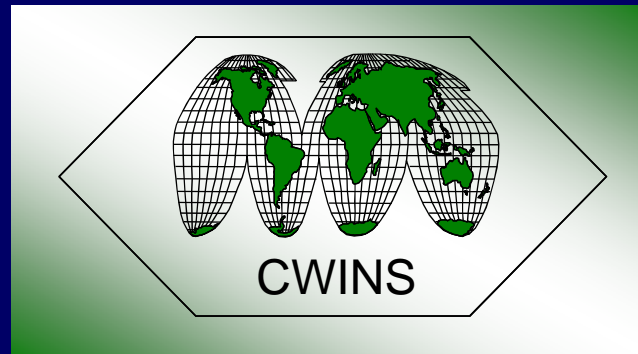


Tohoku University, Tokyo Campus, June 27, 2014
International Symposium on Wireless Sensor Networks and
Related Technologies



**From WLAN to WiFi Localization
- Evolution of a Revolutionary Technology**

K. Pahlavan

June 27, 2014

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What is next in sensor networks ?

“He wrote in three scripts:

The one that he wrote and only he could read

The one that he wrote and he and others could read

And the one that he wrote and neither he nor others could read

I write the third way!”

Jalal ad-Din Muhammad Rumi,
Persian Poet, 1207-1273 C.E.

PART I:
EVOLUTION OF TECHNOLOGY AND MARKET

1G WLAN Products (early-1990's)

Shoe Boxes:

