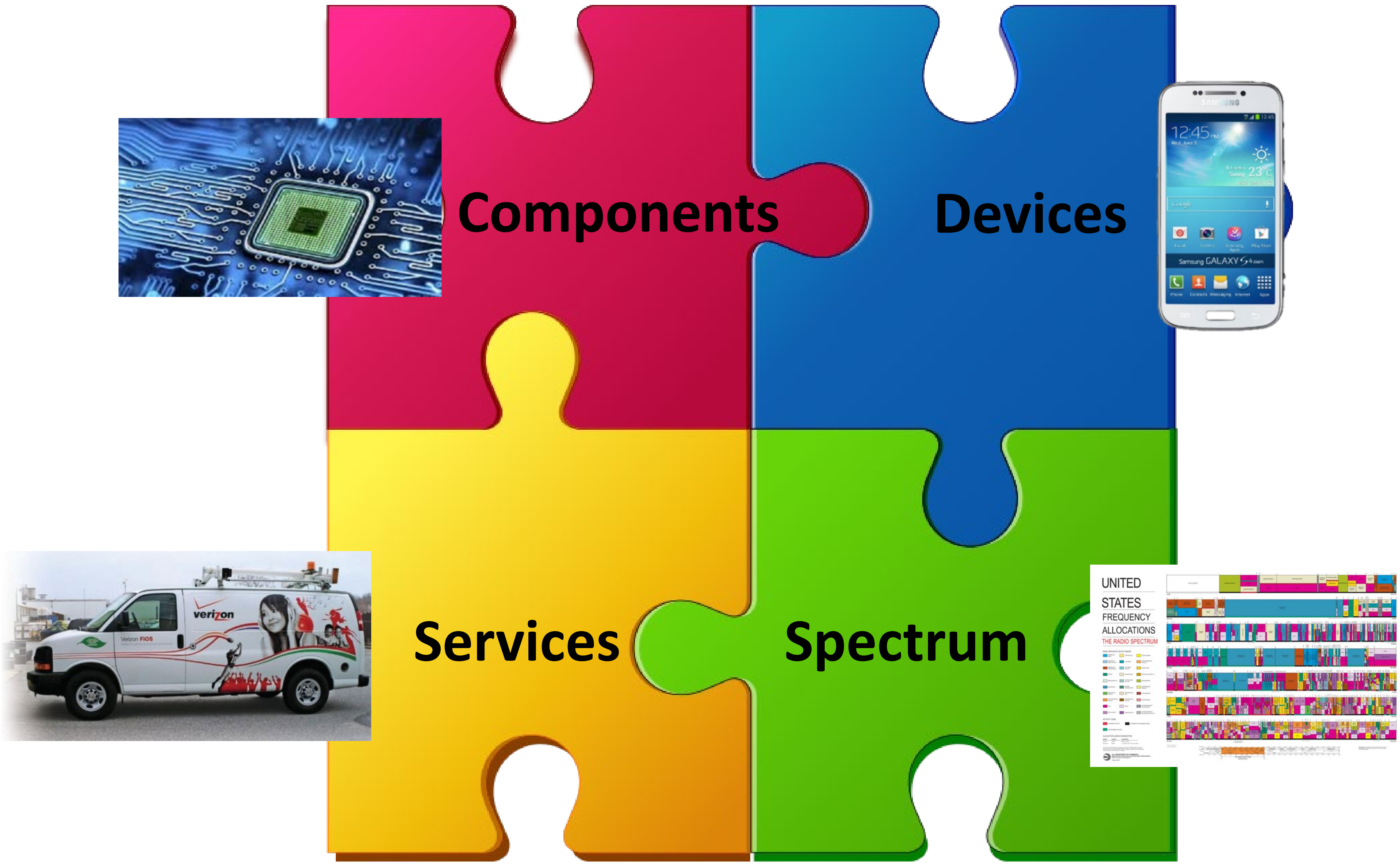
The World of Spectrum Access and Use

The Next Generation Technologies and Architectures

The Spectrum of Uses for the RF Spectrum

- Total revenues reported to the FCC by communications firms was more than $380 billion in 2011. Some estimate the total economic impact as 5-10% of the economy ($700B - $1.4 T)
- Conflict between the increasing needs of all communities: science, defense, commercial, federal government, public safety, and consumers
- Spectrum technology, policy, and management must provide greater user access and spectrum efficiency

Pieces of the Puzzle



The 3 P's of Using RF Spectrum

Multidisciplinary

"Highest and best use"

"Transaction costs"

"Auctions"

"OOBE"

"Structure Programming"

"LNA"

"Child processes"

"dB"

"Intermods"

"Ontologies"

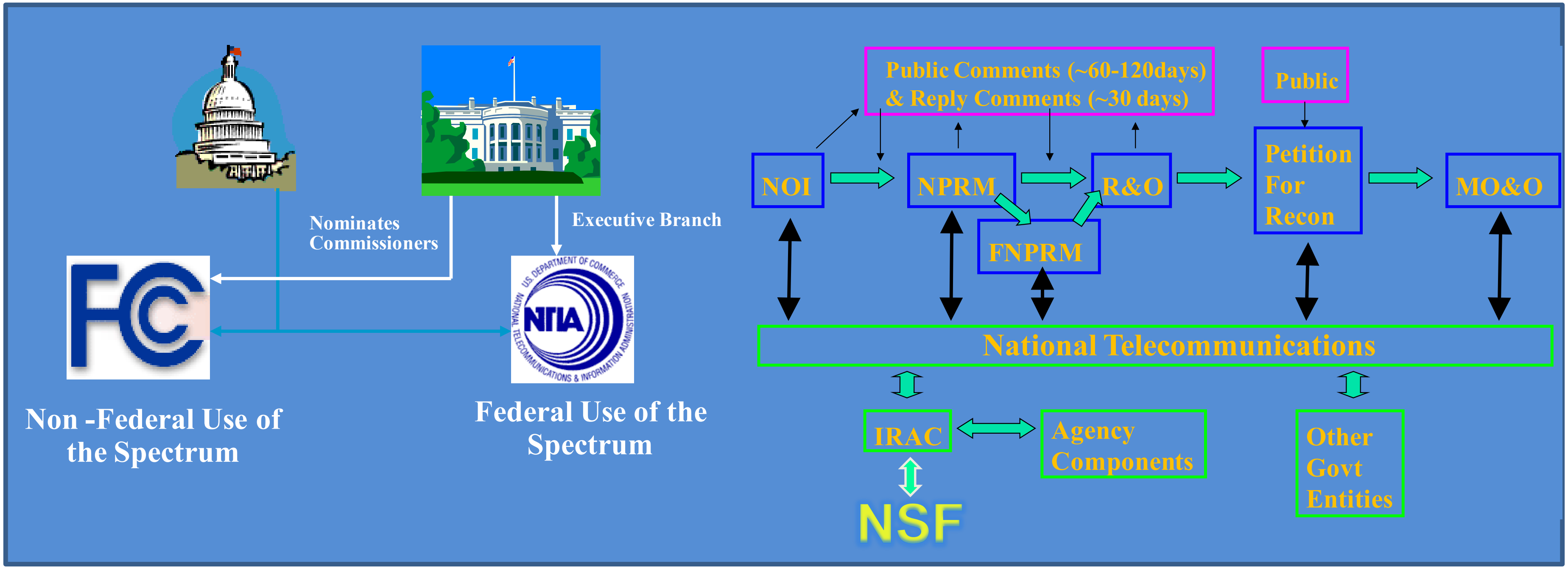
"Dynamic range"

"Provability"

Electrical Engineers, Computer Scientists, Communications Engineers, Lawyers, Policy Makers, Economists, Physicists, Material Scientists, Pontificators

