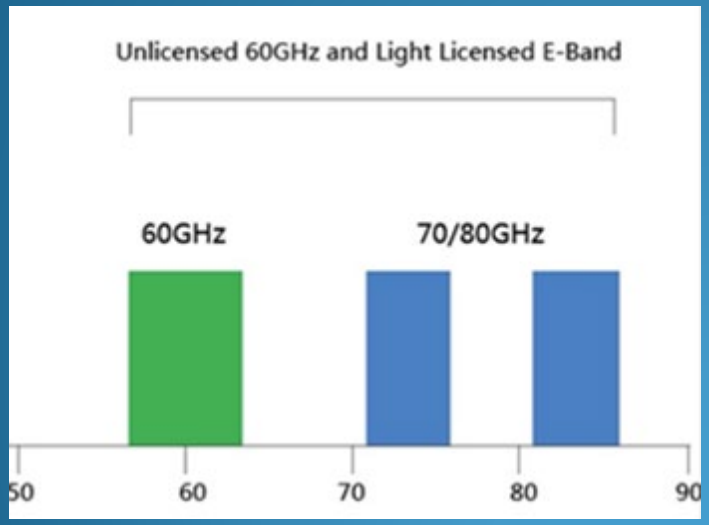
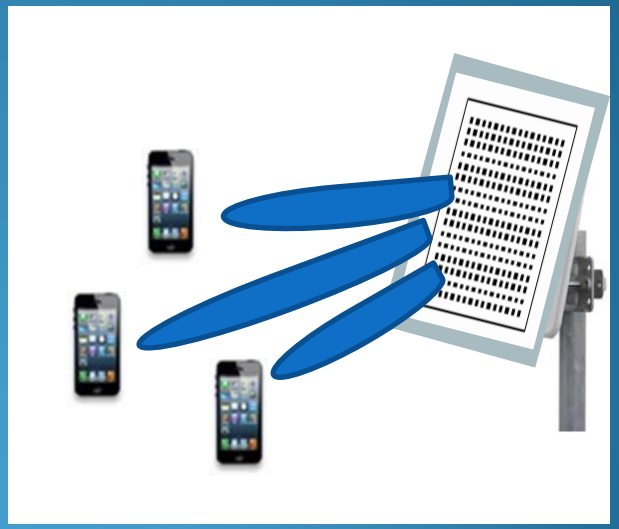
mmWave 101: Technical Basics

