WIRELESS AND MOBILE TELECOMMUNICATIONS - A PERSPECTIVE

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INDIAN WIRELESS COMMUNICATION PARADIGM
-Opportunities and Challenges
IETE KOLKATA CENTRE
IETE FOUNDATION DAY NOVEMBER 2, 2012

OUTLINE OF THE TALK

- INTRODUCTION
- EVOLUTION –HISTORICAL NOTES, STANDARDS
- PRIMARY SIGNAL PROCESSING
  - SOURCE CODING
  - MODULATION TECHNIQUES
  - CHANNEL CODING
  - MULTIPLE ACCESS TECHNIQUES
- WIRELESS DATA NETWORKING
- FUTURE
- *FURTHER READING*

INTRODUCTION

- **Two** Most Important Innovations of the Last Century, having Greatest Impact on the Lives of Common People, are

  - **Television** : Provided Both Entertainment and Education to Masses Most Naturally Without Any Efforts on Their Part.

  - **Mobile Telephones** : Liberated and Empowered People Providing True Freedom of Speech, Communication Any Where Any Time. Thus enabling them to Share Their Worries and Happiness – Relieving Stress Considerably.

Intro…contd…

- **Another** Very Important Invention, Impacting Lives of Primarily Scientific Community and Educated Class, has been

  \- **INTERNET** : Provides Ways and Means to Exchange All Kinds of Information and Computing Power

A Wonder

The Early Mobile Telephones were considered to be luxury and affordable to only Rich and Elite.

Now they have become a Necessity for the Commoner.

Intro...contd...

…Intro…contd

- **What has made this Wonder Gadget possible :**

1. Digital & Micro Electronics. VLSI.
2. Communication Theory – Source and Channel Coding techniques
3. Signal Processing Techniques & Technology
4. Computing Technology

It was beyond comprehension that a phone would become **Pocket Size** – compare with the desk phones.

Intro…contd…

Simple FM Telephone to a Versatile Multi Tasking Gadget – Evolution

- **Early Mobile Phones** were simply FM Radio Telephones – Broadcast **ANALOGUE** FM Radio – Signal to Noise Ratio Advantage. Only Voice Communication.

- **Soon** it became a **DIGITAL** Radio System – Digital Microwave and Satellite Communication Systems.

  Many advantages of Digital Signals and Systems.

  Voice, Data and Picture Communication.

- **Next** – Packet Communication & Network / **INTERNET** –

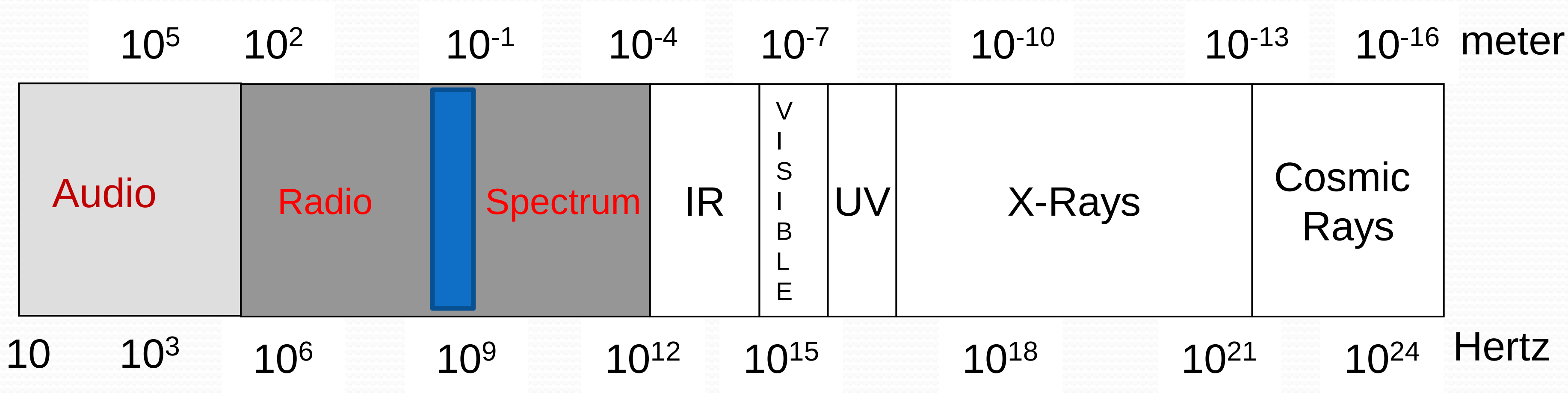
  Advantage of Better Utilization of Channel BW.

  Multimedia Communication.

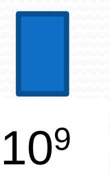
Intro…contd…

...Intro...contd

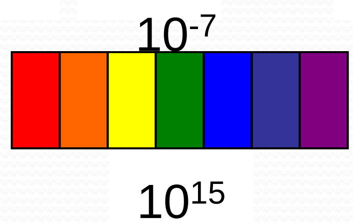
Electromagnetic Spectrum



1MHz = 100m
100MHz = 1m
10GHz = 1cm



Wireless & Mobile



Visible light

< 30 KHz	VLF
30-300KHz	LF
300KHz – 3MHz	MF
3 MHz – 30MHz	HF
30MHz – 300MHz	VHF
300 MHz – 3GHz	UHF
3-30GHz	SHF
> 30 GHz	EHF

Intro...contd...

What is Desired & What are the Problems

Aim

- Ability to Communicate even when on Move
- Every Where Every Time Communication
- Voice, Data and Video - Multimedia
- High Speed - Several Gbps
- Very High Spectral Efficiency
- High Speed Mobility

Major Hurdles

- Limited Spectrum
- Extremely Hostile Channel

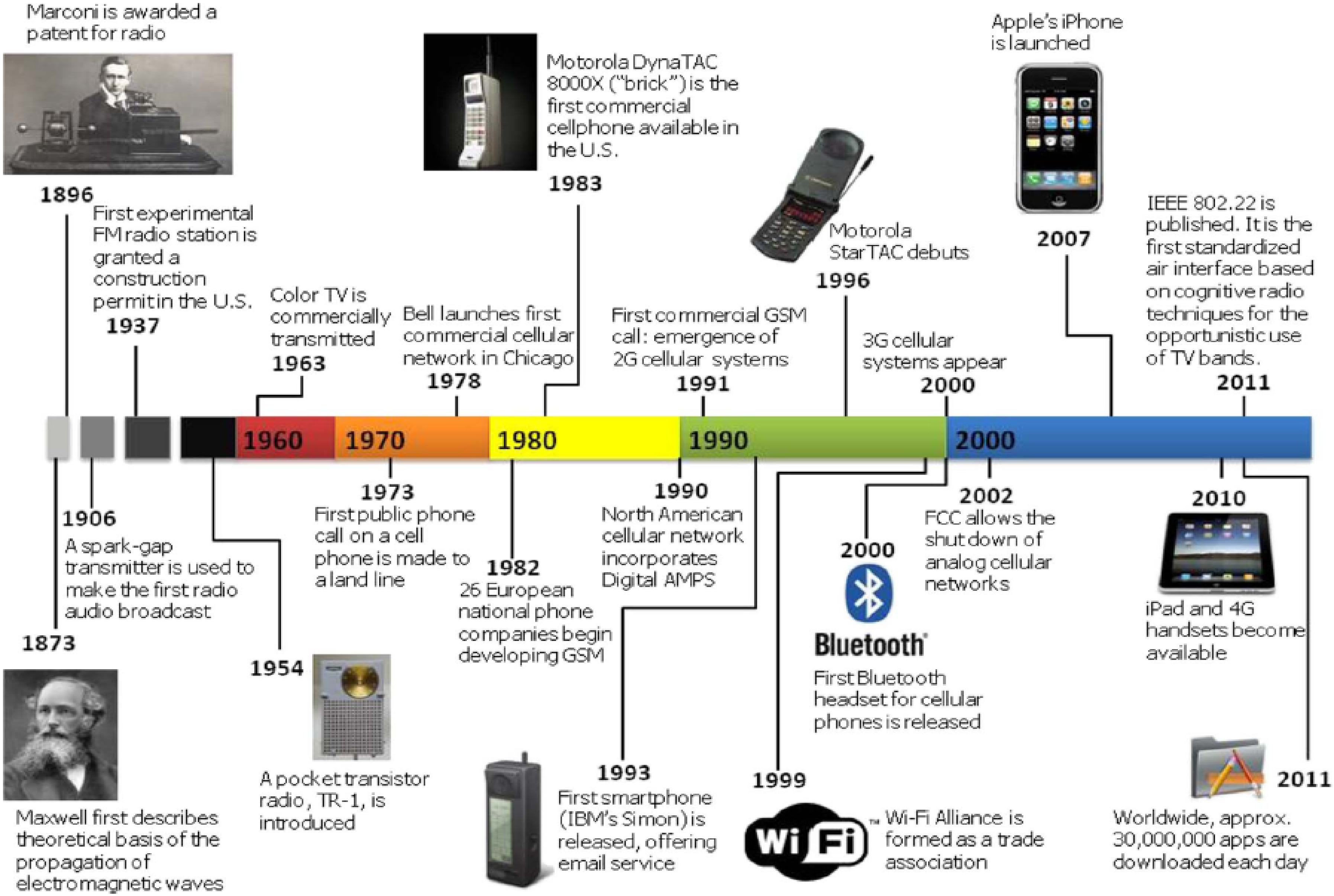
Intro…contd…

Solutions

- Division of the Service Area into Smaller Cells
- Frequency Reuse
- Bandwidth Compression – Source Coding
- Bandwidth Efficient Modulation
- Hand Over
- Channel Monitoring , Estimation & Equalization
- Error Control
- Diversity Techniques

Intro...contd...

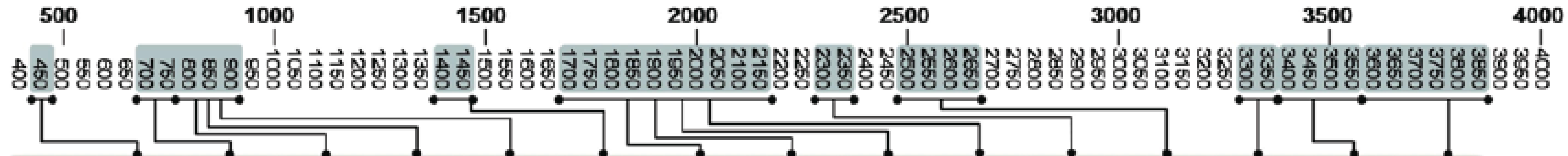
DEVELOPMENT OF RADIO



Reed, J.H.; Bernhard, J.T.; Park, J.; , "Spectrum Access Technologies: The Past, the Present, and the Future," *Proceedings of the IEEE* , vol.100, no. Special Centennial Issue, pp.1676-1684, May 13 2012. doi: 10.1109/JPROC.2012.2187140

...Intro...contd

Global Wireless Spectrum Allocation



	450	700	800	850	900	1500	1700	1800	1900	2100	2300	2500	3300	3500	3700	Total BW (MHz)
GSM	●			●	●			●	●							427
CDMA	●			●					●							199
UMTS		●	●	●	●	●	●	●	●	●		●				956
LTE	●	●	●	●	●	●	●	●	●	●		●				985
WiMAX		●									●	●	●	●	●	848
TDD/FDD	FDD	TDD/FDD	FDD	FDD	FDD	FDD	FDD	FDD	FDD	TDD/FDD	TDD	TDD/FDD	TDD	TDD/FDD	TDD	
UL (MHz)	450.4 457.6 478.8 486	698 806	830 840	824 849	876 915	1427.9 1452.9	1710 1770	1710 1785	1850 1910	1920 1980	2300 2400	2500 2570	3300 3400	3400 3600	3600 3800	
DL (MHz)	460.4 467.6 488.8 496	698 806	875 885	869 894	921 960	1475.9 1500.9	2110 2170	1805 1880	1930 1990	2110 2170	2300 2400	2620 2690	3300 3400	3400 3600	3600 3800	
BW (MHz)	28.8	108	20	50	78	50	120	150	120	120	100	140	100	200	200	

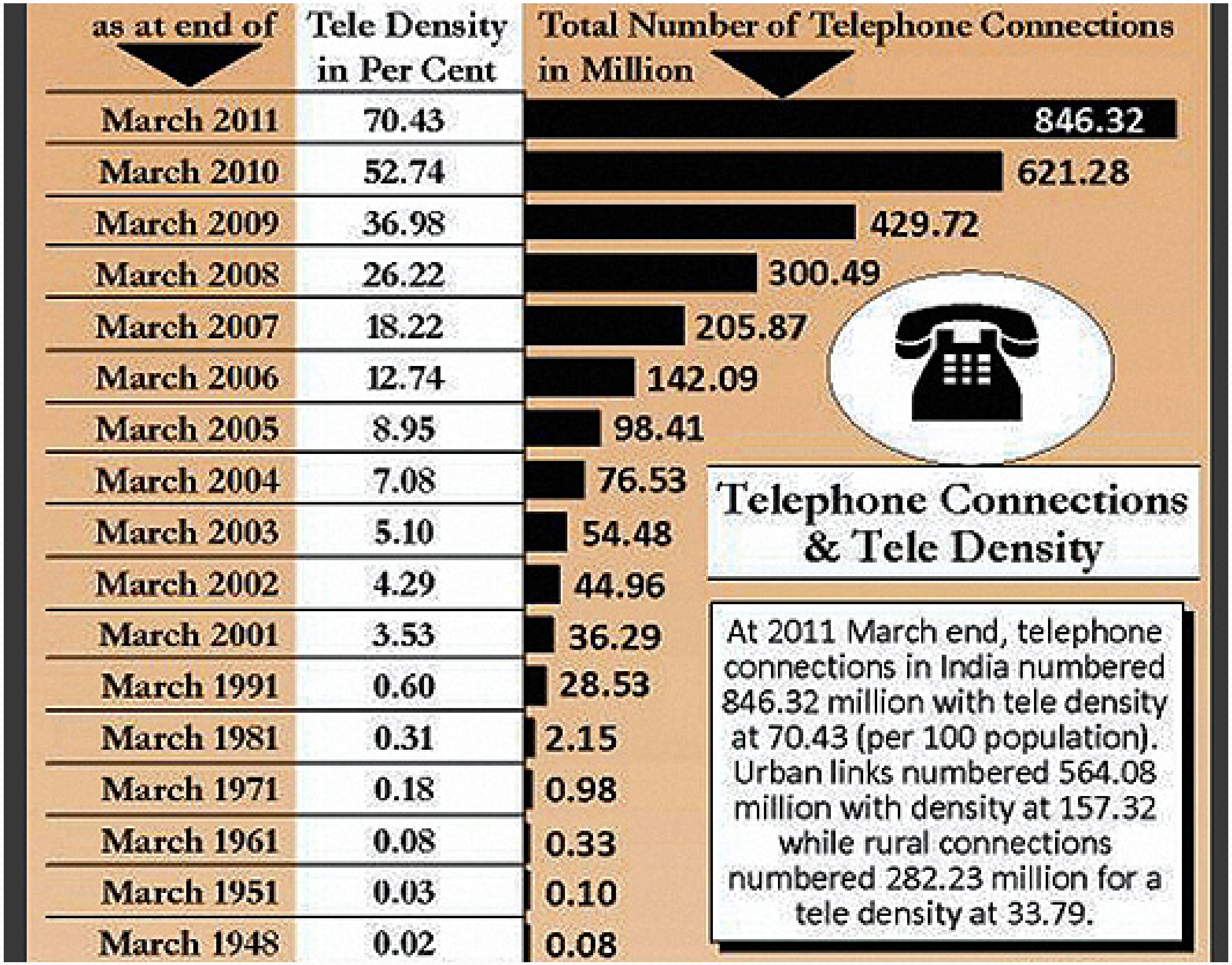
Availability of spectrum allocations by region

	450	700	800	850	900	1500	1700	1800	1900	2100	2300	2500	3300	3500	3700
EMEA	x	x			x			x		x		x		x	x
NA		x		x			x		x	x		x			x
LAC				x	x			x	x	x				x	x
APAC	x			x	x			x		x	x	x	x		

www.motorola.com

Intro...contd...

Tele-density Comparison



as at end of	Tele Density in Per Cent	Total Number of Telephone Connections in Million
March 2011	70.43	846.32
March 2010	52.74	621.28
March 2009	36.98	429.72
March 2008	26.22	300.49
March 2007	18.22	205.87
March 2006	12.74	142.09
March 2005	8.95	98.41
March 2004	7.08	76.53
March 2003	5.10	54.48
March 2002	4.29	44.96
March 2001	3.53	36.29
March 1991	0.60	28.53
March 1981	0.31	2.15
March 1971	0.18	0.98
March 1961	0.08	0.33
March 1951	0.03	0.10
March 1948	0.02	0.08

Telephone Connections & Tele Density

At 2011 March end, telephone connections in India numbered 846.32 million with tele density at 70.43 (per 100 population). Urban links numbered 564.08 million with density at 157.32 while rural connections numbered 282.23 million for a tele density at 33.79.

Source: http://www.marketcalls.in/infographic/tele-density-in-india-infographic.html

Intro...contd...

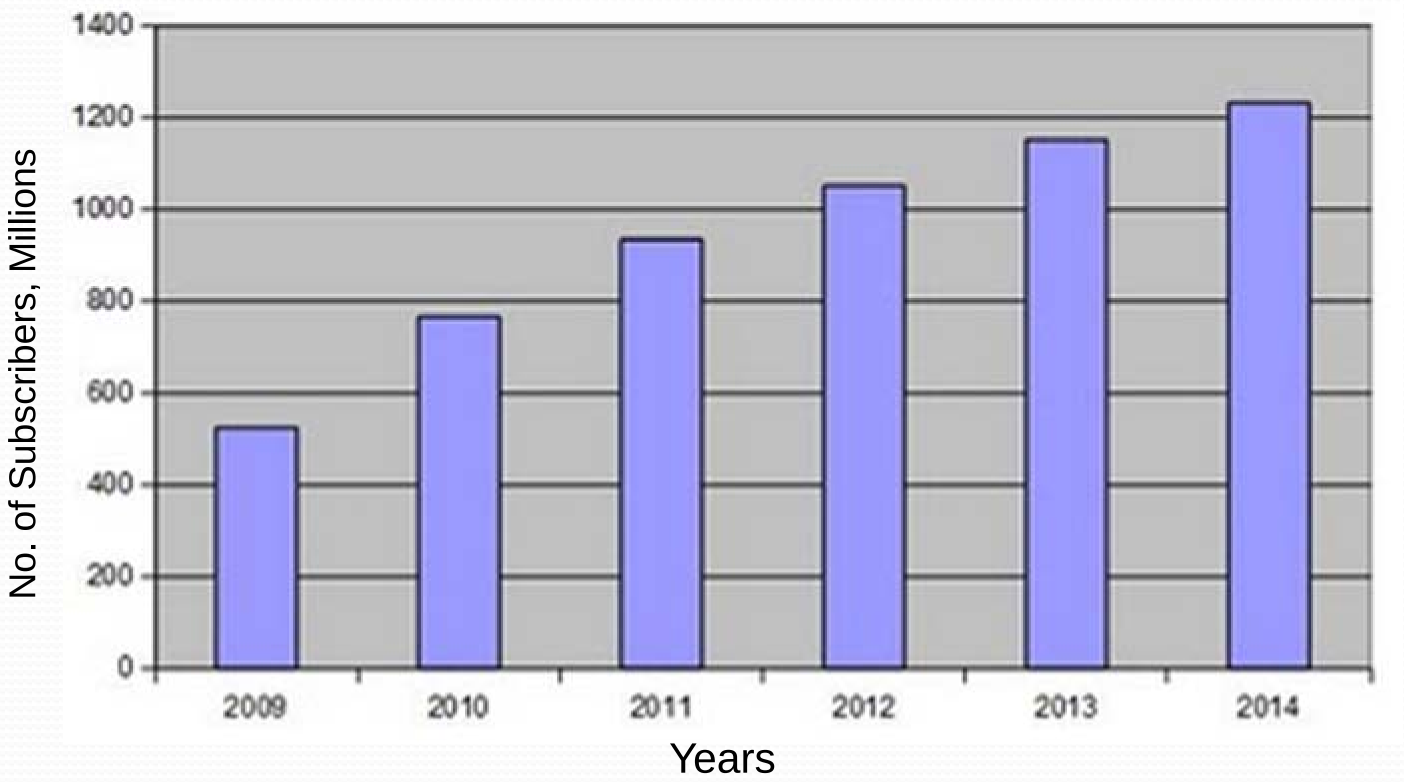
Wireless & Wireline Tele-density Comparison (India-2011)

	Wireless subscribers in mlns	Wireline subscribers in mlns	Teledensity
Total	791.38	34.86	66.36%
Urban	525.17	26.1	146.72%
Rural	266.21	8.76	31.90%
Broadband subscription			11.47%

