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

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Overview

1. Wireless Equipment/Revenue Trends
2. Recent Developments in Wireless PHY
3. Ultra Wideband
4. High Throughput WiFi: 802.11n
5. WiMAX
6. Other Competing Broadband Access Technologies

Part I: Wireless Revenue Trends

- ☐ Home Networking Equipment Trends
- ☐ Global Broadband Wireless Equipment
- ☐ Broadband Market by Regions
- ☐ Fixed vs. Mobile
- ☐ Voice vs. Data

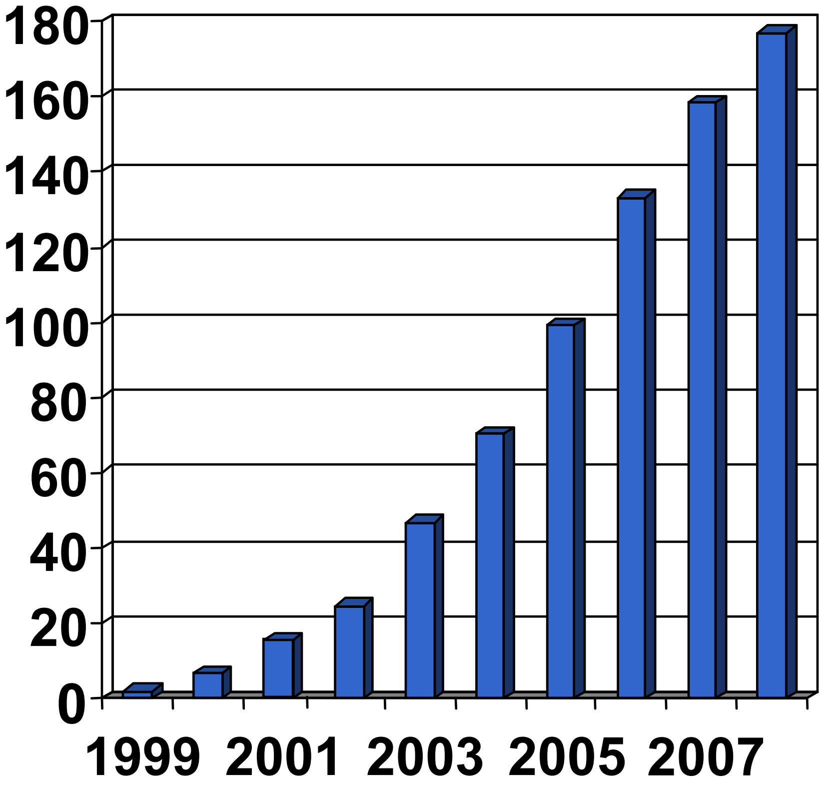
Telecom Revenue

	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%

- 48% revenues are from wireless.
- 26% of revenue from data (vs. voice)
- 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”

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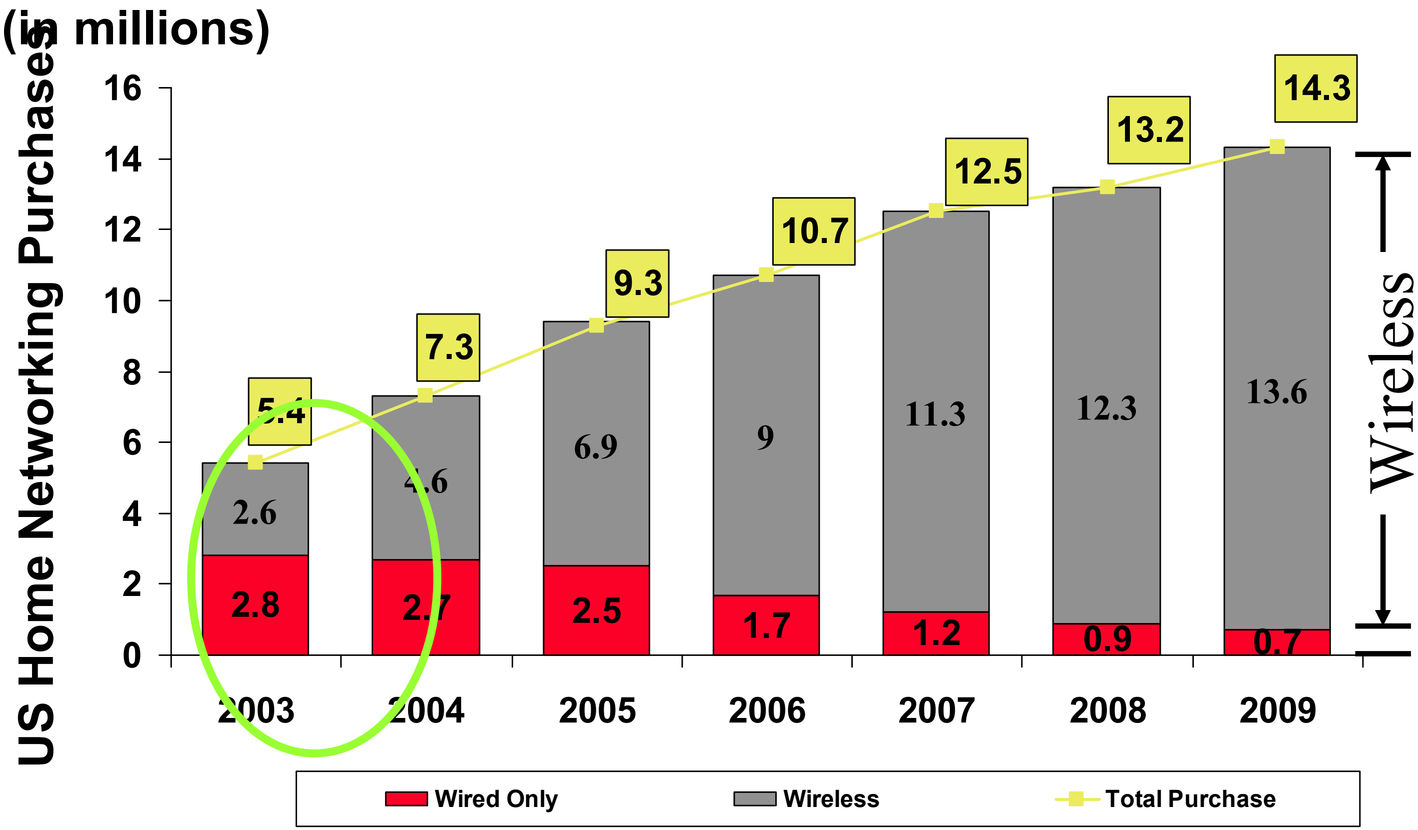
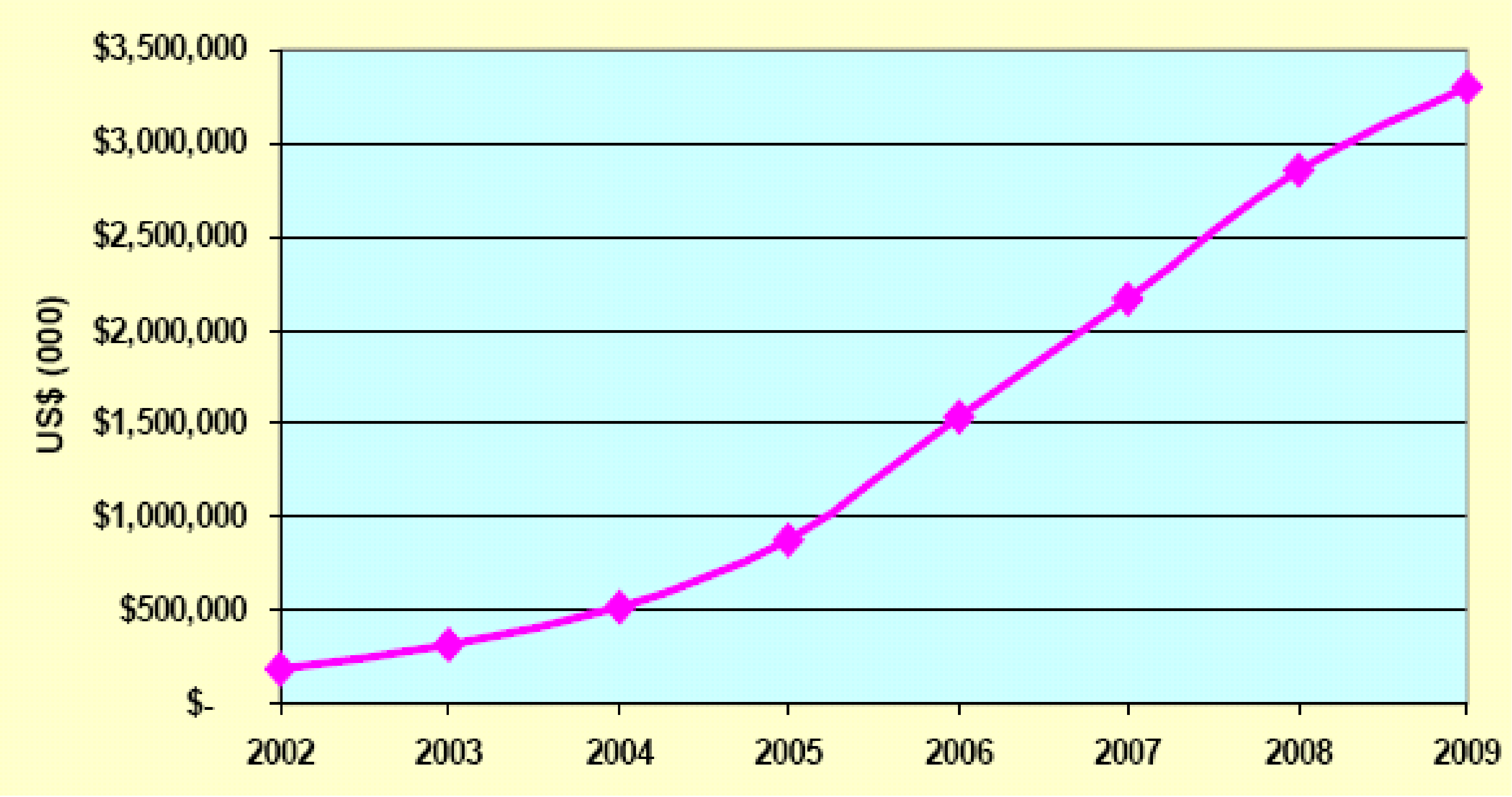
Home Networking Equipment Trends



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

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

Global Broadband Wireless Equipment



- 0-10 GHz, Base stations+Subscriber stations

Source: Skylight Research

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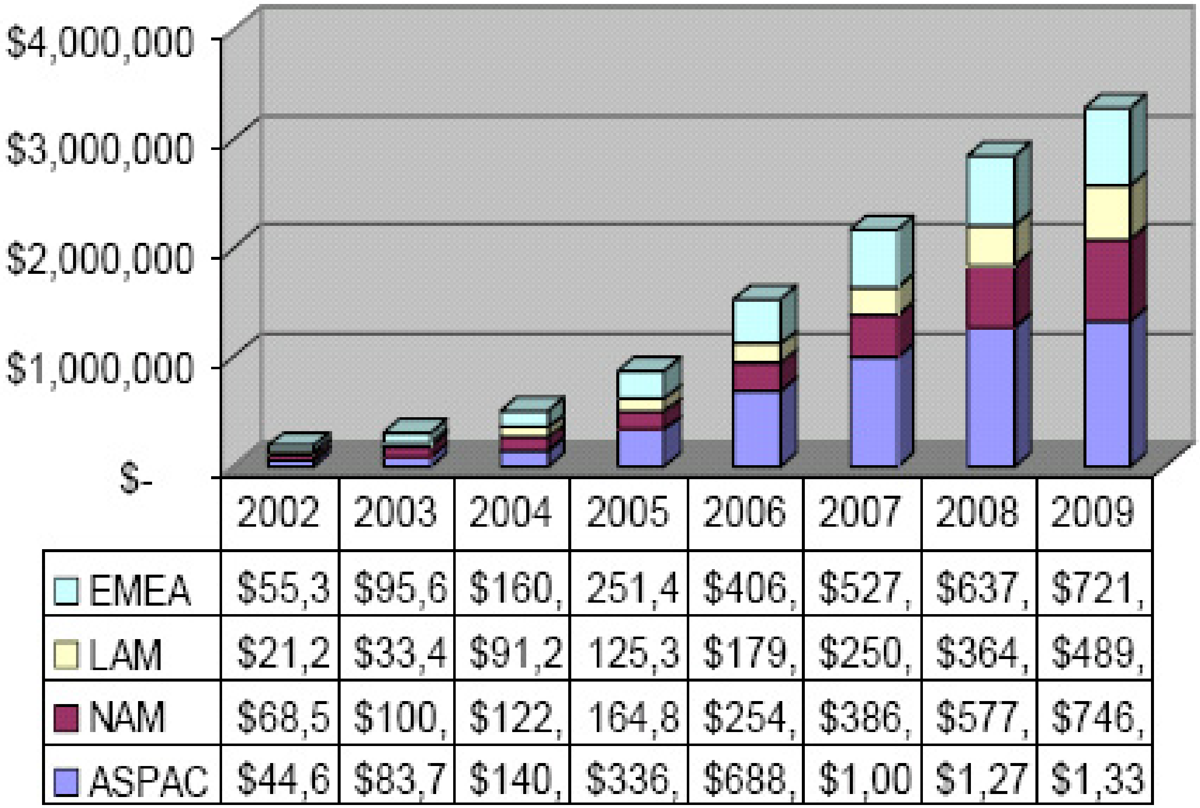
Broadband Market by Regions