Andrea Goldsmith

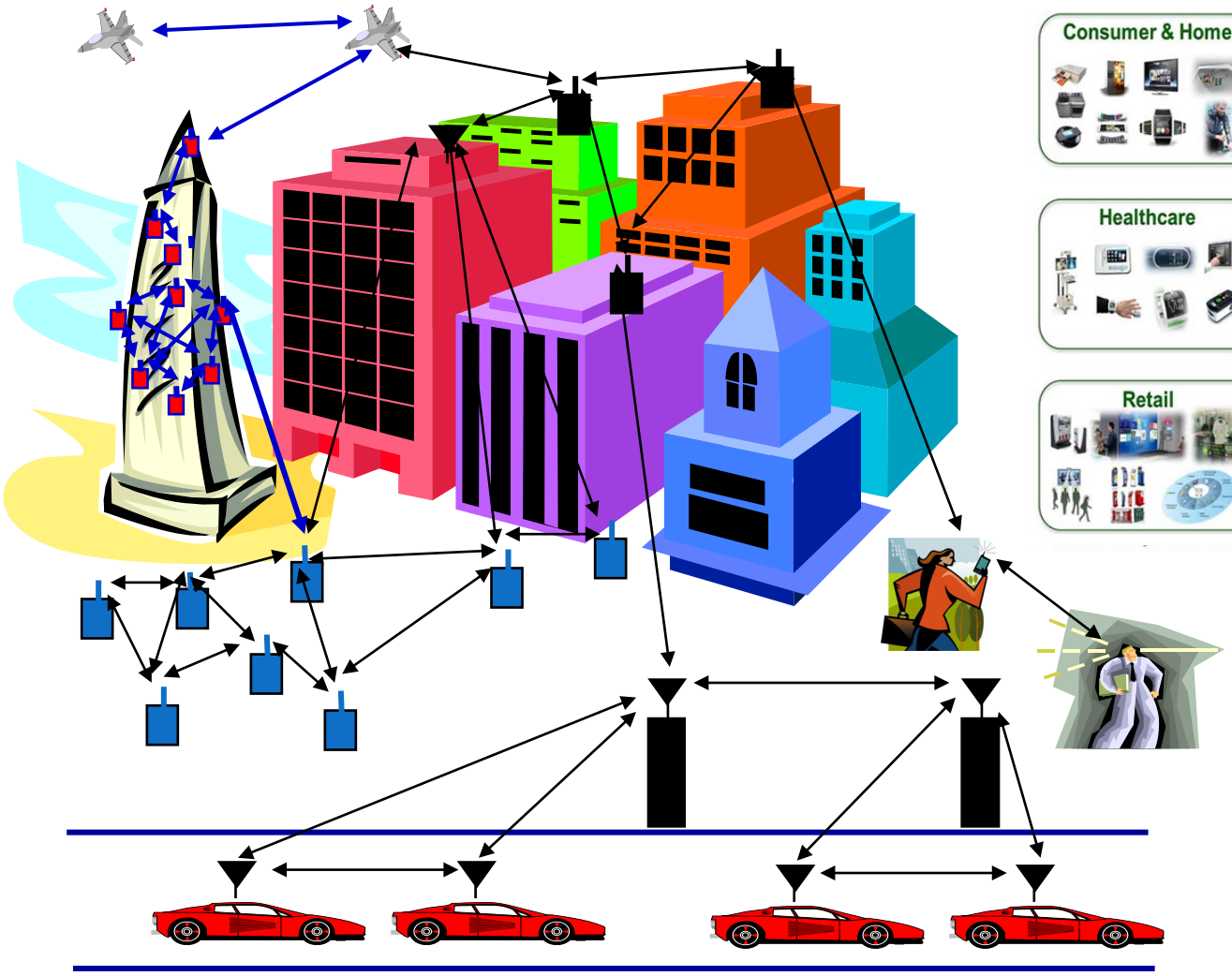
Stanford University

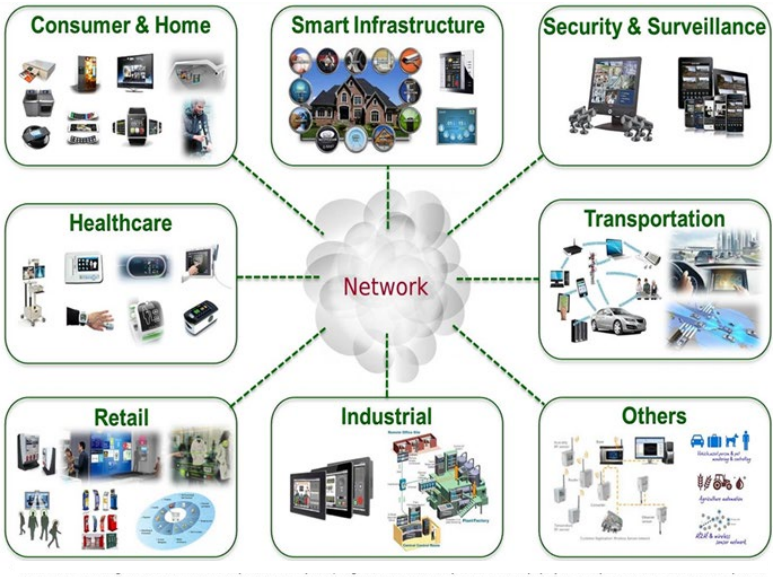




Future Wireless Networks

Ubiquitous Communication Among People and Devices

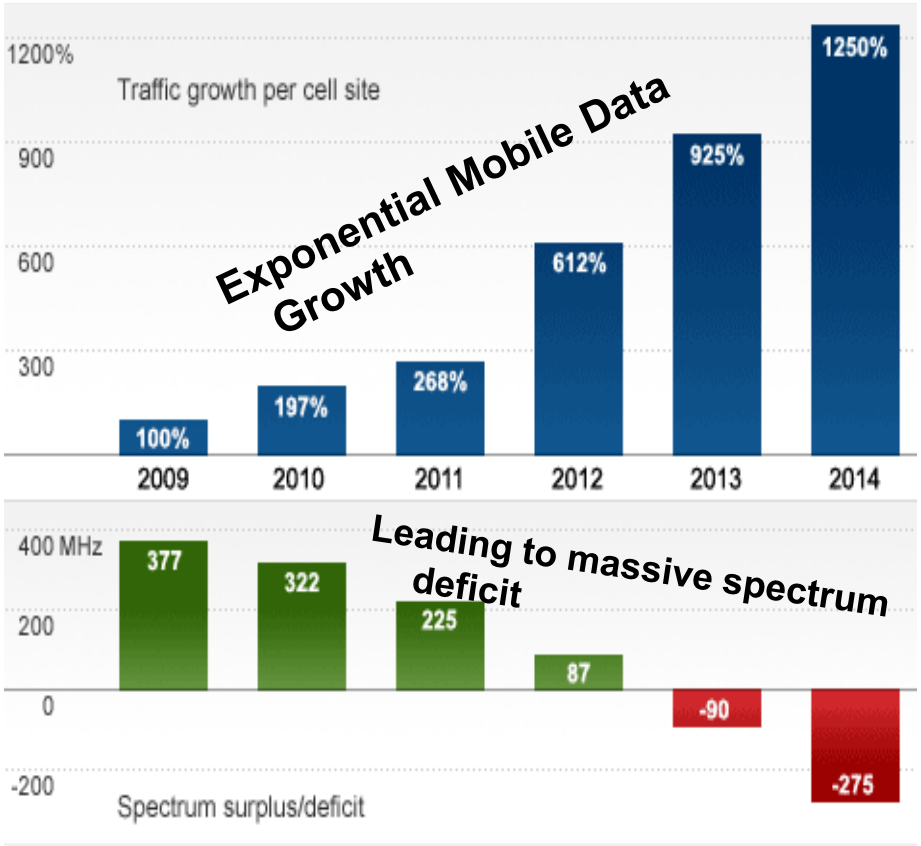




Next-Gen Cellular/WiFi
Smart Homes/Spaces
Autonomous Cars
Smart Cities
Body-Area Networks
Internet of Things
All this and more …

