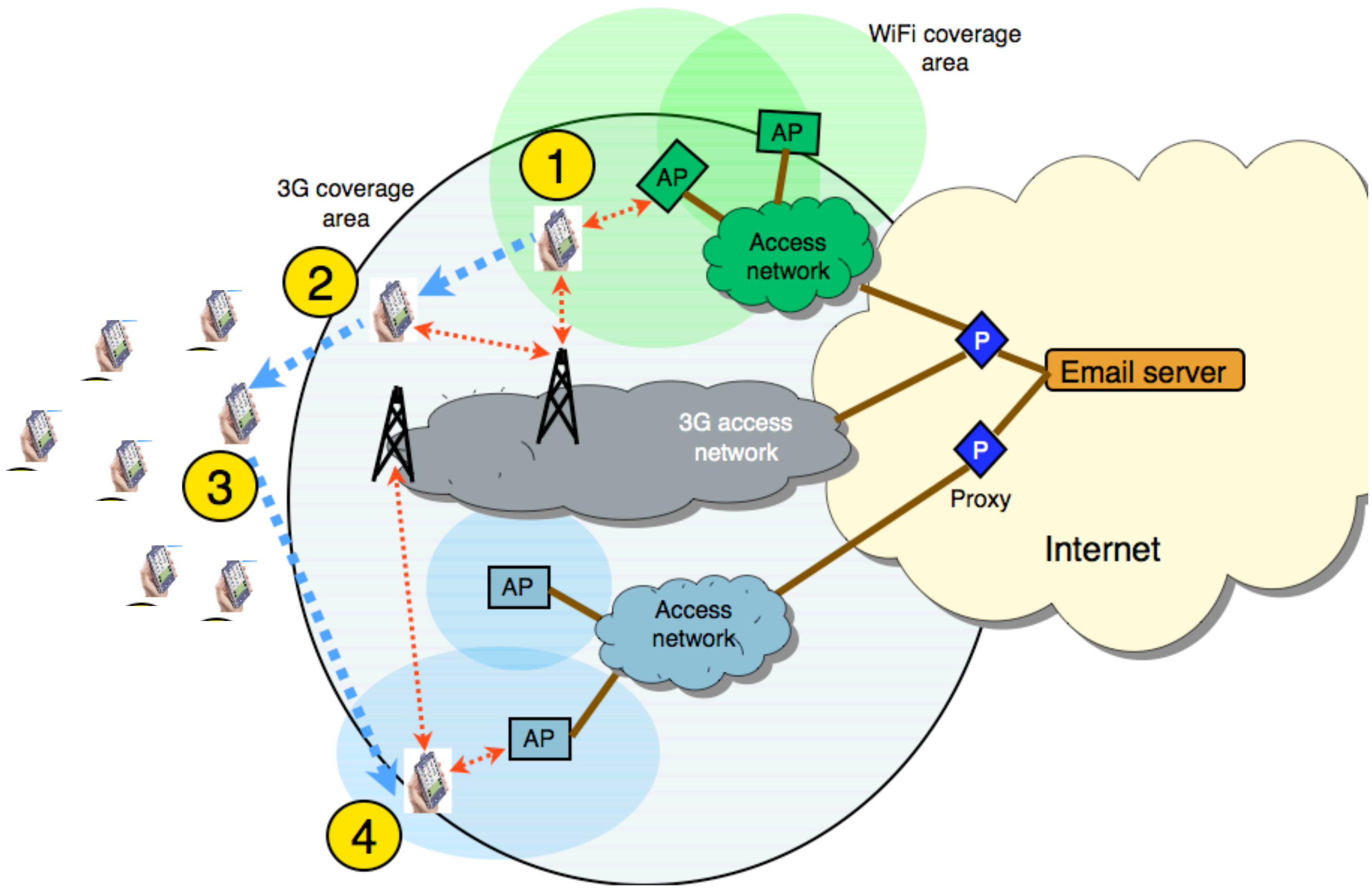
