Wireless Next Gen. Comm. Systems

TU130

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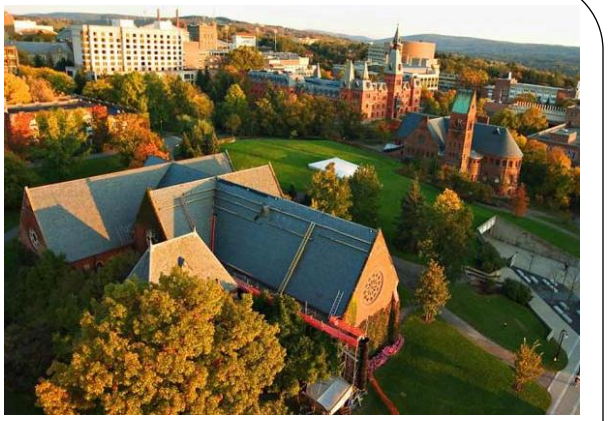
EC @ SIIT

EC = Electronics

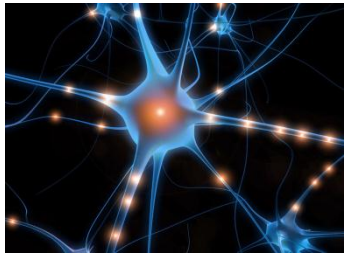
and **Communication**

Me?

prapun.com



- PhD from **Cornell** University
- In Electrical and Computer Engineering
- Minor: Mathematics (Probability Theory)
- PhD Research: Neuro-Information Theory
  - Modeling and analyzing optimality of **neurons** in human brain from communication engineering perspective.
- BS from Cornell University
  - Highest GPA in the engineering class
- Current Research: Wireless Communication
  - Physical layers of **mobile** and **WiFi** systems
- Best Teaching Award, 2009, SIIT



Three Main Topics

1. Wireless Communications and Radio Frequency Spectrum
2. Cellular Systems: 1G, 2G, 2.5G, 3G, **4G**
3. Wireless LAN Systems: WiFi (802.11a/b/g/n/**ac**)

What can you expect…?

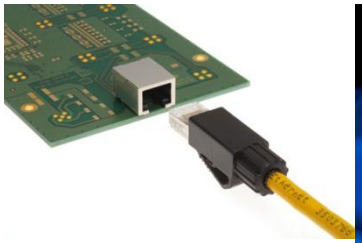
1 Gbps DL,

for **4G** and **802.11ac**

Part 1: Wireless Comm.

Wired Communication

- Cup-and-string communication



- POTS, Ethernet

Wireless communication

- Duncan Wilson's Cup Communicator

- Mobile phones, WiFi

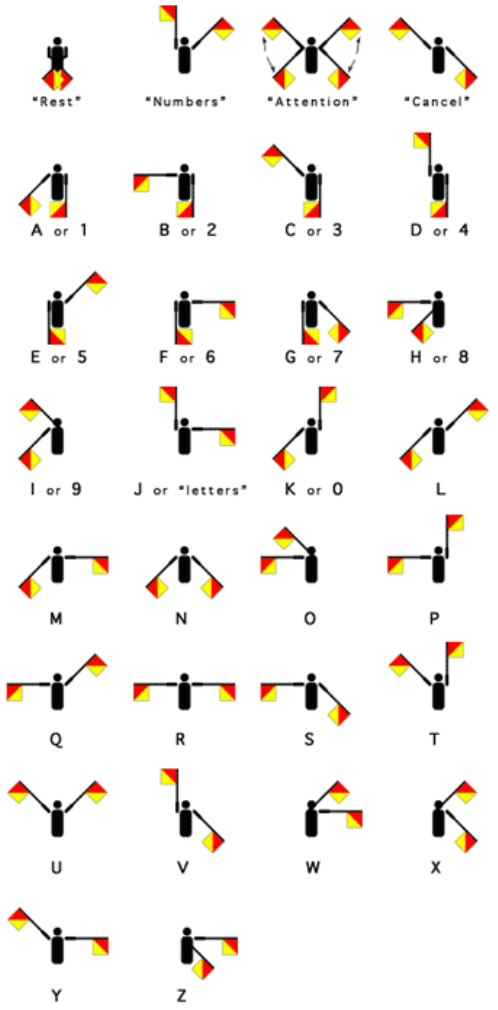
[Goldsmith, 2005, Section 1.1]

History (1)

- The first wireless networks were developed in the pre-industrial age.
- These systems transmitted information over **line-of-sight** distances (later extended by telescopes) using **smoke** signals, torch signaling, flashing mirrors, signal flares, or semaphore **flags**.

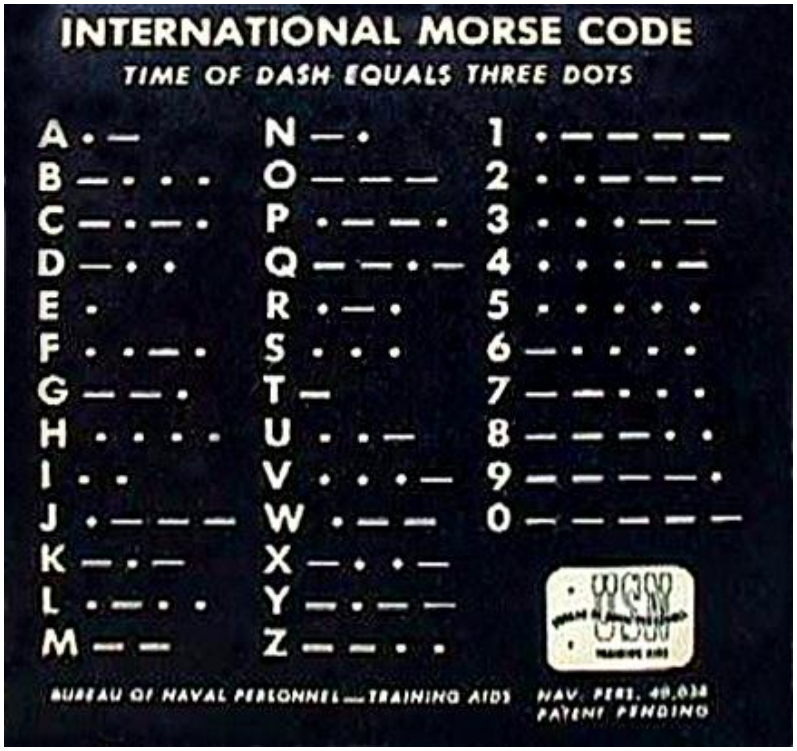
Semaphore


© Original Artist
Reproduction rights obtainable from
www.CartoonStock.com
'I think Lassie is trying to tell us something, ma.'


"Rest"
"Numbers"
"Attention"
"Cancel"
A or 1
B or 2
C or 3
D or 4
E or 5
F or 6
G or 7
H or 8
I or 9
J or "letters"
K or 0
L
M
N
O
P
Q
R
S
T
U
V
W
X
Y
Z

History (2)

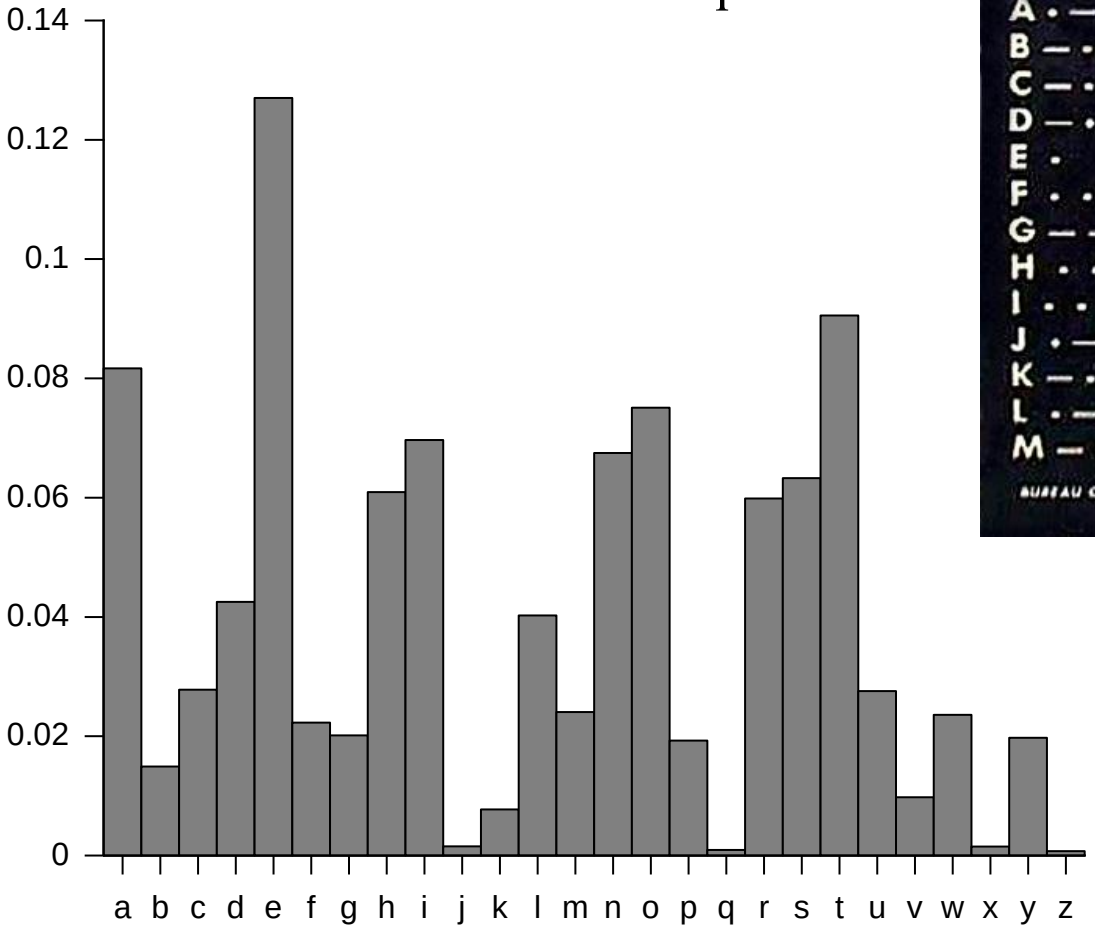
- Early communication networks were replaced first by the **telegraph network** (invented by Samuel **Morse** in 1838) and later by the telephone.