“Sorry America, your airwaves are full*”

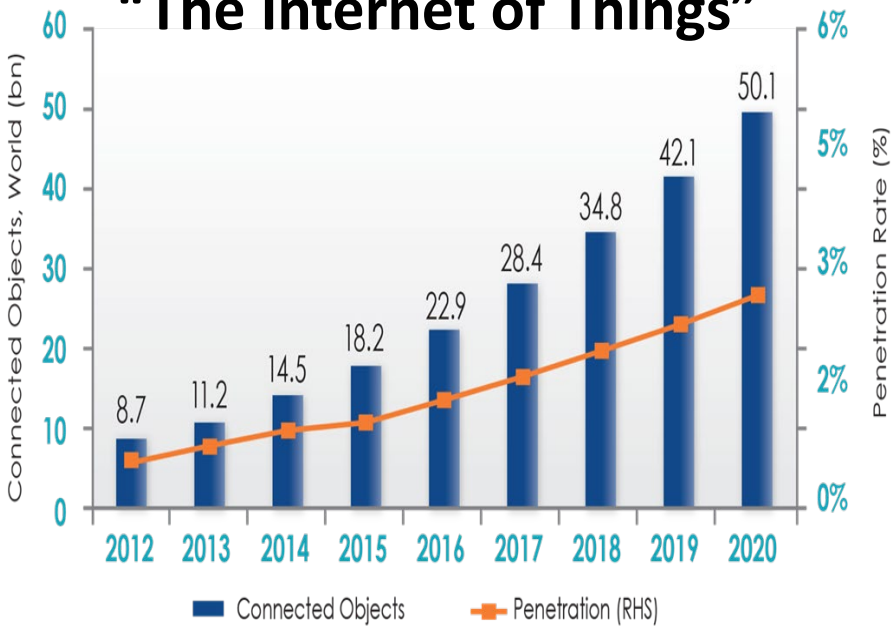
In the licensed bands



Source: FCC

On the Horizon:

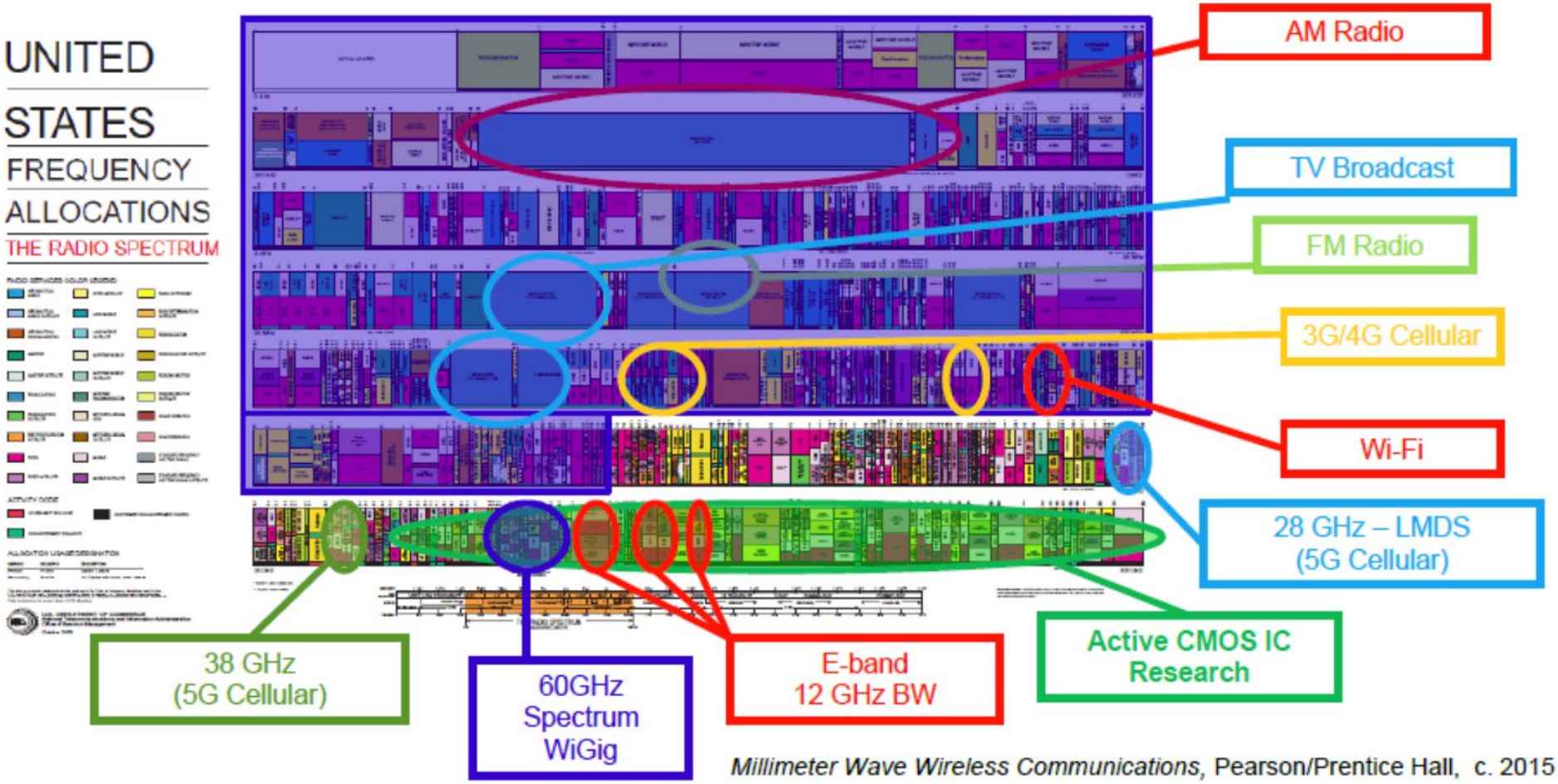
“The Internet of Things”



