Next Generation Wireless Technologies: High Throughput WiFi , WiMAX, and UWB

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1. Wireless Networking: Issues and Trends
2. Recent Developments in Wireless PHY Layer
3. Wireless LAN/MAN Standards: 802.11n, 802.16

1. Wireless Networking: Issues and Trends

- Recent Networking Developments
- Mega-to-Giga Transition
- Hype Cycles of Technologies
- Telecom Revenue
- Wireless Industry Trends
- Home Networking Equipment Trends
- Wireless Research Trends

2. Recent Developments in Wireless PHY

1. Code Division Multiple Access (CDMA)
2. OFDM, OFDMA
3. Adaptive Antenna System (AAS)
4. MIMO
5. Turbo Codes
6. Space-Time Block Codes
7. Ultra-Wideband (UWB)

3. Wireless LAN/MAN Standards: 802.11n, 802.16

- IEEE 802.11n
  - Technology
  - Status
  - Sample Products
- IEEE 802.16 and WiMAX
  - Key Features
  - IEEE 802.16 PHYs
  - Scheduling and Link Adaptation
  - IEEE 802.11 vs. 802.16
  - Sample WiMAX Products

Top 10 Recent Networking Developments

1. Large investments in Security: Message Aware Networking
   ⇒ All messages scanned by security gateways
2. Wireless (WiFi) is spreading (Intel Centrino)
3. More Cell phones than POTS.
   Smart Cell phones w PDA, email, video, images
   ⇒ Mobility
4. Broadband Access is growing faster than cell phones
5. Ethernet extending from Enterprise to Access to Metro …

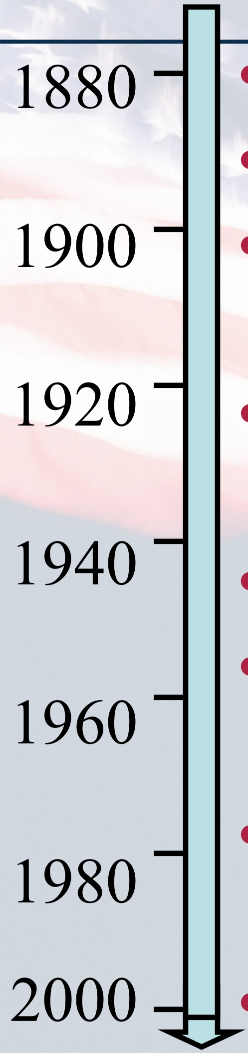
Top 10 Networking Developments (Cont)

6. Wiring more expensive than equipment
   ⇒ Wireless Access
7. Voice over Internet Protocol (VOIP) is in the Mainstream
   VOIP over Broadband/Wi-Fi/Cellular
8. Multi-service IP: Voice, Video, and Data
9. Terabyte/Petabyte storage (Not VoD)
   ⇒ High-Speed Networking
10. Gaming: Internet and wireless based

2002-2005: Mega-to-Giga Transition

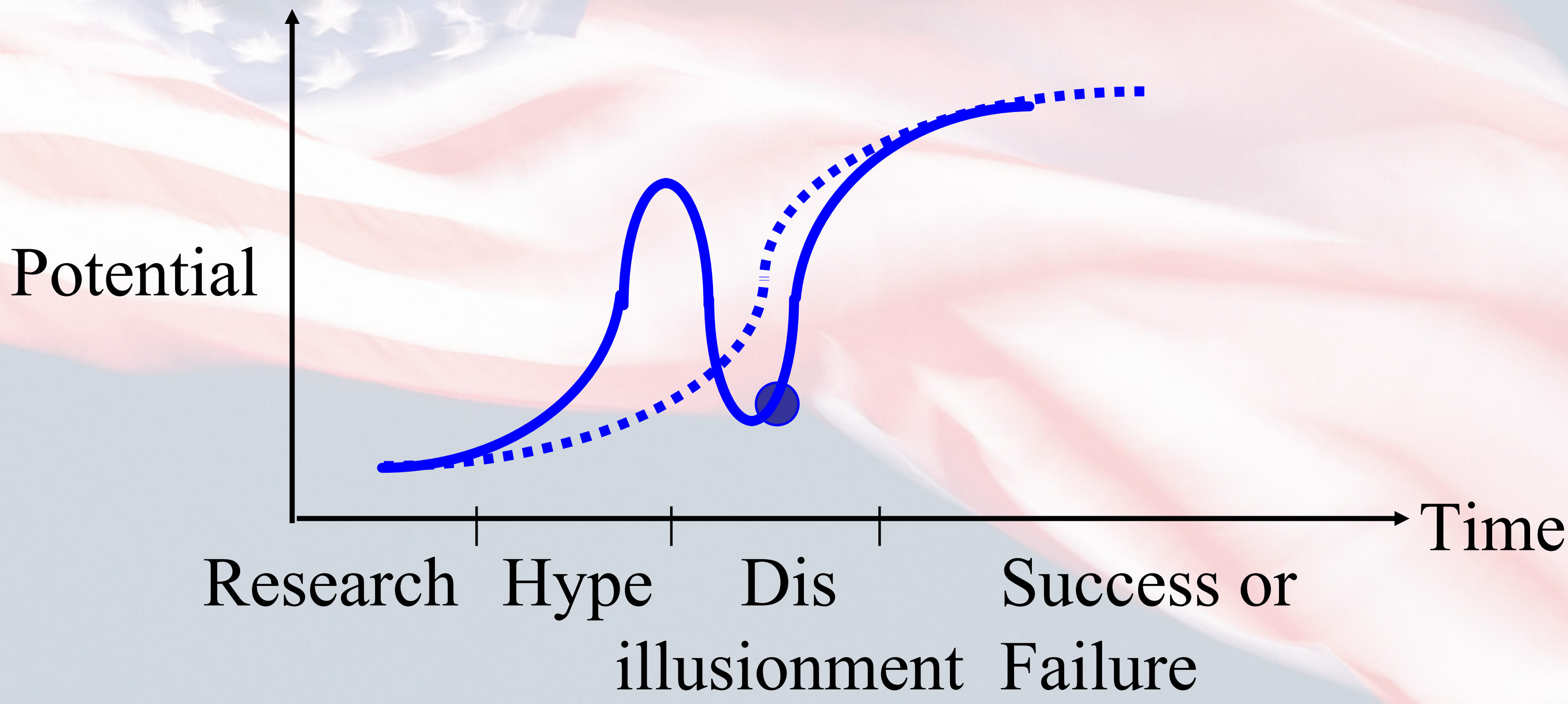
- Memory in Laptops: Megabytes to Gigabytes
- Cordless Phones: 900 Mega Hertz to 2.4/5.8 GHz
- Processors: MIPS (Mega Instructions per second) to GFIPS (Giga Flops)
- Digital Cameras: 100-500 Mega Pixels to Giga Pixels
- Office Networks: 10/100 Mega bps to 1-10 Giga bps
- Worldwide Wireless Network Users: Millions to Billions

Wireless: History

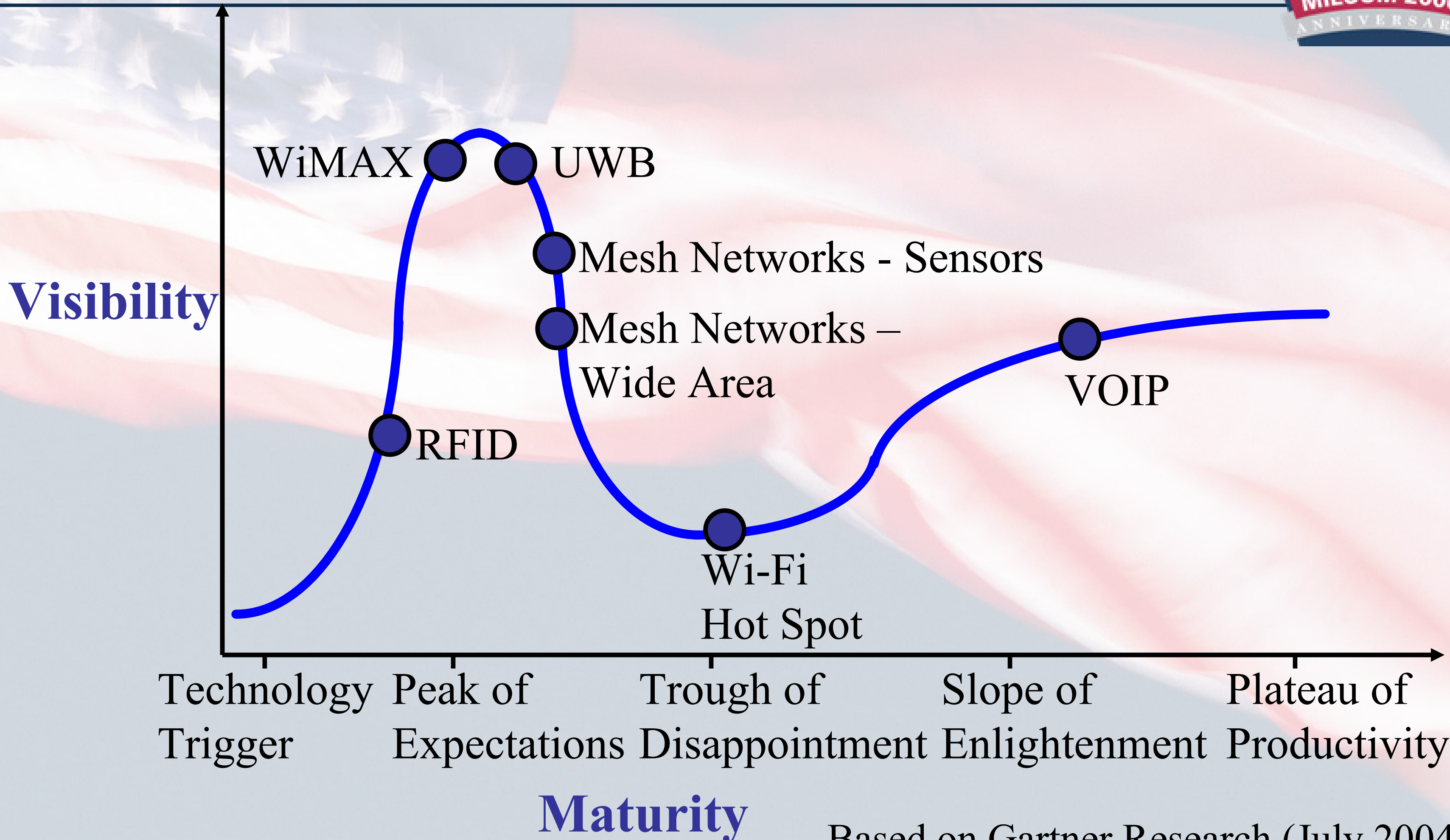


- 1880: Hertz discovered electromagnetic waves
- 1898: First commercial radio data service
- 1921: First Mobile Radio:
  Wireless dispatch system for Detroit Police
- 1946: First Mobile Telephone Service:
  In St. Louis by AT&T. Half-duplex ⇒ Push to talk
- 1970: First Cellular Phone Service: AT&T Chicago
- 1971: First Wireless Data Network:
  Aloha at University of Hawaii
- 1990: First Commercial WLAN Product AT&T WaveLAN
- 1997: First WLAN Standard - IEEE 802.11 2Mbps

