Mobile Computing: the Next Decade

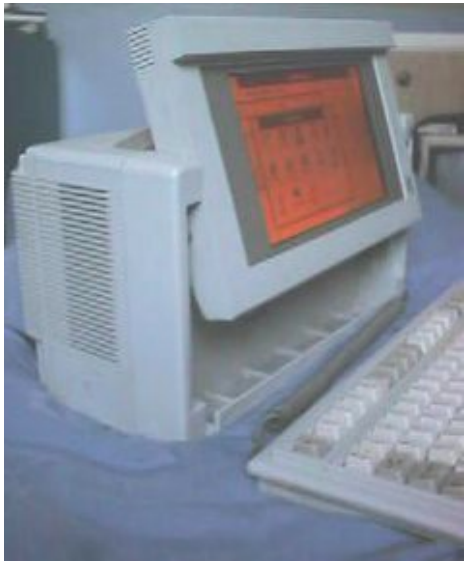
Mahadev Satyanarayanan

School of Computer Science

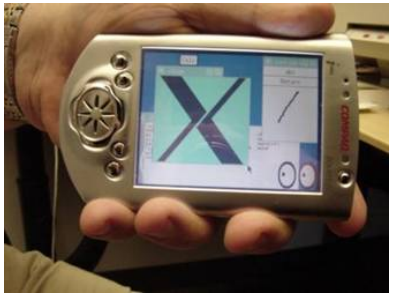
Carnegie Mellon University

Early-90s Dream of Mobile Computing

Phenomenal Hardware Progress



Compaq Luggable
~ 1987



Compaq iPaq
~ 1999

IBM Linux Wristwatch
~ 2000

Google Android
~ 2008

NCR WaveLan
915 MHz
ISA
~1990

802.11b PC cards
~ 1999

~2003

What Will Inspire and Drive Mobile Computing Research in the Next Decade?

Emerging Themes

1. Mobile devices as rich sensors

2. Near-real-time data consistency

3. Opportunism

4. Outreach

Rich Mobile Sensing

Cameras integrated with almost every mobile device today

- rich sensing devices (2D CCD array, temporal if video)
- sound capture is another example (1D, temporal)

"Rich" → high-dimensional and complex

- requires extensive processing by human/software to extract value
- not simple scalar values (e.g. temperature, salinity, light intensity, …)
- data capture easy but interpretation difficult

Sensing community fixated on "smart dust" vision (SenSys, MobiHoc, …)

- cheap, disposable motes + TinyOS
- simple scalar values, little on-board processing, little storage
- dominance of ad hoc wireless networks

"Brilliant rock" better metaphor for mobile sensing than smart dust

- more processing, memory, storage, networking
- but captured data also requires more intense processing
- too expensive to be disposable
- energy considerations still dominate, but more tractable
- typically include human in the loop

Example: Lost Child in Crowd

Macy's Thanksgiving Day Parade

Lost Child Found!

Observations

Opportunism

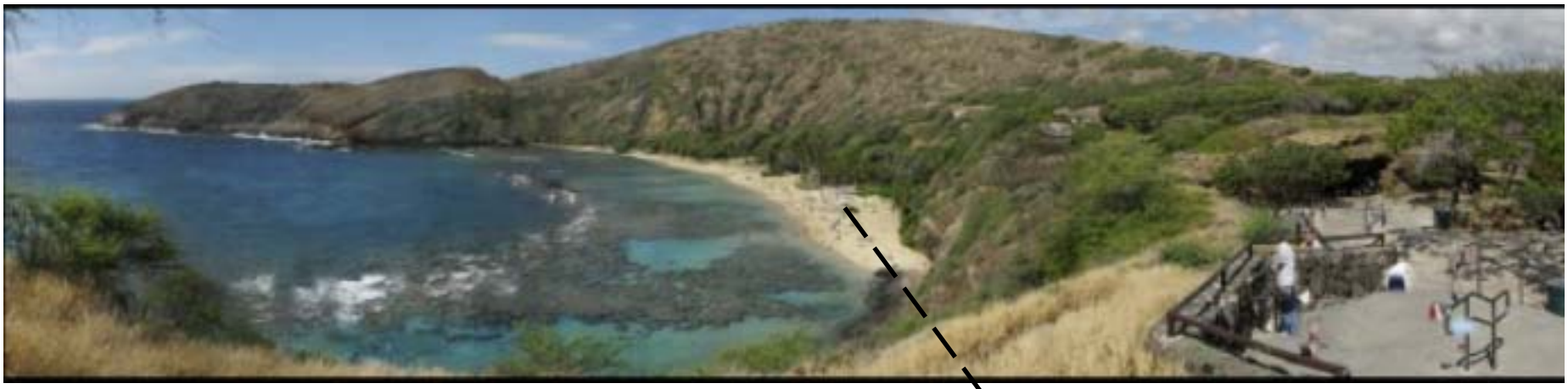
- pictures were taken for some other reason
- captured data rich enough to contain “other extraneous stuff”
- the “other stuff” is focus of someone else’s search later
- how do you index data of this kind?