50 billion devices by 2020

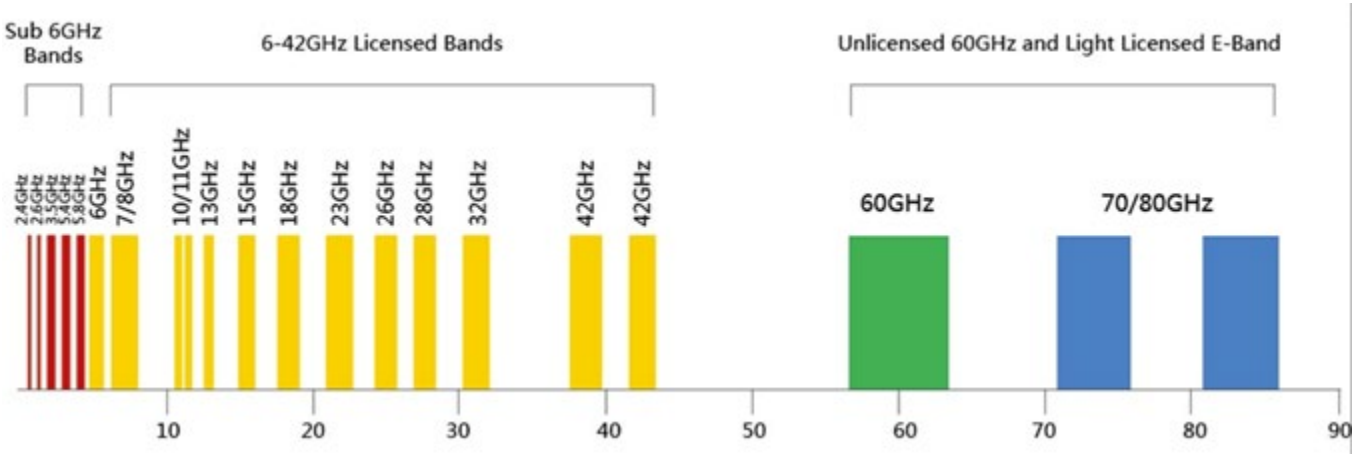
*CNN MoneyTech – Feb. 2012

mmWave: What's the big deal?



All existing commercial systems fit into a small fraction of the mmWave band

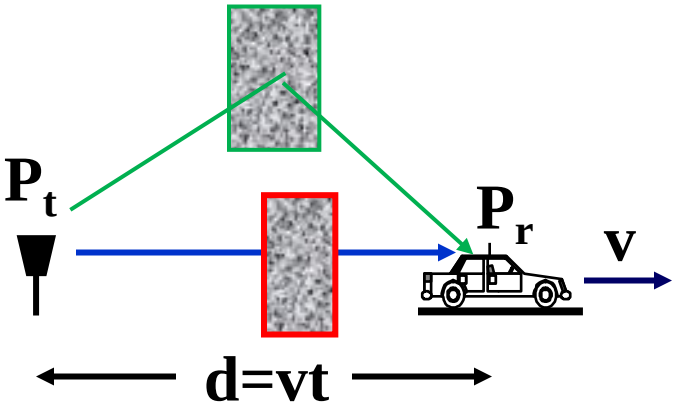
mmWave enables high data rates

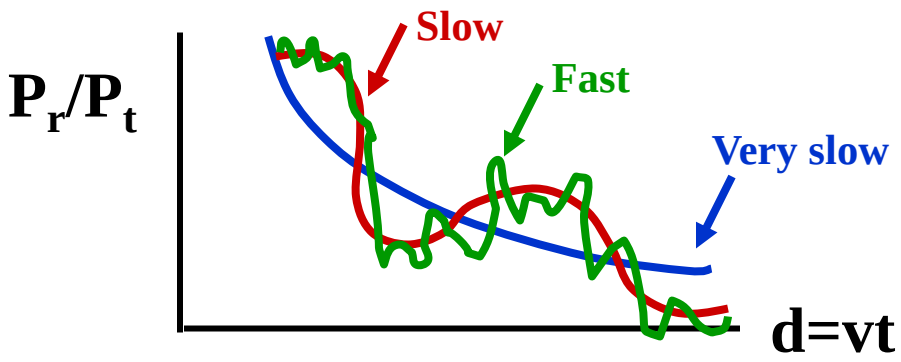


- Large BW allocations
  - 10s of GHz
  - In the 60-120 GHz bands
- mmWave standards already exist for WiFi
  - WirelessHD approved in Jan. 2008 (3.8 Gbps in 60 GHz band)
  - Evolved into 802.11ad; approved in Dec. 2012 (up to 7 Gbps)
  - Use single-stream MIMO, next-gen could go to multi-stream (20 Gbps).

