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CarTel: A Distributed Mobile Sensor Computing System

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MIT CSAIL

Presented by Grigoris Karvounarakis
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(using material from related presentations of the authors)

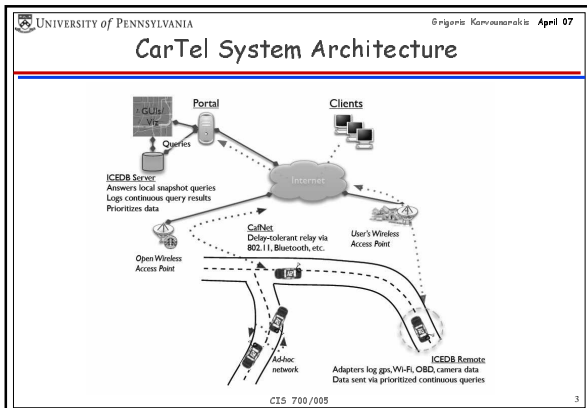
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What is CarTel?

- Distributed software system that makes it easy to:
 - collect,
 - process,
 - deliver,
 - visualize & analyze
 data from *mobile* sensors (cars, phones, etc)
- Goals + Challenges:
 - Intermittent network connectivity + mobility
 - Lots of data ("media-rich" sensors)
 - Heterogeneous data
 - Programmability

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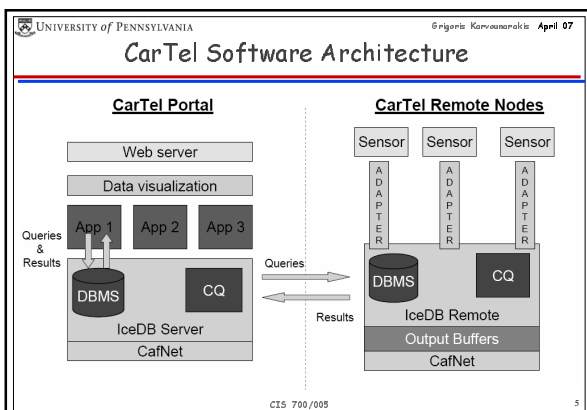
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CarTel Software Components

- **CarTel Portal**: Centralized, visual user interface
- **IceDB**: Intermittently connected DB
 - Centralized declarative queries
 - Executed in distributed fashion by mobile nodes
 - Delay-tolerant continuous query processing
- **CafNet**: CarTel's network stack
 - Handles variable and intermittent connectivity

The diagram shows the flow of data between software components. The 'Portal' (HTTP & Viz) sends 'Queries' to 'Apps'. The 'Apps' send 'Queries' to 'IceDB'. 'IceDB' sends 'Queries' to 'CafNet'. 'CafNet' sends 'Queries' to 'Remote'. 'Remote' sends 'Results' to 'CafNet'. 'CafNet' sends 'Results' to 'Buffering'. 'Buffering' sends 'Results' to 'IceDB Remote'. 'IceDB Remote' sends 'Results' to 'Sensor'.

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IceDB: Intermittently Connected DB

- Delay tolerant, distributed continuous query engine
 - Highly variable connectivity & bandwidth
- SQL extensions to handle intermittent connectivity
 - To prioritize results
- Adapters for managing heterogeneous data types
 - Meta-data package describing attributes of sensor
 - Create local tables for sensor readings
 - Acquire tuples from sensor
 - Parse sensor readings

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(Traditional) Continuous Queries

- Current model for stream processing
 - Process data streams via long-running queries
 - Windowed aggregates, filters, windowed joins, merges, etc.
- Network is assumed to be "always on"
 - Disconnection is a fault to be masked (or a failure occurs)

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Delay-Tolerant Continuous Queries

- IceDB stages data into output buffers to hide variable connectivity
- Key idea: Data in output buffers get re-evaluated dynamically, each time a new item arrives into it

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Result Prioritization

- Limited BW necessitates deliberate ordering
- Three simple SQL extensions
 - For local (per-box) ordering:
 - PRIORITY (for whole queries)
 - DELIVERY ORDER BY (within query results)
 - For global ordering (according to feedback from the portal, possibly across all sensors):
 - SUMMARIZE AS

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PRIORITY

- Idea
 - Some queries are more important than others
- Details
 - Add PRIORITY clause to SQL
 - Drain output buffers in priority order

```

SELECT lat, lon, mph          SELECT oil_temp
FROM gps                      FROM obd
WHERE mph > roads.mph_limit  BUFFER IN engine
BUFFER IN driver             PRIORITY 1
PRIORITY 10

```

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DELIVERY ORDER BY

- Idea
 - Prioritize tuples within query result
- Details
 - Query specifies transmission order via DELIVERY ORDER BY clause
 - User-defined ordering function
 - Operates over entire query output buffer

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SUMMARIZE

- Idea
 - Nodes send server low-resolution summary of output buffer contents
 - Server sends back transmission ordering
- Details
 - Users specify "summarization query" alongside main query
 - Server ranks segments using app-defined metric
 - Ranking pushed to nodes to set output ordering

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CafNet: A Delay-Tolerant Network Stack

- Data moves through regions of highly variable connectivity
- "Mule" = element that stores data to be relayed toward the destination when "the time is right"
 - a delay-tolerant network (DTN)
- CafNet delivers results to portal and queries to nodes

App 1 ... **App N**

Transport Layer

- registers data to be transmitted
- delivers incoming data
- requests data from the application
- notifies application of successful delivery