- **Possible** – Technology for components, radios, intelligence, networking, applications, sensing, and new applications
- **Permissible** – Regulatory: impact on current systems, including interference analysis techniques, new methods for managing rules, etc., e.g. NAS studies
- **Prudent** – Economically-viable (includes interference mitigation); robust security, technology, and economics

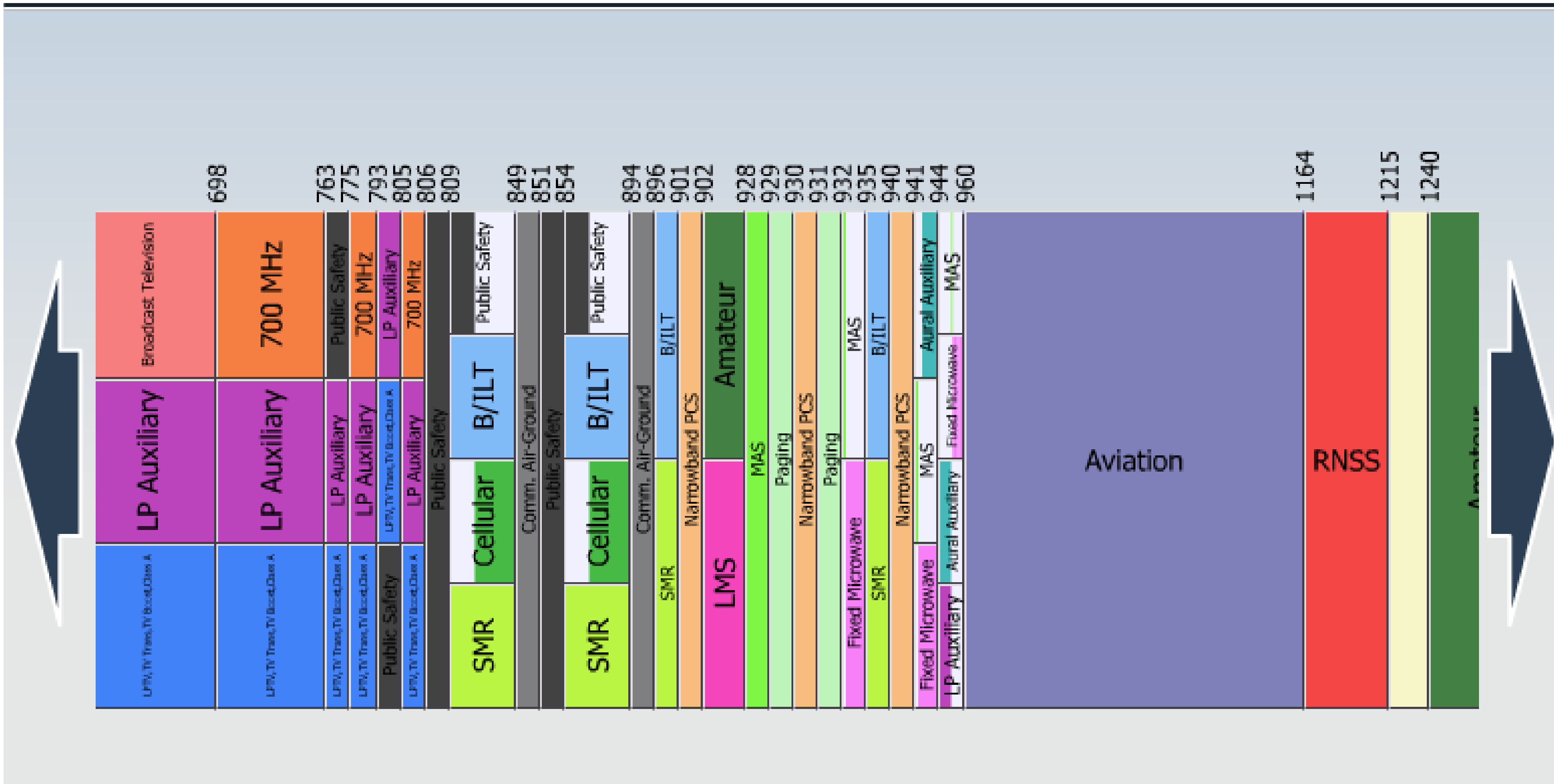
National Spectrum Regulation and Policy



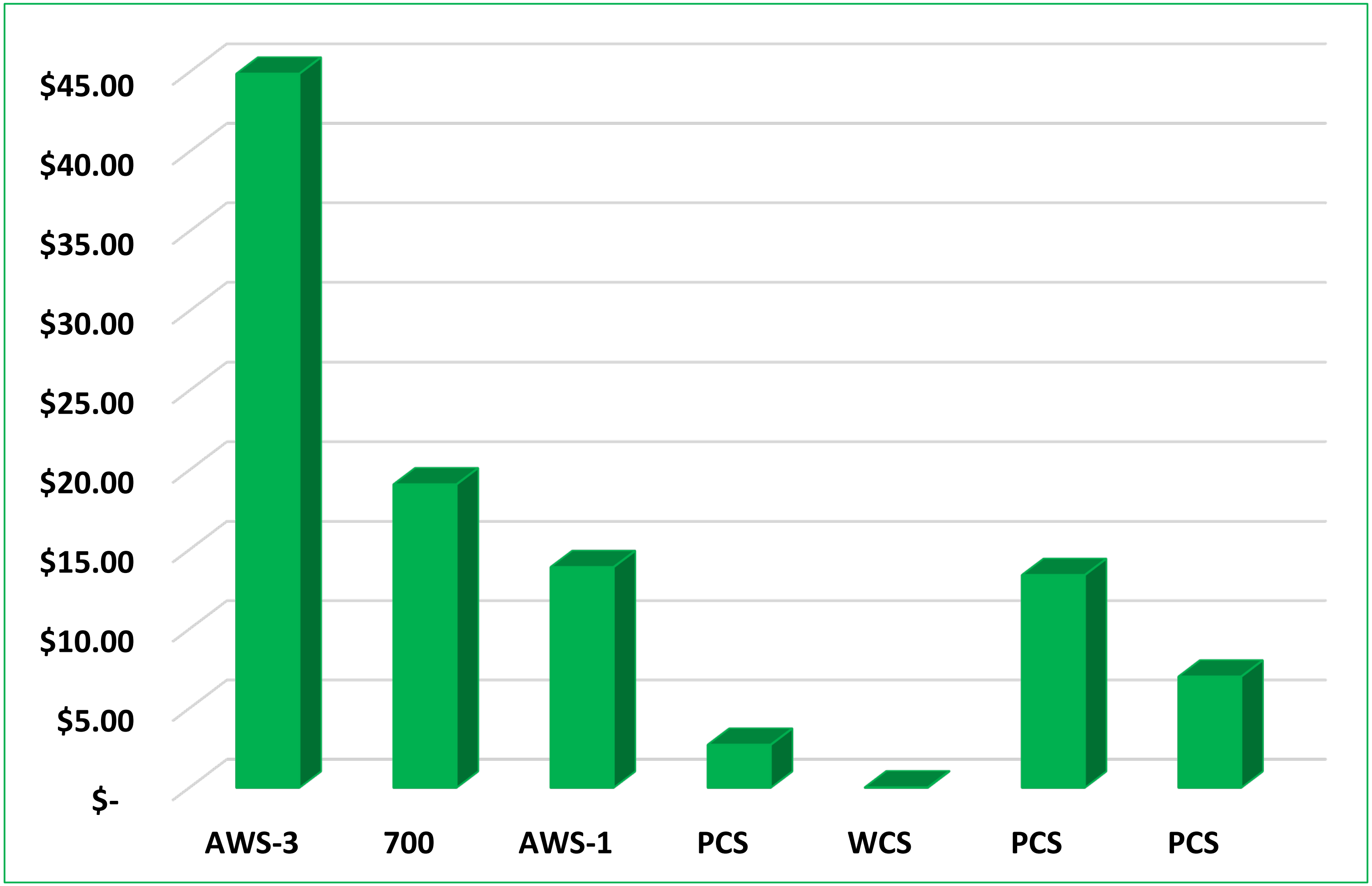
Spectrum Management has a National component (FCC and NTIA) and International Component (ITU)

