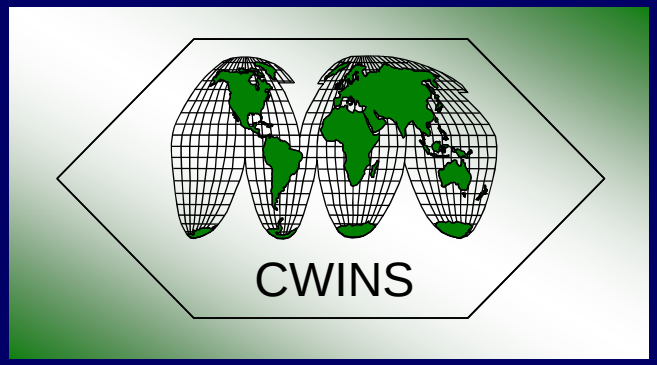
Boston, Massachusetts, September 6, 2015

IEEE Vehicular Technology Conference



Evolution of Wi-Fi Access and Localization – A Revolution in Wireless Networking

K. Pahlavan

What is a revolution?

"An unexpected success against the odds , which changes the paradigm!"

"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.

CWINS Center for Wireless Information Network Studies

WHAT CAN I SHARE WITH YOU ?

"History is who we are and why we are the way we are."

David McCullough

Pulitzer Prize Winner Author

"The only thing new in the world is the history you don't know.“

Harry S. Truman

"Any fool can make history, but it takes a genius to write it.“

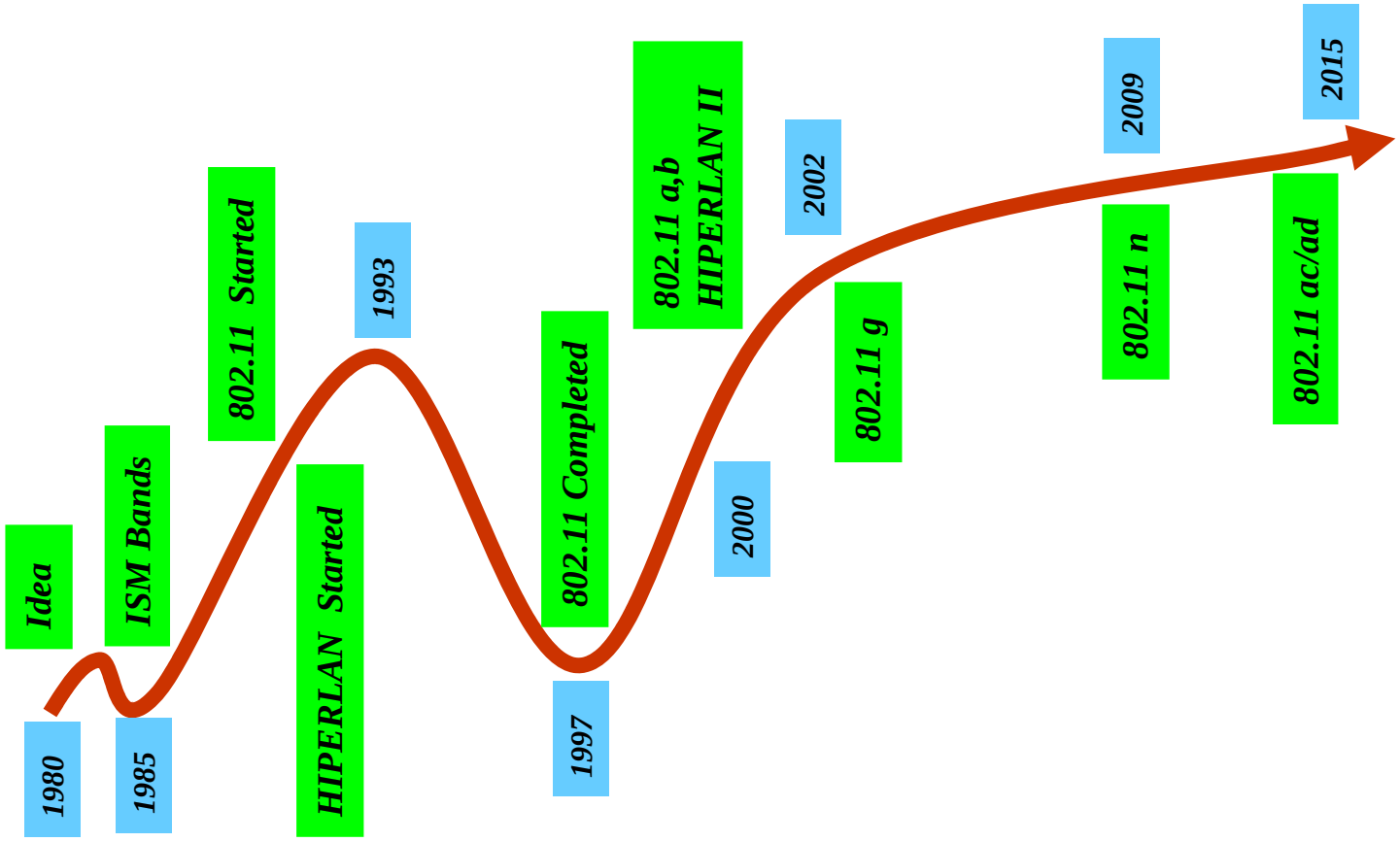
Oscar Wilde

PART I:
EVOLUTION OF WI-FI TECHNOLOGY

How did WLAN technology begin ?

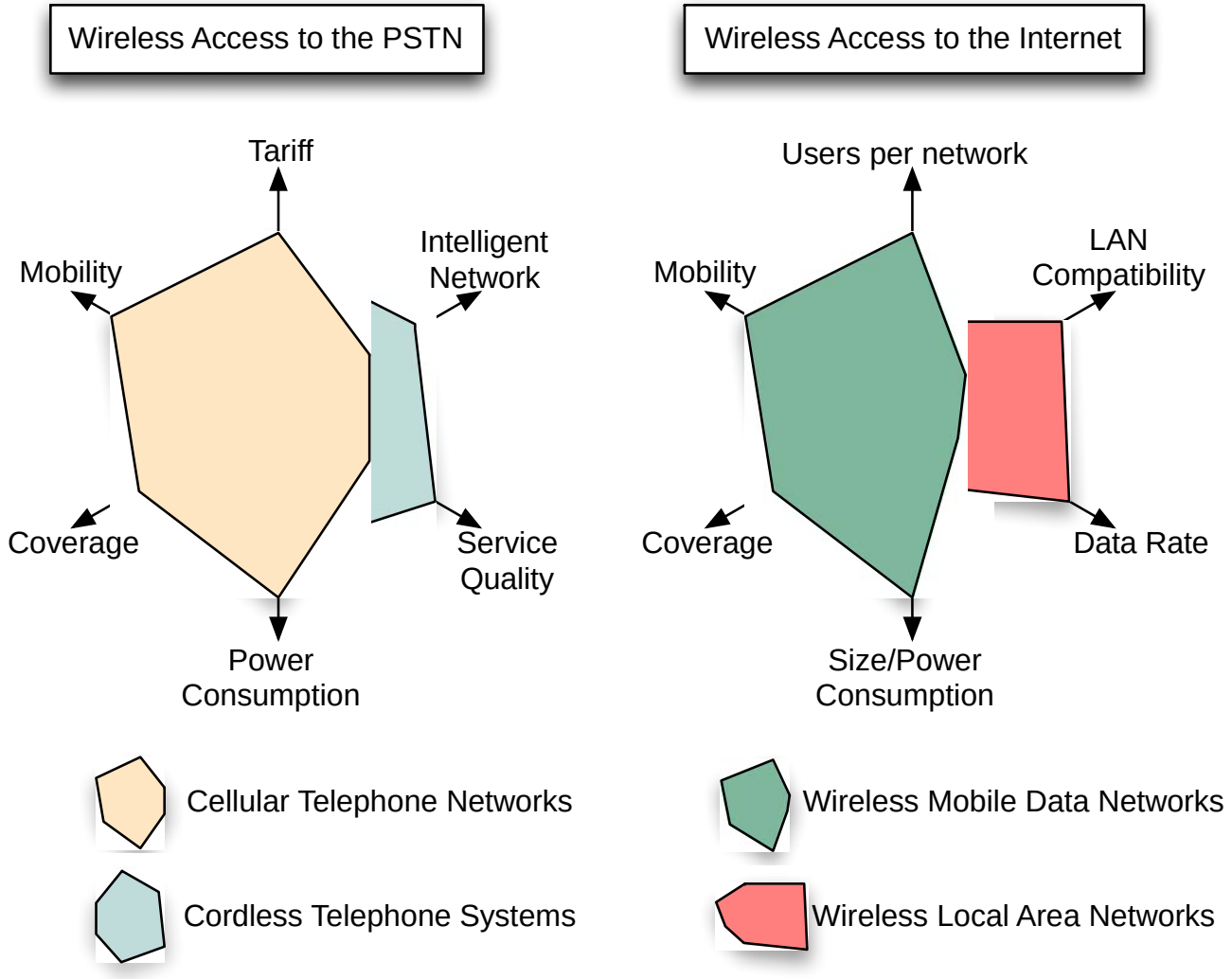
- ***AROUND 1980:***
  - IBM Rueschlikon Laboratory, Zurich, Switzerland: Infrared for Manufacturing floors
    - F.R. Gfeller and U. Bapst, “Wireless in-house data communication via diffuse infrared radiation,” IEEE Proceedings, Dec.1979
  - HP Palo Alto Laboratory, California: DSSS using SAW device as matched filter
    - P. Freret, “Application of spread spectrum radio to wireless terminal communication,” Proceedings of the IEEE National Telecommunication Conference, Dec. 1980.
- ***AROUND 1985:***
  - Release of ISM bands
    - Mike Marcus, "Authorization of Spread Spectrum Systems Under Parts 15 and 90 of the FCC Rules and Regulations" Federal Communications Commission, June 18, 1985.
  - Some visionary surveys:
    - K. Pahlavan, “Wireless Communications for Office Information Networks”, IEEE Communications Magazine, June 1985.
- ***BETWEEN 1985-1993:***
  - Formation of the IEEE 802.11 from 802.4L.
  - NCR, Netherlands and 20-30 start up companies/groups in N. America (Motorola/Altair, Photonics, Proxim, Aironet, Persoft, Hopper, WINDATA, DEC/Roamabout, ….)
    - The first IEEE Workshop on WLANs (collocated with IEEE 802.11 meeting), WPI, May 1991