Source: As per s per TRAI February 2011 report

Intro…contd…

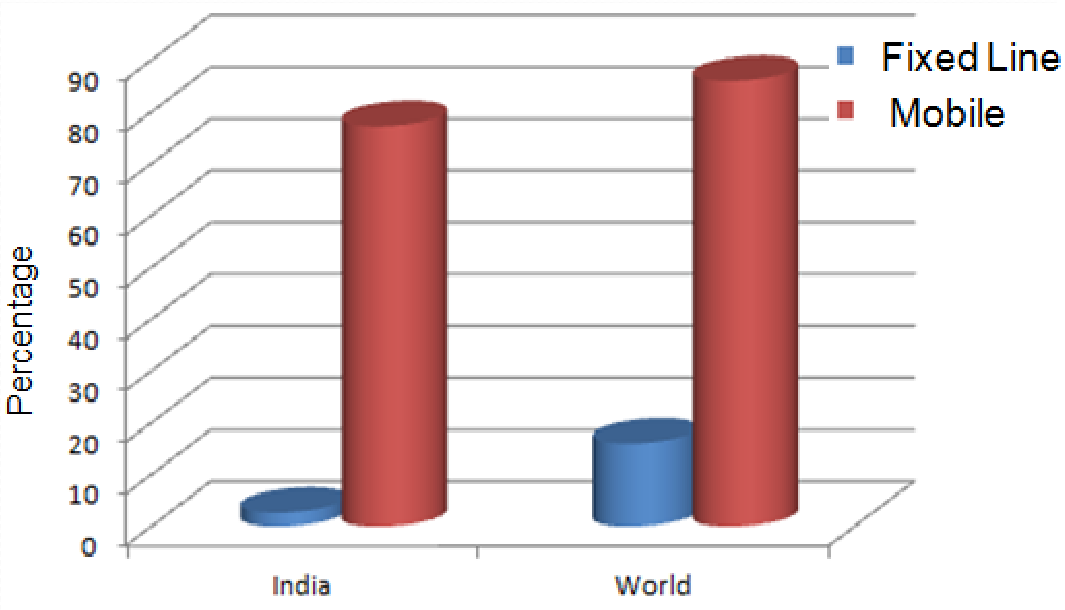
Projected Tele-density in India



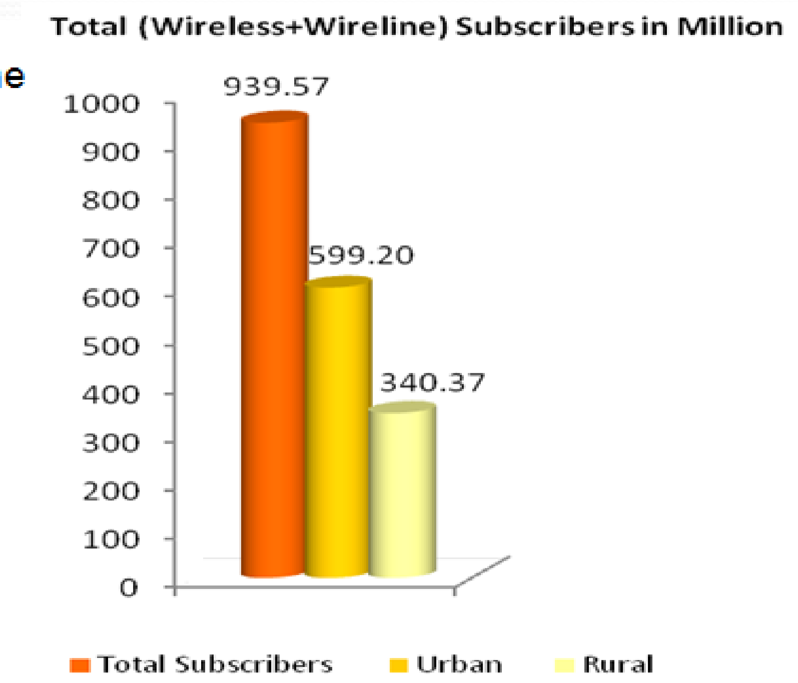
Source: Wireless Research at iSuppli, USA

Intro…contd…

Tele-density Comparison-2012



Tele-density in Year 2012



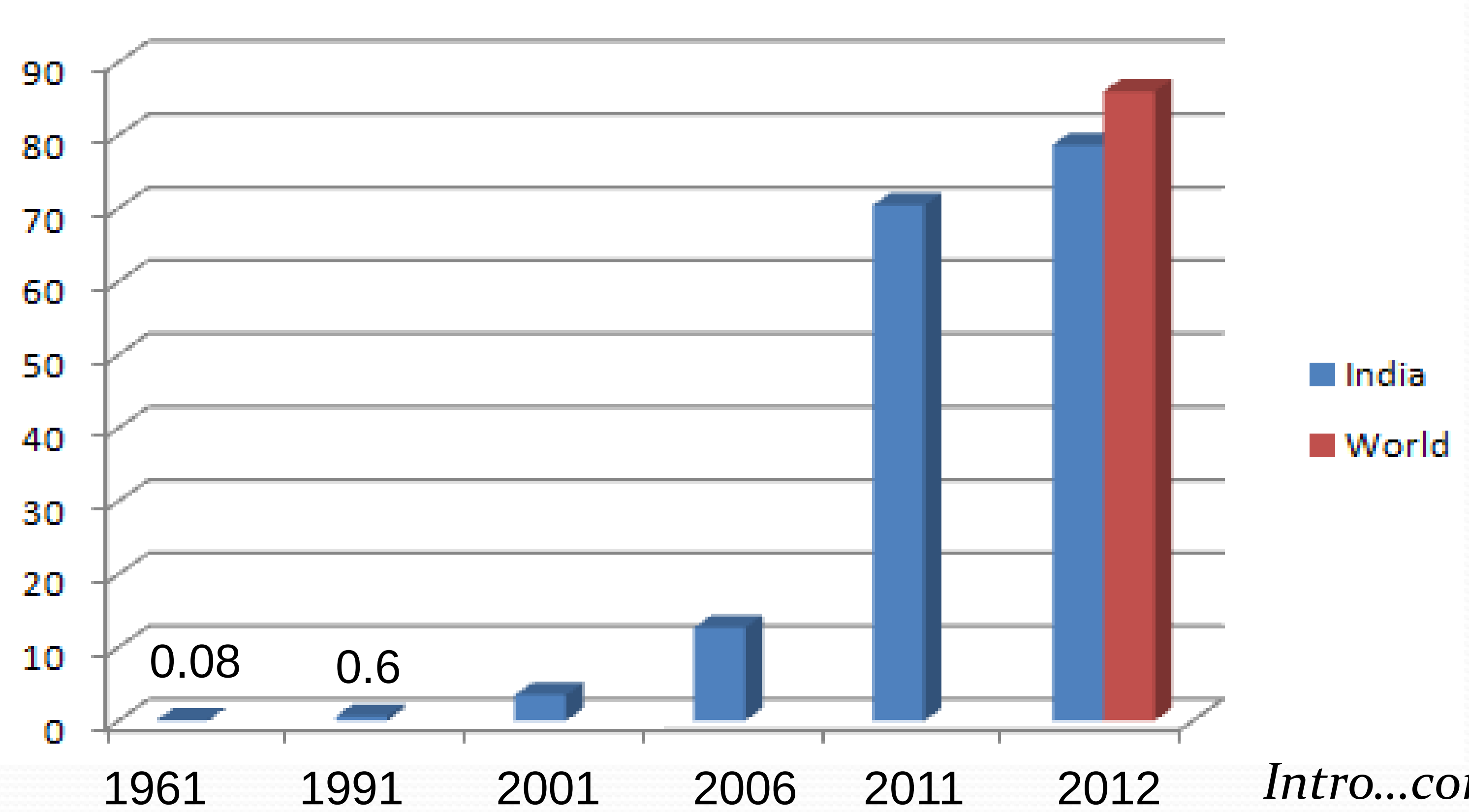
No. of Subscribers for India, year 2012

Intro...contd...

http://www.marketcalls.in/infographic/tele-density-in-india-infographic.html
http://www.trai.gov.in/Content/PressDetails.aspx?PRESS_REL_ID=1972&pg=0
http://www.trai.gov.in/WriteReadData/trai/upload/PressReleases/916/PR-TSD-Aug12.pdf

...Intro...contd

Tele-density Comparison

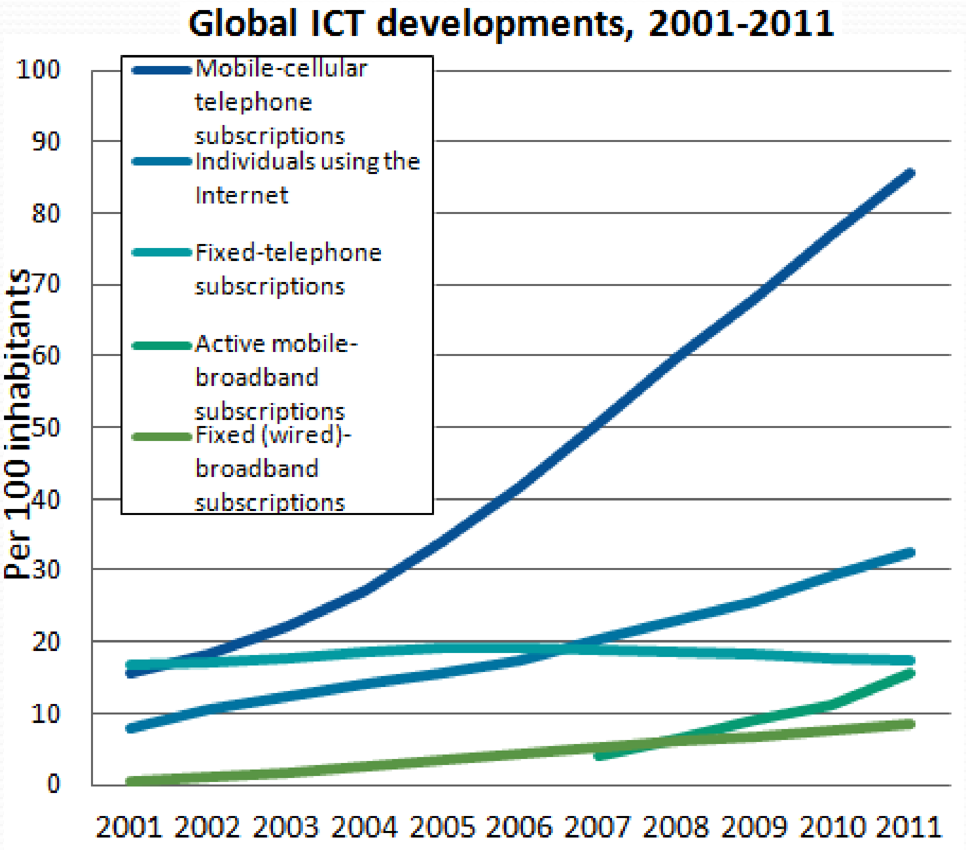


Intro...contd...

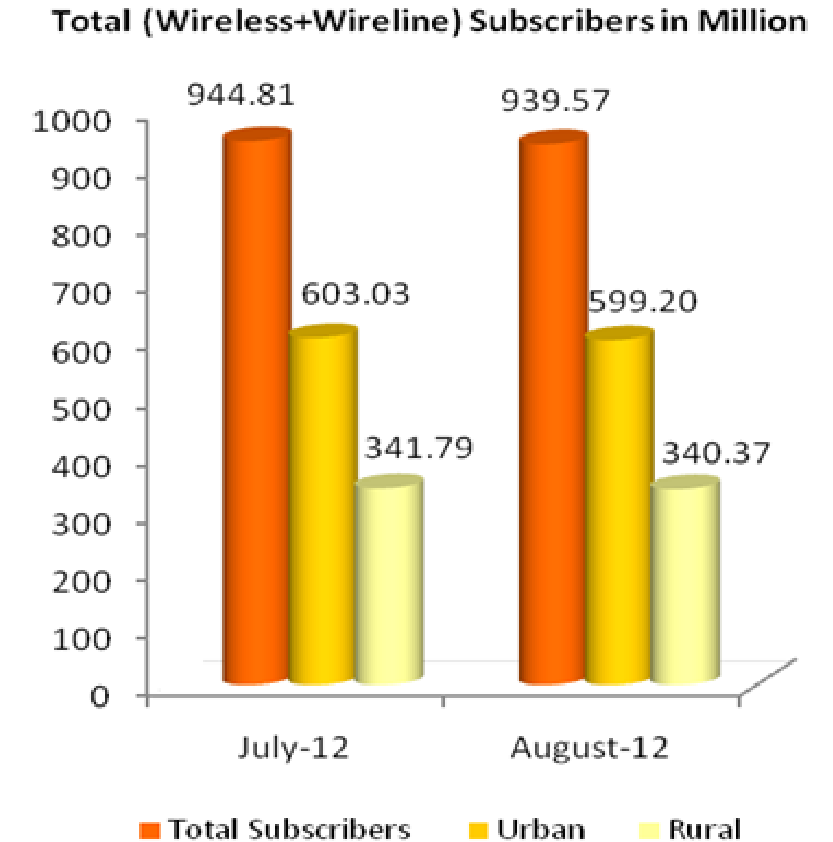
http://www.marketcalls.in/infographic/tele-density-in-india-infographic.html
http://www.trai.gov.in/Content/PressDetails.aspx?PRESS_REL_ID=1972&pg=0

Penetration of Wireless and Wired comparison

In India -2012



Source: ITU World Telecommunication /ICT Indicators database



Source: TRAI Report

Intro...contd...

Comparison of 2G,3G & 4G In India

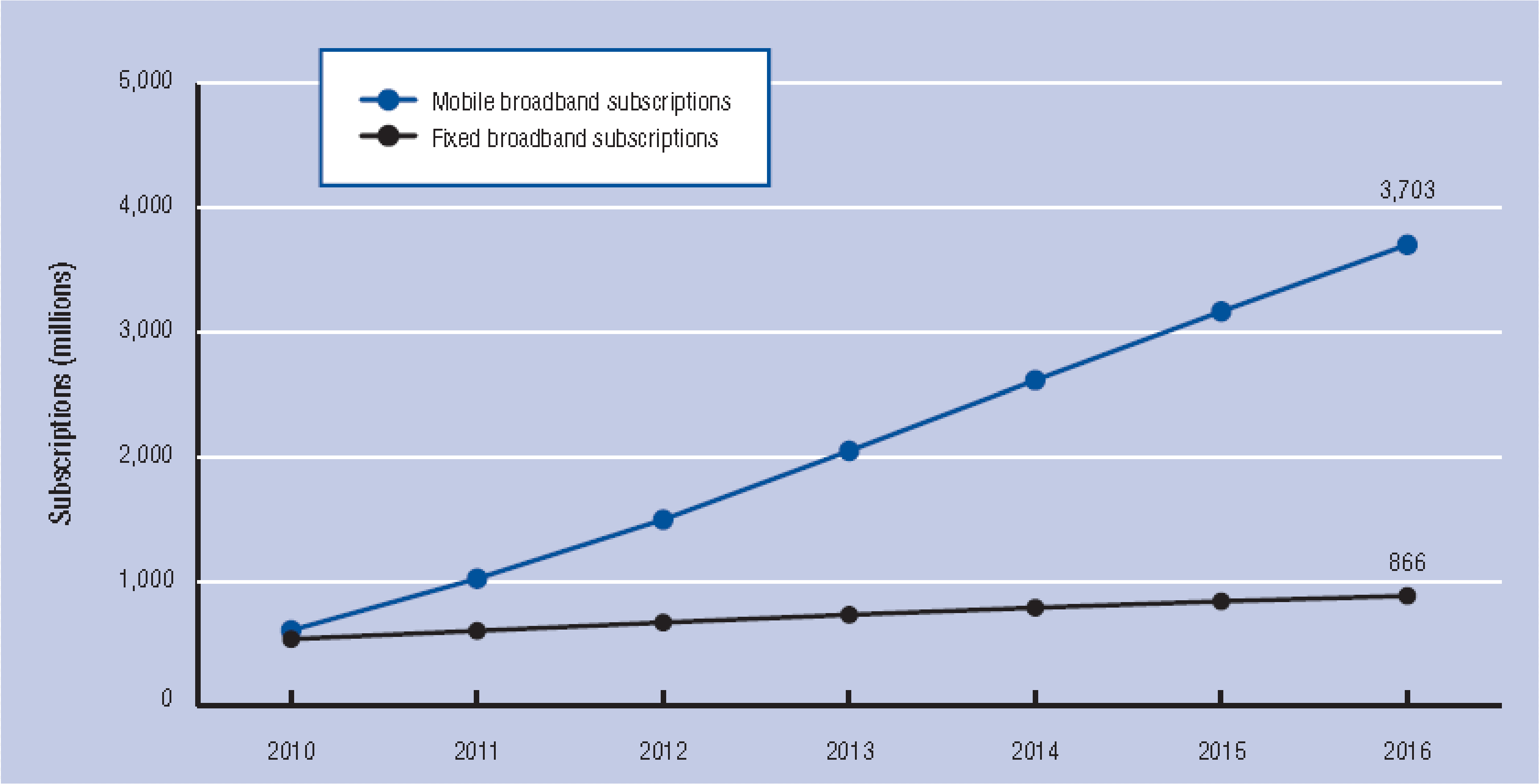
Technology	2012	2015
2G	908 Million	???
3G	50 Million	400 Million
4G	0.1 Million	5 Million

Source: http://www.thinkdigit.com/Mobiles-and-PDAs/4G-coverage-grows-in-India-expected-to_10703.html
http://www.cxotoday.com/story/3g-subscribers-in-india-to-reach-400-million-by-2015-wireless-intelligence/

Intro…contd…

...Intro...contd

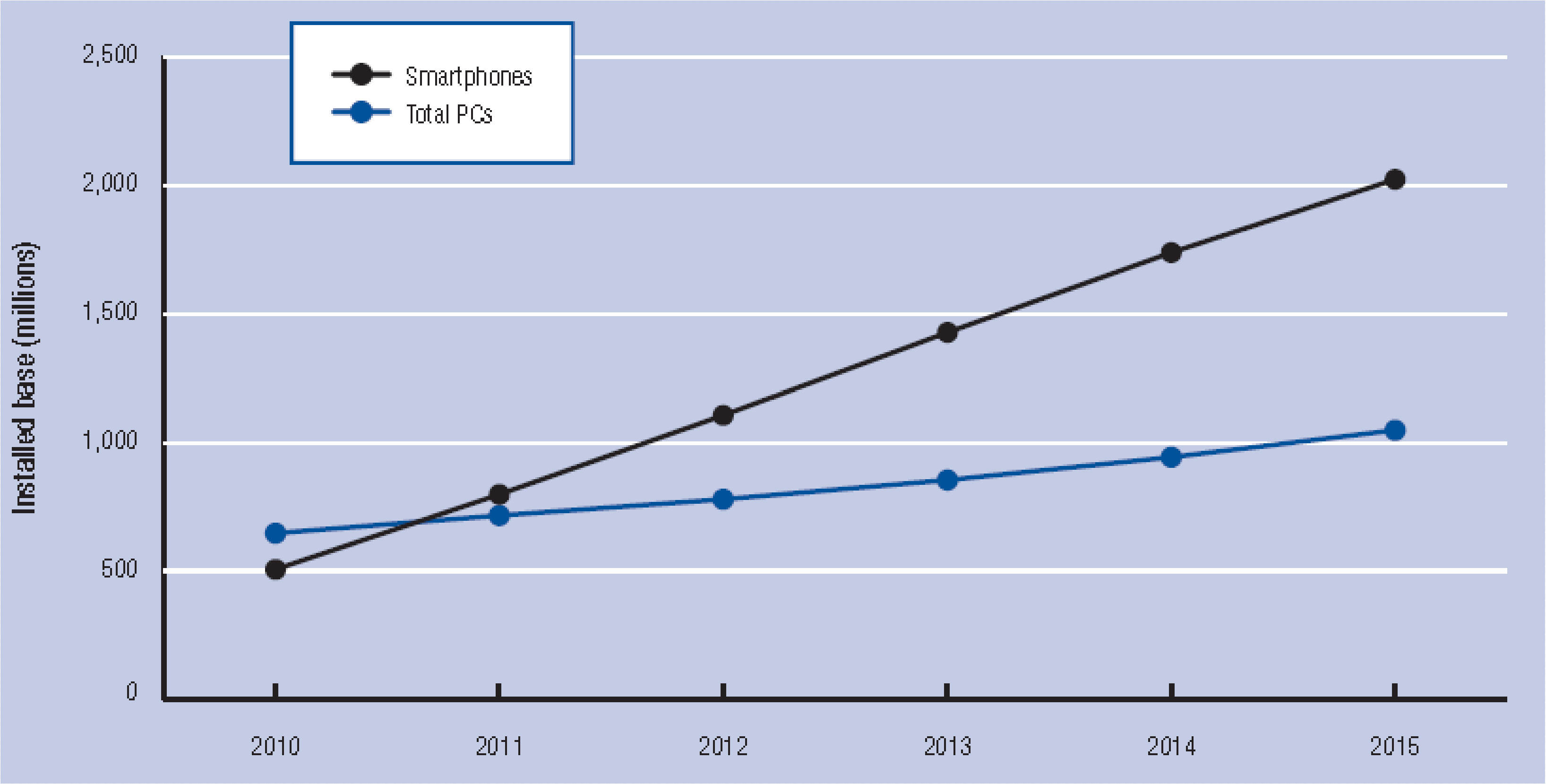
Global Broadband Subscriptions



Sources: Industry analyst firm forecasts. For mobile broadband subscriptions: HSPA, EV-DO, TD-SCDMA, and LTE subscribers: Wireless Intelligence Database, February 2012; for WiMax: ABI Database, February 2012; for fixed broadband subscriptions: Informa Telecoms & Media (WBIS) Database, February 2012.
Note: Mobile broadband technologies include EV-DO, HSPA, TD-SCDMA, LTE, WiMax, and their respective evolutions.

Intro...contd...

Smartphone: The Newest Wave of Computing



Source: Strategy Analytics, September 2011; December 2011.