- Allocation (Define the Service and Technical Rules
- Assignment (License)

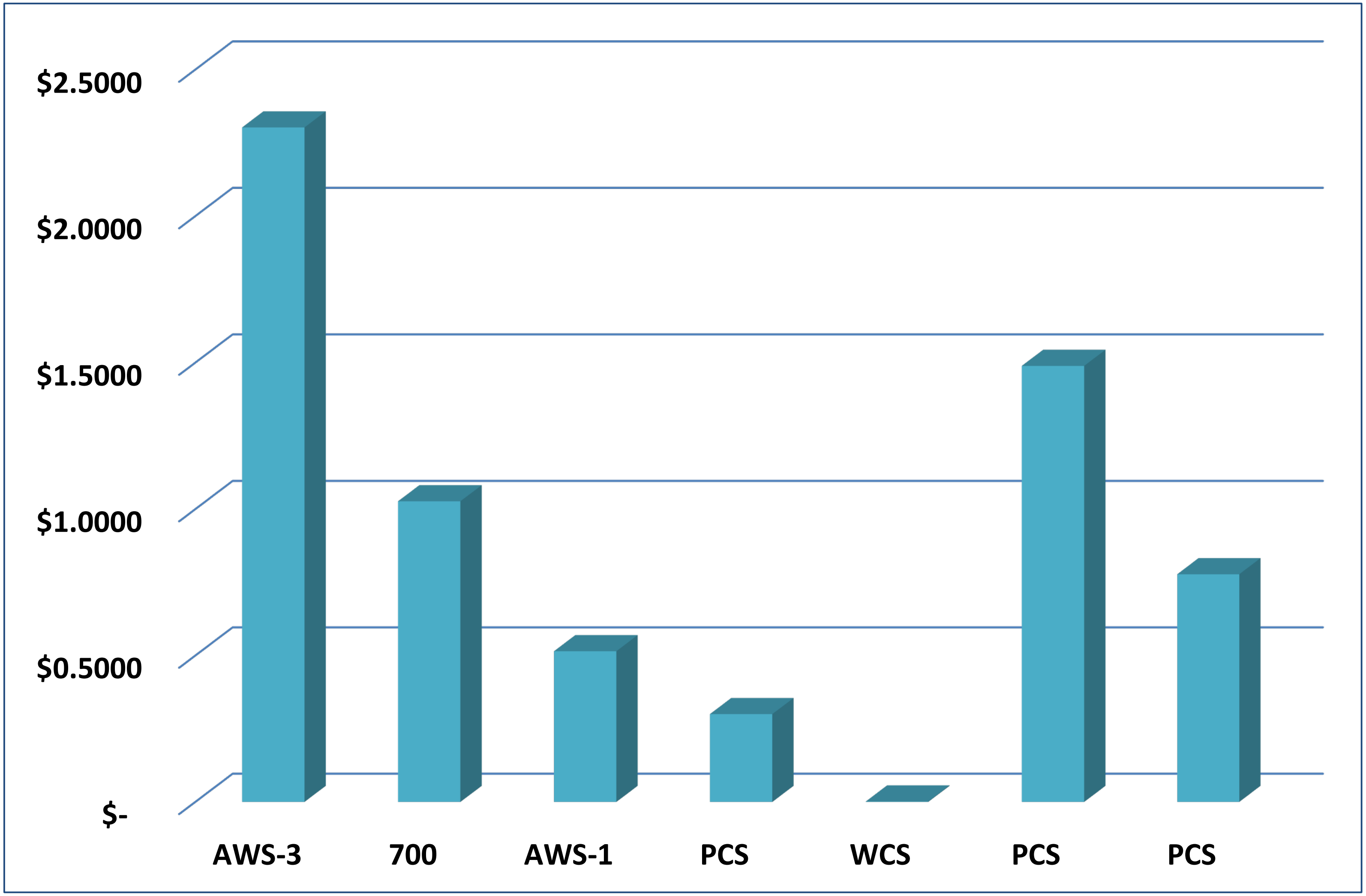
Some Bands are Single Purpose, Some are Multi-Purpose



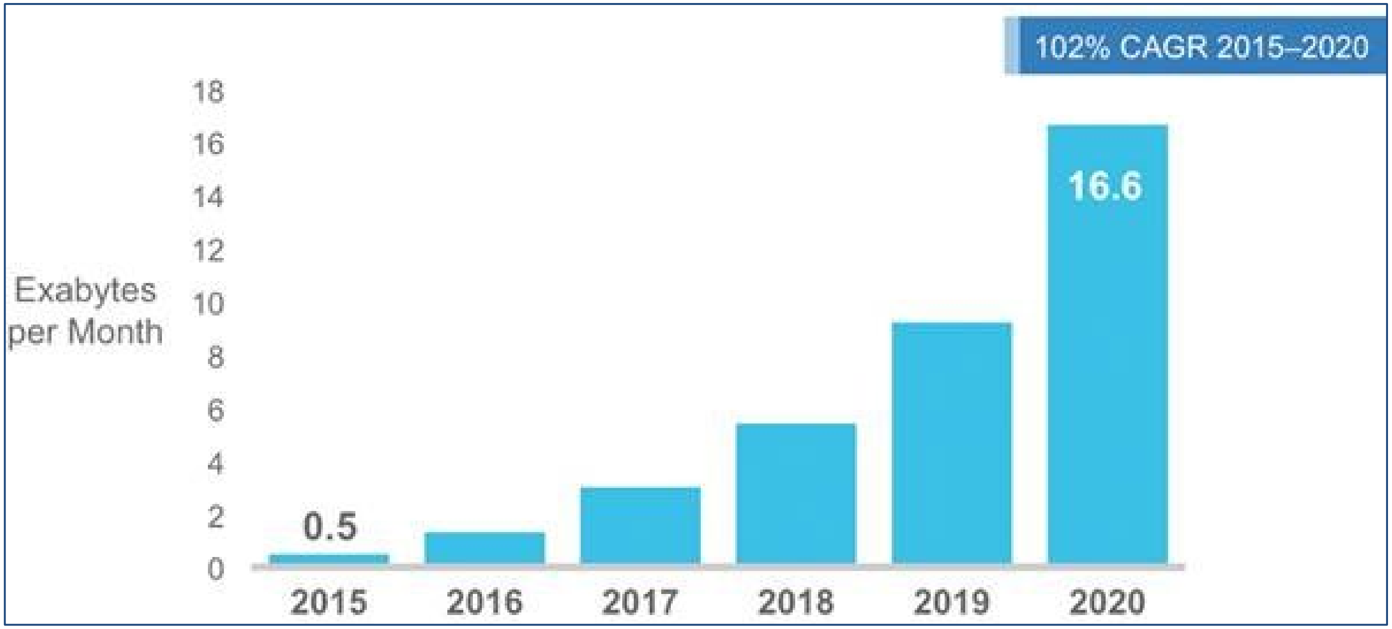
Spectrum Auction Revenues ($B)



Spectrum Auction Values ($/MHz-PoP)



Wireless Use Growing Fast(er)



- **100% growth per year (if realized) cannot be addressed by just more spectrum**
- **High spatial reuse will be required**

