The Future of Mobile Wireless Internet Access

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AT&T
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Neopoint 1000
About $300, 6 ounces, versatile and slim, connects to a PC and has speech recognition.

PDQ Smart Phone
Perhaps from $1000, about 10 ounces, from Qualcomm, combines a phone with a Palm Pilot.

Thin Phone
Probably about $200, 4.2 ounces, also from Qualcomm but has a smaller screen.

Ericsson R380
Heading for the European market, 5 ounces

Motorola i1000 Plus
About $250, 5 ounces, has a phone and pager and handles e-mail.

The new Ericsson R380 phone, which features wireless data functions

The Mitsubishi phone operates as a quad mode TDMA phone for voice services and provides access to Internet and data services over the CDPD network, a packet-based wireless IP network.
Wireless Data Terminal Evolution

Sierra PCMCIA CDPD Modem

Nokia 9110

3COM Palm VII

Nokia 3G vision
AT&T Wireless Services

AT&T serves over 12 million subscribers with advanced digital TDMA technology and some analog technology, and provides packet data service with CDPD technology.

- **TDMA**
  - European GSM over 200 million
  - North American TDMA ~ 40 million
  - Japanese PDC ~ 50 million

- **CDMA**
  - North American CDMA ~ 50 million

GSM MOU and UWCC TDMA industry groups announced cooperation on January 13, 2000 for common technology development, including EDGE for 3G high-speed data services.
# Wireless Standards

<table>
<thead>
<tr>
<th>Wireless Technology</th>
<th>GSM/GPRS/EDGE</th>
<th>IS-136 TDMA</th>
<th>IS-95 CDMA</th>
<th>WCDMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel Bandwidth</td>
<td>200 KHz</td>
<td>30 KHz</td>
<td>1.25 MHz</td>
<td>5 MHz</td>
</tr>
<tr>
<td>Voice bearers 6 to 12 kbps</td>
<td>8 / 16</td>
<td>3 / 6</td>
<td>6 to 20</td>
<td>Up to 100</td>
</tr>
<tr>
<td>Peak data rates (kbps)</td>
<td>9.6 / 144 / 384</td>
<td>9.6</td>
<td>14.4 to 144</td>
<td>Up to 384</td>
</tr>
<tr>
<td>Frame length (msec)</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Frequency reuse</td>
<td>4 / 12 to 1 / 3</td>
<td>7 / 21 to 3 / 9</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Voice bearers Per MHz / base</td>
<td>10 to 30 / 20 to 60</td>
<td>14 to 33</td>
<td>14 to 48</td>
<td>Up to 60</td>
</tr>
<tr>
<td>Micro/Hierarchical cell support</td>
<td>Good</td>
<td>Good</td>
<td>Poor</td>
<td>Fair to Poor</td>
</tr>
<tr>
<td>Number of subs as of 4Q99</td>
<td>~ 200 million</td>
<td>~ 50 million</td>
<td>~ 50 million</td>
<td>N.A.</td>
</tr>
</tbody>
</table>
Wireless Data Technology

• Dedicated wireless packet data systems
  – Ardis
  – RAM Mobitex
• Wireless data access using cellular systems
  – Early systems - circuit access, CDPD & I-mode
  – GPRS - packet data on GSM
  – Packet data on IS-95 CDMA
• 3rd generation systems
  – EDGE (Enhanced Data rates for GSM Evolution)
  – Packet data on WCDMA
  – HDR (High Data Rates for CDMA2000 - IS-95)
• WAP (Wireless Application Part)
• Bluetooth - connecting nearby devices
Macrocellular Wireless Data Evolution

- EDGE
- WCDMA
- CDMA2000
- Wideband OFDM
- HDR
- CDMA2000 EDGE
- WCDMA
- GPRS
- IS-136
- PDC I-mode
- GSM
- CDPD
- IS-95
- 5 M
- 1 M
- 384 k
- 64 k
- 9.6 k

Timeline:
- 1995
- 2000
- 2005
Dedicated Wireless Packet Data Systems - used for e-mail & short messages

**ARDIS**
- Created by IBM & Motorola in 80’s
- 25 KHz channels
- FM modulation
- 4800 bps (2-level)
- 19.2 kbps (4-level)
- National US network operated by American Mobile

**RAM**
- Created by Ericsson in 80’s
- 12.5 KHz channels
- GMSK modulation
- 8 kbps
- National US network operated by BellSouth
Early Data Services on Cellular Systems