Propagation Characteristics (at any carrier frequency)

- Path Loss (includes average shadowing)
- Shadowing (due to obstructions)
  - Buildings, cars, trees, people, body parts, ...
- Multipath Fading

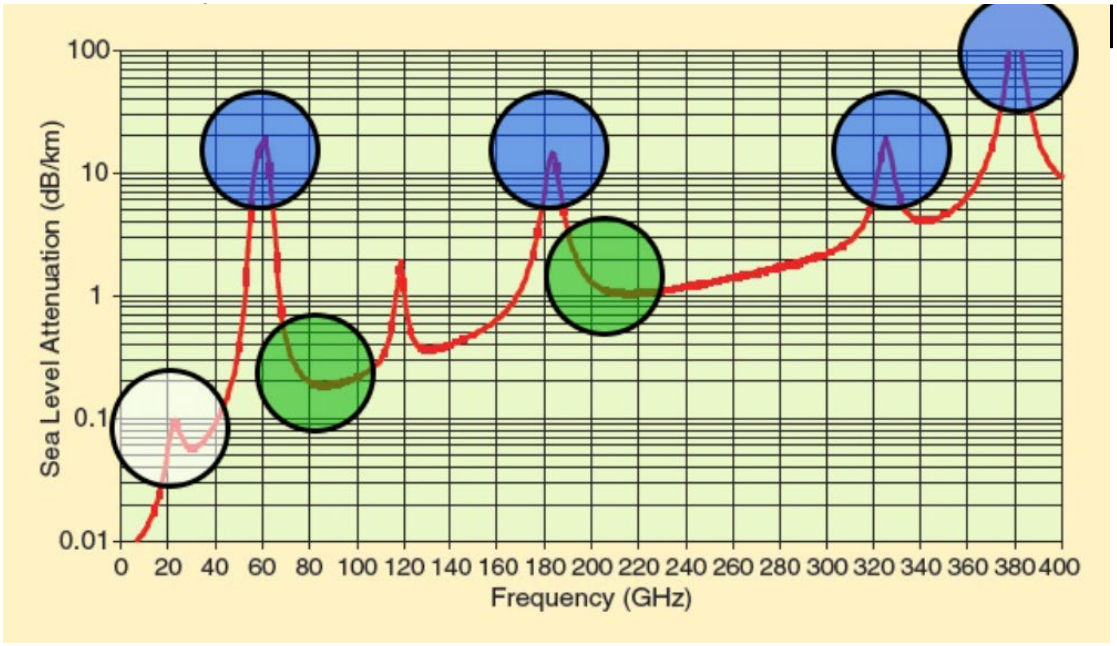


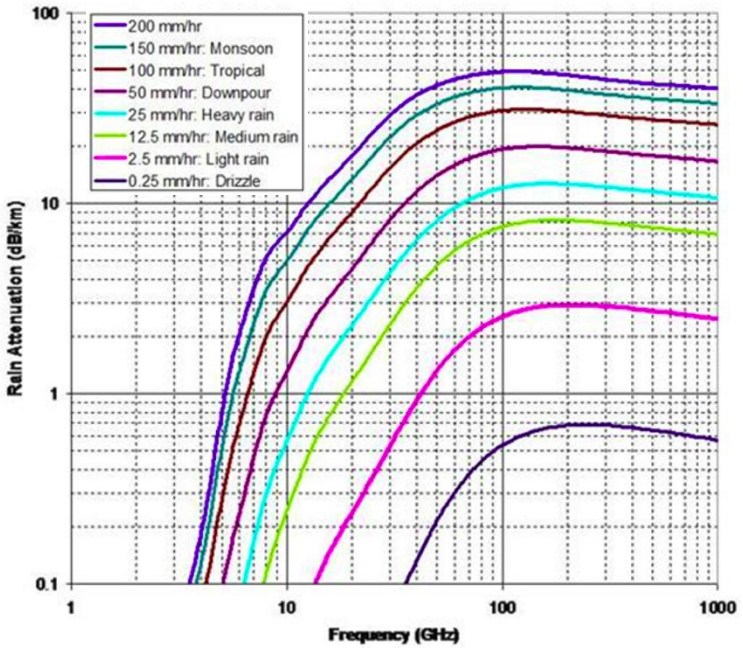


These characteristics are poorly understood for mmWave channels

mmWave Path Loss (60-100GHz)

- Channel models immature
  - Based on measurements, few accurate analytical models
- Path loss proportion to λ^2 (huge), plus nonlinear effects
- Also have rain attenuation

