Evolution of Wireless Mobile Communication

1G (analog)
- AMPS (America)
  - Voice
- TACS, NMT (Europe)
  - Voice

2G (digital)
- IS-95A
  - Voice, 14.4k
- IS-54
  - Voice, 14.4k
- GSM
  - Voice, 14.4k
- CDMA2000
  - Voice, 153k
  - Data, 56k
- GPRS
  - Voice, 384k
- WCDMA
  - Voice, 14.4k
  - Data, 56k
  - Voice, 14.4k
- EVDO
  - Voice, 384k
  - Data only, 2.4M/150k
- HSDPA
  - Voice, 384k
  - 14.4M/5M
  - 14.7M/5.4M ~200M
- EDGE
  - Voice, 384k
  - 20M/5M
  - 40M/10M
- HSPA+
  - Voice, 384k
  - 100M~1G
- LTE
  - Voice, 384k
  - 20M/5M
  - 40M/10M

3G~3.9G (high speed data)
- WCDMA
  - Voice, 384k
  - Data, 56k
- HSDPA
  - Voice, 384k
  - 14.4M/5M
  - 14.7M/5.4M ~200M
- TD-SCDMA
  - China
  - Voice, 384k

4G (very high speed data)
- UMTS
  - Voice, 384k
  - Data, 56k
- WiMAX
  - Wave 1
  - 20M/5M
- WiMAX
  - Wave 2
  - 40M/10M
- LTE
  - Voice, 384k
  - 20M/5M
  - 40M/10M
- TD-SCDMA
  - China
  - Voice, 384k

- 1G (analog)
- 2G (digital)
- 3G~3.9G (high speed data)
- 4G (very high speed data)
1G and 2G cellular Systems

- Advanced Mobile Phone System (AMPS)
  - Developed by Bell Labs in the 1970s and first used commercially in the United States in 1983. It operates in the 800 MHz band (1G) by AT&T
  - Full duplex (FDX) operation: simultaneous two-way communication
    - two 30 kHz channels (forward & reverse)
  - Analog frequency modulation (FM) used exclusively
  - Frequency Division Multiple Access (FDMA)
    - one channel per pair of users
2G cellular Systems

• 2G Overview
  – The European Global System for Mobile Communications (GSM), is introduced in 1992
  – The North American Digital AMPS (D-AMPS), is introduced in 1994
    • IS-54: FDMA/TDMA access mode
    • IS-95: CDMA access mode
  – The First CDMA commercial service was started in Korea in 1996
  – The Japanese Digital Cellular (JDC) system, is introduced in 1992, PDC (Personal Digital Cellular)
  – The North American Personal Communication System operating at 1900 MHz (PCS 1900)
GSM Overview

• Global System for Mobile (GSM) Communication
  – GSM is a second generation cellular standard developed to cater to voice services and data delivery using digital modulation
  – Digital Communication technology
  – GSM networks operate in a number of different frequency ranges
    • Most 2G GSM networks: 900 MHz or 1800 MHz bands.
    • Some countries in the Americas: 850 MHz and 1900 MHz bands
    • Most 3G GSM networks in Europe operate in the 2100 MHz frequency band.

• History
  – Developed by Group Spéciale Mobile (founded 1982) which was an initiative of CEPT (Conference of European Post and Telecommunication)
  – Developed to replace the incompatible analog system
  – Presently the responsibility of GSM standardization resides with special mobile group under ETSI (European telecommunication Standards Institute)
  – Full set of specifications phase-I became available in 1990. Under ETSI, GSM is named as “Global System for Mobile communication”
GSM System (cont’d)

• Advantages
  – Worldwide used with over millions of subscribers.
  – International roaming
  – Robust to channel noise compared to FDMA
  – GSM's maturity means engineers cut their teeth on the technology, creating an unconscious preference.
  – The availability of Subscriber Identity Modules, which are smart cards that provide secure data encryption give GSM advantages.