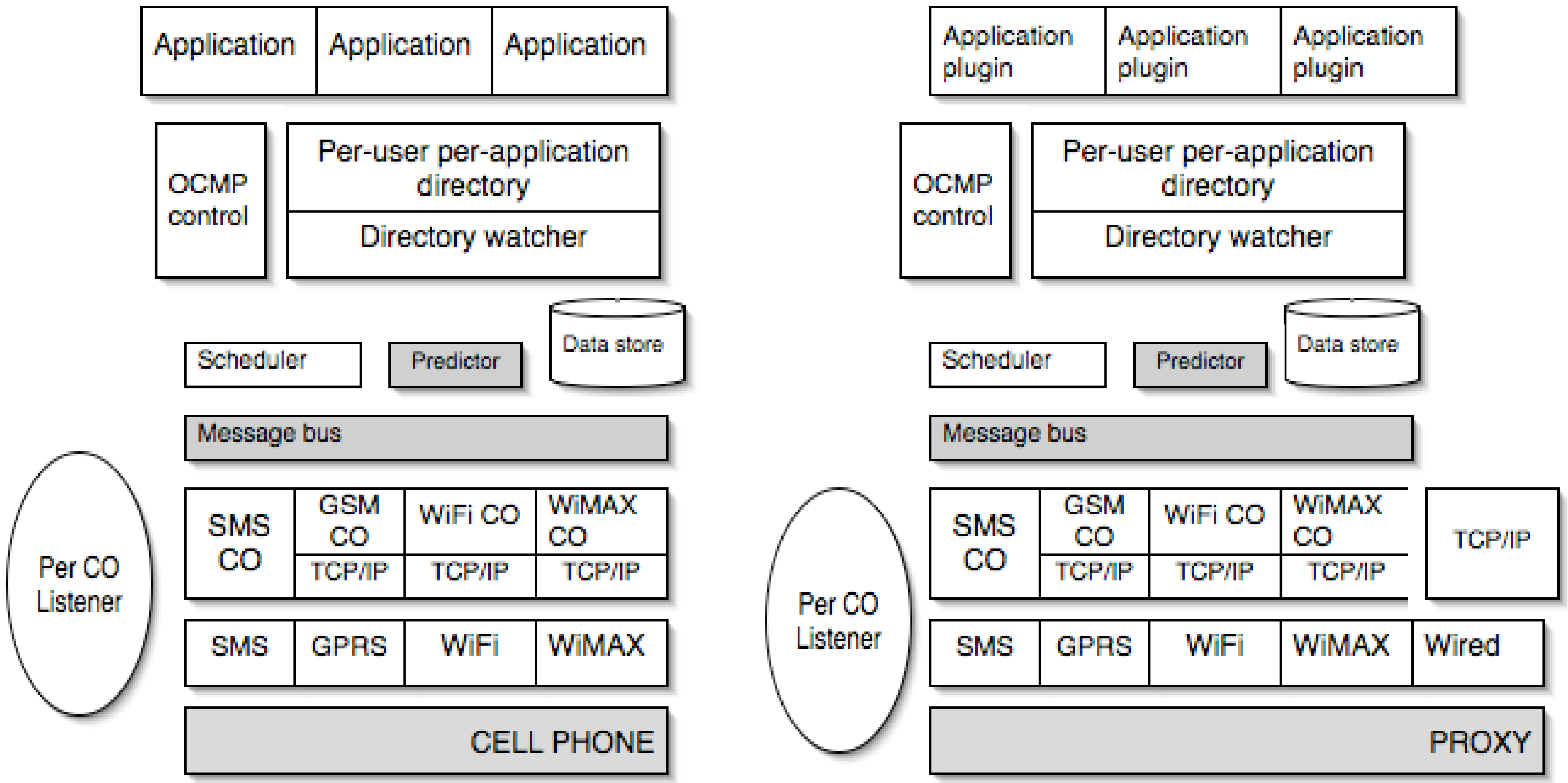
Overview



