3G and 4G Cellular Standards

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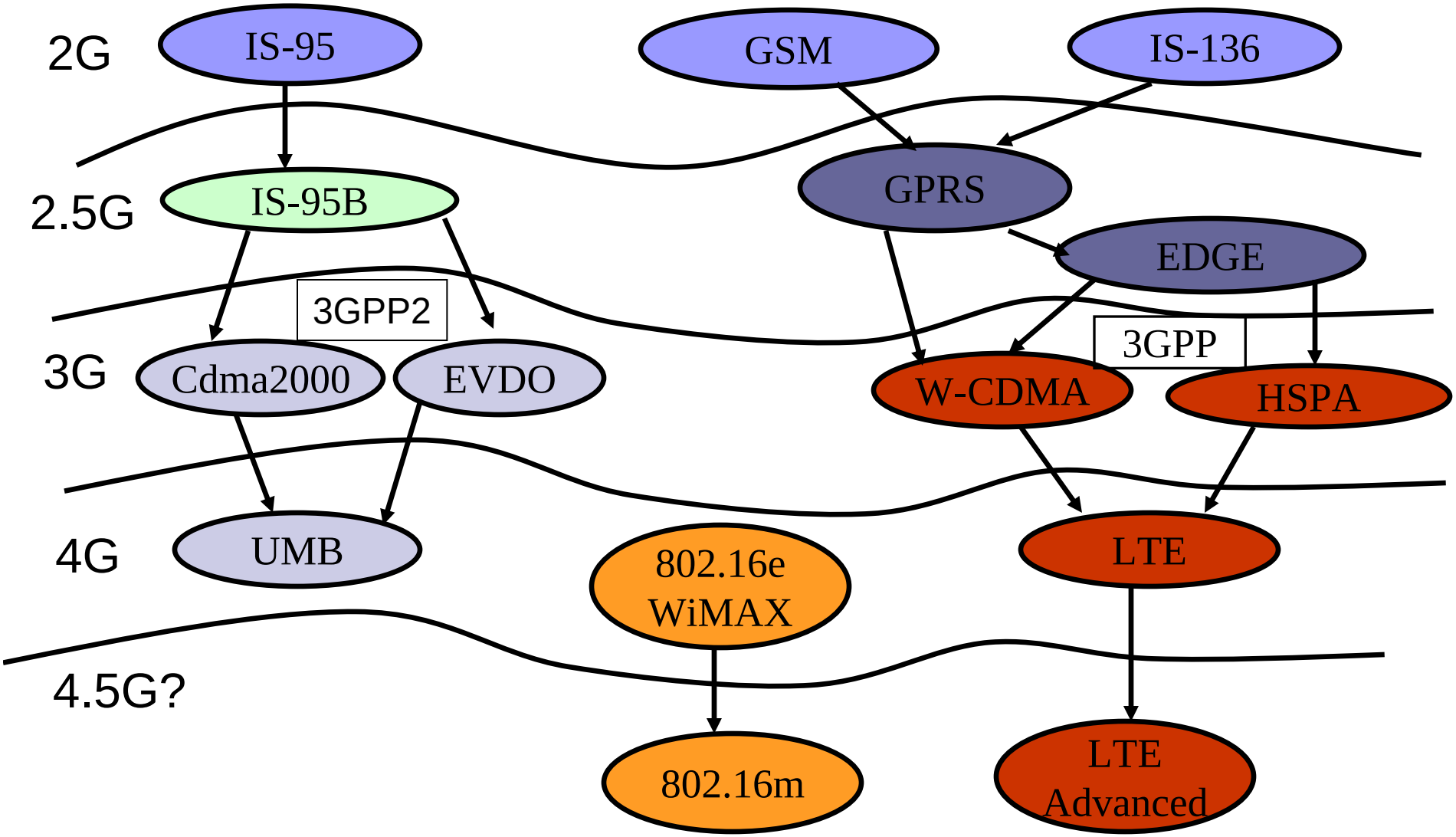
Outline

- Overview of Cellular Standards
- Qualcomm and the 3GPP2 Standards
- UMTS/3GPP 3rd Generation Standards
  - Wideband CDMA (WCDMA)
  - HSPA
- 4th Generation Standards
  - IEEE 802.16/WiMAX
  - 3GPP LTE
- Performance Predictions

The Cellular Family Tree



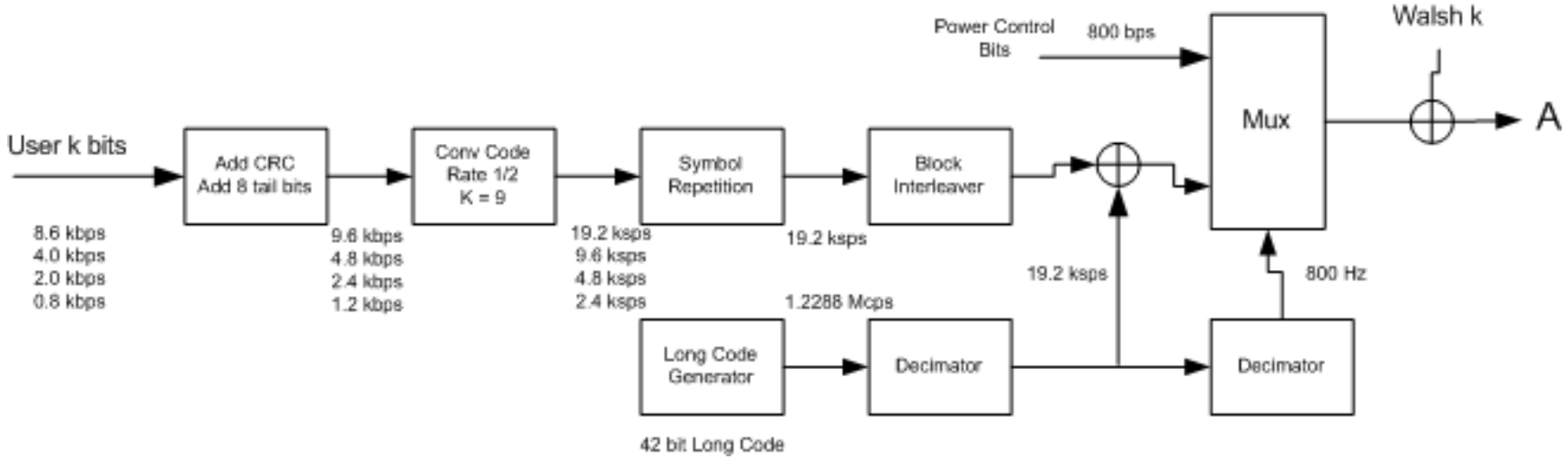
Acronyms

IS-95	Interim Standard 95		LTE	Long Term Evolution
EVDO	Evolution Data Only/Optimized		UMTS	Universal Mobile Telephone System
UMB	Ultra Mobile Broadband		3GPP	3rd Generation Partnership Project
GSM	Global System Mobile		3GPP2	3rd Generation Partnership Project 2
GPRS	General Packet Radio Service		GMSK	Gaussian Minimum Shift Keying
EDGE	Enhanced Data rates for GSM Evolution		MIMO	Multi Input Multi Output (refers to multiple antennas usually)
WCDMA	Wideband CDMA			
HSPA	High Speed Packet Service			
HSD[U]PA	High Speed Downlink [Uplink] Packet Access			
WiMAX	Worldwide Interoperability for Microwave Access			