Hype Cycles of Technologies

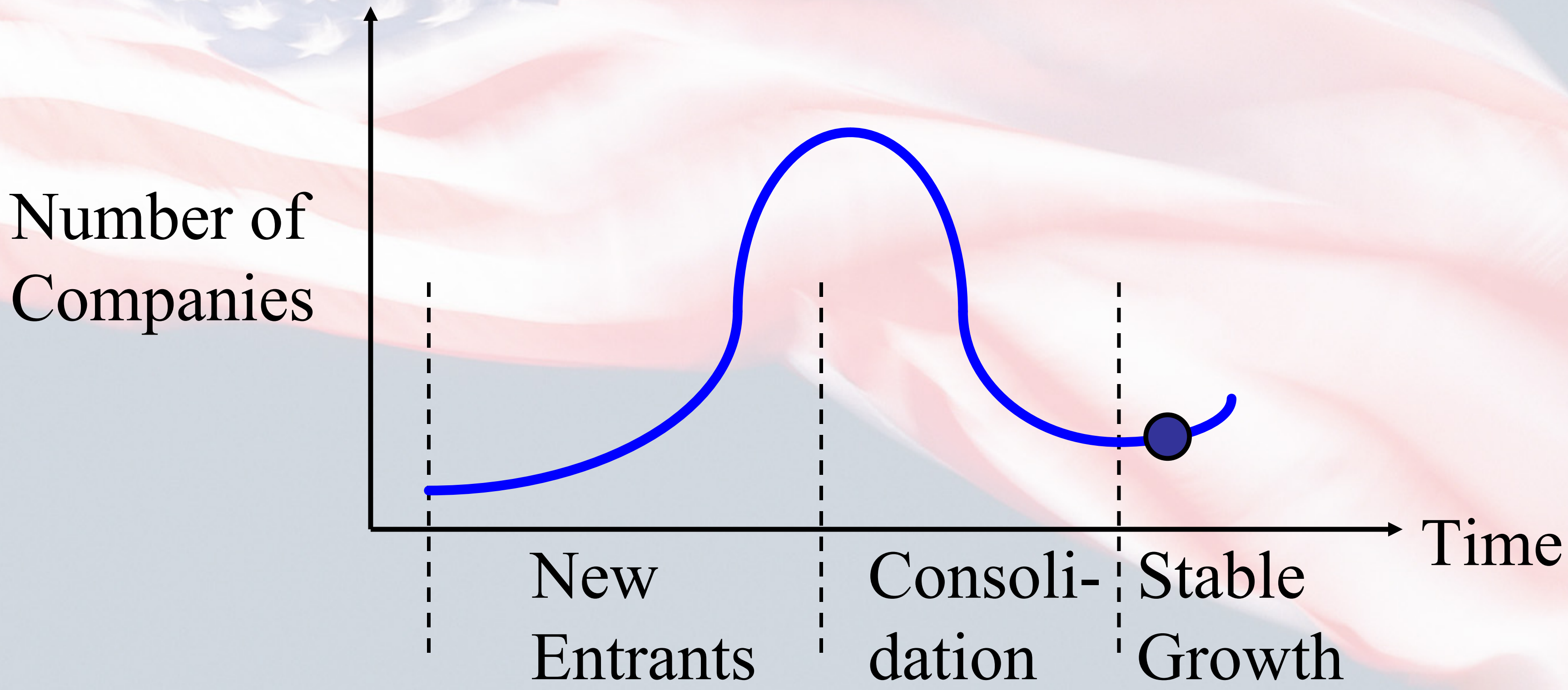


Hype Cycle 2004



Based on Gartner Research (July 2004)

Industry Growth



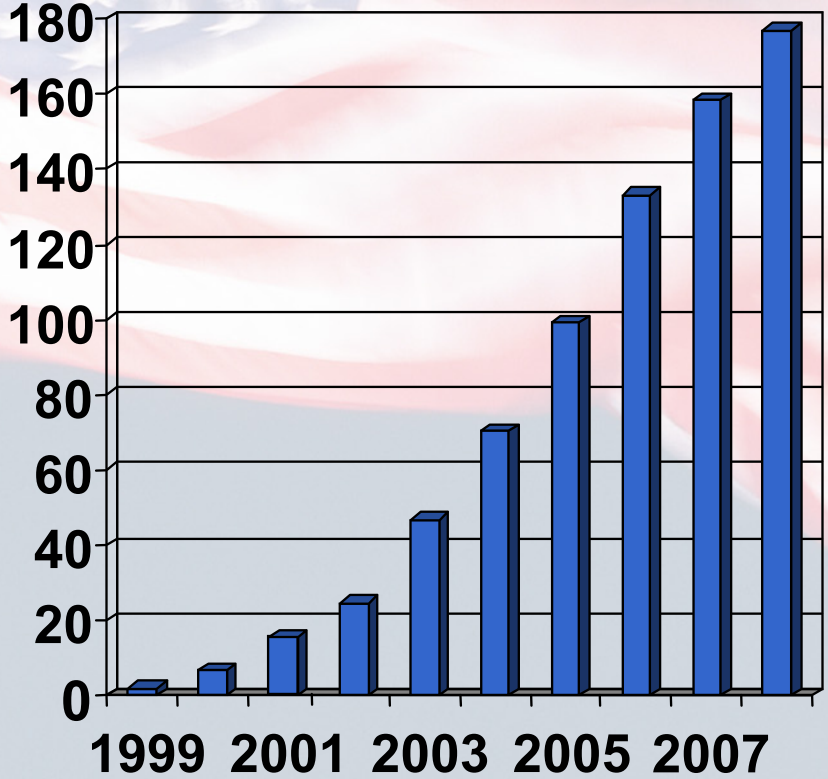
Telecom Revenue

	Revenue in Billions						
	2003	2004	2005	2006	2007	2008	Annual Growth
Video	0.2	0.3	.05	1.0	1.6	2.5	65.7%
Consumer Broadband	2.8	3.5	4.0	4.2	4.6	4.8	11.4%
Consumer long distance	20.7	18.2	16.0	13.6	11.3	9.2	-15.0%
Business local	26.3	26.7	26.4	26.1	25.8	25.5	-0.6%
Business long distance	26.1	24.5	23.0	21.3	19.7	18.2	-7.0%
Business data	44.8	45.6	46.6	47.1	46.8	45.4	0.3%
Consumer local	46.9	42.2	39.0	36.2	34.0	32.3	-7.25%
Wireless	91.5	108.7	119.2	132.8	144.5	153.6	10.9%
Total	260.7	271.5	277.0	285.0	291.3	294.9	2.5%

- Long distance is disappearing.
- Most of the revenues are going to be from wireless.
- Source: Instat/MDR (Business Week, Feb 28, 2005)

Wireless Data Connections

North American Wireless Data Connections (Millions)

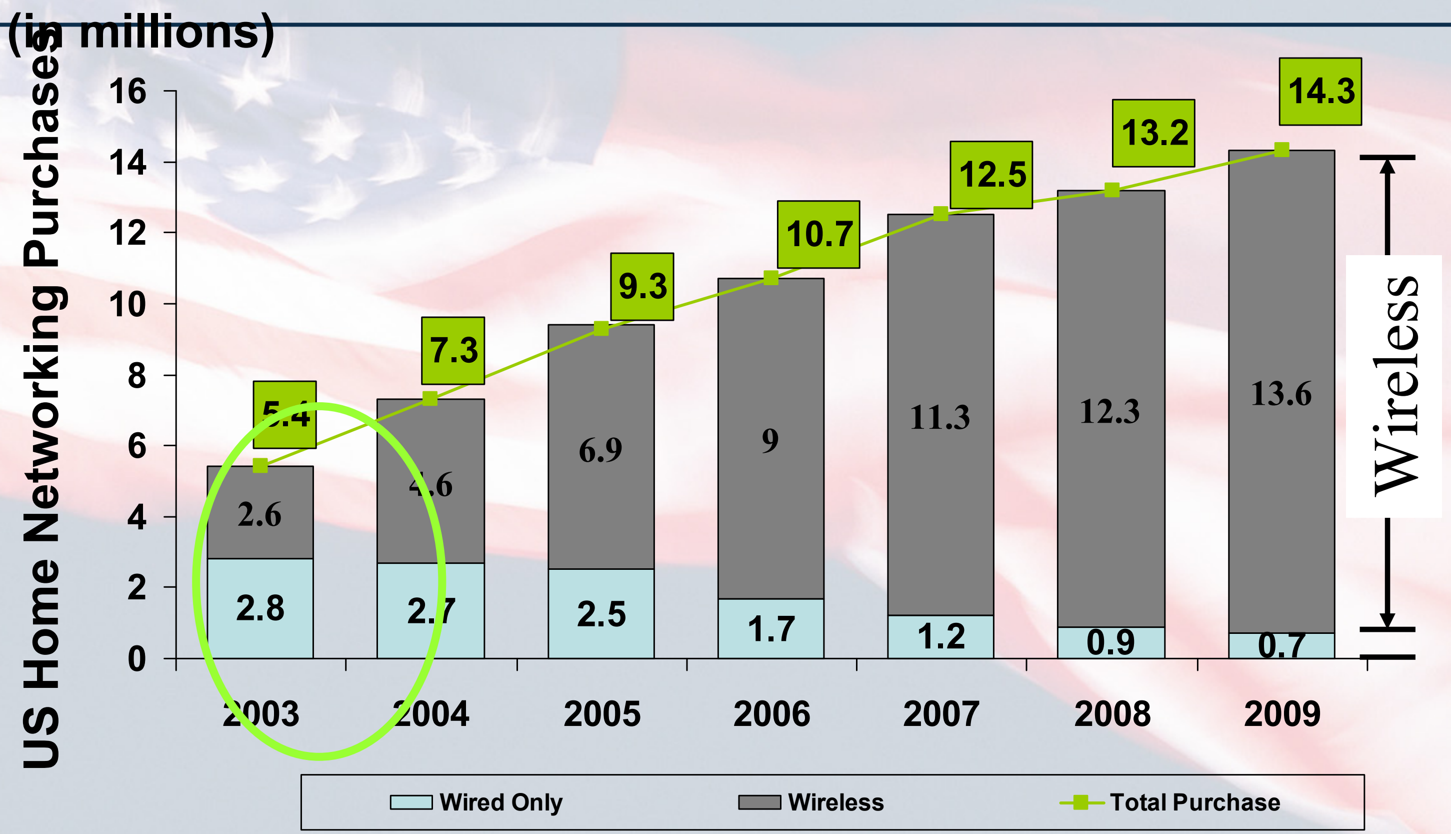


Source: Gartner, "U.S. Wireless Data Market Update, 2004"