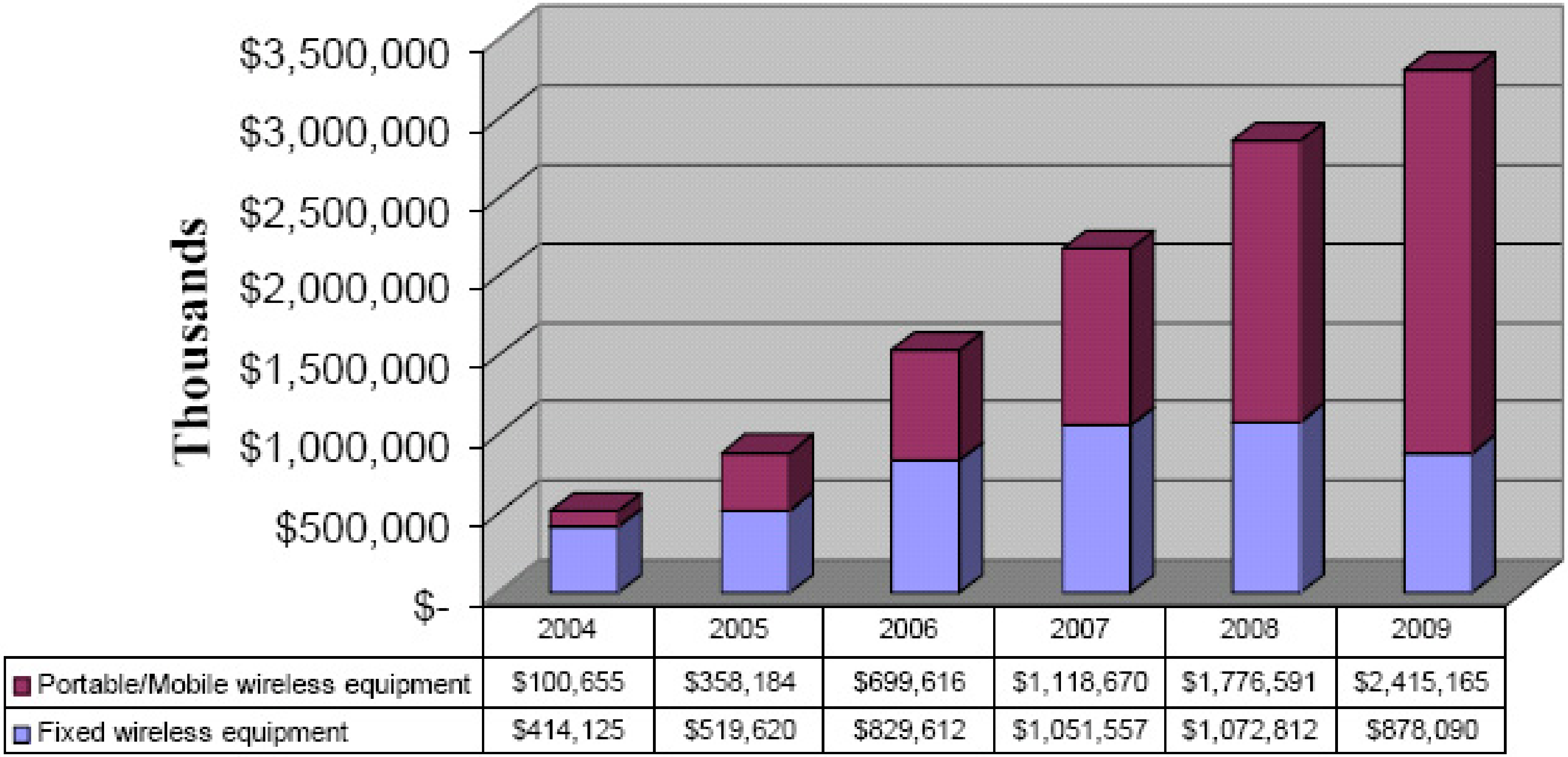


	2002	2003	2004	2005	2006	2007	2008	2009
🟦 EMEA	$55,3	$95,6	$160,	251,4	$406,	$527,	$637,	$721,
🟨 LAM	$21,2	$33,4	$91,2	125,3	$179,	$250,	$364,	$489,
🟥 NAM	$68,5	$100,	$122,	164,8	$254,	$386,	$577,	$746,
🟪 ASPAC	$44,6	$83,7	$140,	$336,	$688,	$1,00	$1,27	$1,33

- ASPAC and EMEA leading the growth

Source: Skylight Research

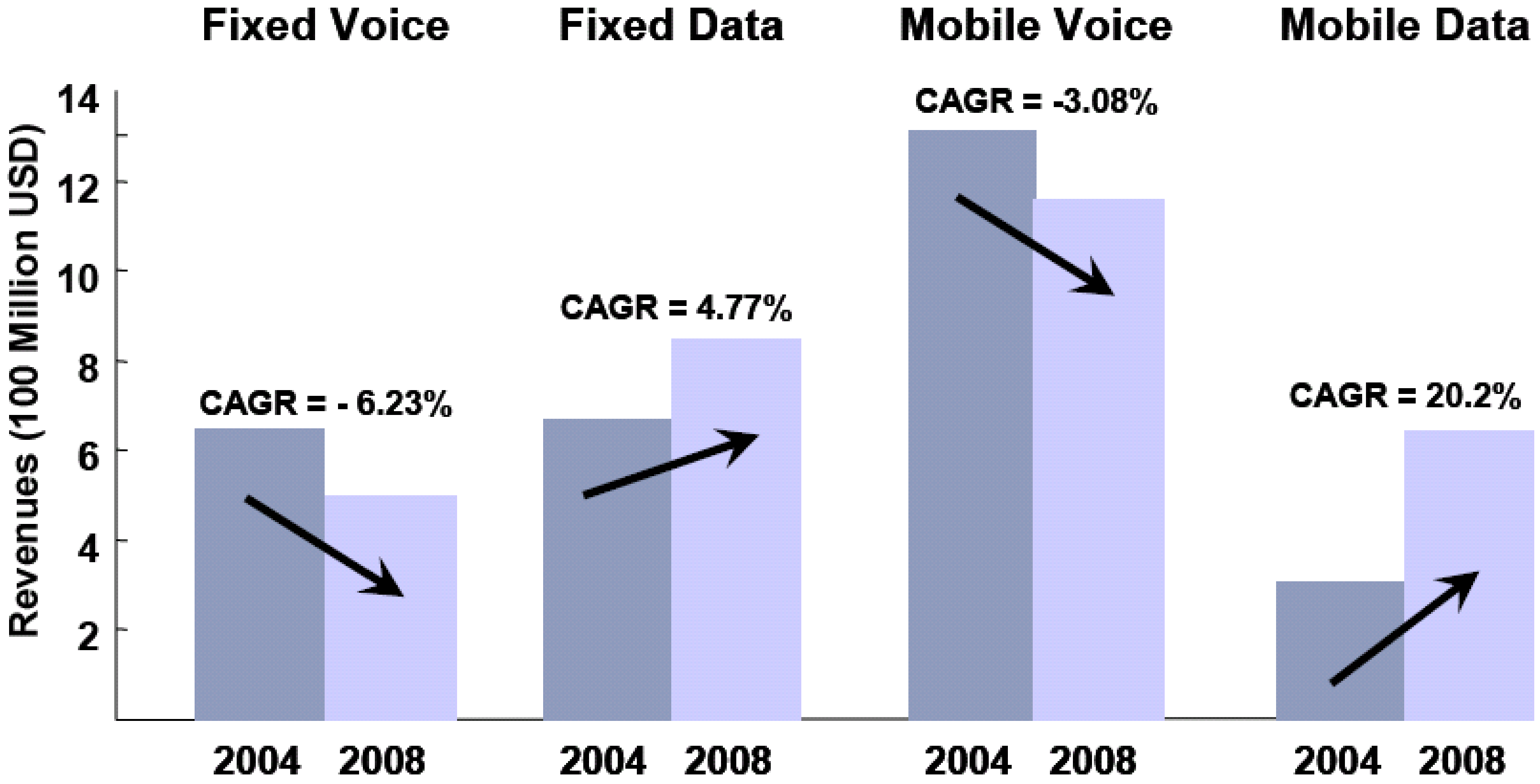
Personal Broadband: Fixed vs. Mobile



	2004	2005	2006	2007	2008	2009
🟥 Portable/Mobile wireless equipment	$100,655	$358,184	$699,616	$1,118,670	$1,776,591	$2,415,165
🟦 Fixed wireless equipment	$414,125	$519,620	$829,612	$1,051,557	$1,072,812	$878,090

Source: Skylight Research

Voice and Data Revenues (Korea)



Source: KISDI 2004

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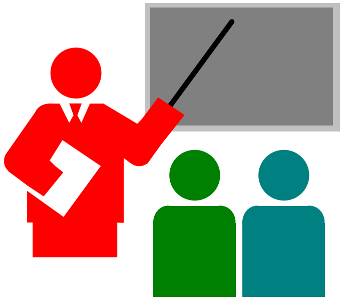
Summary: Wireless Revenue Trends

