Wireless Communications

Chapter 2

Modern Wireless Communication Systems

- The widespread adoption of wireless communications was accelerated in the mid 1990s, when governments throughout the world provided increased competition and new radio spectrum licenses for personal communications services (PCS) in the 1800-2000 MHz frequency bands.
- Wireless local area networks (WLANs) – high data rate, indoor, unlicensed.
- Cellular telephone service – outdoor, licensed.

- It appears that the in-building wireless access market may become a huge battleground between licensed and unlicensed service.
- This is prompting the architects of today's popular cellular standards to design for high data rate packet-based networking capabilities in the next generation of cellular technology.

2.1 Second Generation (2G) Cellular Networks

- First generation cellular systems –
  - ✓ FDMA/FDD
  - ✓ analog FM
- Second generation standards –
  - ✓ digital modulation formats
  - ✓ TDMA/FDD
  - ✓ CDMA/FDD multiple access techniques.

- The most popular second generation standards include three TDMA standards and one CDMA standard:
  - Global System Mobile (GSM) – Europe, Asia, Australia,
  - Interim Standard 136 (IS-136) – North America,
  - Pacific Digital Cellular (PDC) – Japan,
  - Interim standard 95 Coded Division Multiple Access (IS-95) also known as cdmaOne – North America

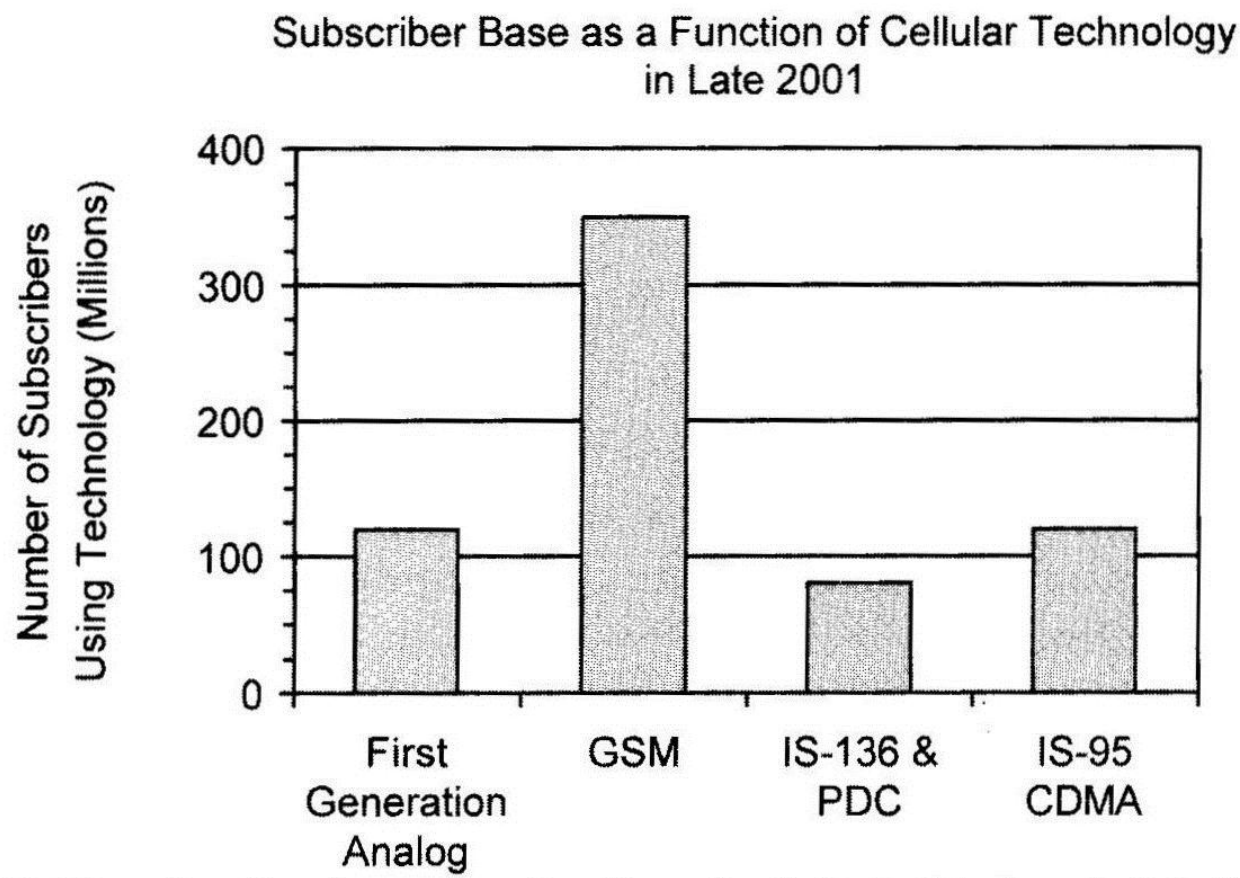


Figure 2.2 Worldwide subscriber base as a function of cellular technology in late 2001.

Table 2.1 Key Specifications of Leading 2G Technologies (adapted from [Lib99])

	cdmaOne, IS-95, ANSI J-STD-008	GSM, DCS-1900, ANSI J-STD-007	NADC, IS-54/IS-136, ANSI J-STD-011, PDC
Uplink Frequencies	824-849 MHz (US Cellular) 1850-1910 MHz (US PCS)	890-915 MHz (Europe) 1850-1910 MHz (US PCS)	800 MHz, 1500 MHz (Japan) 1850-1910 MHz (US PCS)
Downlink Frequencies	869-894 MHz (US Cellular) 1930-1990 MHz (US PCS)	935-960 MHz (Europe) 1930-1990 MHz (US PCS)	869-894 MHz (US Cellular) 1930-1990 MHz (US PCS) 800 MHz, 1500 MHz (Japan)
Duplexing	FDD	FDD	FDD
Multiple Access Technology	CDMA	TDMA	TDMA
Modulation	BPSK with Quadrature Spreading	GMSK with $BT = 0.3$	$\pi/4$ DQPSK
Carrier Separation	1.25 MHz	200 kHz	30 kHz (IS-136) (25 kHz for PDC)
Channel Data Rate	1.2288 Mchips/sec	270.833 kbps	48.6 kbps (IS-136) (42 kbps for PDC)
Voice channels per carrier	64	8	3
Speech Coding	Code Excited Linear Prediction (CELP) @ 13 kbps, Enhanced Variable Rate Codec (EVRC) @ 8 kbps	Residual Pulse Excited Long Term Prediction (RPE-LTP) @ 13 kbps	Vector Sum Excited Linear Predictive Coder (VSELP) @ 7.95 kbps