Five Wireless Industry Trends

1. Wireless industry is stronger than wireline. Particularly strong growth in developing countries.
2. 48% of global telco revenues coming from wireless
3. 26% of wireless revenues coming from data (vs voice)
4. Emerging new applications: Video, Location, Remote monitoring, m-commerce, Video telephony, remote enterprise applications, remote management, Multiparty collaboration
5. Wireless outselling wired home networking gear

Home Networking Equipment Trends

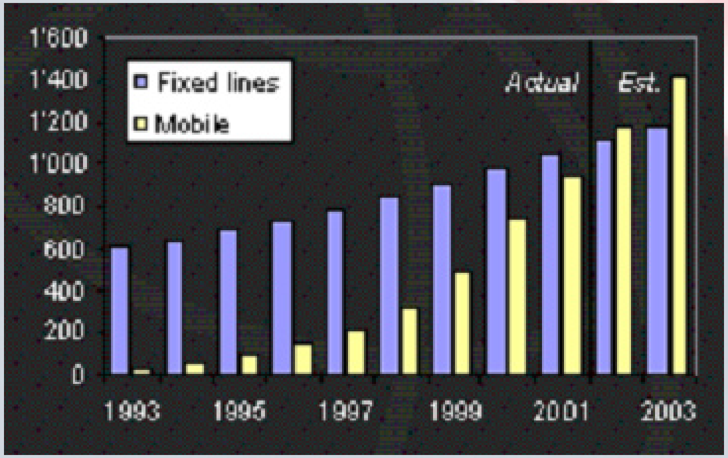


Source: JupiterResearch Home Networking Model, 8/04 (US Only)

- Wireless outsold wired home networking gear for the first time in 2004

Mobility

- 1.35 Billion mobile subscribers vs 1.2 Billion Fixed line subscribers at the end of 2003 [ITU]
- Number of wired phones in USA is declining for the first time since the Great Depression.
- 20% of world population is mobile. Need internet access. 70% of internet users in Japan have mobile access



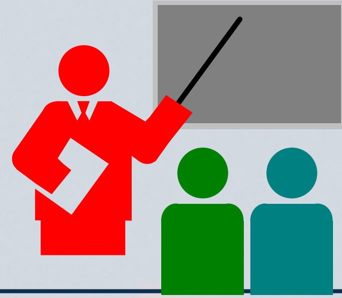
Five Wireless Research Trends

1. NSF funded $40M for networking research over the past three years.
2. Three areas:
   – Software programmable networks
   – Sensor Networks
   – All other type of networking
   – **Two Thirds** of networking funding on wireless
3. Defense Networks are mostly wireless

Wireless Research Trends (Cont)

4. Funding moving to Next Generation Networking Architecture (FIND) ⇒Mobility, Energy conservation ideas from wireless research can be generalized to wired networks
5. $300M+ for next generation test-bed (GENI). Currently a 20-node core network. Need to change to allow significant wireless component.

Summary



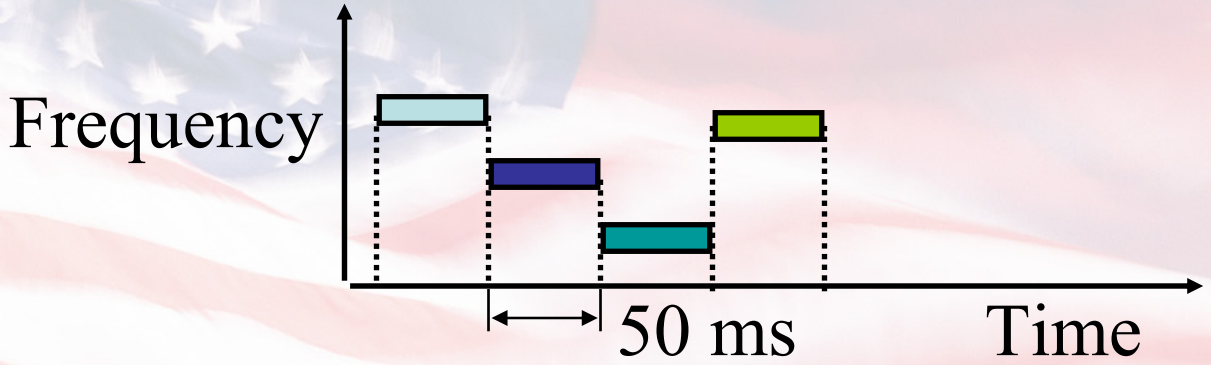
1. Wireless is the major source of carrier revenue
   ⇒ Significant growth in Wireless networking
2. Internet has flattened the world
   ⇒ More mobility and need to be connected
3. NSF, DARPA, and other research agencies see more research opportunities in wireless than in other areas of networking

Recent Developments in Wireless PHY

Recent Developments in Wireless PHY

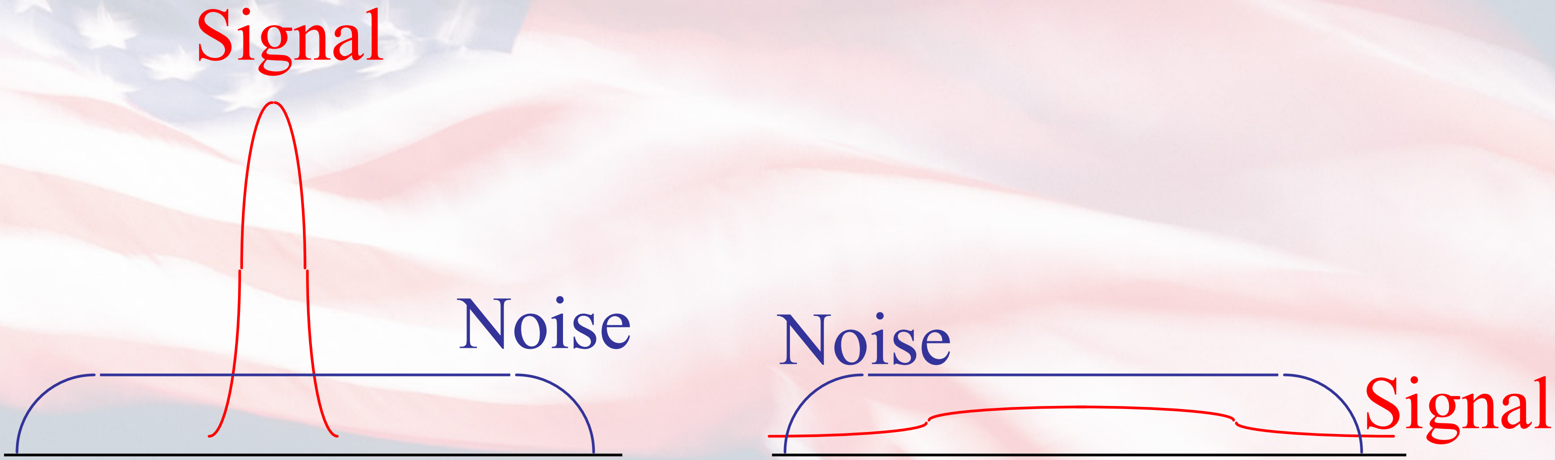
1. Code Division Multiple Access (CDMA)
2. OFDM, OFDMA
3. Adaptive Antenna System (AAS)
4. MIMO
5. Turbo Codes
6. Space-Time Block Codes
7. Ultra-Wideband (UWB)

Frequency Hopping Spread Spectrum



- Pseudo-random frequency hopping
- Spreads the power over a wide spectrum
  ⇒ Spread Spectrum
- Developed initially for military
- Patented by actress Hedy Lamarr
- Narrowband interference can't jam