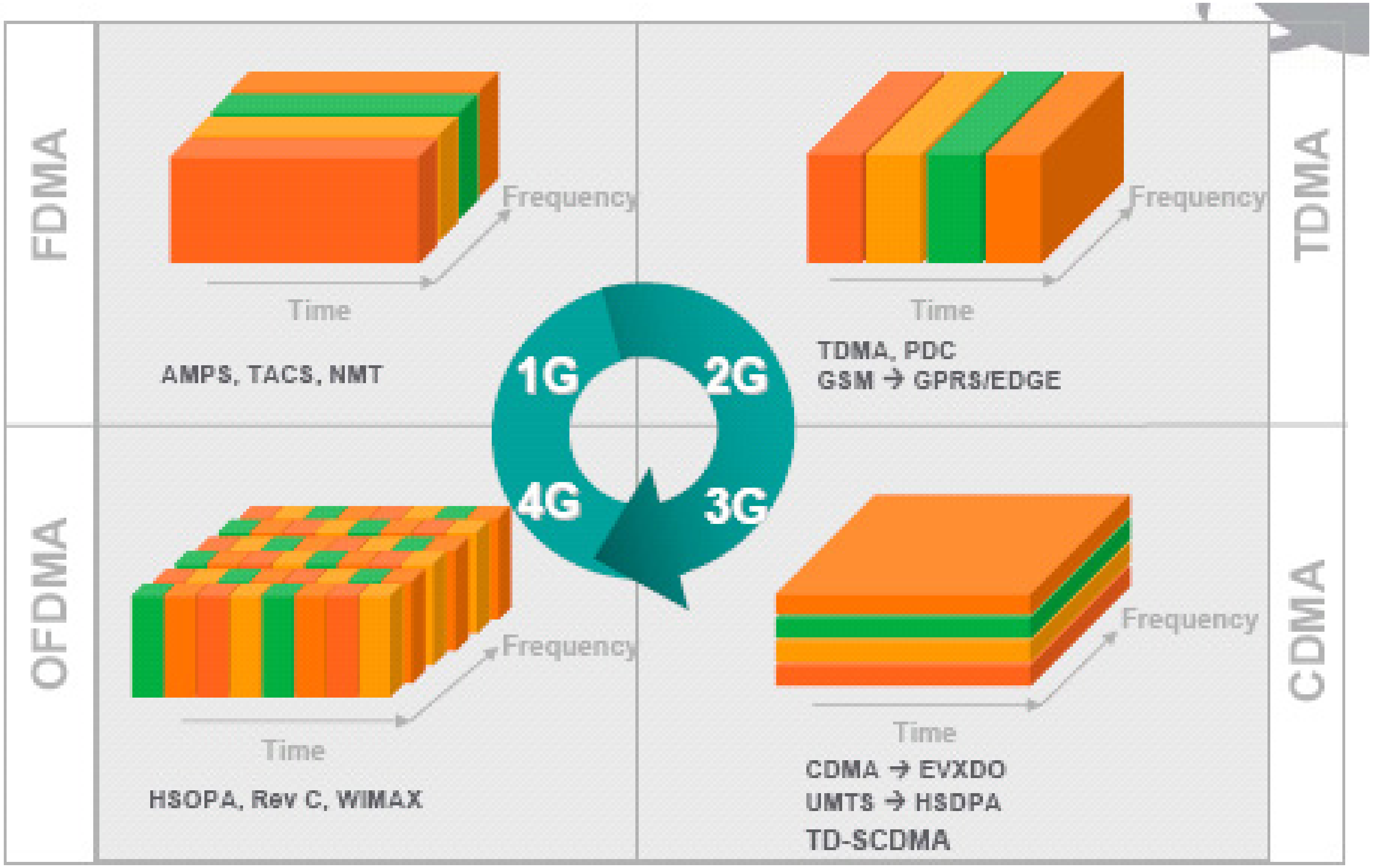


- ☐ Wireless is the major source of carrier revenue
  ⇒ Significant growth in Wireless networking
- ☐ Growth also in home and enterprise market
- ☐ Moving from fixed to mobile wireless
- ☐ Moving from voice to data

Part II:
Recent Developments in Wireless PHY

1. OFDM, OFDMA, SOFDMA
2. Beamforming
3. MIMO
4. Turbo Codes
5. Space-Time Block Codes
6. Time Division Duplexing
7. Software defined radios

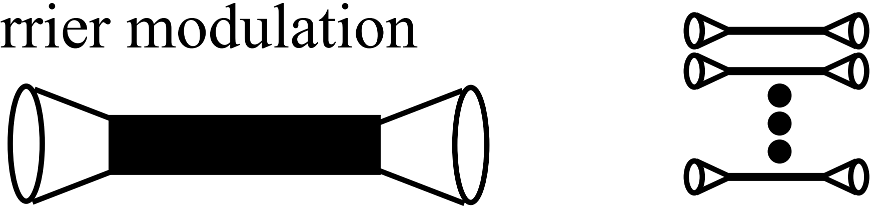
Multiple Access Methods



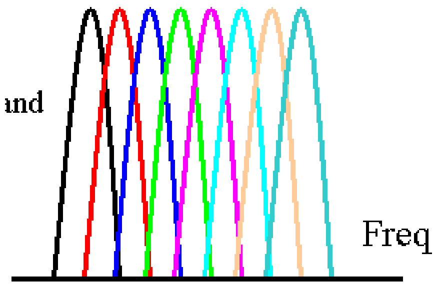
Source: Nortel

1. 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,
  Digital Video Broadcast handheld (DVB-H)
- ❑ Easy to implement using FFT/IFFT



Advantages of OFDM

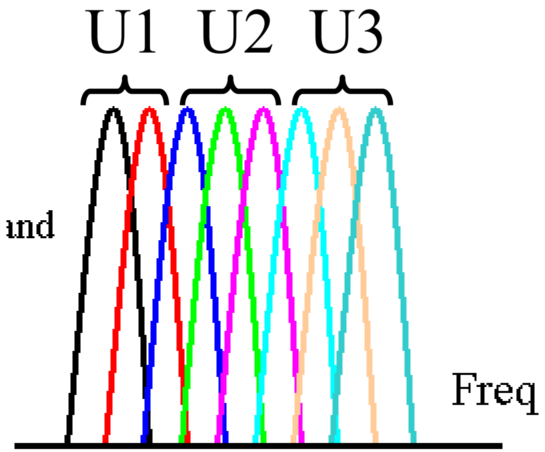
- Easy to implement using FFT/IFFT
- Computational complexity = O(B log BT) compared to previous $O(B^2T)$ for Equalization. Here B is the bandwidth and T is the delay spread.
- Graceful degradation if excess delay
- Robustness against frequency selective burst errors
- Allows adaptive modulation and coding of subcarriers
- Robust against narrowband interference (affecting only some subcarriers)
- Allows pilot subcarriers for channel estimation

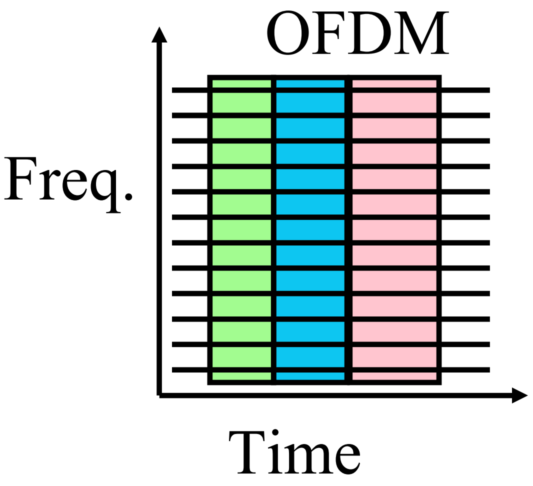
OFDM: Design considerations

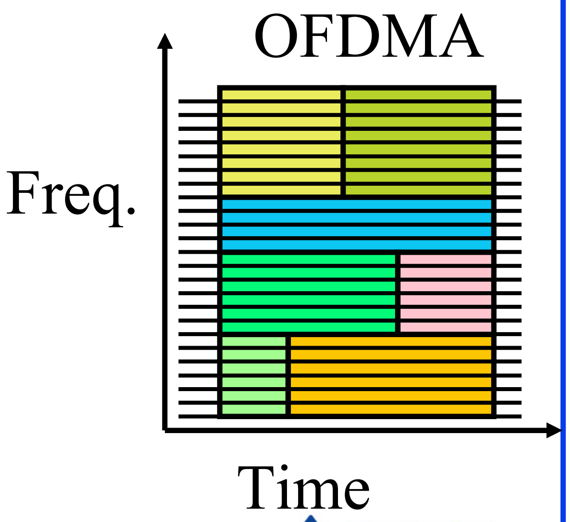
- Large number of carriers ⇒ Larger symbol duration ⇒ Less inter-symbol interference
- Reduced subcarrier spacing ⇒ Increased inter-carrier interference due to Doppler spread in mobile applications
- Easily implemented as Inverse Discrete Fourier Transform (IDFT) of data symbol block
- Fast Fourier Transform (FFT) is a computationally efficient way of computing DFT

OFDMA

- ❑ Orthogonal Frequency Division Multiple Access
- ❑ Each user has a subset of subcarriers for a few slots
- ❑ OFDM systems use TDMA
- ❑ OFDMA allows Time+Freq DMA ⇒ 2D Scheduling





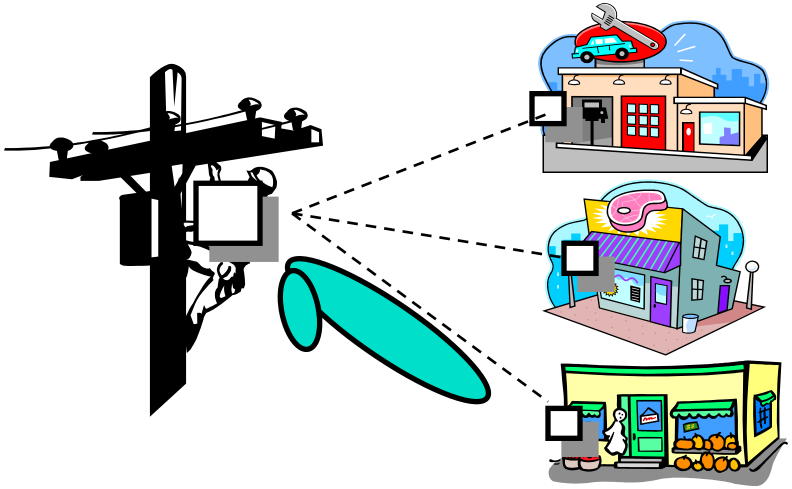


Scalable OFDMA (SOFDMA)

- OFDM symbol duration = f(subcarrier spacing)
- Subcarrier spacing = Frequency bandwidth/Number of subcarriers
- Frequency bandwidth=1.25 MHz, 3.5 MHz, 5 MHz, 10 MHz, 20 MHz, etc.
- Symbol duration affects higher layer operation
  - ⇒ Keep symbol duration constant at 102.9 us
  - ⇒ Keep subcarrier spacing 10.94 kHz
  - ⇒ Number of subcarriers ∝ Frequency bandwidth

  This is known as scalable OFDMA

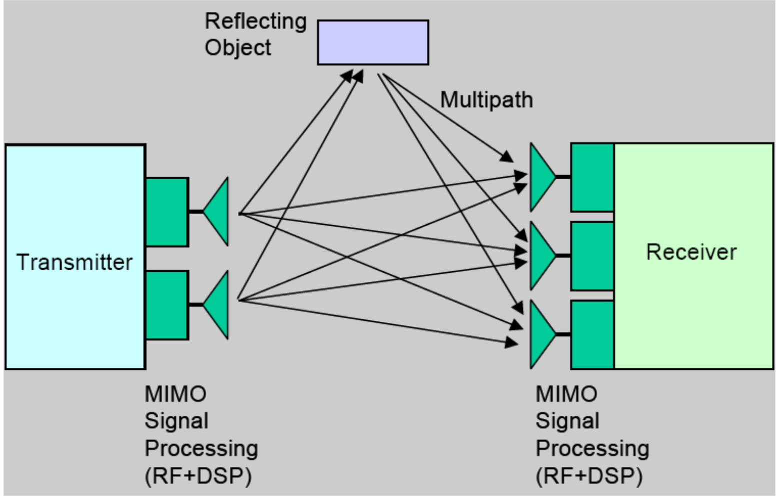
2. Beamforming



- ☐ 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

3. MIMO

- Multiple Input Multiple Output
- RF chain for each antenna
  ⇒ Simultaneous reception or transmission of multiple streams