EVOLUTION

- Origins of Wireless Communications
    - 1864: James Clark Maxwell

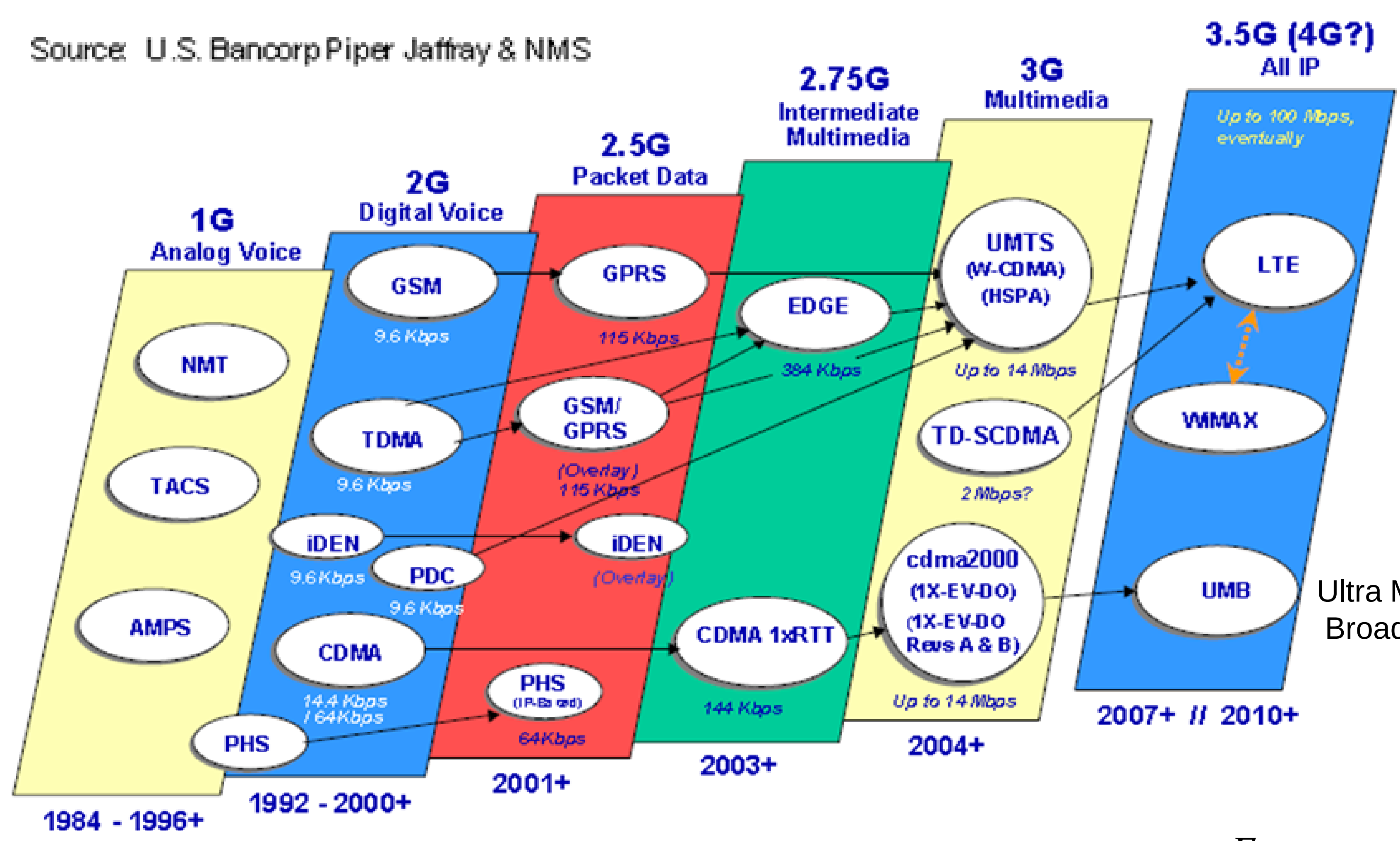
- Predicts existence of radio waves
    - 1886: Heinrich Rudolph Hertz

- Demonstrates radio waves
    - 1895-1901: Guglielmo Marconi

- Demonstrates wireless communications over increasing distances, Also in the 1890s
    - Nikola Tesla, Alexander Stepanovich Popov, Jagdish Chandra Bose and others, demonstrate forms of wireless communications

Evo…contd…

...Evo...contd Mobile Generations, 1G – 4G



Ultra Mobile Broadband

Evo...contd...

Some Technical Features of Different of Mobile Communication Standards

Technology	PHY	MAC Protocol	Frequency band	Channel spacing	Service Bit-Rate (downlink)
Cellular					
2G(GSM)	GMSK	TDMA/FDMA	850MHz &1.9GHz	200kHz	22.8 Kbps
2G(IS95)	QPSK	CDMA	825-849 MHz	1.25MHz	115 Kbps
2.5G (Edge)	GMSK/ 8PSK	FDMA/ TDMA	850MHz &1.9GHz	200kHz	236.8 Kbps
3G (UMTS)	DQPSK	WCDMA	1.8 – 2.5 GHz	5MHz	384- 2048 Kbps
3G+ (CDMA 2000)	BPSK/ QPSK	CDMA	1.8 – 2.5 GHz	5 MHz	2.5 – 15.7 Mbps
3G+ (HSPA)	BPSK/QPSK	CDMA	1.8 – 2.5 Ghz	5 Mhz	22-56 Mbps
4G(LTE)	64QAM/ MIMO	OFDMA/ SC-FDMA	2 - 8 GHz	20MHz	100 Mbps

Raychaudhuri, D.; Mandayam, N.B.; , "Frontiers of Wireless and Mobile Communications," *Proceedings of the IEEE* , vol.100, no.4, pp.824-840, April 2012. doi: 1109/JPROC.2011.2182095

Evo...contd...

Some Technical Features of Different of Mobile Communication Standards

Technology	PHY	MAC Protocol	Frequency band	Channel spacing	Service Bit-Rate (downlink)
WLAN					
802.11a/g/n	64QAM	OFDM	5/2.4/5 GHz	20/20/40 MHz	54/54/200 Mbps
802.11b	DQPSK	FDMA	2.4 GHz	20MHz	11 Mbps
802.11ac	256QAM/ MU-MIMO	OFDM/ SDMA	5 GHz	80MHz	500 Mbps
802.11ad	64QAM	OFDM	60GHz	2160MHz	1 Gbps

Raychaudhuri, D.; Mandayam, N.B.; , "Frontiers of Wireless and Mobile Communications," *Proceedings of the IEEE* , vol.100, no.4, pp.824-840, April 2012. doi: 1109/JPROC.2011.2182095

Evo…contd…

Comparison of Physical Layer Characteristics of Various Telephone N/W Standard

	DECT	GSM	IS-95	WCDMA
Frequency Band	1880-1900 MHz	935-960 MHz 890-915 MHz	869-894 MHz 824-849 MHz	1920-1980 MHz(F) 2110-2117 MHz (R)
Channel BW	1.728 MHz	200 KHz	1.25 MHz	5 MHz
Modulation	GMSK	GMSK	BPSK	QPSK
Data Rate	1.152Mbps	270.8Kbps	1200, 2400, 4800, 9600 bps	Up to 2 Mbps
Access Strategy	FDMA/TDMA/TDD	FDMA/TDMA/FH	FDMA/CDMA	FDMA/CDMA/FDD FDMA/CDMA/TDD
Cell Size	<300 m	<35 km	<35 km	< 35 km
FEC coding	None(16 bit CRC)	Variable(incl. rate-1/2 convol.)	Variable(incl. rate-1/2, 1/3 convol.)	Variable(incl. rate-1/2, 1/3 convol.)
Frame Size	10 ms	4.61 ms	20 ms	10 ms
Voice encoding	ADPCM at 32 KHz	RELP at 13 Kbps	CELP at 9.6 Kbps and 14.4 Kbps	Adaptive multirate ACELP 4.75 to 12.2 Kbps
Traffic Channels/ RF Channel	12	8	Up to 63 in theory	Depend upon data rate
Diversity	Antenna Diversity at BS	Frequency Hopped	Spread spectrum with RAKE receiver	Space time block coding with transmit diversity

Source: Modern Wireless Communications, by S. Haykin, M. Moher

Evo...contd...

Major Cordless Systems Standards

Cordless Systems standards	Frequency Bands	Multiple Access Tech.	Channel BW	Modulation Scheme	Region
PWT	1.91-192 GHz	TDMA/FDMA	1250 KHz	π/4-DQPSK	North America
PACS	1.85-1.99 GHz	TDMA/FDMA	300 KHz	π/4-DQPSK	North America
CT2	864-868 MHz	FDMA	100 KHz	GFSK	Europe
DECT	1.88-1.90 GHz	TDMA	1728 KHz	GFSK	Europe
DCS-1800	1.71-1.88 GHz	TDMA	200 KHz	GMSK	Europe
PHS	1.895-1.907 GHz	TDMA	300 KHz	π/4-DQPSK	Japan

Source: Modern Wireless Communications, by S. Haykin, M. Moher

Evo…contd…

Mobile Communication Systems Standards

		Real World (avg)		Theoretical (max)		Availability
		Download	Upload	Download	Upload	
2.5G	GPRS	32-48Kbps	15Kbps	114Kbps	20Kbps	Today
2.75G	EDGE	175Kbps	30Kbps	384Kbps	60Kbps	Today
3G	UMTS	226Kbps	30Kbps	384Kbps	64Kbps	Today
	W-CDMA	800Kbps	60Kbps	2Mbps	153Kbps	Today
	EV-DO Rev. A	1Mbps	500Kbps	3.1Mbps	1.8Mbps	Today
	HSPA 3.6	650Kbps	260Kbps	3.6Mbps	348Kbps	Today
	HSPA 7.2	1.4Mbps	700Kbps	7.2Mbps	2Mbps	Today
Pre-4G	WiMAX	3-6Mbps	1Mbps	100Mbps+	56Mbps	Today
	LTE	5-12Mbps	2-5Mbps	100Mbps+	50Mbps	End 2010
	HSPA+	-	-	56Mbps	22Mbps	2011
	HSPA 14	2Mbps	700Kbps	14Mbps	5.7Mbps	Today*
4G	WiMAX 2 (802.16m)	-	-	100Mbps mobile / 1Gbps fixed	60Mbps	2012
	LTE Advanced	-	-	100Mbps mobile / 1Gbps fixed	-	2012+

Source: http://www.techspot.com/guides/272-everything-about-4g/

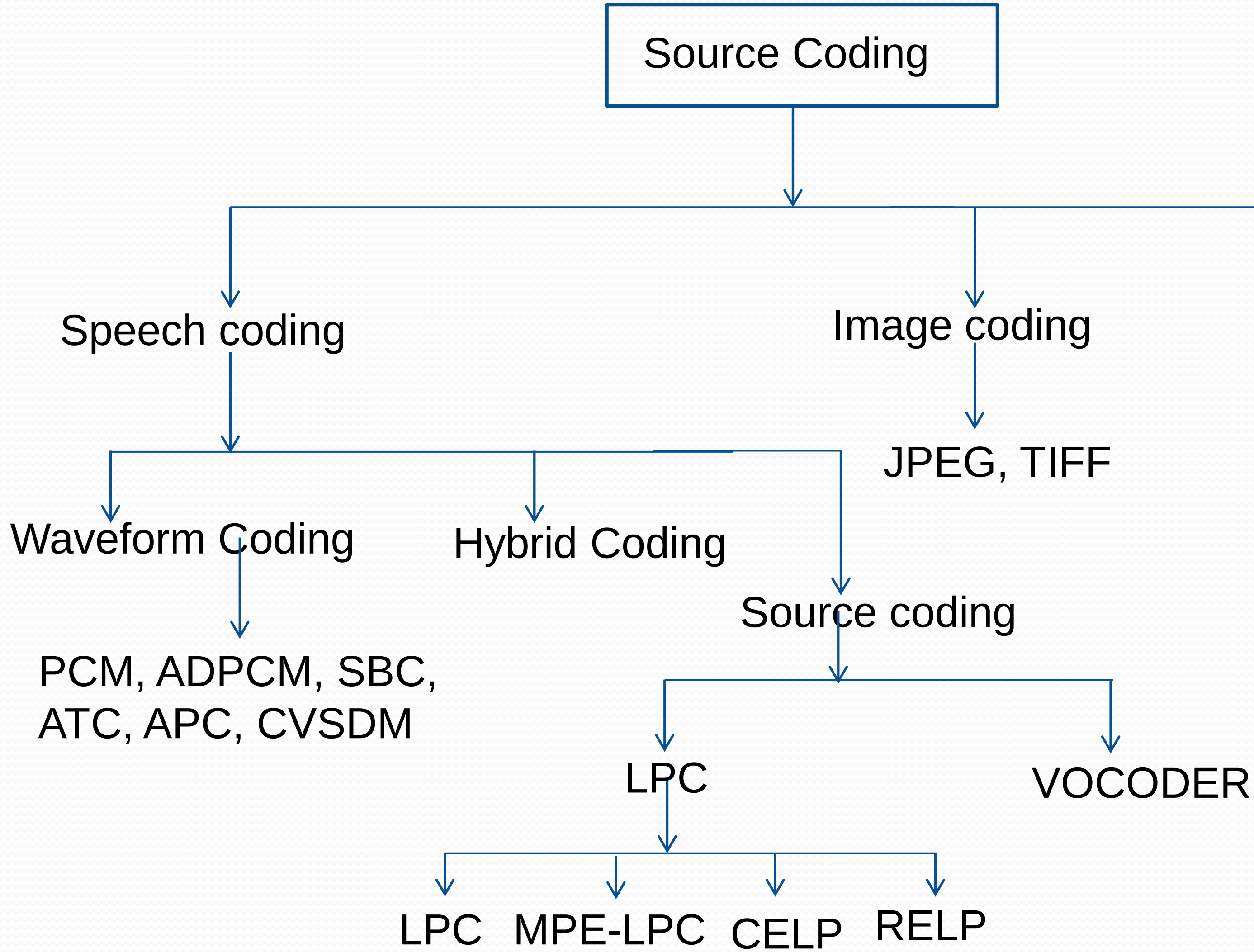
PRIMARY SIGNAL PROCESSING

- Source (Speech, Video) Coding
- Bandwidth Efficient Modulation Techniques
- Channel Coding
- Multiple Access Techniques

Primary...contd...

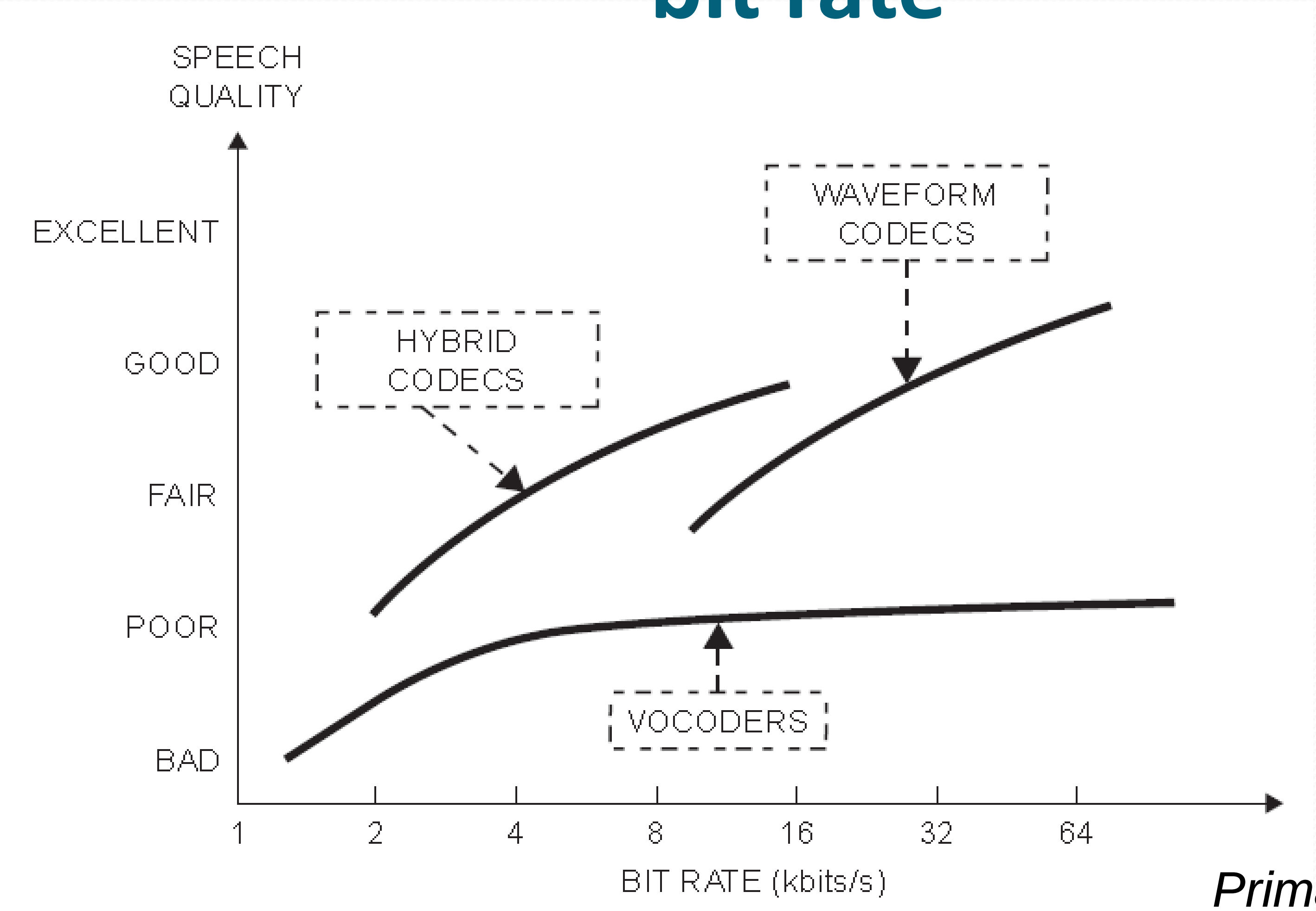
Classification of Source Coding

…Primary…Contd



Primary…contd…

Quality of service versus bit rate



Primary...contd...

Source: Wireless Communications and Networking, by Vijay Garg

Speech coding Standards

- Speech Coding Standards
  - 64 kbits/s PCM Codecs
  - The 32 kbits/s G721 ADPCM Codec
  - The 16 kbits/s G728 Low Delay CELP Codec
  - The 13 kbits/s GSM Codec
  - The 4.8 kbits/s DoD CELP Codec

Primary...contd...

Speech Coders for Mobile Communication

Standard	Service Type	Speech Coder Type	Bit Rate (kbps)
GSM	Cellular	RPE-LTP	9.6, 13
CD-900	Cellular	SBC	16
USDC(IS-136)	Cellular	VSELP	8
IS-95	Cellular	CELP	1.2, 2.4, 4.8, 9.6, 13.4, 14.4
IS-95 PCS	PCS	CELP	13.4, 14.4
PDC	Cellular	VSELP	4.5, 6.7, 11.2
CT2	Cordless	ADPCM	32
DECT	Cordless	ADPCM	32
PHS	Cordless	ADPCM	32
DCS-1800	PCS	RPE-LTP	13
PACS	PCS	ADPCM	32

Source: Wireless Communications and Networking, by Vijay Garg

Primary...contd...

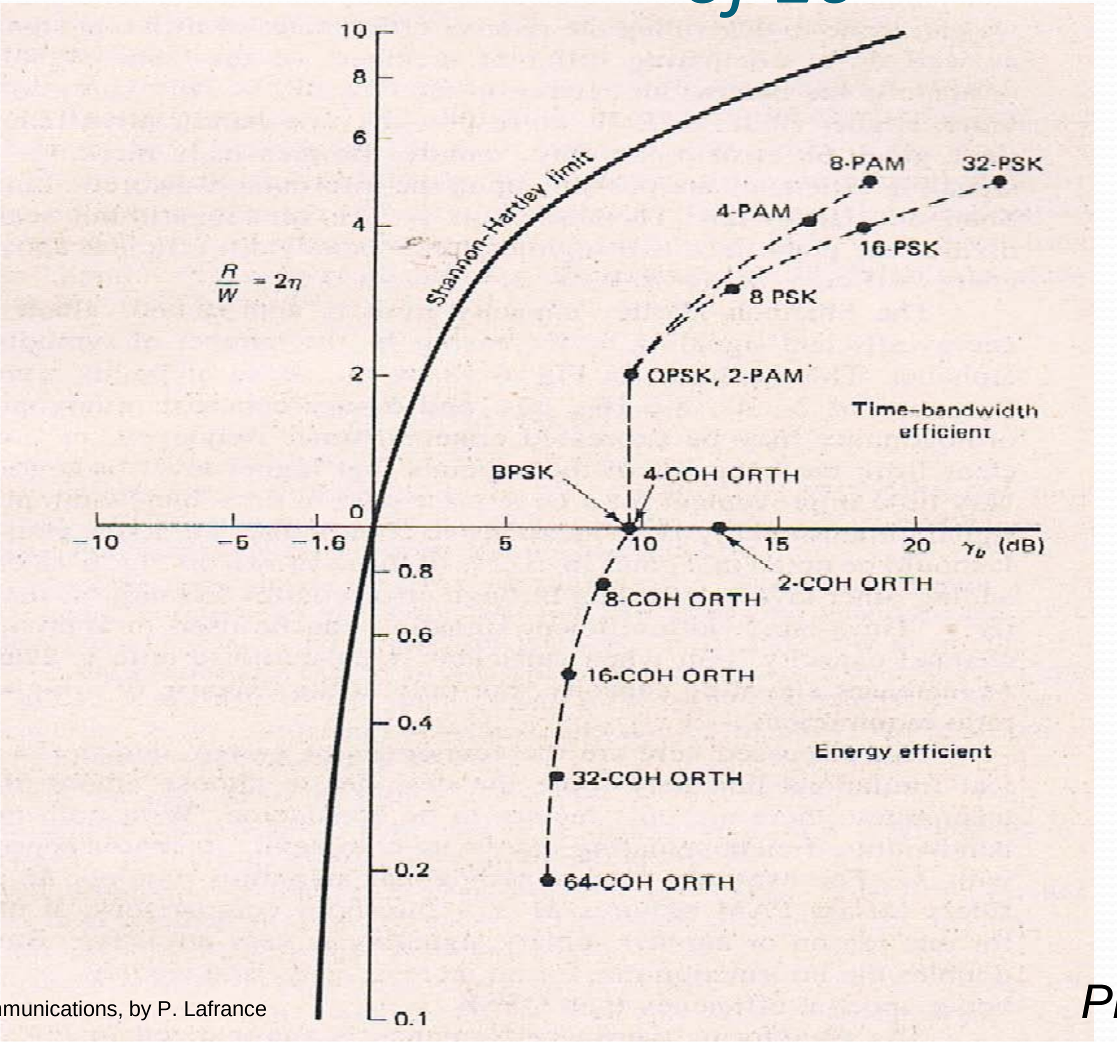
...Primary...Contd

Modulation Techniques

- Different type of Digital Modulation
  - ASK – Amplitude Shift Keying
  - PSK- Phase Shift keying
  - FSK- Frequency Shift Keying
  - QPSK- Quadriphase-Shift Keying
  - QAM- Quadrature Amplitude Modulation
  - GMSK- Gaussian Minimum Shift keying