Near-real-time data consistency

- only pictures taken after child was lost are useful
- bounds on geographic region too (speed of motion)
- implications for caching and data consistency checking?

Example: GigaPan Remapping for Disaster Recovery

GigaPan Zoomable Images



Hanauma Bay, HI; May 2008
(5.6 gigapixels, 378 images)

GigaPan Robots

GigaPan of Hanauma Bay, HI

Potential Value in Disasters

Port Au Prince, Haiti; January 29, 2010

(225 images hand-captured by reported; stitched after return to the US)

What Mobile Computing Architecture Do We Need to Support These Classes of Applications?

3-level Mobile Computing Hierarchy

Historically: 2-level hierarchy (client and server)

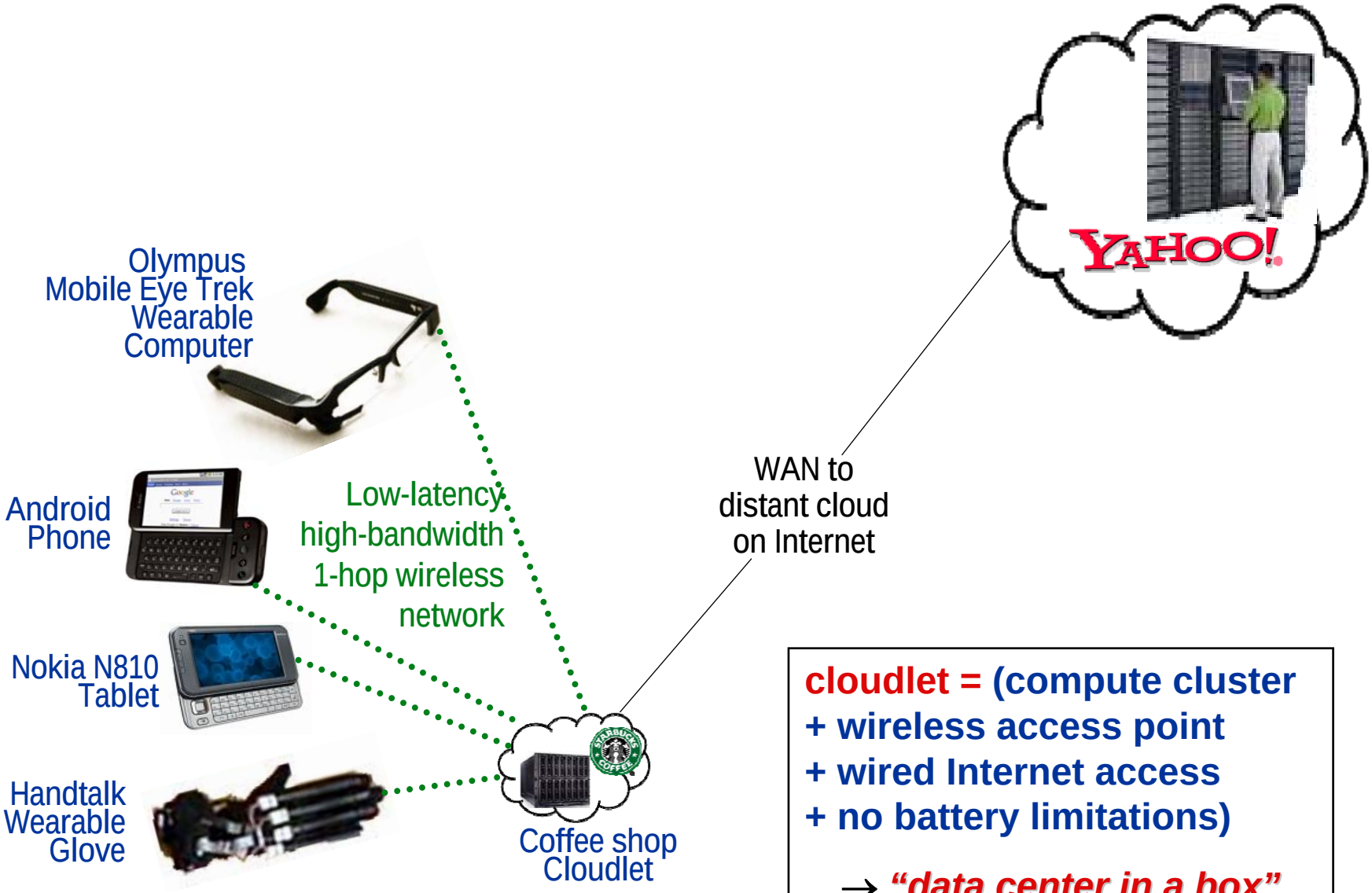
New proposed architecture: 3-level hierarchy