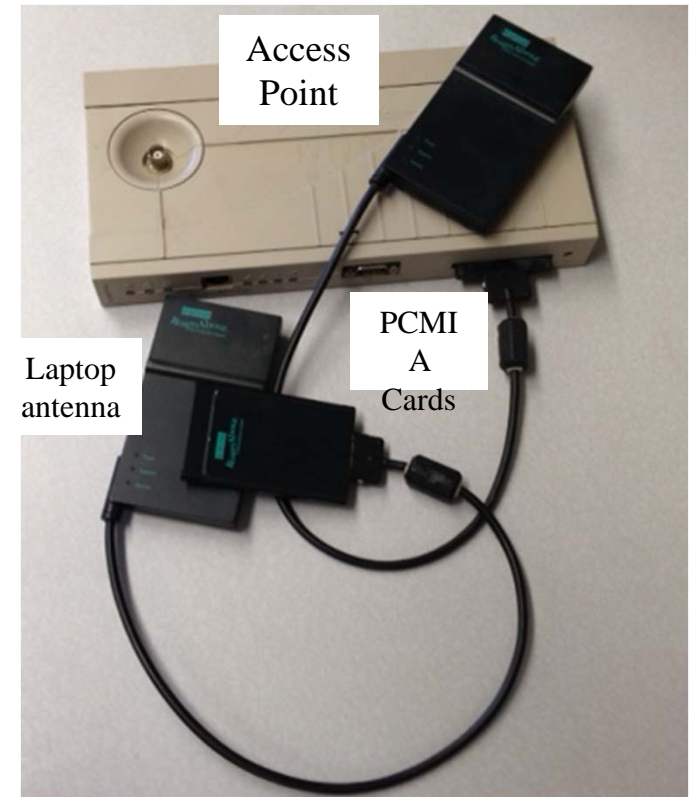
DFIR

DSSS/900MHz

Altair/18GHz

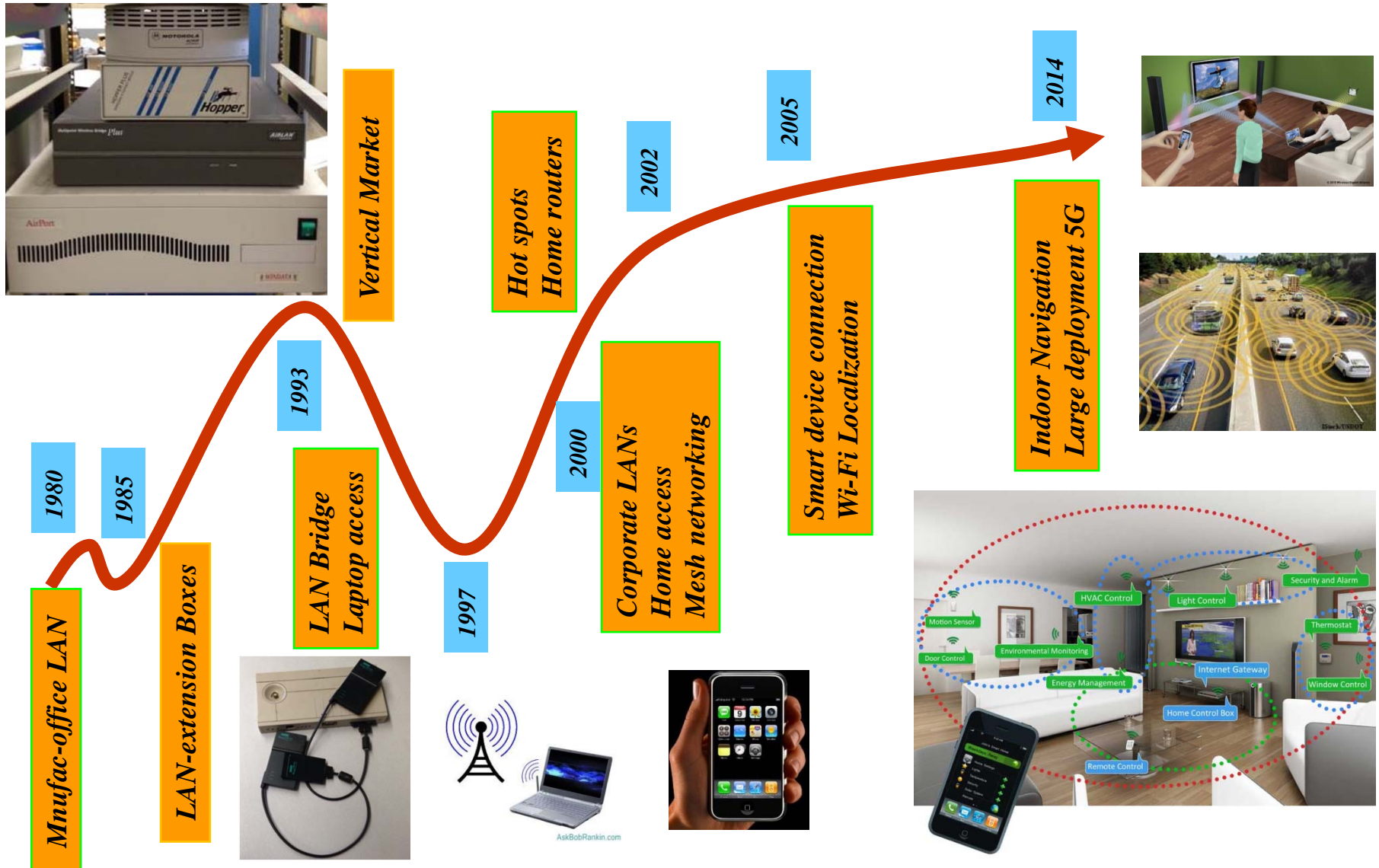
FHSS/900MHz

DSSS/2.4U/5.2D

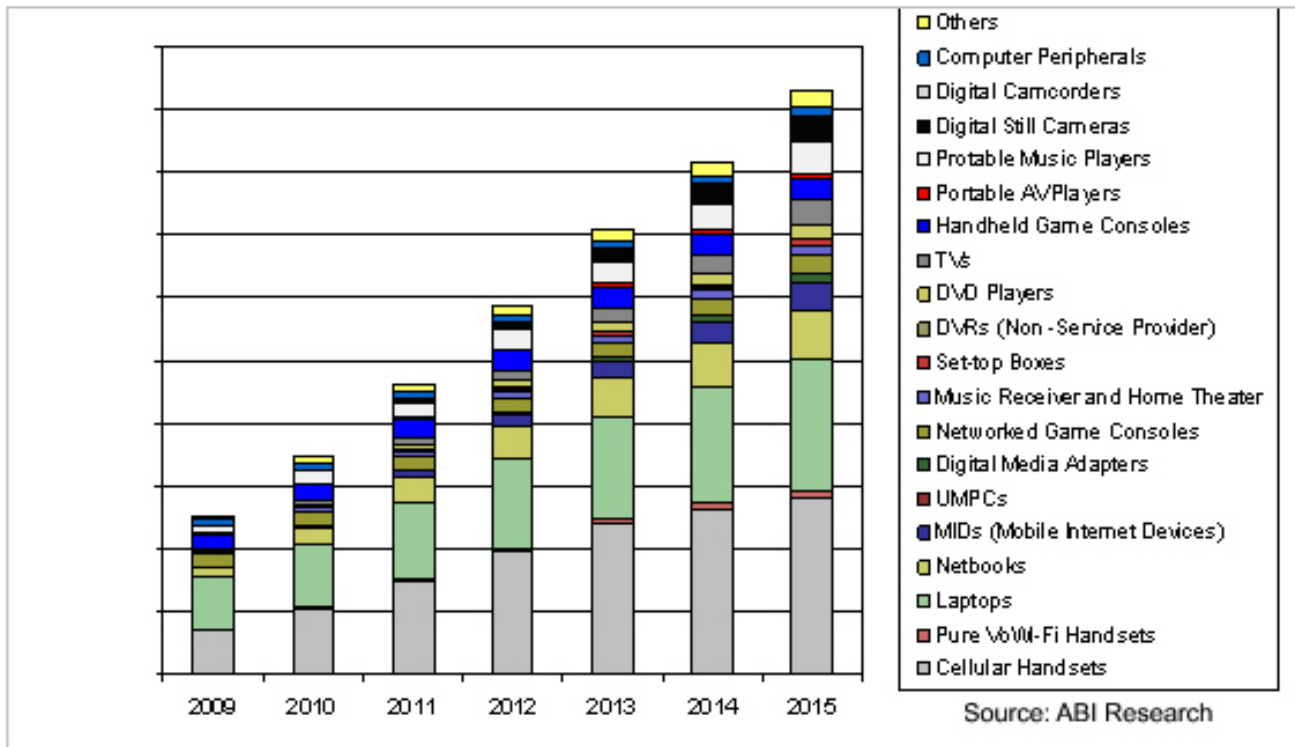