Primary…Contd

M-ary waveform efficiency for a BER of 10^{-5}



Source: Fundamental Concepts in Communications, by P. Lafrance

Primary…Contd

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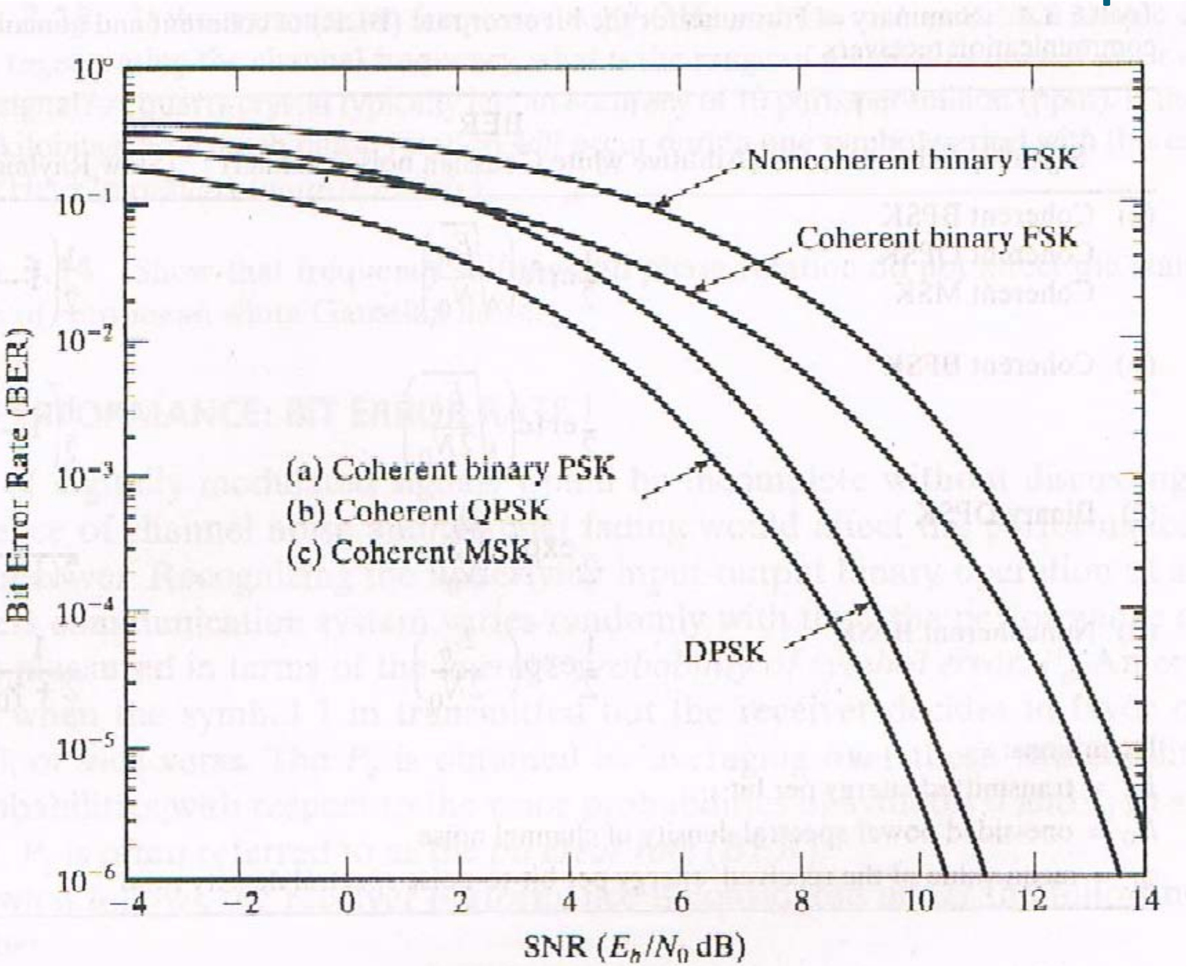
Noise comparison of different modulation techniques



Primary…Contd

Source: Modern Wireless Communications, by S. Haykin, M. Moher

Comparison of different modulation techniques

Digital Modulation Tech.	MINIMUM TRANSMISSION BW	ERROR PERFORMANCE	
	BW	Coherent detection	Non coherent detection
OOK (On Off Keing)	R	$Q\left[\sqrt{\frac{E_b}{N_0}}\right]$	$\frac{1}{2}e^{-\left(\frac{1}{2}\frac{E_b}{N_0}\right)}$ $\frac{E_b}{N_0} > \frac{1}{4}$
BPSK	R	$Q\left[\sqrt{2\frac{E_b}{N_0}}\right]$	Requires coherent detection
PCM/FM	R	$\frac{1}{2}e^{-\left(\frac{1}{2}\frac{E_b}{N_0}\right)}$	
FSK	$2\Delta f + R$ where $\Delta f = f_2 - f_1$ =frequency shift	$Q\left[\sqrt{\frac{E_b}{N_0}}\right]$	$\frac{1}{2}e^{-\left(\frac{1}{2}\frac{E_b}{N_0}\right)}$
DPSK	R	Not used in practise	$\frac{1}{2}e^{-\left(\frac{E_b}{N_0}\right)}$
QPSK	$\frac{1}{2}R$	$Q\left[\sqrt{2\frac{E_b}{N_0}}\right]$	Requires coherent detection
MSK	1,5 R(null bandwidth)	$Q\left[\sqrt{2\frac{E_b}{N_0}}\right]$	$\frac{1}{2}e^{-\left(\frac{1}{2}\frac{E_b}{N_0}\right)}$

Primary…Contd

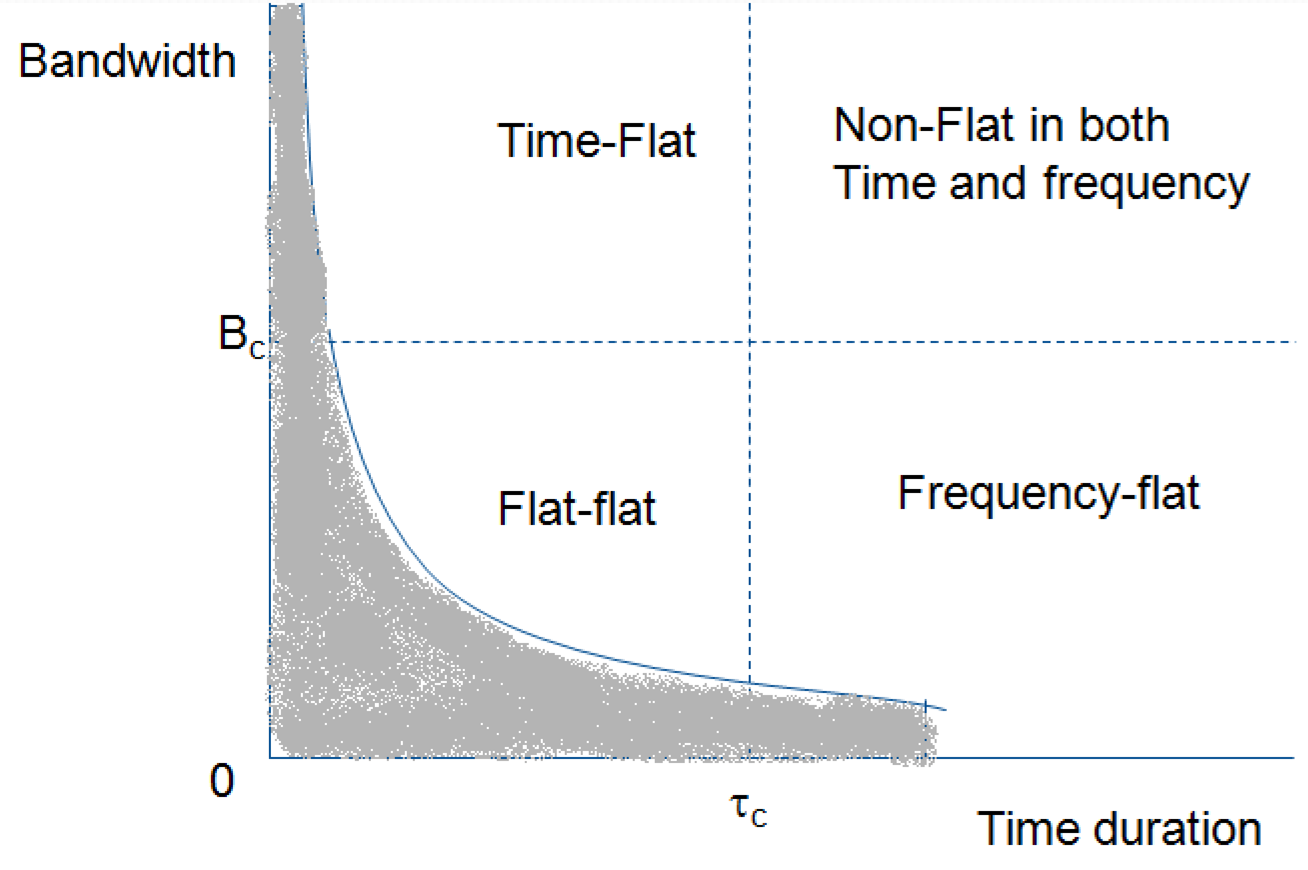
...Primary...Contd

Comparison of different modulation techniques

Modulation Type	Two-Sided Bandwidth, R_B Sideband Attenuation, dB 20	30	40	50	60	Spectrum Improvement Factors[2] Sideband Attenuation, dB 20	30	40	50	60
PCM/PM/NRZ[1]	8.2	10.2	10.2	14.2	16.2	1.3	2.3	7.3	18.4	40.2
PCM/PM/Bi-• [1]	16.2	20.2	24.2	28.2	32.2	0.7	1.2	3.1	9.3	20.2
BPSK/NRZ[1]	8.2	10.2	14.2	16.2	18.2	1.3	2.3	5.3	16.1	35.8
BPSK/Bi-• [1]	20.2	24.2	28.2	32.2	40.2	0.5	1.0	2.6	8.1	16.2
QPSK[1]	5.2	6.2	7.2	8.2	12.2	2.1	3.7	10.4	31.8	53.4
OQPSK[1]	5.2	7.2	8.2	10.2	18.2	2.1	3.2	9.1	25.6	35.8
MSK	1.3	3.0	5. 1	9.1	19.1	8.3	7.7	14.7	28.7	34.1
GMSK (BT_s=1)	1.2	1.9	2.3	2.5	3.0	9.0	12.2	32.5	104.4	217.0
GMSK (BT_s=0.5)	1.0	1.2	1.6	1.9	2.1	10.8	19.3	46.8	137.4	310.0
8-PSK[1]	3.6	4.8	5.6	6.8	8.8	3.0	4.8	13.4	38.4	74.0
FQPSK-B	0.9	1.1	1.4	1.7	2.2	12.0	21.1	53.4	153.5	295.9
Average	**6.5**	**8.2**	**9.8**	**11.9**	**15.7**	**4.2**	**6.6**	**16.6**	**47.6**	**94.4**

Primary…Contd

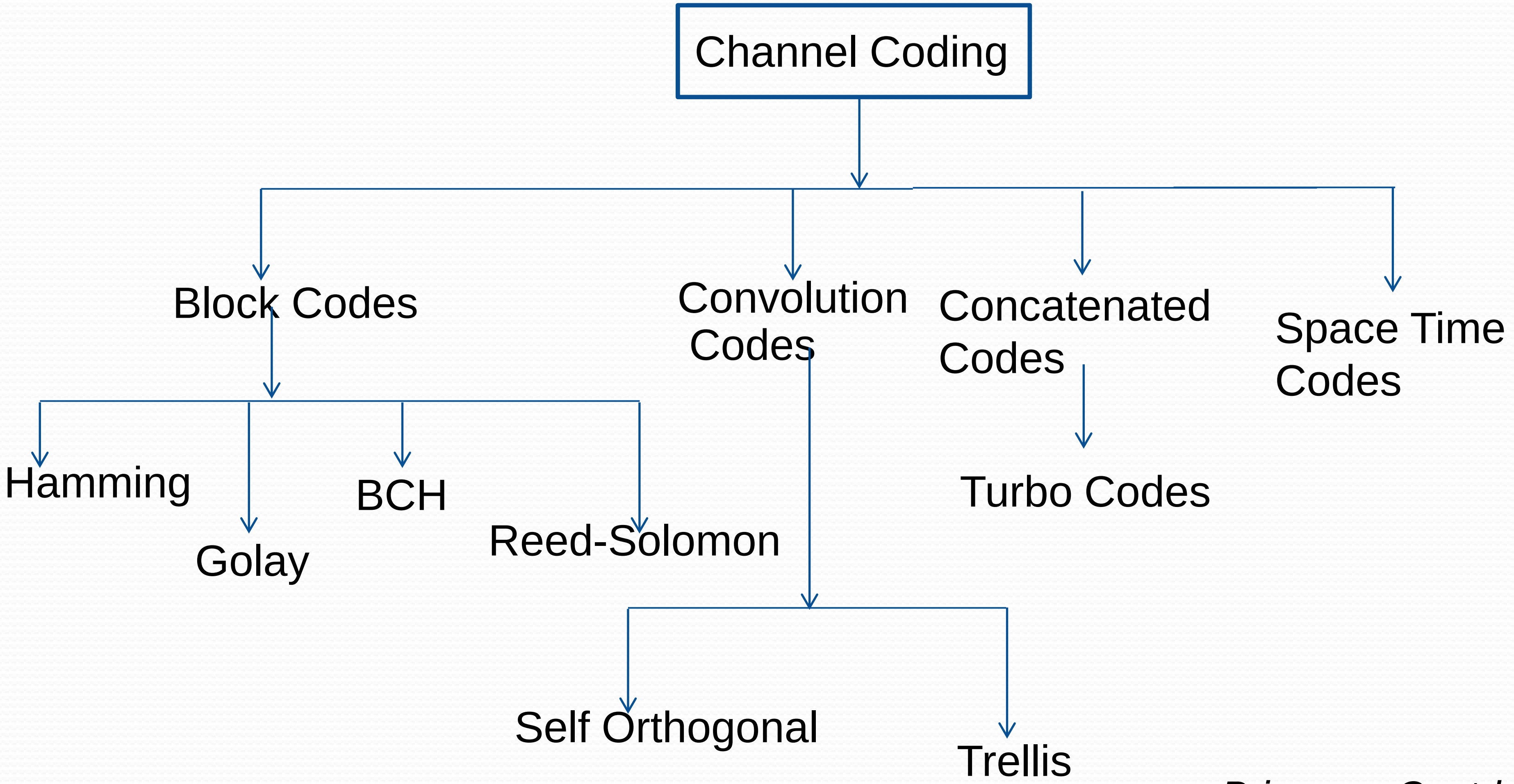
Four classes of Fading



Source: Communication Systems, by S. Haykin,

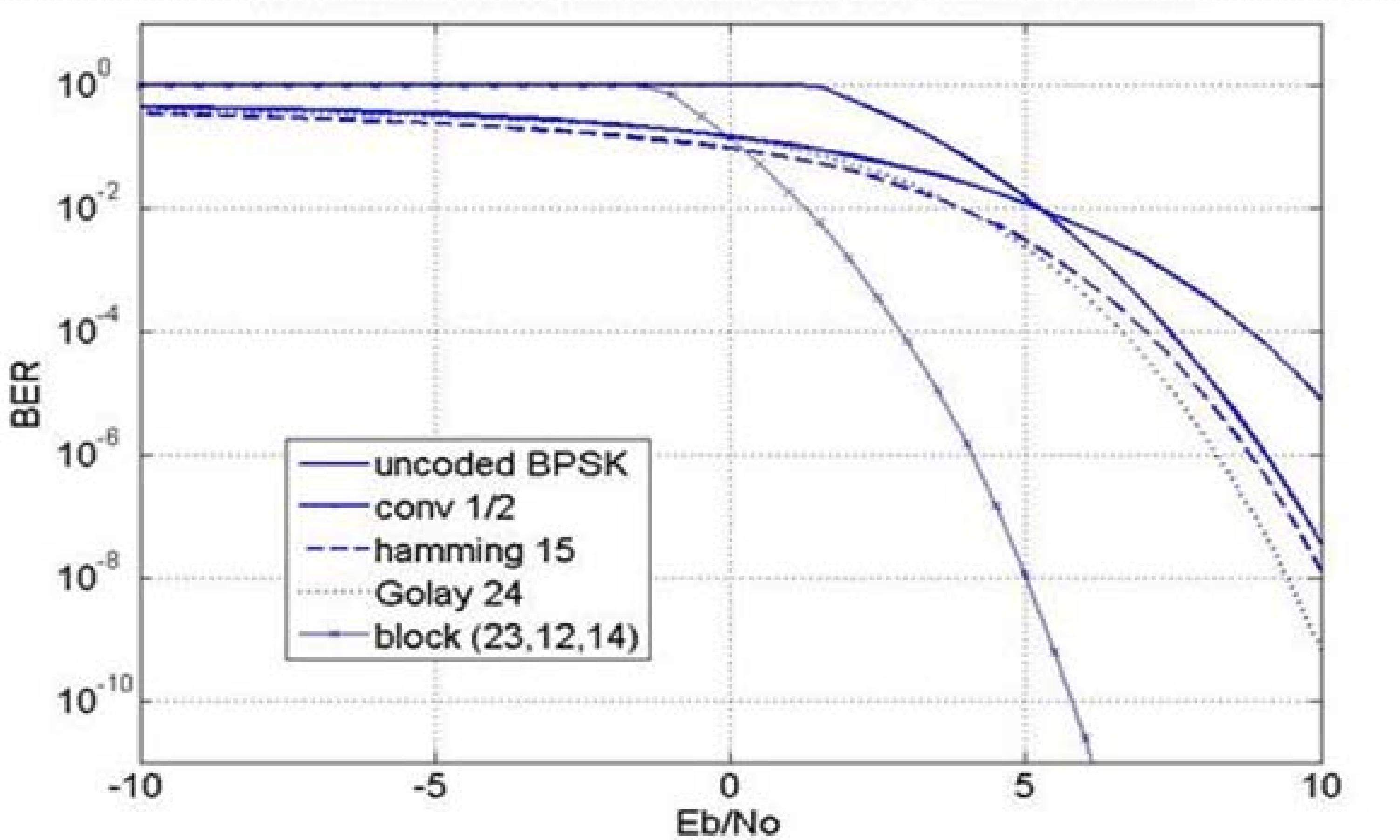
Primary…Contd

Classification Channel Coding



Primary…Contd

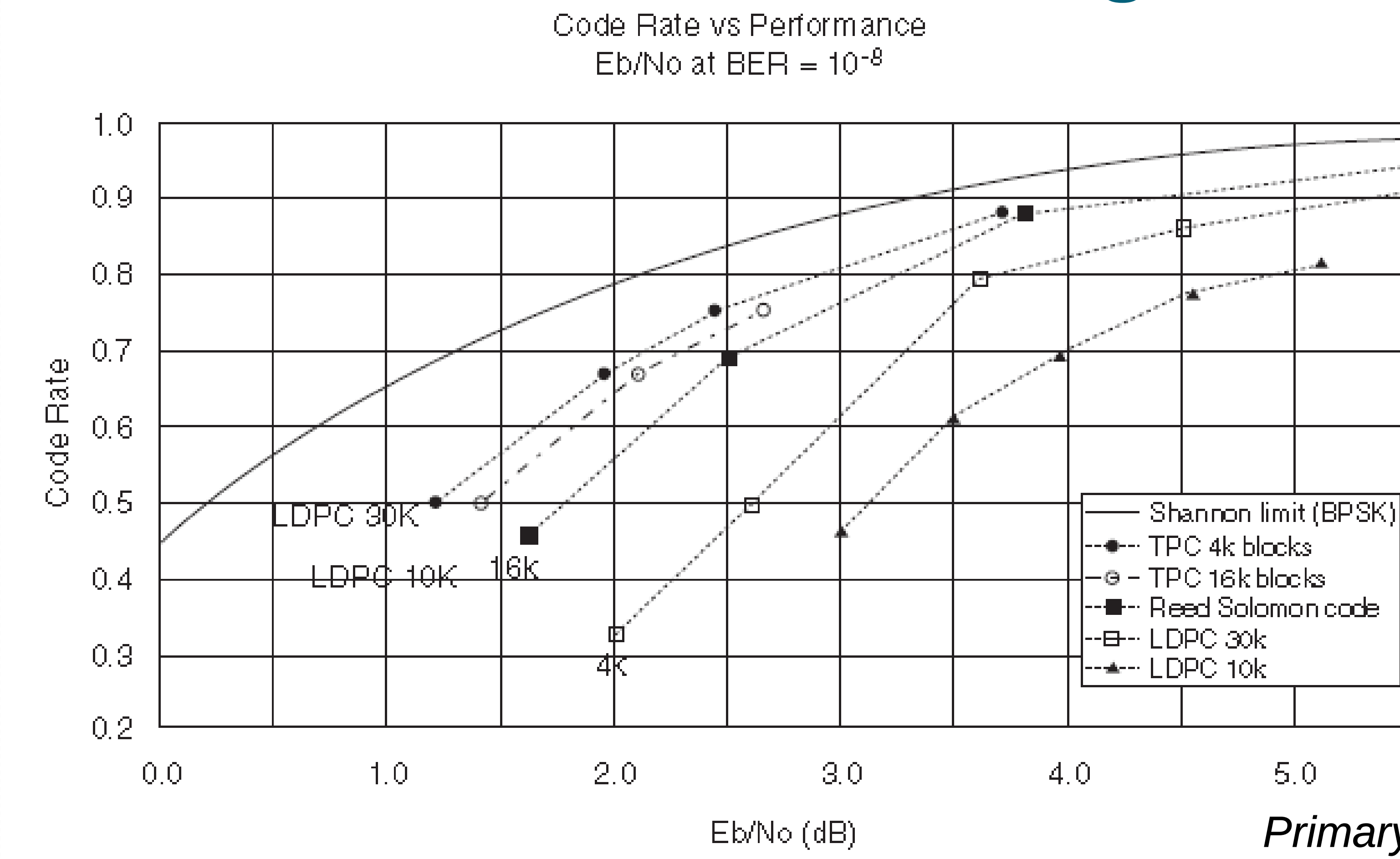
Performance of different Codes



Source: Evaluation of the statistical characteristic s of the signal fading in satellite radio links, A. E. Millán, E.V. Vivas, V. M. Shakhparonov.