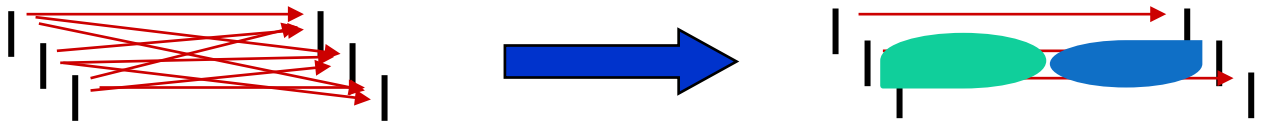




mmWave systems will be short range or require "massive MIMO"

Multiple Input Multiple Output Systems

- MIMO systems have multiple (*M*) transmit and receiver antennas

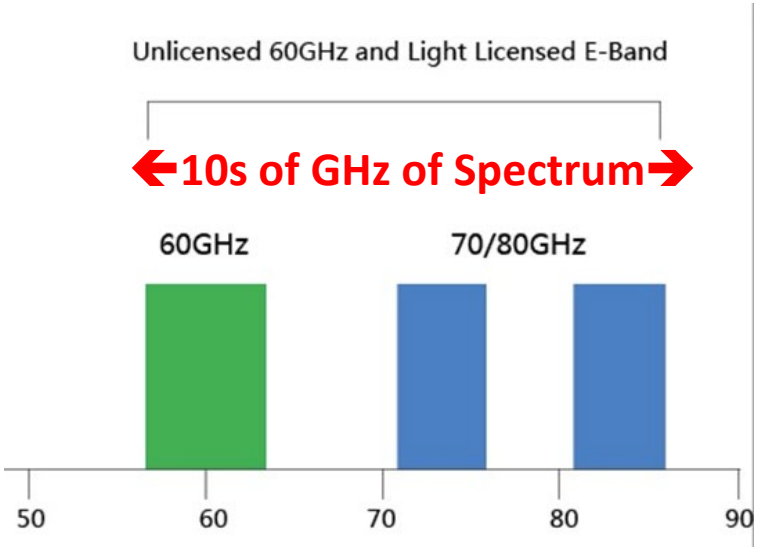


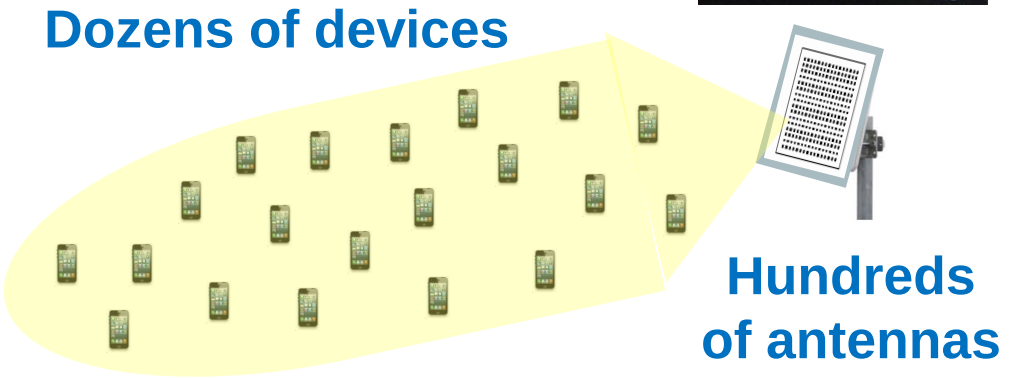
- With perfect channel estimates, decomposes into *M* independent channels
  - *M*-fold capacity increase over single-antenna systems
    - *Without increasing bandwidth or power!*
  - Demodulation complexity reduction when channel known at the transmitter and receiver
  - Can also use antennas for beamsteering

Massive MIMO: What is it?

- Very large antenna array at each base station
  - 10-100x more antennas than in conventional systems
- Large number of users served simultaneously
  - Pencil-thin beams to users (less directivity back)
  - Avoids interference, multipath, path loss
- Can get 10-100x higher data rates on downlink