2x3

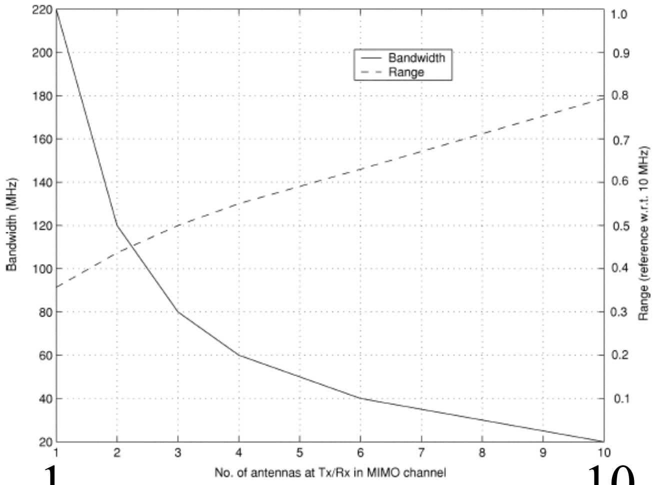
802.16e at 2.5 GHz, 10 MHz TDD, D:U=2:1

T:R	1x1	1x2	2x2	2x4	4x2	4x4
b/Hz	1.2	1.8	2.8	4.4	3.7	5.1

MIMO

- **Antenna Diversity**: Multiple transmit or receive antenna but a single transmit/receive chain
- **MIMO**: RF chain for each antenna ⇒ Simultaneous reception or transmission of multiple streams
  1. **Array Gain**: Improved SNR. Requires channel knowledge (available at receiver, difficult at transmitter)
  2. **Diversity Gain**: Multiple independently fading paths. Get $N_T \times N_R$th order diversity. Transmitter can code the signal suitably ⇒ Space time coding.
  3. **Spatial Multiplexing Gain**: Transmitting independent streams from antennas. Min (N_T, N_R) gain
  4. **Interference Reduction**: Co-channel interference reduced by differentiating desired signals from interfering signals

Gigabit Wireless



Required Bandwidth for 1Gbps

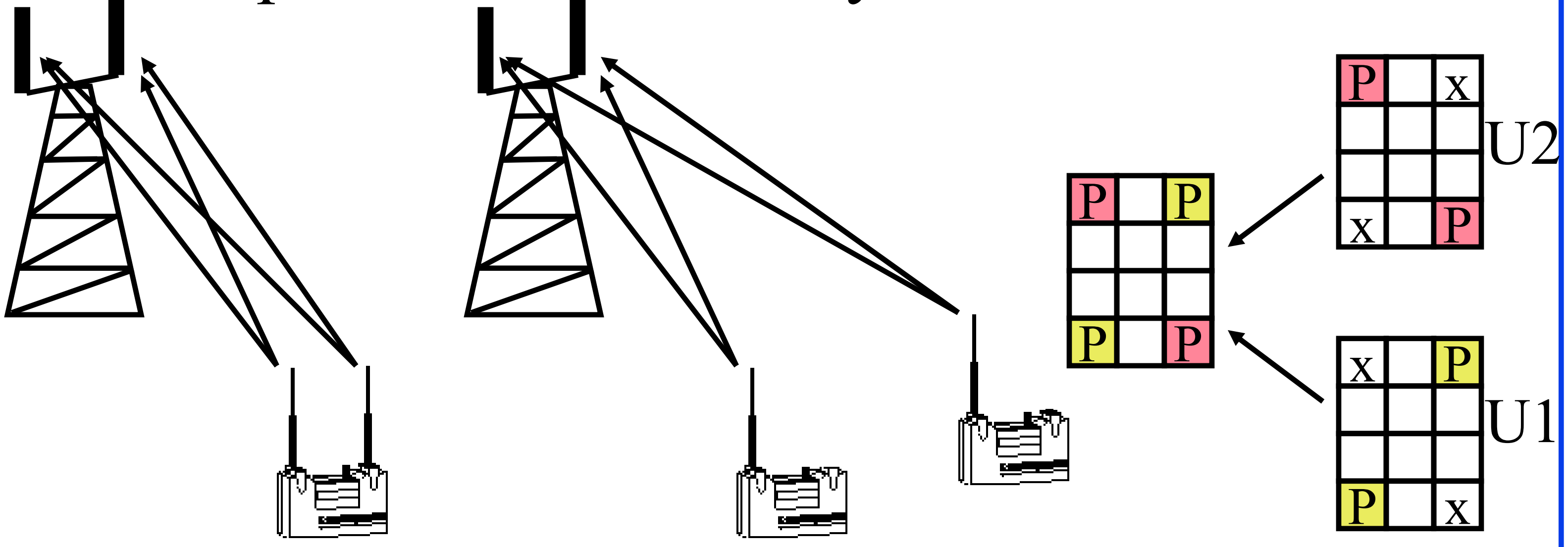
Range

1 # of Antennas 10

- ❑ Max 9 b/Hz in fixed and 2-4 b/Hz in mobile networks ⇒ Need too much bandwidth ⇒ High frequency ⇒ Line of sight
- ❑ Single antenna will require too much power ⇒ high cost amplifiers
- ❑ MIMO improves the range as well as reduces the required bandwidth
- ❑ Ref: Paulraj et al, Proc of IEEE, Feb 2004.

Cooperative MIMO

- ❑ Two subscribers with one antenna each can transmit at the same frequency at the same time
- ❑ The users do not really need to know each other. They just use the pilots as indicated by the base.

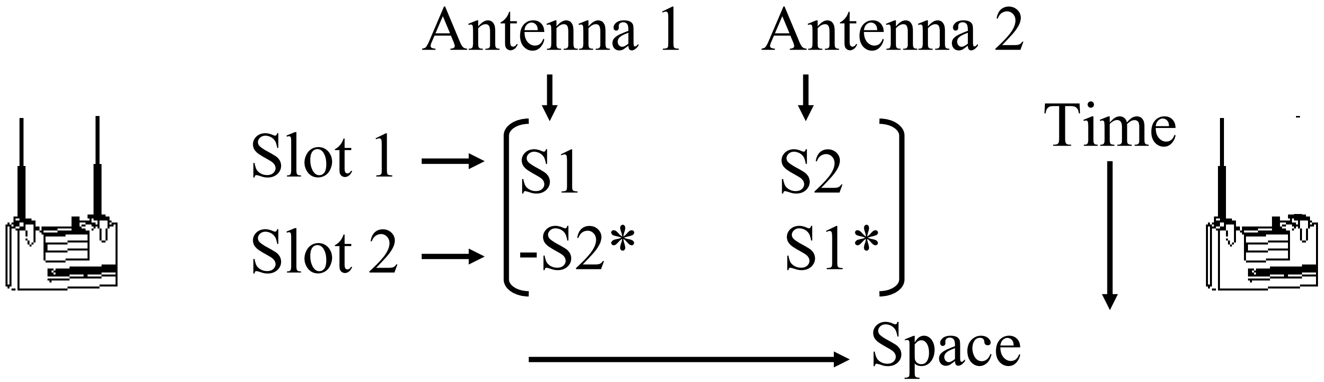


MIMO

Cooperative MIMO

4. 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:

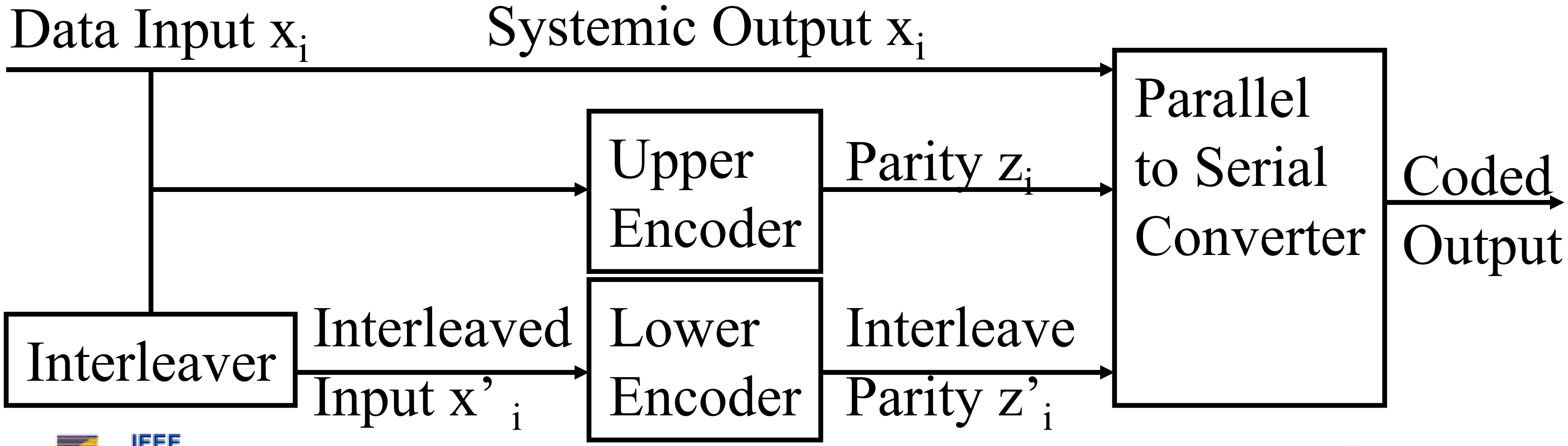


$$\begin{array}{ccc} & \text{Antenna 1} \downarrow & \text{Antenna 2} \downarrow \\ \text{Slot 1} \rightarrow & S1 & S2 \\ \text{Slot 2} \rightarrow & -S2^* & S1^* \end{array}$$

S1* is complex conjugate of S1 ⇒ columns are orthogonal

5. Turbo Codes

- Shannon Limit:= B $\log_2 (1+S/N)$
- 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



Data Input x_i

Systemic Output x_i

Upper Encoder

Parity z_i

Parallel to Serial Converter

Coded Output

Interleaver

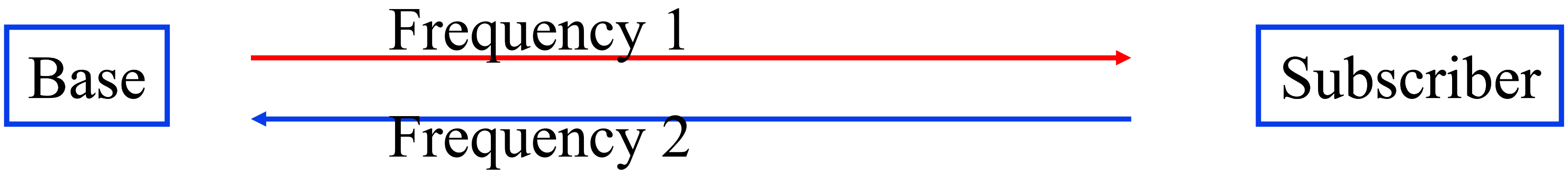
Interleaved Input x'_i

Lower Encoder

Interleave Parity z'_i

6. Time Division Duplexing (TDD)

- Duplex = Bi-Directional Communication
- Frequency division duplexing (FDD) (Full-Duplex)



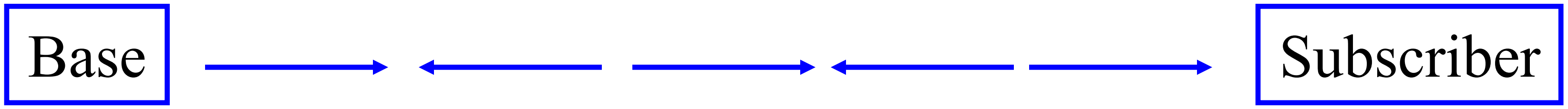
Base

Frequency 1

Frequency 2

Subscriber

- Time division duplex (TDD): Half-duplex



Base

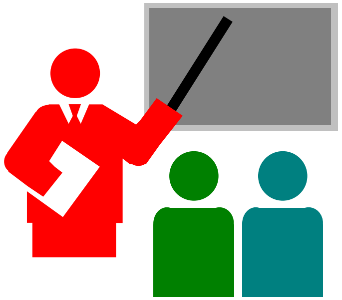
Subscriber

- Most WiMAX deployments will use TDD.
    - Allows more flexible sharing of DL/UL data rate
    - Does not require paired spectrum
    - Easy channel estimation ⇒ Simpler transceiver design
    - Con: All neighboring BS should time synchronize

7. 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.