Primary…Contd

Performance LDPC with TPC and other Coding Schemes

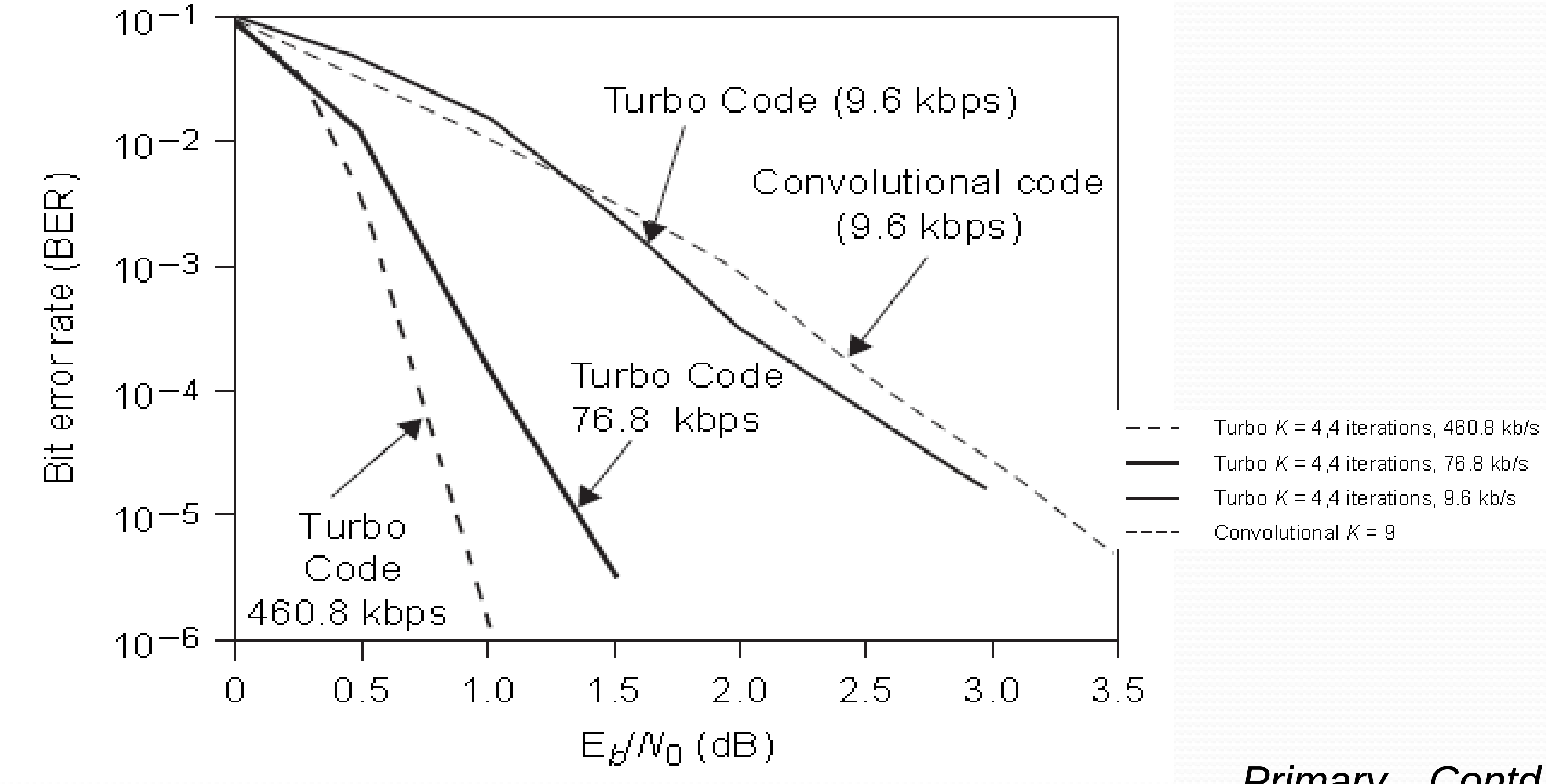


Turbo product codes

Primary…Contd

Source: Wireless & Cellular Telecommunications, by W.C.Y.Lee

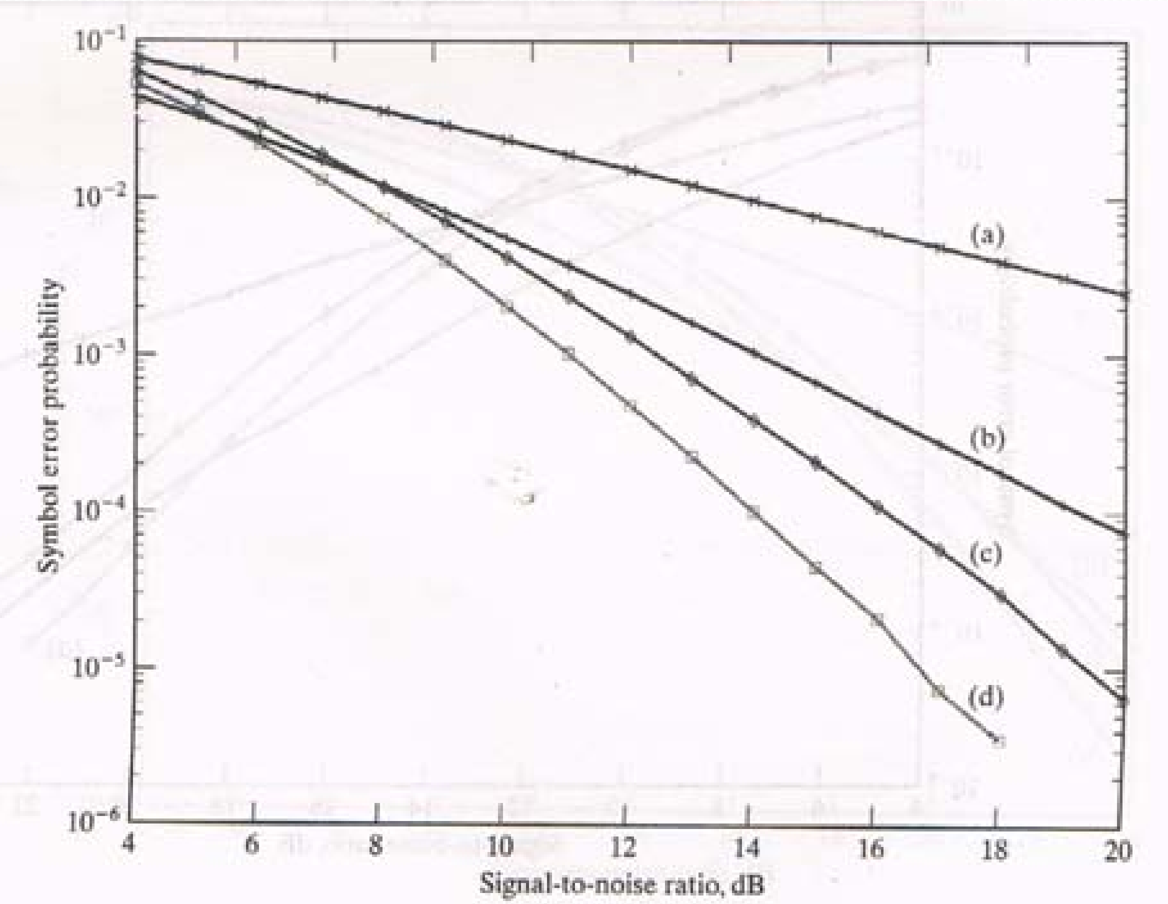
Performance Turbo codes with convolution code



Source: Wireless & Cellular Telecommunications, by W.C.Y.Lee

Primary…Contd

Performance of Space-time codes

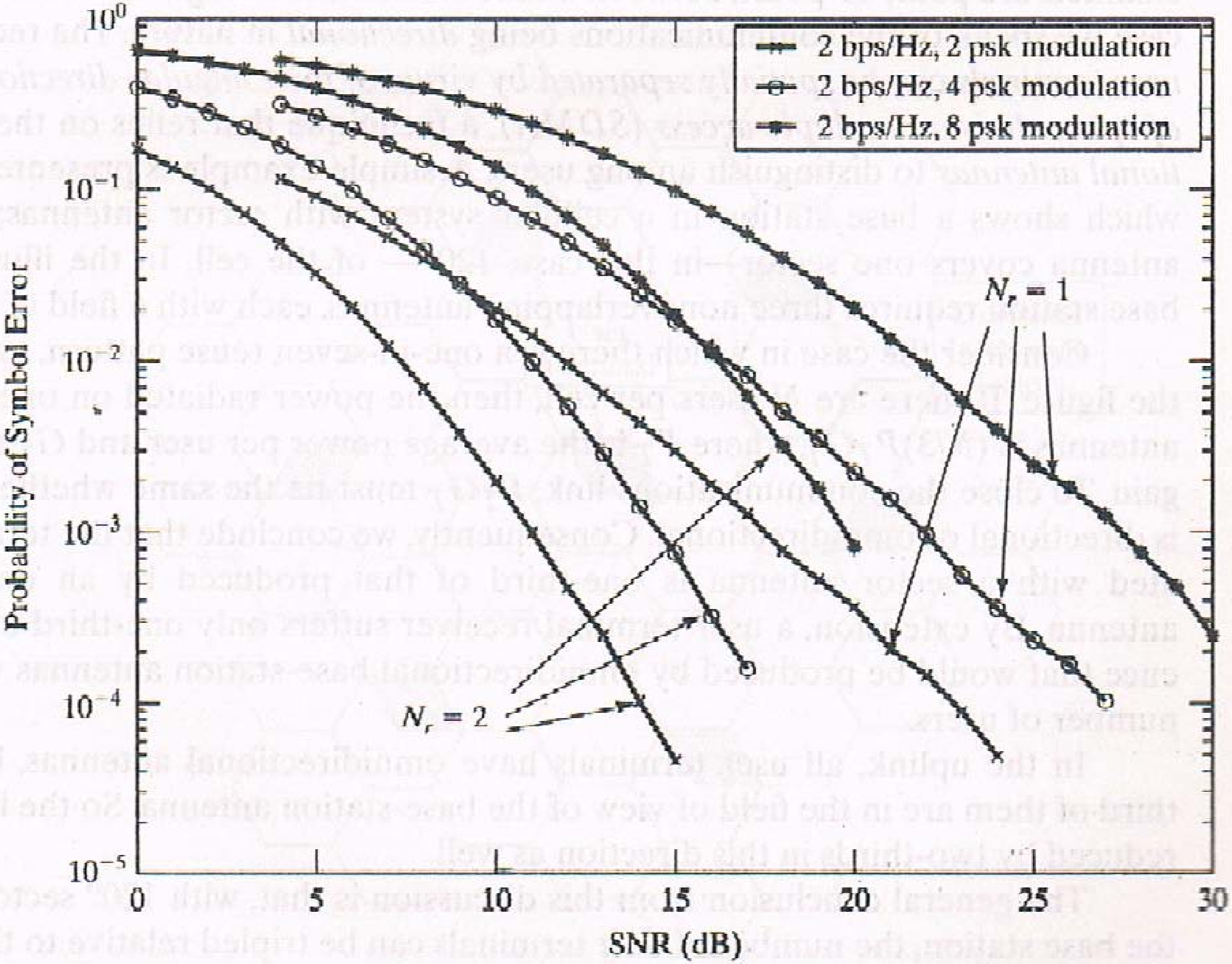


(a) No space-time coding.
(b) Alamouti code (binary PSK).
(c) Generalized code $\mathbf{G}_3$ (QPSK).
(d) Generalized code $\mathbf{G}_4$ (QPSK).

Source: Modern Wireless Communications, by S. Haykin, M. Moher

Primary…Contd

Noise Performance of Space-time codes in a Rayleigh-fading environment



Primary…Contd

Source: Modern Wireless Communications, by S. Haykin, M. Moher

Application of Turbo code

Application	turbo code	termination	polynomials	rates
CCSDS (deep space)	binary, 16-state	tail bits	23, 33, 25, 37	1/6, 1/4, 1/3, 1/2
UMTS, CDMA2000 (3G Mobile)	binary, 8-state	tail bits	13, 15, 17	1/4, 1/3, 1/2
DVB-RCS (Return Channel over Satellite)	duo-binary, 8-state	circular	15, 13	1/3 up to 6/7
DVB-RCT (Return Channel over Terrestial)	duo-binary, 8-state	circular	15, 13	1/2, 3/4
Inmarsat (Aero-H)	binary, 16-state	no	23, 35	1/2
Eutelsat (Skyplex)	duo-binary, 8-state	circular	15, 13	4/5, 6/7
IEEE 802.16 (WiMAX)	duo-binary, 8-state	circular	15, 13	1/2 up to 7/8

Notes:

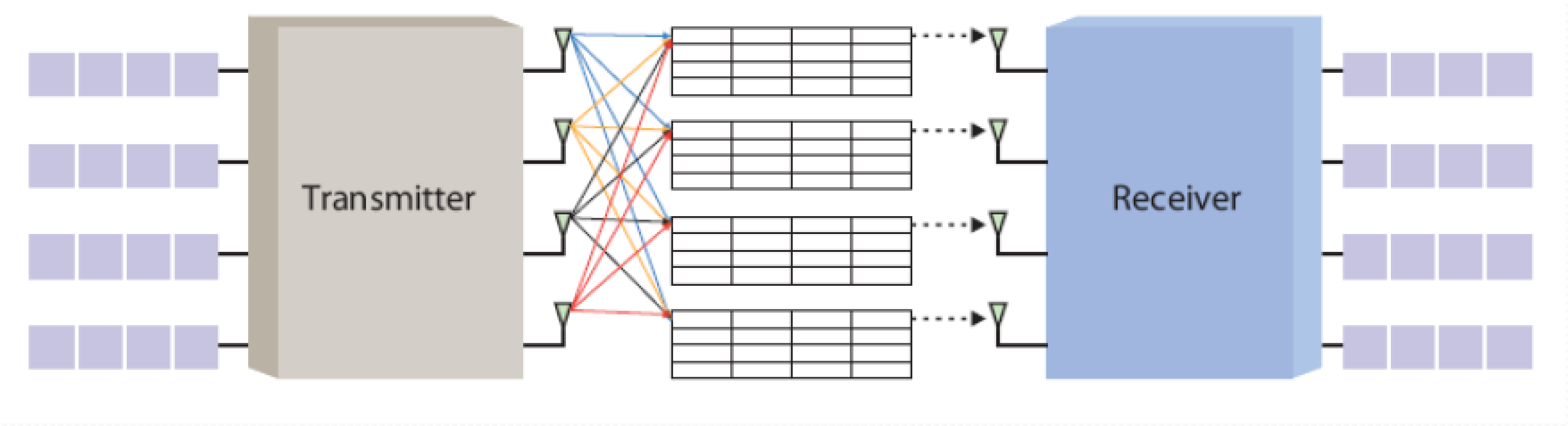
1) "duo-binary" refers to a turbo code with rate-2/3 constituent codes;
2) "termination" refers to the method of forcing the encoder back to a known state following encoding;
3) polynomials, given in octal notation, specify encoder connections.

(Courtesy of C. Berrou)

Source Forney, G.D.; Costello, D.J.; , "Channel Coding: The Road to Channel Capacity," *Proceedings of the IEEE* , vol.95, no.6, pp.1150-1177, June 2007. doi: 10.1109/JPROC.2007.895188

MIMO

MIMO (Multiple Input Multiple Output) works by dividing the data flow into multiple unique flows, and transmits them in the same radio channel at the same time. They will be merged using an algorithm or special signal processing. It consists on the use of multiple antennas in both the receiver and the transmitter in order to use the multipath effects, which reduces the interference and leads to high transmission rates. MIMO is probably the most important feature of LTE for improving the data bit rates and the spectral efficiency.



MIMO Block

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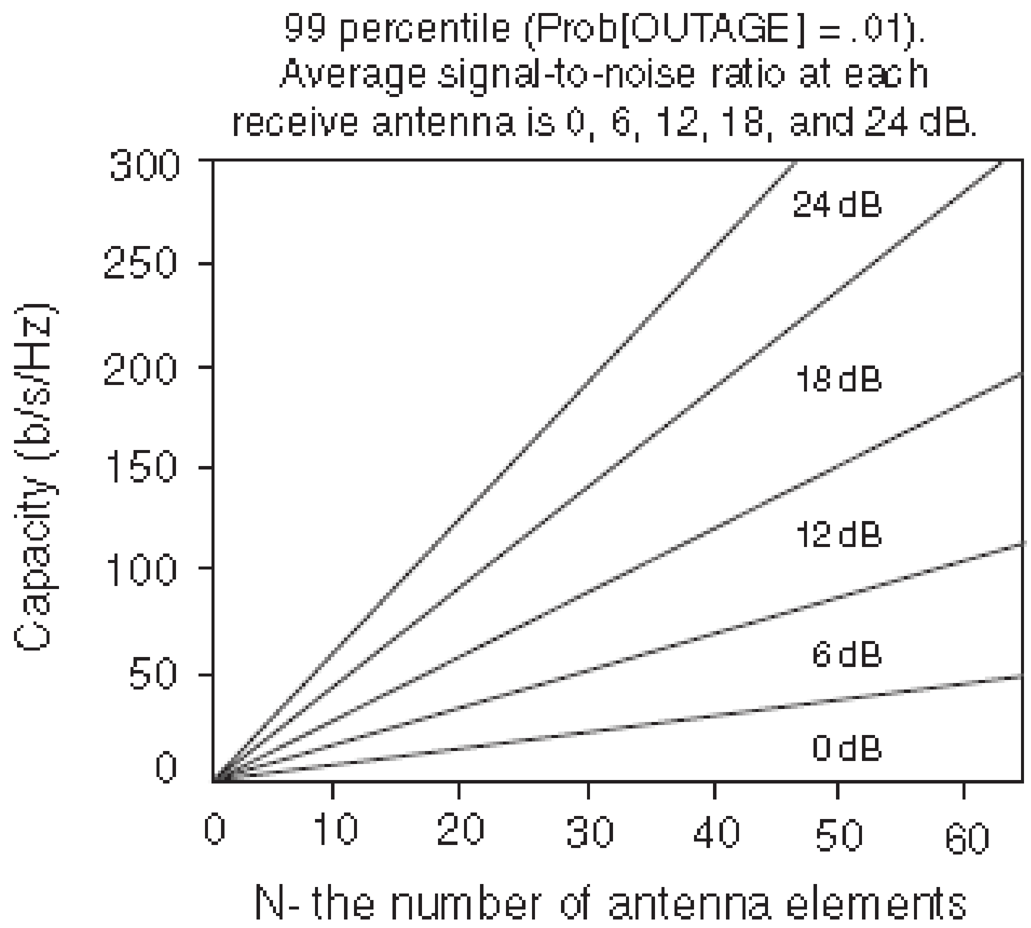
Capacity Vs No. Antenna elements



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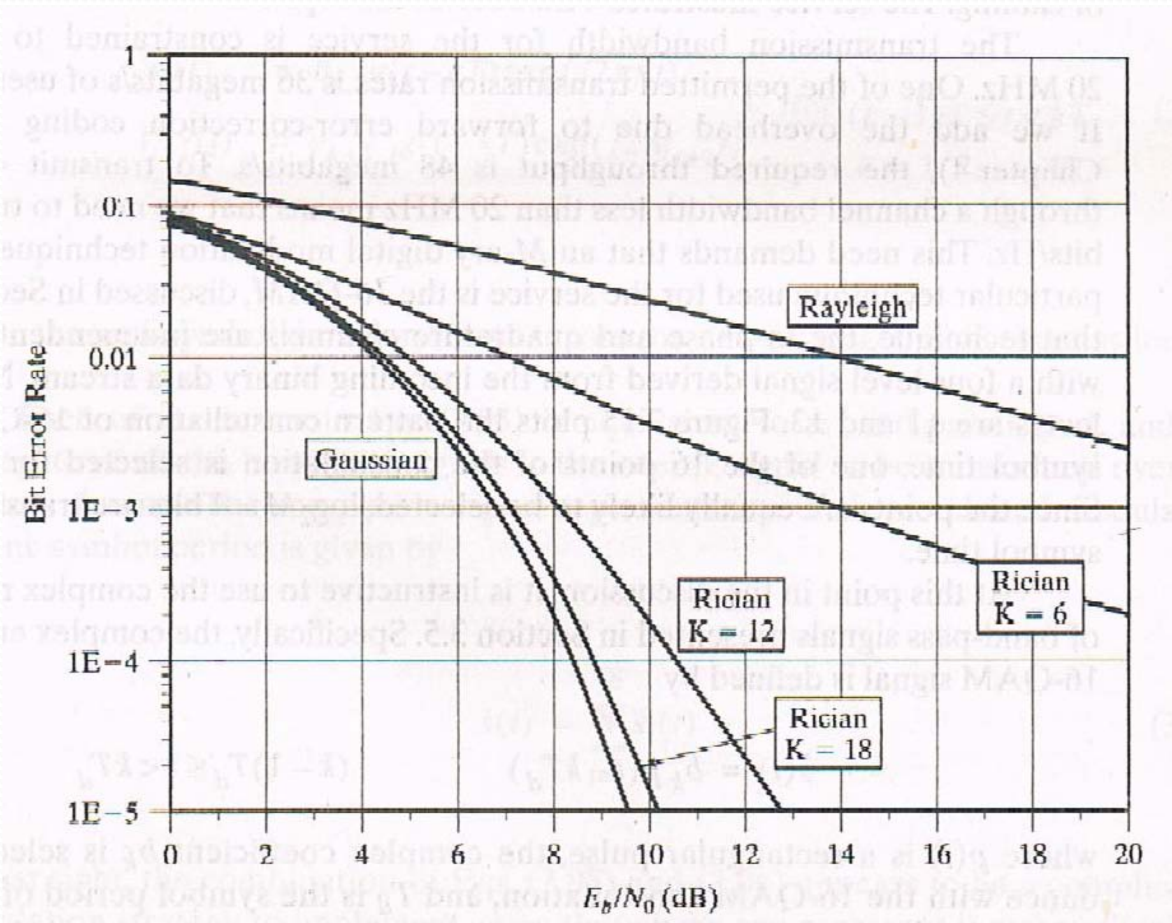
Source: Wireless & Cellular Telecommunications, by W.C.Y.Lee