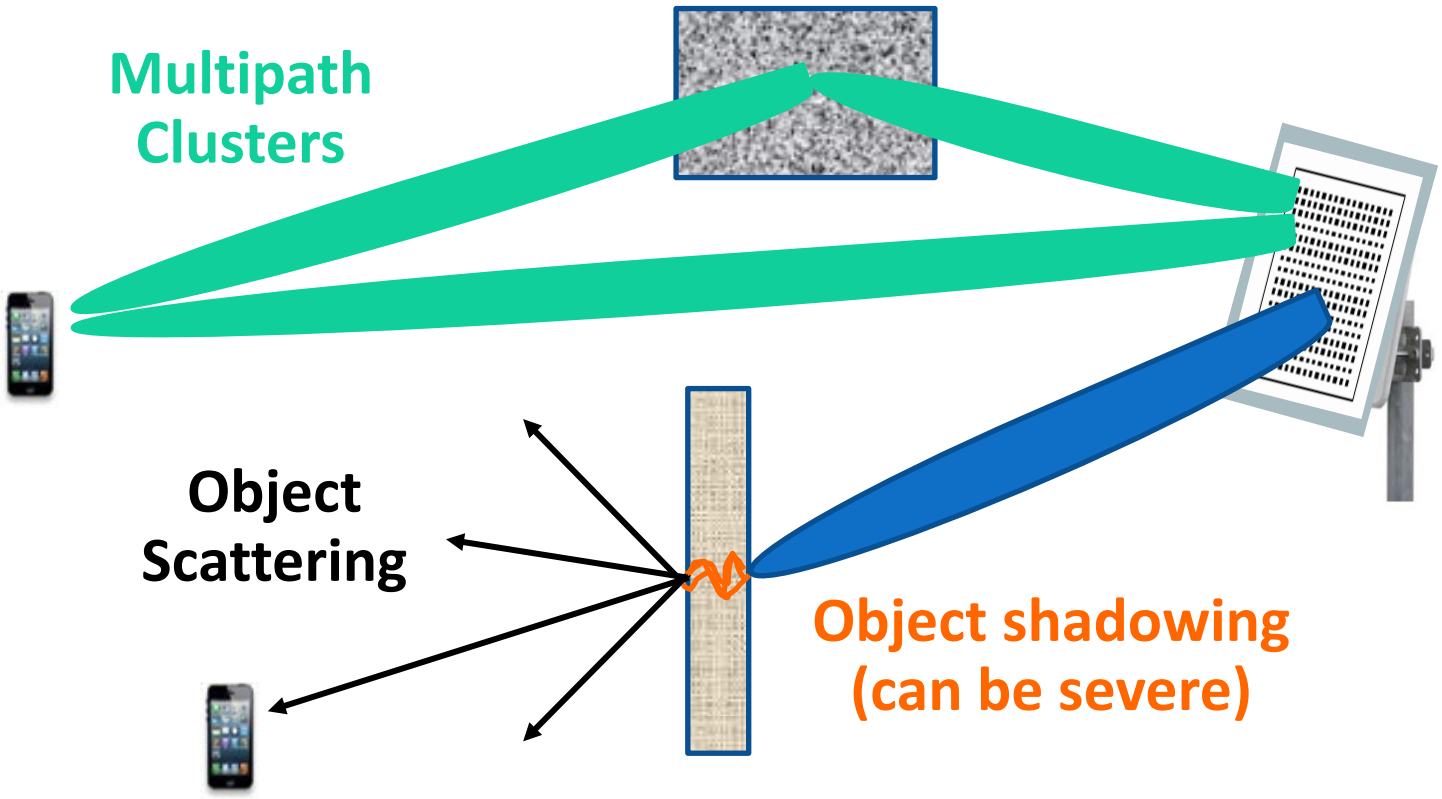
mmWave Massive MIMO





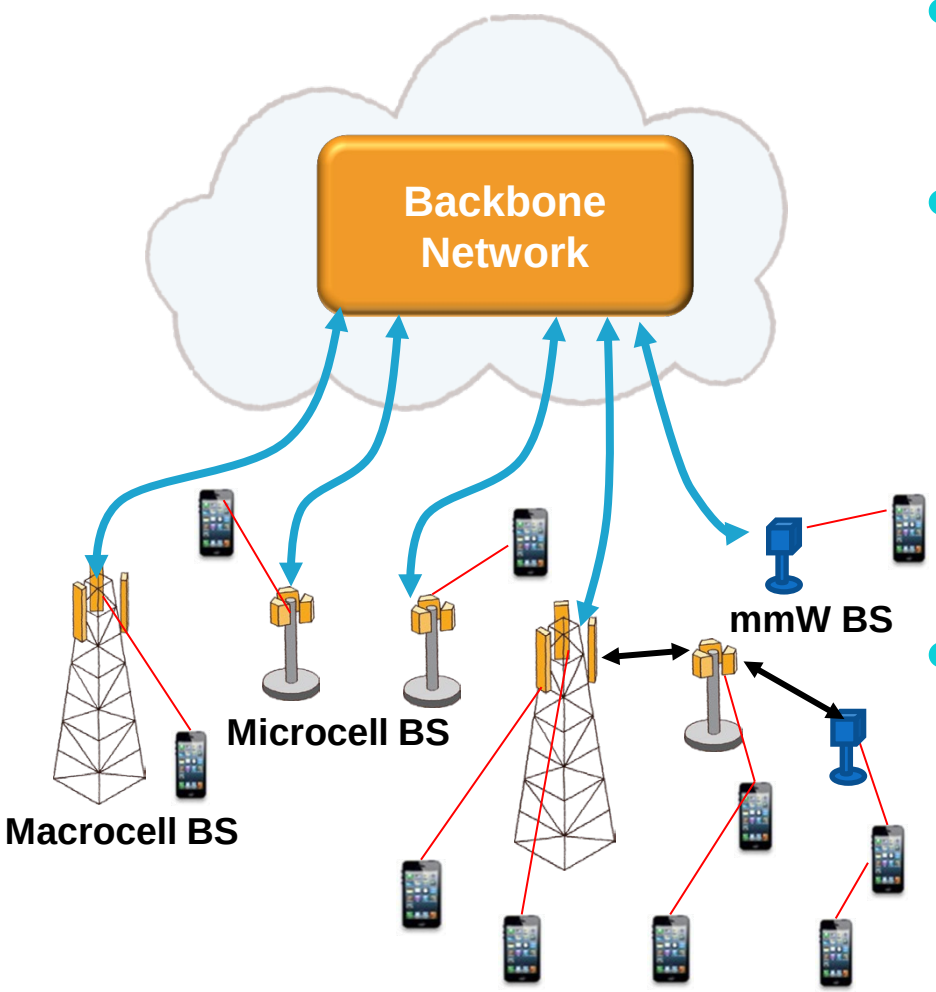
- mmWaves have large attenuation and path loss
- For very large arrays with perfect channel estimates, little path loss, fading, or interference
- mmWave antennas are small: perfect for massive MIMO
  - Design challenges: system complexity and channel estimation
  - mmWave propagation changes drastically with massive MIMO