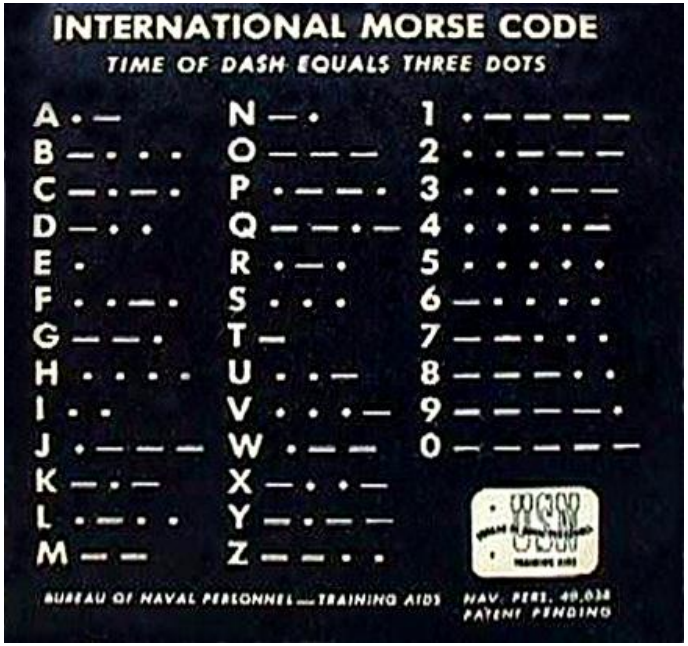


SAMUEL MORSE DICTATES A LETTER TO HIS SECRETARY.

Morse code is digital!

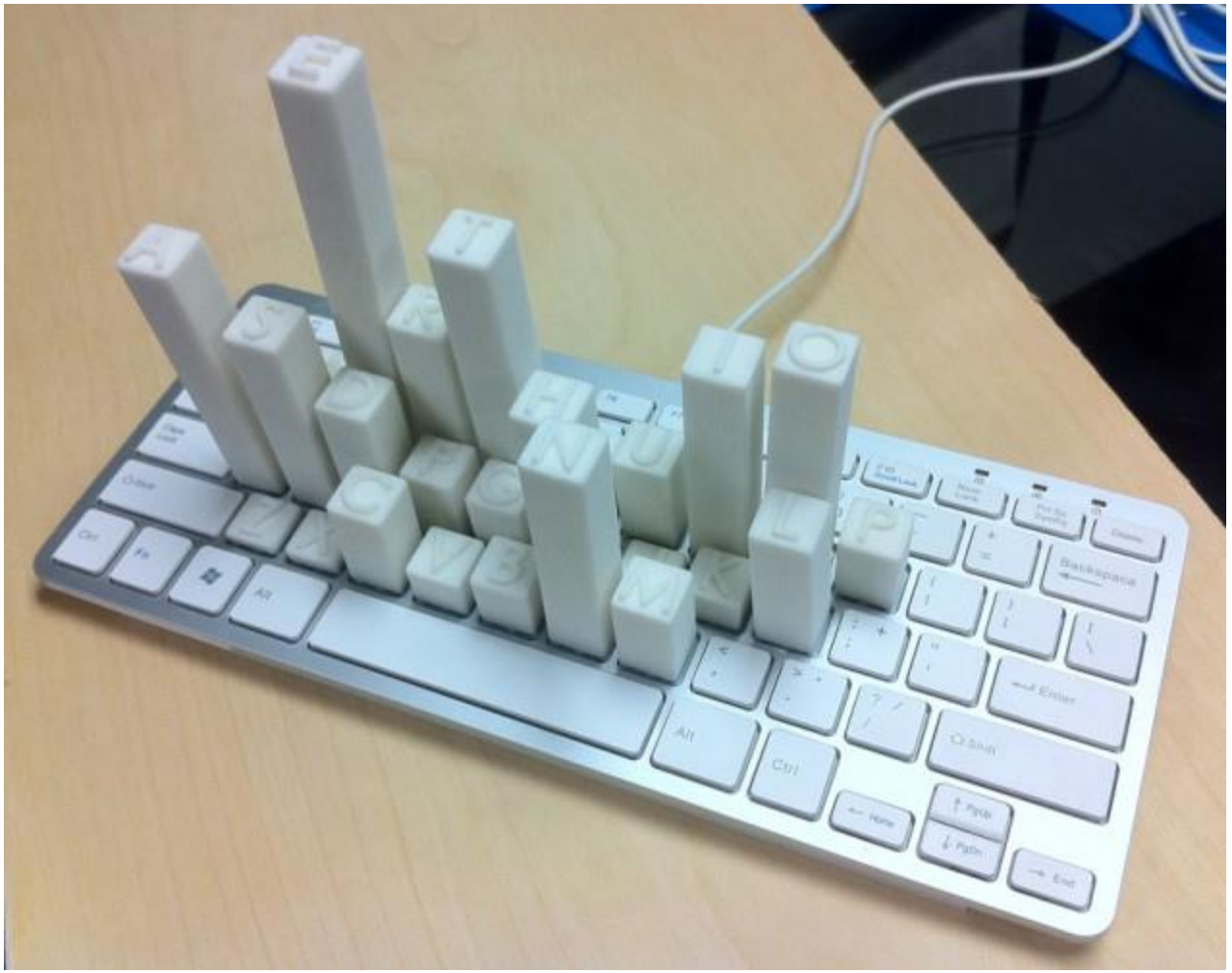
Basic form of compression.





Relative frequencies of letters in the English language

Relative frequencies of letters in the English language (2)



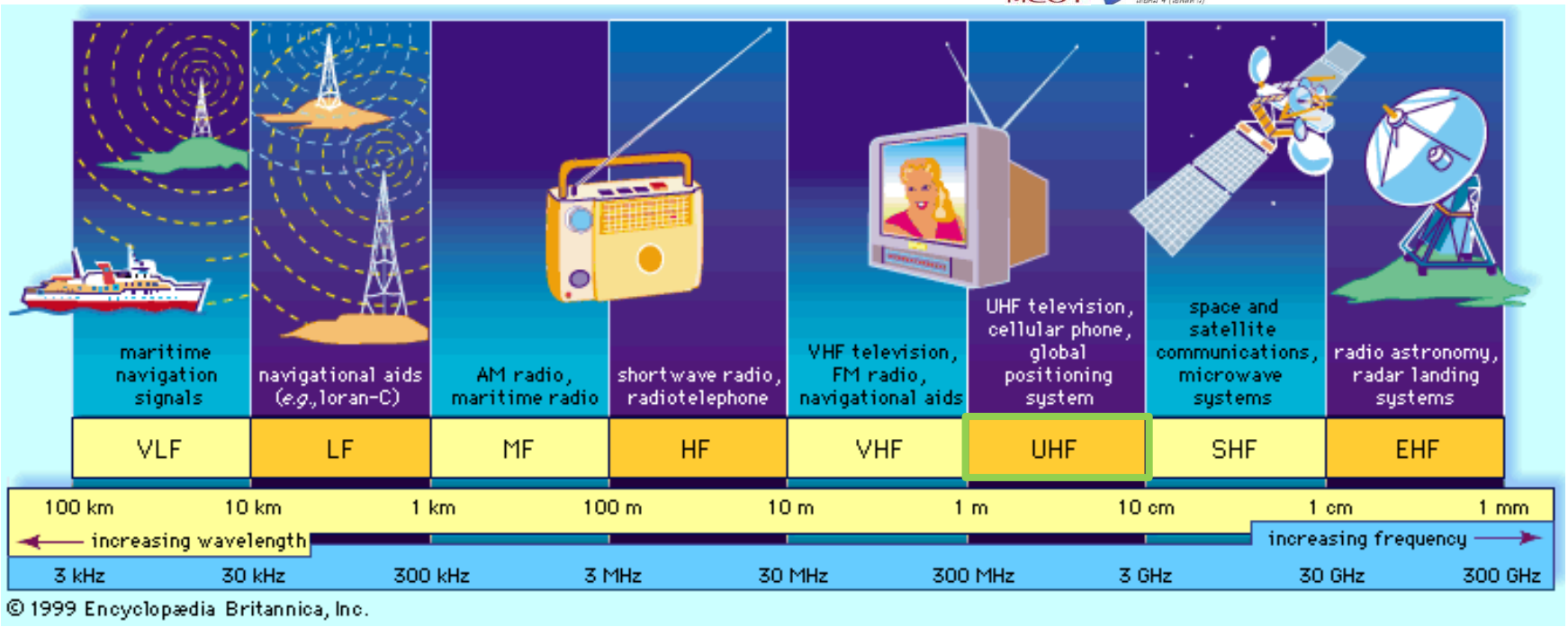
History (2)

- In 1895, **Marconi** demonstrated the first radio transmission.
- Early radio systems transmitted **analog** signals.
- Today most radio systems transmit **digital** signals composed of binary digits (bits).
- **Packet radio** group the bits into packets.
- The first network based on packet radio, **ALOHANET**, was developed at the University of **Hawaii** in 1971.
  - Employed in **Ethernet**
  - Lead to **wireless local area networks** (**WLAN**).