Summary: Wireless PHY

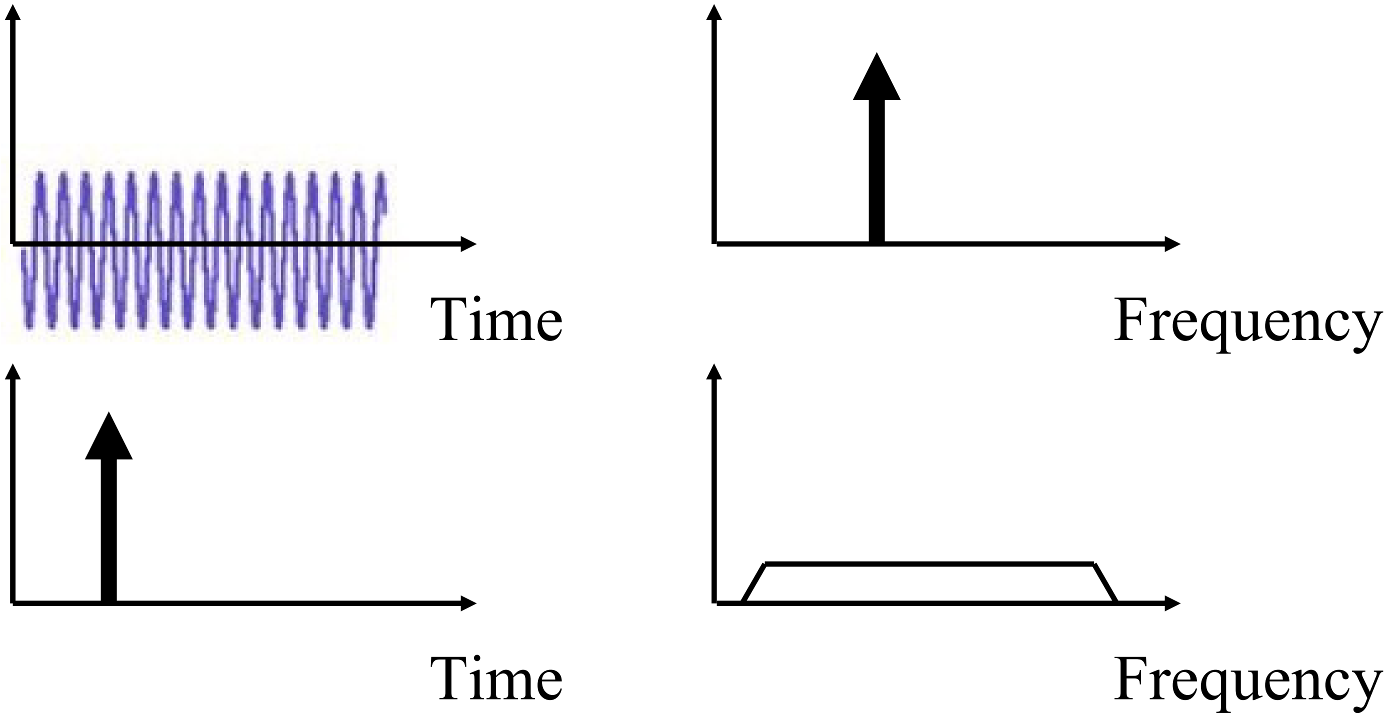


1. OFDM splits a band in to many orthogonal subcarriers. OFDMA = FDMA + TDMA
2. Turbo codes use two coders and a interleaver and operate very close to Shannon's limit
3. Space-time block codes use multiple antennas to transmit related signals
4. MIMO use multiple antennas for high throughput

Part III: Ultra Wideband (UWB)

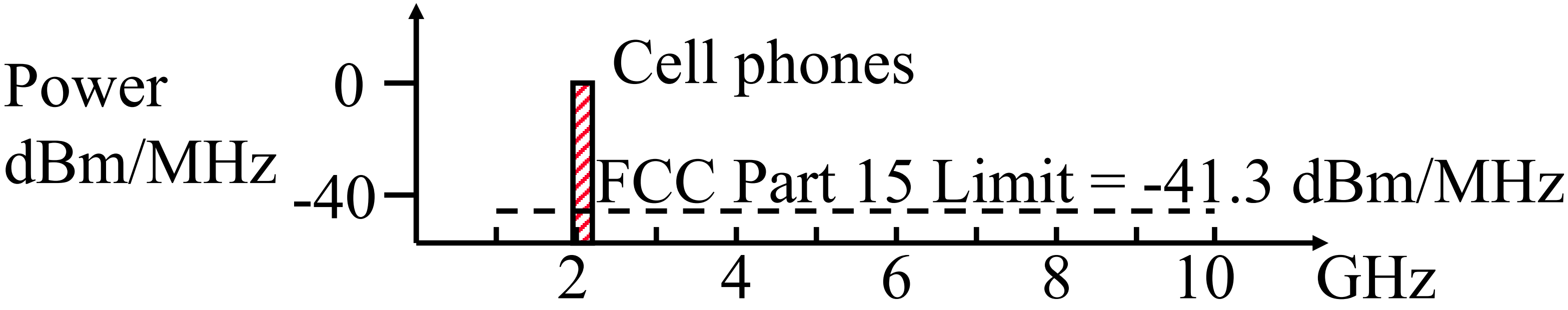
- ☐ Ultra-Wideband: How it works
- ☐ FCC Rules on UWB
- ☐ Advantages of UWB
- ☐ Direct sequence (DS-UWB)
- ☐ Multi-Band OFDM
- ☐ Applications of UWB

Ultra-Wideband



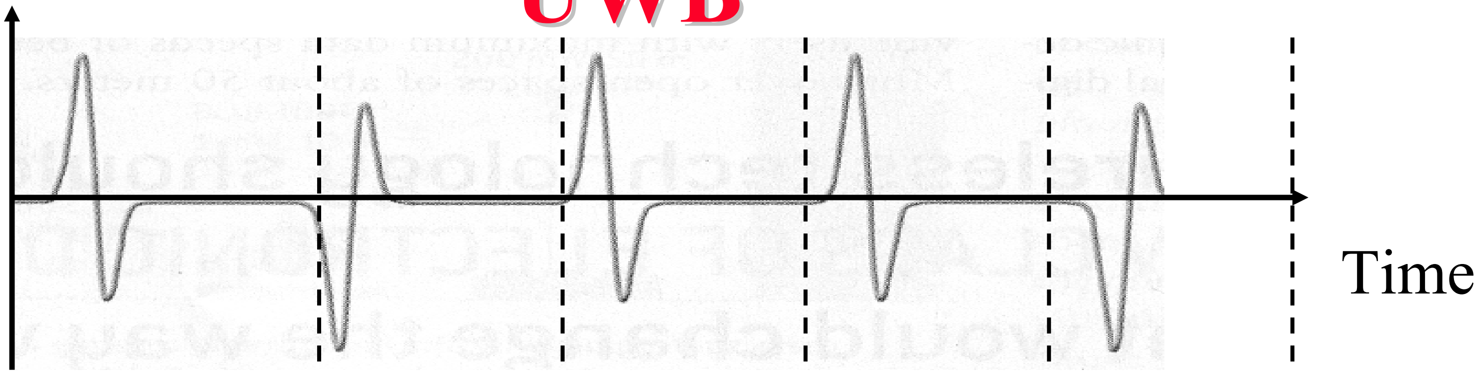
- An impulse in time domain results in a ultra wide spectrum in frequency domain and essentially looks like a white noise to other devices

Ultra-Wideband (UWB)



- FCC rules restrict the maximum noise generated by a wireless equipment (0 dBm = 1mW, -40 dBm = 0.1 mW)
- Very short (sub-ns) pulses ⇒ Spectrum below the allowed noise level ⇒ Get Gbps w 10 GHz spectrum
- FCC approved UWB operation in 2002
  - Between 3.1GHz and 10.6GHz
  - More than 500 MHz bandwidth or more than 20% fractional bandwidth
- High-speed over short distances ⇒ Wireless USB

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

Advantages of UWB

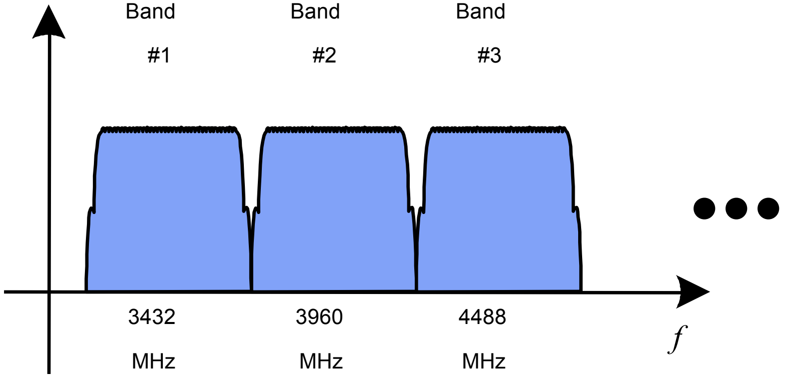
- Shares spectrum with other applications
- Large bandwidth
- Low signal-to-noise ratio
- Low probability of intercept and detection
- Resistance to jamming
- Superior penetration properties at low frequency spectrum
- Simple transceiver architecture. All digital. Low cost.

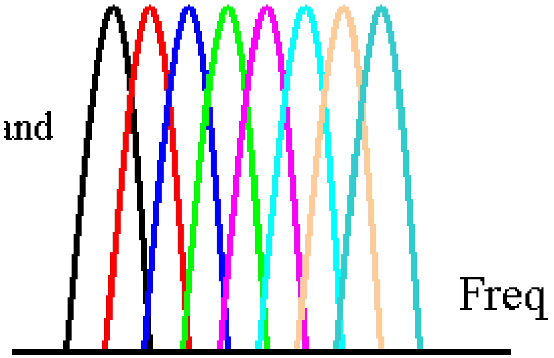
Advantages of UWB (Cont)

- ❑ 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
  - ⇒ Easy to resolve multipath
  - ⇒ Can use multipath to advantage

Multi-Band OFDM

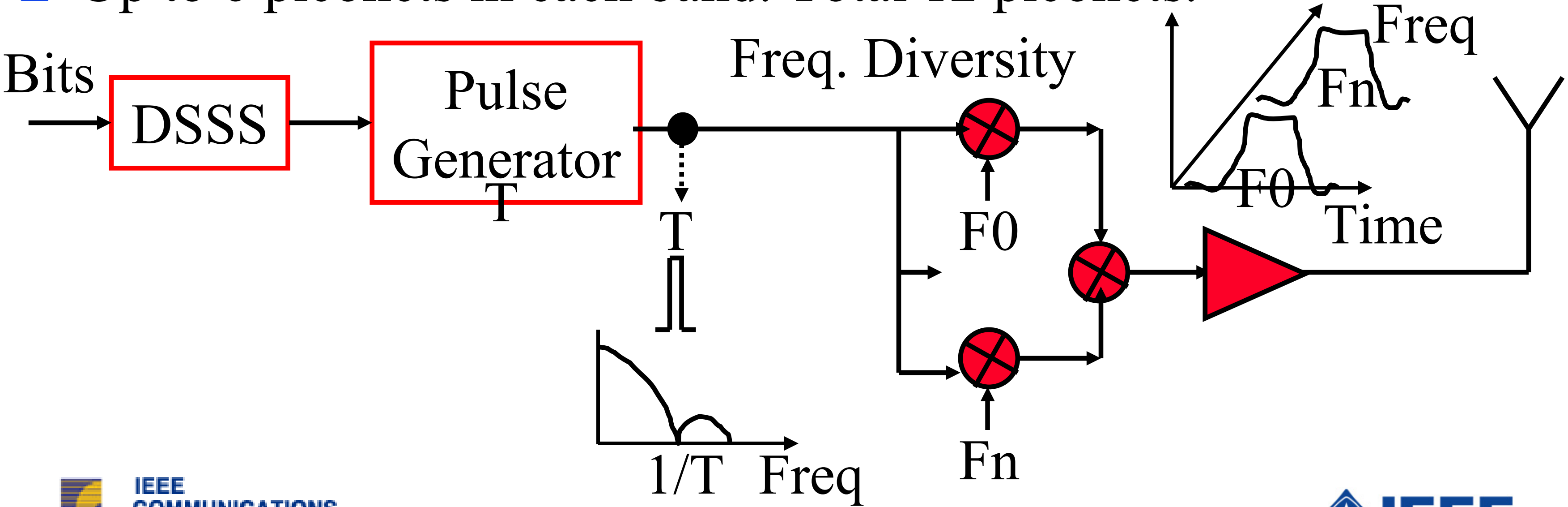
- WiMedia Alliance. Originally by TI. Now many companies
- Divide the 3.1-10.6 GHz spectrum in 14x528 MHz bands (FCC requires min 500 MHz use for UWB)
- Spectrum shaping flexibility for international use
  Move off the band if interference
- Disable a few sub-carriers if required to meet local laws
- ECMA-368, 369 Standard, 2005.