Companies: NCR, Motorola, Photonics, Proxim, Windata, Intersect, DEC, Harris,

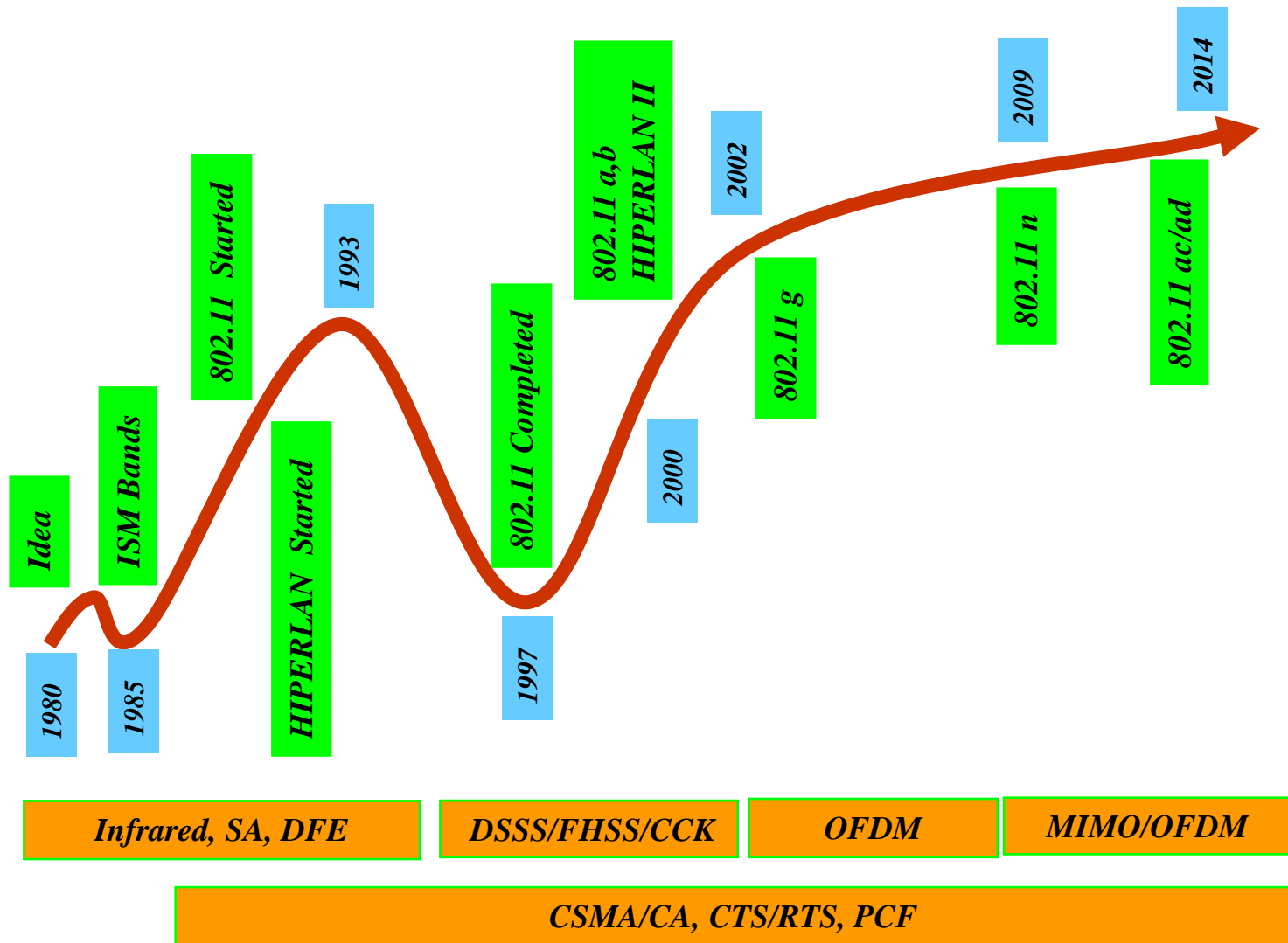
Evolution of “Killer Apps”