[http://www.britannica.com/EBchecked/topic-art/585825/3697/Commercially-exploited-bands-of-the-radio-frequency-spectrum]

Radio-frequency spectrum

- Commercially exploited bands



$$c = f\lambda$$

3×10^{8} m/s

Wavelength

Frequency

Note that the freq. bands are given in decades; the VHF band has 10 times as much frequency space as the HF band.

FM Radio Stations (in MHz)

98.5 Good FM

103.5 FM one

106.0 Life FM

95.5 Virgin Hitz

102.5 Get FM

93.0 Cool 93

99.0 Sports FM

104.5 FAT Radio

106.5 Green Wave

89.0 Banana FM

107.0 MET FM

103.5 FM Max NEW

94 EFM

105.5 Eazy FM

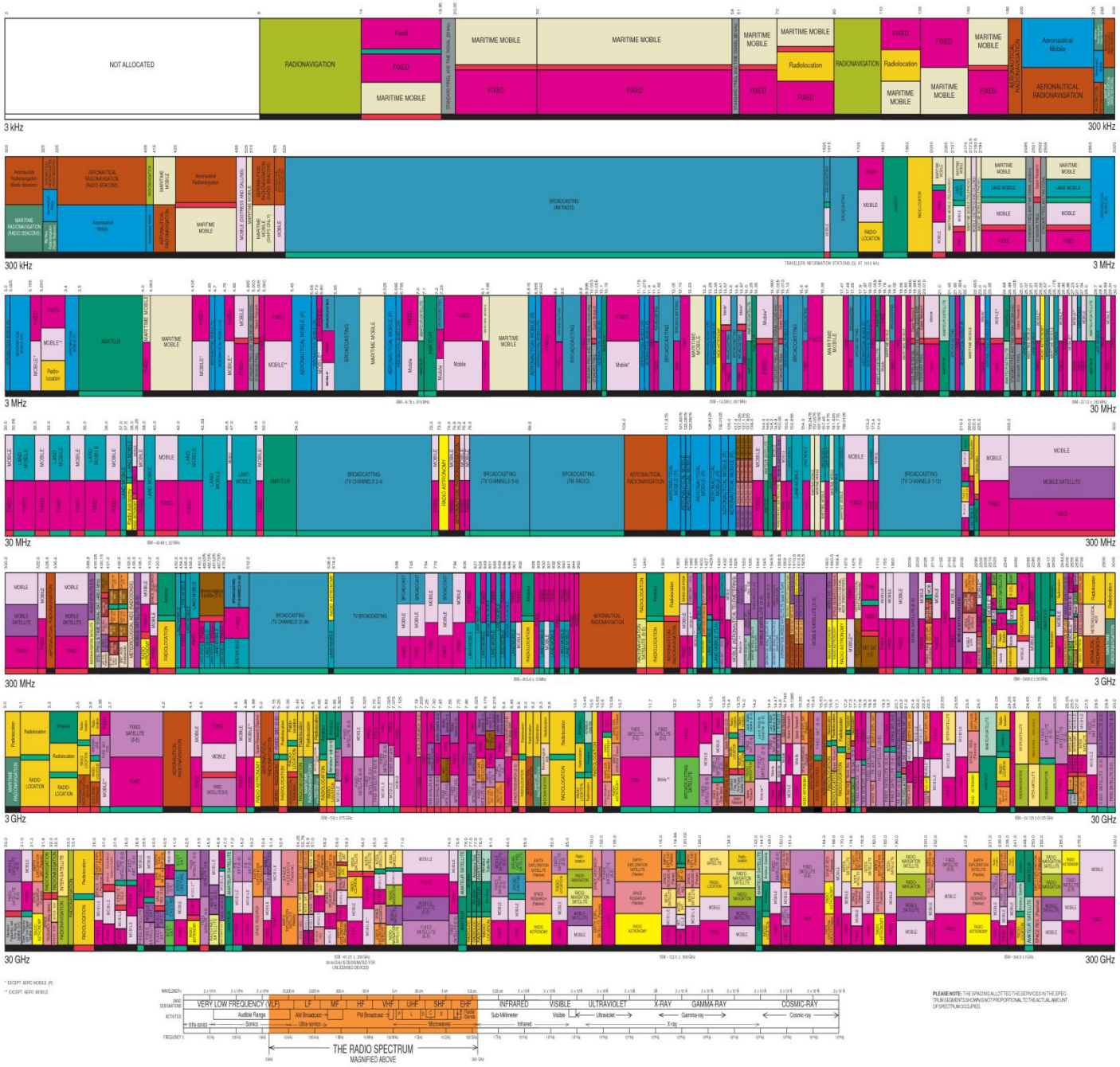
95.0 Luktung FM

91.5 Hotwave

97.5 Seed FM

UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM



RADIO SERVICES COLOR LEGEND

- AERONAUTICAL MOBILE
- AERONAUTICAL MOBILE SATELLITE
- AERONAUTICAL RADIONAVIGATION
- AMATEUR
- AMATEUR SATELLITE
- BROADCASTING
- BROADCASTING SATELLITE
- EARTH EXPLORATION SATELLITE
- FIXED
- FIXED SATELLITE
- INTER-SATELLITE
- LAND MOBILE
- LAND MOBILE SATELLITE
- MARITIME MOBILE
- MARITIME MOBILE SATELLITE
- MARITIME RADIONAVIGATION
- METEOROLOGICAL AIDS
- METEOROLOGICAL SATELLITE
- MOBILE
- MOBILE SATELLITE
- RADIO ASTRONOMY
- RADIODETERMINATION SATELLITE
- RADIOLOCATION
- RADIOLOCATION SATELLITE
- RADIONAVIGATION
- RADIONAVIGATION SATELLITE
- SPACE OPERATION
- SPACE RESEARCH
- STANDARD FREQUENCY AND TIME SIGNAL
- STANDARD FREQUENCY AND TIME SIGNAL SATELLITE

ACTIVITY CODE

- GOVERNMENT EXCLUSIVE
- GOVERNMENT/NON-GOVERNMENT SHARED
- NON-GOVERNMENT EXCLUSIVE

ALLOCATION USAGE DESIGNATION

SERVICE	EXAMPLE	DESCRIPTION
Primary	FIXED	Capital Letters
Secondary	Mobile	1st Capital with lower case letters

PLEASE NOTE: THE SPACING ALLOTTED THE SERVICES IN THE SPECTRUM SEGMENTS ESTABLISHED WAS NOT PROPORTIONAL TO THE ACTUAL AMOUNT OF SPECTRUM OCCUPIED.

This chart is a graphic single-point-in-time portrayal of the Table of Frequency Allocations used by the FCC and NTIA. As such, it does not completely reflect all aspects, i.e., footnotes and recent changes to the Table of Frequency Allocations. Therefore, for complete information, users should consult the Table of Frequency Allocations. Therefore, for complete information, users should consult the most recent publication of the current status of U.S. allocations.