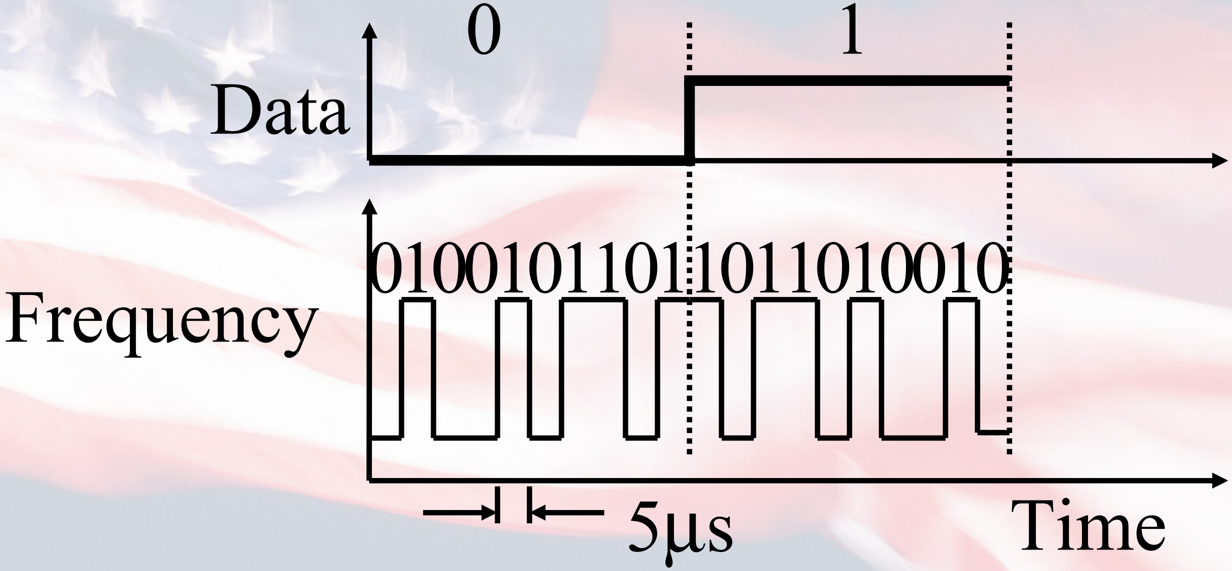
Spectrum



(a) Normal

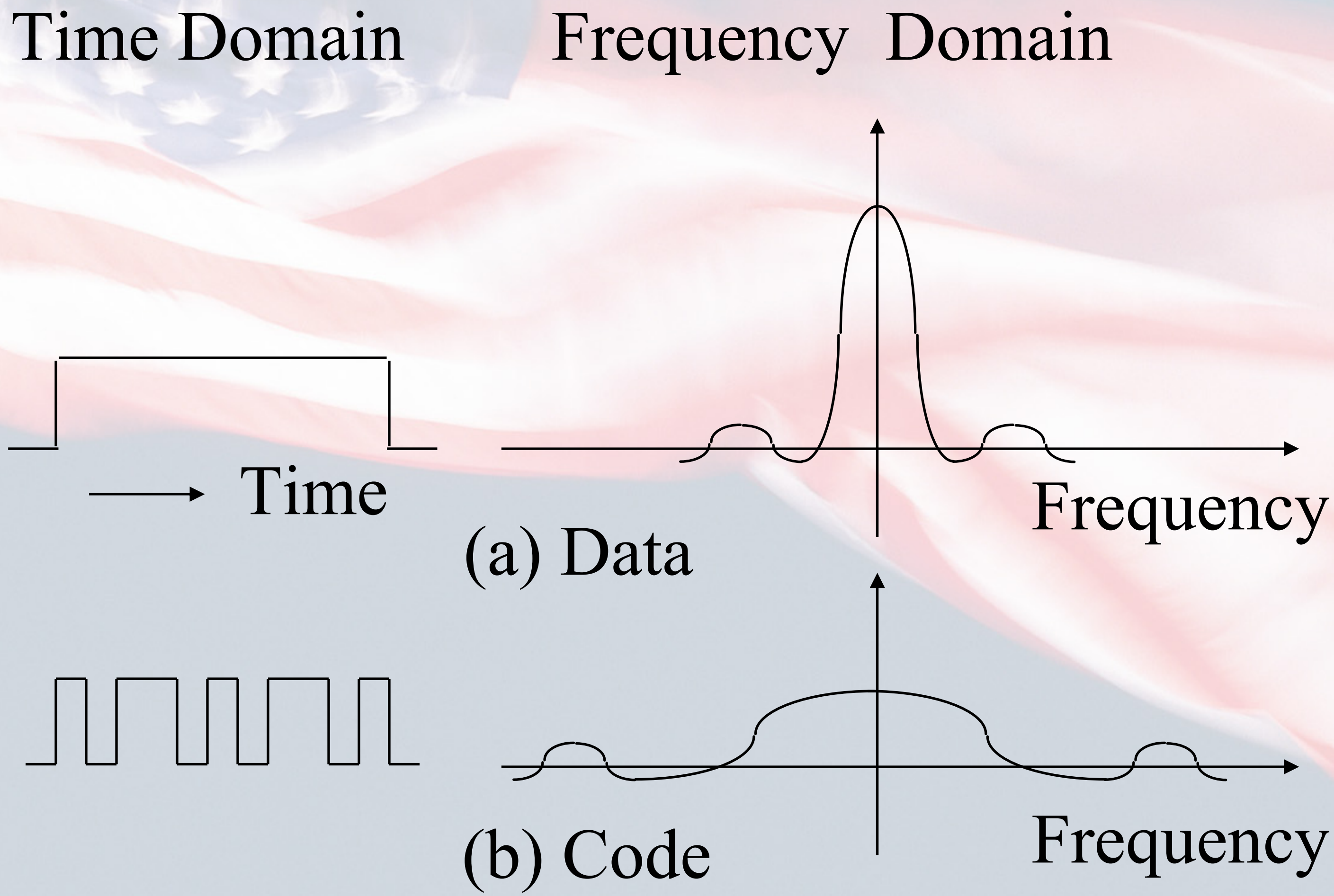
(b) Frequency Hopping

Direct-Sequence Spread Spectrum



- Spreading factor = Code bits/data bit, 10-100 commercial (Min 10 by FCC), 10,000 for military
- Signal bandwidth >10 × data bandwidth
- Correlation between codes ⇒ Interference ⇒□ Orthogonal

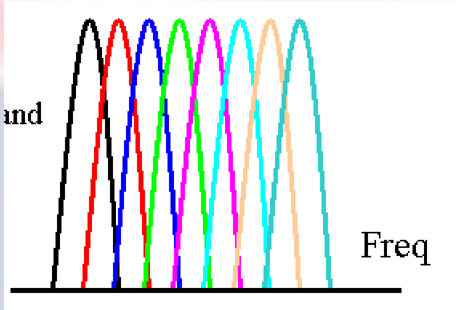
DS Spectrum



Time Domain
Frequency Domain
Time
(a) Data
Frequency
(b) Code
Frequency

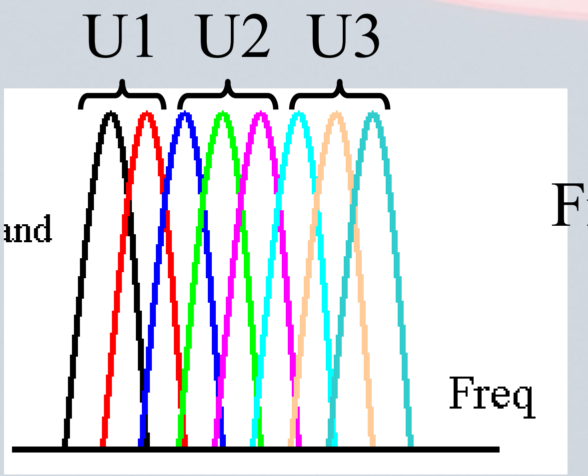
OFDM

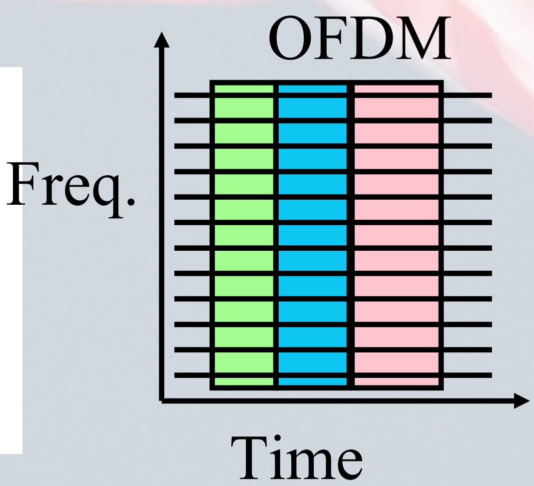
- Orthogonal Frequency Division Multiplexing
- Ten 100 kHz channels are better than one 1 MHz Channel ⇒ Multi-carrier modulation
- Frequency band is divided into 256 or more sub-bands. Orthogonal ⇒ Peak of one at null of others
- Each carrier is modulated with a BPSK, QPSK, 16-QAM, 64-QAM etc depending on the noise (Frequency selective fading)
- Used in 802.11a/g, 802.16, HDTV

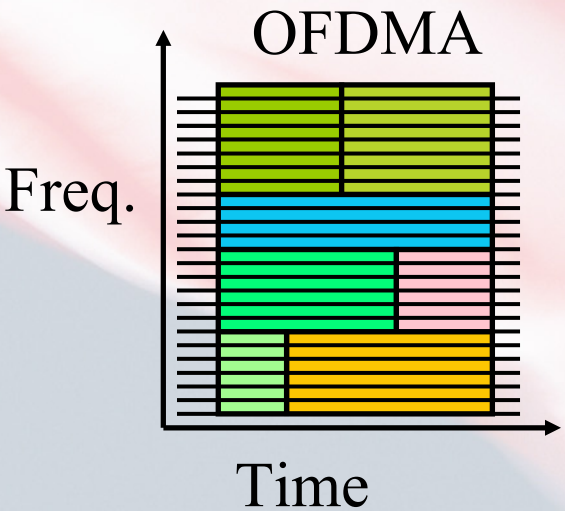


OFDMA

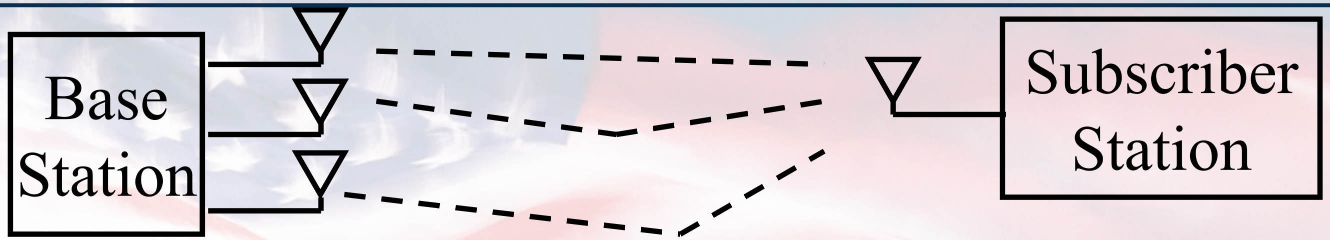
- Orthogonal Frequency Division Multiple Access
- A large number of subcarriers, e.g., 2048
- Each user has a subset of subcarriers for a few slots
- OFDMA is a form of FDMA ⇒ 2D Scheduling





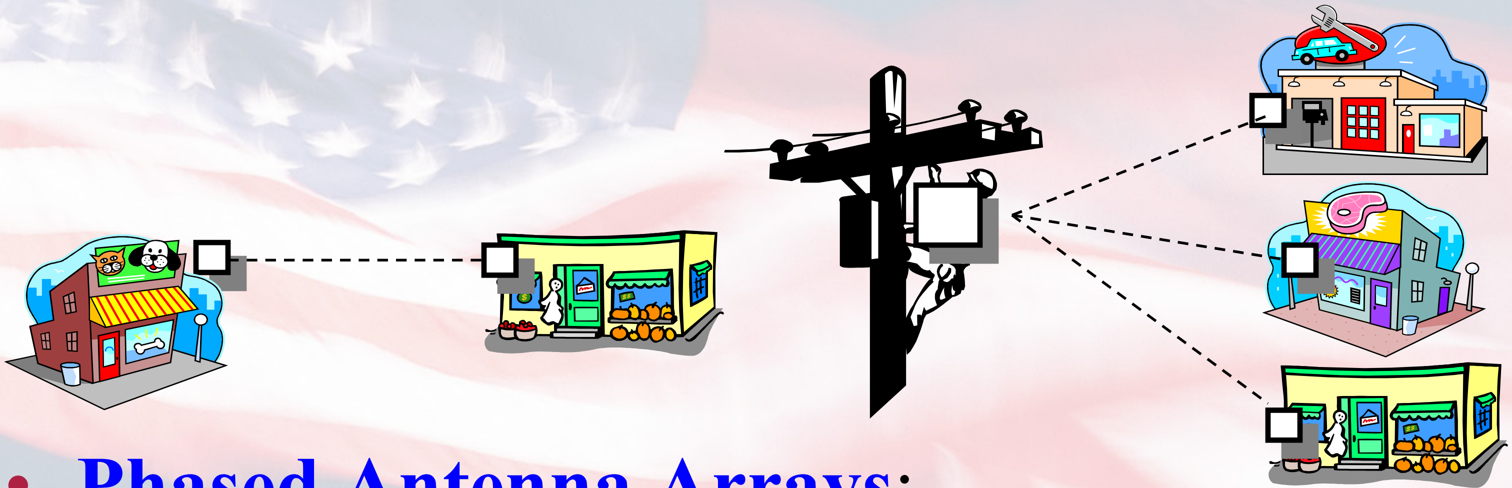


Adaptive Antenna System (AAS)



- Multiple antennas transmit a subset of OFDM subcarriers each
- Example: 4 Antennas. 192 data subcarriers plus 8 pilot subcarriers are divided into 4 groups of 50 subcarriers each. Each of the four antennas transmits one group.
- Receivers perform channel estimation on each beam
- Receivers feedback the channel info to xmitter
- Transmitters adjust the beam forming accordingly