Direct sequence (DS-UWB)

- Championed by UWB Forum (Motorola/XtremeSpectrum)
- Uses CDMA with multiple chips per bit
- Chips are encoded using pulses
- 28 Mbps to 1320 Mbps depending upon the distance
- Two bands: Low (3.1-4.9 GHz), High (6.2-9.7 GHz)
- Up to 6 piconets in each band. Total 12 piconets.



Applications of UWB

1. Data communication:

High bandwidth ⇒ High data rate;

Low spreading factor + Low power ⇒ Short distances ~= 10 m ⇒ PAN

HDTV transmission from set top box or DVD player to TV

Wireless USB = 480 Mbps

2. Sensor Networks: Baseband ⇒ No down conversion ⇒ All digital ⇒ Low cost;

Low data rate ~a few kbps, longer ranges ~=30 to 100m

IEEE 802.15.4a is developing a impulse radio based standard

Very precise location of sensor nodes possible via UWB

3. Location aware communication: Precise location possible ⇒ Firefighters communicating thru burning obstacles.

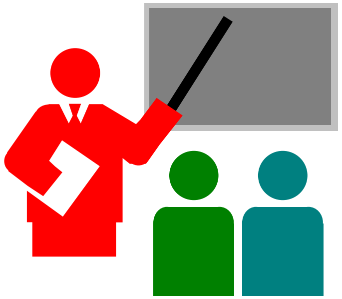
Applications of UWB (Cont)

4. **Body area networks**: Small size and very low power.
   Home automation ⇒ change channel as you walk in,
   Automatically lock/unlock doors
   Identification ⇒ Friend or Foe
5. **UWB Radar**: Short pulse ⇒ Precise position location;
   Can penetrate walls and ground
6. **Ground Penetration Radar**:
   Multi-path resolution ⇒ Locate underground pipes, landmines
7. **Through-Walls Imaging**: Surveillance, urban warfare, locate concealed contrabands in hidden compartments in boats
8. **Vehicular collision avoidance radar**. Adaptive cruise control (match speed to car ahead).

Applications of UWB (Cont)

9. **Biological imaging**: Movement of heart, lungs, bowls, chest, bladder, or fetus. Better than MRI.
   Detection of lumps ⇒ Breast cancer
10. **Localization**: Prisoner tracking, inventory tracking, personnel identification

Summary



- Impulses in time domain result in a wideband frequency spectrum
- FCC requires min 500 MHz band and 20% fractional bandwidth
- The average power is below the noise level ⇒ Shares spectrum with current spectrum users
- Applications in communications, positioning (radar, surveillance), and multi-path imaging

Part IV: High Throughput WiFi: 802.11n

- ❑ Major Components of 11n
- ❑ IEEE 802.11n Status
- ❑ Sample IEEE 802.11n Products
- ❑ Hybrid 802.11 Networks: Issues

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 eliminate 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 v3.0 in October 6, 2007
- Final IEEE publication scheduled for April 2008
- Intel, Broadcom, Marvel have pre-11n chip sets
- Wi-Fi Alliance is planning to certify products based on draft 2.0 of the standard.

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

Hybrid 802.11 Networks: Issues

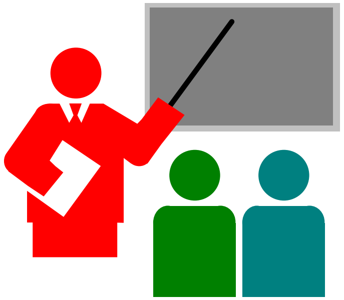
Parameter	802.11b	802.11a	802.11g	802.11n
Data Rate (Mbps)	11	54	54	130 or 270
Modulation	CCK or DSSS	OFDM	CCK, DSSS or OFDM	CCK, DSSS OFDM
Band (GHz)	2.4	5	2.4	2.4 or 5
Spatial streams	1	1	1	4
Channel (MHz)	20	20	20	20 or 40

- You need 11n at both ends to benefit
- A single 802.11b station can force 802.11n AP to operate with CCK or DSSS modulation ⇒ Reduced performance
- 802.11n can consume 2 of 3 non-overlapping channels in 2.4 GHz band ⇒ Can degrade existing 802.11b/g networks ⇒ Move to 5 GHz and 802.11a

Hybrid Networks Issues (Cont)

- Most of the benefits of 802.11n are in 5 GHz band. Enterprise networks are moving from 11b to 11a.
- Upgrade from 11b/a/g to 11n is a forklift upgrade.
- Need gigabit Ethernet backbone with 802.11n

Summary: 802.11n

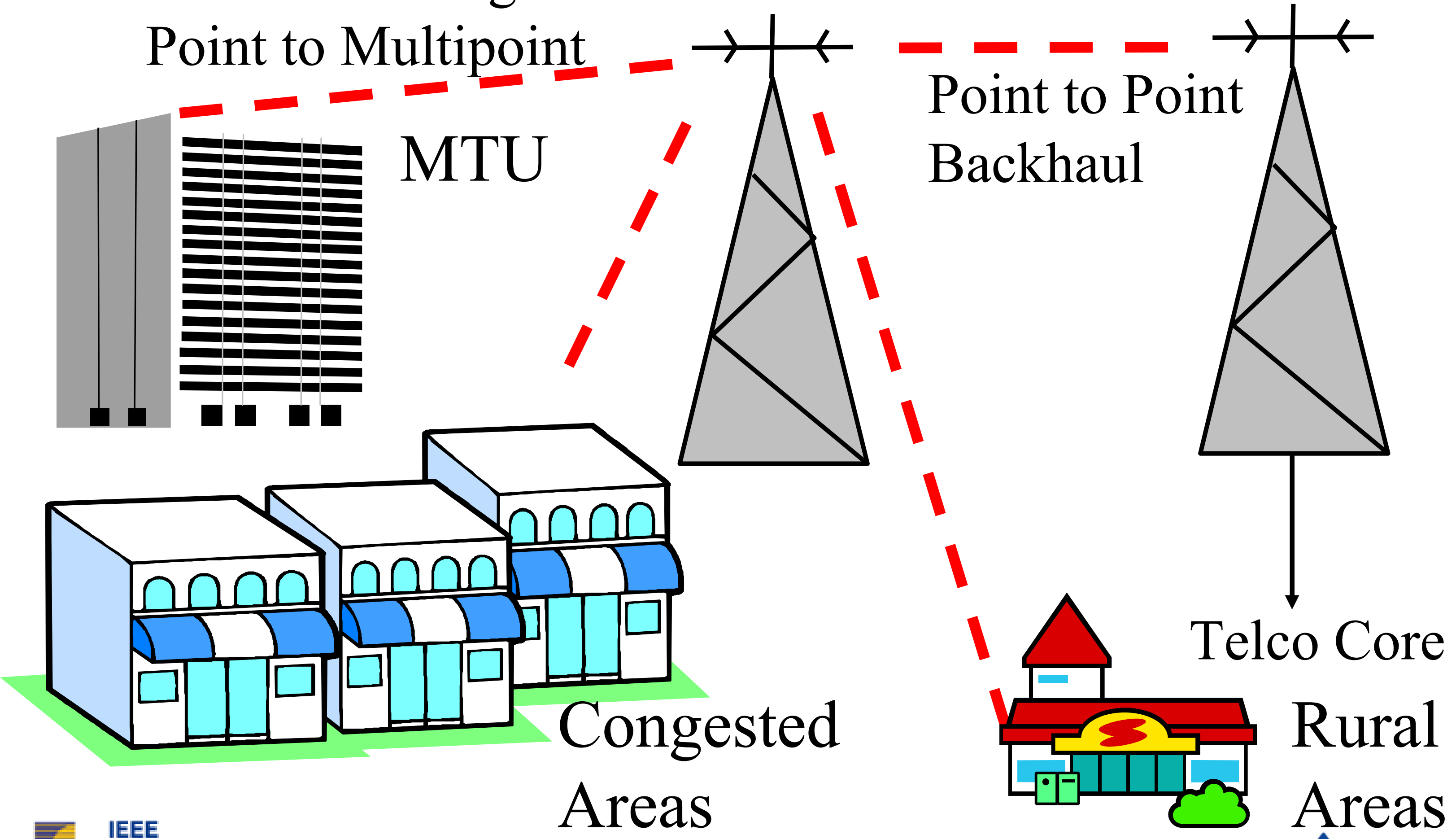


1. 11n gets 100+ Mbps by MIMO, OFDM and wider channels
2. 11b devices can prohibit use of OFDM and may decrease the performance for everyone
3. Wider channels practical only in 5 GHz band ⇒ 11a/n
4. You need 11n at both ends to really benefit

Part V: WiMAX

- Technical and Business Challenges
- Prior Broadband Wireless Efforts
- Spectrum Options
- IEEE 802.16 – QoS Classes
- WiBro
- Sample WiMAX Products

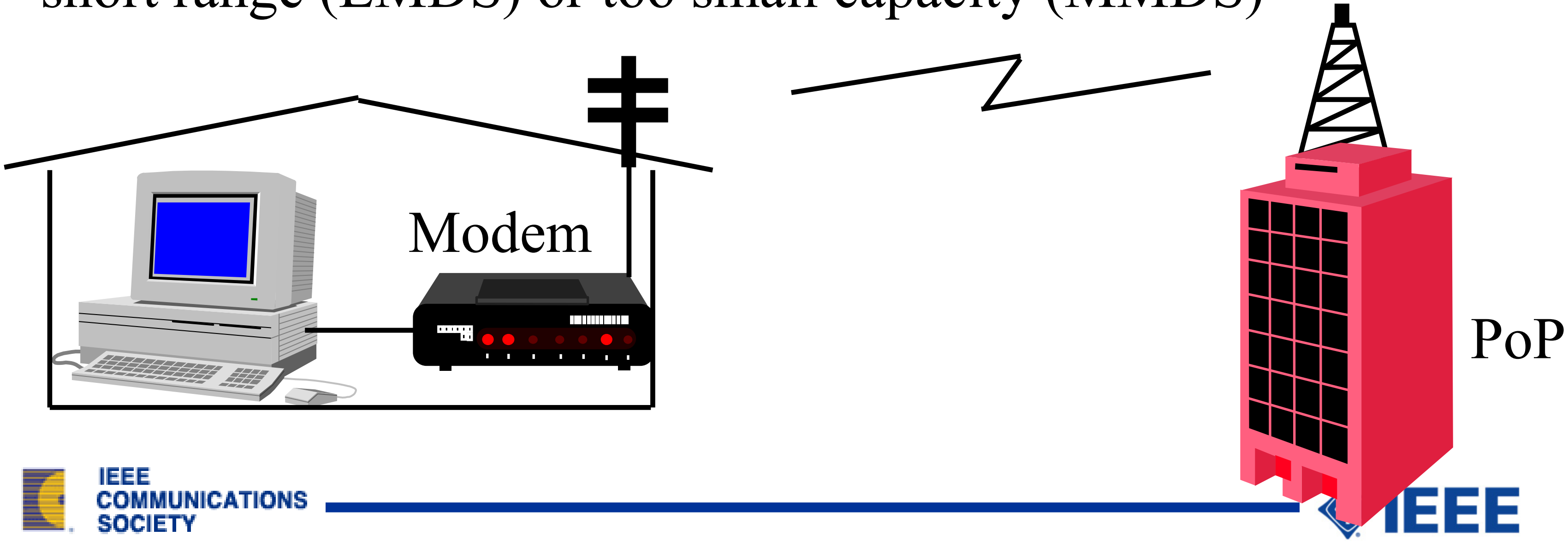
Broadband Wireless Access



Prior Attempts: LMDS & MMDS

- ❑ Local Multipoint Distribution Service (1998)
- ❑ 1.3 GHz around 28 GHz band (Ka Band)
  28 GHz ⇒ Rain effects
- ❑ Multi-channel Multipoint Distribution Services (1999-2001)
- ❑ 2.1, 2.5-2.7 GHz Band ⇒ Not affected by rain