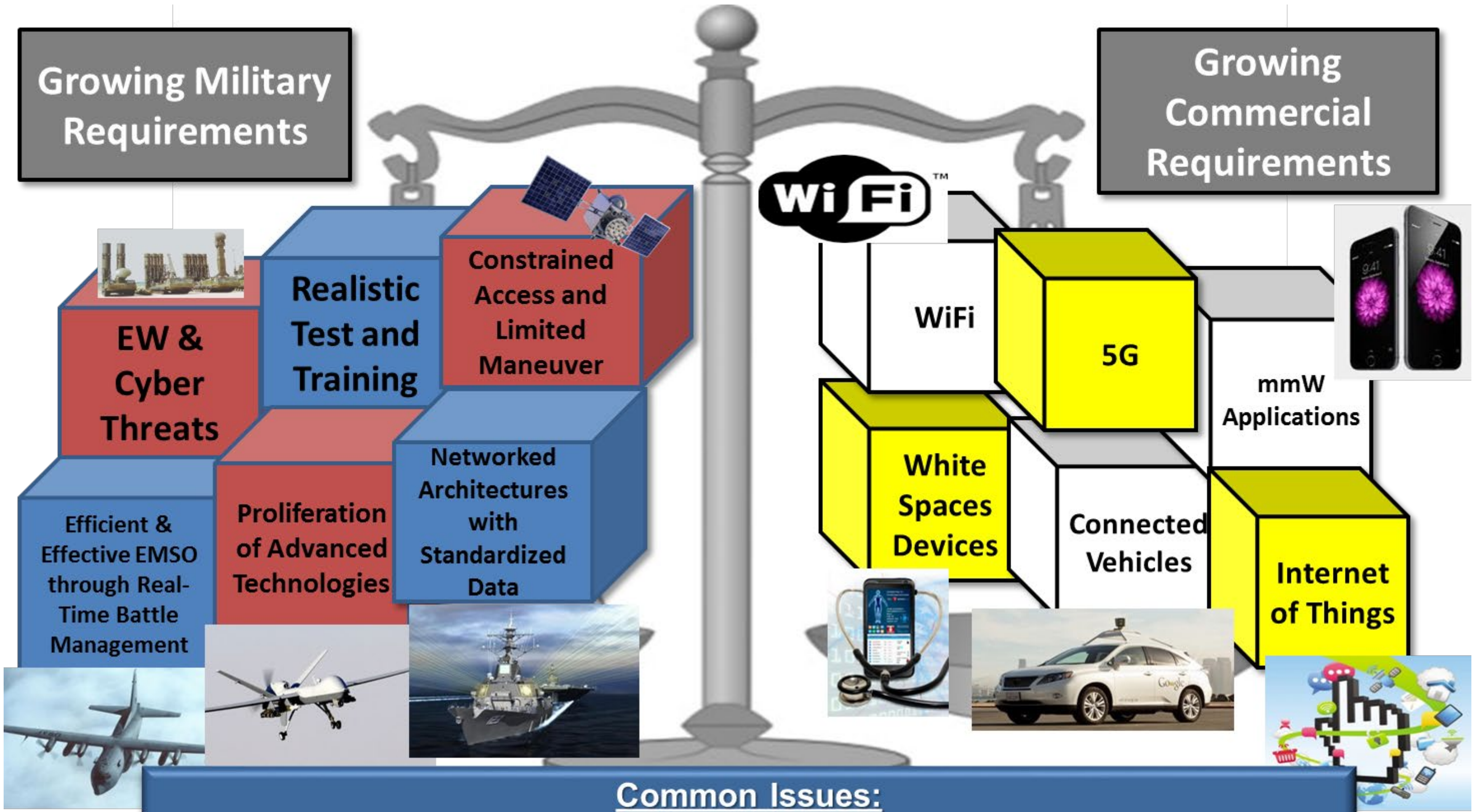
Spectrum is Scalable

- **How does 120 MHz of Spectrum (e.g. VZW) turn into 2 Mbps / customer**
  - 100 million customers
  - 50% spectrum is downlink
  - 1% duty cycle
  - 33% average loading on base station
- **Compute the load overall**
  - So 100×10^6 x 2×10^6 x 0.01 / 0.33 = 6×10^{12} bits/second downlink in the network
- **Cellular exploits spatial reuse**
  - So 50,000 base station x 60 MHz downlink spectrum = 3×10^{12} Hz for the network
  - QPSK modulation (2 bits/second per Hz) → 6×10^{12} bits/second downlink in the network

Great! … so to get 8x more capacity (3 years of growth) you need more spectrum (MMW?) or more (smaller) cells or both

Challenge: Balancing Economic & National Security

"This is not just DoD's problem but all our problem"

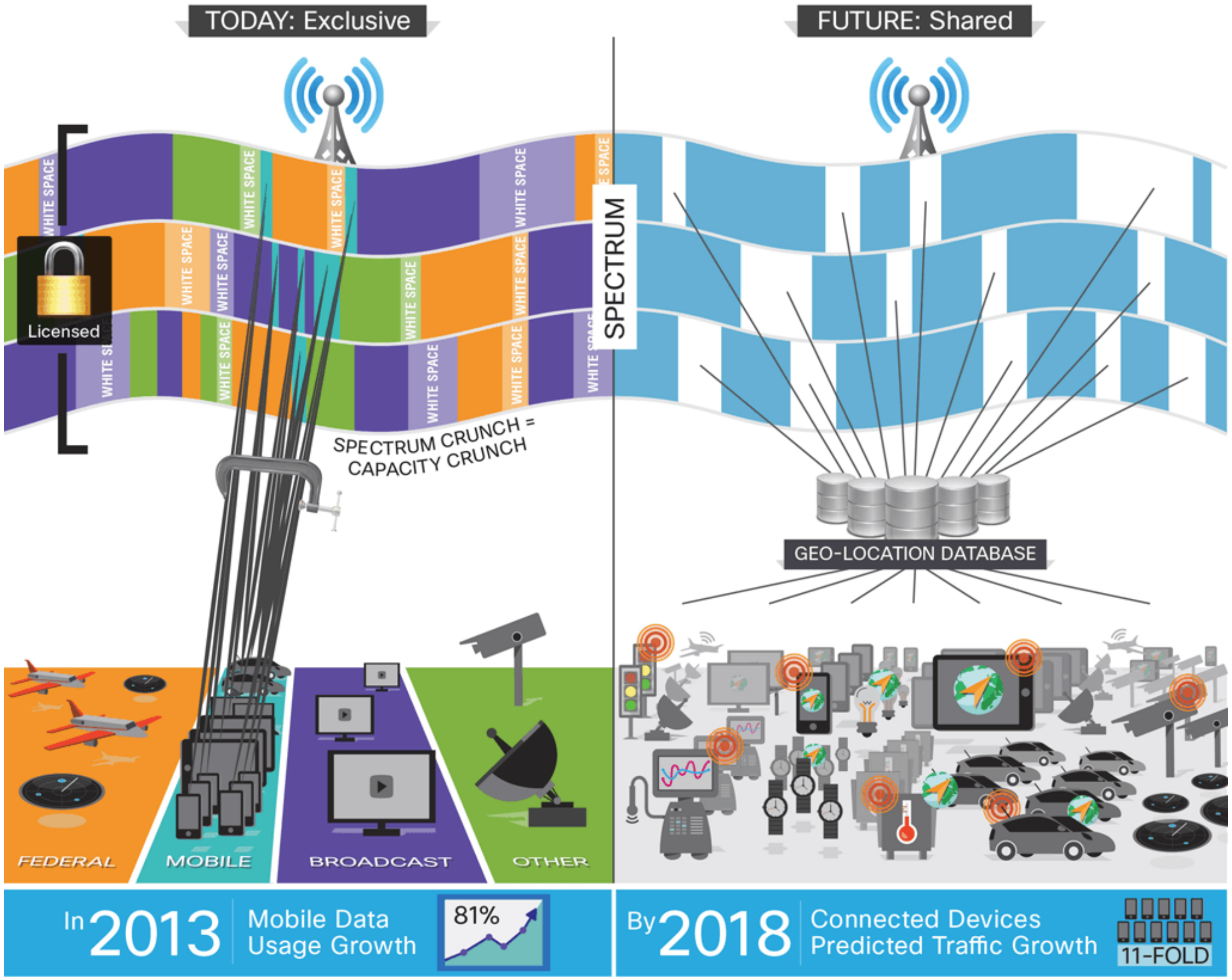


Common Issues:

- Information & Mobility Requirements
- Weaponization of COTS Technology
- Nontraditional Partnerships
- Global Proliferation
- Sharing Opportunities
- S&T/R&D Investments

ADVANCED TECHNOLOGIES

The Future is About Sharing, Co-Existence, Dynamic Access



The Need for Technology is Great

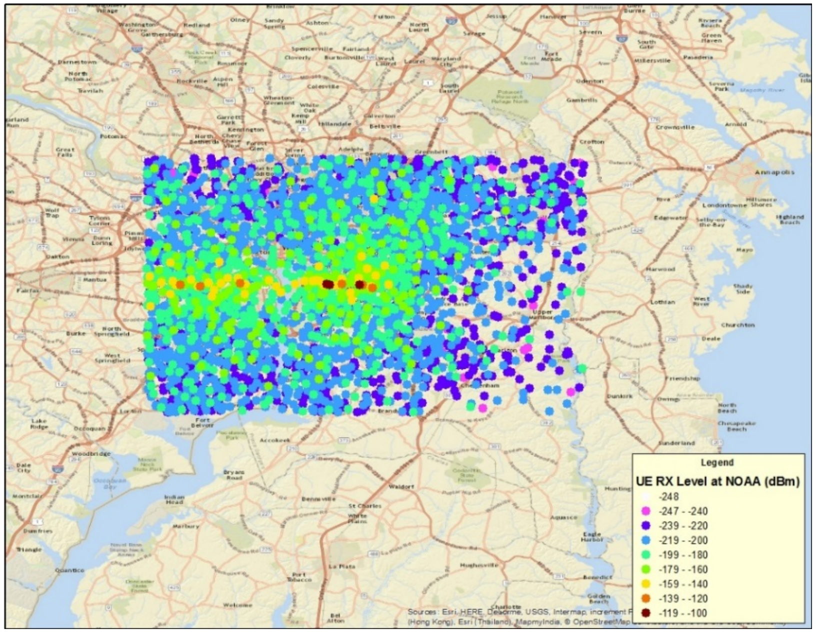
- **Overarching thesis for all resource management**
  - Observability and Controllability
    - Measure More Accurately
    - Adapt More Quickly
    - Predict if Possible
- **Databases: Dynamic and Static**
- **Measurements: Spatial, Temporal, Spectral**
- **Interference Dynamics: Single or Multi-System Optimal**
- **Convergence: Sensing, Communications – PHY and Processing**

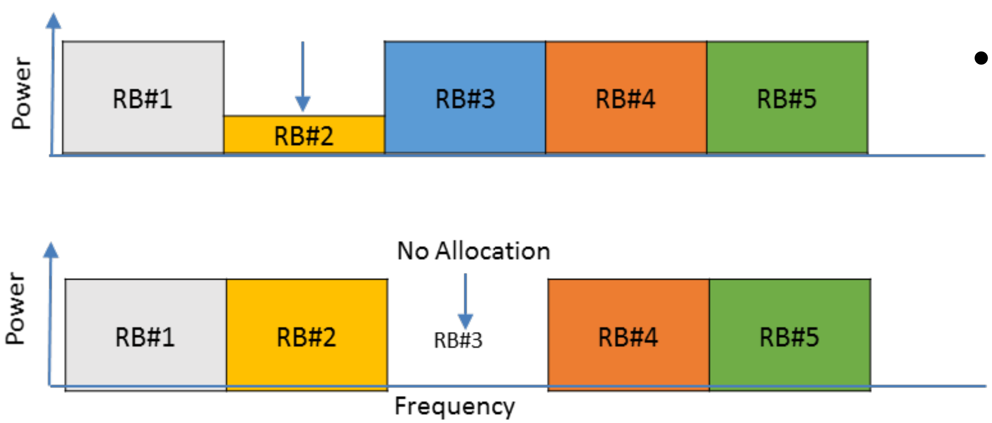
POES/GOES Spectrum Monitoring (AWS-3)

- **Monitoring systems to be deployed around ground stations to determine if interference events are about to occur**
- **Challenge: Protecting a receiver using high aperture gain**
  - Impact is an incoherent integration of many emitters at the aperture
  - How to make cost effective without building a duplicate system
- **Payoff: Cooperative spectrum management to allow for more active control of the secondary service**

Interference and signal monitoring can be extremely challenging for directional systems

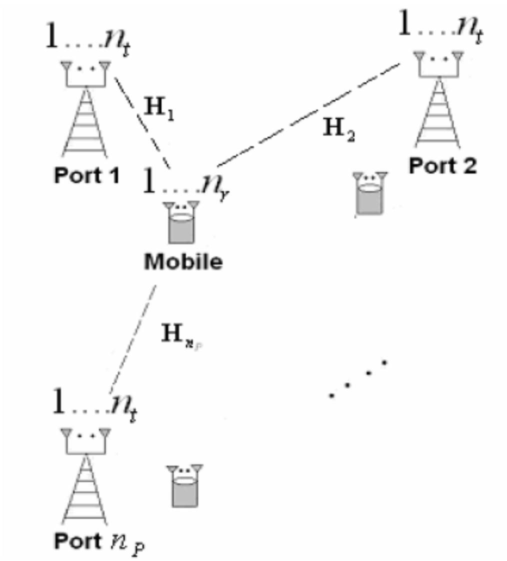
Interference Analysis: Understanding the Physics, Components, and Network



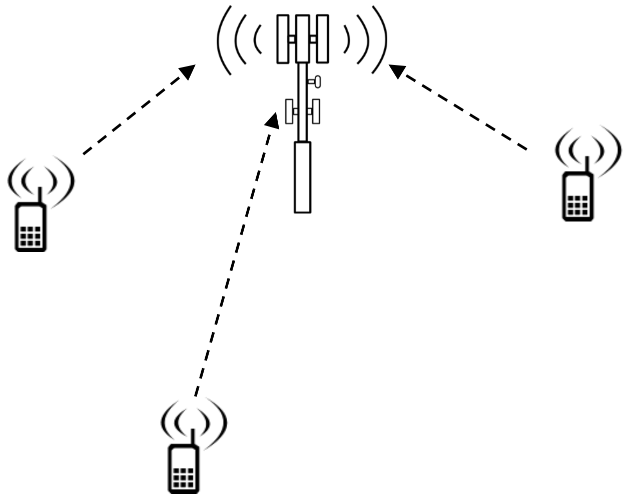


- **Handset-level Simulations**
- **Component-level understanding**
  - Adjacent Channel Leakage
  - PHY-layer control
- **Propagation Physics**
  - Understanding Clutter
  - Measurement Feedback
  - Interference vs Deployment Analysis
- **Network Solutions**
  - Observability vs Controllability
  - Feedback Mechanisms