• Disadvantages
  – Low Data rate
  – Strict synchronization and guard time needed
  – Still susceptible to jamming, and other-cell interference
CDMA System

• History
  – In 1993, TIA recognized CDMA as an IS-95 Standard
  – Korea government promote to commercialize the technology in two parts
    • ETRI and Qualcomm took charge of switch design, prototype development and base transmit station
    • Handset manufactures developed new mobile handsets and switching system
  – Core chip for CDMA communication was successfully developed by Qualcomm
    • Power control was a key issue
    • A complex high tech chip of the times

• Keypoint
  – “multiple access” : a large number of users share a common pool of radio channel bandwidth and any user can gain access to any channel
  – Idea derived from military & developed by Qualcomm, USA around late 1980’s
  – Use Spreading Sequence for spreading gain
  – One common frequency band for all users
  – Separation between users can be done by user-specific code
## CDMA vs. GSM

<table>
<thead>
<tr>
<th>Note</th>
<th>CDMA</th>
<th>GSM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adopted year</td>
<td>1996</td>
<td>1989</td>
</tr>
<tr>
<td>Users rate (’05)</td>
<td>20%</td>
<td>70%</td>
</tr>
<tr>
<td>Region</td>
<td>America, South-Korea, Mongol</td>
<td>Europe, South America, Most country</td>
</tr>
<tr>
<td>3G</td>
<td>CDMA-2000</td>
<td>W-CDMA</td>
</tr>
</tbody>
</table>
Development from 2G to 3G

**1st Gen**
- Japan: TACS
- Europe: NMT/TACS/Other
- Americas: AMPS

**2nd Gen**
- Japan: PDC
- Europe: GSM
- Americas: TDMA
- CDMA

**3rd Gen**
- Japan: W-CDMA/EDGE (EDGE in Europe and Asia outside Japan)
- Europe: EDGE
- Americas: cdma2000

Global strategy based on W-CDMA and EDGE networks, common IP based network, and dual mode W-CDMA/EDGE phones.

Converged TDMA/GSM family of technologies will have dominant market share (~80 percent).

W-CDMA and cdma2000 will be optional modes in one spec. Basic phones will be one or the other. Global phones will have both.
IMT-2000

- **International Mobile Telecommunication (IMT)-2000**
  - Better known as 3G or 3rd Generation, is a family of standards for mobile telecommunications defined by the International Telecommunication Union
  - Which includes GSM EDGE, UMTS, and CDMA2000 as well as DECT and WiMAX
  - Compared to 2G and 2.5G services, 3G allows simultaneous use of speech and data services and higher data rates (up to 14.0 Mbit/s on the downlink and 5.8 Mbit/s on the uplink with HSPA+)
  - Thus, 3G networks enable network operators to offer users a wider range of more advanced services while achieving greater network capacity through improved spectral efficiency
## 2G vs. 3G

<table>
<thead>
<tr>
<th></th>
<th>2G</th>
<th>3G (IMT-2000)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Service</strong></td>
<td>Low-speed Data service (Voice)</td>
<td>High-quality Data service (Multi-media)</td>
</tr>
<tr>
<td><strong>User</strong></td>
<td>Customer -&gt; Customer</td>
<td>Customer &lt;-&gt; Customer, IP &lt;-&gt; Customer</td>
</tr>
<tr>
<td><strong>Traffic trend</strong></td>
<td>Land to Mobile</td>
<td>Mobile to Land</td>
</tr>
<tr>
<td><strong>Mobility</strong></td>
<td>domestic, limited global roaming</td>
<td>Global roaming</td>
</tr>
<tr>
<td><strong>Frequency band</strong></td>
<td>Mobile</td>
<td>1885 ~ 2025MHz</td>
</tr>
<tr>
<td></td>
<td>824 ~ 849MHz</td>
<td>2110 ~ 2200MHz</td>
</tr>
<tr>
<td></td>
<td>869 ~ 894MHz</td>
<td></td>
</tr>
<tr>
<td><strong>Frequency band</strong></td>
<td>PCS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1750 ~ 1780MHz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1840 ~ 1870MHz</td>
<td></td>
</tr>
<tr>
<td><strong>Standard</strong></td>
<td>CDMA, TDMA</td>
<td>W-CDMA, CDMA2000</td>
</tr>
<tr>
<td><strong>Minimum bandwidth</strong></td>
<td>1.25MHz, 30KHz</td>
<td>5MHz</td>
</tr>
</tbody>
</table>
3G Technologies