Evolution of the Technologies

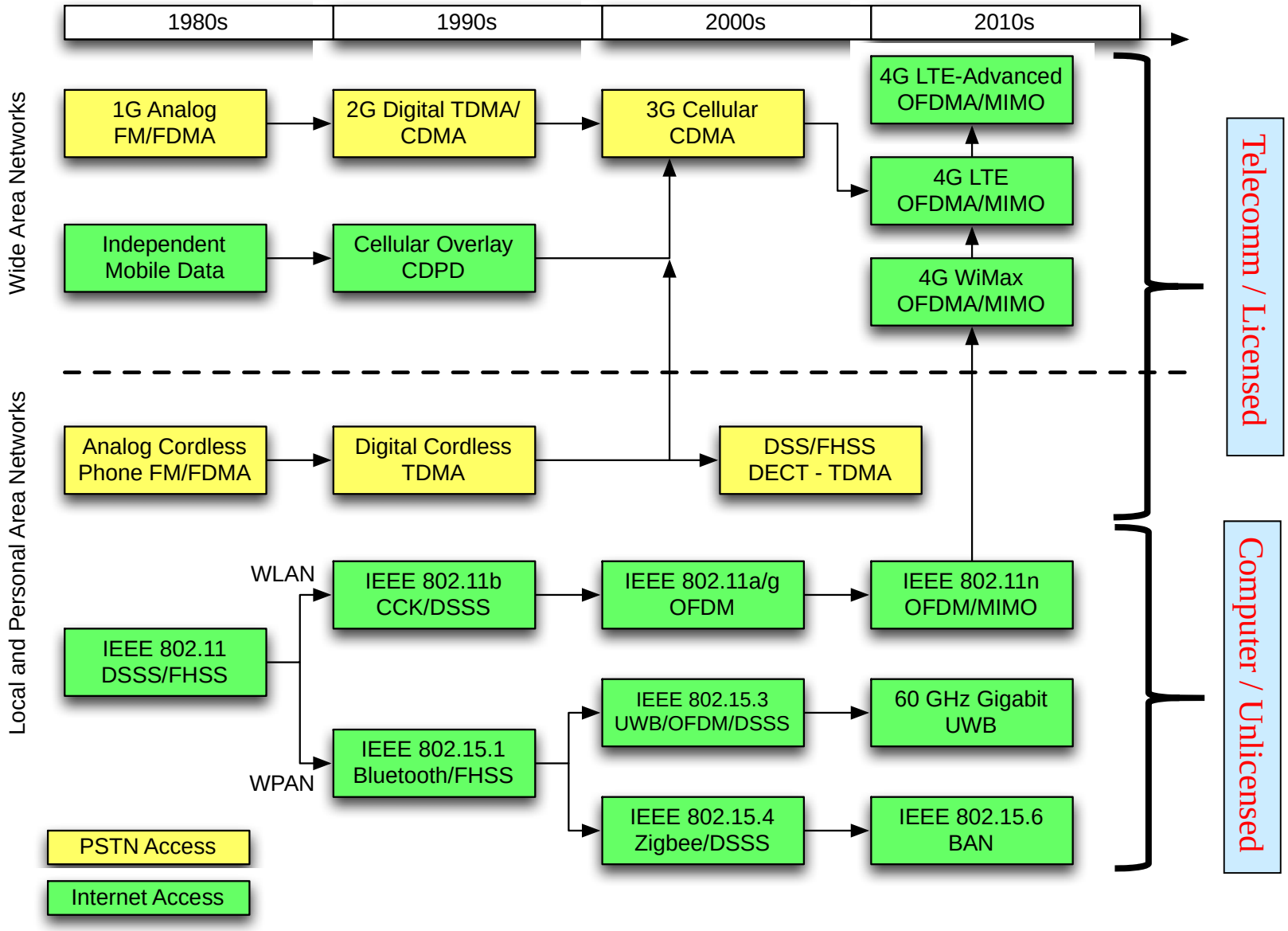


PHY:	*Infrared, 18GHz/SA, DFE*	*DSSS/FHSS/DFIR*	*OFDM*	*MIMO/OFDM*
MAC:	*CSMA/CA, CTS/RTS, PCF*			

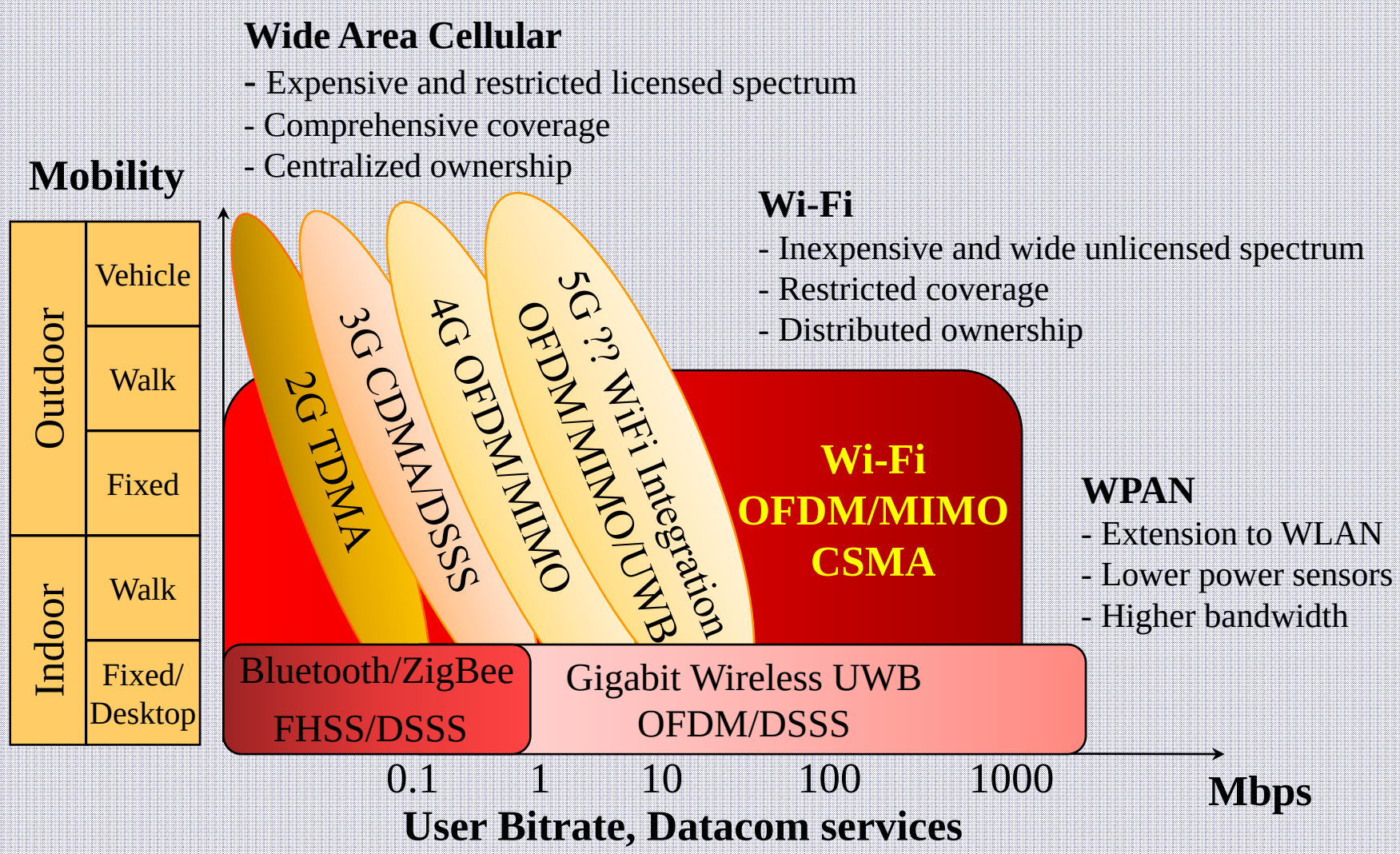
Four Pioneering Wireless Technologies



Evolution of Wireless Technologies



Overview of Wireless Networks



PART II:
EVOLUTION OF WI-FI APPS AND MARKET

In Search of a “Killer Apps”