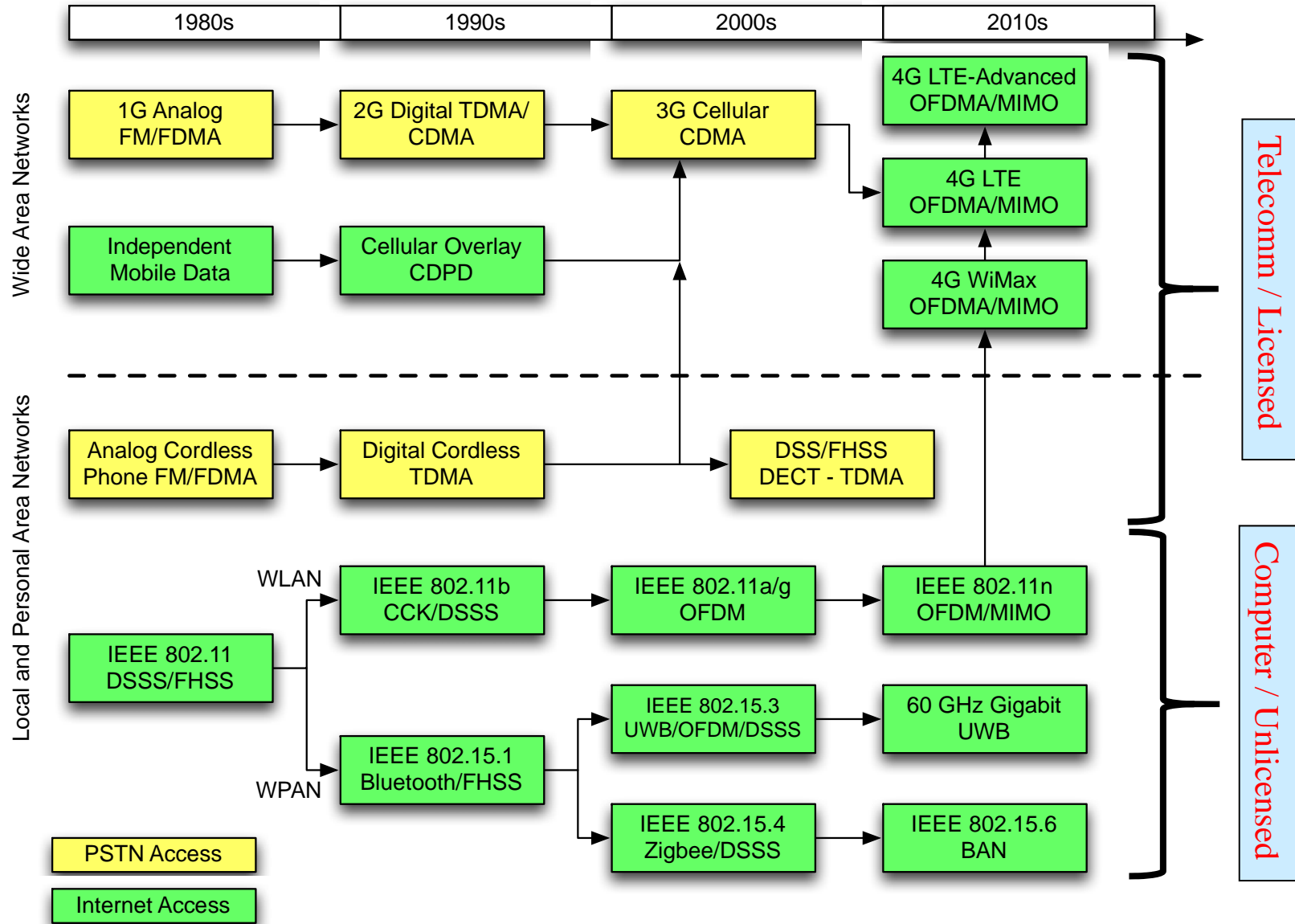
Today's Market



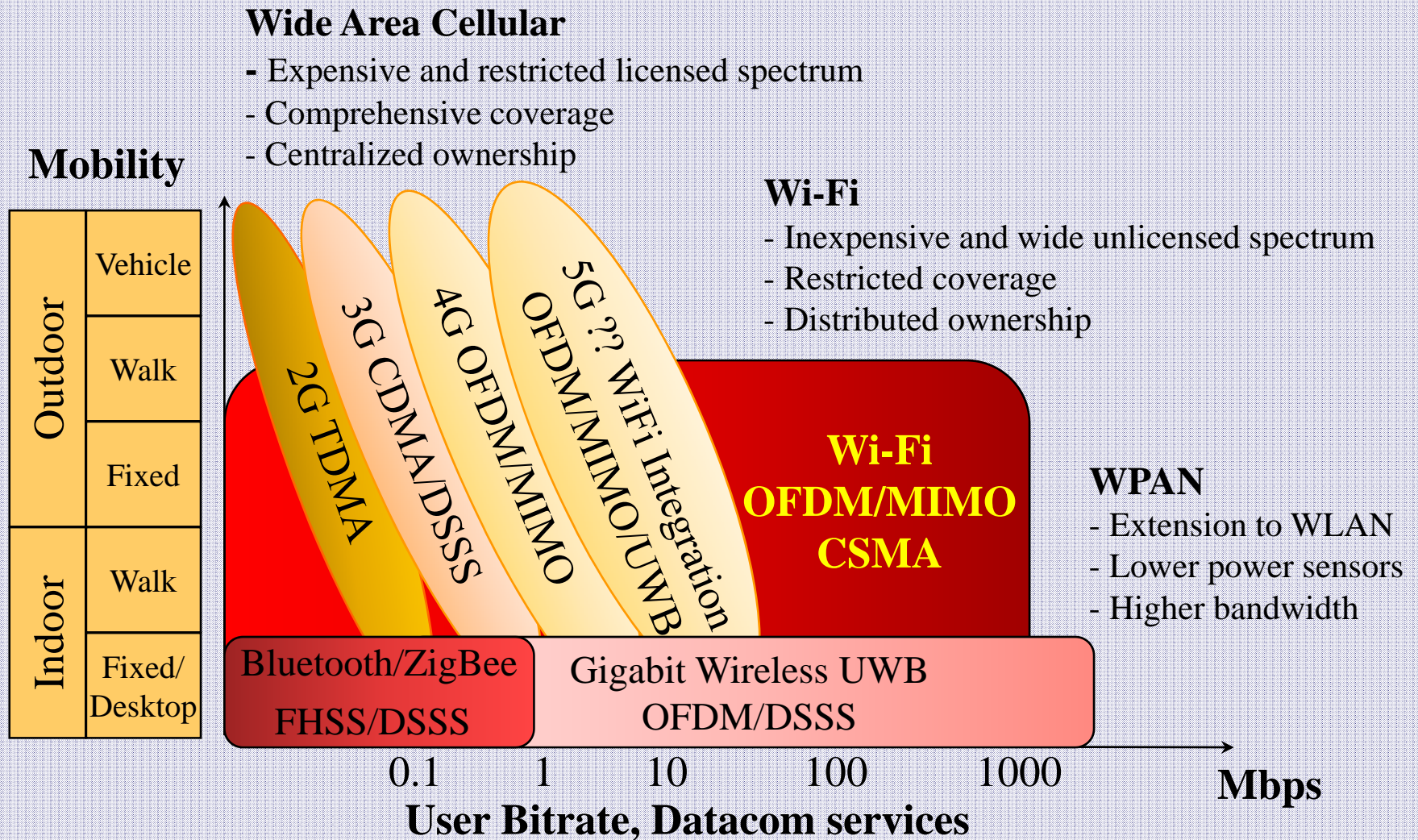
Evolution of Technologies



Evolution of Wireless Technologies



Overview of Wireless Networks



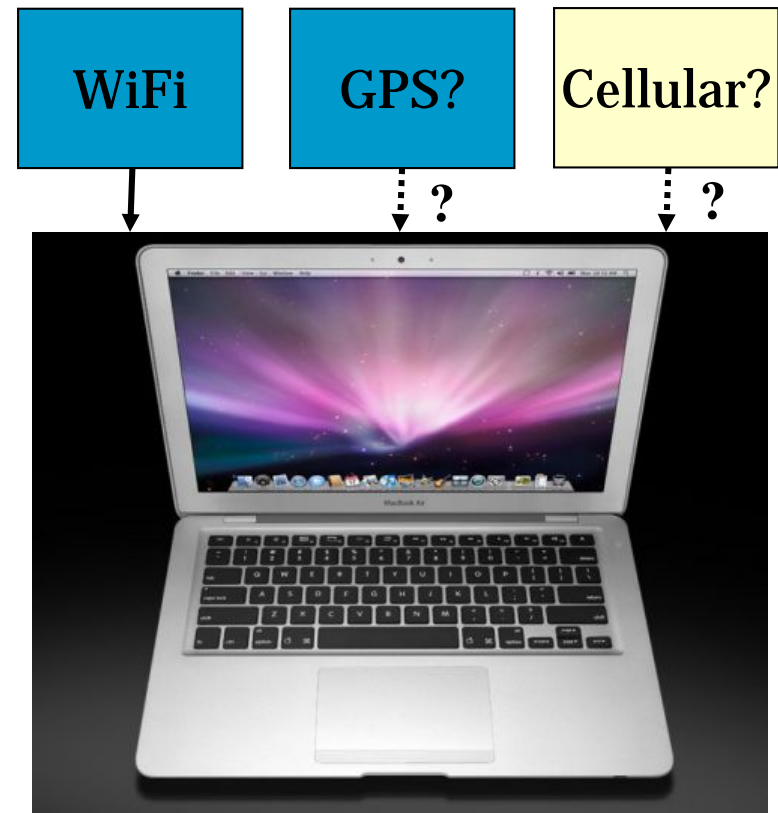
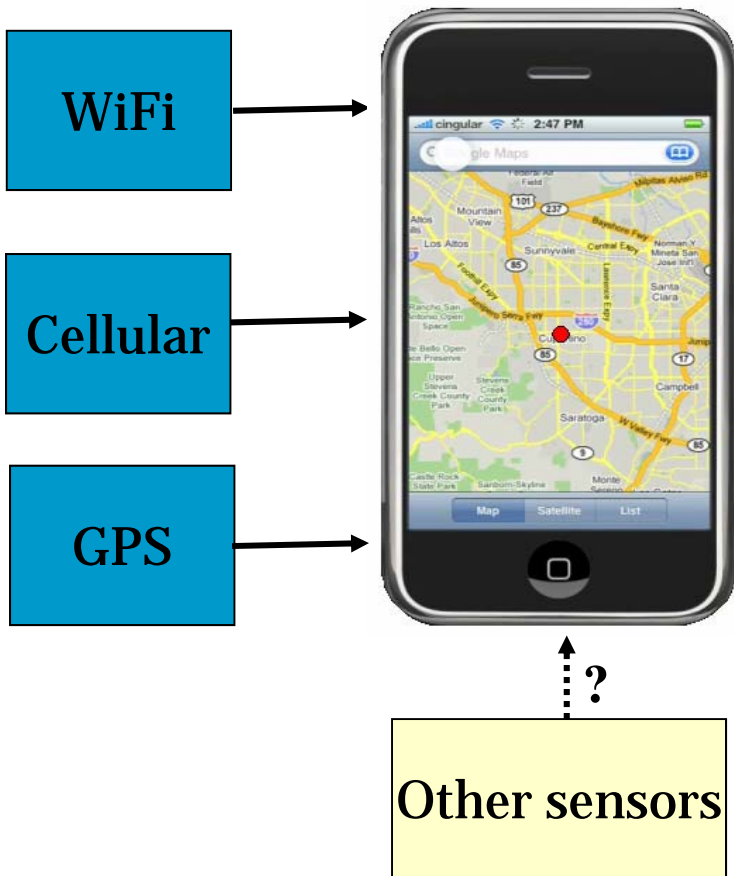
PART II:

**FROM WLAN TO WI-FI LOCALIZATION –
EMERGENCE OF AN UNEXPECTED KILLER APP**

Evolution of Wi-Fi localization

- **Emergence of RF localization industry**
 - RF navigation for military applications (WW II)
 - Military GPS (mid 1970's)
 - Commercial GPS (early 1990's)
 - Non-GPS localization using signals of opportunity (late 1990's)
- **Wi-Fi localization: the technology that prevailed in commerce**
 - Using WLAN infrastructure for localization (2000)
 - RSS-based Wi-Fi indoor localization, called RTLS (2001)
 - RSS-based Wi-Fi localization for smart phones, called WPS (2005)
 - WPS on iPhone (2008)
 - Today Wi-Fi localization is used in hundreds of thousands of applications on smart phones creating several billions of hits per day