Performance of coherently-detected BPSK over different fading channel



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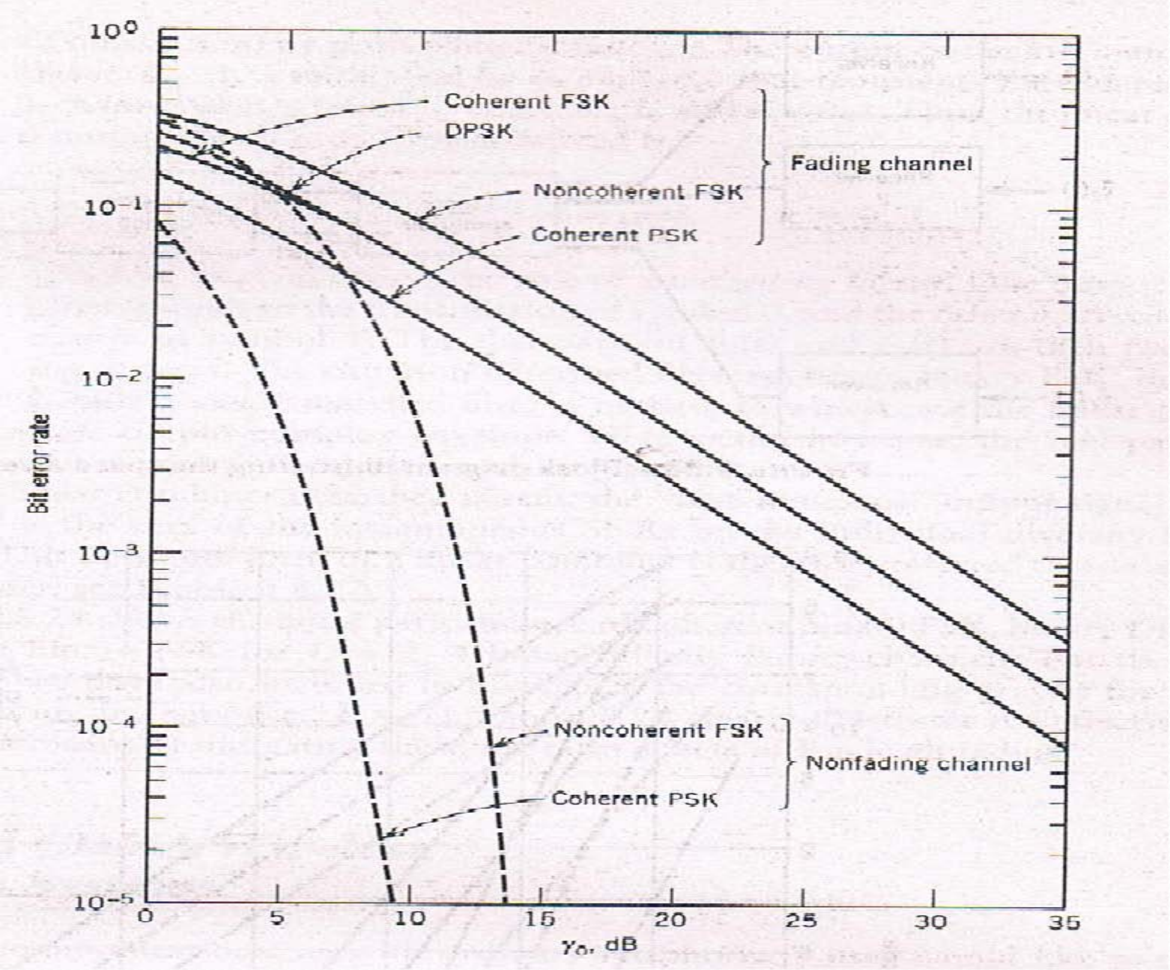
Source: Modern Wireless Communications, by S. Haykin, M. Moher

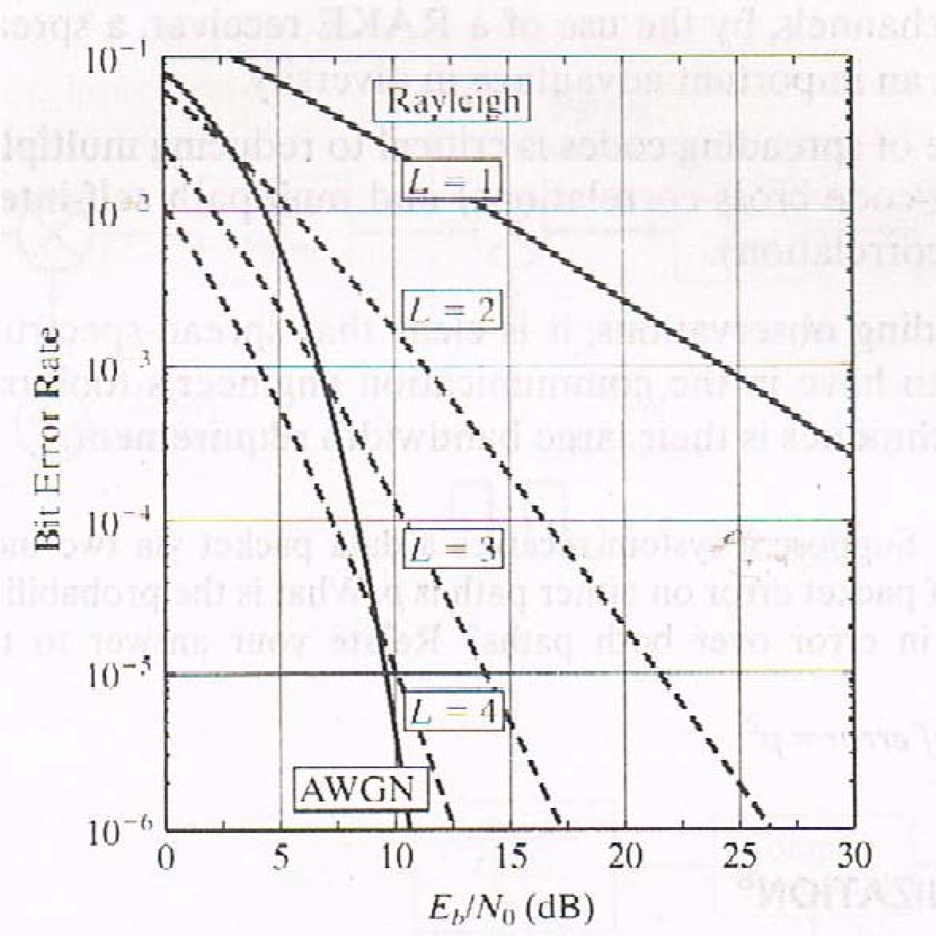
Performance of binary signal scheme over Rayleigh fading channel



Source: Communication Systems, by S. Haykin,

Primary…Contd

…Primary…Contd Performance in AWGN with that of Rayleigh fading with different diversity orders



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Source: Modern Wireless Communications, by S. Haykin, M. Moher

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Multiple Access

- Requirement of Multiple Access techniques
  - Ability to handle several users without mutual interference.
  - Ability to be able to maximize the spectrum efficiency
  - Must be robust, enabling ease of handover between cells.

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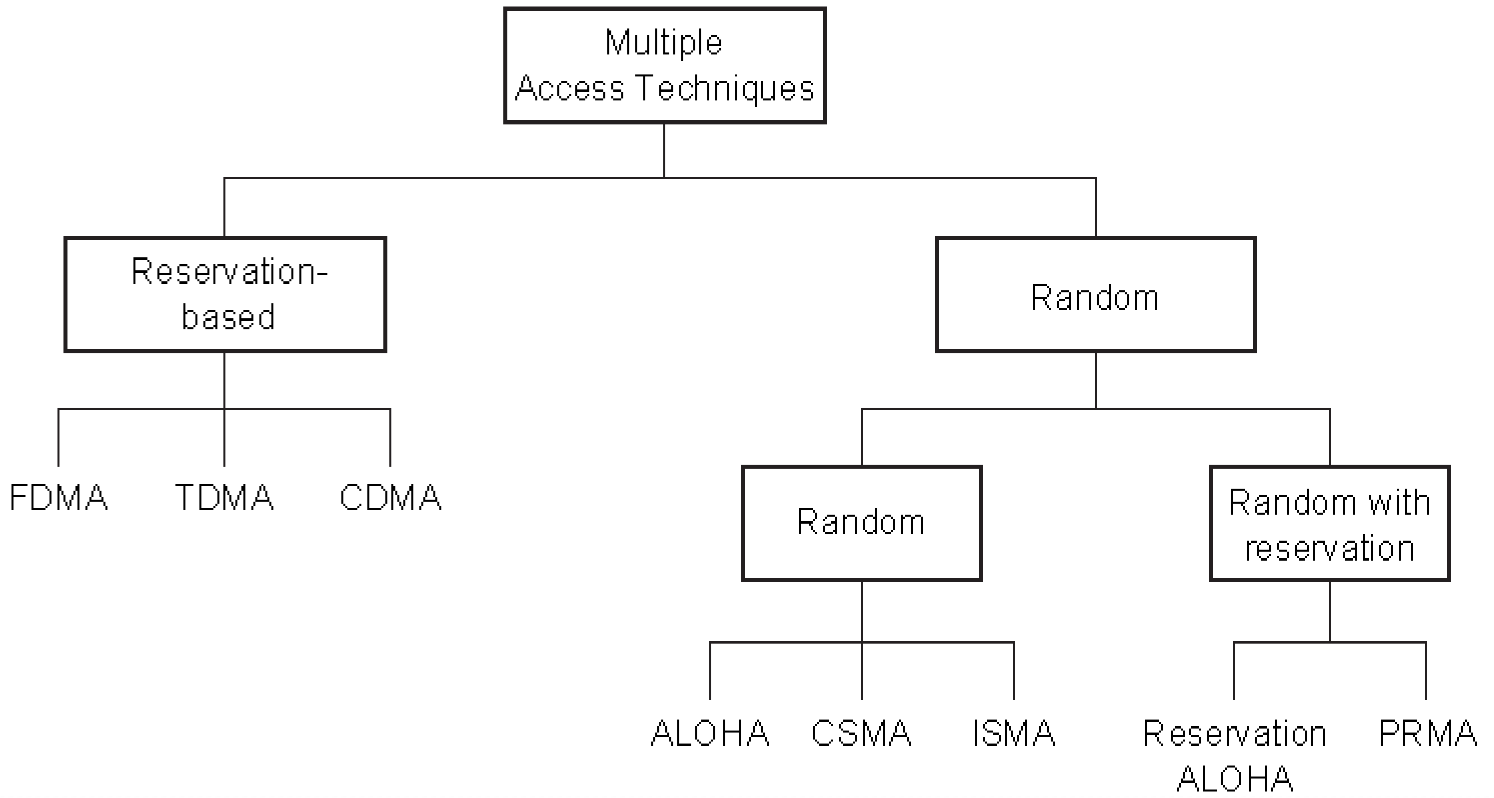
Multiple Access Classification



Primary…Contd

Multiple Access

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- Multiple Access techniques
  1. FDMA – Available BW subdivided in smaller band and assigned to users exclusively. Guard band wastage and bulky filters.
  2. TDMA – An imaginary time frame subdivided into smaller Time Slots and assigned to users exlusivley. Every user uses full BW. Problem of time Synchronization. Advantage of Digital Technology.

…Primary…Contd

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Multiple Access

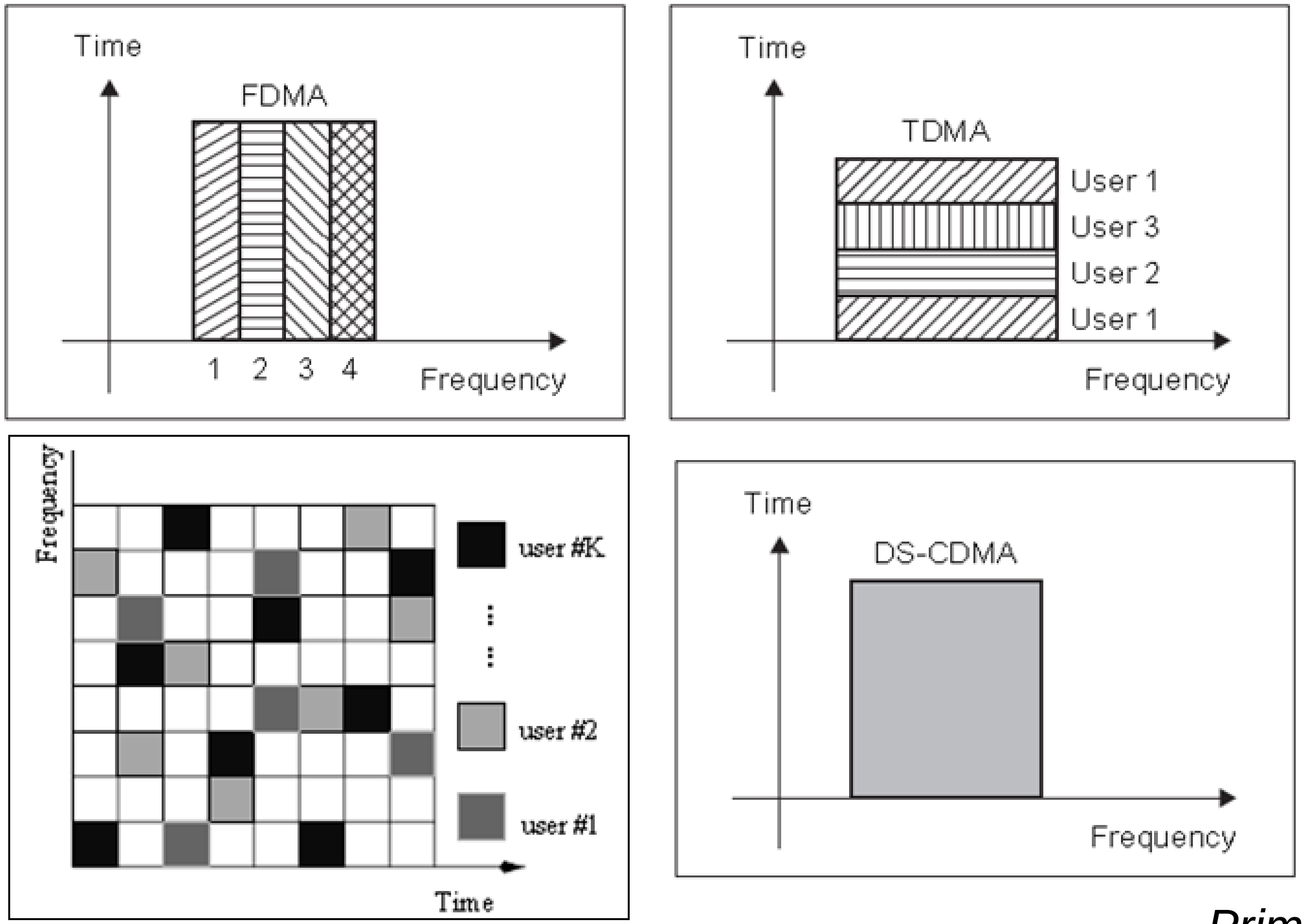
CDMA – Every user assigned a unique binary code like 01100111…. Which occupies the whole time slot as well as Whole BW. Implementation some what complex. Better channel utilization.

Codes – Maximal PNS, Gold, Walsh used popularly.

OFDMA – Each user uses multiple carriers with smaller BW. So it is multi-carrier technique. Different users assigned different combinations of multiple carriers. Useful in frequency selective fading channels.

Primary…Contd

FDMA/TDMA/CDMA



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FDMA/TDMA/CDMA

	FDMA	TDMA	CDMA	SDMA
Modulation	Relies on BW efficient modulation	Relies on BW efficient modulation	Simple modulation	transparent
FEC	Increase power efficiency at expense of BW efficiency	Increase power efficiency at expense of BW efficiency	Can be implemented without affecting BW efficiency	transparent
Source Coding	Improve efficiency	Improve efficiency	Improves efficiency, voice activation advantage	Transparent
Diversity	Requires multiple transmitters & receivers	Requires multiple transmitters & receivers Can be frequency hopped	Includes frequency diversity when implemented with a RAKE receiver	Single antenna reduce space diversity, Orthogonal coding improves diversity with multiple antennas
User terminal Complexity	Simple	Medium complexity	More complex	Requires smart antenna
Handover	Hard	Hard	Soft	Potentially soft
System Complexity	Large no. of simple components	Reduce no. of channel units	Large no. of complex interacting components	Additional complexity related to antenna

Primary…Contd

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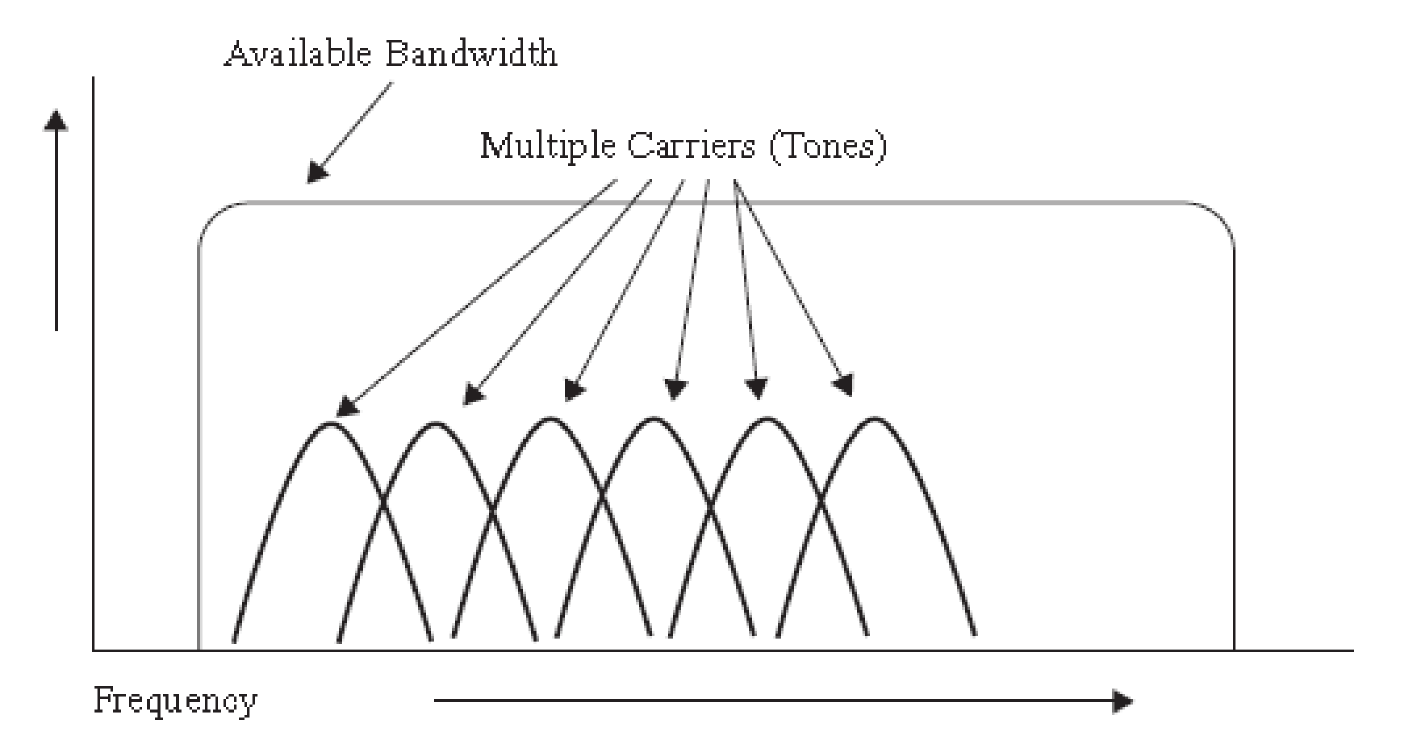
FDMA/TDMA/CDMA

	FDMA	TDMA	CDMA	SDMA
Multiple-access interference	Limited by system planning	Limited by system planning	Dynamic power control	Limited by resolution of antenna
Fading	Flat-fading No diversity Simple to track	May be frequency selective May need equalizer	Frequency-selective diversity via RAKE receiver	Reduced multipath
BW efficiency	Hard limits Based on modulation & channel spacing	Hard limits Based on modulation & channel spacing	Soft limit	Depends on antenna resolution
Synchronization	Low resolution	Mid-resolution	High resolution	Requires terminal location
Flexibility	Fixed data rate	Data rate variable in discrete steps	Can provide a variety of data rate without affecting signal in space	transparent
Voice and Data Integration	Possible, but may requires revision of system	Straightforward using multiple slots	Multicode transmission	Transparent
Evolution	BW to fit application	Requires medium initial BW	Require large initial BW	Flexible can be added as needed

Source: Modern Wireless Communications, by S. Haykin, M. Moher

Primary…Contd

OFDM



Primary…Contd

Source: Wireless & Cellular Telecommunications, by W.C.Y.Lee

Major OFDM PHY Parameter

Information Data Rate	6, 9, 12, 18, 24, 36, 48, and 54 Mbit/s (6, 12 and 24 Mbit/s Are Mandatory)
Modulation	BPSK OFDM QPSK OFDM 16-QAM OFDM 64-QAM OFDM
Error correcting code	K = 7 (64 states) convolutional code
Coding rate	1/2, 2/3, 3/4
Number of subcarriers	52
OFDM symbol duration	4.0 μs
Guard interval	0.8 μs (T_{GI})
Occupied bandwidth	16.6 MHz

Primary…Contd

Source: Wireless & Cellular Telecommunications, by W.C.Y.Lee

OFDMA

- Orthogonal Frequency Division Multiple Access
- OFDMA = Orthogonal Frequency Division Multiplexing (OFDM) plus statistical multiplexing
  - Optimization of time, frequency and code multiplexing
- Already deployed in 802.11a & 802.11g WiFi
  - Ups WiFi from 11 Mbps to 54 Mbps & beyond