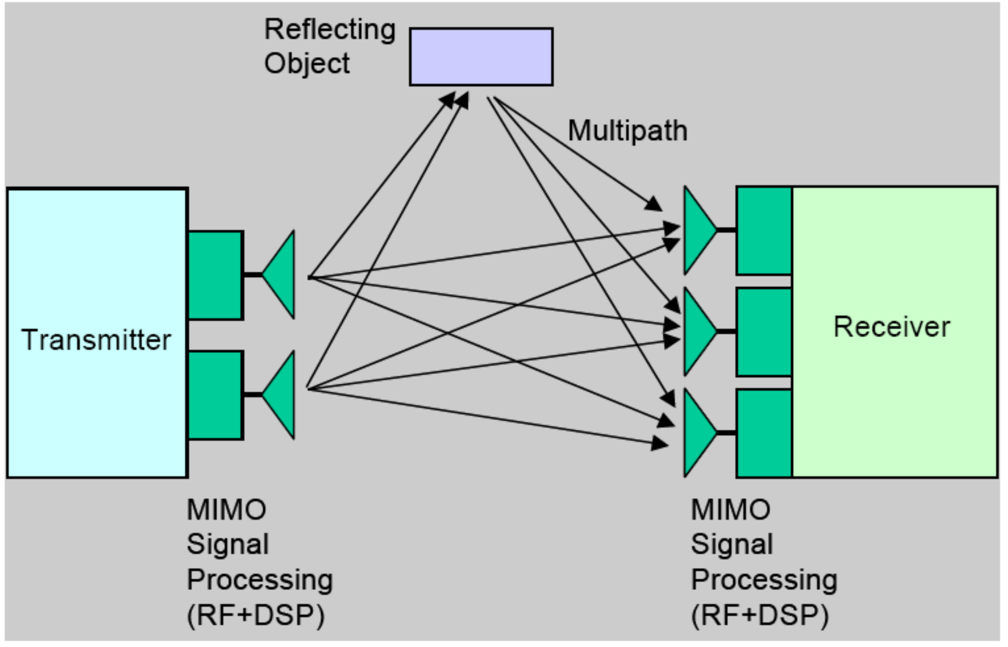
Smart Antennas



- **Phased Antenna Arrays**:
  Receive the same signal using multiple antennas
- By phase-shifting various received signals and then summing ⇒ Focus on a narrow directional beam
- Digital Signal Processing (DSP) is used for signal processing ⇒ Self-aligning

MIMO

- Multiple Input Multiple Output
- 54 Mbps/20 MHz = 2.7 bps/Hz,
  MIMO ⇒ 108 Mbps or 5.4 bps/Hz



2x3

Shannon's Theorem

- Bandwidth = B Hz
  Signal-to-noise ratio = S/N
- Maximum number of bits/sec = $B \log_2 (1+S/N)$
- Example: Phone wire bandwidth = 3100 Hz

$$S/N = 30 \text{ dB}$$

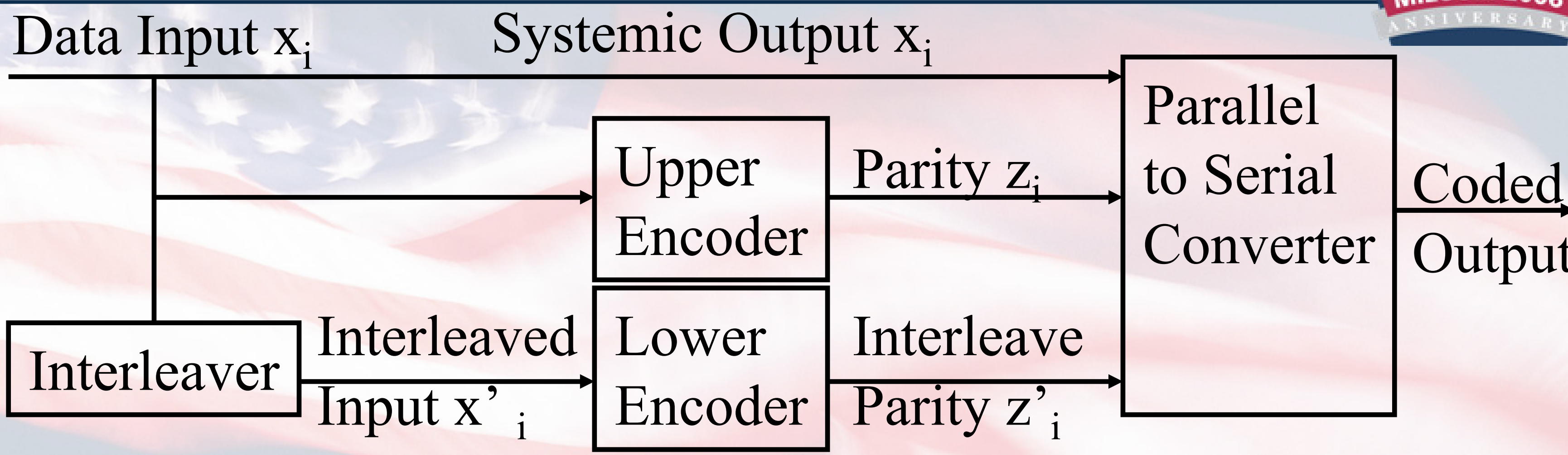
$$10 \text{ Log}_{10} S/N = 30$$

$$\text{Log}_{10} S/N = 3$$

$$S/N = 10^3 = 1000$$

$$\text{Capacity} = 3100 \log_2 (1+1000)$$
$$= 30{,}894 \text{ bps}$$

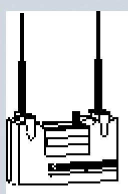
Turbo Codes



- Normal FEC codes: 3dB below the Shannon limit
- Turbo Codes: 0.5dB below Shannon limit
  Developed by French coding theorists in 1993
- Use two coders with an interleaver
- Interleaver rearranges bits in a prescribed but irregular manner

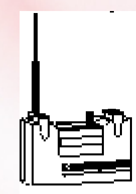
Space Time Block Codes (STBC)

- Invented 1998 by Vahid Tarokh.
- Transmit multiple redundant copies from multiple antennas
- Precisely coordinate distribution of symbols in space and time.
- Receiver combines multiple copies of the received signals optimally to overcome multipath.
- Example: Two antennas:



	Antenna 1	Antenna 2
Slot 1 →	S1	S2
Slot 2 →	-S2*	S1*

Time ↓   Space →

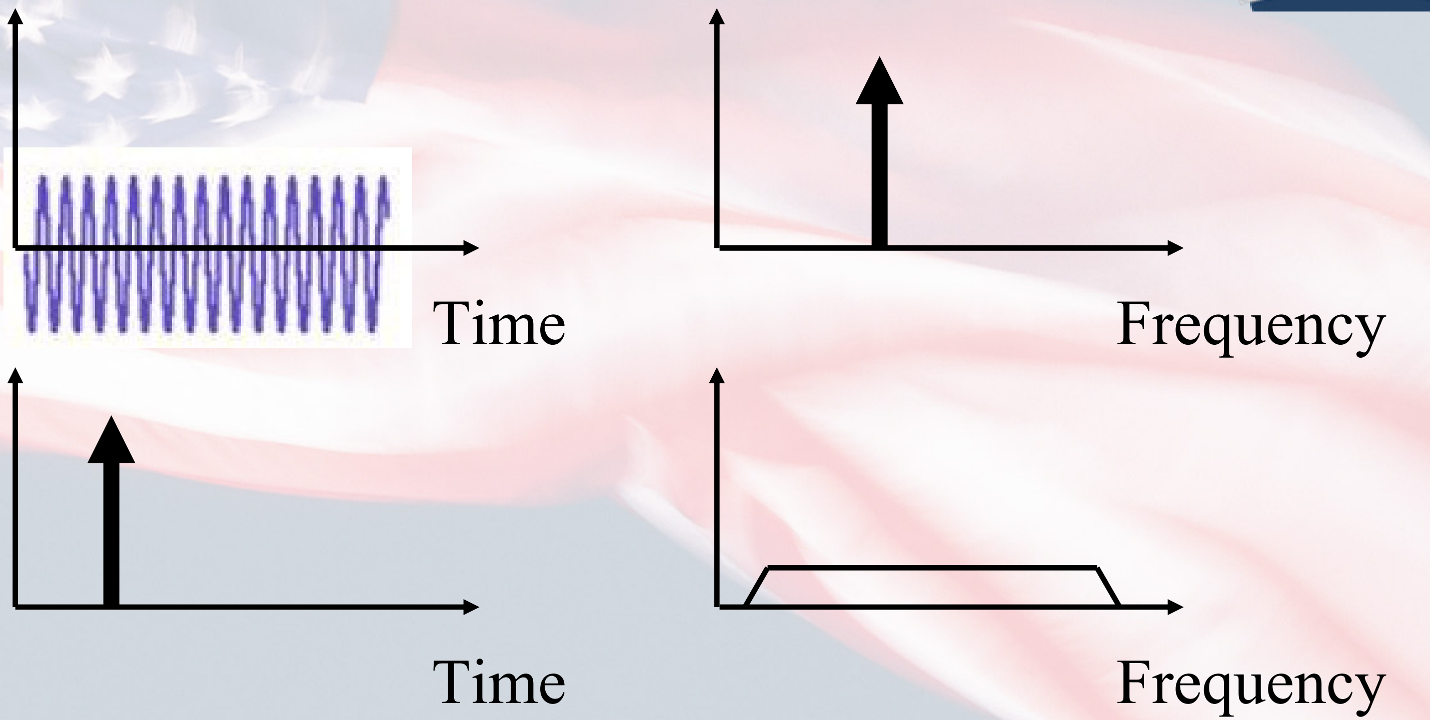


S1* is complex conjugate of S1 ⇒ columns are orthogonal

Software Defined Radio

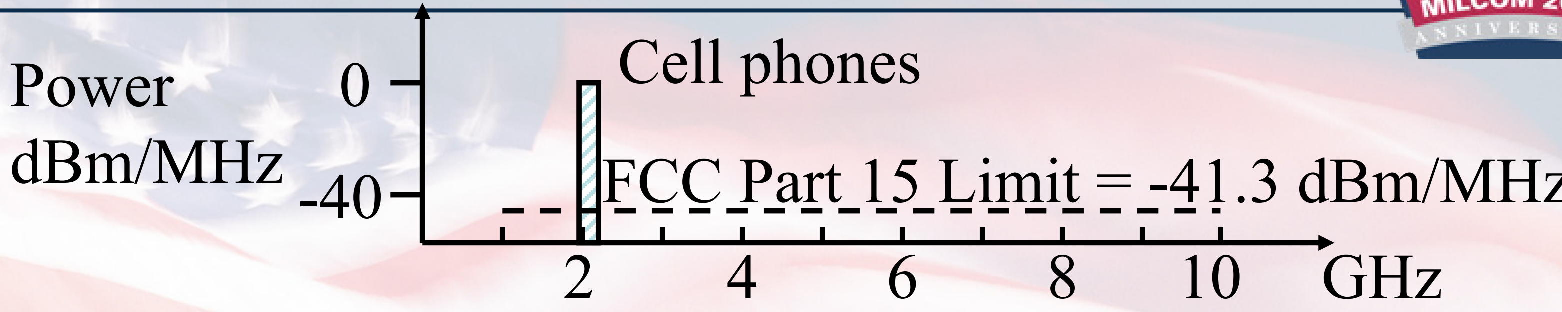
- GSM and CDMA incompatibility => Need multimode radios
- Military needs to intercept signals of different characteristics
- Radio characteristics (Channel bandwidth, Data rate, Modulation type) can be changed by software
- Multiband, multi-channel, multi-carrier, multi-mode (AM, FM, CDMA), Multi-rate (samples per second)
- Generally using Digital Signal Processing (DSP) or field programmable gate arrays (FPGAs)
- Signal is digitized as close to the antenna as possible
- Speakeasy from Hazeltine and Motorola in mid 80's was one the first SDRs. Could handle 2 MHz to 2 GHz.