- All 2G technologies offer at least a three-time increase in spectrum efficiency.
- In mid 2001, there are two universal and competing third generation (3G) cellular mobile radio technologies:
    - one based on the philosophy and backward compatibility of GSM
    - the other based on the philosophy and backward compatibility of CDMA

2.1.1 Evolution to 2.5G Mobile Radio Networks

- The 2G digital standards were designed before the widespread use of the Internet. (Since the mid 1990s)
- GSM, CDMA, and IS-136 standards only support 9.6 kbps transmission rates for data messages.
- Short messaging service (SMS) is a popular feature of GSM, even with relatively small user data rates.

- 2G standards use a circuit switched approach to transmit data.
- 2.5G standards have been developed to allow 2G technologies to be upgraded incrementally for faster Internet data rates.

2.1.2 Evolution for 2.5G TDMA standards

- The three TDMA upgrade options include:
  - High Speed Circuit Switched Data (HSCSD)
  - General Packet Radio Service (GPRS)
  - Enhanced Data Rates for GSM Evolution (EDGE)

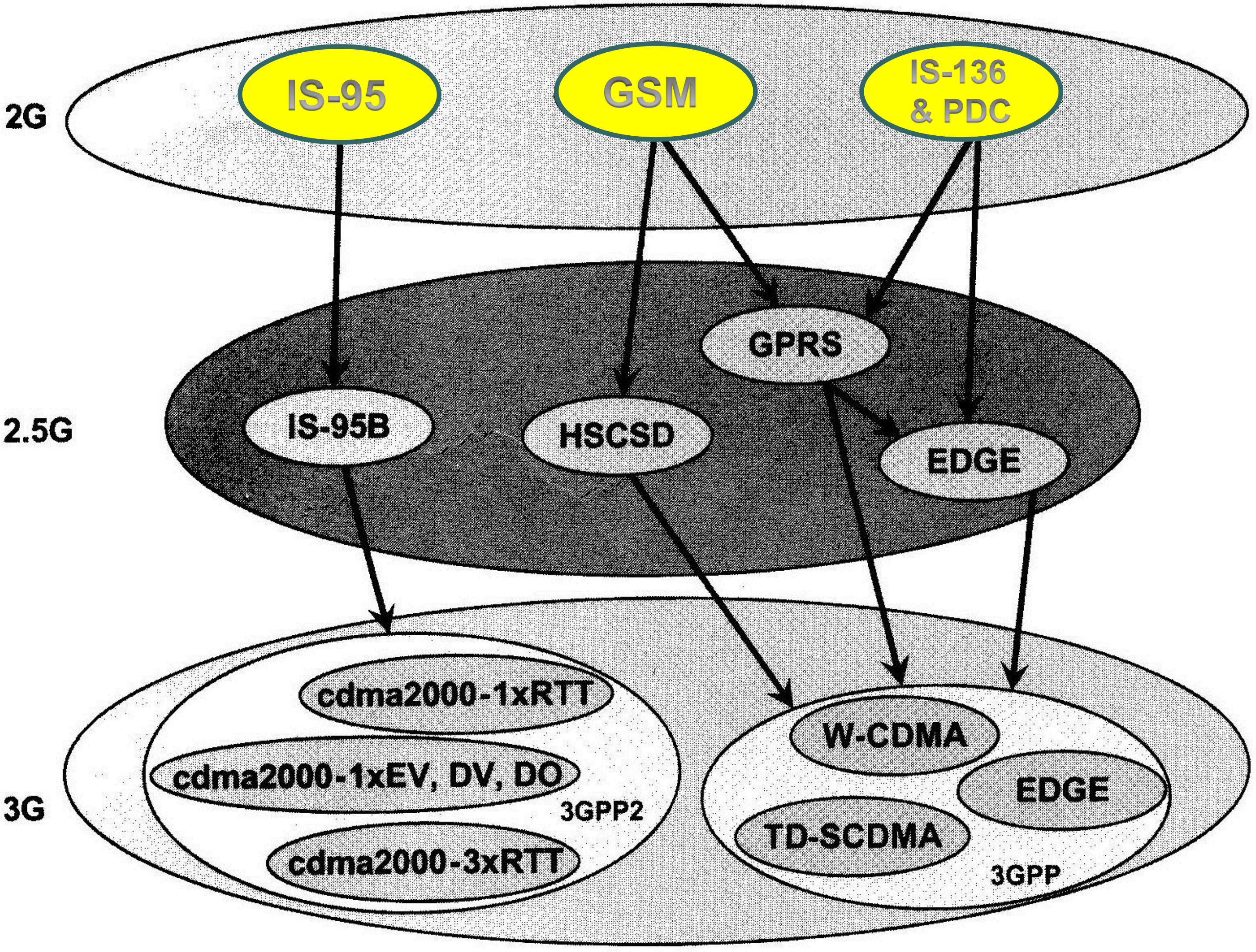


Figure 2.3 Various upgrade paths for 2G technologies.