Primary…Contd

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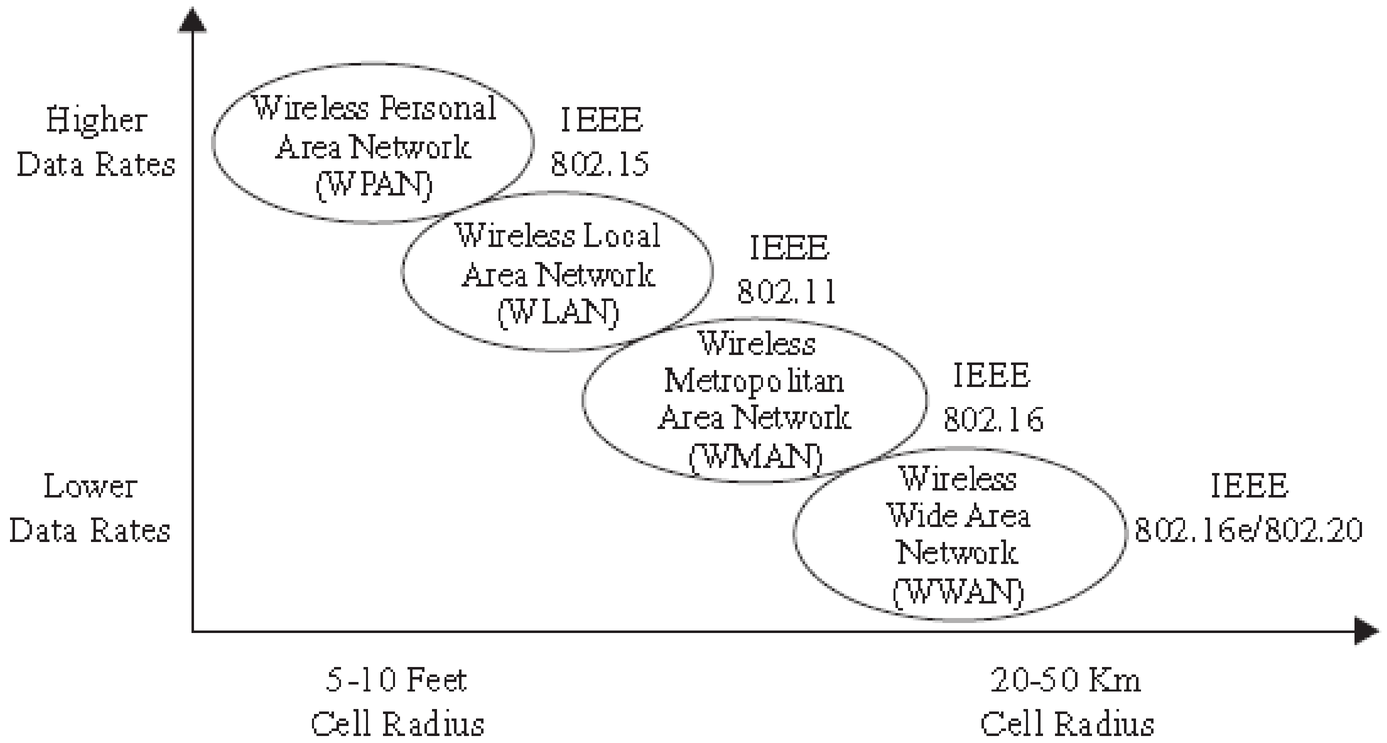
OFDM Advantages	CDMA Advantage
OFDM can combat multipath interference with greater robustness and less complexity. Equalisation can be undertaken on a carrier by carrier basis. OFDMA can achieve higher spectral efficiency with MIMO than CDMA using a RAKE receiver. Cell breathing does not occur as additional users connect to the base station. Can be used to provide a single frequency network. It is relatively easy to aggregate spectrum. It can be scaled according to the requirements relatively easily	Not as complicated to implement as OFDM based systems As CDMA has a wide bandwidth, it is difficult to equalise the overall spectrum - significant levels of processing would be needed for this as it consists of a continuous signal and not discrete carriers. Not as easy to aggregate spectrum as for OFDM

WIRELESS DATA COMMUNICATION

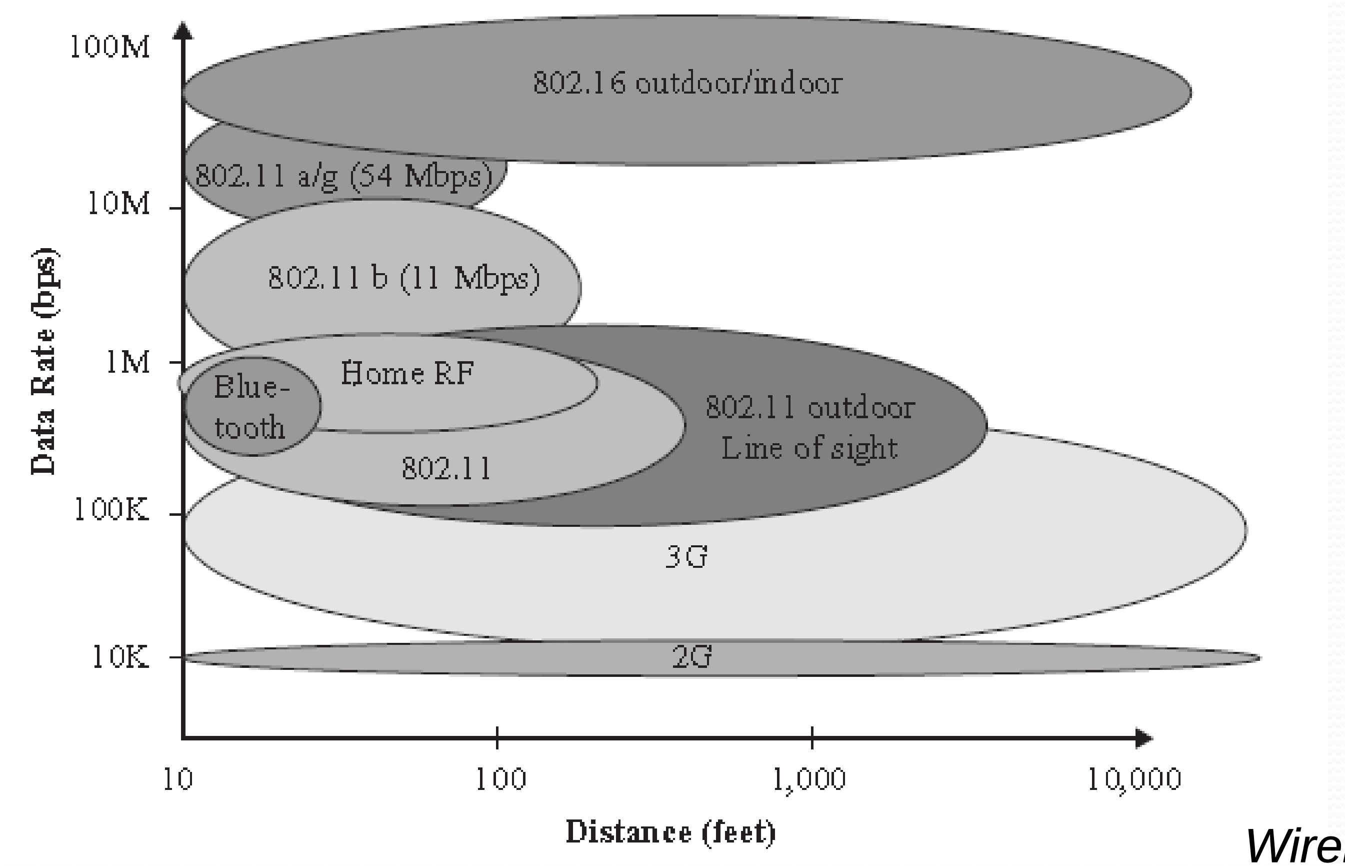


IEEE Wireless Standards

Wireless…Contd

Source: Wireless & Cellular Telecommunications, by W.C.Y.Lee

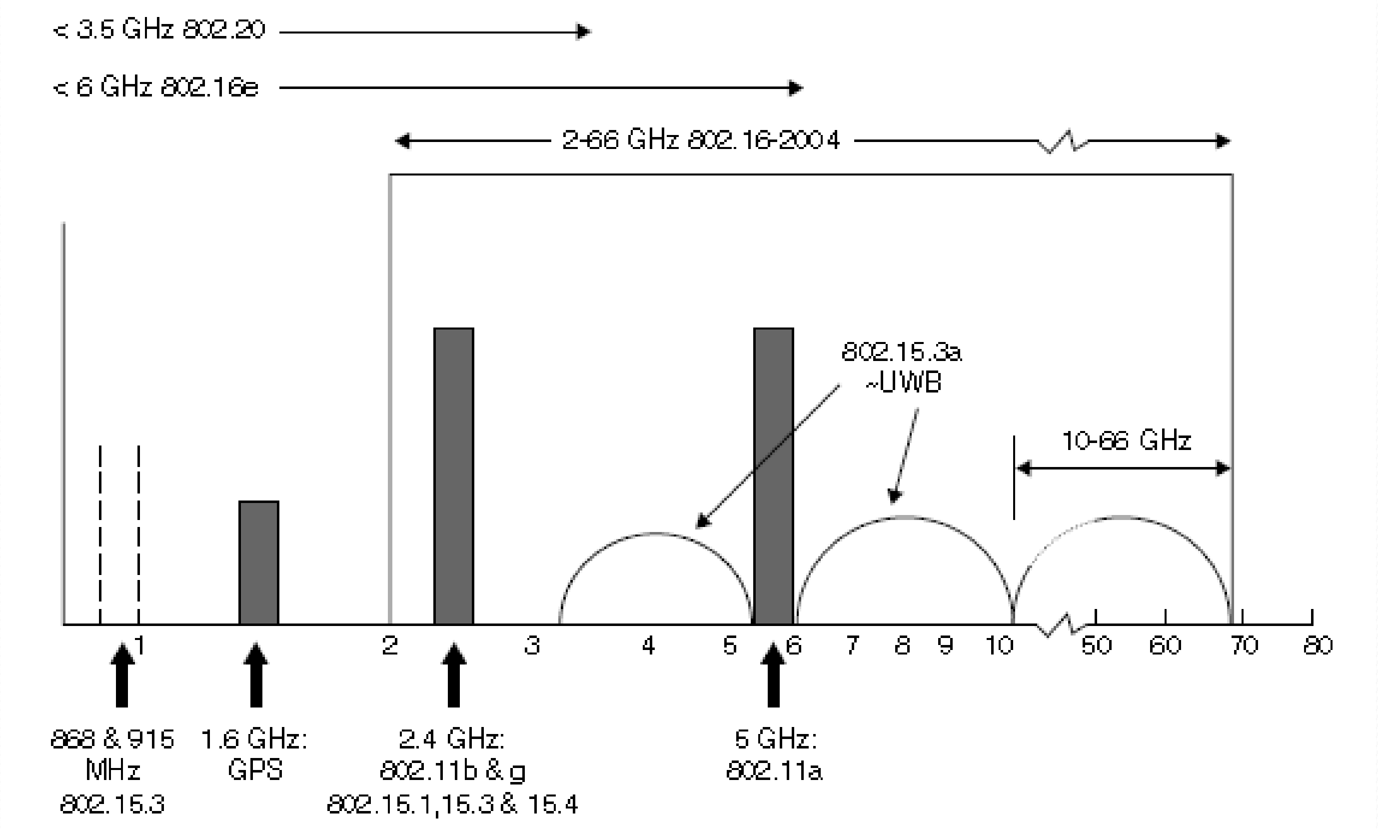
Wireless Tech. Comparison



Wireless…Contd

Source: Wireless & Cellular Telecommunications, by W.C.Y.Lee

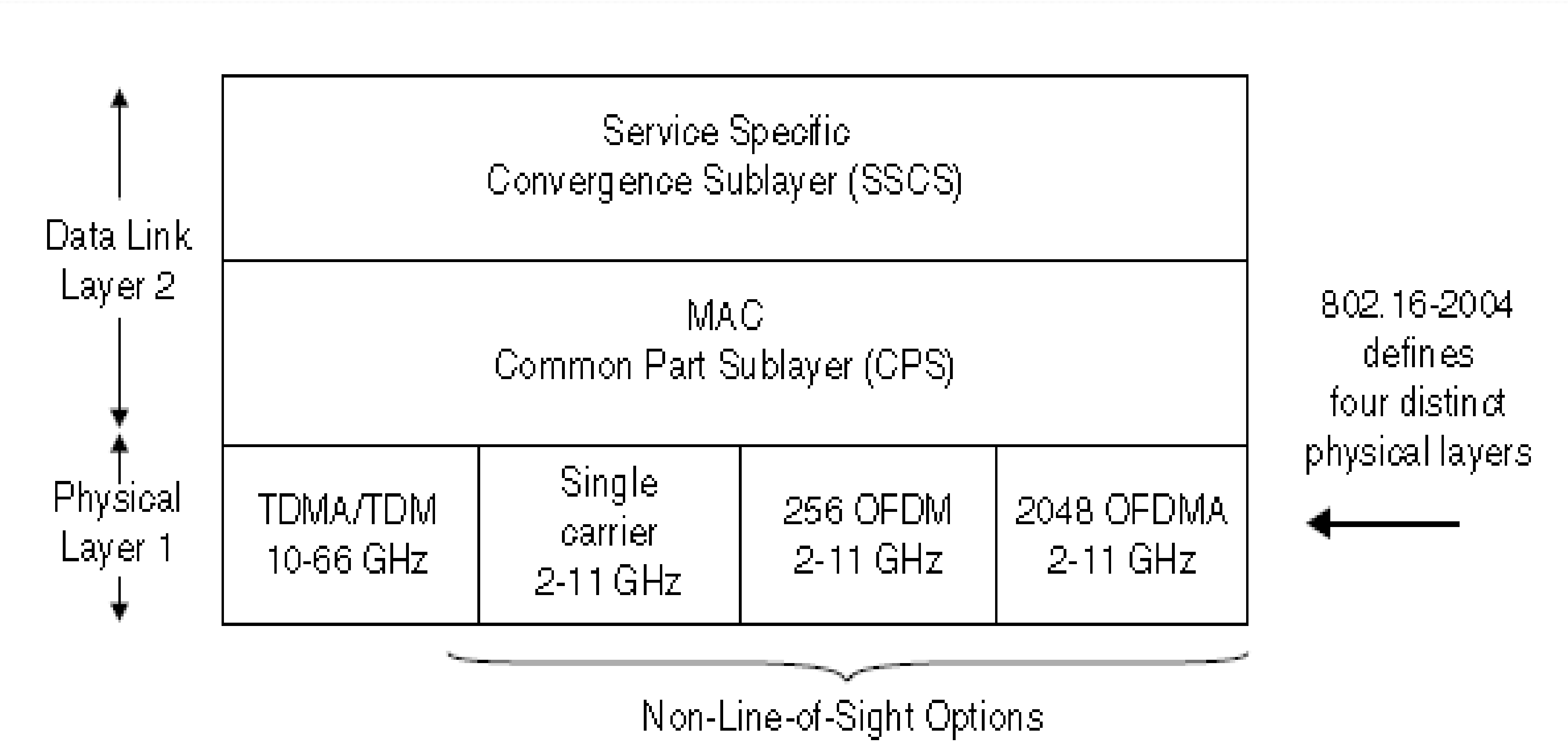
IEEE wireless standards operating frequencies



Wireless…Contd

Source: Wireless & Cellular Telecommunications, by W.C.Y.Lee

802.16-2004 reference model



Wireless…Contd

Source: Wireless & Cellular Telecommunications, by W.C.Y.Lee

…Wireless…contd

Wireless Data Technology	Channel BW	Duplex	Data Rate
HSCSD	200 KHz	FDD	57.6 Kbps
GPRS	200 KHz	FDD	171.2 Kbps (21.4 Kbps /channel)
EDGE	200 KHz	FDD	384 Kbps
W-CDMA	5 MHz	FDD	2 Mbps
IS-95B	1.25 MHz	FDD	64 Kbps
Cdma2000	1.25 MHz	FDD	307 Kbps
Bluetooth	1 MHz		1 Mbps
Wi-Fi	20 MHz	FDD	11 & 54 Mbps
UWB	> 500 MHz		100-500 Mbps
WIMAX	10 MHz		75 Mbps

Source: Wireless Communications by T.S. Rappaport

…Wireless…Contd

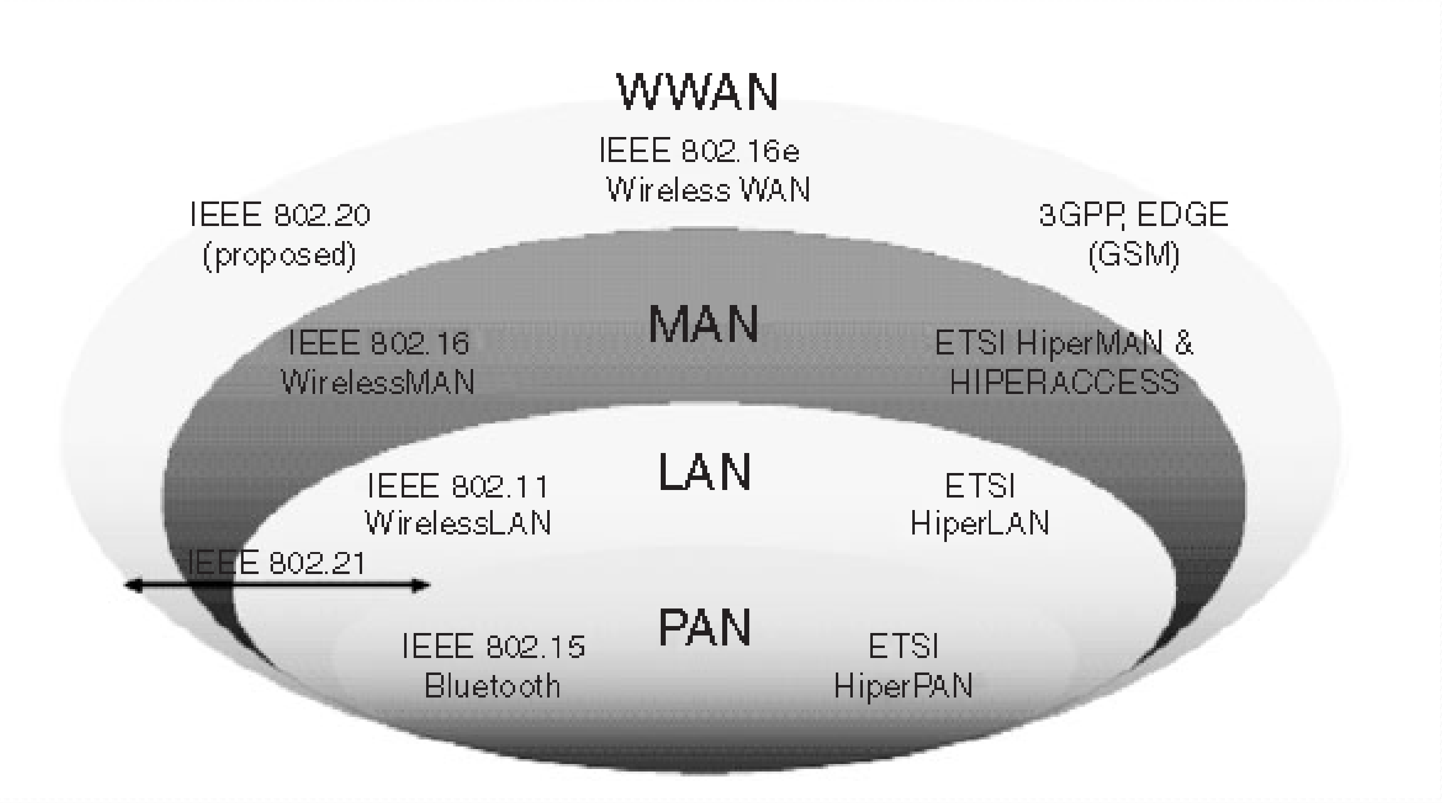
IEEE 802.11 a Physical layer specification

Modulation Scheme	FEC coding	Coding bits per subcarrier	Codes bits per OFDM symbol	Data bit per OFDM symbol	Data rate
BPSK	½	1	48	24	6 Mbps
BPSK	¾	1	48	36	9 Mbps
QPSK	½	2	96	48	12 Mbps
QPSK	¾	2	96	72	18 Mbps
16-QAM	½	4	192	96	24 Mbps
16-QAM	¾	4	192	144	36 Mbps
64-QAM	2/3	6	288	192	48 Mbps
64-QAM	3/4	6	288	216	54 Mbps

Source: Wireless Communications by T.. L. Singal

Wireless…Contd

IEEE standards



Source: Wireless & Cellular Telecommunications, by W.C.Y.Lee

…Wireless…Contd

Comparison of all 802.11 standards

Standard	802.11b	802.11a	802.11g	802.11n
Transmission technique	DSSS	OFDM	OFDM	Probably OFDM
Channel BW	22 MHz	20 MHz	22 MHz	17- 20 MHz
Data rates	1 or 2 Mbps Barker codes, 5.5 or 11 Mbps complementary code keying	6, 9,12, 18, 24, 36, 48 and 54 Mbps	1, 2, 5.5, 11 Mbps DSSS and 6, 9, 12, 18, 24, 36, 48, 54 Mbps OFDM	Upto 100 Mbps
Channel spacing	25 MHz	20 MHz	20 MHz	Not determined
Frequency Band	2.4 GHz	5.8 GHz	2.4 GHz	5.8 GHz
Short preamble	Optional	N/A	N/A	Not determined

Wireless…Contd

Source: Wireless & Cellular Telecommunications, by W.C.Y.Lee

Throughput Comparison

Technology	Data rate (Mbps)	Approximate Throughput (Mbps)
802.11b	11	6
802.11g w 802.11b client using RTS/CTS protection	54	8
802.11g w 802.11b clients using CTS-to-self protection	54	12
802.11g w no 802.11b clients	54	22
802.11a	54	26

Source: Wireless & Cellular Telecommunications, by W.C.Y.Lee

FUTURE

- Future technology
    - World Wide Microwave Interoperability for Microwave Access (WiMAX)
    - Long Term Evolution –Advance (LTE-A)

Fut…Contd…

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WiMAX

Generation	4G
Physical layer	DL-OFDMA, UL-OFDMA
Duplex Mode	TDD & FDD
User Mobility	upto 350 Kmph
Coverage	50 Km
Channel Bandwidth	5, 10, 20, 40 MHz
Peak data Rate	DL > 350 Mbps(4X4 antenna), UL > 200 Mbps (2X4 antenna) At 20 MHz FDD
Spectral efficiency	DL > 2.6 bps/ Hz (2x2), UL > 1.3 bps/ Hz (1X2)
Latency	Link Layer < 10ms, Handoff < 30 ms
VoIP capacity other quality	> 30 users per sector/ MHz (FDD), 3G compatible

Fut…Contd…

LTE – A Targets

Ever increasing use of Smart Wireless Devices requires significantly Higher Spectral Resources for which it is necessary to achieve

- Peak Data Rates of 1 Gbps With Spectrum BW of 100 MHz using High Order MIMO
- Mix of New System Concepts like Coordinated Multipoint (CoMP) Transmission
- Advanced Heterogeneous Networks (HetNets), Relay and Cross-Layer Optimization
- Enhanced Cell Capacity & Larger Coverage
- LTE-A Carrier Aggregation

Fut…Contd…

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LTE-A

- LTE-A also features a mix of new system concepts, such as
  - coordinated multipoint (CoMP) transmission,
  - advanced heterogeneous networks (HetNets),
  - relay, and
  - cross-layer optimization,

with the ultimate goal of designing a system that is drastically enhanced in both cell capacity and coverage.