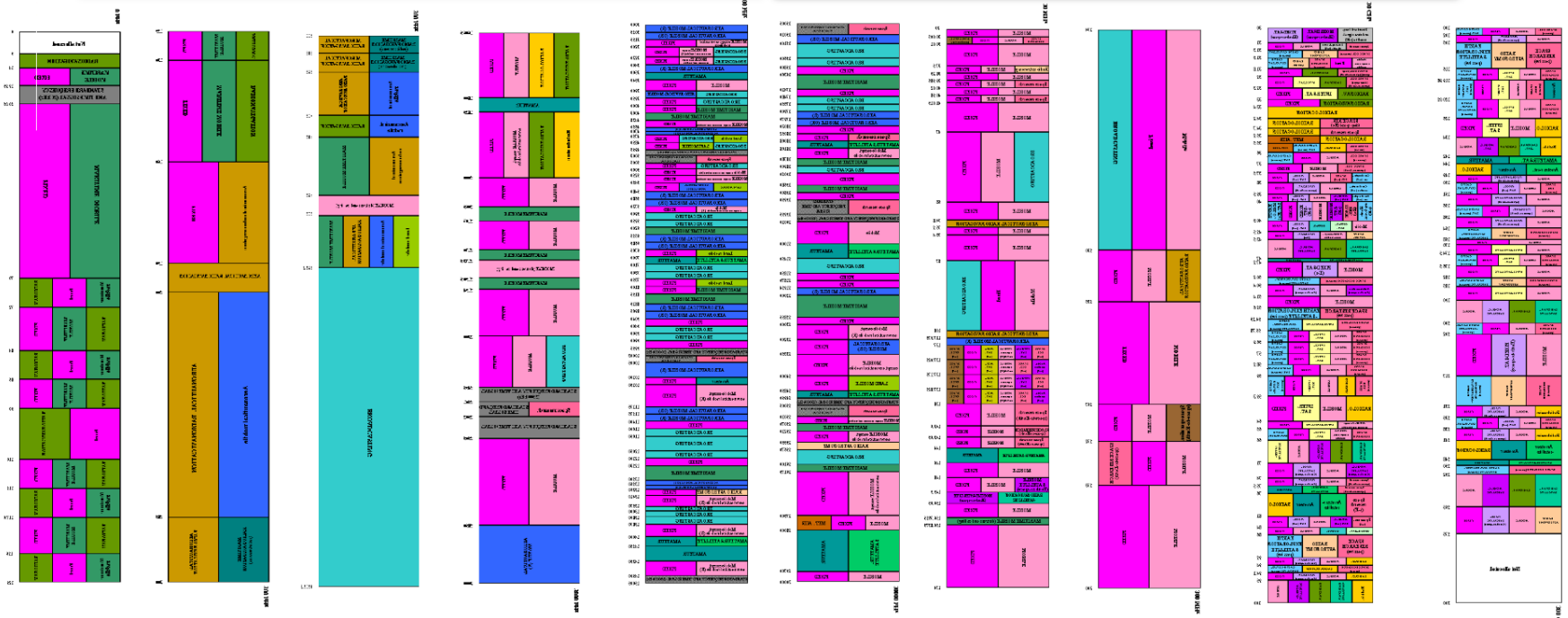
U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Office of Spectrum Management

October 2003

Thailand Freq. Allocations Chart

RADIO SERVICES COLOR LEGEND	
Aeronautical mobile	Meteorological aids
Aeronautical radionavigation	Meteorological-satellite
Amateur	Mobile
Amateur-satellite	Mobile-satellite
Broadcasting	Radio astronomy
Broadcasting-satellite	Radiodetermination-satellite
Earth exploration- satellite	Radiolocation

Fixed	Radionavigation
Fixed-satellite	Radionavigation- satellite
Inter-satellite	Space operation
Land mobile	Space research
Maritime mobile	Standard frequency and time signal
Maritime radionavigation	Standard frequency and time signal-satellite



http://www.ntc.or.th/uploadfiles/freq_chart_thai.htm

Spectrum Allocation

- Spectral resource is limited.
- Most countries have government agencies responsible for allocating and controlling the use of the radio spectrum.
- Commercial spectral allocation is governed
  - **globally** by the International Telecommunications Union (**ITU**)
    - ITU Radiocommunication Sector (**ITU-R**) is responsible for radio communication.
  - in the U.S. by the Federal Communications Commission (**FCC**)
  - in Thailand by the National Telecommunications Commission (**NTC**; คณะกรรมการกิจการโทรคมนาคมแห่งชาติ; กทช.)
    - replaced by the National Broadcasting and Telecommunications Commission (**NBTC**; คณะกรรมการกิจการกระจายเสียง กิจการโทรทัศน์และกิจการโทรคมนาคมแห่งชาติ ; กสทช.)
- Blocks of spectrum are now commonly assigned through **spectral auctions** to the highest bidder.

Unlicensed bands

- In addition to spectral auctions, spectrum can be set aside in specific frequency bands that are **free to use** with a license according to a specific set of **etiquette rules**.
- The purpose of these unlicensed bands is to encourage innovation and low-cost implementation.
- Many extremely successful wireless systems operate in unlicensed bands, including **wireless LANs, Bluetooth, and cordless phones**.
- Major difficulty: Interference
  - If many unlicensed devices in the same band are used in close proximity, they generate much **interference** to each other, which can make the band unusable.

Unlicensed bands (2)

- Unlicensed spectrum is allocated by the governing body within a given country.
- Often countries try to match their frequency allocation for unlicensed use so that technology developed for that spectrum is compatible worldwide.
- The following table shows the unlicensed spectrum allocations in the U.S.

ISM Band I (Cordless phones, 1G WLANs)	902-928 MHz
ISM Band II (Bluetooth, 802.11b WLANs)	2.4-2.4835 GHz
ISM Band III (Wireless PBX)	5.725-5.85 GHz
NII Band I (Indoor systems, 802.11a WLANs)	5.15-5.25 GHz
NII Band II (short outdoor and campus applications)	5.25-5.35 GHz
NII Band III (long outdoor and point-to-point links)	5.725-5.825 GHz

[Tse Viswanath, 2005, Section 4.1]

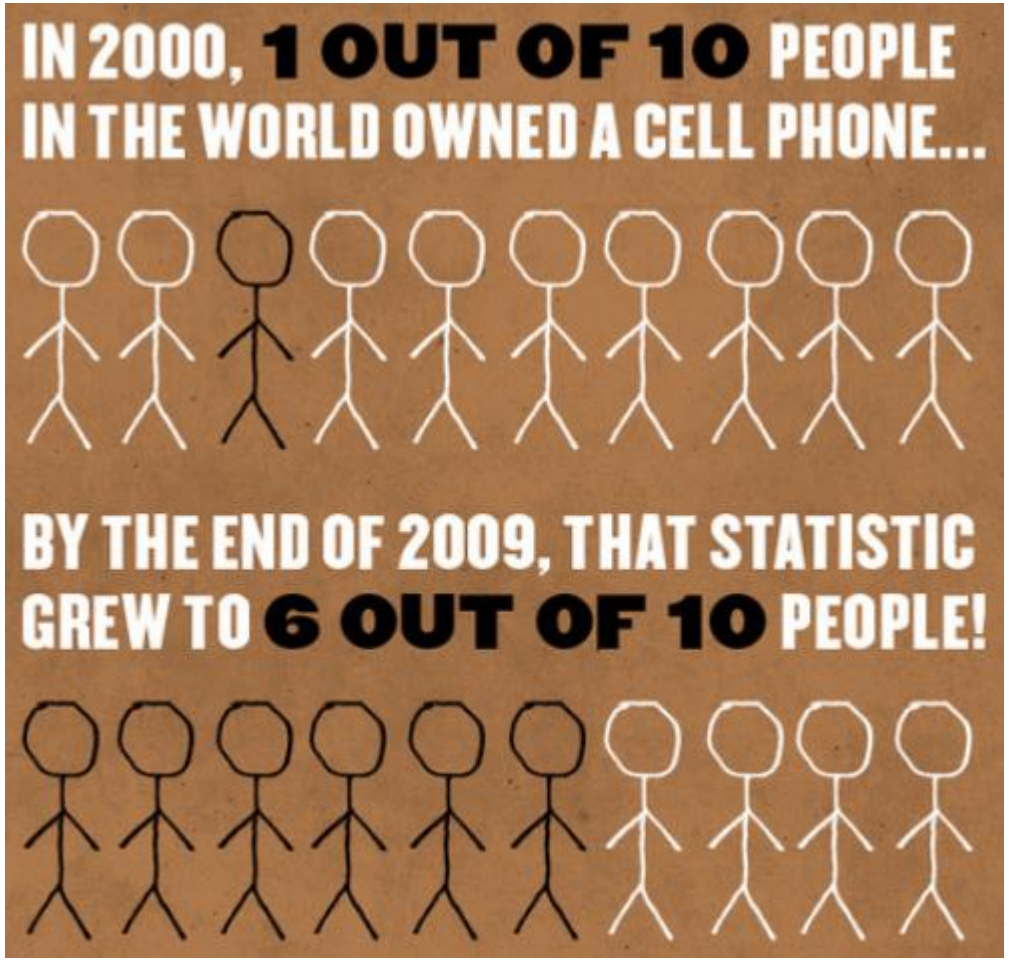
Licensed vs. Unlicensed Spectra

Licensed	Unlicensed
Typically nationwide. Over a period of a few years. From the spectrum regulatory agency.	For experimental systems and to aid development of new wireless technologies.
Bandwidth is very expensive.	Very cheap to transmit on.
No hard constraints on the power transmitted within the licensed spectrum but the power is expected to decay rapidly outside.	There is a maximum power constraint over the entire spectrum.
Provide immunity from any kind of interference outside of the system itself.	Have to deal with interference.