Table 2.2 Current and Emerging 2.5G and 3G Data Communication Standards

Wireless Data Technologies	Channel BW	Duplex	Infrastructure change	Requires New Spectrum	Requires New Handsets
HSCSD	200 KHz	FDD	Requires software upgrade at base station.	No	Yes New HSCSD handsets provide 57.6 Kbps on HSCSD networks, and 9.6 Kbps on GSM networks with dual mode phones. GSM-only phones will not work in HSCSD networks.
GPRS	200 KHz	FDD	Requires new packet overlay including routers and gateways.	No	Yes New GPRS handsets work on GPRS networks at 171.2 Kbps, 9.6 Kbps on GSM networks with dual mode phones. GSM-only phones will not work in GPRS networks.
EDGE	200 KHz	FDD	Requires new transceiver at base station. Also, software upgrades to the base station controller and base station.	No	Yes New handsets work on EDGE networks at 384 Kbps, GPRS networks at 144 Kbps, and GSM networks at 9.6 Kbps with tri-mode phones. GSM and GPRS-only phones will not work in EDGE networks.
W-CDMA	5 MHz	FDD	Requires completely new base stations.	Yes	Yes New W-CDMA handsets will work on W-CDMA at 2 Mbps, EDGE networks at 384 Kbps, GPRS networks at 144 Kbps, GSM networks at 9.6 Kbps. Older handsets will not work in W-CDMA.
IS-95B	1.25 MHz	FDD	Requires new software in base station controller.	No	Yes New handsets will work on IS-95B at 64 Kbps and IS-95A at 14.4 Kbps. CdmaOne phones can work in IS-95B at 14.4 Kbps.
cdma2000 1xRTT	1.25 MHz	FDD	Requires new software in backbone and new channel cards at base station. Also need to build a new packet service node.	No	Yes New handsets will work on 1xRTT at 144 Kbps, IS-95B at 64 Kbps, IS-95A at 14.4 Kbps. Older handsets can work in 1xRTT but at lower speeds.
cdma2000 IxEV (DO and DV)	1.25 MHz	FDD	Requires software and digital card upgrade on 1xRTT networks.	No	Yes New handsets will work on 1xEV at 2.4 Mbps, 1xRTT at 144 Kbps, IS-95B at 64 Kbps, IS-95A at 14.4 Kbps. Older handsets can work in 1xEV but at lower speeds.
cdma2000 3xRTT	3.75 MHz	FDD	Requires backbone modifications and new channel cards at base station.	Maybe	Yes New handsets will work on 95A at 14.4 Kbps, 95B at 64 Kbps, 1xRTT at 144 Kbps, 3xRTT at 2 Mbps. Older handsets can work in 3X but at lower speeds.

- HSCSD is a circuit switched technique that allows a single mobile subscriber to use consecutive user time slots in the GSM standard.
- GPRS is a packet-based data network.
- EDGE is sometimes referred to as Enhanced GPRS, or EGPRS.

- incremental redundancy – user will quickly reach a condition that uses the minimum amount of overhead.
- Therefore, providing acceptable link quality for each user while maximizing user capacity on the network.

2.1.3 IS-95B for 2.5G CDMA

- Unlike the several GSM and IS-136 evolutionary paths to high speed data access, CDMA (often called cdmaOne) has a single upgrade path for eventual 3G operation.

2.2 Third Generation (3G) Wireless Networks

- In mid-1995, the International Telecommunications Union (ITU) formulated a plan to implement a global frequency band in the 2000 MHz range that would support a single, ubiquitous wireless communication standard for all countries throughout the world.

ITU headquarters, Geneva

- This plan called International Mobile Telephone 2000 (IMT-2000).

- However, the hope for a single worldwide standard has not materialized.
- The worldwide user community remains split between two camps :
  - Cdma2000 – from 2G CDMA systems
  - Wideband CDMA (W-CDMA), also called Universal Mobile Telecommunications Service (UMTS) – from GSM, IS-136, and PDC systems.

- The ITU IMT-2000 standards organizations are currently separated into two major organizations :
  - 3GPP (3G Partnership Project for Wideband CDMA standards based on backward compatibility with GSM and IS-136/PDC)
  - 3GPP2 (3G Partnership Project for cdma2000 standards based on backward compatibility with IS-95)

- ITU's 2000 World Radio Conference established the 2500-2690 MHz, 1710-1885 MHz, and 806-960 MHz bands as candidates for 3G.
- In the US, additional Spectrum in the upper UHF television bands near 700 MHz is also being considered for 3G.
- Five 3G licenses in England - $ 35.5Billion USD.
- Four 3G licenses in Germany - $ 46 Billion USD.

2.2.1 3G W-CDMA (UMTS)

- The UMTS is a visionary air interface standard that has evolved since late 1996 under the auspices of the European Telecommunications Standards Institute (ETSI).
- UMTS was submitted to ITU'S IMT-2000 body in 1998. At that time, UMTS was known as UMTS Terrestrial Radio Access (UTRA).

Table 2.3 Leading IMT-2000 Candidate Standards as of 1998 (adapted from [Lib99])

Air Interface	Mode of Operation	Duplexing Method	Key Features
cdma2000 US TIA TR45.5	Multi-Carrier and Direct Spreading DS-CDMA a N = 1.2288 Mcps with N = 1, 3, 6, 9, 12	FDD and TDD Modes	• Backward compatibility with IS-95A and IS-95B. Downlink can be implemented using either Multi-Carrier or Direct Spreading. Uplink can support a simultaneous combination of Multi-Carrier or Direct Spreading • Auxiliary carriers to help with downlink channel estimation in forward link beamforming.
UTRA (UMTS Terrestrial Radio Access) ETSI SMG2	DS_CDMA at Rates of $N \times$ 0.960 Mcps with N = 4, 8, 16	FDD and TDD Modes	• Wideband DS_CDMA System. • Backward compatibility with GSM/DCS-1900. • Up to 2.048 Mbps on Downlink in FDD Mode. • Minimum forward channel bandwidth of 5 GHz. • The collection of proposed standards represented here each exhibit unique features, but support a common set of chip rates, 10 ms frame structure, with 16 slots per frame. • Connection-dedicated pilot bits assist in downlink beamforming.
W-CDMA/NA (Wideband CDMA) North America) USA T1P1-ATIS			
W-CDMA/Japan (Wideband CDMA) Japan ARIB			
CDMA II South Korea TTA			
WIMS/W-CDMA USA TIA TR46.1			
CDMA I South Korea TTA	DS-CDMA at $N \times$ 0.9216 Mcps with N = 1, 4, 16	FDD and TDD Modes	• Up to 512 kbps per spreading code, code aggregation up to 2.048 Mbps.
UWC-136 (Universal Wireless Communications Consortium) USA TIA TR 45.3	TDMA - Up to 722.2 kbps (Outdoor/Vehicular), Up to 5.2 Mbps (Indoor Office)	FDD (Outdoor/ Vehicular), TDD (Indoor Office)	• Backward compatibility and upgrade path for both IS-136 and GSM. • Fits into existing IS-136 and GSM. • Explicit plans to support adaptive antenna technology.
TD-SCDMA China Academy of Telecommunication Technology (CATT)	DS-CDMA 1.1136 Mcps	TDD	• RF channel bit rate up to 2.227 Mbps. • Use of smart antenna technology is fundamental (but not strictly required) in TD-SCMA.
DECT ETSI Project (EP) DECT	1150-3456 kbps TDMA	TDD	• Enhanced version of 2G DECT technology.