WiFi coverage area
3G coverage area
1
2
3
4
AP
AP
Access network
P
Email server
3G access network
P
Proxy
Internet
AP
Access network
AP

Architecture



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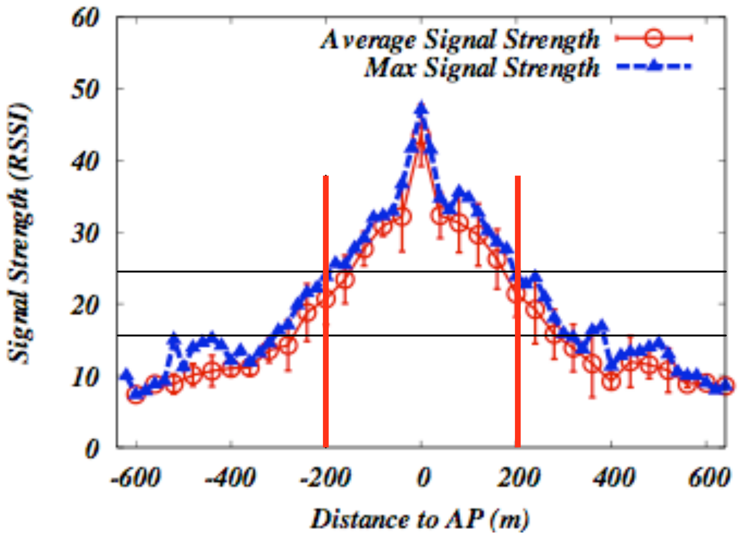
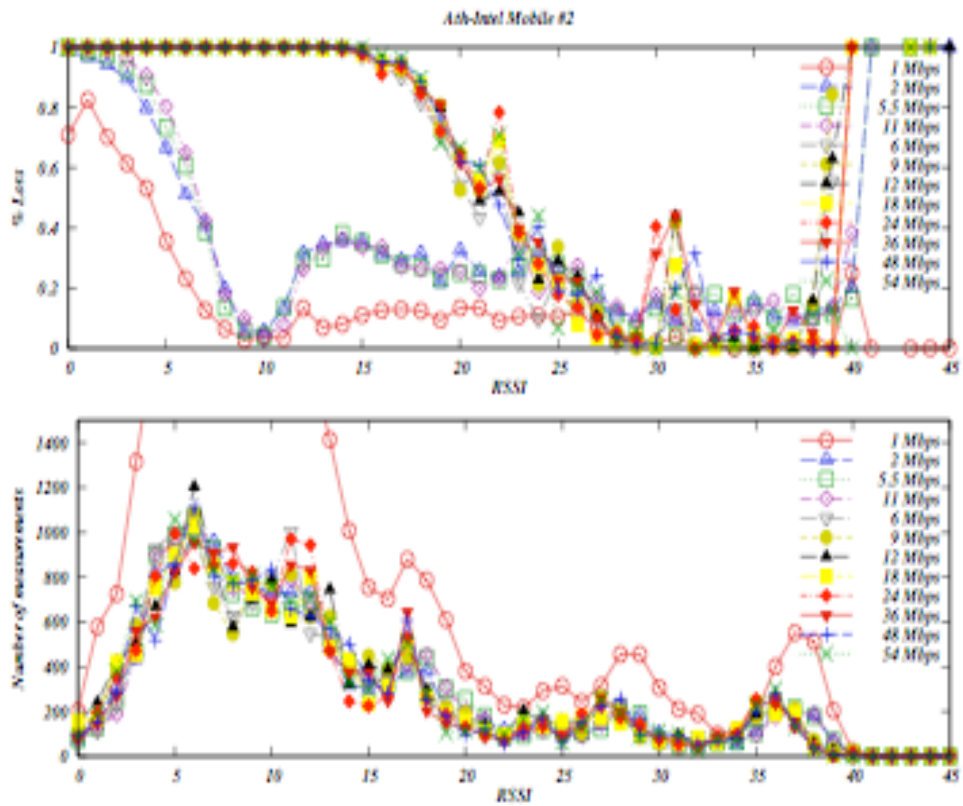
Gaining robustness