Parameter	Fixed WiMAX	Mobile WiMAX	HSPA	1x EV-DO Rev A	Wi-Fi
Standards	IEEE 802.16-2004	IEEE 802.16e-2005	3GPP Release 6	3GPP2	IEEE 802.11a/g/n
Peak down link data rate	9.4Mbps in 3.5MHz with 3:1 DL-to-UL ratio TDD; 6.1Mbps with 1:1	46Mbps[a] with 3:1 DL- to-UL ratio TDD; 32Mbps with 1:1	14.4Mbps using all 15 codes; 7.2Mbps with 10 codes	3.1Mbps; Rev. B will support 4.9Mbps	54 Mbps[b] shared using 802.11a/g; more than 100Mbps peak layer 2 through-put using 802.11n
Peak uplink data rate	3.3Mbps in 3.5MHz using 3:1 DL-to-UL ratio; 6.5Mbps with 1:1	7Mbps in 10MHz using 3:1 DL-to-UL ratio; 4Mbps using 1:1	1.4Mbps ini-tially; 5.8Mbps later	1.8Mbps	
Bandwidth	3.5MHz and 7MHz in 3.5GHz band; 10MHz in 5.8GHz band	3.5MHz, 7MHz, 5MHz, 10MHz, and 8.75MHz initially	5MHz	1.25MHz	20MHz for 802.11a/g; 20/40MHz for 802.11n
Modulation	QPSK, 16 QAM, 64 QAM	QPSK, 16 QAM, 64 QAM	QPSK, 16 QAM	QPSK, 8 PSK, 16 QAM	BPSK, QPSK, 16 QAM, 64 QAM
Multiplexing	TDM	TDM/OFDMA	TDM/CDMA	TDM/ CDMA	CSMA
Duplexing	TDD, FDD	TDD initially	FDD	FDD	TDD
Frequency	3.5GHz and 5.8GHz initially	2.3GHz, 2.5GHz, and 3.5GHz initially	800/900/1,800/ 1,900/ 2,100MHz	800/900/ 1,800/ 1,900MHz	2.4GHz, 5GHz
Coverage (typical)	3–5 miles	< 2 miles	1–3 miles	1–3 miles	< 100 ft indoors; < 1000 ft outdoors
Mobility	Not applicable	Mid	High	High	Low

Part 2: Cellular Systems

World Market Penetration

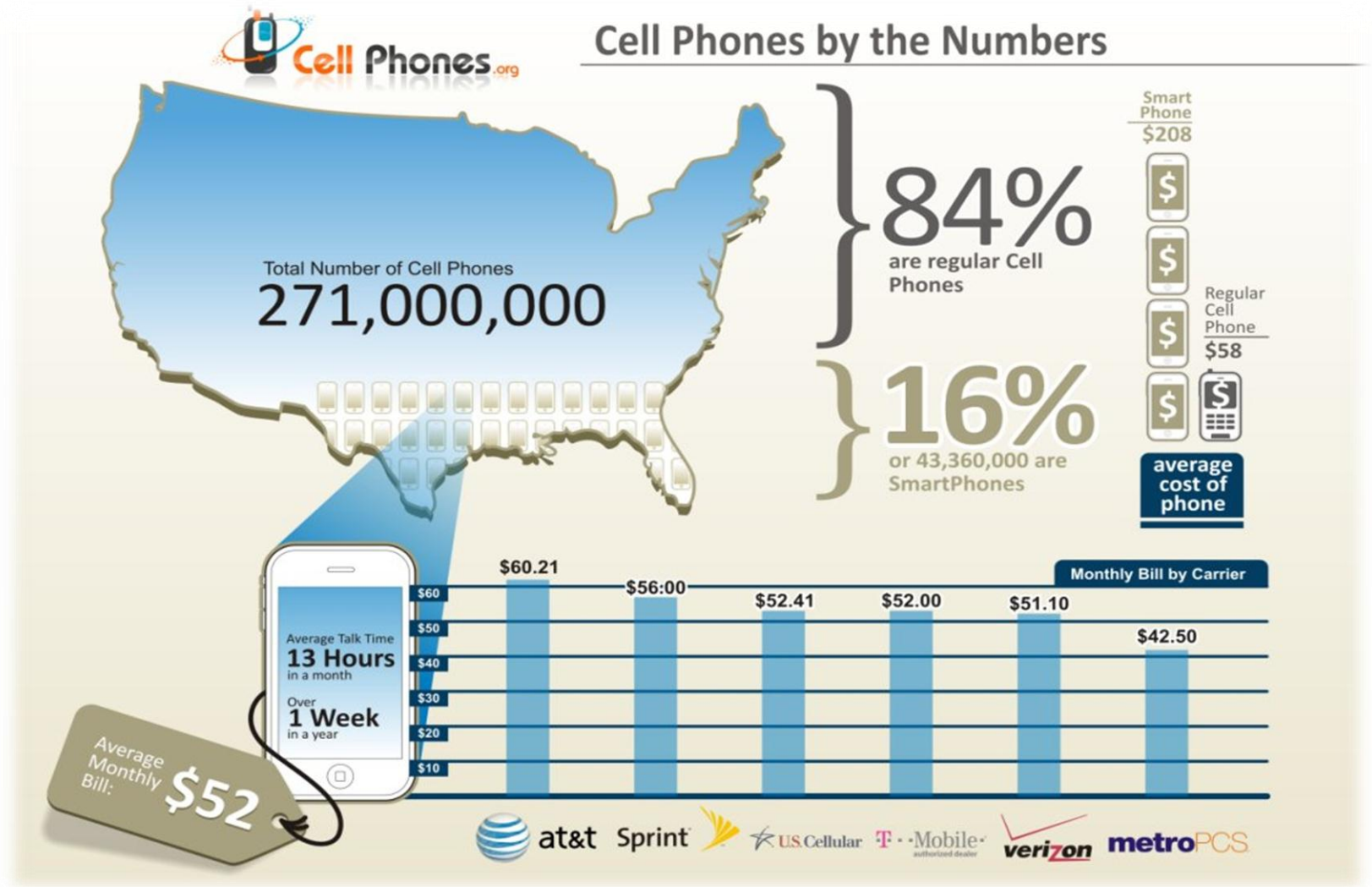


4,239,956 PEOPLE are having a cell phone conversation at any given **SECOND** in the world

People in countries with no running water are able to keep in touch with others thanks to cellular technology

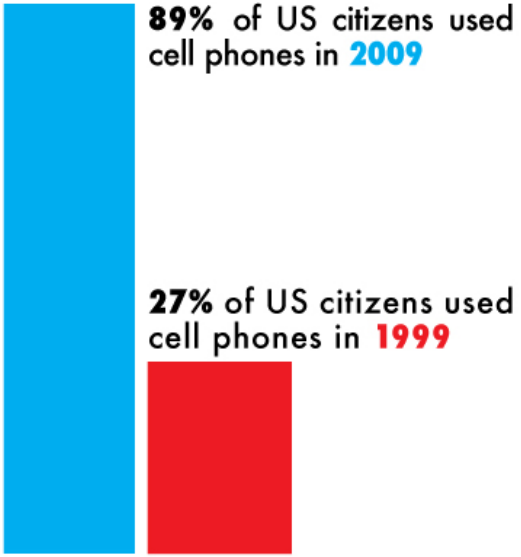
[http://cellphones.org]

US Market


Cell Phones.org
Cell Phones by the Numbers
Total Number of Cell Phones
271,000,000
84%
are regular Cell Phones
16%
or 43,360,000 are SmartPhones
Smart Phone
$208
Regular Cell Phone
$58
average cost of phone
Monthly Bill by Carrier
$60.21
$56:00
$52.41
$52.00
$51.10
$42.50
$60
$50
$40
$30
$20
$10
Average Talk Time
13 Hours
in a month
Over
1 Week
in a year
Average Monthly Bill: $52
at&t
Sprint
U.S. Cellular
T-Mobile
verizon
metroPCS

Social Influence

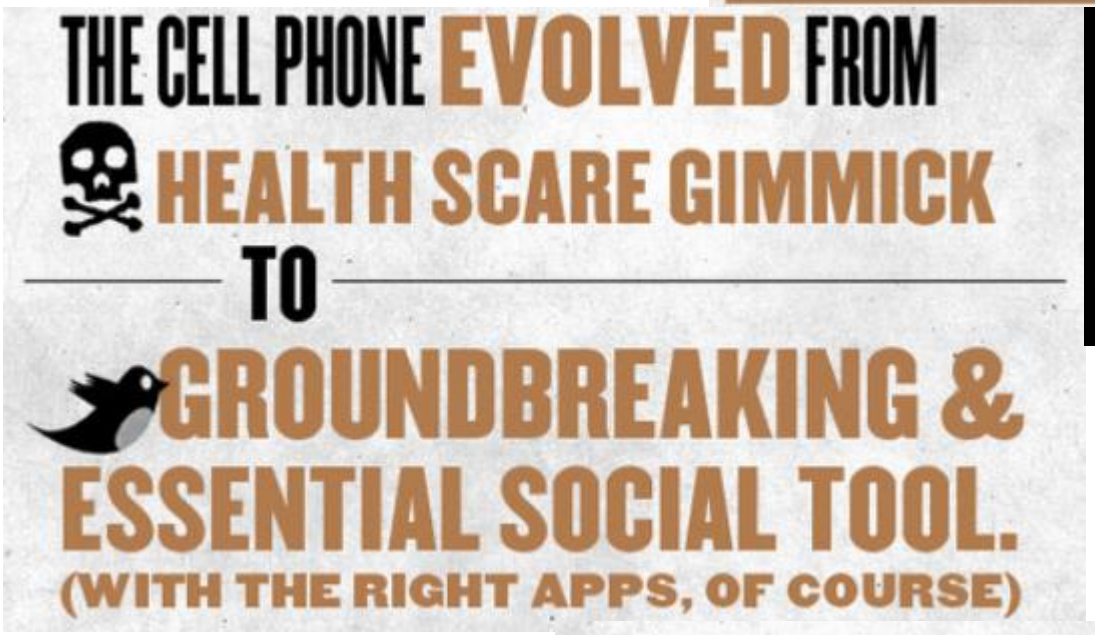
32% OF MEN and **23% OF WOMEN** say they **CAN'T LIVE WITHOUT** their cell phone

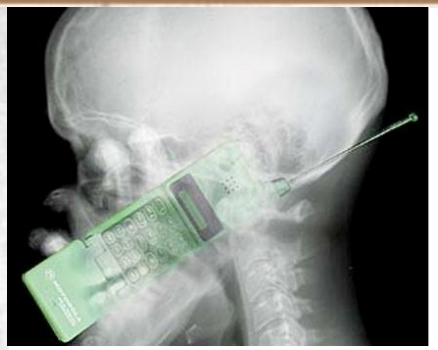


47% OF TEENS say their social lives would end without text messaging.