3GPP2 Standards Body

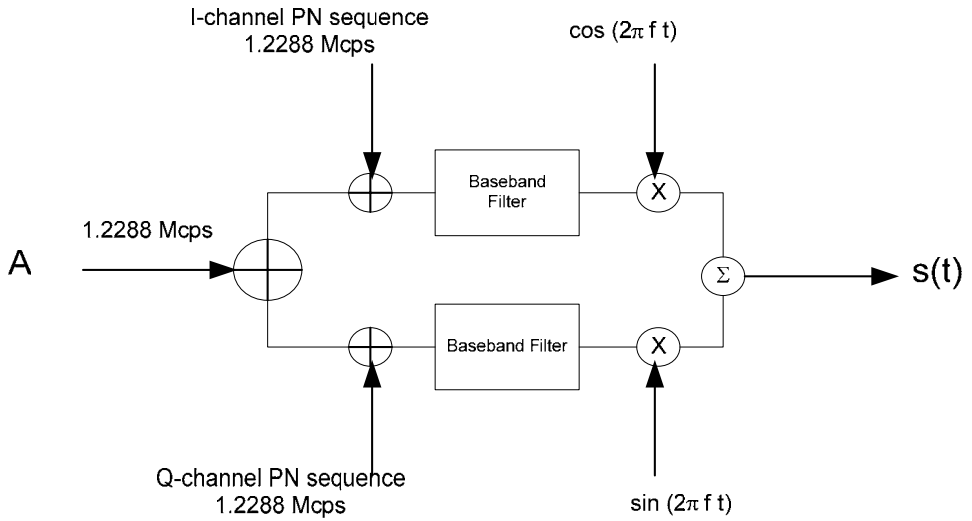
- Dominated by Qualcomm
- IS-95 – First commercial CDMA standard, developed by Qualcomm, ratified in 1995
  - Still forms basis for CDMA voice access
  - 1.23 MHz of bandwidth
  - Total spreading factor of 128 (full-rate voice)
- EVDO (Evolution Data “Optimized”)
  - Developed in 1999 as “HDR”
  - Hybrid TDMA/CDMA system, works in 1.23 MHz

The IS-95 Forward Link

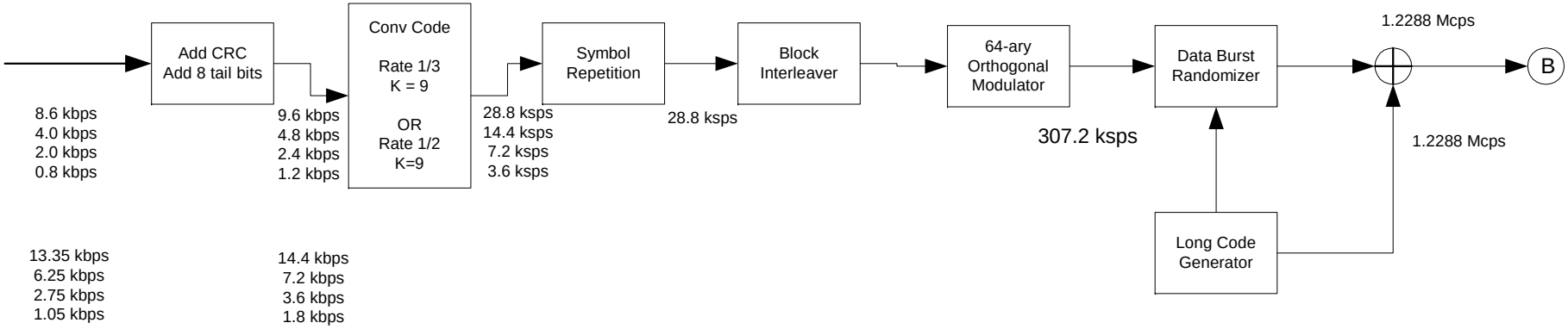


Walsh codes (SF = 64) used to separate users

PN codes only used for data randomization

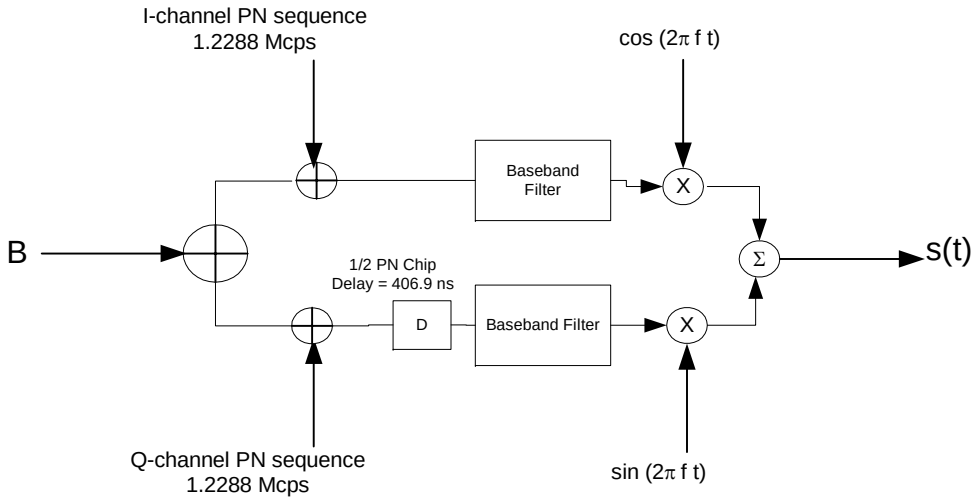


The IS-95 Reverse Link

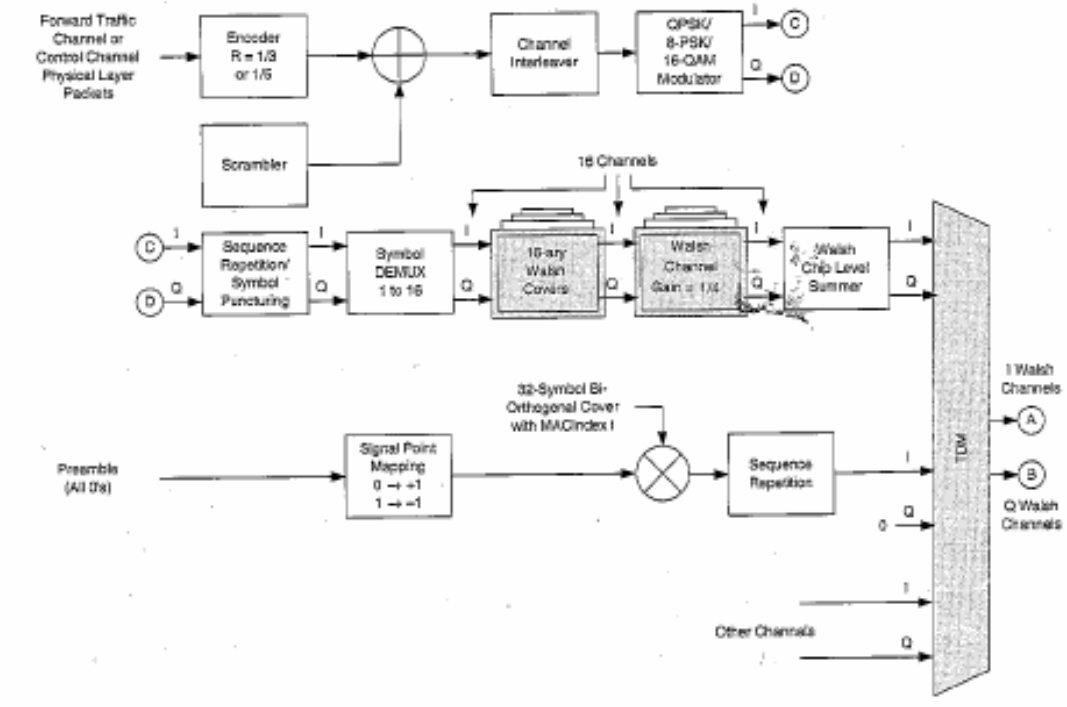


Long PN codes (SF = 4) used to separate users

Most of “spreading” is actually error correction: Conv Codes + 6/64 rate Orthogonal Modulation



Evolution Data Optimized (EVDO)



Key Aspects

- CDMA (16-ary Walsh Codes)
- Multicode, each user can use 1-16 codes (see table)
- TDMA also, usually with Proportional Fair Scheduling
- Adaptive modulation and coding (see table)
- Alamouti OSTBC