First popular devices: iPhone and laptops



APs in California and NE



Bay Area

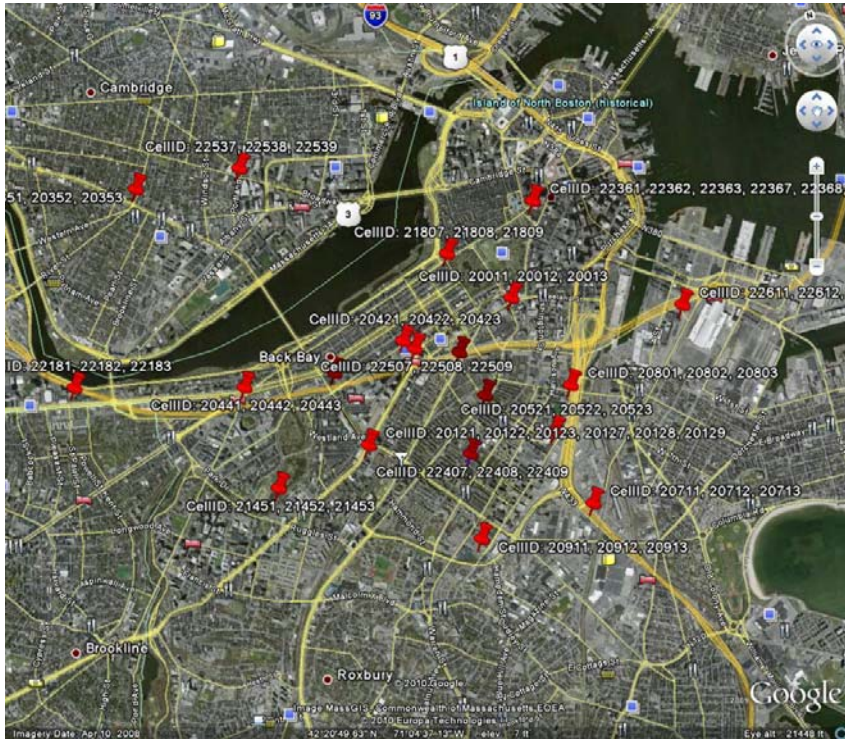
San Diego Area

North East

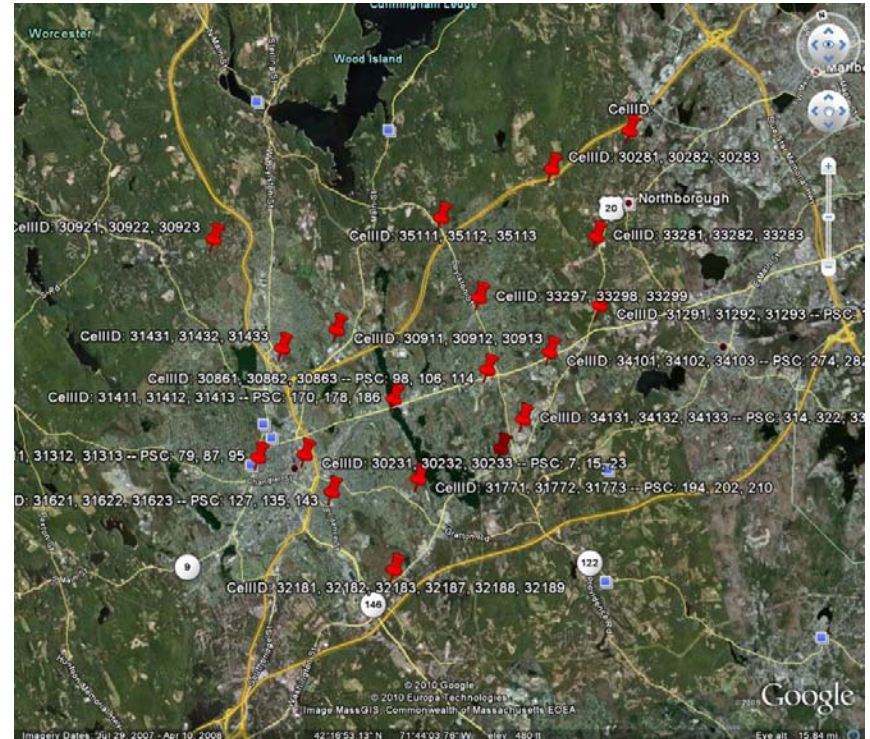
- Skyhook physically maps location of all Wi-Fi and cell towers with a large fleet of data collectors in metro areas. They have several hundreds of millions APs and several hundreds of thousands of cell towers in the database
- Client software calculates location using reference database for WiFi, cell tower, and the GPS