Ultra-Wideband



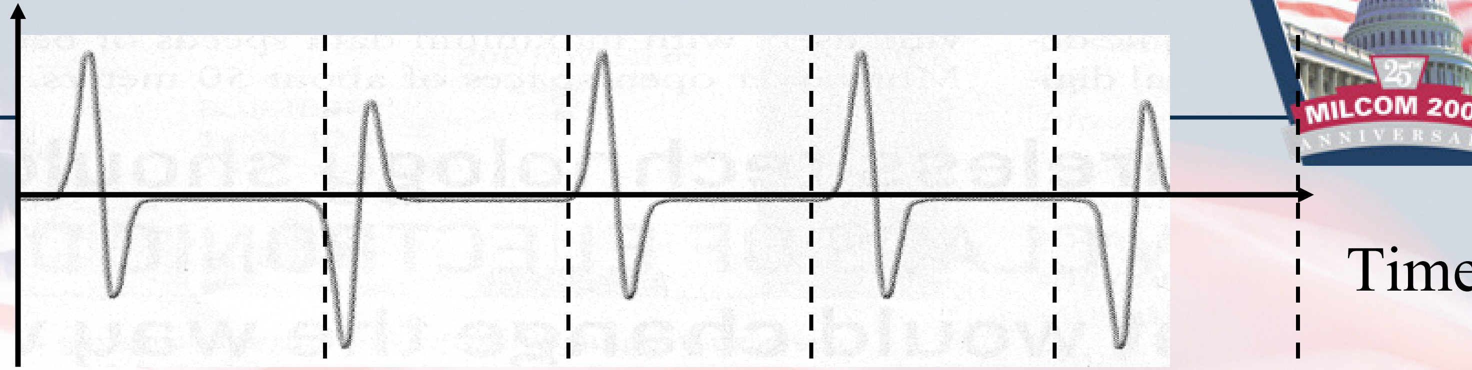
- An impulse in time domain results in a ultra wide spectrum in frequency domain and essentially looks like a white noise to other devices

Ultra-Wideband (UWB)



- FCC rules restrict the maximum noise generated by a wireless equipment (0 dBm = 1mW, -40 dBm = 0.1 μW)
- Very short (sub-ns) pulses ⇒ Spectrum below the allowed noise level ⇒ Get Gbps w 10 GHz spectrum
- FCC approved UWB operation in 2002
- High-speed over short distances ⇒ Wireless USB
- UWB can see through trees and underground (radar) ⇒ collision avoidance sensors, through-wall motion det

UWB



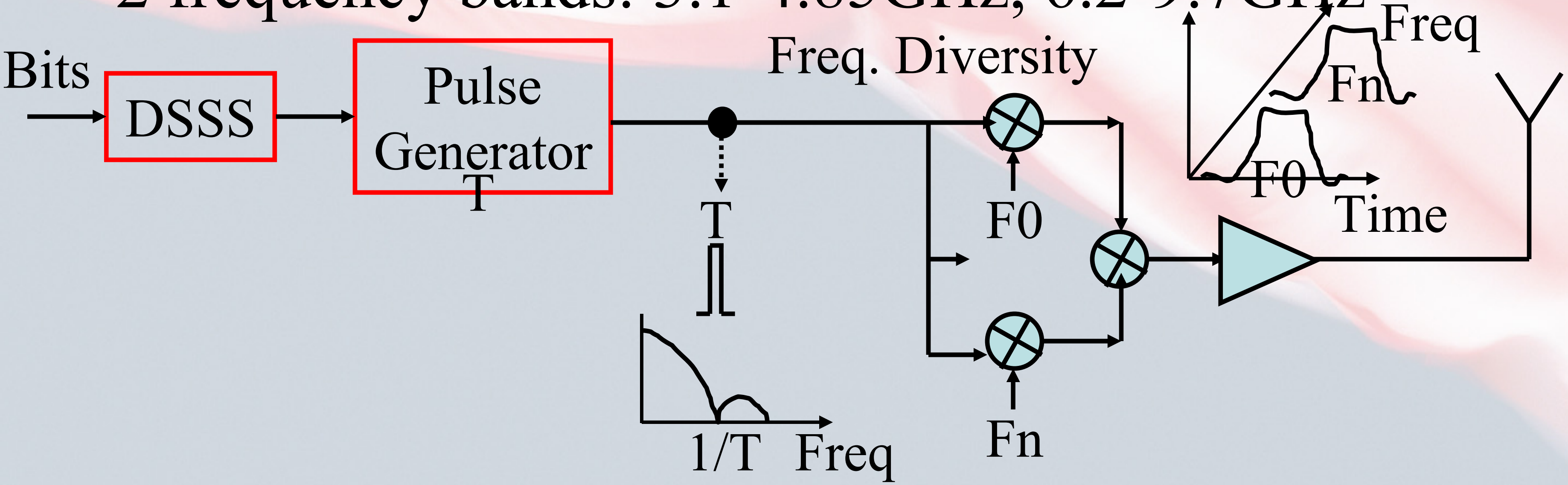
- Sub-nanosecond impulses are sent many million times per second. Pulse width = 25 to 400 ps
- 0.25 ns Impulse ⇒ 4 B pulses/sec ⇒ 100's Mbps
- Became feasible with high-speed switching semiconductor devices
- May be position, amplitude, or polarity modulated
- Two leading proposals: DS-UWB and MB-OFDM

Advantages of UWB

- Very low energy consumption: Good Watts/Mbps
- Line of sight not required. Passes through walls.
- Sub-centimeter resolution allows precise motion detection. Track high-value assets
- Pulse width much smaller than path delay
  $\Rightarrow$ Easy to resolve multipath
  $\Rightarrow$ Can use multipath to advantage
- Difficult to intercept (interfere)
- All digital logic $\Rightarrow$ Low cost chips

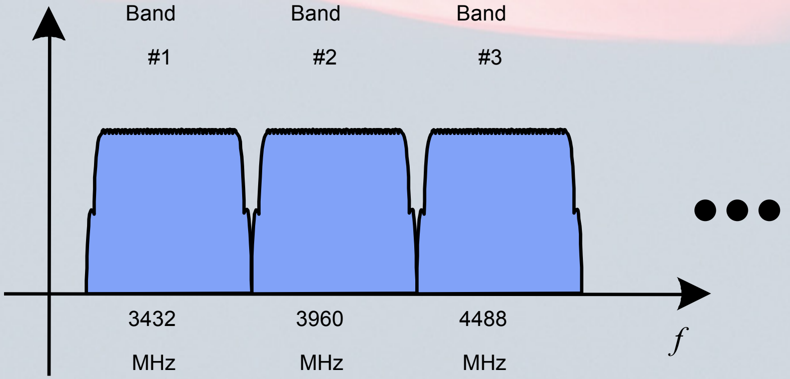
Direct sequence (DS-UWB)

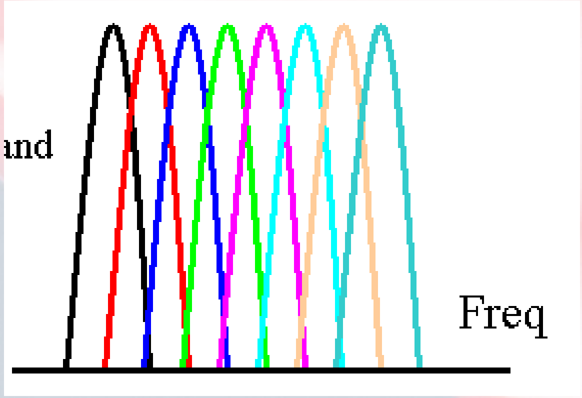
- Championed by UWB Forum (Motorola/XtremeSpectrum)
- Uses CDMA with multiple chips per bit
- Chips are encoded using pulses
- 2 frequency bands: 3.1-4.85GHz, 6.2-9.7GHz



Multi-Band OFDM

- From WiMedia Alliance.
- Originally proposed by TI. Now many companies
- Divide the 3.1-10.6 GHz spectrum in 14x528 MHz bands (FCC requires min 500 MHz use for UWB)





- Simple devices need to support 3 lowest bands

Multi-Band OFDM (Cont)

- Spectrum shaping flexibility for international use
  Move off the band if interference
- Use OFDM with 128 subcarriers in a band: Similar in nature to 802.11a/g
- Disable a few sub-carriers if required to meet local laws
- ECMA-368, 369 Standard, 2005.

Sample UWB Products

- Wireless USB from Staccato Communications
- PulsON 200 UWB evaluation kits from Time Domain Corp
- UWB antennas from Omran
- Click n' Share Wireless USB Flash Memory Drives from Memsen
- UWB chips from Intel, Artimi, and Wisair
- Locating bodies in disaster situations by Ultravision

Sample UWB Products (Cont)

- Mini-PCI UWB radio modules and evaluation kits from Focus Semiconductor
- Wireless video in cars using Focus UWB radio
- Wireless High-Definition Multimedia Interface (HDMI) solutions form Tzero, Analog Devices, and Gefen
- Wireless HD gaming over UWB by Pulse-Link
- Ref: http://www.ultrawidebandplanet.com/products/

Summary

1. Frequency hopping and Direct Sequence are two methods of code division multiple access or spread spectrum
2. OFDM splits a band in to many orthogonal subcarriers. OFDMA = FDMA + TDMA
3. Turbo codes use two coders and a interleaver and operate very close to Shannon's limit
4. Space-time block codes use multiple antennas to transmit related signals
5. MIMO use multiple antennas for high throughput

Wireless LAN/MAN Standards: 802.11n, 802.16

Wireless LAN/MAN Standards: 802.11n, 802.16

- IEEE 802.11n
  - Technology
  - Status
  - Sample Products
- IEEE 802.16 and WiMAX
  - Key Features
  - IEEE 802.16 PHYs
  - Scheduling and Link Adaptation
  - IEEE 802.11 vs. 802.16
  - Sample WiMAX Products

IEEE 802.11n

- Trend: HDTV and flat screens are taking off
  Media Center Extenders from Linksys and other vendors
- Application: HDTV and streaming video (over longer distances than permitted by 802.15.3 WPANs)
- IEEE 802.11n = Next Generation of 802.11
- At least 100 Mbps at MAC user layer
  $\Rightarrow$ 200+ Mbps at PHY $\Rightarrow$ 4x to 5x faster than 11a/g
  (802.11a/g have 54 Mbps on air and 25 Mbps to user)
- Pre-11n products already available