- **cloud**
- ***cloudlet***
- **mobile device**

Cloudlet provides compute resources for "cyber foraging"

- **offloads intense computations (e.g. GigaPan stitching, image search)**
- **low-latency 1-hop wireless access for human-in-loop interactions**
- **allows "cellular" style computational coverage for small regions**

Cloudlet = Small Cloud Nearby



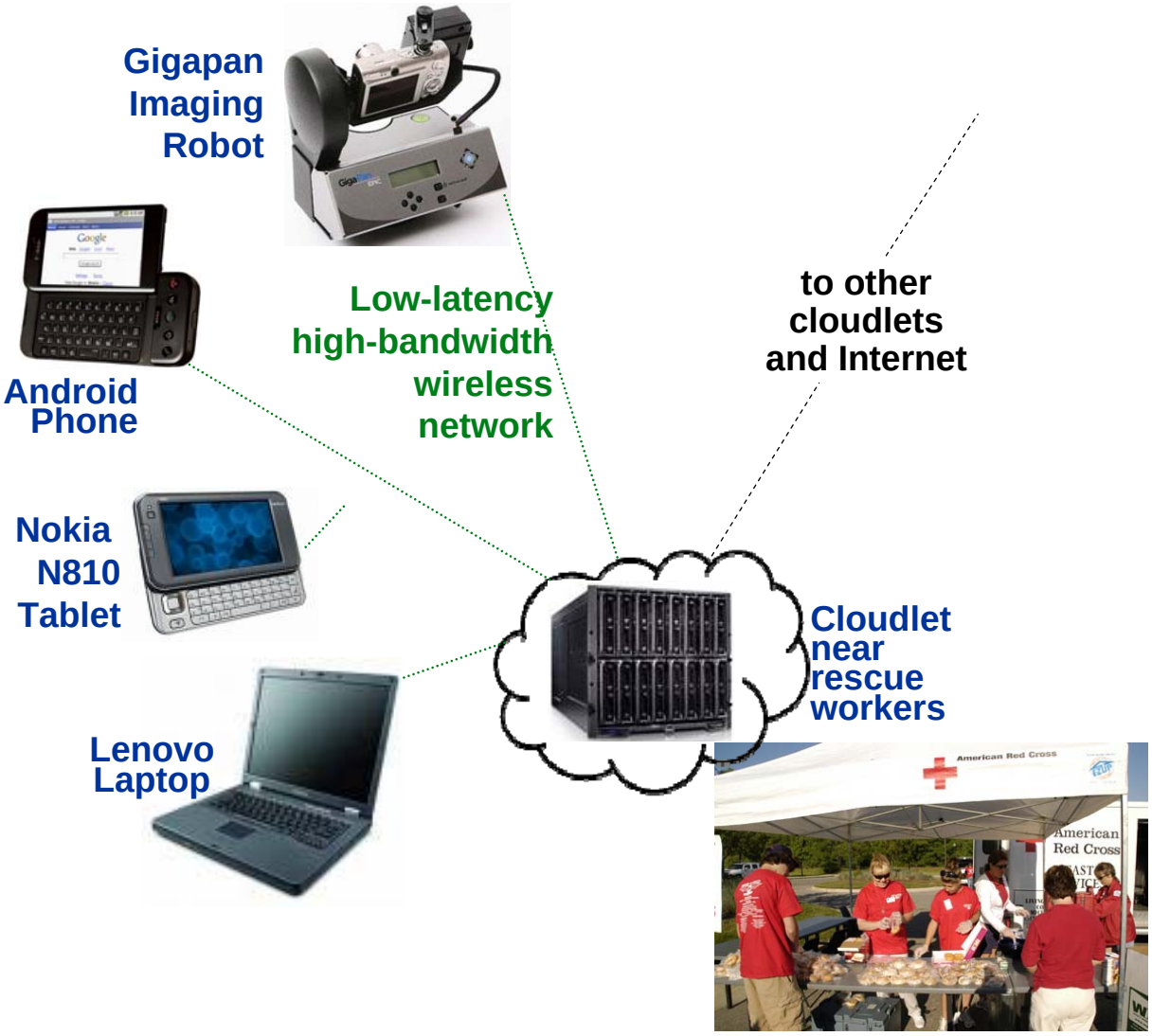
cloudlet = (compute cluster
+ wireless access point
+ wired Internet access
+ no battery limitations)