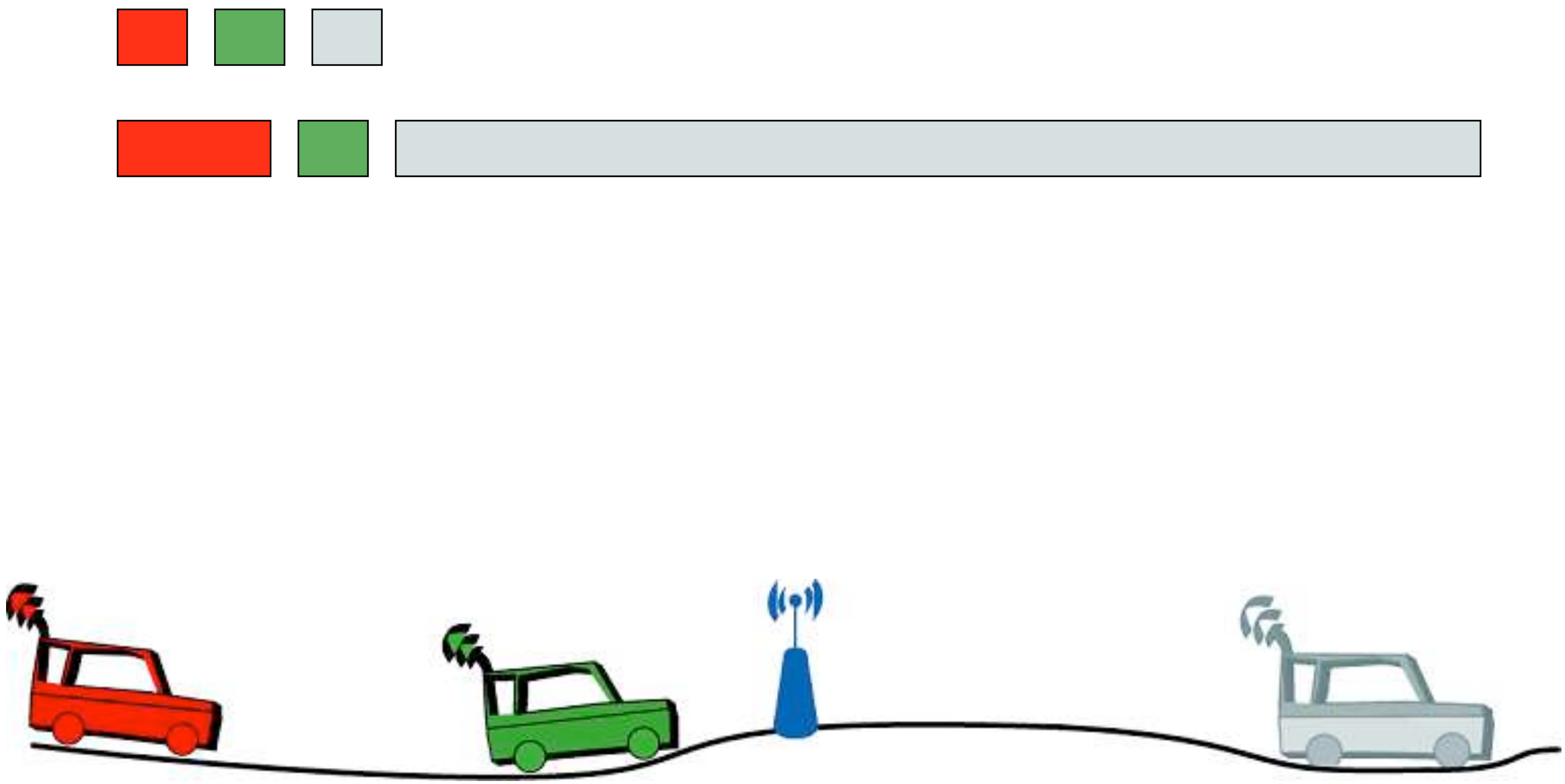
- MAC
  - Avoid the fringe
  - Avoid performance coupling
- Network
  - Flooding-based routing
  - Priority for less-replicated data items
  - Death certificates
- Transport
  - Hop-by-hop TCP
- Application
  - Directories
- Overall
  - Use databases for volatile state
  - Route detection and dissemination
  - Choose simpler solutions