2.2.2 3G cdma2000

- The first 3G CDMA interface – cdma2000 1xRTT.
- 1x – one times the original cdmaOne channel bandwidth (1.25MHz)
- RTT – Radio Transmission Technology.
- cdma2000 1xEV, DO (data only), DV (data and voice).

2.2.3 3G TD-SCDMA

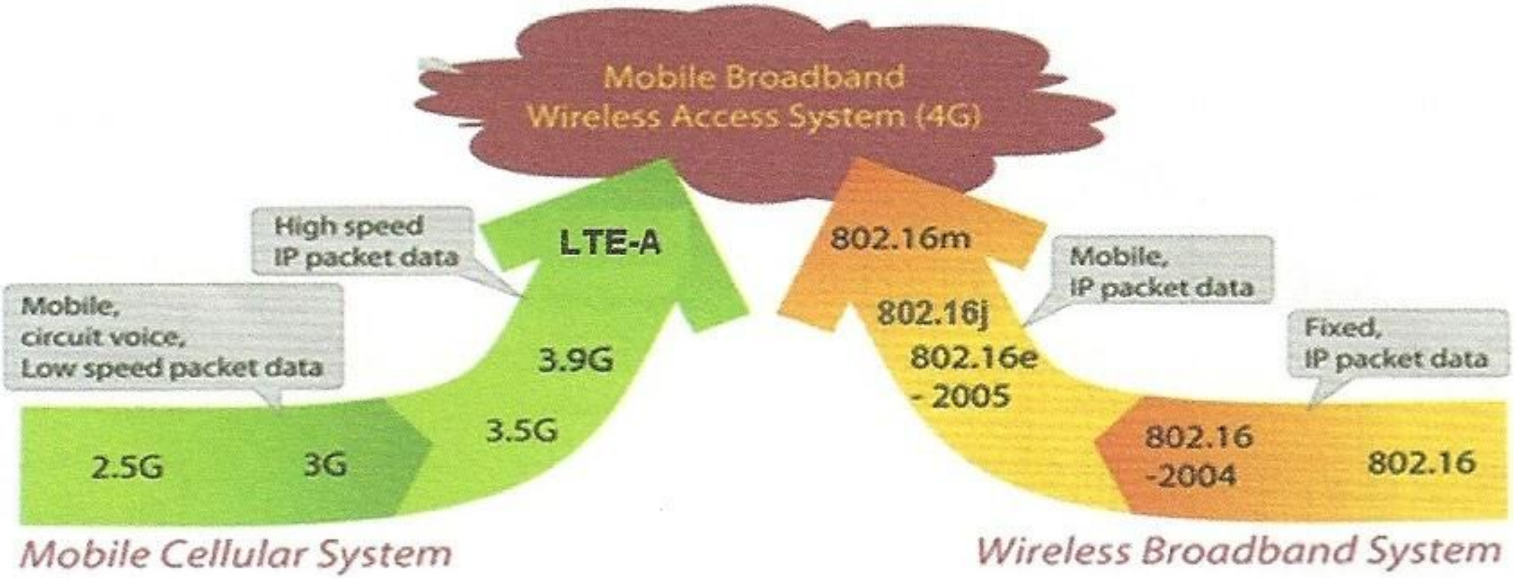
- In China, GSM is the most popular wireless air interface standard.
- The wireless subscriber growth in china is unmatched anywhere in the world in 2001.
- The China Academy of Telecommunications Technology (CATT) and Siemens Corporation submitted and IMT-2000 3G standard proposal in 1998 – Time Division – Synchronous Code Division Multiple Access (TD-SCDMA).

Fourth Generation (4G) Wireless Networks

- 2010年10月國際電信聯盟(ITU-R)決定採納 LTE-Advanced (LTE-A)與 WirelessMAN-Advanced (WiMAX2)，作為下世代全球無線行動通寬頻通信 IMT-Advanced (4G)技術標準。
- 2008年3月ITU開始於第 5研究組(國際移動通信工作組) WP5D啟動徵求 IMT-Advanced候選技術工作，且決定於2009年10月為提交截止期限。

- 總共有來自中國、日本、韓國、3GPP和 IEEE的六項候選技術提案，主要為「3GPP LTE Release 10 and beyond」(即LTE-Advanced) 技術與 IEEE 802.16m技術兩大陣營。
- 2010年10月21日，國際電信聯盟完成了評估，最後融合為 LTE-Advanced 和 WirelessMAX-Advanced (WiMAX2) 兩種技術。

ITU-R Declares LTE-A, 802.16m as 4G Standards



Geneva, 21 October 2010 - ITU's Radiocommunication Sector (ITU-R) has completed the assessment of six candidate submissions for the global 4G mobile wireless broadband technology, otherwise known as IMT-Advanced. Harmonization among these proposals has resulted in two technologies, "LTE-Advanced" and "WirelessMAN-Advanced" being accorded the official designation of IMT-Advanced, qualifying them as true 4G technologies.