1980 — *Mnufac-office LAN*

1985 — *LAN-extension Boxes*

1993 — *LAN Bridge*
Laptop access

Vertical Market

1997

2000 — *Corporate LANs*
Home access
Mesh networking

Hot spots
Home routers

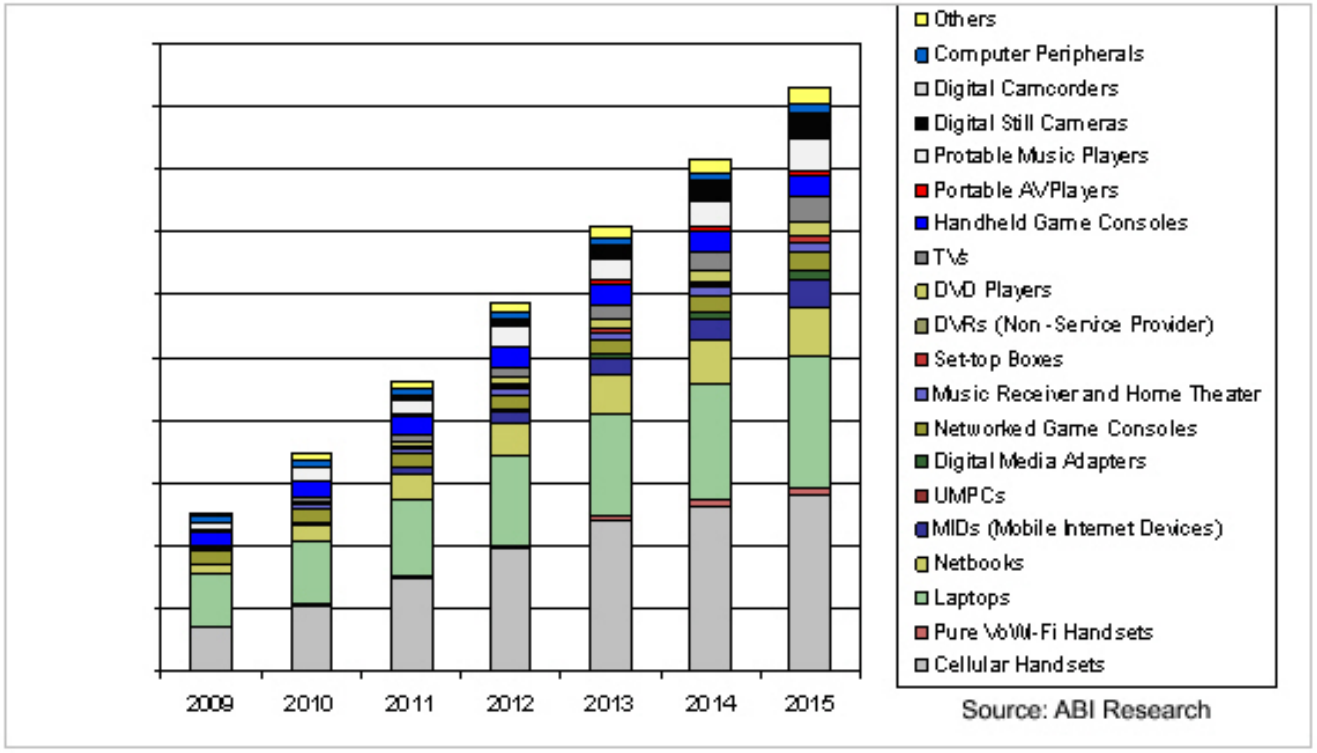
2002

2005 — *Smart device connection*
Wi-Fi Localization

2015 — *Indoor Navigation*
Large deployment

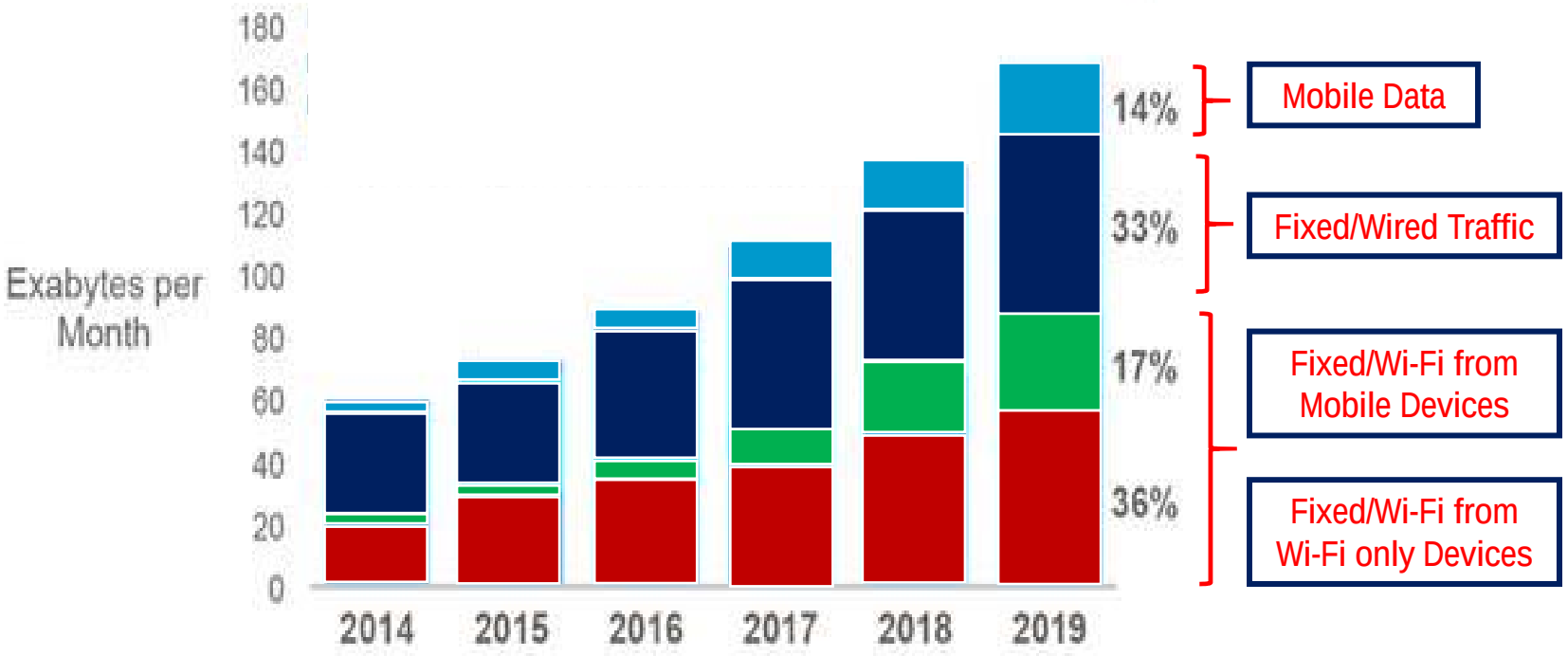
Source for images: Google Images

Today Wi-Fi is in numerous devices!



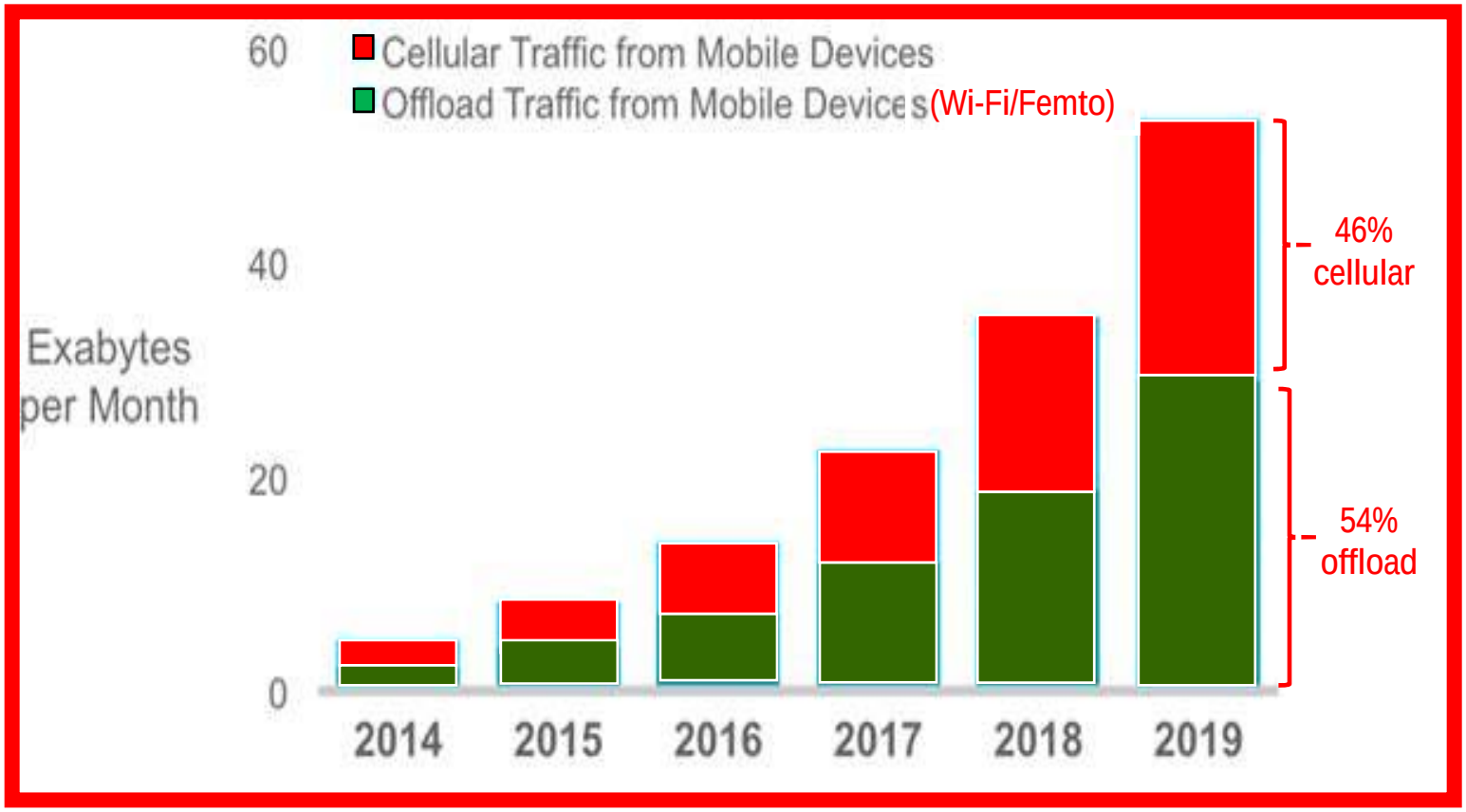
Global Wired and Wireless IP Traffic

By 2019 66% of IP traffic is Wireless (Wi-Fi and Mobile)



Source: Cisco VNI Mobile, 2015

Global Mobile Data Traffic



Source: Cisco VNI Mobile, 2015

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 coming back?!***

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

PART III:

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)
  - Indoor RSS-based Wi-Fi localization: RTLS (2001)
  - RSS-based Wi-Fi localization for smart phones: 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

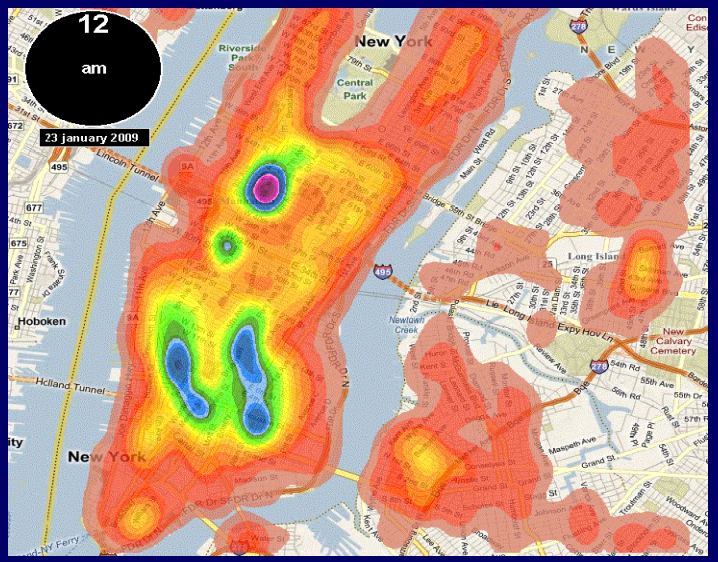
Source: Skyhook Wireless

K. Pahlavan, F. Akgul, Y. Ye, T. Morgan, F. A.-Shabdiz, M. Heidari, C. Steger, "Taking Positioning Indoors: Wi-Fi Localization and GNSS", InsideGNSS, vol. 5, no. 3, May, 2010.

Localization for smart devices

- Billions of smart devices use location information for hundreds of thousands of Apps:
  - Directly: direction finding, Yelp, Kayak, ….
  - Indirectly: gaming, tracking customers, …..
- Precision requirement are quite diversified
  - Centimeters in gaming, meters in indoor geolocation, tens of meters in turn-by-turn direction, hundreds of meters for advertisement
- Smart devices carry a number of location sensors:
  - RF Based: GPS, Wi-Fi, Cell Phone, iBeacon, ……
  - Mechanical: magnetometer, barometer, accelerometer, …
- Location sensor tracks are widely used for location intelligence

Location Intelligence



- Location-time traffic analysis
- Geo fencing (elderly, pets, children, prisoners, ….)
- Real world consumer behavior
- Location certification for security
- Positioning IP addresses
- Customizing contents and experiences

Source: Skyhook Wireless, Boston, MA

PART IV:

HOW CAN WE SUPPORT LARGE DEPLOYMENT ?