Multipath and Shadowing under Beamsteering



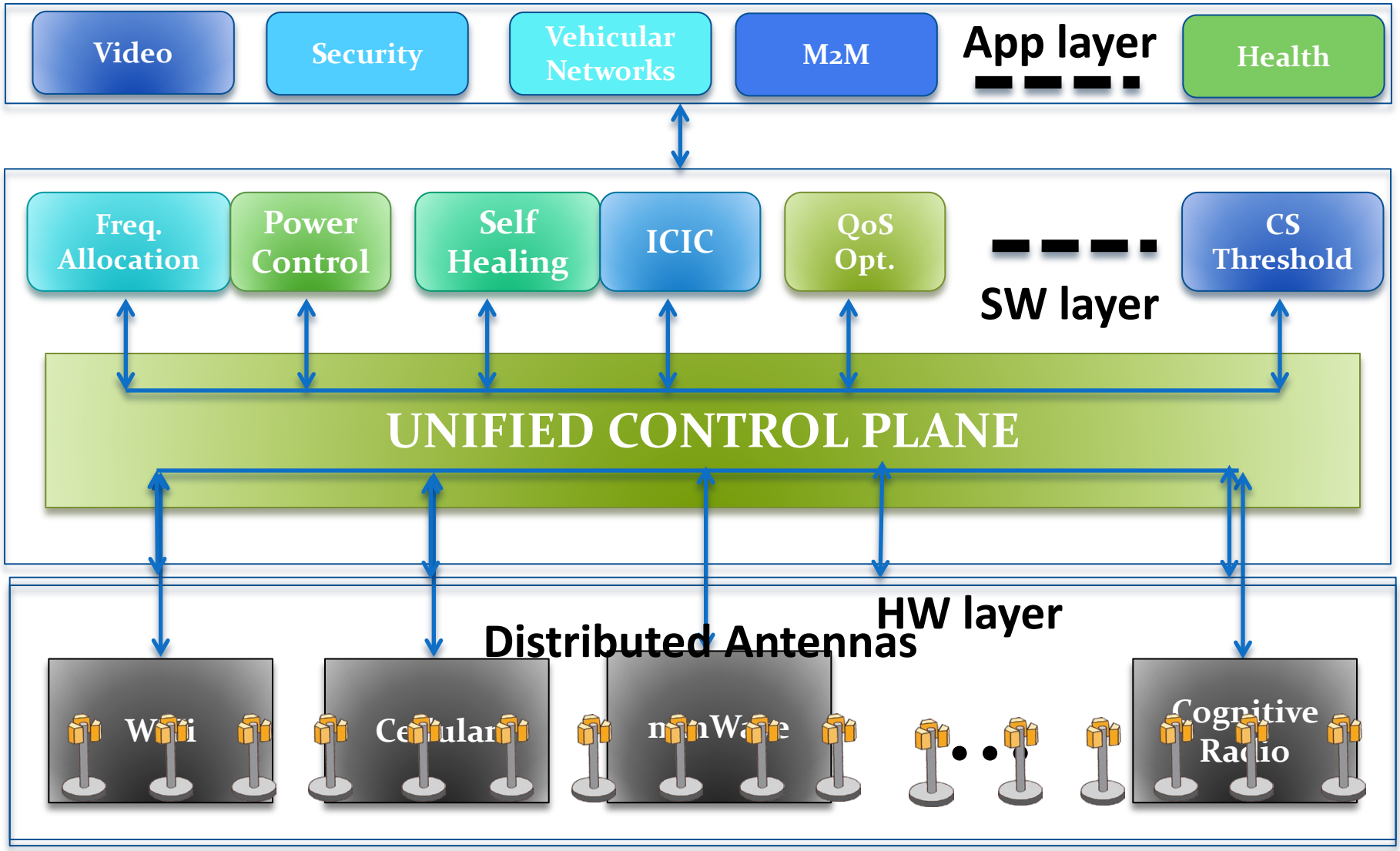
Propagation fundamentally different than in current systems and not well understood

mmWave is the ultimate small cell



- As cell size shrinks, capacity grows exponentially
- Future cellular networks will be hierarchical
  - Large cells for coverage
  - Small cells for capacity and power efficiency
  - May have caching at BSs
- Multihop routing may be needed, especially in mmW
  - For both mobiles and BSs
  - Overcomes short range
  - Saves transmit power

Managing Hierarchical Networks



Summary

- mmWave bands offer significant new spectrum for high-rate communications
- Path loss of mmWave propagation can be overcome with massive MIMO
  - Introduces complexity and channel estimation challenges
  - Propagation of mmWave poorly understood
- mmWave cells introduce a cellular system hierarchy
  - Can be optimally managed via a unified control plane