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Network Layer

- notifies transport layer of free buffers
- schedules data for transmission
- selects routes
- buffers data for transmission

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Mule Adaptation Layer

- provides uniform neighbor discovery

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Device Driver

↕

Device Driver

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CafNet Optimizations

- Basic version: Callback + no buffering
- Problem: Connectivity may not even be long enough to package and send data
- Solution:
 - Add buffering at CNL level
 - CNL sends whatever is in the buffer as soon as connectivity is available
 - Callback when there is space in buffer
- Buffer size requirements vary (vs. dynamic priority)
 - Allow applications to set desired size

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CarTel Portal: Traces and Interest Regions

Trace Explorer

Query Options: Date: [All Dates] Tags: [Anywhere] Operator: [Intersects] Refine | Reset

Date	Time	Dur.	Dist.	Mark
[Details]	Tue, Apr 4	12:11 AM	00:53:08	44.79 miles
[Details]	Mon, Apr 3	9:25 PM	00:32:32	9.25 miles
[Details]	Mon, Apr 3	10:00 PM	00:00:35	0.16 miles
[Details]	Mon, Apr 3	11:38 AM	00:02:33	0.39 miles
[Details]	Fri, Mar 31	8:55 PM	00:16:35	4.60 miles
[Details]	Fri, Mar 31	6:45 PM	00:18:39	5.03 miles
[Details]	Fri, Mar 31	1:52 PM	00:11:42	3.97 miles
[Details]	Thu, Mar 30	12:16 PM	00:27:45	7.58 miles
[Details]	Wed, Mar 29	12:07 PM	00:34:05	8.37 miles
[Details]	Tue, Mar 28	5:16 PM	01:01:38	0.85 miles
[Details]	Mon, Mar 27	12:04 PM	00:29:00	7.40 miles
[Details]	Sun, Mar 26	8:15 PM	00:00:41	0.23 miles
[Details]	Sun, Mar 26	6:08 PM	00:00:23	0.09 miles
[Details]	Sun, Mar 26	7:06 PM	00:03:27	1.37 miles
[Details]	Sun, Mar 26	6:58 PM	00:01:07	0.18 miles

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CarTel Portal: a Single Trace

Trace Detail: Fri,03/10/06 - 8:59 PM

Duration: 00:06:17
Distance: 3.52 miles
Vehicle: []

Sensor Data Overlays

Avg. Speed: 33.63 mph
Max. Speed: 58.06 mph

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Library for Geographic Overlays

Traffic Hotspots

Start: [7 am] End: [10 am] Grid: [005] Update

Rank	Avg MPH	Std-dev	Count
1	25.3 mph	26.7 mph	176
2	29.3 mph	24.6 mph	315
3	33.0 mph	22.8 mph	207
4	38.4 mph	22.5 mph	245
5	18.0 mph	18.0 mph	729
6	32.8 mph	17.5 mph	187
7	20.4 mph	17.1 mph	635
8	34.2 mph	16.2 mph	63
9	17.8 mph	15.9 mph	365
10	17.2 mph	15.9 mph	313

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Other vehicle-based Applications

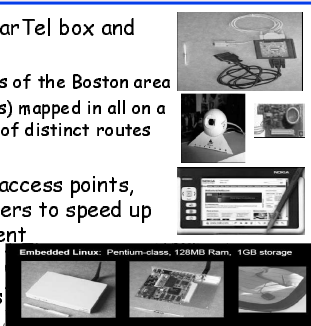
- Smart route finding & congestion mgmt
 - Past + current data
- Fleet mgmt/automotive diagnostics
 - E.g., trucks, taxis, buses
- Visual mapping (images, video) of regions
 - Pictures for driving directions
 - Surveillance videos
- Civil and environmental monitoring
 - E.g., to measure pollution or potholes
- Wireless network monitoring
 - "can you hear me now"

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Experimental Setup

- 6 cars equipped with CarTel box and software
 - Driving normally in parts of the Boston area
 - ~32K access points (APs) mapped in all on a relatively small number of distinct routes
 - ~300 drive hours
- Fast scanning of WiFi access points, caching of AP parameters to speed up connection establishment
- 25sec connections
- Median upload: 30KB/s

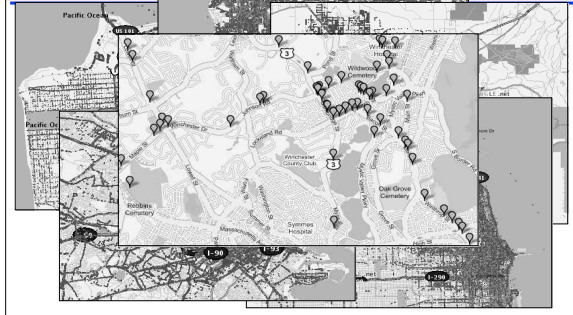


Embedded Linux, Pentium-class, 128MB Ram, 1GB storage

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Wi-Fi To Everywhere



CIS 700/005 Images from WIGLE.net and CarTel²⁰

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Conclusions

- Mobile sensor networks can sense at much higher scale over large areas than static networks
- Several applications: traffic, fleet management, automotive diagnostics, wireless network monitoring, civil/environmental monitoring, ...
- Key challenges: heterogeneous data, intermittent connectivity, programmability, privacy
- In urban areas, Wi-Fi is a viable uplink technology
 - Legal/privacy issues?
 - Cheaper than using cell-based?
 - They also discuss using CarTel on cell phones

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