APs in California and NE

Bay Area

San Diego Area

North East

Billions of Wi-Fis worldwide mostly residential.

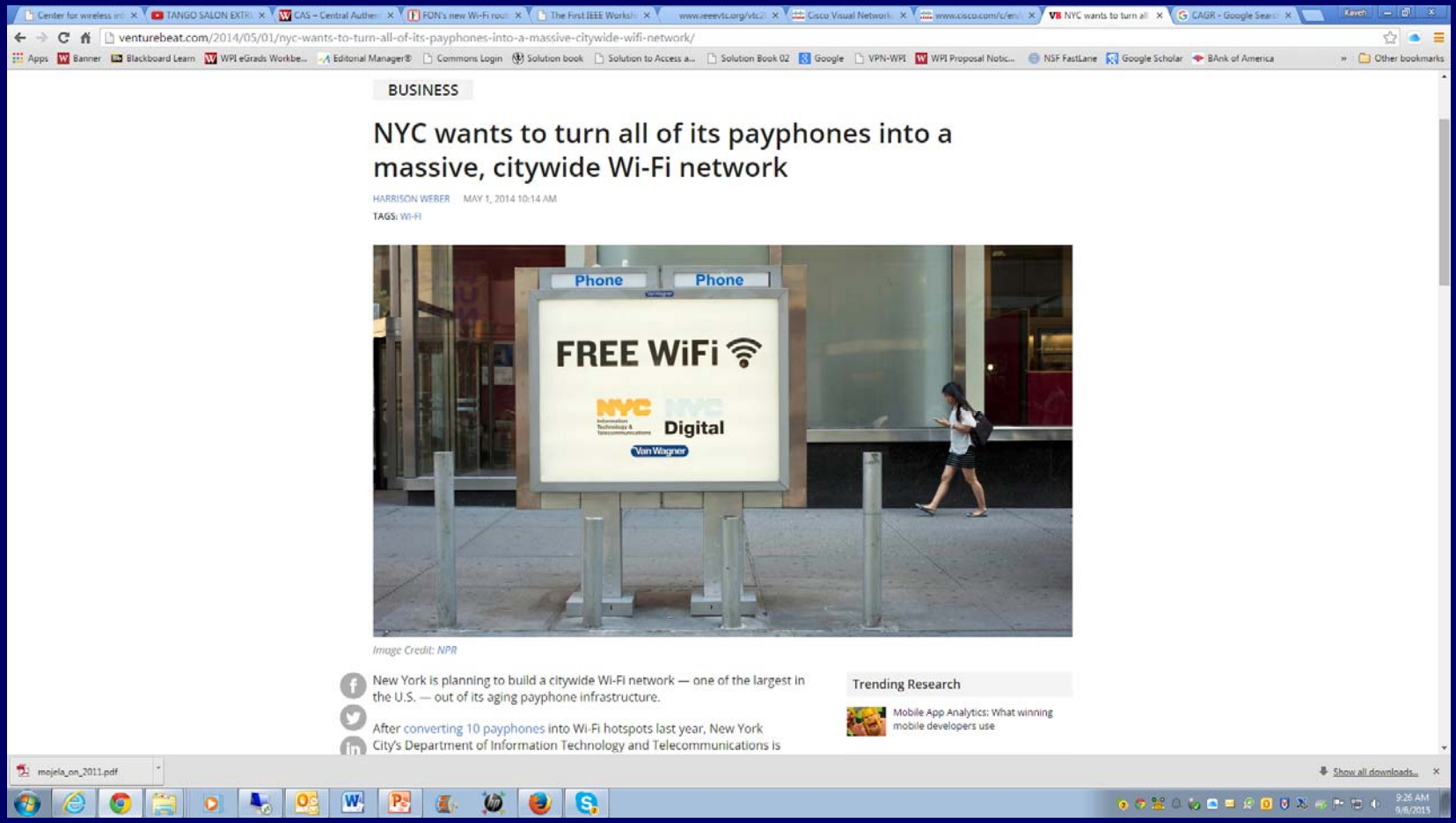
How can we coordinate/integrate them ?