Issues: Equipment too expensive, Roof top **LoS** antennas, short range (LMDS) or too small capacity (MMDS)



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
- Centralized scheduler
- QoS for voice, video, T1/E1, and bursty traffic
- Robust Security

WiMAX

- WiMAX ≠ IEEE 802.16
- Worldwide Interoperability for Microwave Access
- 420+ members including Semiconductor companies, equipment vendors, integrators, service providers. Like Wi-Fi Alliance
- Narrows down the list of options in IEEE 802.16
- Plugfests started November 2005
- WiMAX forum lists certified base stations and subscriber stations from many vendors
- http://www.wimaxforum.org

IEEE 802.16 – QoS Classes

Connection oriented: one or more unidirectional connections between subscriber and base

Five Service Classes:

1. Unsolicited Grant Service (UGS): CBR traffic like voice
2. Enhanced Real-time Service (ertPS): Silence suppressed voice.
3. Real-Time Polling Services (rtPS): rtVBR like MPEG video
4. Non-Real-Time Polling Service (nrtPS): nrtVBR, e.g., FTP
5. Best Effort (BE)

Spectrum Options

Designation	Frequency GHz	Bandwidth MHz	Notes
3.5 GHz	3.4-3.6; 3.3-3.4; 3.6-3.8	200 Total. 2×(5 to 56)	Not in US. Considering 3.65-3.70 for unlicensed
2.5 GHz	2.495-2.690	194 Total. 16.5+6 paired.	In USA.
2.3 GHz	2.305-2.320; 2.345-2.360	2×5 paired. 2×5 unpaired.	US, Kr, Au, Nz
2.4 GHz	2.405-2.4835	80 Total	Lic exempt. World-wide.
5 GHz	5.250-5.350; 5.725-5.825	200 MHz	Worldwide.
700 MHz	0.698-0.746; 0.747-0.792	30+48	US
Adv W. Serv.	1.710-1.755; 2.110-2.155	2×45 paired	Used for 3G

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

Status of WiMAX

- WiBro service started in Korea in June 2006
- More than 200 operators have announced plans for WiMAX
- About half are already trialing or have launched pre-WiMAX
- Two dozen networks in trial or deployed in APAC
- 15 in Western Europe
- Sprint-Nextel in 2.3/2.5 GHz with equipment supplied by Intel, Motorola, Samsung, Nokia, and LG
- Initial deployment in Washington DC and Chicago
- Intel will sample a multi-band WiMAX/WiFi chipset in late 2007
- M-Taiwan

Sample WiMAX Subscriber Stations

Alvarion

Airspan

Axxcelera

Siemens

Aperto

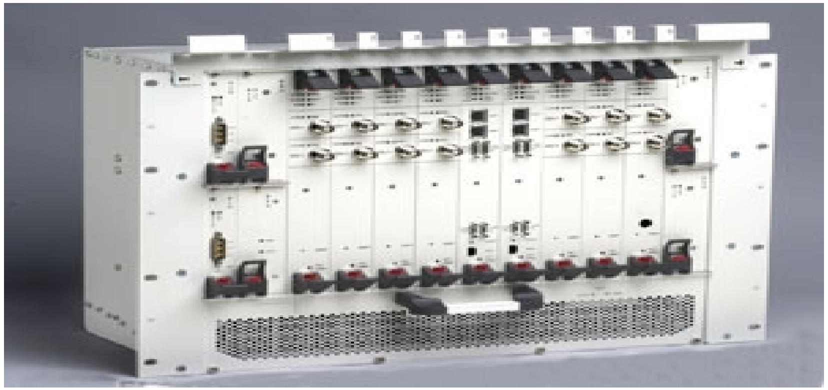
Redline

SR Telecom

Telsima

Sample WiMAX Base Stations

Axxcelara



Alverian

Redline

Airspan

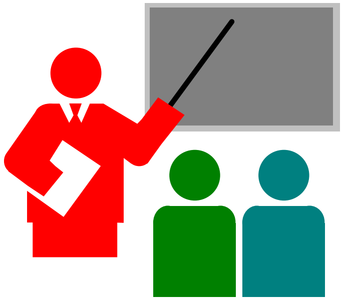
Aperto

SR Telecom

WiMAX Technical Solutions

Issue	Solution
Multipath fading	OFDM
Noise	Coding
Interference	Sectorization; dynamic frequency selection
High spectral efficiency	Adaptive modulation and coding; diversity, spatial multiplexing, Cellular architecture
Radio resource management	Efficient scheduling
QoS	Classes of service
Mobility	Scalable OFDMA
Seamless Handover	Roaming database
Long battery life	Sleep/idle modes; power efficient modulation
Security	Encryption; Authentication and access control
Low cost	IP based architecture

Summary: WiMAX



1. Previous broadband access technologies had problems with antenna placement and cost
2. WiMAX allows indoor, non-line of sight operation
3. Many different spectral bands are possible.
WiMAX forum is working on a worldwide band.
4. WiBro service in Korea started. Sprint/Nextel starting in USA next year.
5. Key features: TDD, OFDMA, MIMO, centralized scheduling, QoS

Part VI: Other Broadband Technologies

- IEEE 802.11
- High Speed Downlink Packet Access (HSDPA), High Speed uplink packet access (HSUPA), High speed packet access (HSPA)
- Evolution data optimized (EV-DO)
- Long Term Evolution (3GPP)
- Ultra Mobile Broadband (3GPP2)

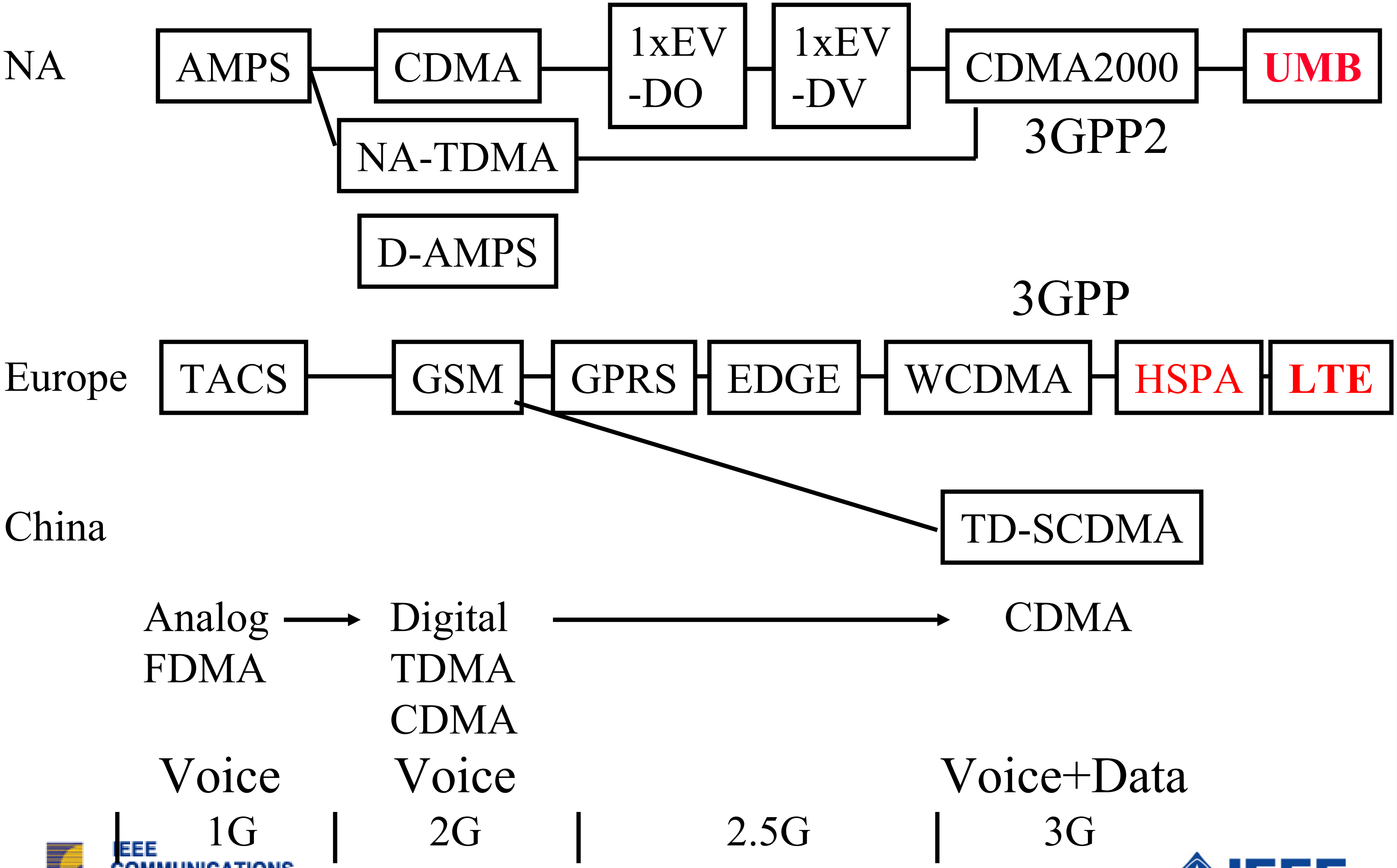
IEEE 802.11 vs. 802.16

	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

Cellular Telephony Generations



NA

AMPS

CDMA

1xEV -DO

1xEV -DV

CDMA2000

UMB

NA-TDMA

3GPP2

D-AMPS

3GPP

Europe

TACS

GSM

GPRS

EDGE

WCDMA

HSPA

LTE

China

TD-SCDMA

Analog → Digital → CDMA

FDMA

TDMA

CDMA

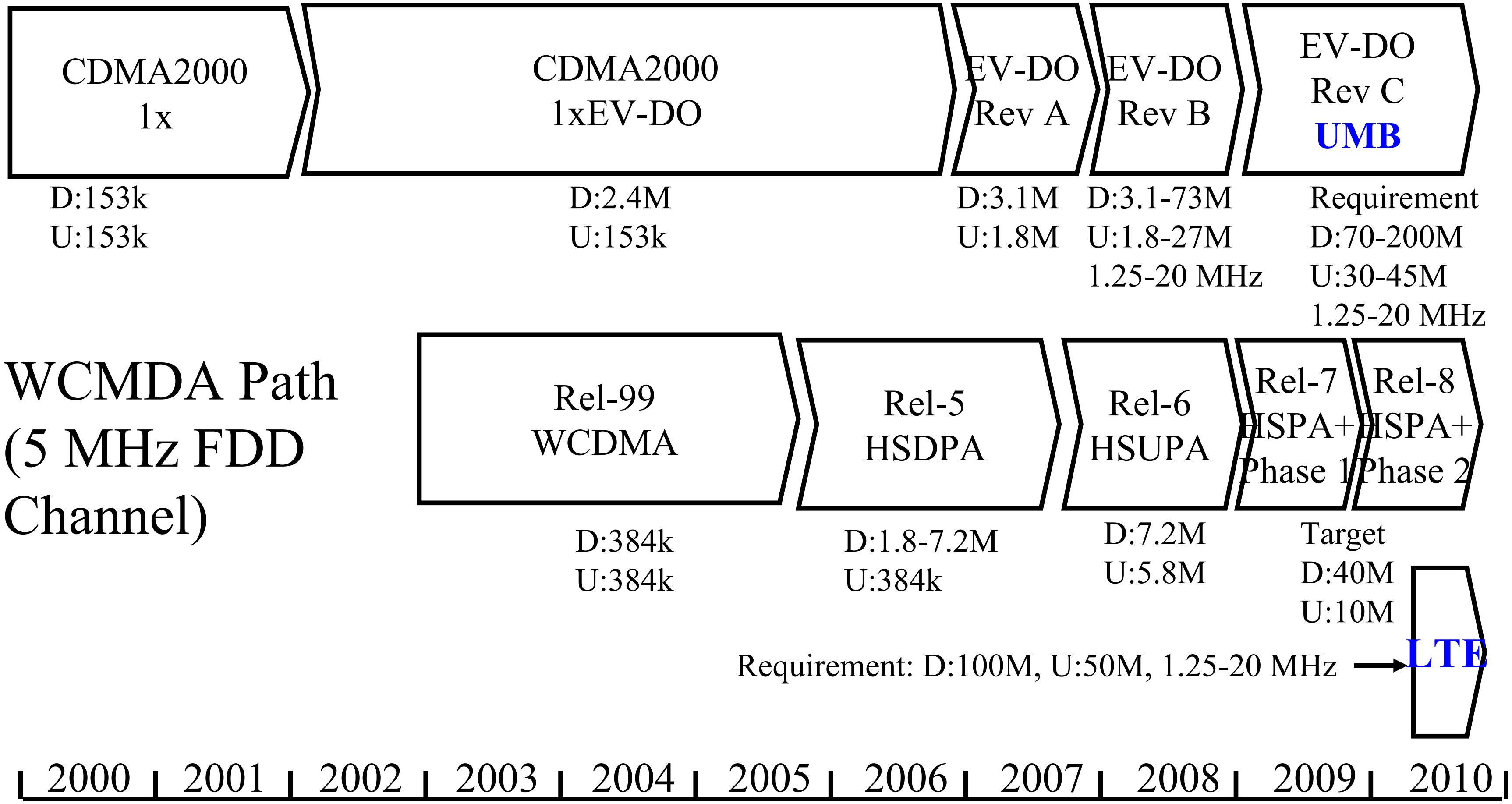
Voice

Voice

Voice+Data

| 1G | 2G | 2.5G | 3G

3G Technologies: Bit Rates



CDMA2000 Path (1.25 MH FDD Channel)