Source: Skyhook Wireless

Cell towers in Boston and Worcester

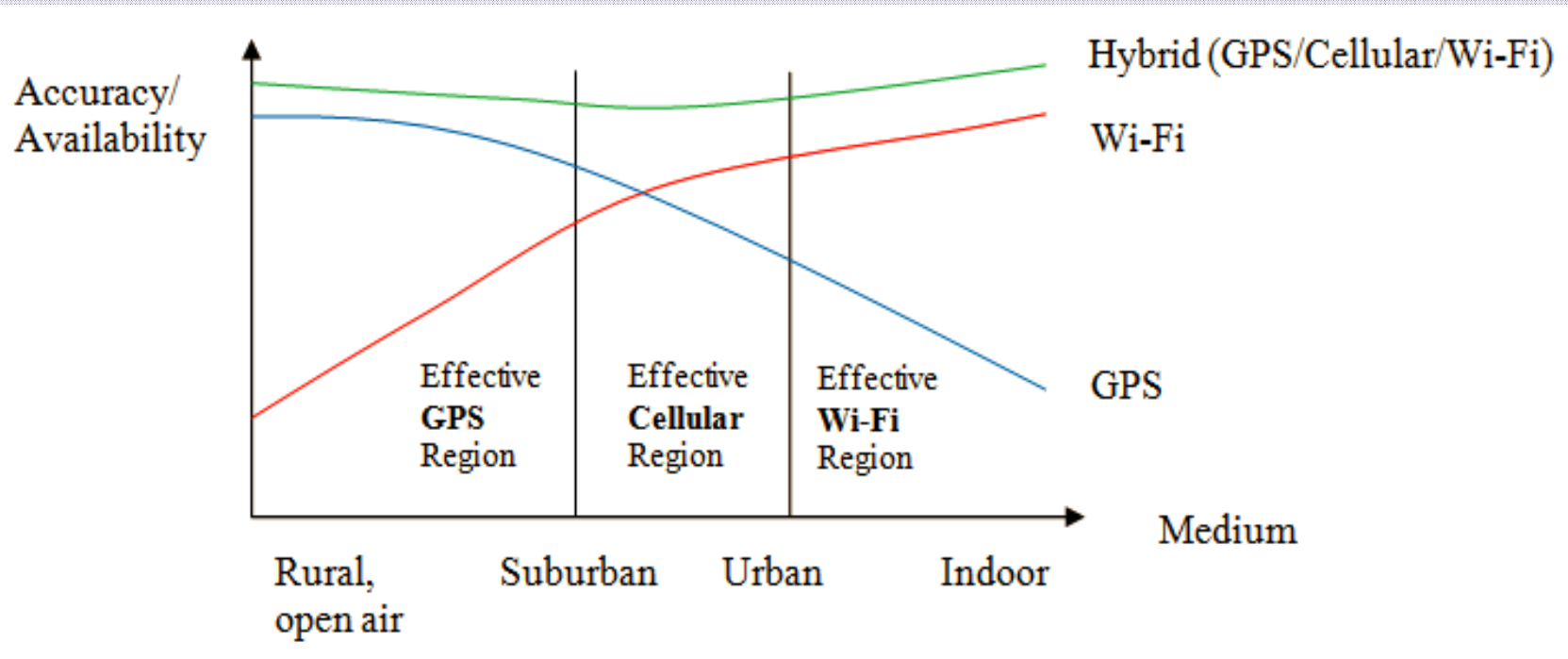


Boston



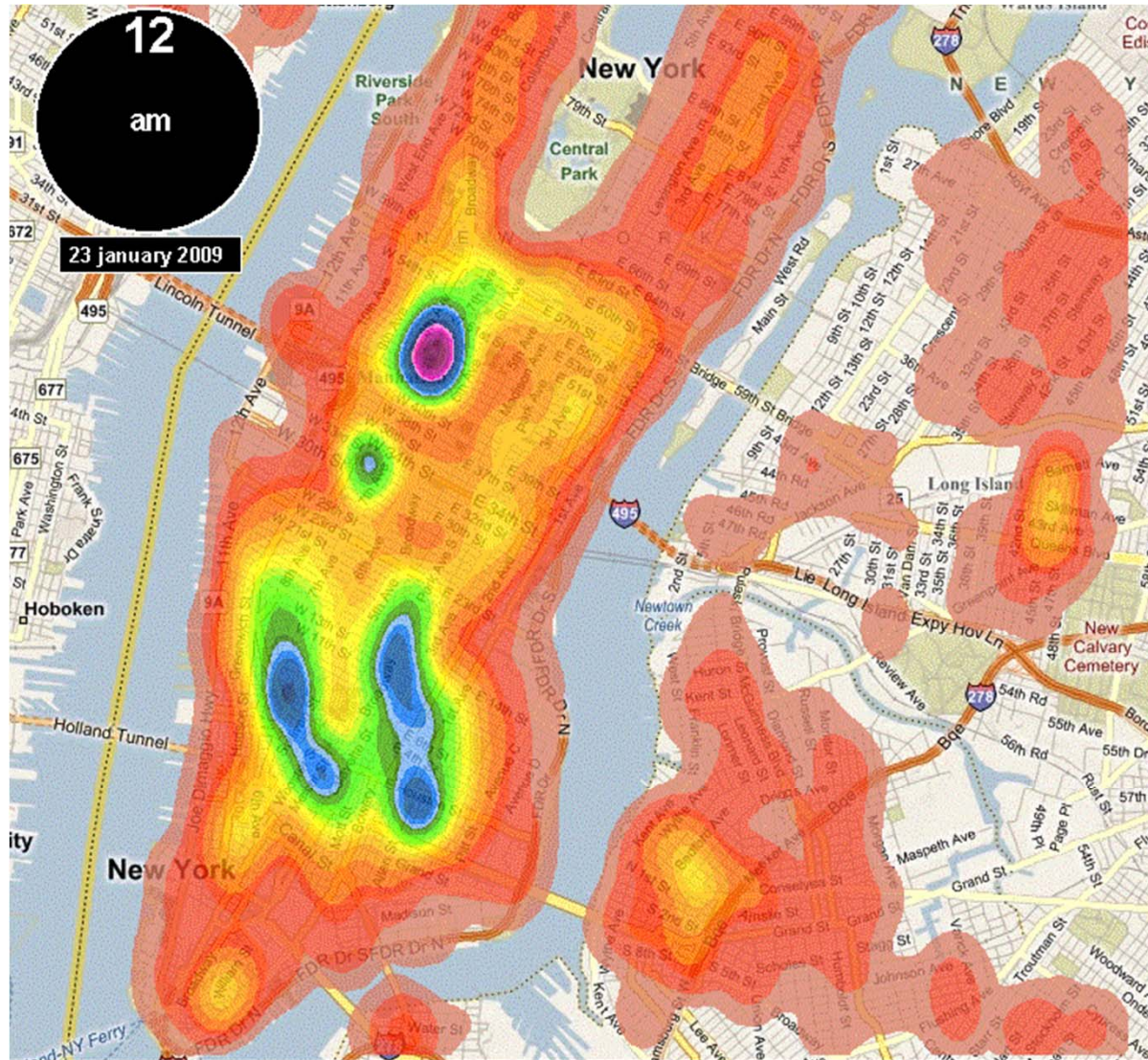
Worcester

Localization Technologies



Wireless and Human Behavior

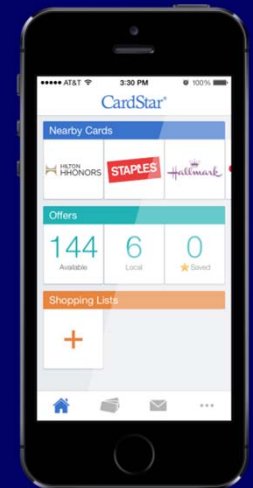
WiFi Hits on iPhone in NYC



Source: Skyhook

Current events in localization

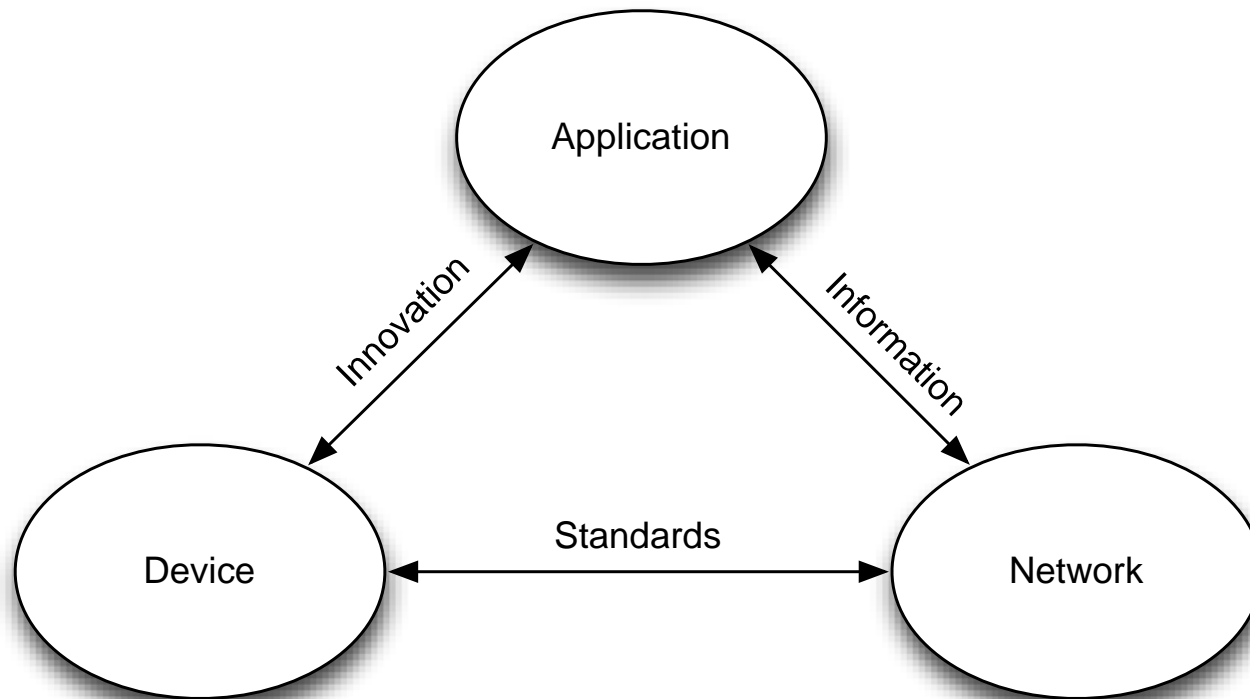
- WiFi localization is the most popular in diversity of applications
- After release of indoor Google maps, Indoor geolocation becomes more popular
- New FCC regulations on E-911 mandates accuracies only achieved by Wi-Fi localization
- Skyhook receives around a billion hit per day
 - Geospatial insight
 - Geo-fencing
 - User intelligence
 - We're the only provider that positions IP addresses down to a 100-meters radius and below. We don't stop there. Now, an IP address is more than just 12 digits, a city and a state. Dig into the deep contextual layers of people, places, demographics and time. Increase the effectiveness of your bidding algorithms and the value of your ad inventory by reaching consumers where and when they are in decision-making mode.
 - Behavioral data for media planning, economic forecasting and retail strategies