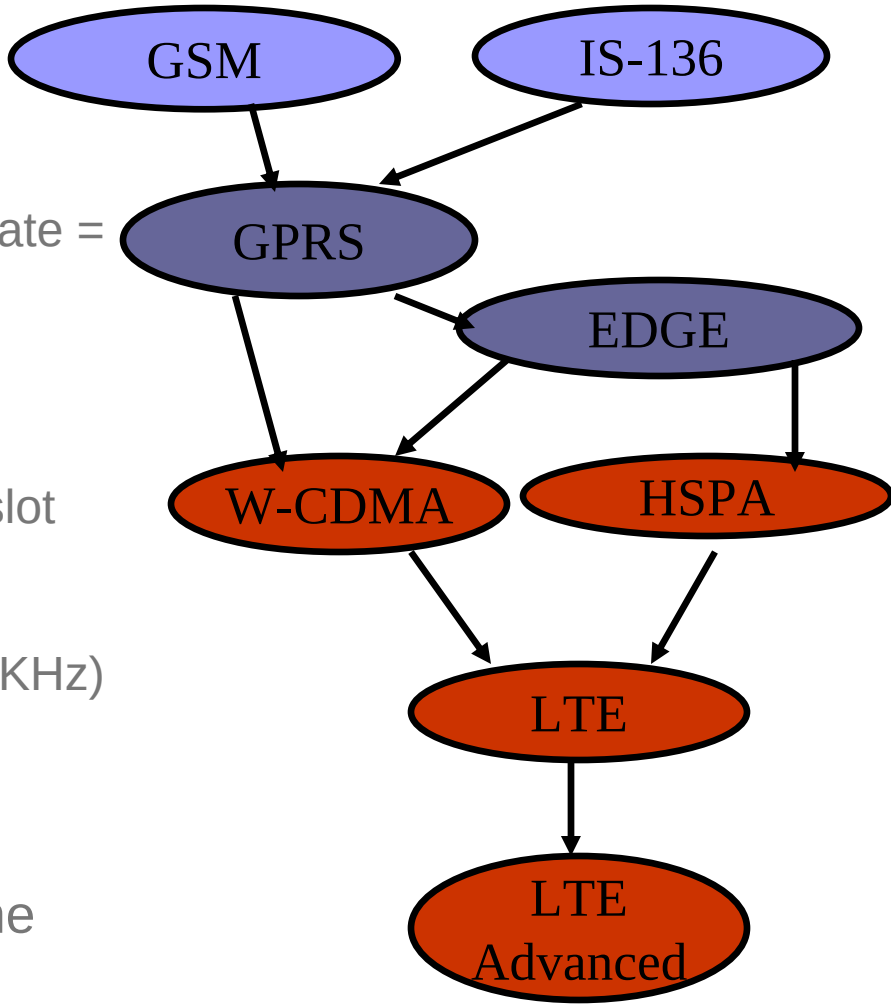
Rate (kbps)	Users per Slot	Code Rate	Modulation
38.4	16	1/5	QPSK
76.8	8	1/5	QPSK
153.6	4	1/5	QPSK
307.2	2	1/5	QPSK
614.4	1	1/3	QPSK
307.2	4	1/3	QPSK
614.4	2	1/3	QPSK
1228.8	1	1/3	QPSK
921.6	2	1/3	8-PSK
1843.2	1	1/3	8-PSK
1.228.8	2	1/3	16 QAM
2457.6	1	1/3	16 QAM

3GPP2 Status

- Has approximately 500 million subscribers
  - Most in US and N. America, but also S. Korea, Brazil, India, a few other places
- IS-95/cdma200 voice capacity is about 60/sector
  - Turns out, it's downlink limited! (A surprise)
  - Only 64 Walsh Codes, some are overhead
- The future is not clear: most 3GGP2 operators seem to be migrating to LTE

The UMTS/3GPP Standards

- Largest global standards body
- GSM
  - 200 KHz channel spacing (symbol rate = 270 KHz!)
  - GMSK (binary) modulation
  - Rate ½ Conv. Codes (v = 5)
  - 8 slots per 4.615 msec frame
  - Guardtime + windowing = 52 usec/slot (9% overhead)
- WCDMA and HSPA
  - 5 MHz spacing (symbol rate = 3.84 KHz)
  - Variable rate and spreading factors
- LTE “Long Term Evolution”
  - Radical departure from 3G
- Details on HSPA and LTE later in the presentation



WCDMA and HSPA

- WCDMA and HSPA are largely compatible and complimentary
- WCDMA is quite similar to IS-95 and cdma2000. Some distinctions:
  - Generally more complicated block diagram
  - Reverse link pilot on Q channel
  - Wider choice of rates/spreading factors
  - Multi-code possible (a user takes more than one code to increase their data rate)
  - Alamouti-style space-time coding generally used

High Speed Packet Access (HSPA)

- Release 5 = HSDPA
  - High speed access added for downlink
    - 14.4 Mbps advertised peak
    - 3.6/7.2 Mbps typically supported
    - 1.8 Mbps/3.6 Mbps supported by handsets today
- Release 6 = HSUPA
  - Uplink brought closer to downlink speeds
    - 5.8 Mbps advertised peak
    - 1.4 Mbps typically supported
- Release 7 = HSPA or HSPA+
  - Even higher speeds promised on both links in same 5 MHz bandwidth via MIMO, 64QAM, no coding
    - 28 Mbps DL, 11.5 Mbps UL
  - Questionable whether these rates are practically viable or if demand exists

HSDPA – How it Works

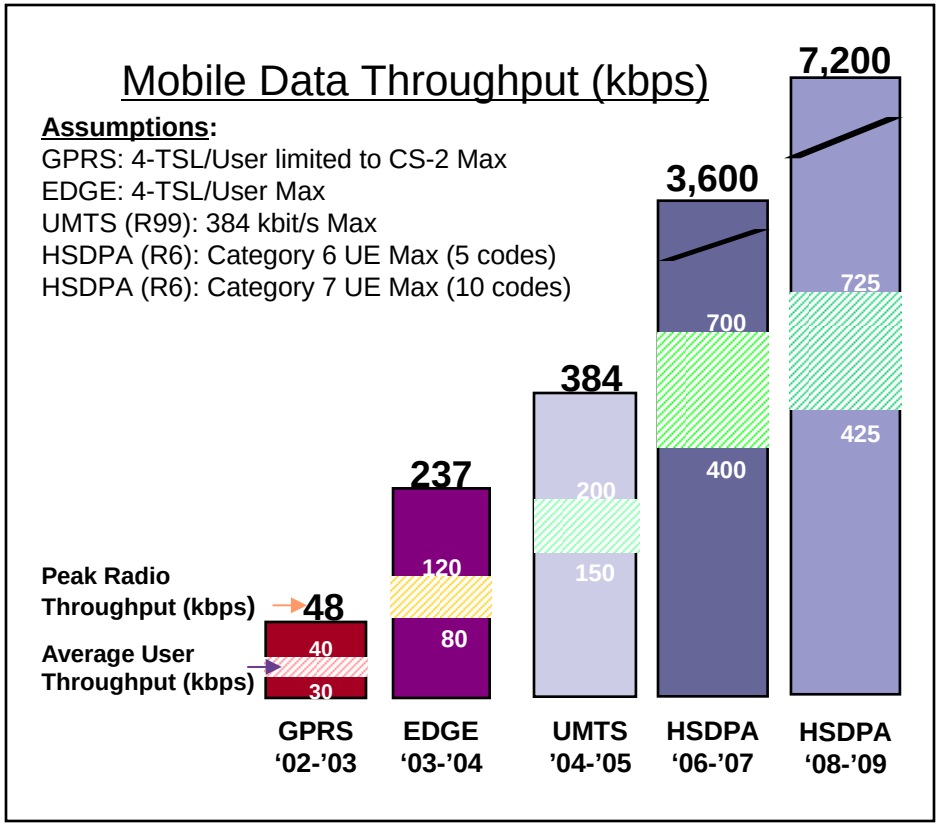
- Quite similar to EVDO
- SF = 16 Walsh Codes
  - Can use 5, 10, or 15 codes at a time
  - Using just 1 = WCDMA
  - 1 channel is reserved for overhead
- Turbo codes
  - r = ¾, ½, ¼
- Adaptive Modulation
  - QPSK and 16QAM