CDMA2000
1x
D:153k
U:153k

CDMA2000
1xEV-DO
D:2.4M
U:153k

EV-DO
Rev A
D:3.1M
U:1.8M

EV-DO
Rev B
D:3.1-73M
U:1.8-27M
1.25-20 MHz

EV-DO
Rev C
UMB
Requirement
D:70-200M
U:30-45M
1.25-20 MHz

WCMDA Path
(5 MHz FDD
Channel)

Rel-99
WCDMA
D:384k
U:384k

Rel-5
HSDPA
D:1.8-7.2M
U:384k

Rel-6
HSUPA
D:7.2M
U:5.8M

Rel-7
HSPA+
Phase 1

Rel-8
HSPA+
Phase 2

Target
D:40M
U:10M

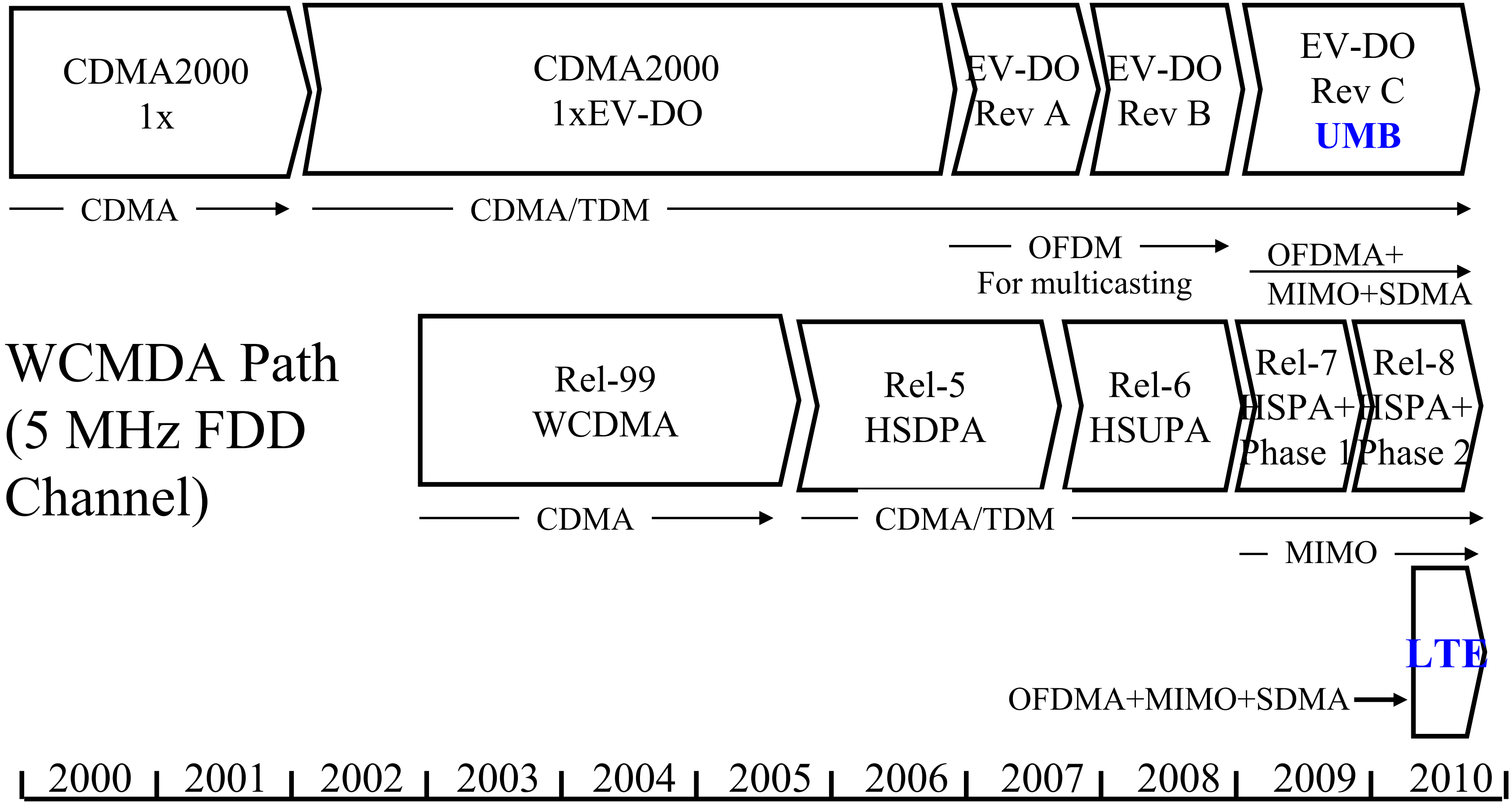
Requirement: D:100M, U:50M, 1.25-20 MHz → **LTE**

Note: WiMAX is also a 3G Technology now.

Source: www.cdg.org

3G Technologies: PHY

CDMA2000 Path (1.25 MH FDD Channel)



CDMA2000 1x

CDMA2000 1xEV-DO

EV-DO Rev A

EV-DO Rev B

EV-DO Rev C **UMB**

CDMA →

CDMA/TDM →

OFDM → For multicasting

OFDMA+ → MIMO+SDMA

WCMDA Path (5 MHz FDD Channel)

Rel-99 WCDMA

Rel-5 HSDPA

Rel-6 HSUPA

Rel-7 HSPA+ Phase 1

Rel-8 HSPA+ Phase 2

CDMA →

CDMA/TDM →

MIMO →

LTE

OFDMA+MIMO+SDMA →

2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010

Source: www.cdg.org

3G Technologies (Cont)

- All data rates are for FDD
  ⇒ 20MHz = 2×20 MHz
- On the downlink, LTE uses a modified version of OFDMA called DFT-Spread OFDMA, also known as single-carrier FDMA.
- UMB may utilize a combination of OFDMA and CDMA or OFDM and CDMA
- Data rates depend upon level of mobility

4G: IMT-Advanced

- International Mobile Telecommunications – Advanced or 4G
- Wireless broadband access to be standardized around 2010 and deployed around 2015
- 1 Gbps for nomadic/fixed and 100 Mbps for high mobility (150 km/h)
- Requirements will be set in 2008
- Set of 4G technologies will be selected by 2010

Ref: ITU-R M.1645, “Framework and overall objectives of the future development of IMT-2000 and systems beyond IMT-2000” (2003)

IEEE 802.16m

- Peak data rate:
  - Downlink (BS->MS) > 6.5 bps/Hz,
    Uplink (MS->BS) > 2.8 bps/Hz
    After PHY overhead
  - 20 MHz => 130 Mbps
- Mobility: Optimized for 0-15 km/h, marginal degradation 15-120 km/h, maintain connection 120-350 km/h
- 3 dB improvement in link budget over 16e
- Optimized for cell sizes of up to 5km. Graceful degradation in spectral efficiency for 5-30km. Functional for 30-100 km.

Ref: Draft IEEE 802.16m requirements, June 8, 2007,

http://ieee802.org/16/tgm/docs/80216m-07_002r2.pdf

700 MHz

- February 19, 2009: TV vacates 700-MHz
- FCC just approved 700 MHz for broadband access
- 108 MHz total available
  - 60 MHz available by Auction in January 16, 2008
  - 24 MHz for Public Safety
  - 24 MHz already owned by Access Spectrum, Aloa Partners, Pegasus Comm, Qualcomm,Verizon, DirecTV, Echostar, Google, Intel, Skype, and Yahoo!
- **Open Access**: Open applications, Open devices, Open services, and open networks
- **White spaces**: Unused spectrum between 54 and 698 MHz. (Channel 2 through 51)

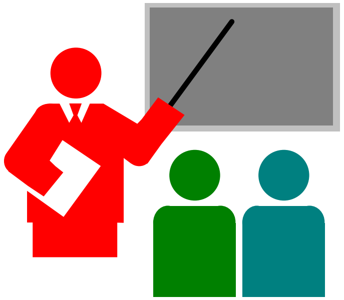
Evolution of 3GPP2

- System requirement document (SRD) for next air interface for CDMA2000 approved in May 2006
- Scalable bandwidths up to 20 MHz
- Peak 100 Mbps down and 50 Mbps up in Mobile
- Peak 500 Mbps down 150 Mbps up in stationary indoor
- Reduced system latency for VOIP
- DL uses OFDMA, MIMO, Spatial division multiple access (SDMA)
- UL uses quasi-orthogonal OFDMA with non-orthogonal user multiplexing with Layered-superimposed OFDMA (LS-OFDMA) and also supports CDMA for control and low-rate low-latency traffic

WiMAX Competition: Summary

1. IEEE 802.11 and 802.16 are complementary
2. 3G is currently CDMA based
   Limited by 5MHz channel bandwidth
3. Next generation of 3G is evolving. Taking the best of WiMAX: OFDMA, MIMO
4. Next generation WiMAX 802.16m will run at 100 Mbps

Overall Summary



1. Wireless is the major source of carrier revenue
   ⇒ Significant growth in Wireless networking
2. CDMA is past. OFDM/OFDMA is taking over.
3. OFDM splits a band in to many orthogonal subcarriers.
   OFDMA = FDMA + TDMA
4. MIMO uses multiple antennas for high throughput
5. Impulses in time domain result in a wideband frequency spectrum ⇒ UWB

Overall Summary (Cont)

6. The average UWB power is below the noise level
   ⇒ Shares spectrum with current spectrum users
7. UWB applications in communications, positioning (radar, surveillance), and multi-path imaging
8. 11n gets 100+ Mbps by MIMO, OFDM and wider channels
9. 11b devices can prohibit use of OFDM and may decrease the performance for everyone
10. You need 11n at both ends to really benefit
11. Previous broadband access technologies had problems with antenna placement and cost
12. WiMAX allows indoor, non-line of sight operation

Overall Summary (Cont)

14. WiMAX works on many different spectral bands. WiMAX forum is working on a worldwide band.
15. Key WiMAX technical features: TDD, OFDMA, MIMO, centralized scheduling, QoS
16. WiMAX products with fixed profile are available. Mobile profile certification is just beginning.
17. IEEE 802.11 and 802.16 are complementary
18. 3G is currently CDMA based
    Limited by 5MHz channel bandwidth
19. Next generation of 3G is evolving.
    Taking the best of WiMAX: OFDMA, MIMO
20. Next generation WiMAX 802.16m will run at 100 Mbps

References

- See http://www.cse.wustl.edu/~jain/refs/gc07.htm