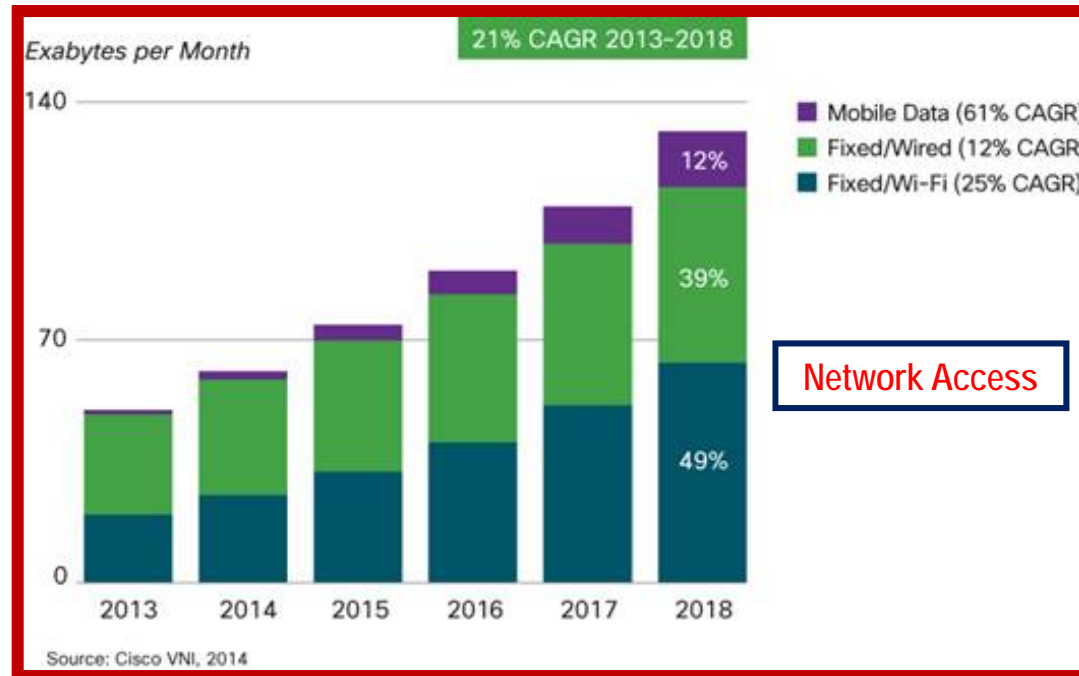
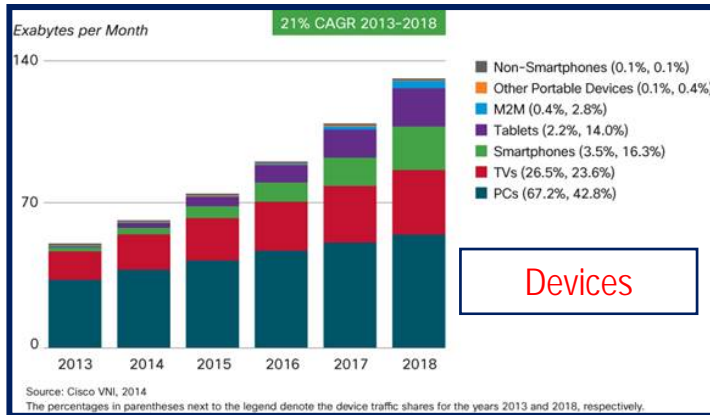
PART III:

A REVOLUTIONARY TECHNOLOGY FOR 5G ?

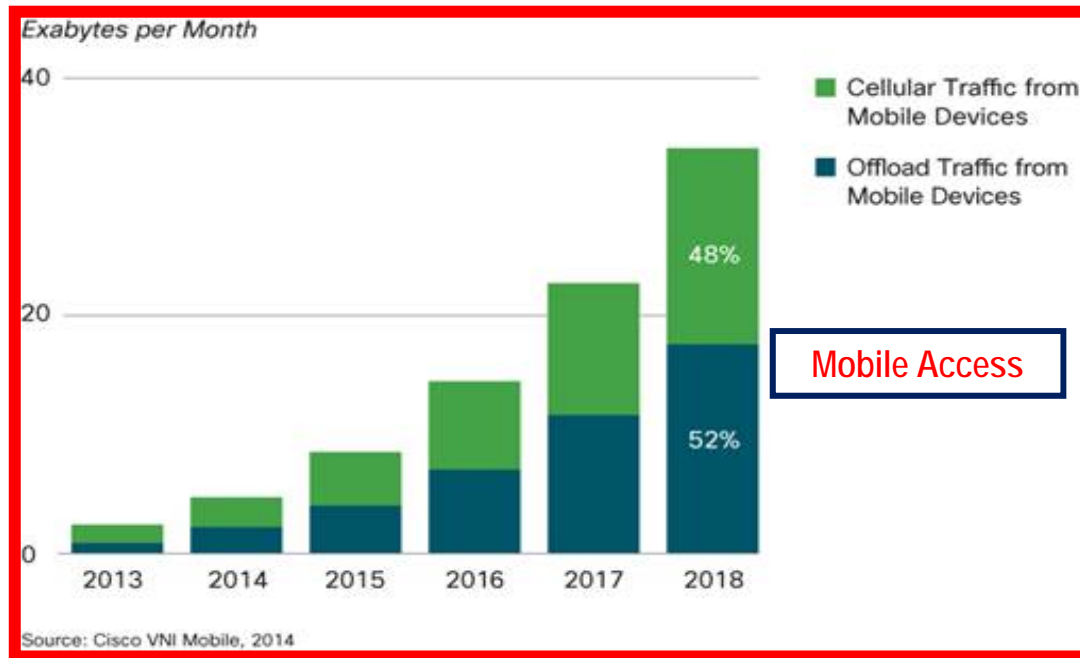
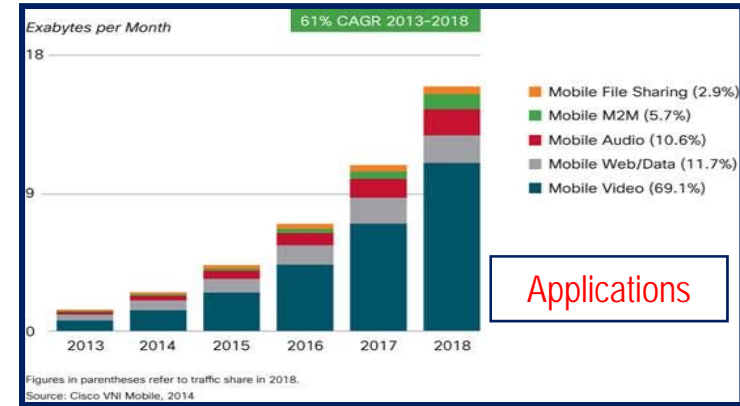
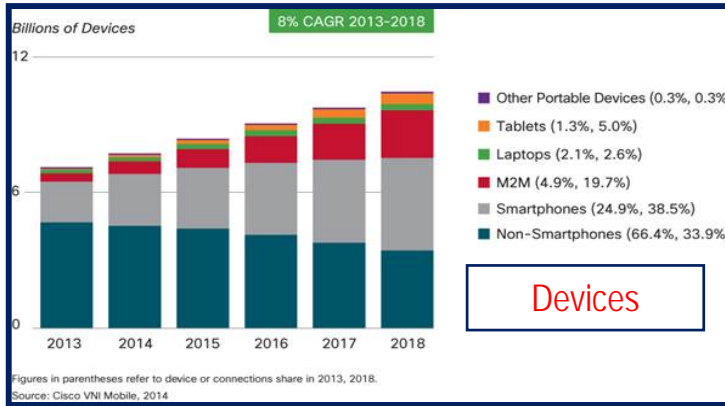
Elements of Information Networks