<u>Design Choices and Issues</u>

- SF = 16 helps with multipath, but equalizer often still needed
- Receivers can actually be more complex than in LTE
- Primary multiple access is TDMA
  - Proportional Fair scheduling is the norm

UMTS 3G – Current Status

- **GSM is ubiquitous**
- **Most Providers Pretty Far Along on WCDMA Transition**
  - **e.g. "3G iPhone"**
- **HSPA family based on WCDMA, used for data**
  - HSDPA is widely deployed
  - HSUPA currently being deployed
  - Typical User Experience
    - **500 kbps-2 Mbps** DL
    - **500 kbps-1 Mbps** UL
    - **100-200ms** ping delays



4th Generation Standards

- There is still some debate about what 4G actually is
- Key Attributes of 4th Generation Standards
  - Data rates and supportable bandwidths much higher in both "theory" and reality than 3G
  - IP-based rather than circuit switched
    - This has a significant impact on voice
- In practice, common distinguishing features vs. 3G include:
  - Multicarrier (OFDM) based physical layer
  - OFDMA MAC layer with time-frequency scheduling
  - All IP
  - Aggressive multi-antenna technologies supported
  - Variable bandwidth, up to 20 MHz

Evolution of WiMAX

- The 802.16 Standard Family
  - 1998: IEEE formed 802.16 group to develop a standard for a wireless metropolitan area network (MAN) – primary interest was fixed wireless access
  - First 10–66 GHz band considered; later modified to work in 2–11GHz to enable NLOS (802.16a)
  - 2004: IEEE 802.16-2004 standard ratified, subsuming 802.16, 802.16a, 802.16c
    - First 802.16-2004 product certified in Jan. 2006
  - Dec. 2005: 802.16e completed, to allow mobility applications and scalability in 2–6 GHz
- Vision has changed a lot in the last 10 years
  - Started as fixed broadband, now is really the first 4G standard

802.16 and WiMAX

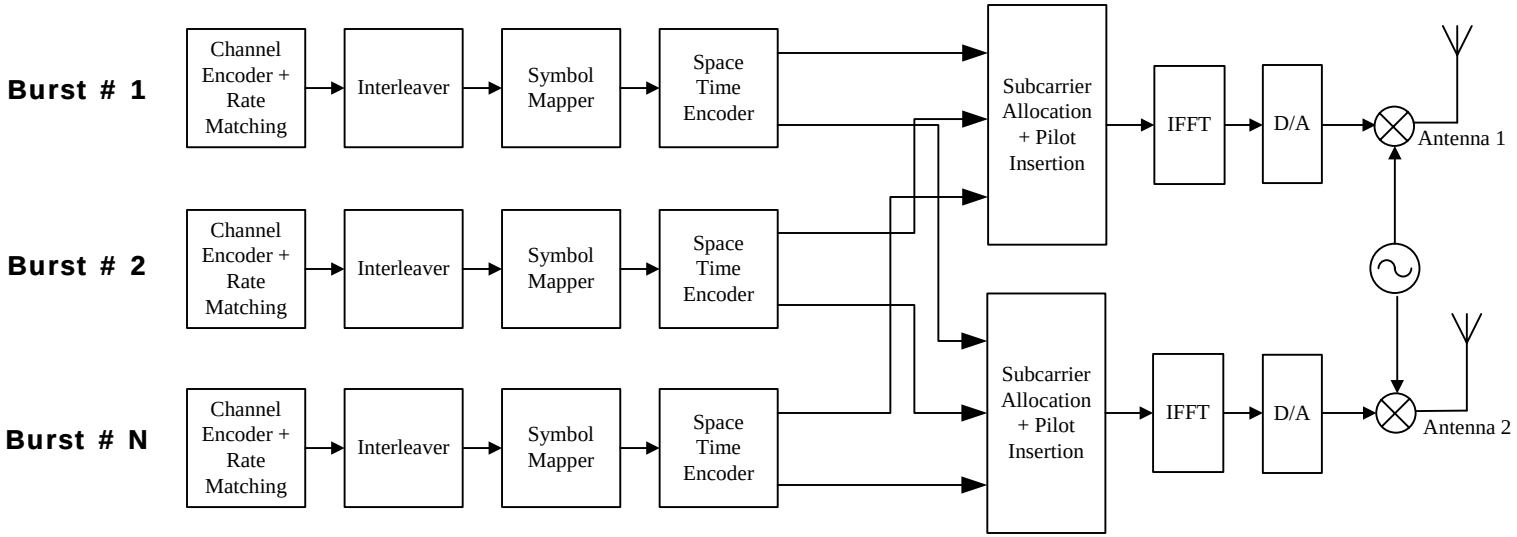
- The 802.16 standards have very broad scope, millions of incompatible options
- The WiMAX forum defines commercial "profiles" of options, frequency bands, etc.
- Similar to the Wi-Fi Alliance
  - Promotes interoperability of products through testing and certification
- The WiMAX forum has 15 Board members (companies), ~150 Principal members, 300+ Regular members

Current Certification Profiles

- Global Spectrum Availability is a key challenge for WiMAX
- Range vs. Cost/Availability tradeoff
  - Would prefer lower frequencies like 700 MHz, but expensive and scarce

Band Index	Frequency	Channel Bandwidth	FFT Size	Duplexing
Fixed WiMAX Profiles				
1	3.5 GHz	3.5 MHz	256	FDD
		3.5 MHz	256	TDD
		7 MHz	256	FDD
		7MHz	256	TDD
2	5.8 GHz	10 MHz	256	TDD
Mobile WiMAX Rel 1.0 Profiles				
1	2.3 - 2.4 GHz	5 MHz	512	TDD
		10 MHz	1024	TDD
		8.75 MHz	1024	TDD
2	2.305 - 2.320 & 2.345 - 2.360 GHz	3.5 MHz	512	TDD
		5 MHz	512	TDD
		10 MHz	1024	TDD
3	2.496 - 2.690 GHz	5 MHz	512	TDD
		10 MHz	1024	TDD
4	3.3 - 3.4 GHz	5 MHz	512	TDD
		10 MHz	1024	TDD
5	3.4 - 3.8 GHz	5 MHz	512	TDD
		7 MHz	1024	TDD
		10 MHz	1024	TDD
Mobile WiMAX Rel 1.5 Profiles				
6	1.710 - 1.755 & 2.110 - 2.155 GHz	5 MHz	512	FDD
		10 MHz	1024	FDD
7	776 - 787 MHz 788 - 793 793 - 798	5 MHz	512	FDD
		10 MHz	1024	FDD
	698 - 862 MHz	5 MHz	512	TDD
		10 MHz	1024	TDD