Will the Real Distributed MIMO Stand-Up



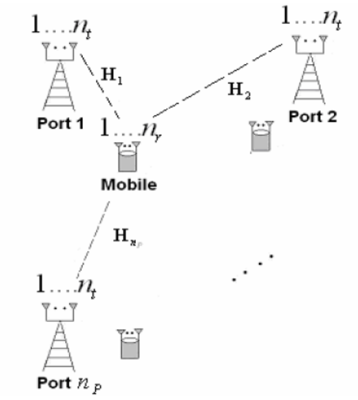
Multi-Base Stations

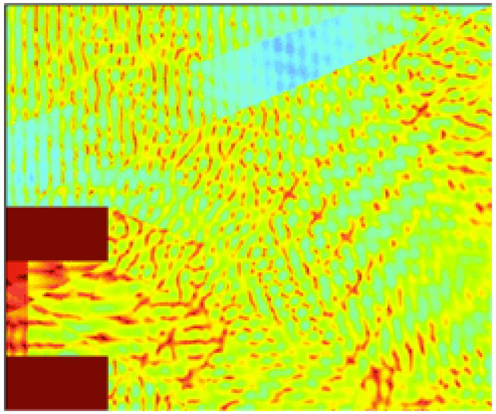


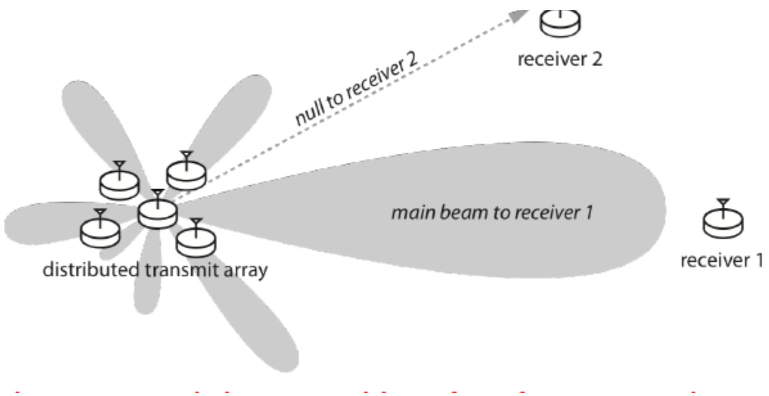
Multi-User Equipment

- **Current D-MIMO: Multi-Base Station (or widely distributed Base Station Antennas) – boosting capacity**
- **New D-MIMO: Multi-User Equipment – reducing interference and allowing co-channel operations**

Distribute Apertures Challenges Classic Thinking about Power, Aperture, Interference







- **Multi-antenna systems with coherent gain (EIRP???)**
  - Distributed MIMO (including Macro-MIMO) are becoming viable technologies
  - Given the large extend of the “array”, get many grating lobes, etc
  - Signal level varies wildly from coherent gain regions to incoherent gain areas
- **So measurements may be only valid at a precise location**
  - Challenge problem for all measurement needs

Spatial reuse is become a primary driver (if it isn’t already) for meeting capacity → spatial analysis may become critical

Research Topics

- **Statistical analysis to meet the requirements**
  - What is needed for each applications (before, during, after sharing)
  - Single platform / multiple platform techniques
  - Coherent versus incoherent measurements
  - Statistical analysis versus noise floor

- **Impact of space on measurements**
  - Environmental Blocking (buildings, etc) versus NLOS propagation
  - Beamforming
  - Distributed MIMO

Research Topics

- **Advanced Measurement Architectures**
  - Quantity vs Quality
  - Mobile vs Fixed
  - Coordinated vs Coherent

- **Impact of Policy to Measurements**
  - How can policy make measurements easier?
  - How can measurements address privacy-security concerns?

ADVANCED SERVICES & ARCHITECTURES

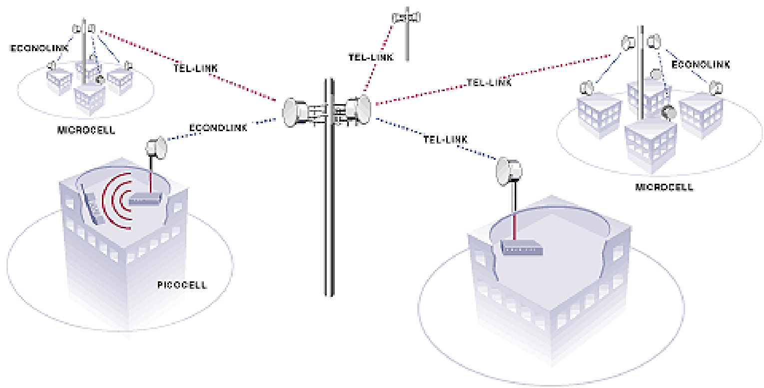
Driver 1: Segments of the RadioSpace

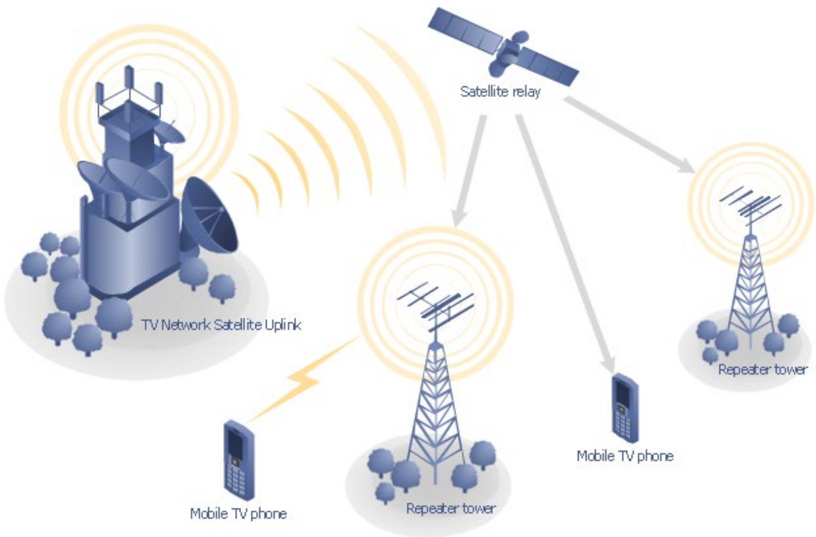
Applications	Protocols	RF – Spectrum	Architectures
Plethora	WiFi AMPS GSM/CDMA LTE / LTE-A NTSC/ATSC ATSC 3.0 Multi-Carrier	Cellular 2.4/5 GHz PCS AWS 700 MHz 600 MHz	Cellular Broadcast HetNets AP-Clients
1 year or less	5-10 years	10-20 years	20-40 years

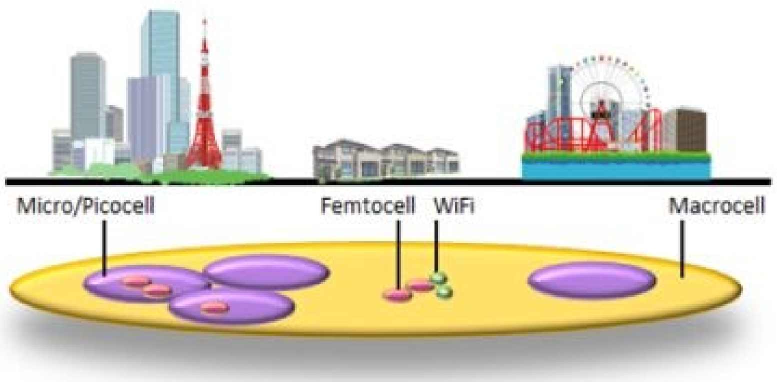
Driver 2: Longevity of the Applications

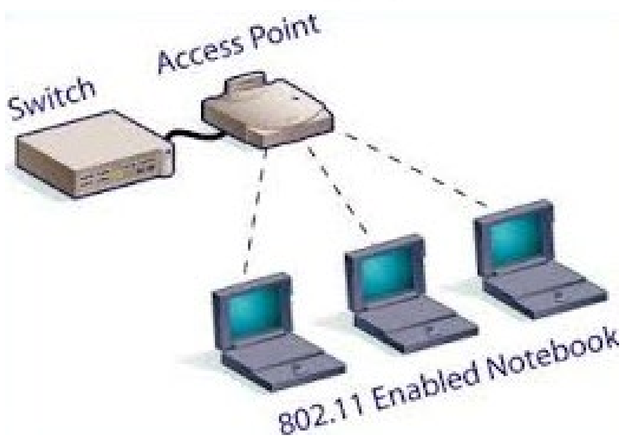
IoT Disposables	Mobile Phones	Autos	TVs	Military
1 year or less	1-5 years	5-10 years	10-20 years	20-40 years