- Two key Technologies: All based on CDMA technology
- Synchronous Vs. Asynchronous
  - Synchronous (3GPP2)
    - Synchronous method that obtain standard time using GPS
    - Each Base Station uses the same PN code
    - Base Station classification PN code with time epoch difference
    - CDMA2000 1X, EV-DO, EV-DV
  - Asynchronous (3GPP)
    - Asynchronous method with different PN code for each Base Station
    - W-CDMA, HSPA, HSPA+
# 3G Technologies

<table>
<thead>
<tr>
<th></th>
<th>W-CDMA</th>
<th>CDMA2000</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Leading area</strong></td>
<td>Europe, Japan</td>
<td>North America</td>
</tr>
<tr>
<td><strong>Standard organization</strong></td>
<td>3GPP</td>
<td>3GPP2</td>
</tr>
<tr>
<td><strong>Sync. Between BS</strong></td>
<td>Asynchronous method with different PN code for each base station</td>
<td>Synchronous method that obtain standard time using GPS</td>
</tr>
<tr>
<td><strong>Initial time Sync.</strong></td>
<td>Relatively long</td>
<td>Relatively short (Same PN code)</td>
</tr>
<tr>
<td><strong>Cell Planning</strong></td>
<td>Relatively easy (Asynchronous BS does not consider neighbor BS and cell radius)</td>
<td>Relatively difficult (Synchronous BS considers time-offset of neighbor BS’s PN code)</td>
</tr>
<tr>
<td><strong>System developer</strong></td>
<td>Ericsson, Nokia, NTT DoCoMo</td>
<td>Qualcomm, Lucent, Motorola</td>
</tr>
<tr>
<td><strong>Core Network</strong></td>
<td>GSM-MAP</td>
<td>ANSI-41</td>
</tr>
<tr>
<td><strong>Base technology</strong></td>
<td>GSM</td>
<td>IS-95</td>
</tr>
<tr>
<td><strong>Chip rate</strong></td>
<td>3.84Mcps</td>
<td>3.6864Mcps</td>
</tr>
</tbody>
</table>
CDMA2000 (3GPP2)

CDMA2000 Subscriber Statistics: June 2009

<table>
<thead>
<tr>
<th>Region</th>
<th>Subscribers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asia Pacific</td>
<td>263,055,000</td>
</tr>
<tr>
<td>North America</td>
<td>155,520,000</td>
</tr>
<tr>
<td>Caribbean &amp; Latin America</td>
<td>40,200,000</td>
</tr>
<tr>
<td>Europe</td>
<td>4,150,000</td>
</tr>
<tr>
<td>Middle East</td>
<td>5,960,000</td>
</tr>
<tr>
<td>Africa</td>
<td>25,420,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>494,305,000</strong></td>
</tr>
</tbody>
</table>

Worldwide Total: 494,305,000

- Asia Pacific: 53.2%
- North America: 31.5%
- Caribbean & Latin America: 8.1%
- Europe: 0.8%
- Middle East: 1.2%
- Africa: 5.2%

Reported by the CDMA Development Group, June 2009
4G Wireless - 3GPP LTE

- 3GPP LTE (Long Term Evolution)
  - the last step toward the 4th generation (4G) of radio technologies designed to increase the capacity and speed of mobile telephone networks
  - Considered as 3.5G system
  - Uses Orthogonal Frequency Division Multiple Access (OFDMA) on the downlink
  - Downlink peak rates of at least 100 Mbps, an uplink of at least 50 Mbit/s
  - RAN round-trip times of less than 10 ms
  - Supports scalable carrier bandwidths, from 20 MHz down to 1.4 MHz
  - Supports both FDD and TDD
  - Adopted all-IP signaling and networking (A significant departure from 3G W-CDMA, which adopts circuit switching)
3GPP LTE

- High Data Rates at High Speed
  - Bit rates: 50(UL), 100Mbps(DL)
  - Speed: Walking to bullet-train

- Reduced Cost/GByte
  - Higher system capacity
  - Lower cost/GByte

- Reduced Latency
  - Quick response time

- Optimized for packet-switching
  - Better support for VoIP & data

- Cost Efficient Roll-out
  - Reuse 3G/2G spectrum
  - Bandwidth flexibility
  - Minimum Frequency planning
## 3GPP LTE