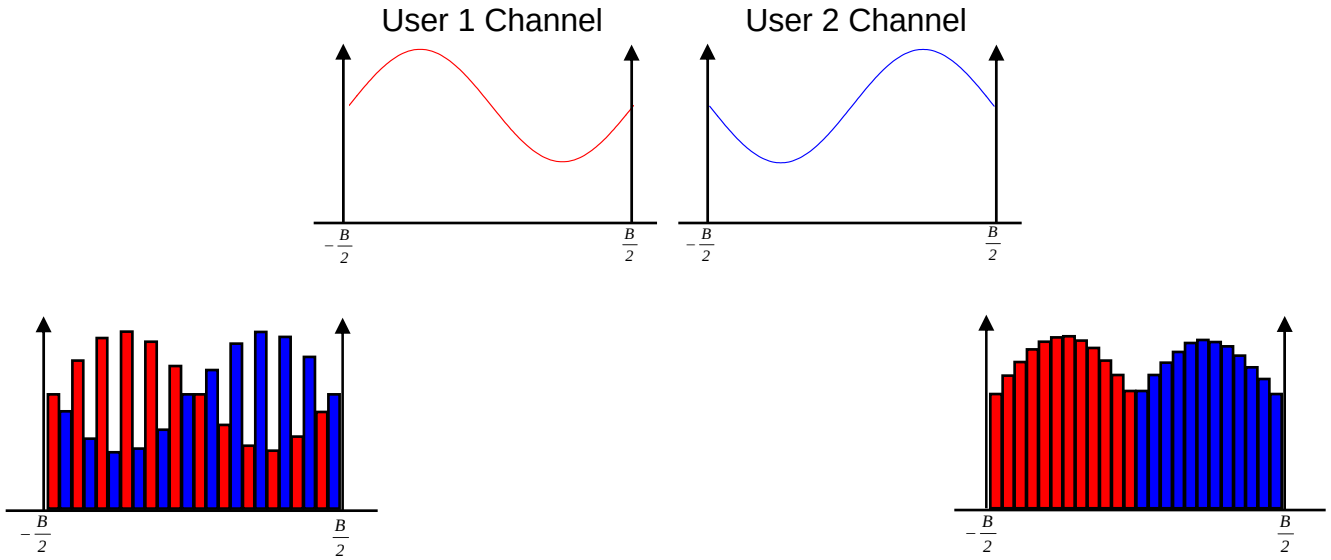
WiMAX Physical Layer



- IFFT size is most commonly 1024
- Turbo codes are used with r = ½ and ¾
- Symbol Mapper is for QPSK, 16QAM, 64QAM
- Many possible MIMO modes
  - Mobiles required to have two antennas
  - Alamouti 2 x 2 is starting point, more aggressive techniques soon

OFDM Subcarrier Allocation

- In WiMAX multiple subcarriers are grouped together to create what is called a sub-channel. Usually consists of 48 data subcarriers.



Distributed Subcarrier

Each sub-channel consists of subcarriers that are distributed throughout the channel bandwidth.

Provides better frequency diversity which is beneficial at higher speeds.

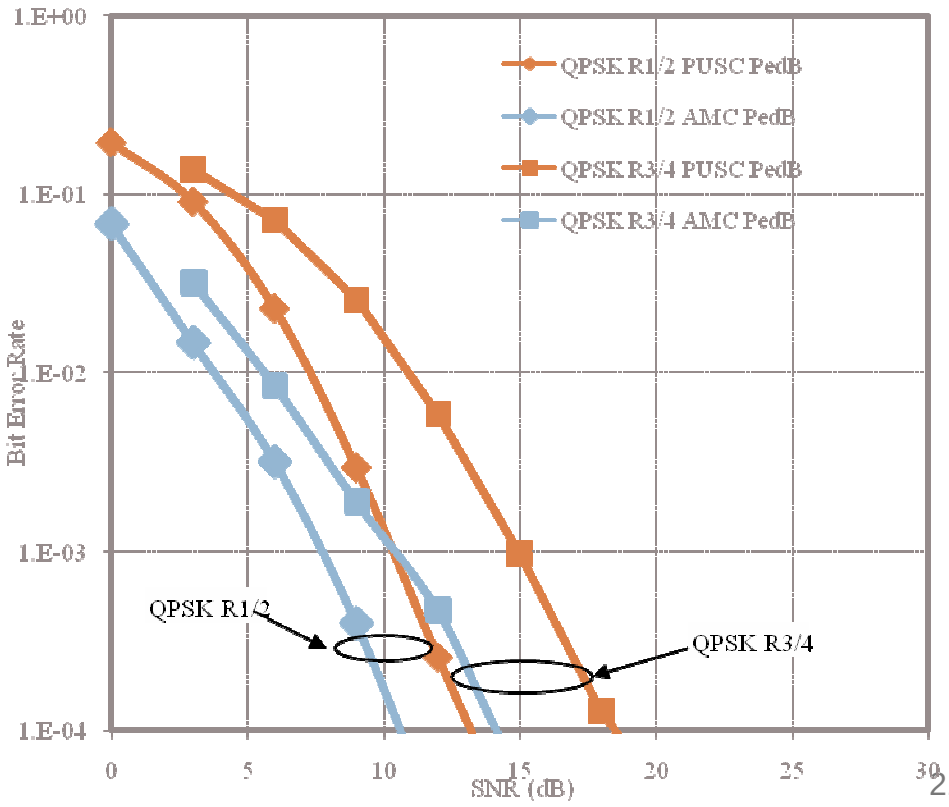
Adjacent Subcarrier

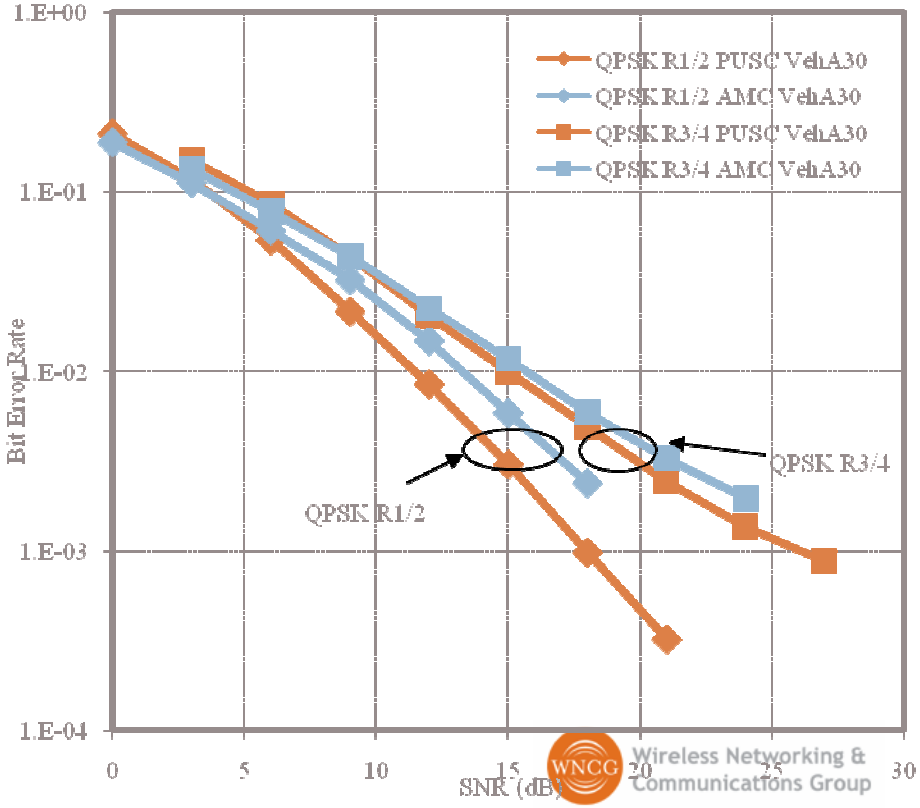
Each sub-channel consists of subcarriers adjacent to each other.

Provides better multi user diversity and is useful for closed loop multi-antenna techniques.