- Voice-band modems over analog cellular
  - end-to-end
  - with a cellular inter-working function
- 9.6 kbps circuit & FAX access over GSM, IS-136, PDC & IS-95 using a single time-slot or code and an interworking functions to standard modems
- CDPD - Cellular Digital Packet Data
- I-Mode - 9.6 kbps packet data over PDC - Japanese Personal Digital Communications (cellular)
CDPD - Cellular Digital Packet Data

- Proposed by IBM in 1991
- 30 KHz channels (compatible with AMPS)
- Shared base stations with cellular & an overlay network
- GMSK modulation at 19.2 kbps
- Supports TCP/IP connectivity
- Multi-mode CDPD/AMPS & CDPD/TDMA handsets & PCMCIA cards
- Service provided by AT&T, Bell Atlantic & others
I-Mode Packet Data Service

- NTT DoCoMo introduced packet data using PDC time-slots in 1997 with 9.6 kbps peak rates
- NTT DoCoMo introduced I-Mode service in early 1999
- Dual-mode PDC voice and packet data handsets
- Micro-browser and IP based
- 1000’s of content providers
  - weather
  - stocks
  - sports
  - horoscopes
  - short message service,
- Over 5 million subscribers in 1st year of service
GSM Evolution

• Circuit data - 9.6 kbps
• HSCD - 32 kbps circuit data
• GPRS - 144 kbps packet data
• 1/3 & 1/1 reuse frequency hopping
• EDGE - peak data rates of 384 kbps
• VoIP over EDGE
GPRS Airlink

- General Packet Radio Service (GPRS)
- Same GMSK modulation as GSM
- 4 channel coding modes
- Packet-mode
- Flexible time slot allocation (1-8)
- Radio resources shared dynamically between speech and data services
- Independent uplink and downlink resource allocation (Uplink State Flag polls uplink)
EDGE

- Extends GPRS packet data with adaptive modulation/coding
- 8-PSK/GMSK at 271 kbps in 200 KHz RF channels supports 9.02 to 69.2 kbps per time slot
- Supports peak rates over 384 kbps
- Requires linear amplifiers with < 3 dB peak to average power ratio using linearized GMSK pulses
- Initial deployment with 2x 1 MHz using 1/3 reuse with EDGE Compact as a complementary data service
Adaptive Modulation & Link Performance of EDGE

Throughput - kbps

C/I dB

MCS-1 (R=1/2)
MCS-2 (R=2/3)
MCS-3 (R=6/7)
MCS-4 (R=1)
MCS-5 (R=3/8)
MCS-6 (R=1/2)
MCS-7 (R=3/4)
MCS-8 (R=1)
EDGE Development

• R’1999 supports best effort packet data
  – trials in 2001
  – commercialization in 2002
• R’2000 supports Voice over IP over EDGE
  – commercialization in 2003
• Key features
  – IP centric
  – dual-mode IS-136 & EDGE terminals
  – launching R’99 with EDGE Compact in 1 MHz x2 of spectrum
  – launching R’2000 with ~ 2 MHz x2 of spectrum
WCDMA Packet Access

Dual mode scheme with adaptive mode selection based on packet-traffic characteristics

Small infrequent packets appended to random access request

| Random Access Request | Small packet | Random access channel |

Large or frequent packets transmitted on dedicated channel to maintain closed loop power control and assign dedicated code

| Random Access Request | Random access channel |

Dedicated channel

packet — packet — packet
Orthogonal Variable Spreading Factor (OVSF) codes.

$c_{1,1} = (1)$
$c_{2,1} = (1,1)$
$c_{2,2} = (1,-1)$
$c_{4,1} = (1,1,1,1)$
$c_{4,2} = (1,1,-1,-1)$
$c_{4,3} = (1,-1,1,-1)$
$c_{4,4} = (1,-1,-1,1)$

SF = 1
SF = 2
SF = 4
CDMA2000 Wireless Data

- 1.25 MHz carriers
- up to 384 kbps
- integrated voice & data airlink
- multicode operation
IS-95 CDMA HDR

- Based on separate carriers for voice and data
- Asymmetrical
- 1.25 MHz channels
- 1.22 MHz chip rates
- No soft-handoff
- No power control on downlink
- Uplink power control, similar to CDMA2000 & max of about 150 kbps
- Synchronized base stations
- Modulation/coding/spreading adaptation
- Reuse of 1
IS-95 CDMA HDR (cont’d)