Source: Skyhook Wireless

Community Hotspot

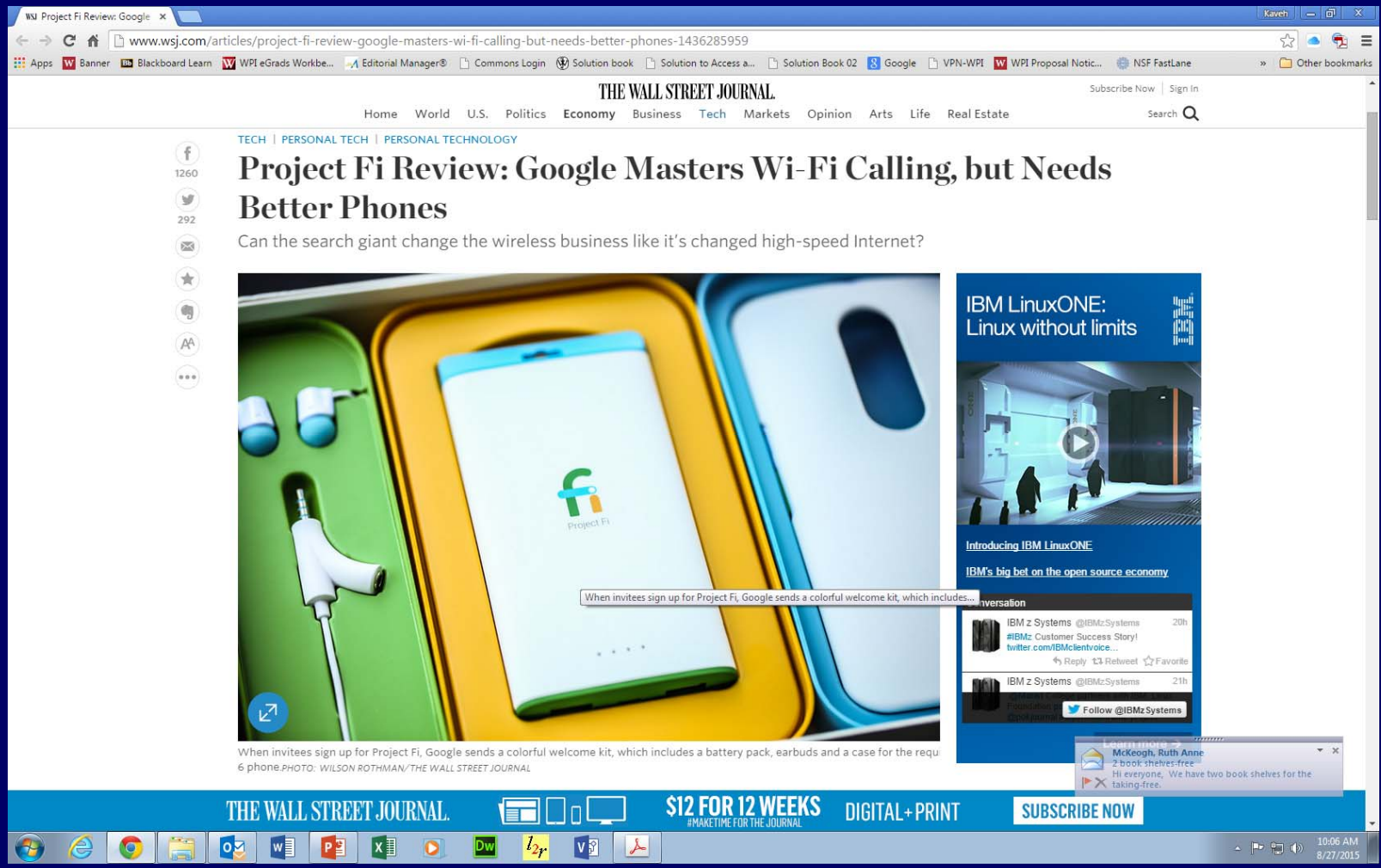
Giant Free Public Hotspots

Massive citywide Wi-Fi deployment



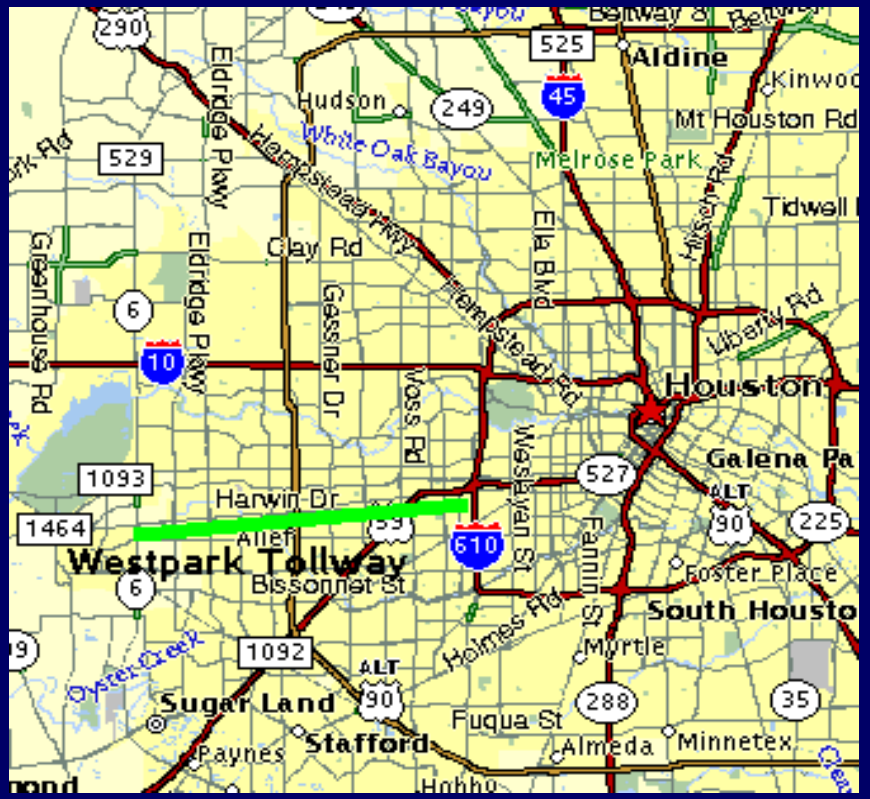
Wi-Fi Phone plans

What is the role of Wi-Fi Phones ?