Comparison of distributed vs. adjacent

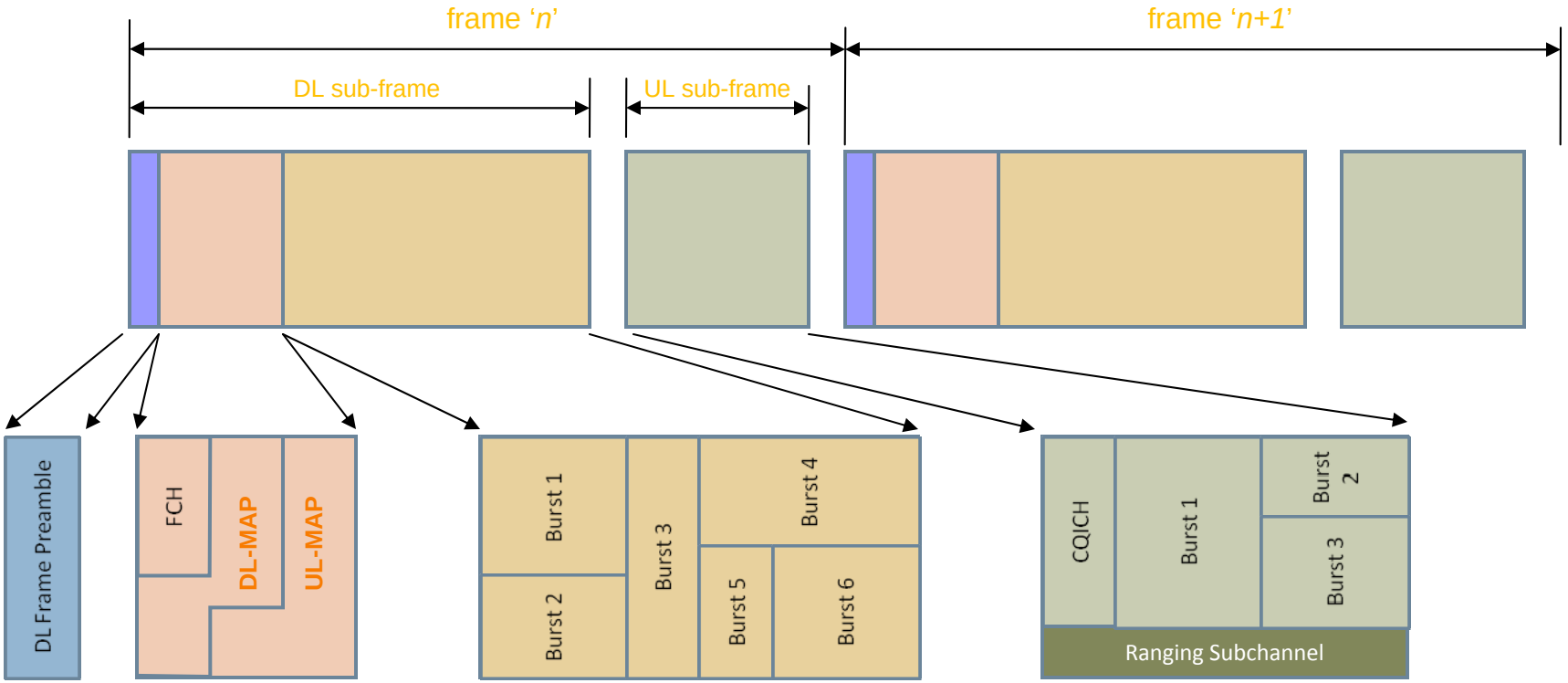
- Band AMC (adjacent allocation) exploits multi-user diversity and frequency selectivity by allocating each resource to a user with high SINR
  - Requires timely channel quality feedback (CQI)
  - At high vehicular speeds, this CQI quickly becomes obsolete
- Distributed or permuted subcarrier assignment (known as PUSC) is more robust to mobility, averages the channel in frequency





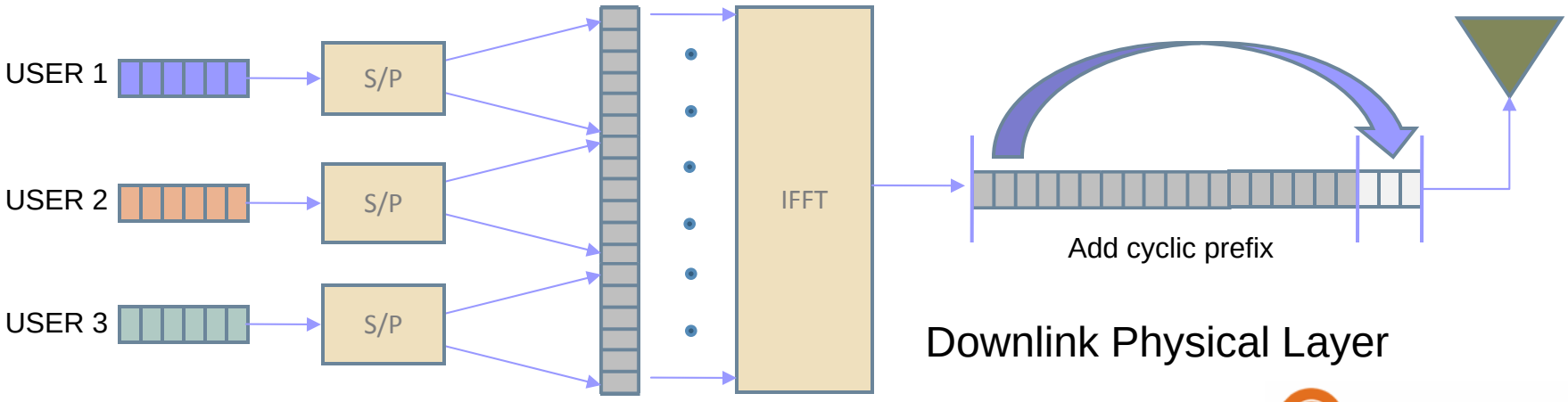
Burst Profiles, Mapping Messages, Frame Structure

- DL-MAP and UL-MAP messages specify
  - Subcarriers allocation to each mobile in the DL and UL
  - Burst (AMC) profile: what coding type/rate and constellation to use: 802.16e has a staggering 52 different profiles



3GPP's Long Term Evolution (LTE)

- LTE is technically 3GPP release 8
  - Recall that HSPA+ was release 7
- It is however a radical departure, much more similar to WiMAX than to HSPA
- Standard is not quite finalized as of Nov. 2008, but most key elements are