圖 1：IMT-Advanced 技術趨勢衍進（資料來源：ITU-R，工研院整理）

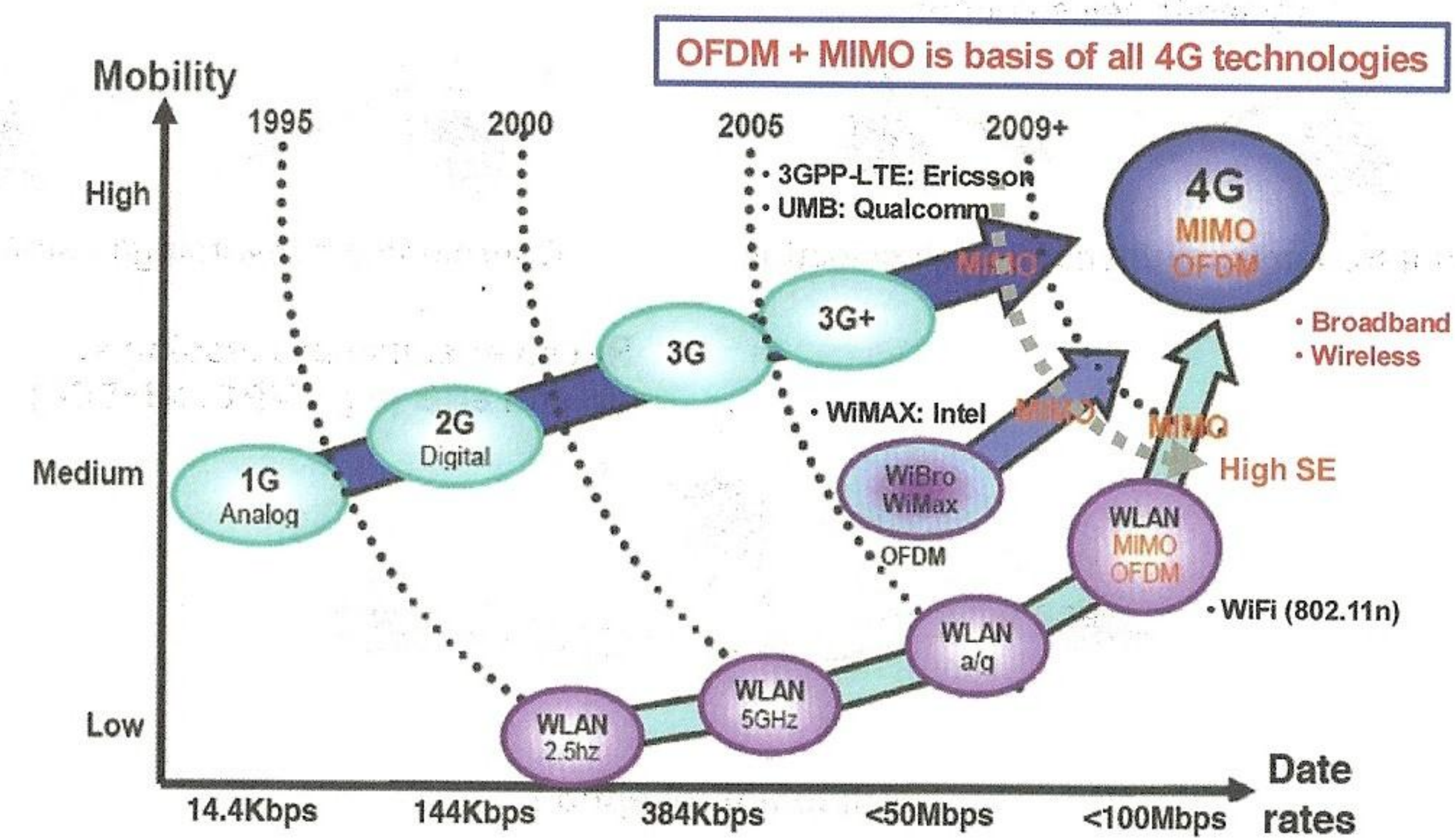


圖 6：通往 4G 的三大途徑及其發展演進 (參考來源 ITU-R M. (IMT-VIS) [Doc.8/110])

- LTE-Advanced系統共包含以下重點發展技術：
  1) 載波聚合 (Carrier Aggregation) 技術
  2) Advanced MIMO technologies
  3) Coordinated multiple-point (CoMP) transmission and reception
  4) 機器型態通訊 (Machine Type Communication, MTC)
  5) Relay中繼站技術

- MIMO-OFDM為 4G最主要的核心技術。
- 從1999年 IEEE 802.16 專案成立以來，IEEE 802.16m 已於2011年1月在台北舉辦的第70會期 (Session #70) 標準會議獲得 802.16 工作小組 (802.16 Working Group, 802.16WG) 投票通過，成為第一個達到 ITU IMT-Advanced 要求的通訊標準。

- 802.16系列標準仍在持續演進，802.16 工作小組於2010年成立了兩個新的任務小組 (task group)：IEEE 802.16p 與 IEEE 802.16n。
- IEEE 802.16p 主要目的為進一步加強 IEEE 802.16 系統對機器間 (Machine to Machine, M2M) 通訊服務的支援。
- IEEE 802.16n 主旨在於讓 802.16系統能在環境較差或高穩定度要求的網路中 (如高空監視、救難現場、與智能電網) 提供兼具強固性與穩定度的通訊服務。

LTE 技術發展

- 目前市場主流的 3G，係為 ITU所制定的全球標準 IMT-2000。
- IMT-2000共核准 6個技術標準 – CDMA2000, WCDMA, TD-SCDMA, EDGE, DECT 及 WiMAX)，其中以 WCDMA佔有率最大。
- 2006年，ITU將 Beyond 3G (B3G) 技術稱為 IMT-Advanced (4G) 技術，規定靜止時要達到1Gbps，高速移動時(120 km/h)要達到100Mbps。

- 二大陣營 – Intel為首的 WiMAX (IIEEE 82.16系列) 陣營與 Ericsson為首的 3GPP LTE陣營。
- 為了提升 3G的技術性能，3GPP又陸續完成了高速下行鏈路封包接取(High Speed Downlink Packet Access, HSDPA)及高速上行鏈路封包接取(High Speed Uplink Packet Access, HSUPA)。
- 2007年，3GPP完成 HSPA^{+} 技術 (Release 7)，達到 11.5Mbps 的傳輸速率，但與 4G的技術需求相比，差距仍然很大，因此 3GPP逐提出 LTE的技術標準(3.9G)(下行 100Mbps，上行 50Mbps)。