<table>
<thead>
<tr>
<th></th>
<th>3G and Enhanced 3G</th>
<th>4G</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spectrum</strong></td>
<td>3G spectrum (2GHz band the additional band(s))</td>
<td>New spectrum</td>
</tr>
<tr>
<td><strong>Radio aspect</strong></td>
<td>WCDMA</td>
<td>HSDPA, EDCH etc</td>
</tr>
<tr>
<td><strong>Radio Access</strong></td>
<td>Direct-Sequence CDMA</td>
<td>Ultimate enhancement</td>
</tr>
<tr>
<td><strong>Min. TTI (Latency)</strong></td>
<td>10msec</td>
<td>2ms</td>
</tr>
<tr>
<td><strong>Carrier Bandwidth</strong></td>
<td>5MHz</td>
<td>5-20MHz</td>
</tr>
<tr>
<td><strong>Data rate</strong></td>
<td>384k-2Mbps</td>
<td>14Mbps</td>
</tr>
<tr>
<td><strong>NW aspect</strong></td>
<td>CS and PS</td>
<td>PS only</td>
</tr>
<tr>
<td></td>
<td>GTP(tunneling) [IP routing in CN]</td>
<td></td>
</tr>
</tbody>
</table>
### Overview of Mobile Communication

<table>
<thead>
<tr>
<th>Technology-oriented System</th>
<th>Service-oriented System</th>
<th>User-oriented System</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2G</strong></td>
<td><strong>3G</strong></td>
<td><strong>4G (2011~)</strong></td>
</tr>
<tr>
<td>Voice + SMS</td>
<td>Voice + Data</td>
<td>Voice + Data + Wireless Internet + Sensing</td>
</tr>
<tr>
<td>cdmaOne(9.6~13kbps)</td>
<td>W-CDMA/HSDPA (384kbps~2Mbps/14.4Mbps)</td>
<td>WiBro (30/50Mbps)</td>
</tr>
<tr>
<td>GSM (13kbps)</td>
<td>cdma2000 (153.6kbps)</td>
<td>cdma2000 R A, B/HSUPA (3~70Mbps/5.8Mbps)</td>
</tr>
<tr>
<td></td>
<td>DMB/Digital Camera /MP3 Phone</td>
<td>Game/Video Phone</td>
</tr>
<tr>
<td><strong>Service-oriented System</strong></td>
<td><strong>Technology-oriented System</strong></td>
<td><strong>User-oriented System</strong></td>
</tr>
<tr>
<td>High-speed Wireless Internet (Broadband)</td>
<td>(Voice Quality/Roaming)</td>
<td>Ubiquitous Convergence Service (Broadband, Ubiquitous, Convergence, Intelligence)</td>
</tr>
</tbody>
</table>

#### Data Rates

- **2G**: cdmaOne/GSM (9.6~13kbps)
- **3G**: 3GPP LTE 100Mbps, WiBro Evolution 200Mbps, WiBro/ Mobile WiMAX 30~50Mbps, WiMAX 36Mbps, WLAN 802.11n 270Mbps, WPAN Bluetooth, Zigbee
- **4G (2011~)**: WiBro Advanced, VHT (NoLA) 수 Gbps, Multi-bits 60GHz/3~6Gbps, IEEE 802.15c / ECMA, 600Mbps 이상

#### Key Technologies

- **HSDPA**: High-Speed Downlink Packet Access
- **HSUPA**: High-Speed Uplink Packet Access
- **WPAN**: Wireless Personal Area Network
- **NeMA**: New Mobile Access
- **NoLA**: New Nomadic/Local Area Wireless Access
- **OFDM**: Orthogonal Frequency Division Multiplexing
- **MIMO**: Multiple Input Multiple Output
- **SDR**: Software Defined Radio
- **3GPP LTE**: 3GPP Long Term Evolution
- **GSM**: Global System for Mobile Communications
- **ECMA**: European Computer Manufacturers Association
Harmonization of IMT-2000
Capabilities of IMT

- **Systems beyond IMT-2000** will encompass the capabilities of previous systems.
- Recommendation ITU-R M.1645
- "IMT-ADVANCED"

**Peak useful data rate (Mbit/s)**

- **High**
- **Low**

**Mobility**

- **Interconnection**
- **Nomadic / Local Area Access Systems**
- **Digital Broadcast Systems**

**Enhancement**

- Enhanced IMT-2000
- New Mobile Access
- New Nomadic / Local Area Wireless Access

Dashed line indicates that the exact data rates associated with systems beyond IMT-2000 are not yet determined.