Architectures





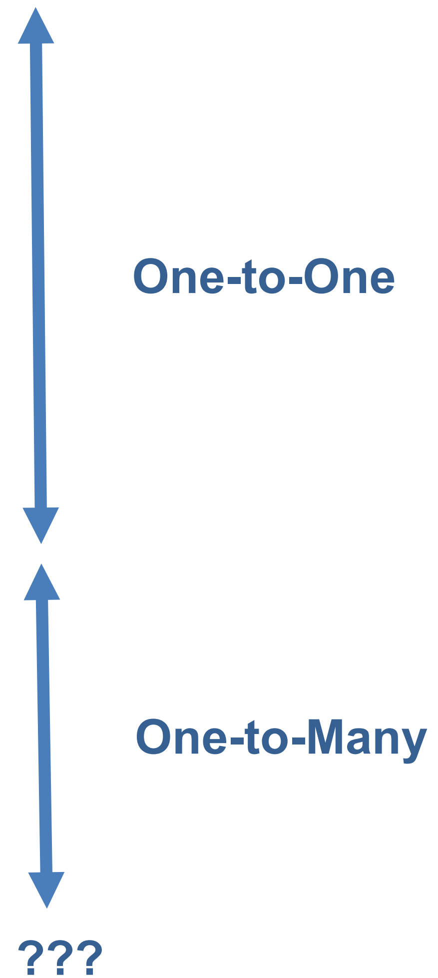




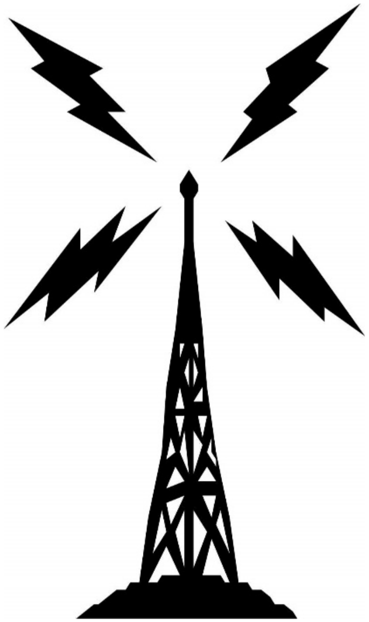
Broadcast, Point to Point, Cellular, Access Point, etc

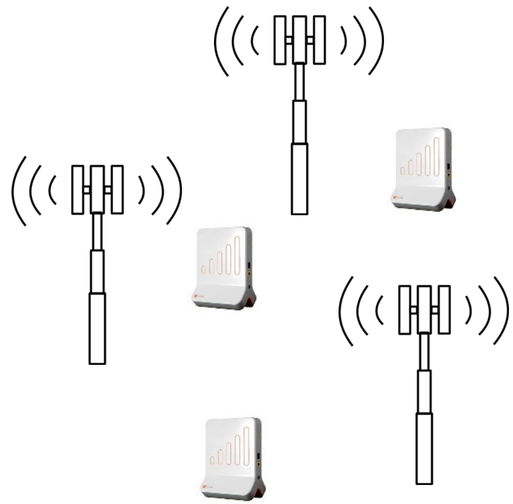
Migration of Applications

- **Voice**
- **Data – email**
  - Photos
- **Data – web**
- **Data – services**
  - Download
  - Cloud (download)
- **Video**
  - Streaming
  - On Demand
- **Social Networking**
- **IoT**



All Wireless is Broadcast





Broadcast
Downlink Only
UDP-like

Streaming Video,
Time, GPS,
One-to-Many

UniCast
Uplink/Downlink
TCP-like

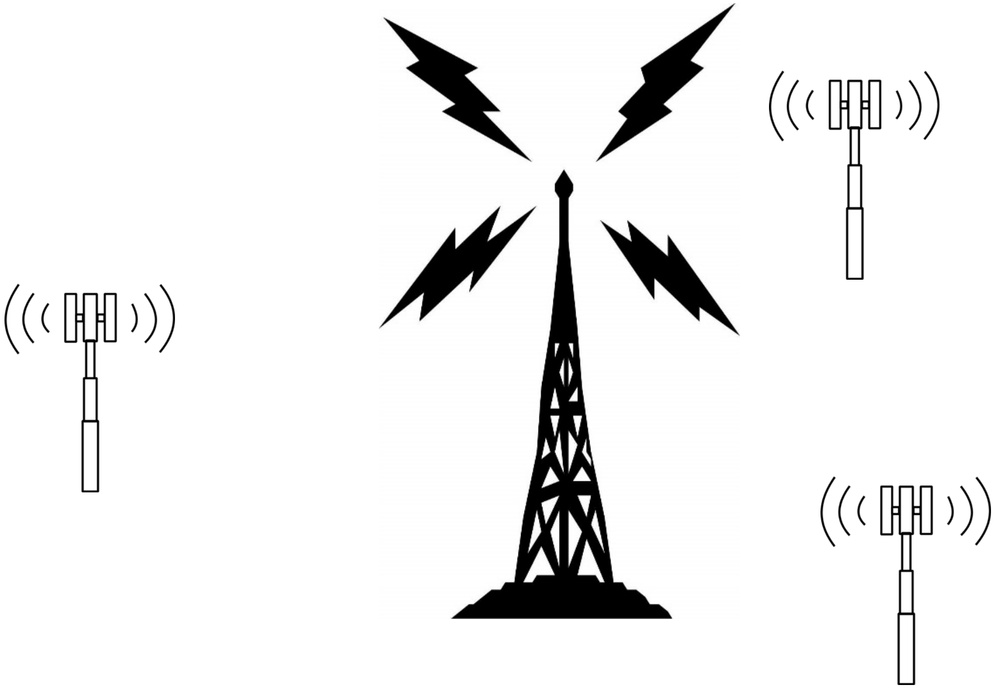
Voice, Data,
Everything,
One-to-One

Hybrid
Uplink/Downlink
TCP-like

IoT, VoD, Social
Networks,
Many-to-Many

Hybrid Architectures

- **Goal – deliver to the customer what the customer wants**
- **Insight**
  - Sometimes many customers want the same content, and usually it is the “large” content
  - Memory is inexpensive and transmissions are expensive



Summary

- Access to spectrum will require sharing and new analytical methods to measure the spectrum, adapt devices, and control interference
- Distributed antennas, bands, and content continue to grow in importance within the ecosystem
- The application space drives architectures … so why are we using architectures developed for 2-way voice
- These are challenges for engineers, scientists, economists, lawyers, businesses, and policymakers