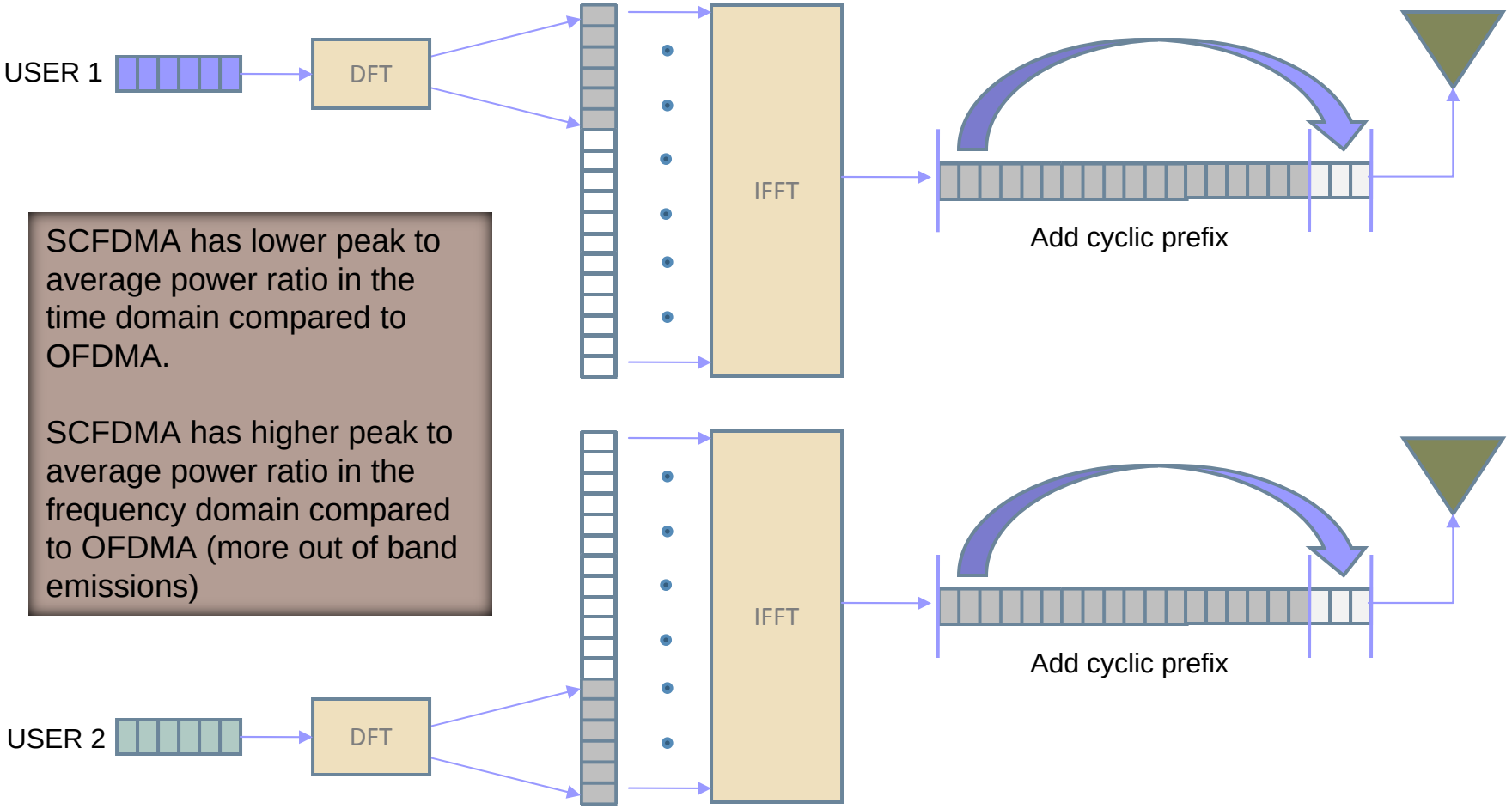


Downlink Physical Layer

Key Features of LTE

- LTE also has scalable OFDMA physical layer for the DL
- LTE uses SC-FDMA (single carrier FDMA) in the UL
- Flat IP architecture
- Variable bandwidth: 1.4, 3, 5, 10, 15, or 20 MHz
- Multi-antenna techniques such as transmit diversity, open loop MIMO, closed loop MIMO
- Resource block is 7 OFDM symbols (in time) by 12 subcarriers
  - Dedicated control channels rather than mapping messages are used to assign resources
  - Persistent allocation for VoIP (big win for voice capacity)
- 10 msec frame and 1 msec sub-frame for FDD and TDD
  - The 1 msec subframe allows for much faster feedback and ARQ

SC-FDMA in LTE Uplink



LTE Status

- Standard is still being “finalized” but chipsets already in production
  - Demonstrations by Ericsson, Samsung and others
- Has pretty well squashed Qualcomm’s UMB, seems poised to dominate 4G cellular standards
- Commercial solutions available in 2010/2011
- Widespread commercial service probably not until about 2012
  - Operators need to recover massive investment in 3G networks before replacing them
- WiMAX seems best positioned for emerging markets, since is available now

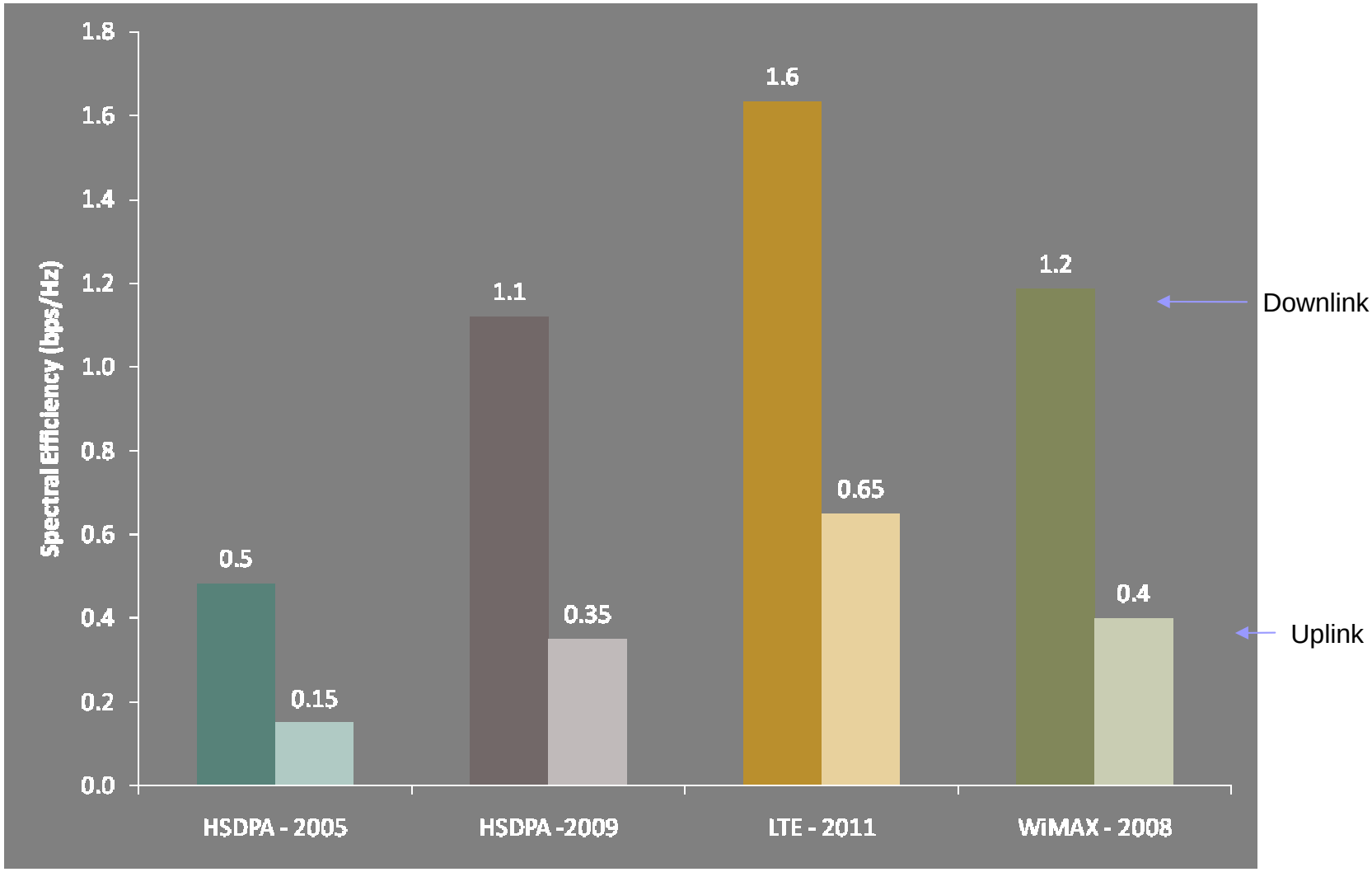
Comparison and Summary

	WiMAX	LTE	EVDO	HSDPA
Modulation DL	OFDM	OFDM	Direct Sequence Spread Spectrum	Direct Sequence Spread Spectrum (DSSS)
Multiple Access DL	OFDMA	OFDMA	CDMA/TDMA	CDMA/TDMA
Modulation UL	OFDM	SCFDMA	DSSS	DSSS
Multiple Access UL	OFDMA	SC-FDMA	CDMA/TDMA	CDMA/TDMA
Duplexing	TDD	FDD/TDD	FDD	FDD
Channel Bandwidth	Scalable 3.5, 5, 7, 8.75, 10 MHz	Scalable 1.4, 3, 5, 10, 15, 20 MHz	1.23 MHz	5 MHz
Frame Length (feedback interval)	5 msec	1 msec	1.667 msec (slot)	2 msec
MIMO Schemes	Tx Diversity, OL MIMO, AAS	Tx Diversity, OL MIMO, CL MIMO	Alamouti STBCs	Alamouti STBCs CL MIMO
Maximum MIMO Rank	2	4	1	2
Multicodeword MIMO	No	Yes	No	Yes
Modulation	QPSK, 16QAM, 64QAM	QPSK, 16QAM, 64QAM	QPSK, 8PSK, 16QAM	QPSK, 16QAM, 64QAM
Channel Coding	Convolutional,Turbo and RS Codes r = ½ , 2/3, ¾, 5/6	Turbo Codes r = 1/3, 1/2, 3/4, 1	Turbo Codes r =1/3,1/5	Turbo Codes r = ¾, ½, ¼
HARQ	Yes	Yes	Yes	Yes
Persistent Scheduling	No*	Yes	No	No