Perception


BREAKING NEWS FROM 2000:
FDA REMAINS UNDECIDED WHETHER CELL PHONE RADIATION IS DANGEROUS OR MYTH...

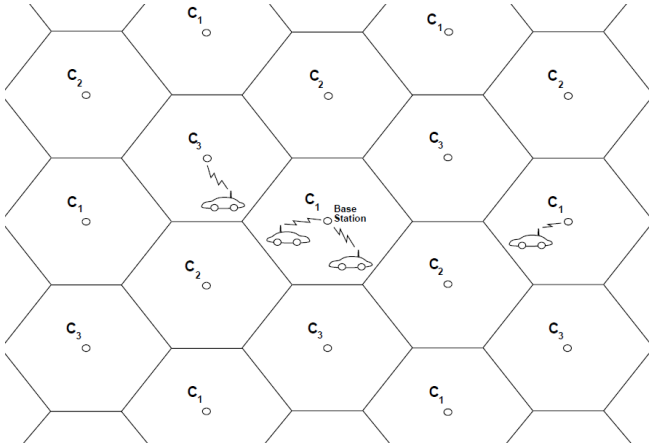

THE CELL PHONE EVOLVED FROM
HEALTH SCARE GIMMICK
TO
GROUNDBREAKING &
ESSENTIAL SOCIAL TOOL.
(WITH THE RIGHT APPS, OF COURSE)




BREAKING NEWS FROM 2009:
CELL PHONE VIDEO AND TWITTER REVEAL DEATH OF IRANIAN PROTESTOR, NEDA AGHA-SOLTAN...

History: 1G Cellular (1)

- The **cellular concept** was developped by researchers at AT&T **Bell Lab**oratories
- 1968: AT&T proposed the concept to the FCC
- Cellular systems exploit the fact that the power of a transmitted signal falls off with distance.
- Thus, two users can operate on the same frequency at spatially-separate locations with minimal interference between them.
  - Frequency reuse



Marty Cooper: Cellphone Inventor

- 1973
- Motorola
- Weighed nearly two kilos
- Cost approximately $1 million for Motorola to produce.
- 20 minutes battery life

  Not a problem because you could not hold it up for twenty minutes; it was so heavy.

[http://gizmodo.com]

History: 1G Cellular (2)

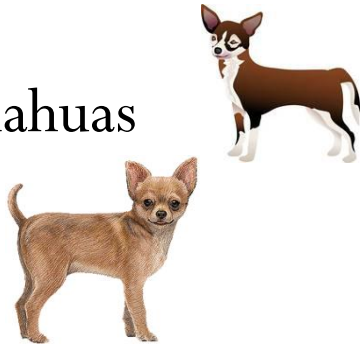
- **Japan** had the **world's first commercially available** cellular phone system.
  - Nippon Telegraph and Telephone (NTT) created a cellular test system for Tokyo in 1975, with the result coming to market in 1979.
- The first trial in America of a complete, working cellular system was held in Chicago in the late 1970's.
- 1983: Advanced Mobile Phone System (**AMPS**)
  - First US cellular telephone system
  - Deployed in 1983 by Ameritech in Chicago, IL.
  - Worked well. (FM, FDMA)
  - May even have worked too well.
    - Its satisfactory performance lowered the demand for a better system, allowing Europe to take the lead by creating a digital cellular system first.

Old Cell Phone

Motorola's DynaTAC

First **commercially available** cell phone in 1983

- Weighed about 2 lbs (1 Kg)
- 10 inches high, making it larger than some Chihuahuas
- Battery life: 30 minutes of talk time
- $4,000



History: 2G Cellular

- The **first-generation (1G)** systems introduced in the 1980s were characterized by **analog speech transmission**.
- The second generation (**2G**) of cellular systems, first deployed in the early 1990's, were based on **digital** communications.
- The shift from analog to digital was driven by its higher capacity and the improved cost, speed, and power efficiency of digital hardware.
- 1991: US Digital Cellular (**USDC** – **IS-54** > IS-136)
  - Three times capacity of AMPS because digital modulation, speech coding, and TDMA
- While second generation cellular systems initially provided mainly **voice** services, these systems gradually evolved to support **data** services such as email, Internet access, and short messaging.

Two important 2G systems

- **GSM** supports SMSs and user data at rates only up to **9.6 kb/s**.
  - Security features including (for example) the encryption of data and signaling messages on the path between the mobile phone and the BS.
  - Subscriber identity module (SIM)
    - A smart card
    - Contain the subscriber's personal details
    - Can be moved from one handset to another.

- **IS-95B** (**cdmaOne**) provides data rates in the range of **64 to 115 kb/s** in increments of 8 kb/s over a 1.25 MHz channel.
  - Each cell uses a carrier with a bandwidth of 1.25MHz, which is divided into 64 data and signalling channels by the use of orthogonal CDMA codes.

History: 2G Standard Proliferation

- Unfortunately, the **great market potential** for cellular phones led to a proliferation of (incompatible) second generation cellular standards.
- As a result of the **standard proliferation**, many cellular phones today are **multi-mode**.

Major Mobile Radio Standards in North America

Standard	Type	Year of Introduction	Multiple Access	Frequency Band	Modulation	Channel Bandwidth
AMPS	Cellular	1983	FDMA	824-894 MHz	FM	30 kHz
NAMPS	Cellular	1992	FDMA	824-894 MHz	FM	10 kHz
USDC	Cellular	1991	TDMA	824-894 MHz	π/4-DQPSK	30 kHz
CDPD	Cellular	1993	FH/ Packet	824-894 MHz	GMSK	30 kHz
IS-95	Cellular/ PCS	1993	CDMA	824-894 MHz 1.8-2.0 GHz	QPSK/ BPSK	1.25 MHz
GSC	Paging	1970s	Simplex	Several	FSK	12.5 kHz
POCSAG	Paging	1970s	Simplex	Several	FSK	12.5 kHz
FLEX	Paging	1993	Simplex	Several	4-FSK	15 kHz
DCS-1900 (GSM)	PCS	1994	TDMA	1.85-1.99 GHz	GMSK	200 kHz
PACS	Cordless/ PCS	1994	TDMA/ FDMA	1.85-1.99 GHz	π/4-DQPSK	300 kHz
MIRS	SMR/PCS	1994	TDMA	Several	16-QAM	25 kHz
iDen	SMR/PCS	1995	TDMA	Several	16-QAM	25 kHz

[Rappaport, 2002, Table 1.1]

Major Mobile Radio Standards in Japan

Standard	Type	Year of Introduction	Multiple Access	Frequency Band	Modulation	Channel Bandwidth
ETACS	Cellular	1985	FDMA	900 MHz	FM	25 kHz
NMT-450	Cellular	1981	FDMA	450-470 MHz	FM	25 kHz
NMT-900	Cellular	1986	FDMA	890-960 MHz	FM	12.5 kHz
GSM	Cellular /PCS	1990	TDMA	890-960 MHz	GMSK	200 kHz
C-450	Cellular	1985	FDMA	450-465 MHz	FM	20 kHz/ 10 kHz
ERMES	Paging	1993	FDMA	Several	4-FSK	25 kHz
CT2	Cordless	1989	FDMA	864-868 MHz	GFSK	100 kHz
DECT	Cordless	1993	TDMA	1880-1900 MHz	GFSK	1.728 MHz
DCS-1800	Cordless /PCS	1993	TDMA	1710-1880 MHz	GMSK	200 kHz

[Rappaport, 2002, Table 1.3]

[http://3g.siamphone.com/articles/2009/3g/page.htm]

History (Thailand)

- 1G
  - 1986 (2529): NMT470 (TOT)
    - Nordic Mobile Telephone System @ 470MHz
  - AMPS (Advanced Mobile Phone System)
    - 1990 (2533): Cellular 900 (AIS)
    - Worldphone 800 (TAC)
- 2G: GSM (Global System for Mobile Communication)
  - 2537: GSM Advance @ 900 Mhz (AIS)
  - Worldphone 1800 (TAC)

2.5G: GSM Enhancement

- Want to deliver ***data*** as well as voice.
- **General Packet Radio Service (GPRS)**
- **Enhanced Data Rates for GSM Evolution (EDGE)**

2.5G: GPRS

- **General Packet Radio Service**
- The first commercial launches for GPRS took place in 2001.
- Provide connectivity to IP networks (Internet).
- Construction of a **packet switched** core network, to run alongside the **circuit switched** network that was originally built for GSM.
  - "always on" connection that remains active as long as the phone is within range of the service.
- A single time slot may be shared by multiple users for transferring packet mode data
- Each slot can handle up to 20 kb/s. Each user may be allocated up to 8 slots
  - Data rates up to about 160 kb/s per user are possible.
  - A good approximation for throughput in "average" conditions is 10 Kbps per time slot. [Korhonen, 2003]

2.75?G: EDGE

- **Enhanced Data Rates for GSM Evolution**
  - Originally this acronym stood for Enhanced Data rates for GSM Evolution, but now it translates into **Enhanced Data rates for Global Evolution**, as the EDGE idea can also be used in systems other than GSM [Korhonen, 2003]
- Support IP-based services in GSM at rates up to **384 kb/s**
- Only requires a **software upgrade** to base stations
  - if the RF amplifiers can handle the non-constant envelope modulation with EDGE's relatively high peak-to-average power ratio (PAPR).
- EDGE is popular in North America, where the allocation of carrier frequencies has made it hard for GSM operators to upgrade to UMTS.