• 32 kbps to 2.4 Mbps rates
• Typical peak rates of 250 to 500 kbps
• Spectral efficiency of 400 to 600 kbps/base/MHz
• Uplink request downlink mode 600 times per second
• 2-branch RX proposed for terminal
• TDMA with intelligent scheduling on downlink
• IP networking to the base station
• IP based mobility management
• voice or packet data access (not simultaneous - possible in the future with multi-carrier CDMA terminals)
4G Wireless

• IP packet data centric
• A “wireless cable modem”
  – Asymmetric access
  – WOFDM downlinks (peak rates of 5 to 10 Mbps)
  – 3G (EDGE) uplinks
• High-speed service to advanced handsets, laptops, PDAs, body-computers with heads-up displays, dash-board computers,….
• Complements 2G/3G Wireless
• Targets spectrum from 500 MHz to 3 GHz
• Flexible bandwidth - 200 KHz to 5 MHz
• Full macro-cell coverage
• Very high spectrum efficiency for downlink & uplink
OFDM/Multi-carrier Applications

- Military HF modems
- Voice-band modems
- Digital Broadcasting
- ADSL
- WLANs (IEEE 802.11 & HiperLAN II)
- WDM fiber optics
- Cable modems
OFDM Characteristics

• High peak-to-average power levels
• Preservation of orthogonality in severe multi-path
• Efficient FFT based receiver structures
• Enables efficient TX and RX diversity
• Adaptive antenna arrays without joint equalization
• Support for adaptive modulation by subcarrier
• Frequency diversity
• Robust against narrow-band interference
• Efficient for simulcasting
• Variable/dynamic bandwidth
• Used for highest speed applications
• Supports dynamic packet access
Smart Antennas significantly improve wireless system performance

- Interference suppression ⇒ Quality and capacity improvement (2x capacity is practical)
- Multipath diversity ⇒ Improve reliability
- Higher antenna gain ⇒ Range extension and lower cost (50 to 100% greater coverage possible)
Network Based Dynamic Packet Assignment

1. Mobile locks to the STRONGEST Base

2. Mobile sends measurements of path losses for nearby Bases to serving Base

3. Serving Base forwards measurements to nearby Bases

4. Bases assign channels to all packets/mobiles to maximize throughput/QOS

5. Bases forward channel assignment info to nearby Bases
Wireless Application Protocol (WAP)

- Mobile computing architecture supporting virtually all wireless network technologies
- Provides an inter-working function between a wireless client and a fixed server to mitigate low bandwidth and unreliable wireless access issues
- Uses Handheld Device Markup Language (HDML) and Wireless Markup Language (WML)
- Orientation to low-speed access
WAP Architecture

- Web server
- HTML Filter
- WAP Proxy
- WTA Server
- Wireless Network

WAP - Wireless Application Protocol
WTA - Wireless Telephony Application
WML - Wireless Markup Language
HTML - HyperText Markup Language
Bluetooth
(named after Harold Bluetooth, Danish King)

• Goal is low-cost & short range radio link to connect devices locally (ex. handset & laptop)
• Supports simultaneous isochronous voice and asynchronous data
• Global specification using the 2.4 GHz ISM band
• Conceived by Ericsson
• Founders are Ericsson, IBM, Intel, Nokia, Toshiba
• Over 800 companies have joined as Adopters
• Version 1 specification 2Q99
• Chipsets available in 2000
Bluetooth Networking

Cordless

Ad Hoc

LAN

corporate

public

Internet

LAN

cellular
Bluetooth Air Interface

- 2.4 to 2.48 GHz operation
- 1600 frequency hops per second
- GFSK modulation at 1 Mbps
- Discriminator detection
- Coding rate 1, 2/3 (Hamming 15,10) and 1/3 (repetition)
- 0 dBm or up to 20 dBm TX power
- 0.1% BER max at -70 dBm RX
- Packet data and/or circuit voice operation
- 64 kbps CVSD voice coding
- Peak data rates of 721 kbps
Wireless Internet Milestones

• 80’s - Ardis & RAM dedicated packet data networks
• 90’s - CDPD and circuit data over GSM & CDMA
• 1999 - Imode in Japan
• 2000 - many GPRS deployments planned
• 2001 - initial WCDMA & EDGE launches
• 2001 - HDR launches
• ? - 4G & WOFDM