表一、3G及LTE技術發展期程表

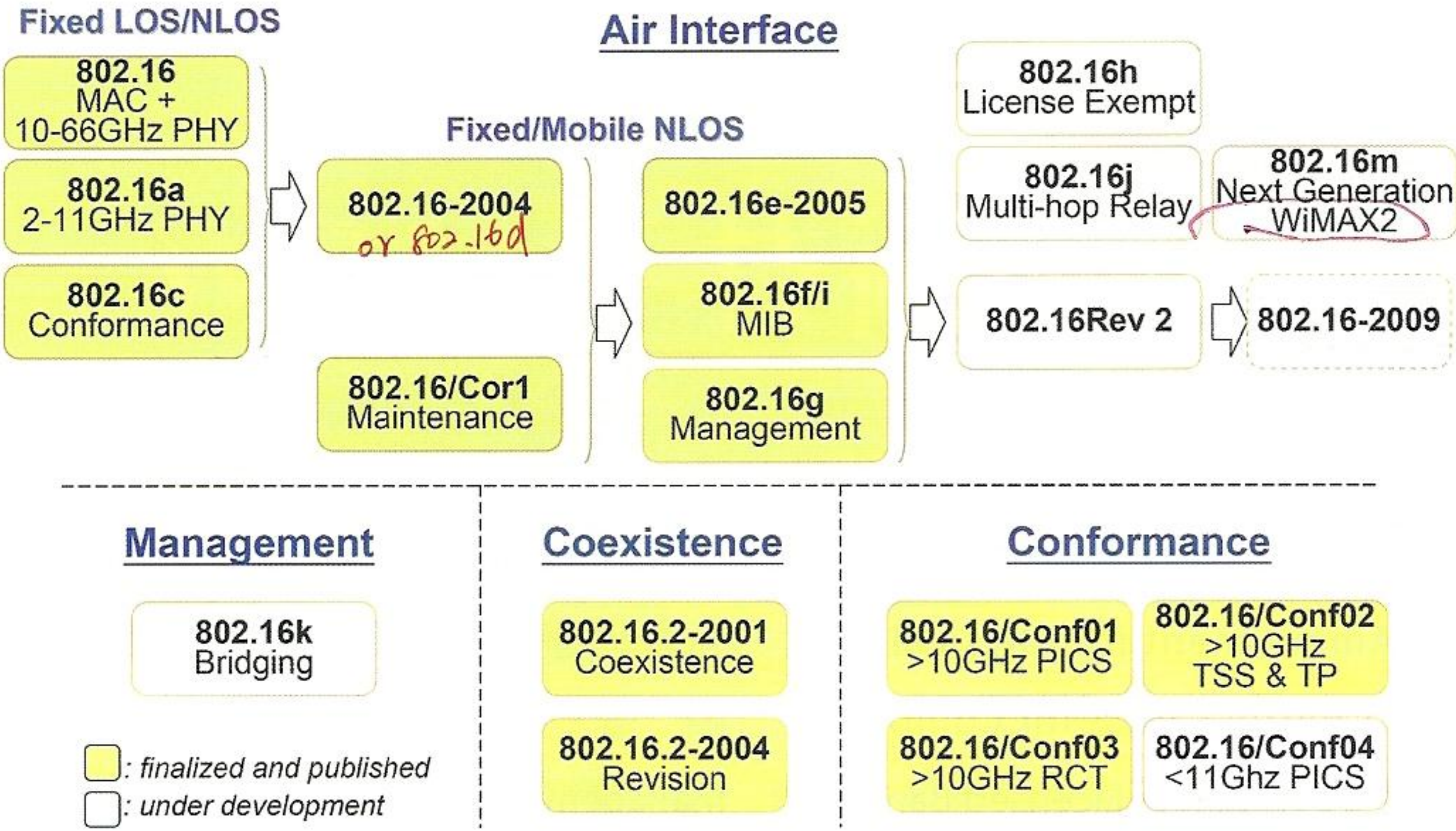
3GPP技術規範版本	年份	概述
Release 99	2000 Q1	第一個以WCDMA系統的3G商用網路規範
Release 4	2001 Q2	新增 all-IP核心網路
Release 5	2002 Q1	新增 IMS 與 HSDPA技術規範
Release 6	2004 Q4	新增 HSUPA技術規範
Release 7	2007 Q4	新增 HSPA+技術規範及SIM卡高速協議
Release 8	2008 Q4	新增LTE及All-IP網路之進階技術
Release 9	2009 Q4	增強WiMAX及LTE/UMTS之間的互通性
Release 10	2010 Q2	LTE Advanced技術制訂規劃
Release 11	制訂中	增強跨網路IP化應用服務互連技術規範

資料來源：3GPP，電信技術中心整理

WiMAX 技術發展

- 主導電腦數據傳輸協定的 IEEE 802 工作群於1999年開始推動新一代 IEEE 802.16無線寬頻技術。
- IEEE 802.16系列規格是一種國際標準的無線通訊技術，主要針對大樓林立的都會型網路 (MAN)制定 MAC層與PHY層的規範。

- 2004年6月通過規格書 IEEE 802.16d，稱為 IEEE 802.16-2004 (Air Interface for Fixed Broadband Wireless Access Systems) – Fixed WiMAX。
- 2004年12月通過 IEEE 802.16e，命名為 IEEE 802.16-2005，主要針對移動用戶，故又稱 Mobile WiMAX。
- IEEE 802.16e實體層採用 Scalable OFDMA(SOFDMA) 技術，並輔以 MIMO 天線技術。



圖一：IEEE 802.16x 規格發展圖

2.3 Wireless Local Loop (WLL) and LMDS

- Fixed wireless equipment is extremely well suited for rapidly deploying a broadband connection in many instances.
- Modern fixed wireless systems are usually assigned microwave or millimeter radio frequencies in the 28 GHz band and higher.
- At these higher frequencies, the wavelengths are extremely small, which in turn allows very high gain directional antennas to be fabricated in small physical form factors.

- Supports the transmission of very wide bandwidth signals, because of rejecting multipath signals.
- Fixed wireless networks at very high microwave frequencies are only viable where there are no obstructions.
- Microwave wireless links can be used to create a wireless local loop (WLL).