11n Technology

- Uses multiple input multiple output antenna (MIMO)
- Data rate and range are enhanced by using spatial multiplexing (N antenna pairs) plus antenna diversity
- Occupies one WLAN channel, and in compliance with 802.11
- Backwards compatible with 802.11 a,b,g
- One access point supports both standard WLAN and MIMO devices

Major Components of 11n

1. Better OFDM: Higher code rate gives 65 Mbps instead of 54 Mbps
2. Space Division Multiplexing: Up to 4 spatial streams
3. Diversity: More receive antennas than the number of streams. Select the best subset of antennas.
4. Beam Forming: Focus the beam directly on the target antenna
5. MIMO Power Save: Use multiple antennas only when needed
6. 40 MHz Channels
7. Aggregation: Transmit bursts of multiple data packets
8. Reduced Inter-Frame Spacing
9. Greenfield Mode: Optionally eleminate support for a/b/g

IEEE 802.11n Status

- Enhanced Wireless Consortium (EWC) was formed in October 2005 to accelerate the development
- WWise, TGnSync and EWC proposals were merged and a draft was accepted in January 2006.
- IEEE 802.11n draft v1.04 in September 2006
- Working on coexistence analysis of 20 and 40 MHz modes
- Final IEEE publication scheduled for April 2008
- Intel, Broadcom, Marvel have pre-11n chip sets

Sample IEEE 802.11n Products

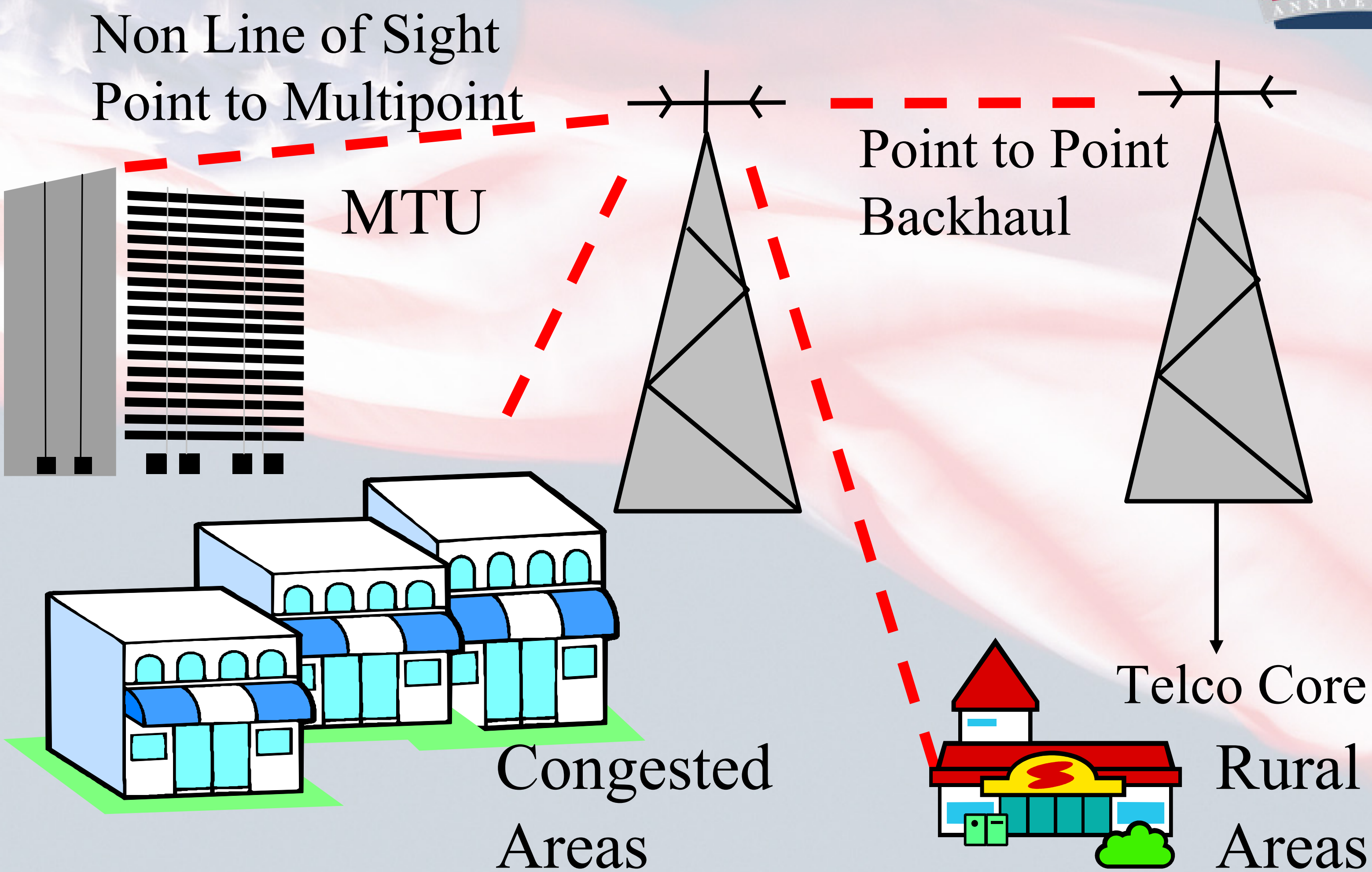
- Linksys, Belkin, D-Link, Netgear have pre-11 wireless routers
- Not compatible with each other
  Not guaranteed to be upgradeable to full 802.11n
  Actual throughputs up to 40 Mbps
- Wi-Fi Alliance will certify pre-11n products

Belkin

D-Link

Linksys

Broadband Wireless Access



IEEE 802.16: Key Features

- Broadband Wireless Access
- Up to 50 km or Up to 70 Mbps.
- Data rate vs Distance trade off w adaptive modulation. 64QAM to BPSK
- Offers non-line of site (NLOS) operation
- 1.5 to 28 MHz channels
- Hundreds of simultaneous sessions per channel
- Both Licensed and license-exempt spectrum
- QoS for voice, video, T1/E1, and bursty traffic
- Support Point-to-multipoint and Mesh network models

WiMAX

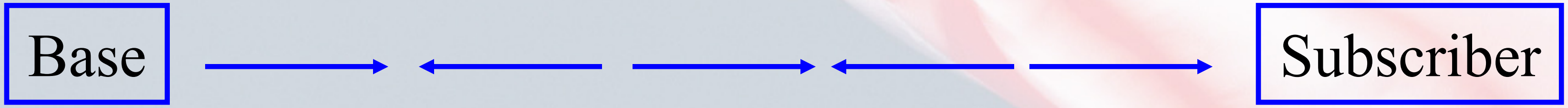
- A vendor organization for ensuring interoperability
- Plugfests started November 2005
- WiMAX forum lists certified base stations and subscriber stations from many vendors
- More to come:
  - Outdoor subscriber stations similar to satellite dish by 2006 ≈$350
  - Indoor subscriber stations by 2006-2007 ≈ $250
  - Portable modems for laptops by 2007-2008 ≈ $100

Duplexing Options

- Duplex = Bi-Directional Communication
- Full-Duplex = Both directions at the same time

This is known as Frequency division duplexing (FDD)

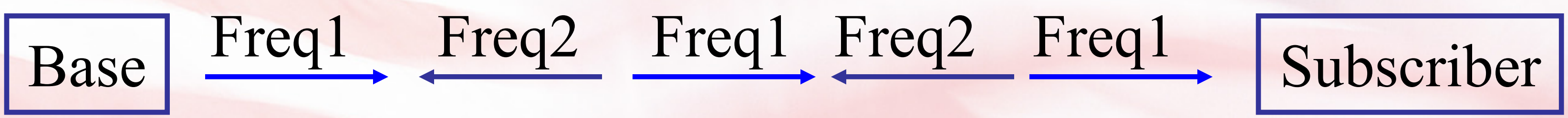
- Half-duplex = One direction at a time



This is known as Time division duplex (TDD)

Duplexing Options (Cont)

- Half-Duplex FDD (HFDD): Two frequencies. But either transmitter or receiver is on.



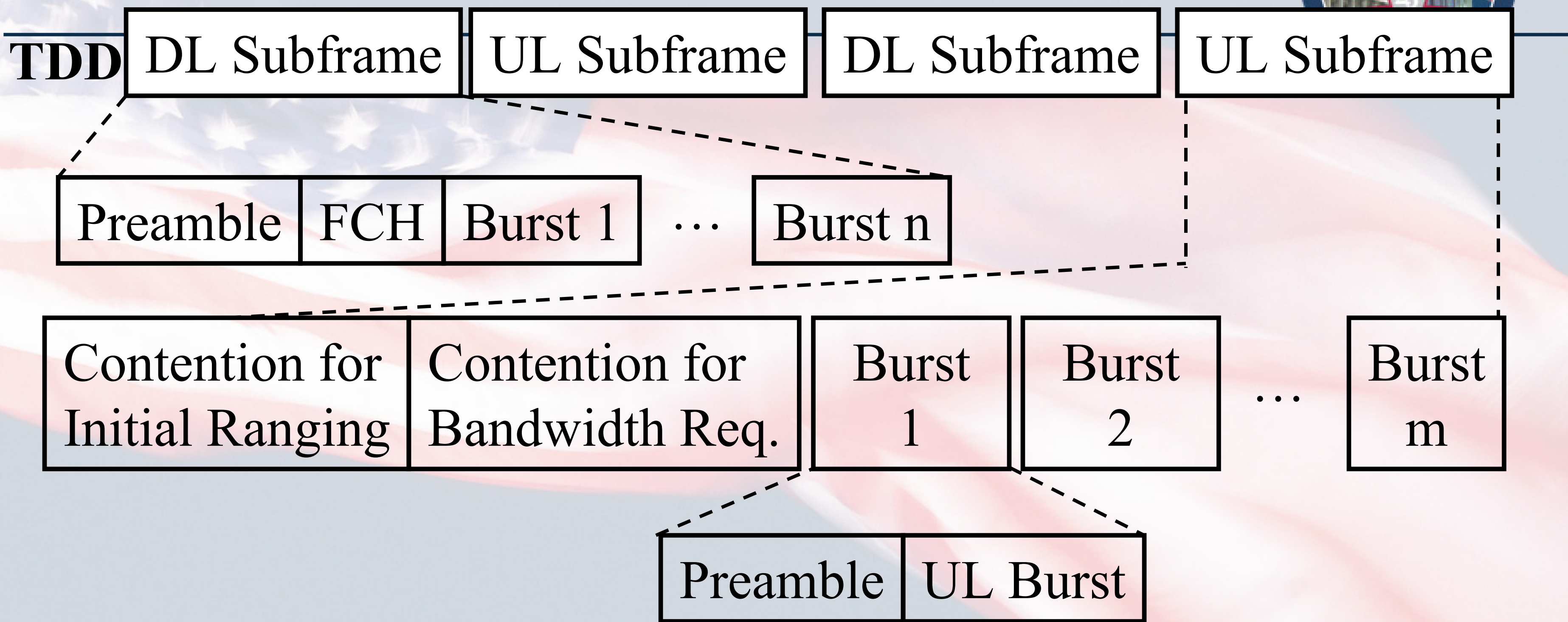
IEEE 802.16 PHYs

	Function	LOS	Freq. Band	Carrier	Duplexing
WirelessMAN SC	Pt-to-pt	LOS	10-66 GHz	Single	TDD, FDD
WirelessMAN SCa	Pt-to-pt	LOS	2-11 GHz Licensed	Single	TDD, FDD
WirelessMAN OFDM	Pt-to-mpt	NLOS	2-11 GHz Licensed	256	TDD, FDD
WirelessMAN OFDMA (16e)	Pt-to-mpt	NLOS	2-11 GHz Licensed	2048	TDD, FDD
WirelessHUMAN (High-speed Unlicensed)	Pt-to-mpt	NLOS	2-11 GHz License Exempt	1/256/ 2048	TDD Dynamic Freq. Sel.