- Dynamic switching between single-user MIMO (SU-MIMO) and multi-user MIMO (MU-MIMO) provides a significant gain over the traditional SU-MIMO-only operation.

Fut…Contd…

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LTE & LTE-A

	LTE (3GPP Release 8)
Generation	3.9G
First release	2009
Physical layer	DL: OFDMA UL: SCFDMA
Duplex mode	time- and frequency- division duplex (TDD & FDD)
User mobility	up to 350 kmph
Coverage	up to 100 km
Channel bandwidth	1.4, 3, 5, 10, 15, 20 MHz
Peak data rates	DL: 300 Mbps (4 x 4 antennas) UL: 75 Mbps (2 x 4 antennas) at 20 MHz, FDD
Spectral efficiency	DL: 1.91 bps / Hz (2 x 2) UL: 0.72 bps / Hz (1 x 2)
Latency	Link layer: < 5 ms Handoff: < 50 ms
VoIP capacity	80 users per sector / MHz (FDD)
other qualities	Full IP-based architecture 3G compatible QoS support

	LTE-Advanced (3GPP Release 10)
Generation	4G
Expected release	2011
Physical layer	DL: OFDMA UL: SCFDMA
Duplex mode	time- and frequency division duplex (TDD & FDD)
User mobility	up to 350 kmph
Coverage	up to 100 km
Channel bandwidth	up to 100 MHz
Peak data rates	DL: 1 Gbps UL: 300 Mbps
Spectral efficiency	DL: 30 bps / Hz UL: 15 bps / Hz
Latency	Link layer: < 5 ms Handoff: < 50 ms
VoIP capacity	>80 users per sector / MHz (FDD)
other qualities	Full IP-based architecture 3G compatible QoS support

Fut…Contd…

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Technical specification

	LTE (3GPP R8)	LTE-Advanced (3GPP R10)	WiMAX 802.16e (R1.0)	WiMAX 802.16m (R2.0)
Physical layer	DL:* OFDMA† UL:* SC-FDMA‡	DL: OFDMA UL: SC-FDMA	DL: OFDMA UL: OFDMA	DL: OFDMA UL: OFDMA
Duplex mode	FDD and TDD§	FDD and TDD	TDD	FDD and TDD
User mobility	217 mph (350 km/h)	217 mph (350 km/h)	37 to 74 mph (60 to 120 km/h)	217 mph (350 km/h)
Channel bandwidth	1.4, 3, 5, 10, 15, 20 MHz	Aggregate components of Release 8	3.5, 5, 7, 8.75, 10 MHz	5, 10, 20, 40 MHz
Peak data rates	DL: 302 Mbps (4 × 4 antennae) UL: 75 Mbps (2 × 4) at 20 MHz FDD	DL: 1 Gbps UL: 300 Mbps	DL: 46 Mbps (2 × 2) UL: 4 Mbps (1 × 2) at 10 MHz TDD 3:1 (downlink/uplink ratio)	DL > 350 Mbps (4 × 4) UL > 200 Mbps (2 × 4) at 20 MHz FDD
Spectral efficiency	DL: 1.91 bps/Hz (2 × 2) UL: 0.72 bps/Hz (1 × 2)	DL: 30 bps/Hz UL: 15 bps/Hz	DL: 1.91 bps/Hz (2 × 2) UL: 0.84 bps/Hz (1 × 2)	DL > 2.6 bps/Hz (4 × 2) UL > 1.3 bps/Hz (2 × 4)
Latency	Link layer < 5 ms Handoff < 50 ms	Link layer < 5 ms Handoff < 50 ms	Link layer – 20 ms Handoff – 35 to 50 ms	Link layer < 10 ms Handoff < 30 ms
VoIP capacity	80 users per sector/ MHz (FDD)	>80 users per sector/ MHz (FDD)	20 users per sector/ MHz (TDD)	>30 users per sector/ MHz (TDD)

*Downlink/uplink, †Orthogonal frequency-division multiple access, ‡Single-carrier frequency-division multiple access, §Frequency-division duplexing and time-division duplexing

Fut…Contd…

Source: http://ComputingNow.computer.org/ITPRO

...Fut...Contd Comparison Between WIMAX & LTE

	WiMAX	LTE
Current deployment	More than 500 networks	Only 1 network
Support	IEEE and computer companies; waning support from telecommunications companies	Telecommunications companies and international standards bodies
Performance	Similar data rates, mobility support, and latency	
Special technical feature	—	Innovative SC-FDMA uplink saves battery power
Support of emerging markets	Strategy of targeting emerging markets and developing a relays standard could prove beneficial	—
Strength	Leverages wide deployment, so it could remain a 4G technology even if LTE gathers more support from now on	Benefits from the support of telecommunications companies because it evolved from previous telecommunications standards
Major benefit from IMT-Advanced proposal	Taking a chunk of the mobile market, which was typically telecommunications territory	3GPP continues to lead mobile technology in the new era of broadband services

Source: http://ComputingNow.computer.org/ITPRO

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Future Applications

- **Mobile payment : Includes m-commerce, contactless payments, m-ticketing and m-coupons.**
    - **Mobile commerce (m-commerce)**
    - **Mobile tickets (m-ticketing)**
    - **Mobile coupons (m-coupons)**
  - In Year 2015, more than 400 million people on the Indian Sub-Continent will purchase digital goods via mobile.
- Mobile Heath care
- Mobile Personal Identification
- Mobile Banking
- Mobile GPS
- Mobile video conferencing

Fut…Contd…

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- Future Technology
  - Fixed & Mobile Convergence
  - Software Defined Radio
  - Cognitive Radio
  - Context Aware Computing & Communication
  - Several Gbps Speed
  - Mobile Internet
  - Mobile TV
  - Mobile Audio and Video Conferencing

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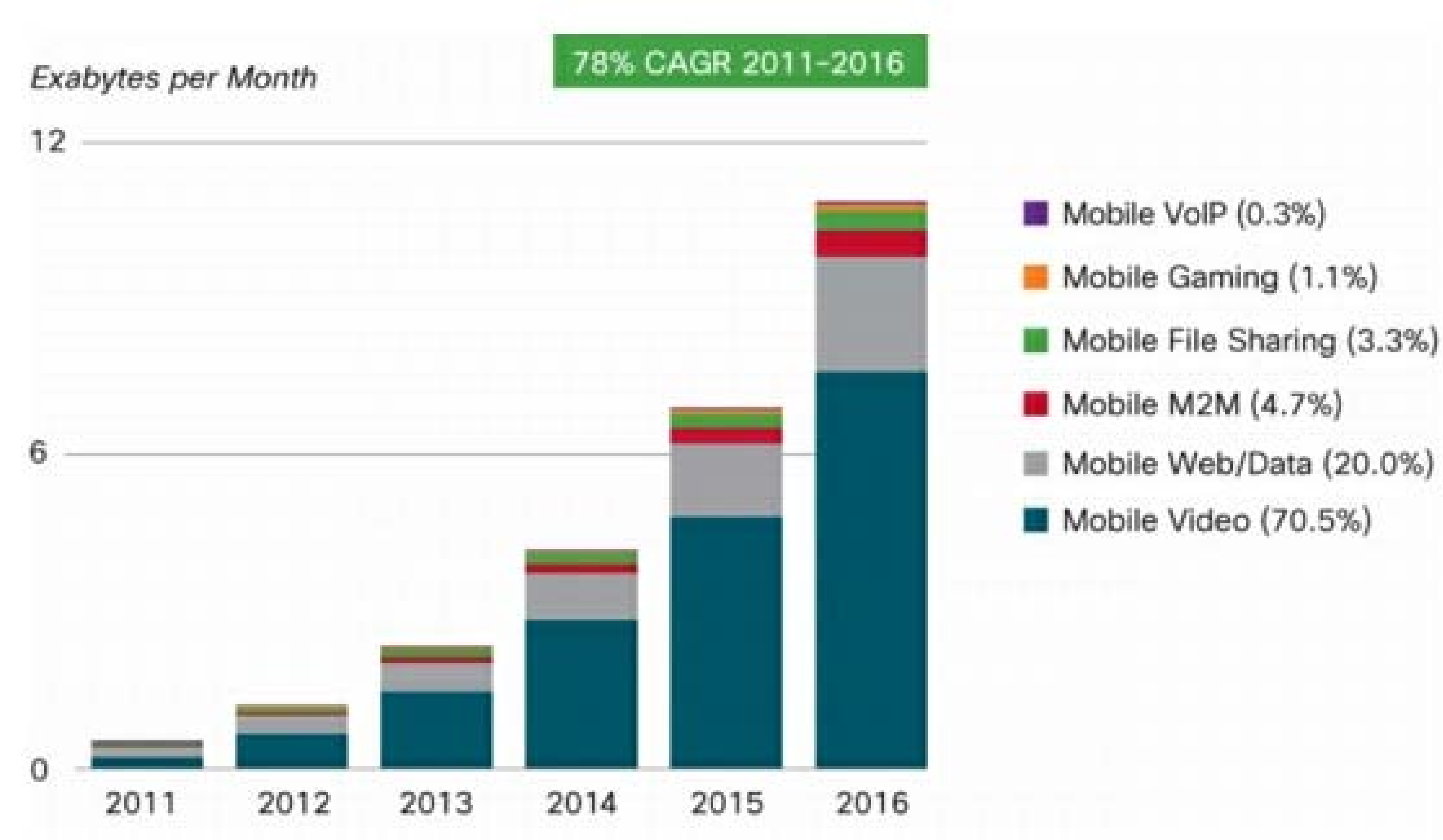
Future Technology Time Line



Source: Cisco Visual Networking Index (VNI) Global Mobile Data Traffic Forecast Update

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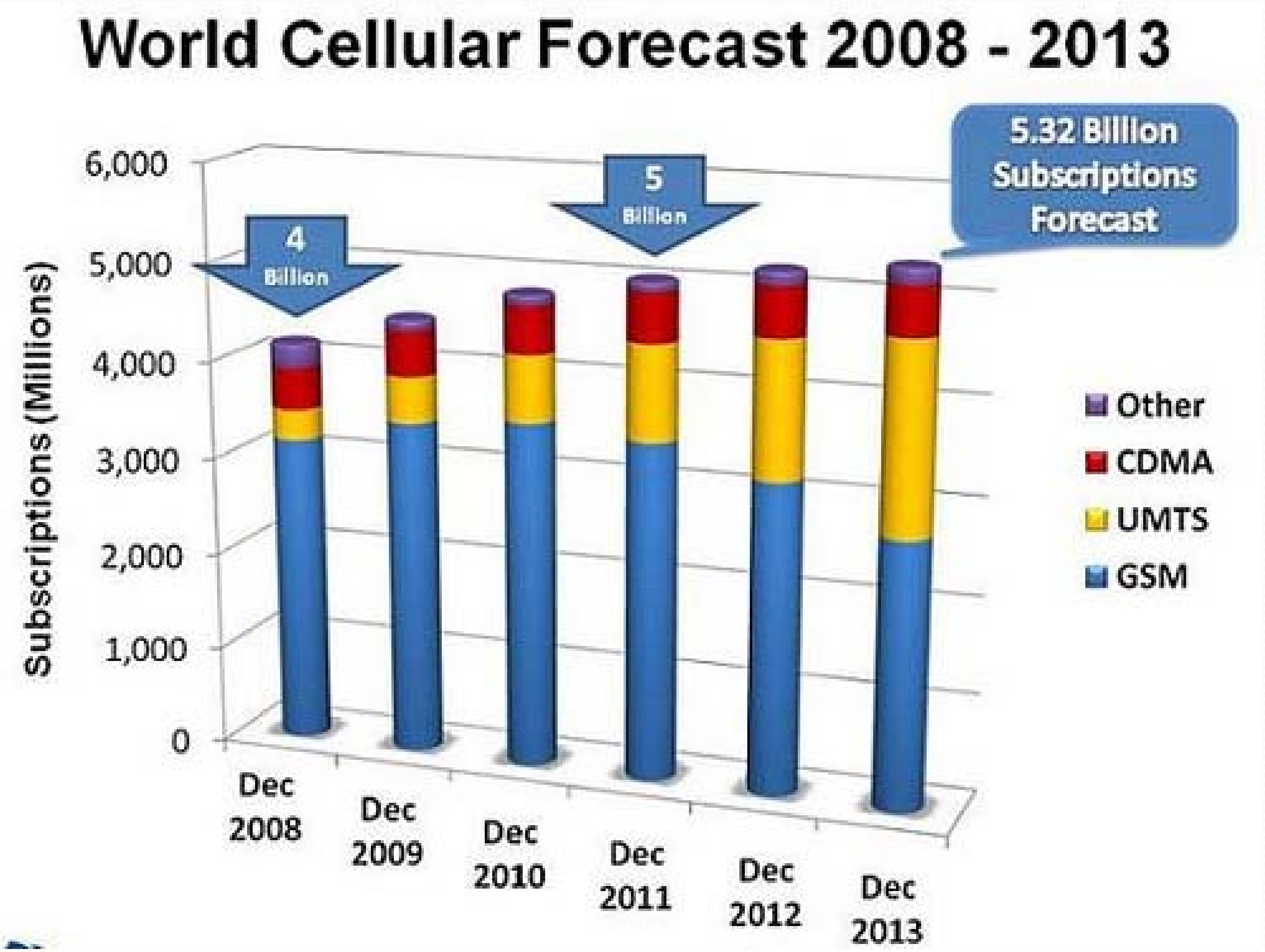

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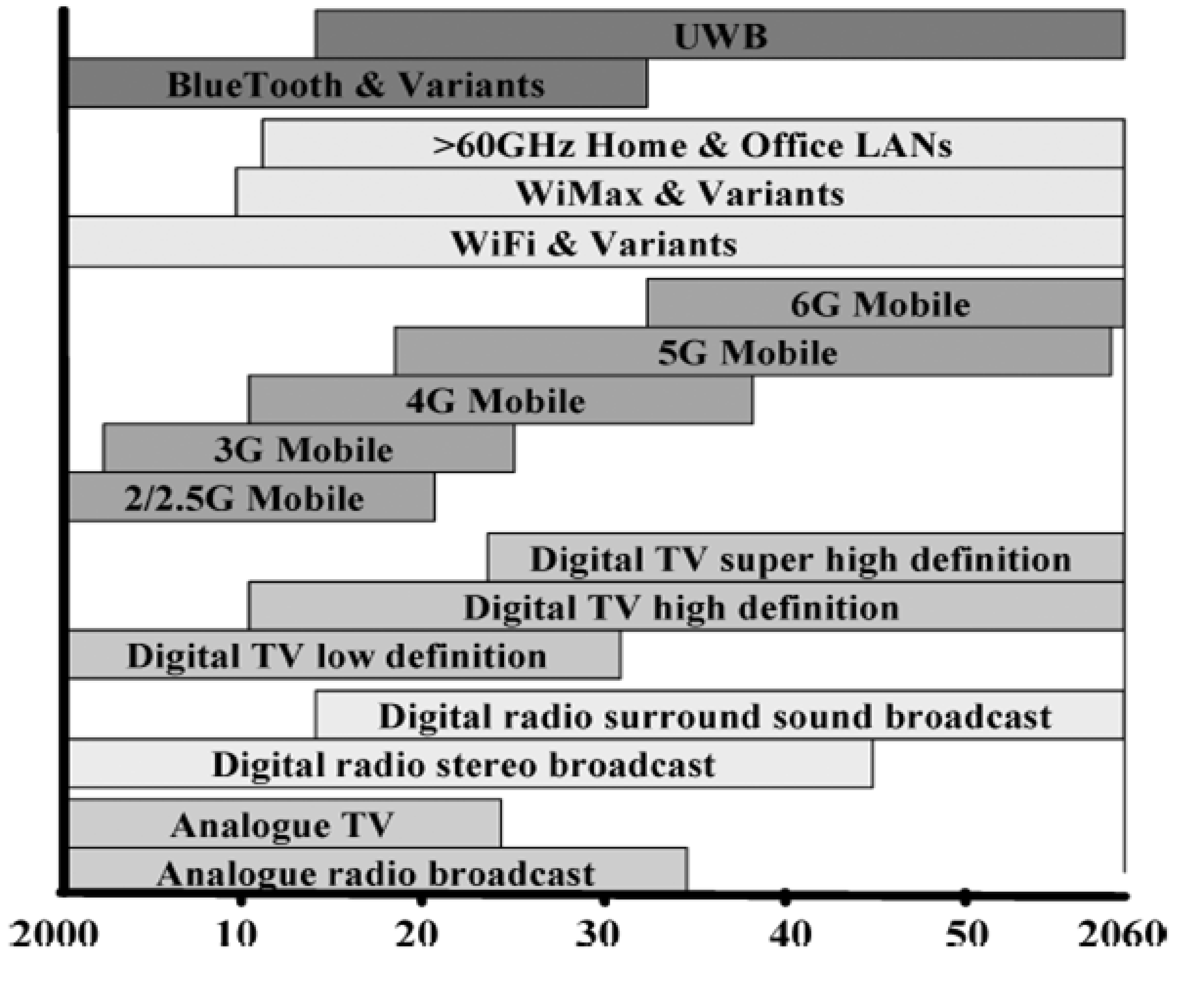
Source: http://www.dailywireless.org/2009/08/12/lte-marketing-ramps-up/

Future Technology Time Line



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- Present technology reach

		Real World (avg)		Theoretical (max)		Availability
		Download	Upload	Download	Upload	
3G	UMTS	226Kbps	30Kbps	384Kbps	64Kbps	Today
	W-CDMA	800Kbps	60Kbps	2Mbps	153Kbps	Today
	EV-DO Rev. A	1Mbps	500Kbps	3.1Mbps	1.8Mbps	Today
	HSPA 3.6	650Kbps	260Kbps	3.6Mbps	348Kbps	Today
	HSPA 7.2	1.4Mbps	700Kbps	7.2Mbps	2Mbps	Today
Pre-4G	WiMAX	3-6Mbps	1Mbps	100Mbps+	56Mbps	Today
	LTE	5-12Mbps	2-5Mbps	100Mbps+	50Mbps	End 2010
	HSPA+	-	-	56Mbps	22Mbps	2011
	HSPA 14	2Mbps	700Kbps	14Mbps	5.7Mbps	Today*

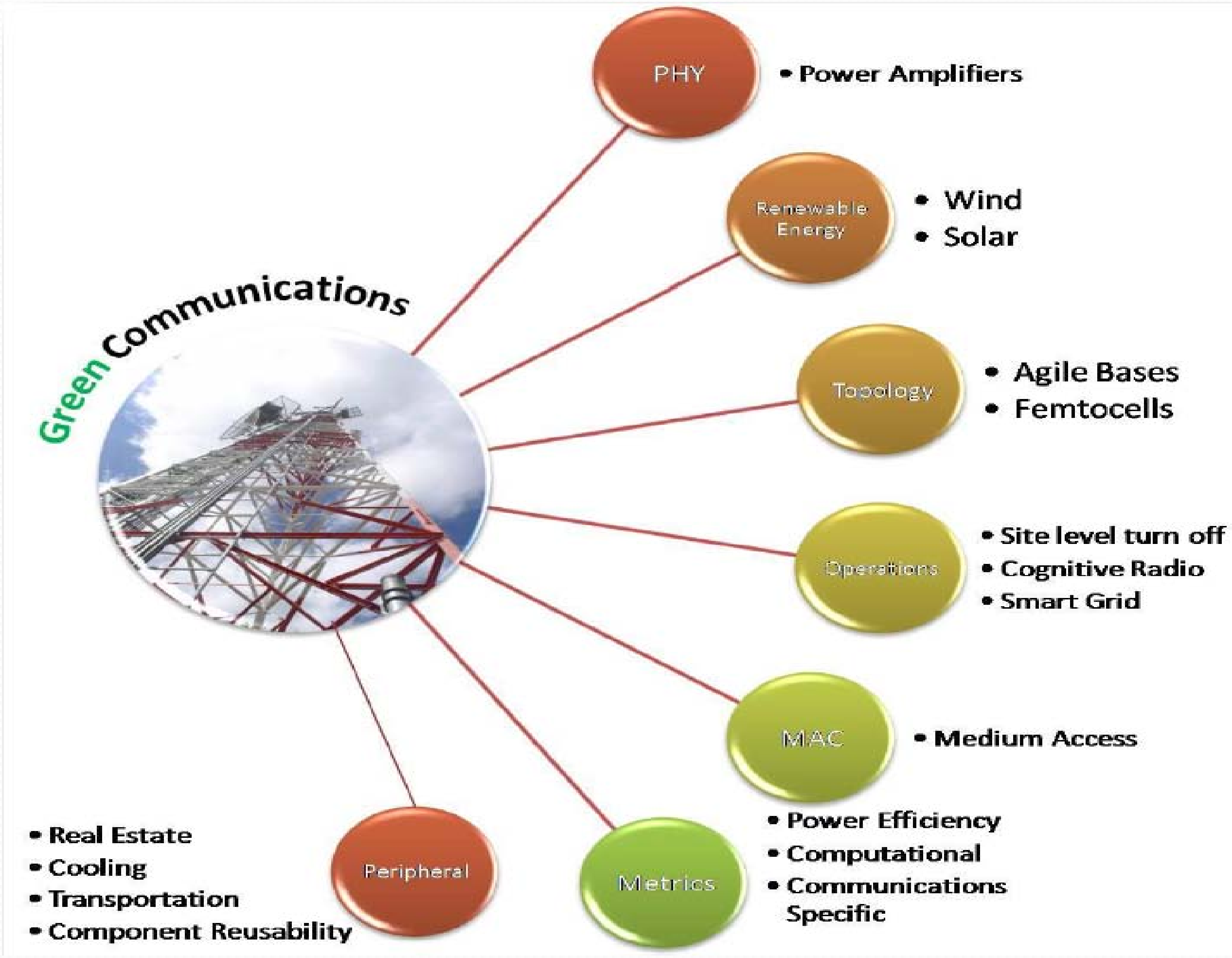
Fut…Contd…

- Future Desire

		Real World (avg)		Theoretical (max)		Availability
		Download	Upload	Download	Upload	
4G	WiMAX 2 (802.16m)	-	-	100Mbps mobile / 1Gbps fixed	60Mbps	2012
	LTE Advanced	-	-	100Mbps mobile / 1Gbps fixed	-	2012+

Fut…Contd…

Green Communication



Source: Wireless @virginia Technology

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Futher…condt…

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Thank You