Motivation

Voice/SMS

~9.6Kbps

Mobile Narrow Band Internet

14.4~64Kbps

Low-QoS Mobile Multimedia Services

64~144Kbps

High-quality, Smooth and Low-delay Video, Voice, and Music Services

20~300Kbps

Mobile Broadband Internet Surfing

64~300Kbps

Abundant and High-quality New Mobile Services

300K~5Mbps

3G

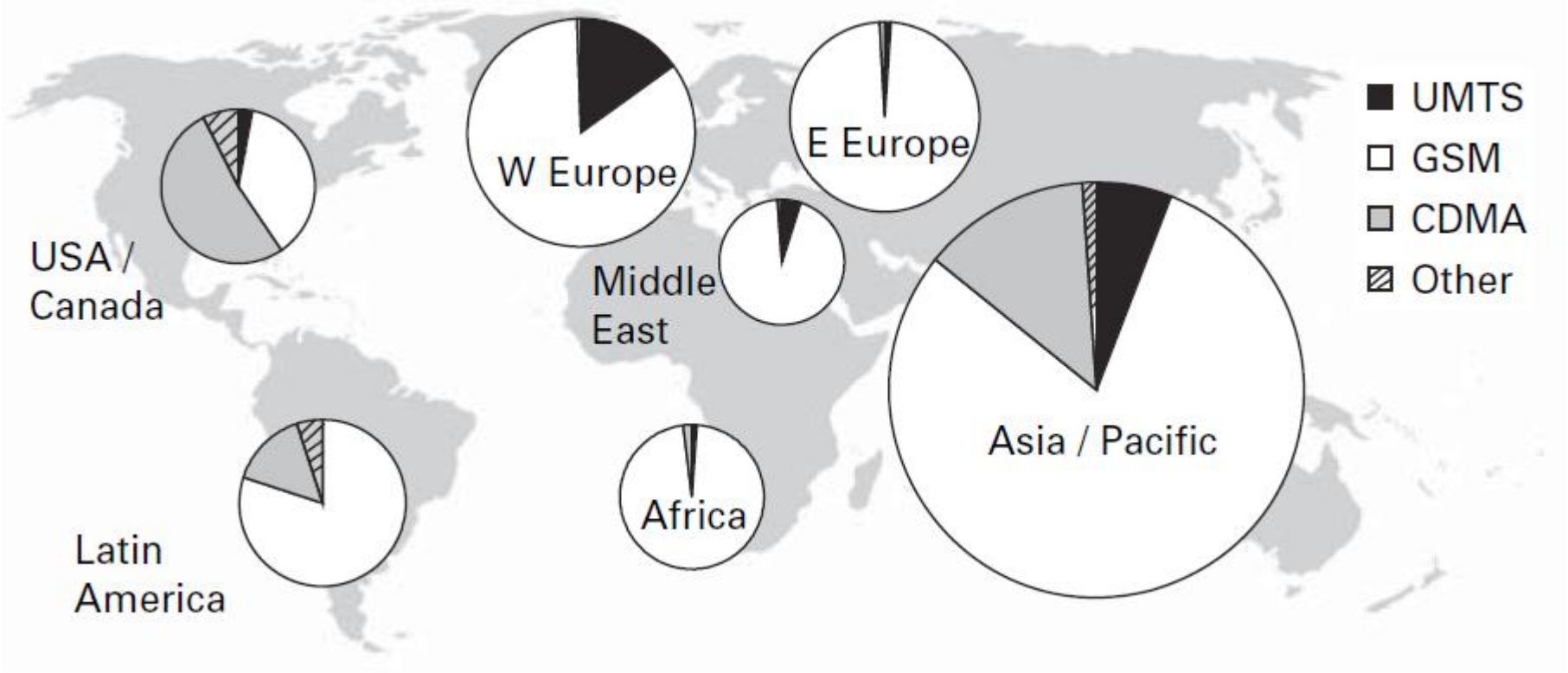
- International Mobile Telecommunications-2000 (**IMT-2000**)
  - A subgroup of the International Telecommunication Union (**ITU**)
  - Published a set of performance requirements of 3G (for both packet-switched and circuit-switched data):
    - A minimum data rate of 144 Kbps in the vehicular environment
    - A minimum data rate of 384 Kbps in the pedestrian environment
    - A minimum data rate of 2 Mbps in the fixed indoor and picocell environment
- There are several wireless standards and systems that qualify as third generation (3G) systems
  - UMTS
  - CDMA2000

UMTS

- **Universal Mobile Telecommunications System (UMTS)**
- The research activity on UMTS started in **Europe** at the beginning of the 1990s.
  - Even before the earliest 2G systems arrived on the market
- Designed to support wideband services with data rates up to **2Mbit/s**.
- Developed **from GSM**
  - Keep the core network more-or-less intact
  - Change the air interface to use **CDMA**
- Compatibility between UMTS and GSM:
  - Most UMTS mobiles also implement GSM, and the network can hand them over from a UMTS base station to a GSM one if they reach the edge of the UMTS coverage area.
  - However, network operators cannot implement the two systems in the same frequency band, so they are not fully compatible with each other.

Market Share

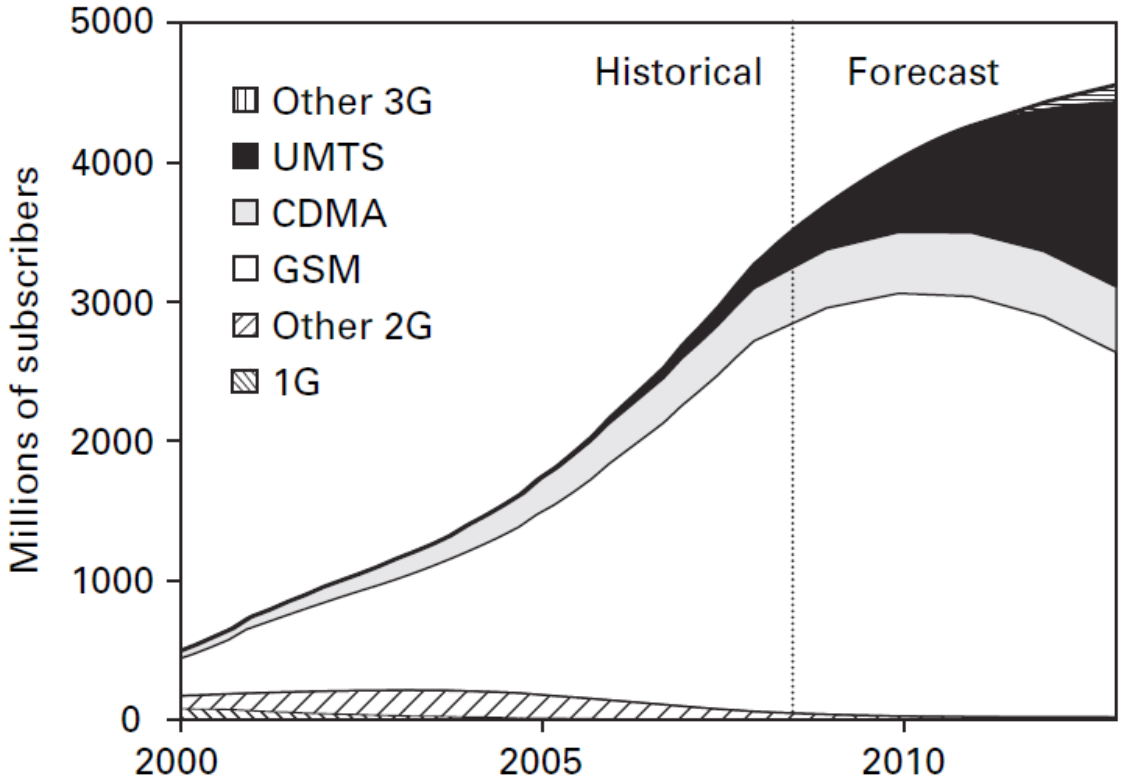
- Numbers of subscribers to different mobile communication technologies in 2008.