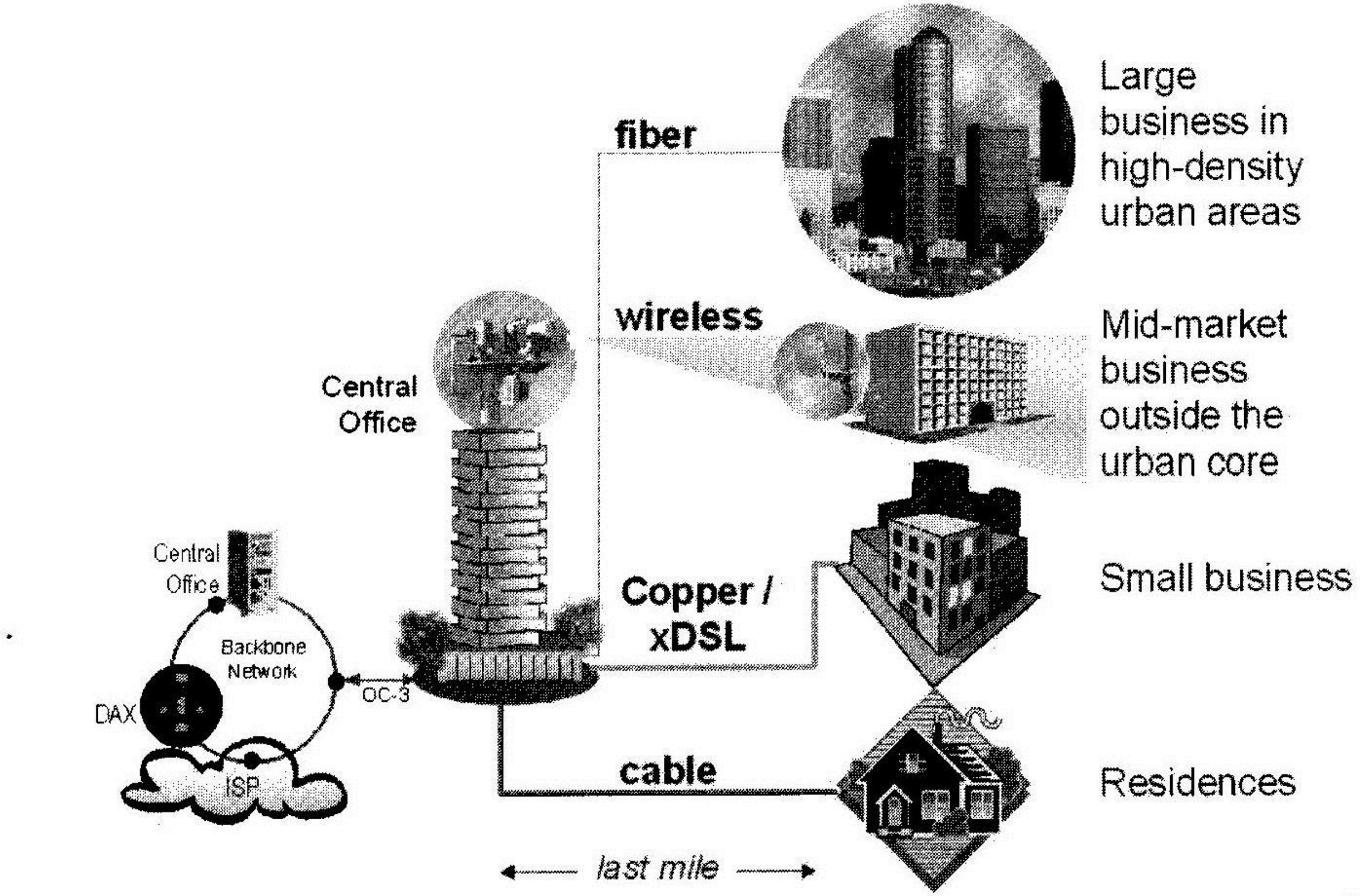


Figure 2.4 Example of the emerging applications and markets for broadband services. (Courtesy of Harris Corporation, ©1999, all rights reserved.)

- No additional costs after the wireless equipment is paid,
- In 1998, 1300 MHz of unused spectrum in the 27-31 GHz band was auctioned by the US government to support Local Multipoint Distribution Service (LMDS).