→ ***"data center in a box"***

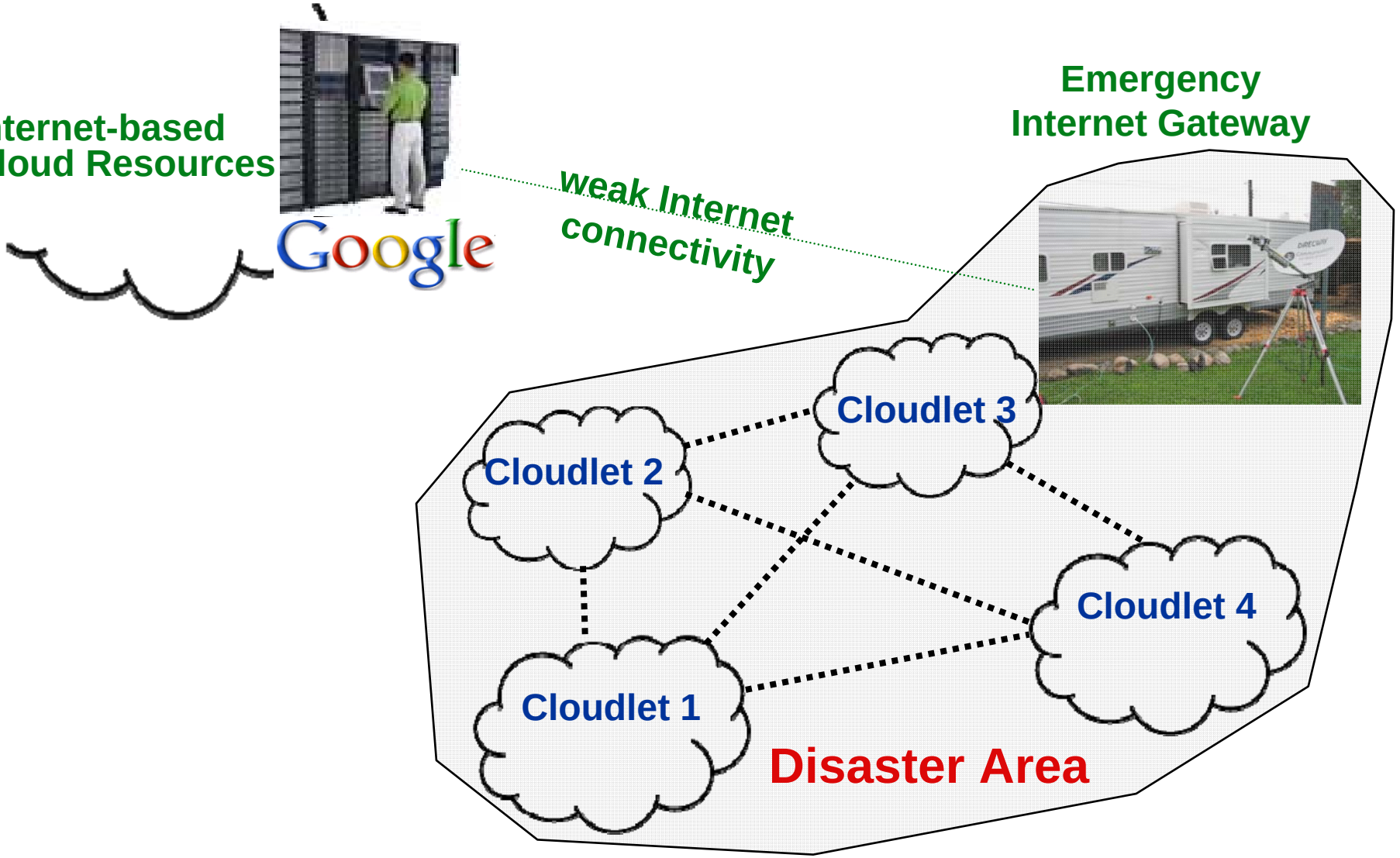
Cloudlet vs. Cloud

	Cloudlet	Cloud
State	Only soft state	Hard and soft state
Management	Appliance model: self-managed; little professional attention	Utility model: professionally administered, 24x7 operator coverage
Environment	"Data center in a box" at customer premises	Machine room with power conditioning and cooling
Ownership	Decentralized ownership by local business	Centralized ownership by Amazon,Yahoo!, etc.
Network	LAN latency and bandwidth	Internet latency and bandwidth
Sharing	Few users at a time	100s to 1000s of users

Cloudlets in Disaster Scenarios



Cloud Computing in the Face of Disrupted Internet Connectivity



Closing Thoughts

Embrace challenging real-world applications

- **rich crowd-sourced mobile sensing**
- **developing countries**
- **disaster relief**
- **environmental sensing (Gulf recovery?)**
- **• • • •**

Drivers of mobile computing advances in the next decade

- **identify common themes and requirements**
- **distill into mobile architectures, system support and infrastructure**