Performance Predictions

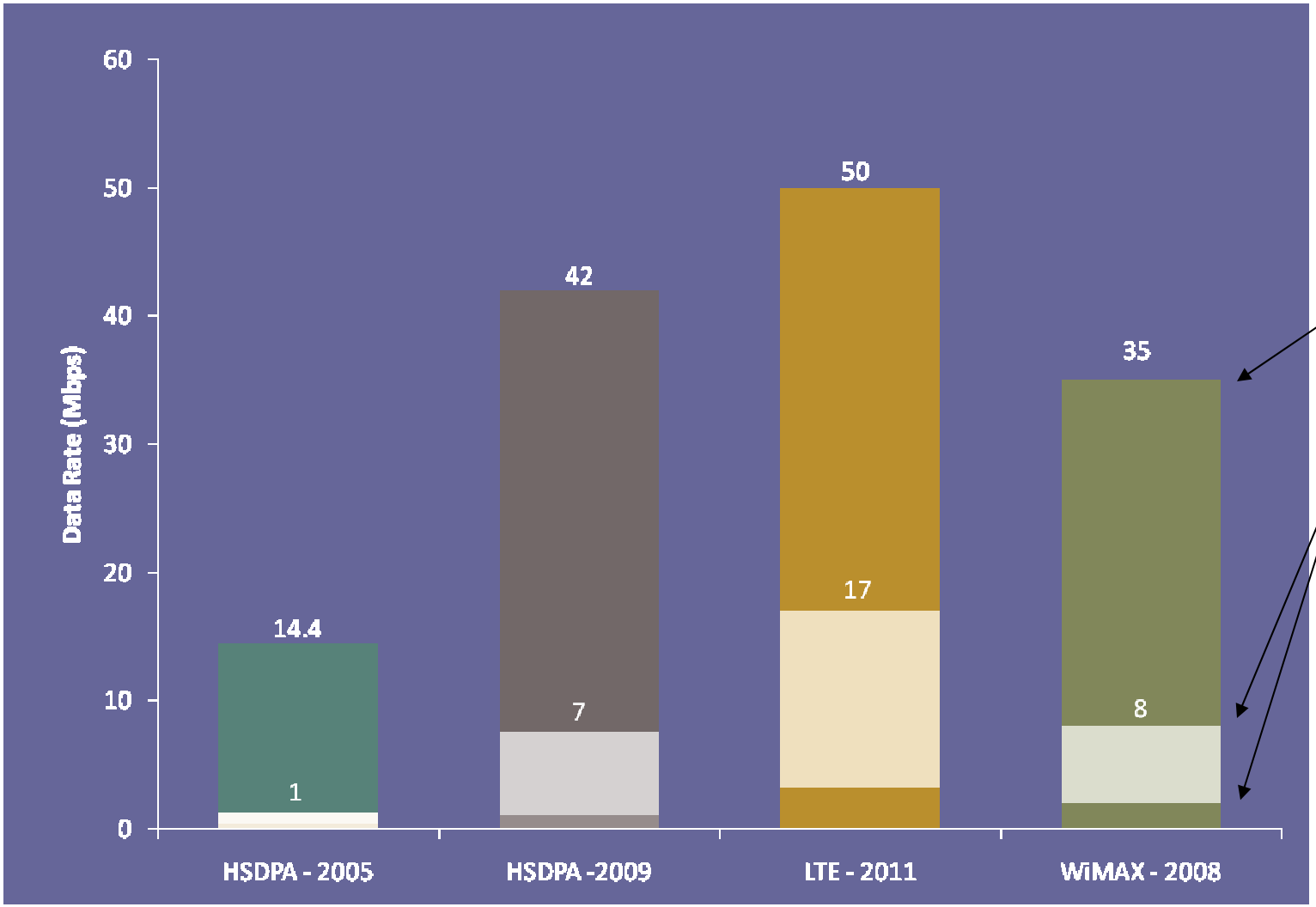
Disclaimer: these are based on private simulations and no guarantees are made to their accuracy. Different models may result in different values.

Spectral Efficiency Comparison



Results shown at 2.1 GHz with 1 km cell radius and 20 dB in building loss

Typical Data Rate Comparison



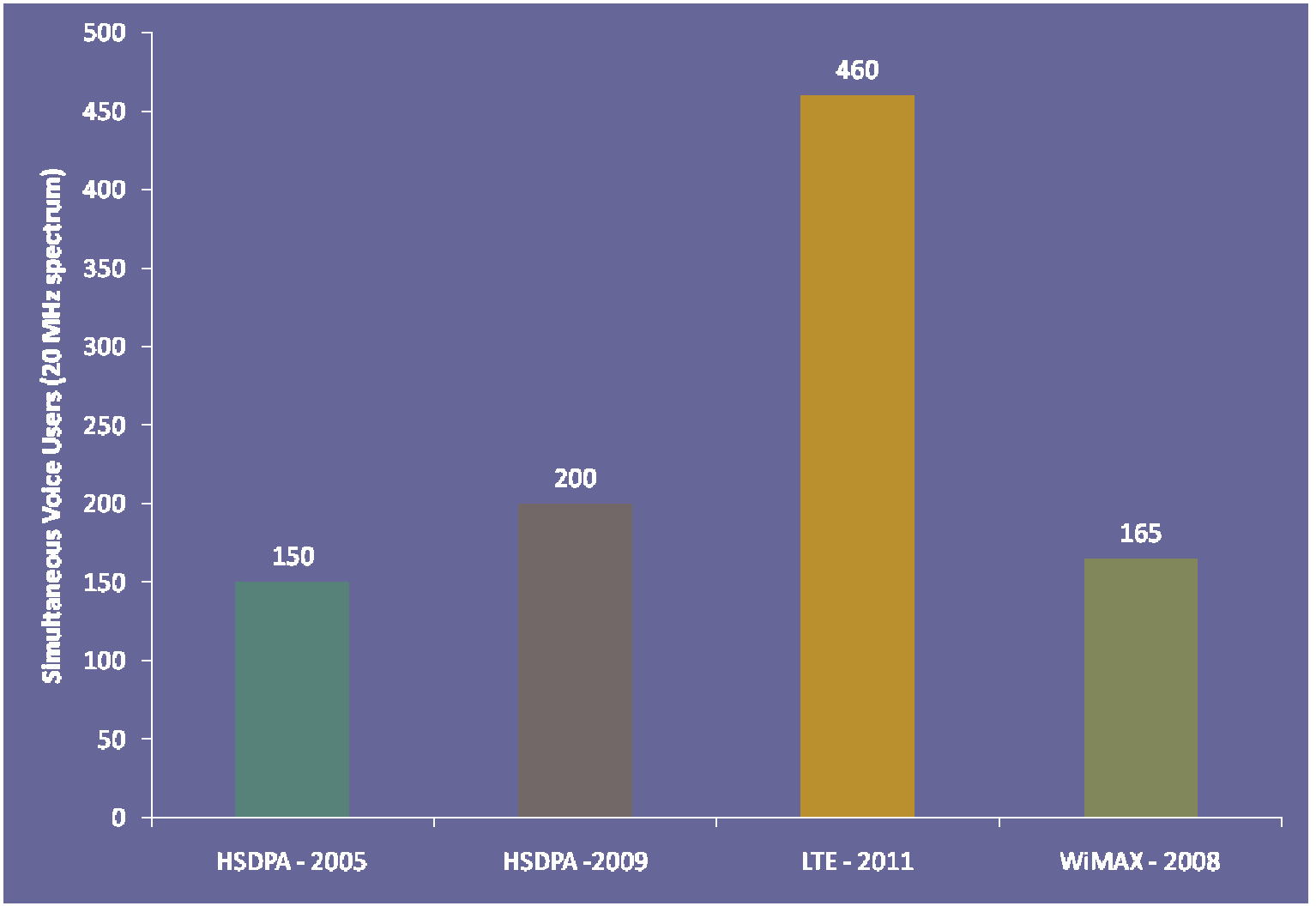
Theoretical peak data rate

Typical data rate range

HSDPA 5 MHz FDD
LTE 10 MHz FDD
WiMAX 10 MHz TDD

All MS are equipped with dual antennas in the DL

Voice Capacity (20 MHz spectrum)



Acknowledgments

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  - Avneesh Agrawal (Qualcomm)
  - Robert Heath (UT Austin)