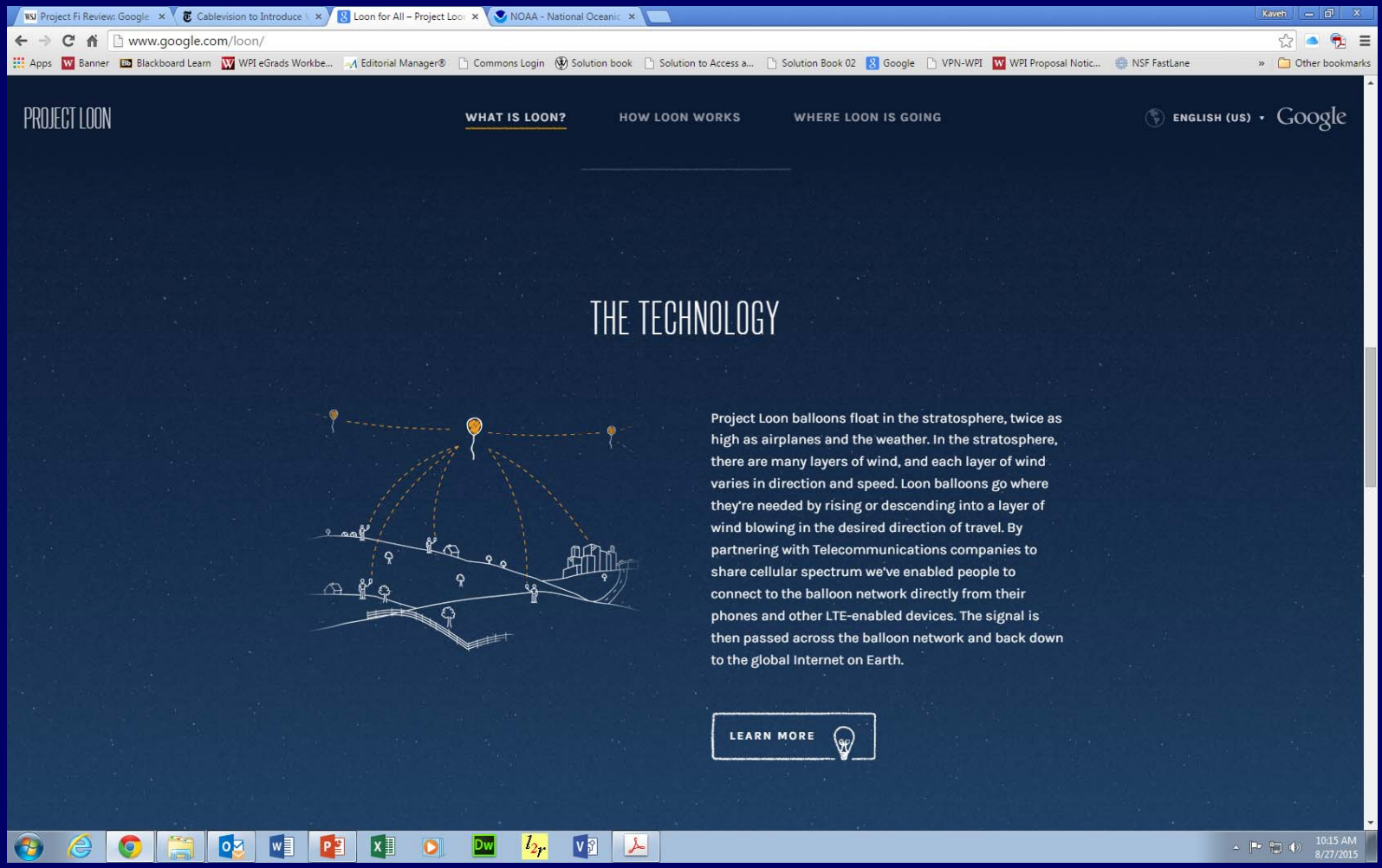
Wi-Fi vs Cellular

- 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

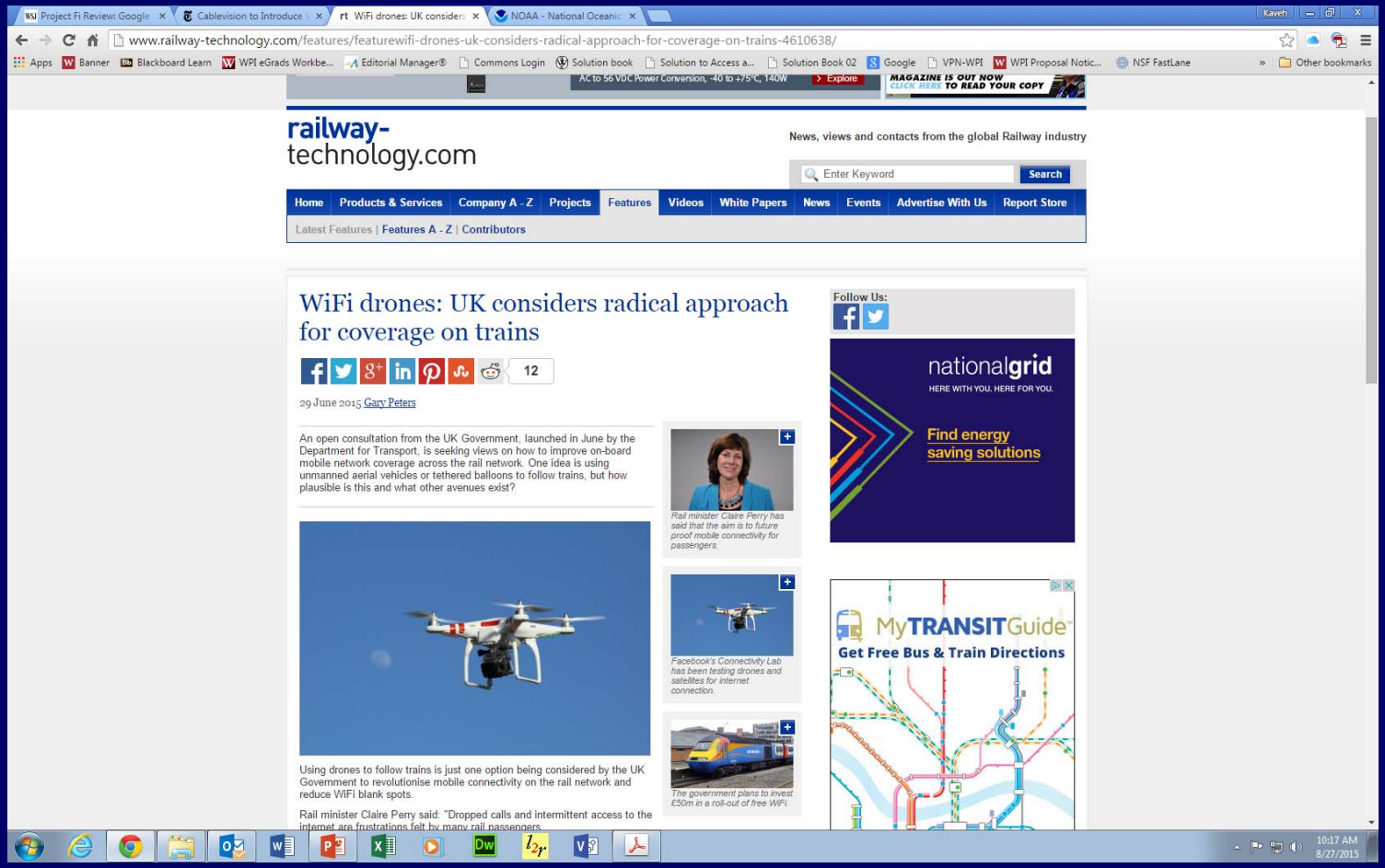


PART V:
SOME CHALLENGES

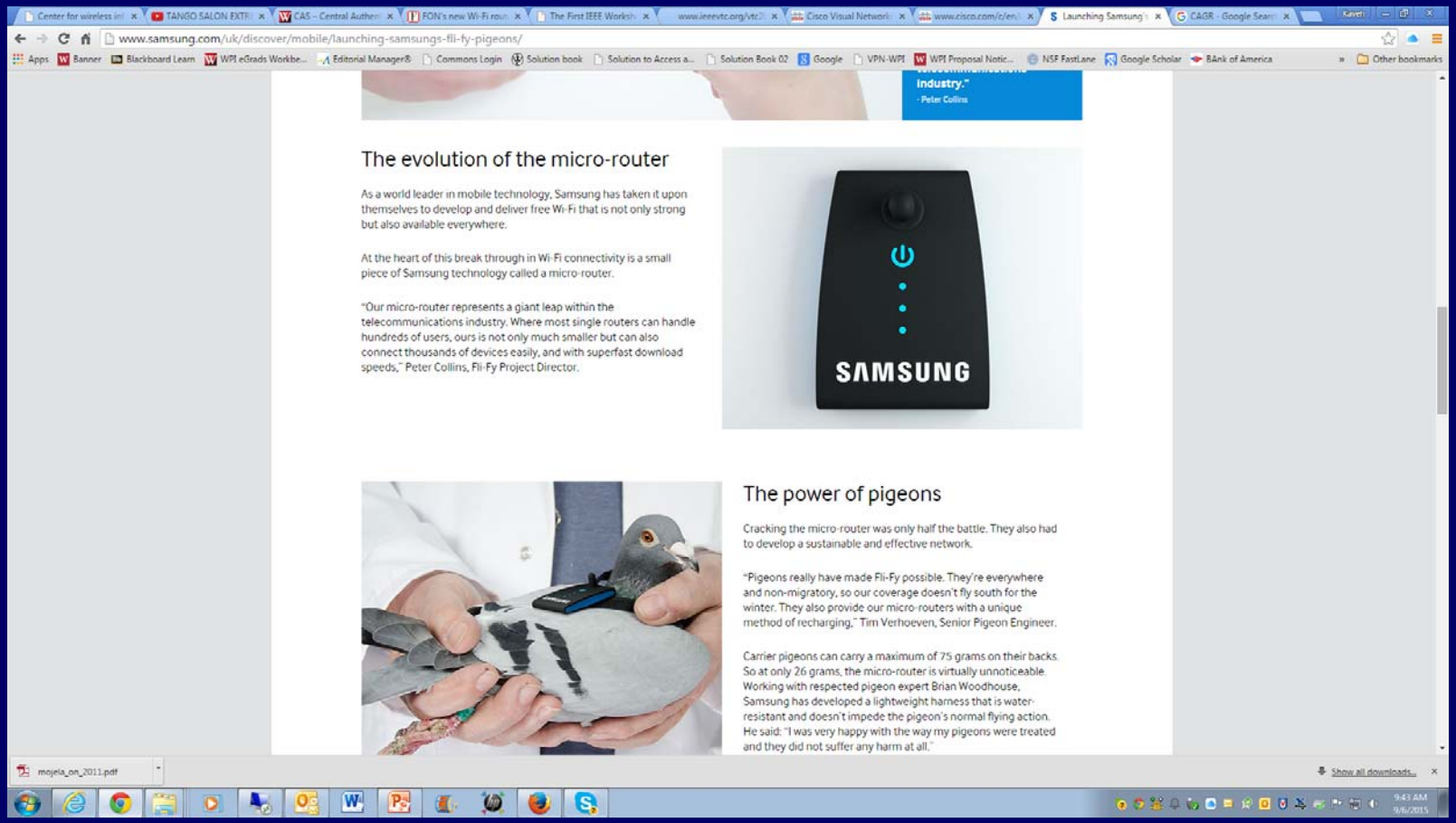
Wi-Fi in Balloons for Remote Areas



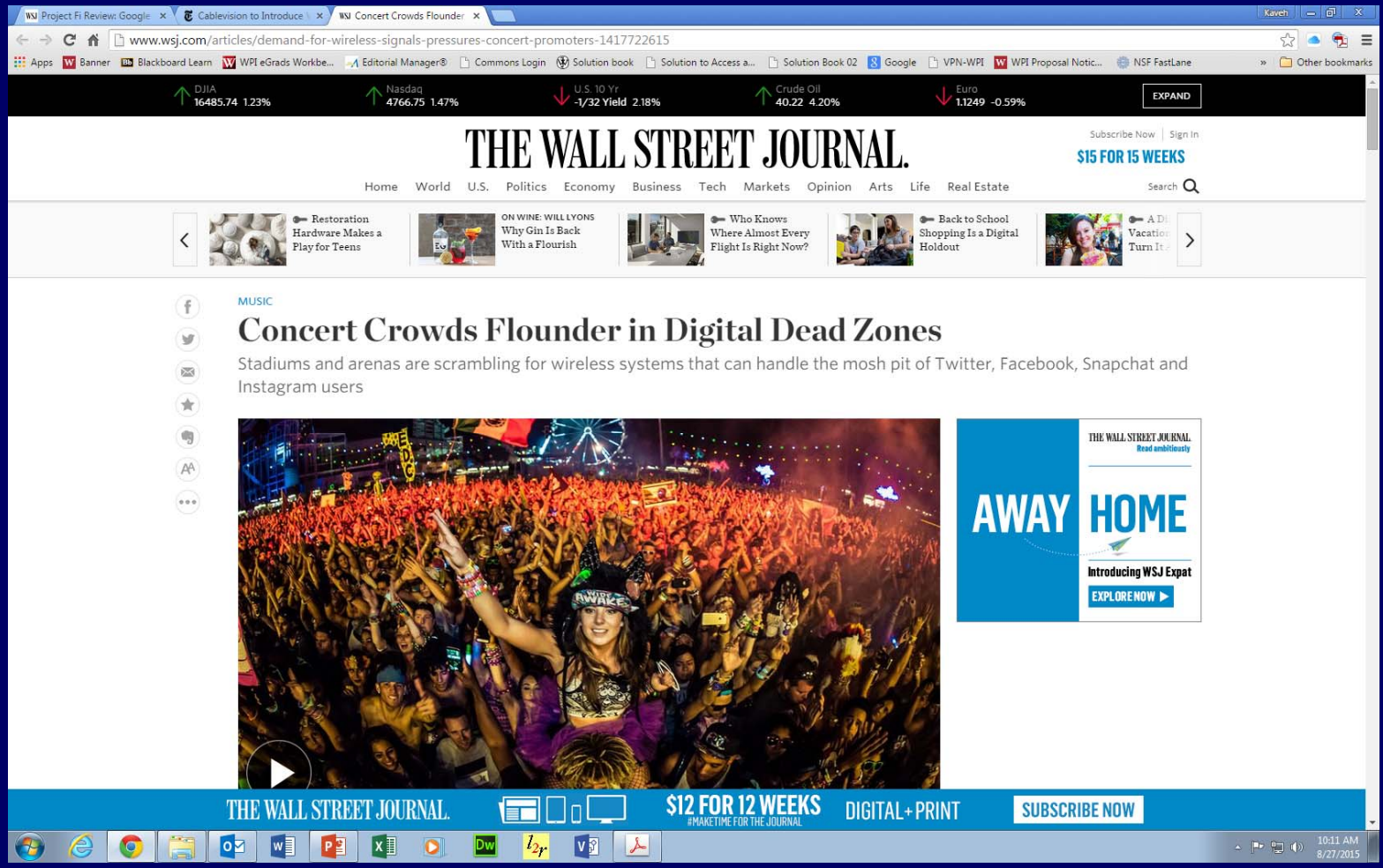
Wi-Fi in Drones for Trains



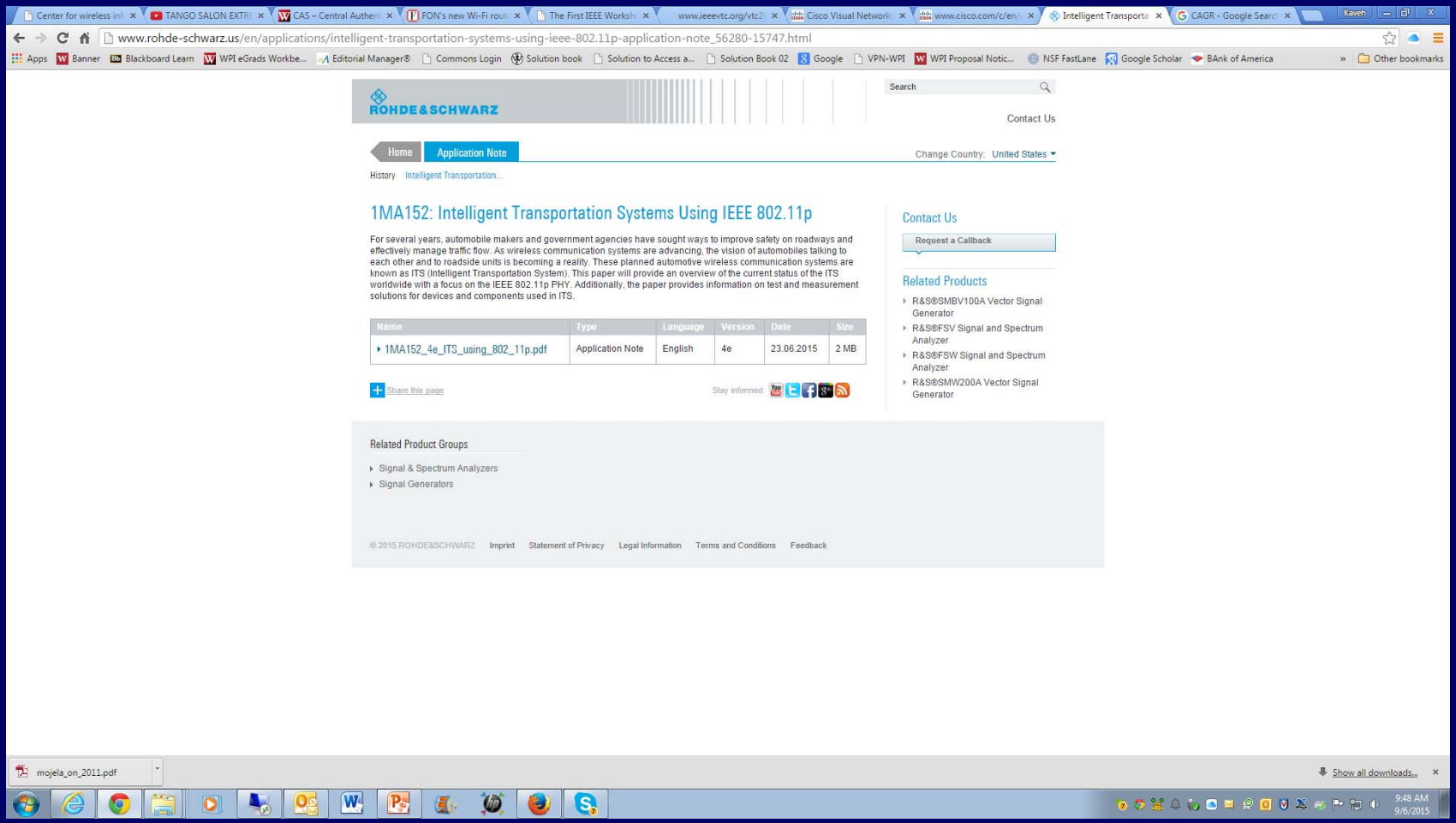
Can pigeons help coverage?



Wi-Fi in crowded areas ?

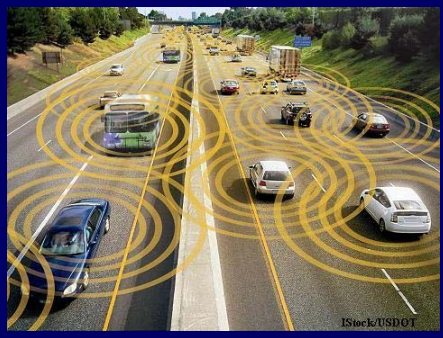


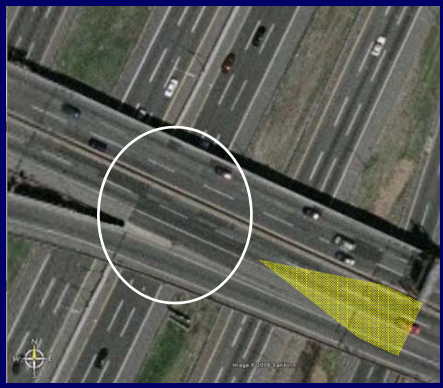
Wi-Fi in Transportation



Wi-Fi in Transportation

- Cars need to communicate for smart transportation to support
  - Communications-enabled road and vehicle safety
  - Real-time traffic monitoring
  - Intersection management technologies
  - Future telematics applications
  - Intelligent transportation services