IEEE 802.16 PHY: Other Features

- Adaptive Modulation and Coding
- Space Time Block Codes (STBC)
- Adaptive Antenna System

802.16 Frame Structure



TDD = Time Division Duplexing

DL = Downlink (Base to subscriber)

FCH = Frame control header

FDD = Freq Div Duplexing

UL = Uplink

Burst Profile, Down-link map, Uplink map, DL channel descriptor, etc.

IEEE 802.16 – QoS Classes

- Connection oriented: one or more unidirectional connections between subscriber and base
- Four Service Classes:
  1. Unsolicited Grant Service (UGS): CBR traffic like voice
  2. Real-Time Polling Services (rtPS): rtVBR like MPEG video
  3. Non-Real-Time Polling Service (nrtPS): nrtVBR, e.g., FTP
  4. Best Effort (BE)

Scheduling and Link Adaptation

- Scheduling:
  - Base schedules usage of the air link among the SSs
  - Packet schedulers at the base and subscribers give transmission opportunities to multiple connection Qs
- Link Adaptation: Base determines
  - Contents of the DL and UL portions of each frame
  - Appropriate burst profile (code rate, modulation level and so on) for each subscriber
  - Bandwidth requirements of the individual subscribers based on the service classes of the connections and on the status of the traffic queues at the base and subscriber.

IEEE 802.16 Standards

- **Air Interface**:
  - 802.16-2001: Air Interface for 10-66GHz (Obsolete)
  - 802.16a-2003: Amendment for 2-11GHz, Licensed and Licensed Exempt (Obsolete)
  - 802.16c-2002: 10-66 GHz Profiles, Coexistence and Interoperability (Obsolete)
  - **802.16-2004**: Revision incorporating and obsolescing above 3. A.k.a. 802.16d
  - **802.16f-2005**: Amendment for MIBs for fixed systems
  - 802.16-2004/Cor1-2005: Corrigendum to 802.16-2004
  - **802.16e-2005**: Enhancements to support mobility

IEEE 802.16 Standards (Cont)

- **Coexistence:**
  - **802.16.2-2001**: Coexistence for 10-66 GHz
  - **802.16.2-2004**: Revision including 2-66 GHz
- **Conformance:**
  - **802.16/Conformance01-2003**: 10-66 GHz Protocol Implementation Conformance Statement (PICS)
  - **802.16/Conformance02-2003**: 10-66 GHz Test Suite Structure and Test Purposes (TSS&TP)
  - **802.16/Conformance03-2004**: 10-66 GHz Radio Conf
  - **802.16/Conformance04-2006**: <11 GHz

IEEE 802.16 Activities

- P802.16g: Management Plane Procedures and Services
- P802.16i: Mobile MIB
- P802.16k: 802.1D bridging
- P802.16j: Mobile Multihop Relay (MMR)
- P802.16h: License-exempt channel coordination

IEEE 802.11 vs. 802.16

	802.11	802.16
Application	In-Building, Enterprise	Service providers => Carrier Class
Range	Optimized for 100m	Optimized for 7-10 km Up to 50 km
Range Spread	No near-far compensation	Handles users spread out over several kms
# Users	10's of users	Thousands of users
Coverage	Optimized for indoor	Optimized for outdoor. Adaptive modulation. Advanced Antenna
Bands	License exempt	License and license exempt bands Allows Cell Planning
Channels	Fixed 20 MHz Channel	1.5 MHz to 20 MHz Channels Size chosen by operator
Spectral Efficiency	2.7 bps/Hz ⇒54 Mbps in 20 MHz	3.8 bps/Hz ⇒ 75 Mbps in 20 MHz 5 bps/Hz ⇒ 100 Mbps in 20 MHz
Delay Spread	Designed to handle indoor multipath Delay spread of 0.8 μs	Designed for longer multipaths. Multipath delay spread of 10 μs.

IEEE 802.11 vs. 802.16 (Cont)

	802.11	**802.16**
Duplexing	TDD only - Asymmetric	TDD/FDD/HFDD – Symmetric or asymmetric
MAC	Contention based. Distributed control.	Grant based. Centralized control.
QoS	No delay or throughput guarantees	Guarantees QoS
User Differentiation	All users receive same service	Different users can have different levels of service. T1 for businesses. Best effort for residential.
Security	WEP, WPA, WPA2	128-bit 3DES and 1024-bit RSA

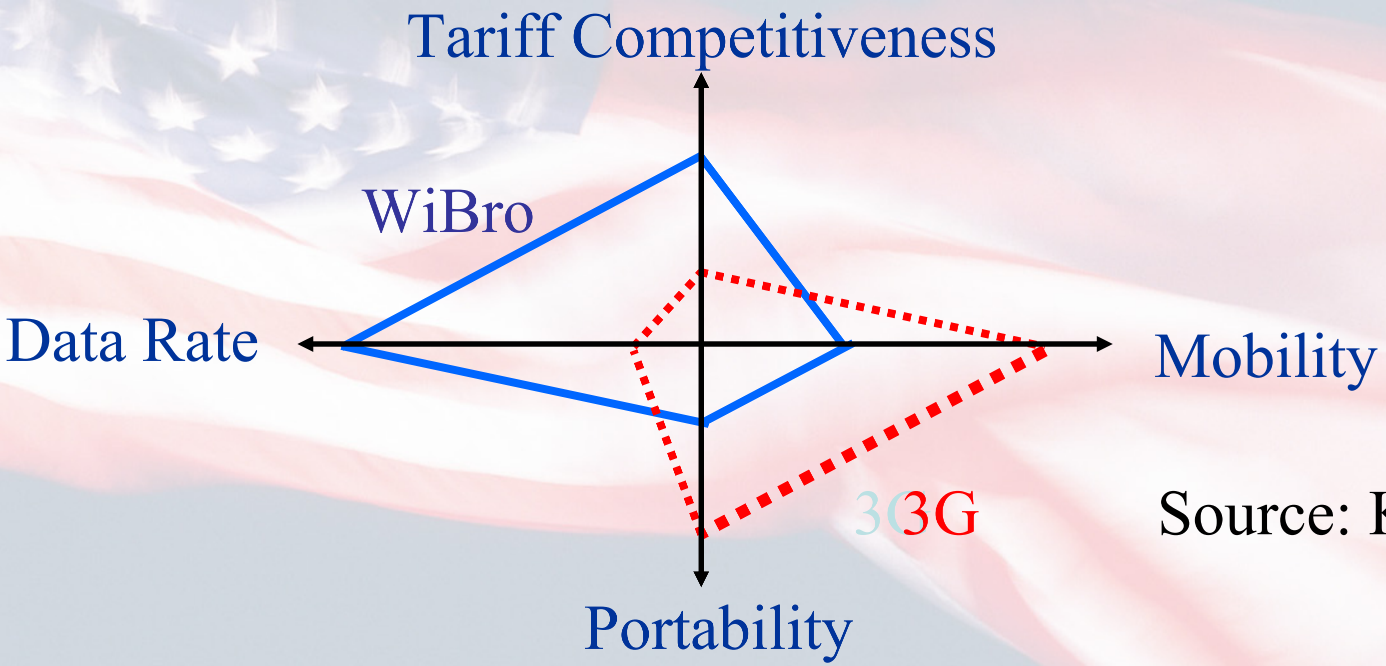
WiBro

- Mobile broadband access standard for Korea
- A pre-standard version of 802.16e
  Will conform to 802.16e in the near future
- Standardized 1H04, Licenses issued 1H05, Service starts 1H06
- Up to 60 km/h mobility, 1km cells
- Spectral efficiency:
  Max: 6 bps/Hz/sector UL/ 2 bps/Hz/sector DL
  Avg: 2 bps/Hz/sector UP/ 1 bps/Hz/sector DL

WiBro (Cont)

- 10 MHz channel in 2.3 GHz band
- OFDMA with QPSK, QAM16, QAM64 modulation
- Per Subscriber Data rate:
  DL/UL = 3 Mbps/1 Mbps (max) = 512 kbps/128 kbps (mobile)
- Handoff $\leq$ 150 ms

Wibro vs. 3G



Source: KT

Sample WiMAX Subscriber Stations

Alvarion

Airspan

Axxcelera

Siemens

Aperto

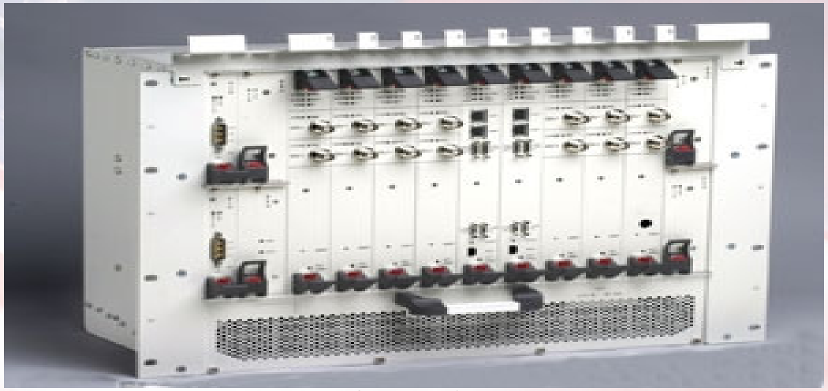
Redline

SR Telecom

Telsima

Sample WiMAX Base Stations


Axxcelara


Alverian


Redline

Airspan


Aperto

SR Telecom

IEEE 802.20

- Mobile Broadband Wireless Access (MBWA)
- Vehicular mobility up to 250 Km/h
- Optimized for IP data transport
- Licensed band below 3.5 GHz
- >1 Mbps data rate
- Designed for green field wireless data providers
- Intel and Motorola vs. Qualcomm and Kyocera
- Stopped operation on June 8, 2006. Restarted Sept 19, 2006.

Summary

1. IEEE 802.11n uses MIMO and provides 4 times the 11a/g throughput.
2. IEEE 802.16 or WiMAX is designed for metro-wide access at high speed.
3. 802.16 MAC provides Strong QoS using per subscriber coding, resource allocation, and scheduling
4. 802.16 PHY uses OFDMA, Space time block codes, Adaptive antenna system

References

- See http://www.cse.wustl.edu/~jain/refs/milcom06.htm