Elements of Global IP Traffic

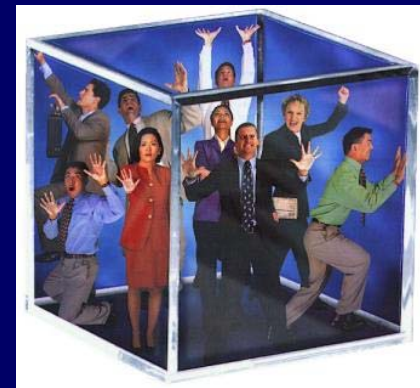


Elements of Global Mobile Data



How to handle exponential growth?

- Improving the MAC similar to cellular
 - TDMA, CDMA, OFDMA vs CSMA/CD
- Improving the PHY similar to WLAN
 - DSSS, OFDM, MIMO, UWB-PT
- More bands
 - Shared spectrum, dynamic spectrum access
- Smaller cells
 - Large scale deployment
 - Wi-Fi vs Femto



Wi-Fi is Local Cellular is Wide area

■ Comparison of technologies

- Assigned access (AA) vs random access (RA)
- Wide area is mostly mobile phone with many users
- Local is dominated by data with a few users

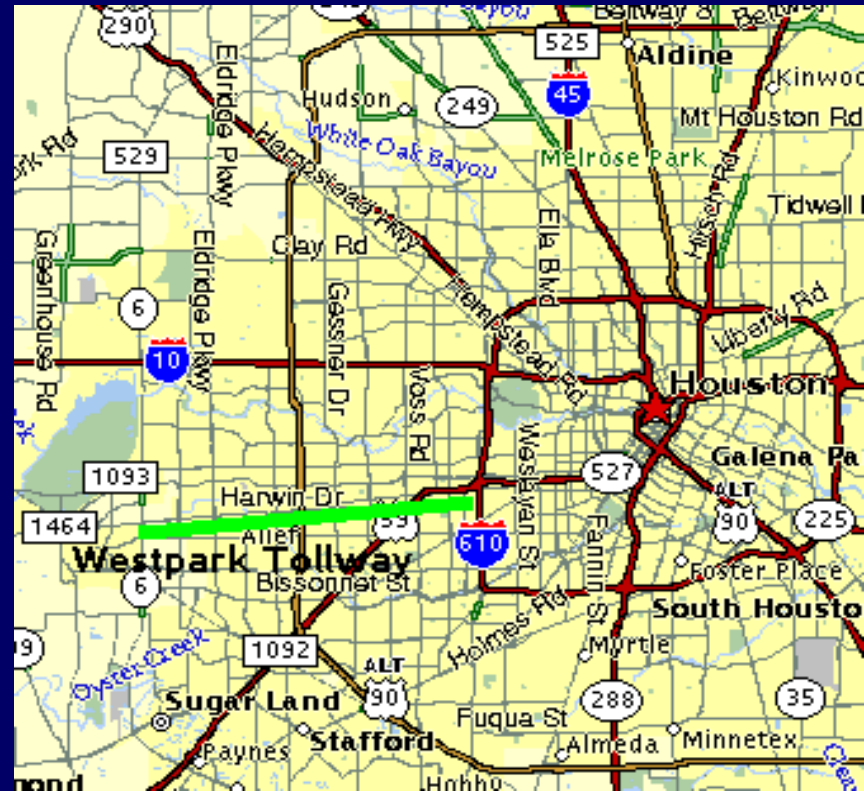
■ Evolution of Standards

- IEEE 802.11 started late 1980's (LRA)
- HIPERLAN-1 began early 1990's (LAA)
- ***Wireless ATM was mid-1990's (LAA)****
- HIPERLAN-II was late-1990's (LAA)
- Wi-MAX followed by 4G evolved (WAA)
- ***Femto-cell (LAA) - Is this wireless ATM back?!***

* K. Pahlavan, A. Zahedi and P.Krishnamurthy, "Wideband local access: Wireless LAN and wireless ATM", Communications Magazine, IEEE 35.11 (1997): 34-40.

Wi-Fi vs Cellular

- **Cellular looks like the toll roads**
 - Good for outdoor wide areas
 - User should pay
 - Has comprehensive coverage
 - Higher total capacity by a single provider
 - Owned by large organization
 - Planned deployment and controlled QoS
 - More complex architecture
- **Wi-Fi is the back roads**
 - Good for indoor local
 - Free access most of the time
 - Has small coverage area
 - Higher capacity per user
 - Owned by small organization
 - Random deployment
 - Simple architecture



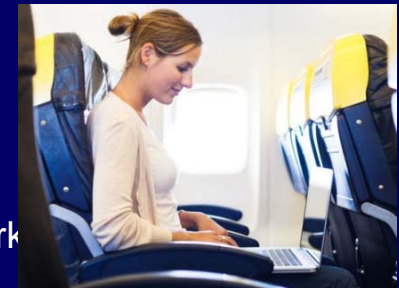
Current interesting issues in Wi-Fi

■ What is the problem?

- Party reception syndrome!
- Coverage has holes
- Handoff and roaming is difficult
- With many owners, revenue model is not there
- Secure sharing at Global scale

■ WiFi deployment issues

- Samsung's Fli-Fy Pigeons with Micro-routers
- Wi-Fi sharing (FON)
- Wi-Fi relays, time-capsule
- Smart Wi-Fi ??
- P-Cell for Wi-Fi ?? (multiple streaming with interference cancellation)
- NYC wants to turn all of its payphones into a massive, citywide Wi-Fi network



Was Wi-Fi a Revolutionary Technology ?

- Wireless industry impacted all aspects of life so it was revolutionary
- The wireless technologies evolved around the Wi-Fi
- The WLAN industry was not initiated by Giant Telecomm companies
 - Because it was data-oriented
- WLAN was not initiated by Giant Computer companies
 - Because it was not reliable and had bandwidth limitations
- As we saw these rebel companies enforced themselves to both Giants
 - To telecom by emergence of smart phones that transformed that voice centric industry to a data industry
 - To computer giants, because it allowed flexibility to access connection and avoiding the wiring problem at micro-level
 - Not only that, they are taking away localization business from cell tower localization as well as GPS