- IEEE 802.11p is addressing these issues
- Cars carry several thousands of sensors, how can we integrate them into the IoT





Some Challenges for Evolution of Wi-Fi

- How to control the inference in massive deployments?
- How to handle coverage holes?
  - How Wi-Fi relay works in interference environment?
- How to handle crowded areas?
  - Balloons, Drone or Pigeons?
- How to handle sharing home deployments
  - How does private and public Wi-Fi at home work?
  - Who owns the home router (cable company or owner of the property)?
  - What is a good business model for massive home Wi-Fi deployment?
- How to manage secure sharing at Global scale?
- How to handle handoff for mobile voice?
- How to increase Wi-Fi localization accuracy?

Was Wi-Fi a Revolutionary Technology ?

- The WLAN industry was not initiated by Giant Telecomm companies
  - Because it was data-oriented
- The WLAN industry was not initiated by Giant Computer companies
  - Because it was not reliable and had bandwidth limitations
- The WLAN industry was integrated un both Giants after completion
  - To telecom industry when smart phones were introduced, which transformed that voice centric industry to a data centric industry
  - To computer giants, because it allowed flexibility to access connection and avoiding the wiring problem at micro-level
  - Not only that, Wi-Fi toke away localization business from cell tower localization as well as GPS industry
- WLAN industry has impacted all aspects of life unexpectedly, from that point of view, it was a revolutionary technology!

"An unexpected success against the odds, which changed the paradigm!"