[Cox, 2008, Fig 1.15]

Growth

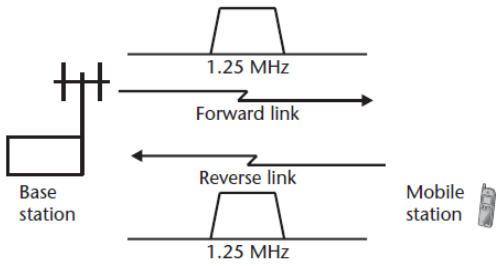
- Growth in the use of different mobile telecommunication technologies, with historical data from 2000 to 2008, and forecasts from 2008 to 2013.



[Cox, 2008, Fig 1.16]

cdma2000

- Another 3G mobile technology standard
- Multicarrier, direct-sequence CDMA FDD system.
- Backward-compatible with its previous 2G iteration IS-95 (cdmaOne).
- **CDMA2000 1X (IS-2000)**
  - also known as 1x and 1xRTT
  - 1x = Spreading Rate 1 = use the same chip rate of IS-95 (i.e., 1.2288 Mcps).
    - Same RF bandwidth as IS-95: a duplex pair of 1.25 MHz radio channels.
  - Core CDMA2000 wireless air interface standard.
  - Almost doubles the capacity of IS-95 by adding 64 more traffic channels to the forward link, orthogonal to (in quadrature with) the original set of 64.



Evolution of UMTS Specifications

Release	Functional freeze	Main UMTS feature of release
Rel-99	March 2000	Basic 3.84 Mcps W-CDMA (FDD & TDD)
Rel-4	March 2001	1.28 Mcps TDD (aka TD-SCDMA)
Rel-5	June 2002	HSDPA
Rel-6	March 2005	HSUPA (E-DCH)
Rel-7	December 2007	HSPA+ (64QAM downlink, MIMO, 16QAM uplink) LTE and SAE feasibility study

Also dubbed 3.5G, 3G+ or turbo 3G

HSPA

3.5G?

- **High Speed Packet Access (HSPA)** is a collection of two mobile telephony protocols
  - High Speed **Downlink** Packet Access (HSDPA) and
  - High Speed **Uplink** Packet Access (HSUPA)
- Extend and improve the performance of existing WCDMA/UMTS protocols.
- Current HSDPA deployments support down-link speeds of 1.8, 3.6, **7.2** and 14.0 Megabit/s.
- Many HSPA rollouts can be achieved by a **software upgrade** to existing 3G networks, giving HSPA a head start over WiMAX, which requires dedicated network infrastructure.
- There is also a further standard, **Evolved HSPA (HSPA+)**.

3.9G?

  - HSPA+ provides speeds of up to **42 Mbit/s** downlink and 84 Mbit/s with Release 9 of the 3GPP standards.

3G in Thailand: HSPA, HSPA+

- TOT: 2.1 GHz
- Truemove: 850 MHz
- Dtac: 850 MHz
- AIS: 900 Mhz
- Be careful!

Iphone 4

- GSM model:
  - 2G: Quadband GSM/EDGE (850, 900, 1800, 1900 MHz)
  - 3G: UMTS/HSDPA (7.2 Mbps)/HSUPA (850, 900, 1900, 2100 MHz)
- CDMA model: CDMA EV-DO Rev. A (800, 1900 MHz)
- Wi-Fi 802.11b/g/n
  - WLAN (Wireless LAN)
  - 802.11n 2.4GHz only
- Bluetooth v2.1+ EDR
- A-GPS navigation

Samsung Galaxy SII

- The version released on Sprint will be called the Samsung Within, on AT&T, the Attain, and on Verizon, the Function.
- Two models for 3G (HSPA+)
  - 850/2100 MHz
  - 900/2100 MHz
- Wi-Fi 802.11b/g/n
- Bluetooth 3.0

“4G” in the US


Sprint
Mobile WiMax
Sprint
Seattle
Spokane
Portland
Billings
Omaha
Reno
Kansas City
Indianapolis
Wichita
Albuquerque
Oklahoma City
Little Rock
Phoenix
Tucson
San Antonio
Boston
Virginia Beach


verizon wireless
LTE
verizon


T··Mobile·
HSPA+
T··Mobile·

Comparison

	Sprint	verizon	T-Mobile
"4G" Technology	WiMax	LTE	HSPA+
Speed	Downstream average speeds of 3-6 Mbps, 10 Mbps peak. "10x faster than 3G."	5-12 Mbps downstream and 2-5 Mbps upstream	Peak downstream of 21Mbps, peak upstream of 5.7Mbps. "Up to 3x faster than 3G."
Coverage	Nationwide coverage of many major cities and markets.	38 markets and 60 major airports on December 5th, 2010. Full nation-wide coverage by 2013.	Nationwide coverage of many major cities and markets.
OS Compatibility	All OS' (via Mobile HotSpot)	Windows-only (at launch, Mac OS X support to come)	Windows and Mac
Devices	USB Modems and Mobile Hotspot	USB Modems	USB Modems and Netbook
Monthly Cost	$60 for unlimited 4G data and 5GB of 3G data.	$50 for 5GB, $80 for 10GB, $10/GB overage fee.	$25 for 200MB, $40 for 5GB and no ovarage fees.

[lifehacker.com]

LTE: Around the World

[Wireless Week Magazine, February 2011]

802.16 (WiMAX)

- **WirelessMAN**
- Provide wireless data over long distances.
- **Certification** is done by the WiMAX Forum

- Oct 2007: ITU officially approved WiMAX as part of the 3G standard. It is the first non-cellular tech to get approval as 3G.

Original 802.16

- Completed in **2001**
- Intended primarily for telecom **backhaul** applications in **point-to-point line-of-sight** configurations using spectrum above 10 GHz.
- Use a radio interface based on a ***single-carrier waveform***.
- Ex. RF signal provided the communication between the two hubs located on top of big buildings that could see each other, and each hub was connected through wires to other nodes inside the building.

“Fixed” WiMAX

- **802.16-2004** based systems
- Fixed broadband wireless MAN
- Added multiple radio interfaces, including one based on OFDM-256 and one based on **OFDMA**.
- Support **point-to-multipoint** communications, sub-10 GHz operation, and **non-line-of-sight** communications.
- Potential applications include wireless Internet Service Provider (ISP) service, local telephony bypass, as an alternative to cable modem or DSL service, and for cellular backhaul for connections from cellular base stations to operator infrastructure networks.

“Mobile” WiMAX

- Used to describe **802.16e-2005** based systems.
- 802.16e-2005 = 802.16-2004 standard + 802.16e amendment
- Specify **scalable** OFDM for the physical layer and makes further modifications to the MAC layer to accommodate high-speed mobility
- Adds **mobility** capabilities including support for radio operation while mobile, handovers across base stations, and handovers across operators.
- Not backward-compatible with IEEE 802.16-2004 networks
- Employ many of the same mechanisms as HSPA to maximize throughput and spectral efficiency, including high-order modulation, efficient coding, adaptive modulation and coding, and Hybrid Automatic Repeat Request (HARQ).
- The principal difference from HSDPA is the use of **OFDMA**.
  - OFDM systems exhibit greater orthogonality on the uplink, so IEEE 802.16e-2005 may have slightly greater uplink spectral efficiency than even HSUPA.

UMTS to LTE

(Collaboration between groups of telecommunication associations (partners))

3rd Generation Partnership Project

International Telecommunication Union

ITU-R

R = Radiocommunication Standardization Sector

Scope

International Mobile Telecommunications systems

3G: IMT-2000 | UMTS (W-CDMA) | CDMA2000

Long Term Evolution

4G: IMT-Advanced | LTE-Advanced

LTE-Advanced

- Won't be so much about speed (although it can deliver the goods if optimized)
- About saving money
- Downlink:
  - Upto **1 Gbps** fixed mobile broadband
    - Need 40 MHz of spectrum and 8×8 MIMO antenna solution, or about 100 MHz of spectrum without using MIMO
  - 100 Mbps for actual mobile broadband (like when you're in your car or on a train.)
- Uplink: up to 200 Mbps for fixed mobile broadband

Part 3: WiFi

(Local Area Network)

WiFi (Wireless LAN – IEEE 802.11)

IEEE 802.11

- In 1997, the Institute of Electrical and Electronics Engineers (IEEE) released the standard IEEE 802.11 for wireless local area network (WLAN) applications.

	Frequency [GHz]	Max Rate [Mbps]
b	2.4	11
g	2.4	54
a	5.0	54

IEEE 802.11n-2009

- 11 September 2009
- Took seven years and involved 400 members from 20 countries.
- Improve network throughput over the two previous standards (a and g)
  - maximum raw data rate from 54 Mbit/s to **600 Mbit/s**
  - can achieve up to 600Mbps PHY layer data rate [Zhu et al, 2011]
- The use of four spatial streams at a channel width of 40 MHz.
- Since 2007, the Wi-Fi Alliance has been certifying interoperability of "draft-N" products based on what was draft 2.0 of IEEE 802.11n specification.
- All draft-n certified products remain compatible with the products conforming to the final standards.