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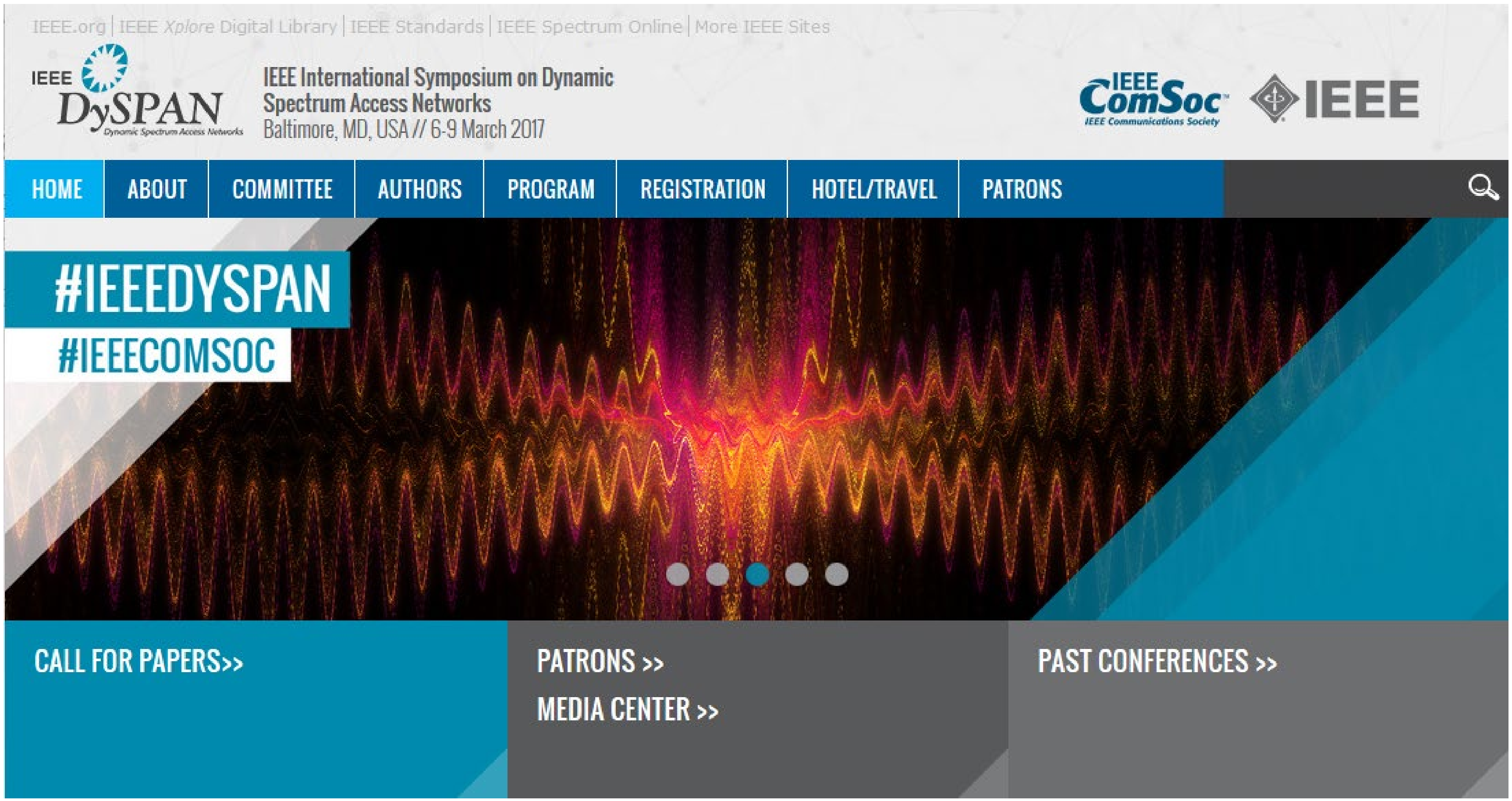
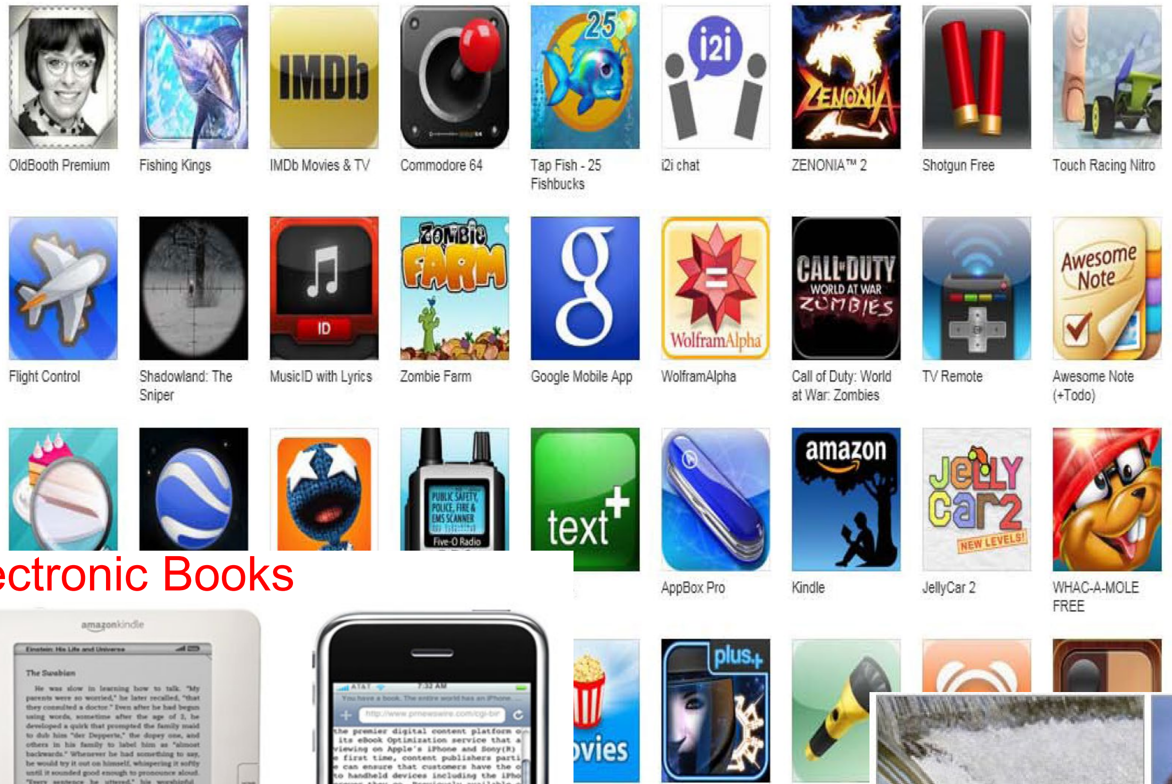
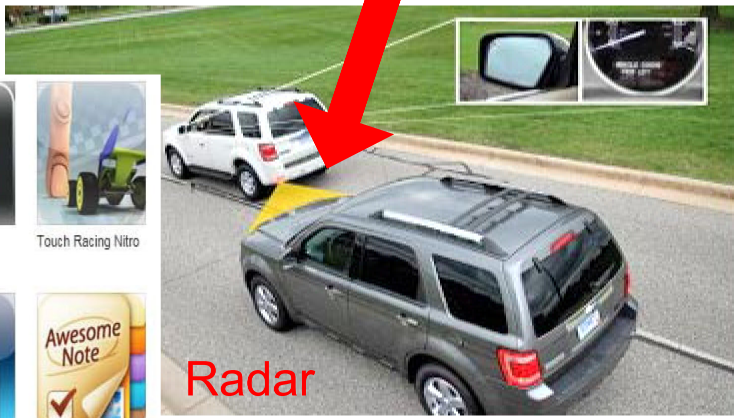


- Electronic devices and user applications continue to be developed in larger scales and on shorter timelines. Wireless communications architectures, however, tend to move at a much slower pace. And spectrum access, the raw material, is driven by national and international policies and migrate at something barely faster than glaciers. The question is “How do we harmonize these timescales?”
- LTE, a.k.a. long-term employment, is an advanced waveform stack that has the capacity to support many end-user applications. This one-size-fits-all approach not only strains the development of new devices and applications but also the means in which to access the RF spectrum. New approaches need to be developed.
- This seminar will provide a look into the world of spectrum access and spectrum use. We will start with spectrum and how it is accessed with a focus on new emerging technologies. Then provide a look into new architectures that break the mold of traditional communication systems. And finally, we will delve into the impacts of these changes on the development of new technologies.

Applications are only Limited by our Imagination

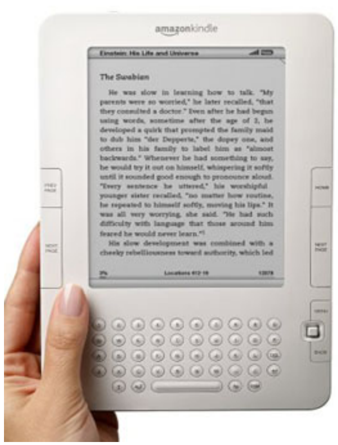
iPhone Apps





Radar

Electronic Books



Garage Door Opener

Wildlife Tracking Tags

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