Avoid the fringe

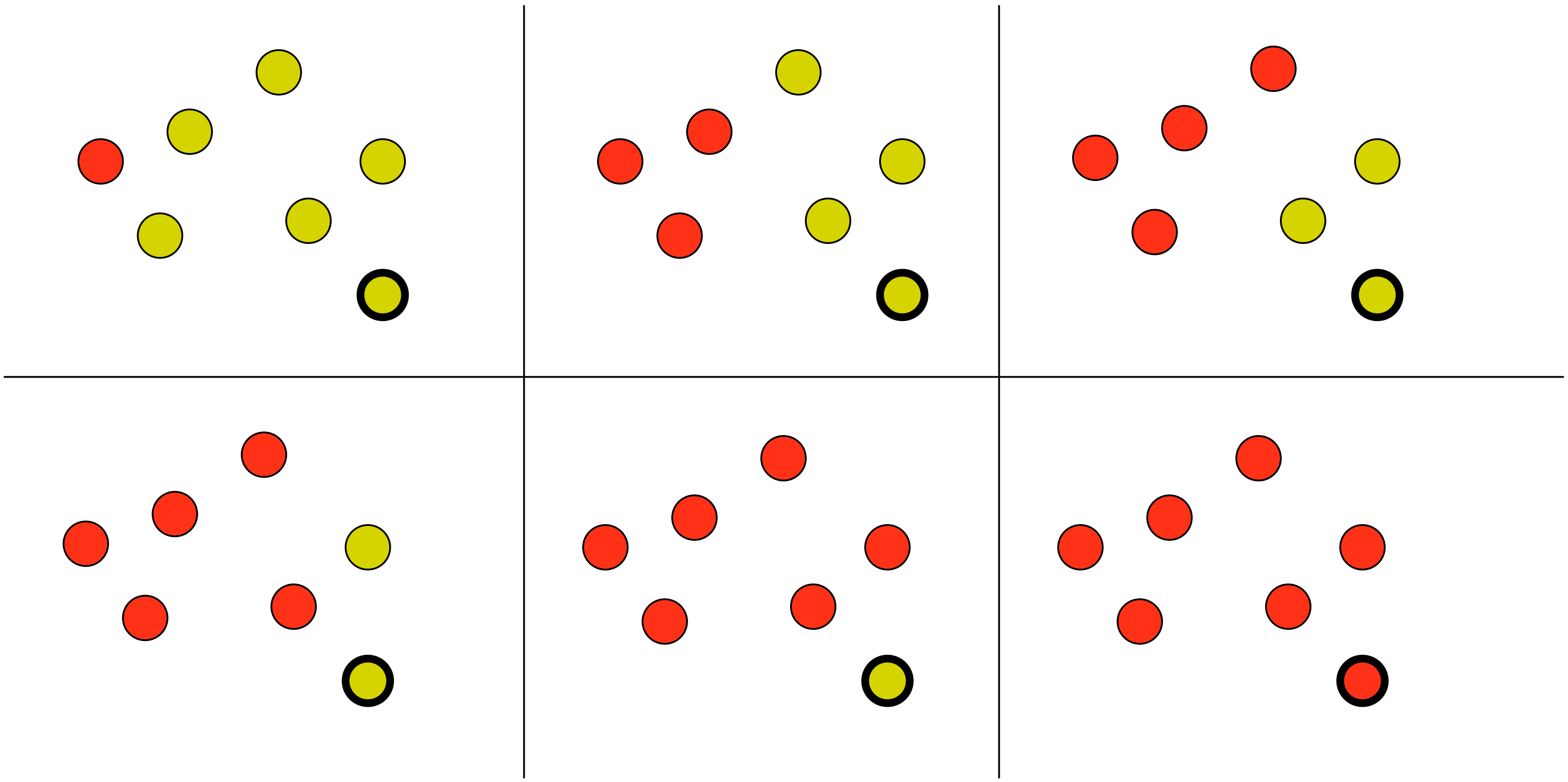




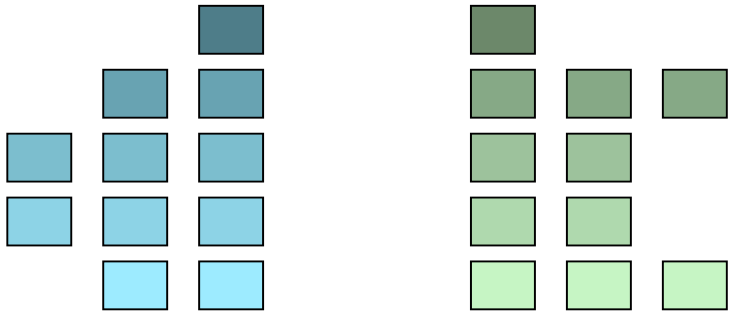
Avoid performance coupling



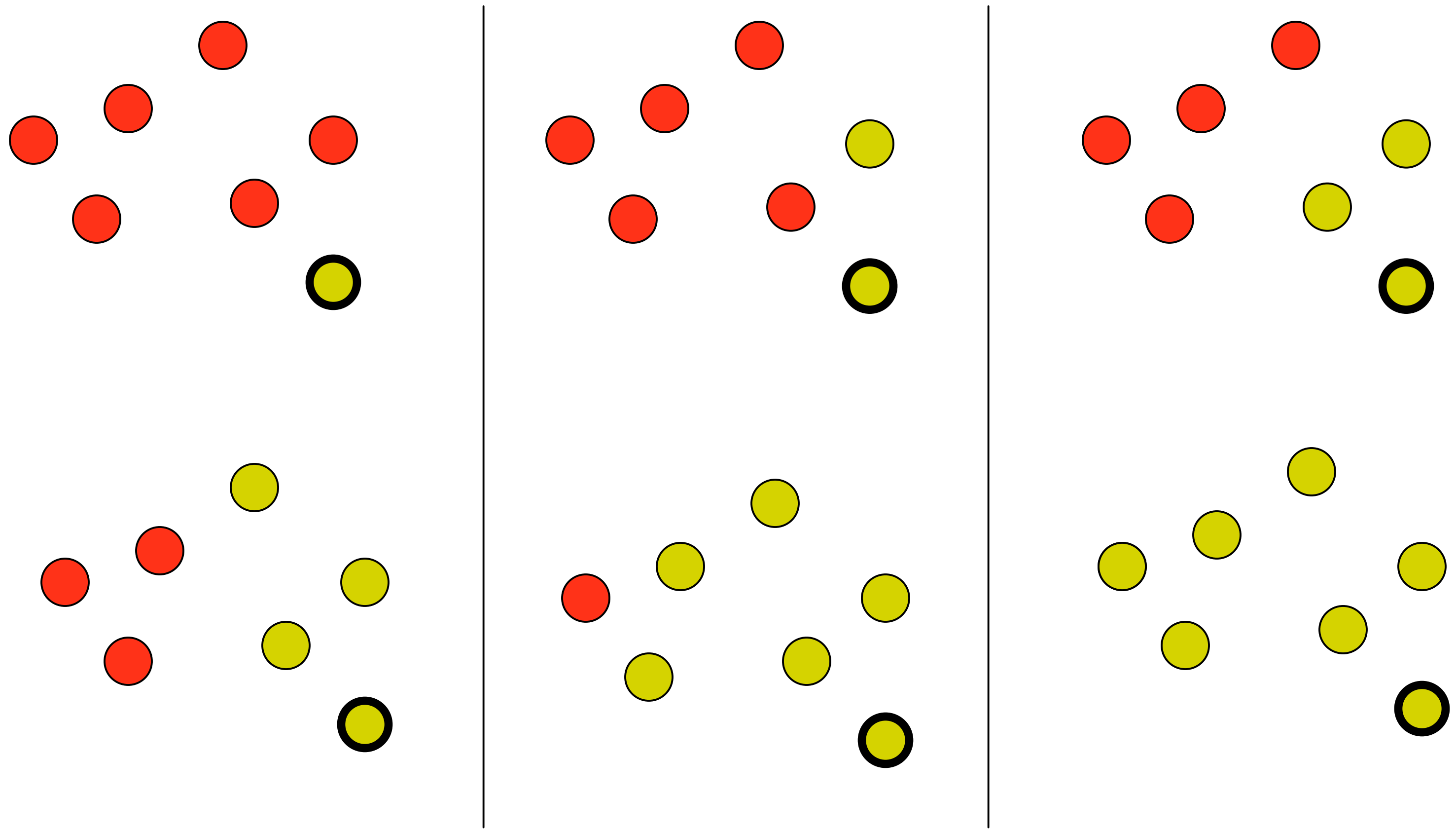
Flooding-based routing



Priority for less-replicated data items



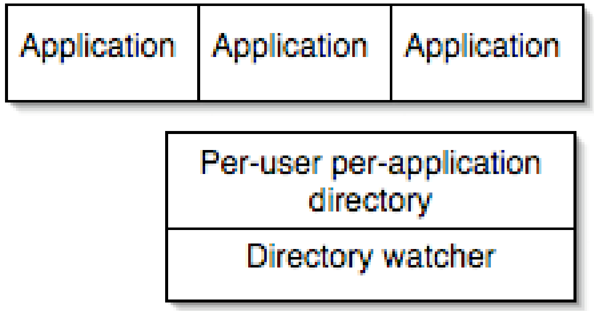
Death certificates

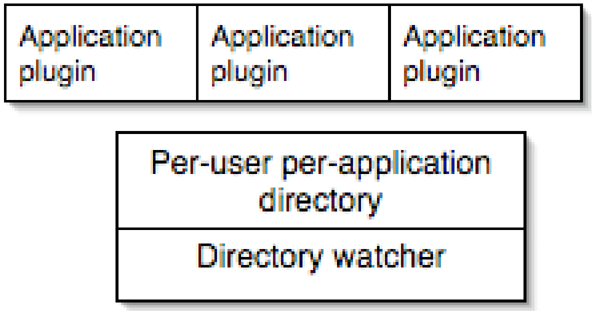


Hop by hop TCP

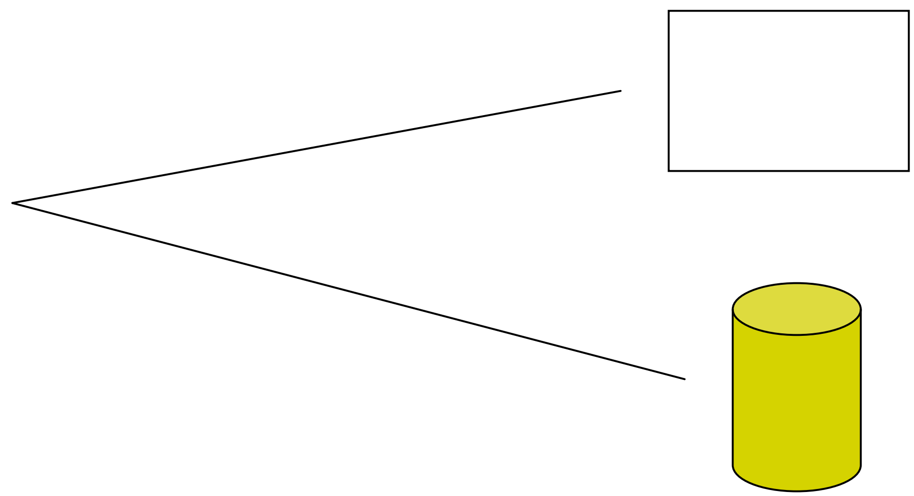
- TCP hop by hop instead of end-to-end
- Allows recovery from wireless errors
  - One socket's worth of buffers may need retransmission

Directory-based API





Databases for volatile state



On reboot, restore cache from db

Route detection and dissemination

For scheduled services

- Each device keeps track of sequence of other devices visited and visited times
- Schedules are automatically computed
  - Deviations can be detected and debugged

Use simpler solutions

- Initial version used complex systems: DHT, HIBC, flat names
- Tried and tested solutions worked better!
  - DNS
  - PKI
  - Hierarchical names

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Summary

- Opportunistic communication allows new *classes* of applications
- But affects every layer of the protocol stack
- We have developed general design principles for robust opportunistic communication
  - at different layers
  - overall

Thank you!

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- **Staff support**: G. Chopiak