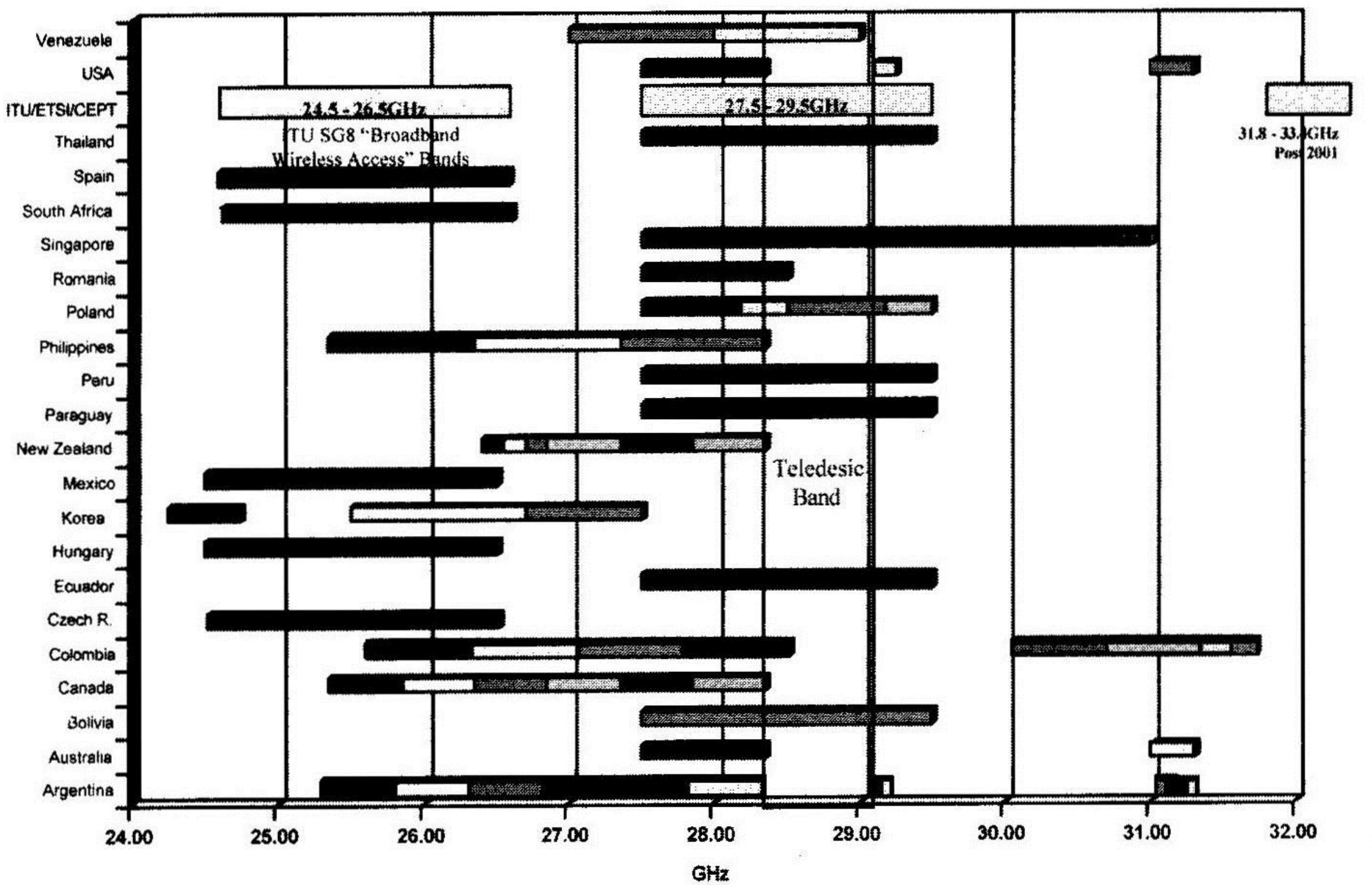
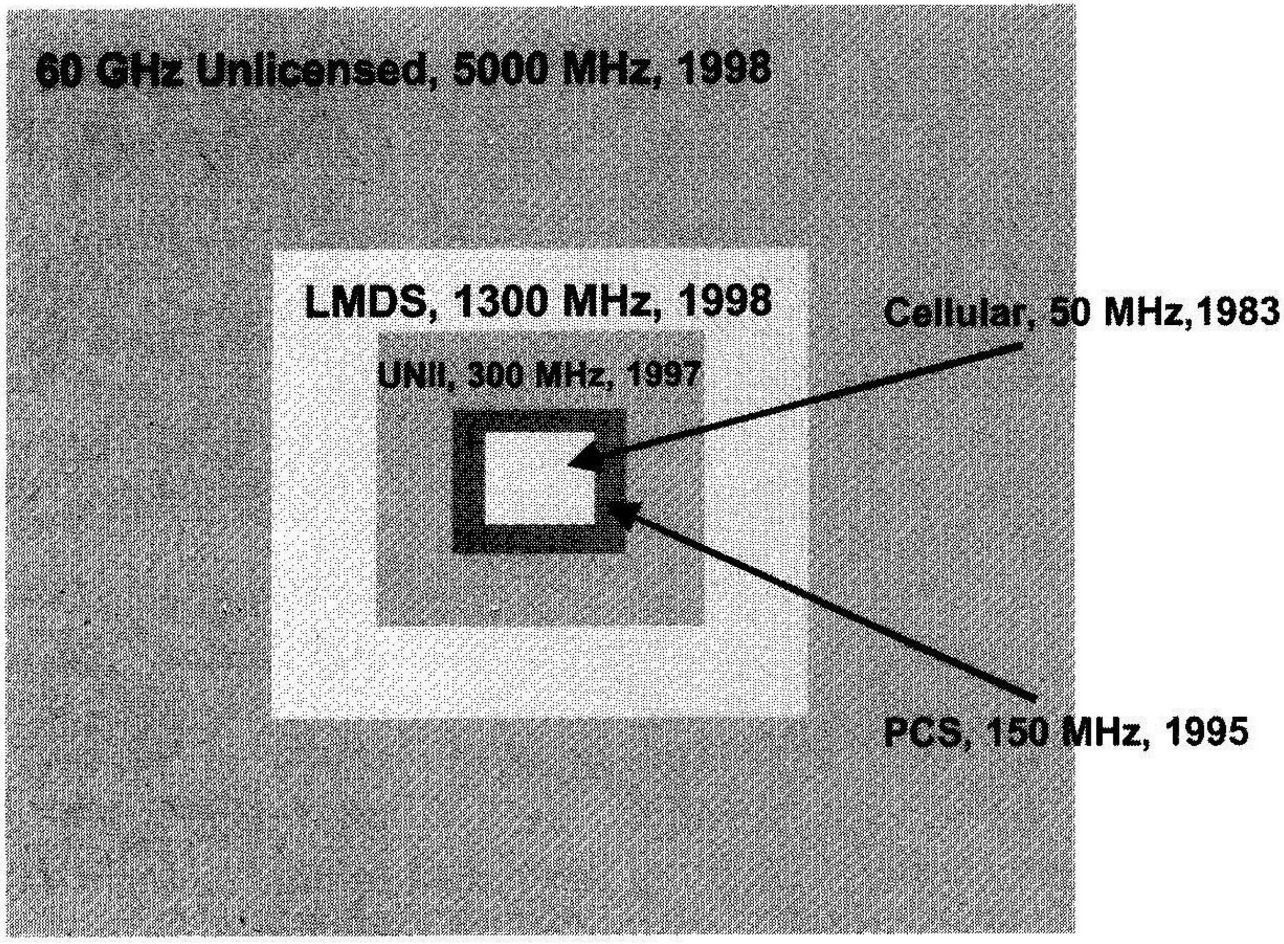


Figure 2.5 Allocation of broadband wireless spectrum throughout the world. (Courtesy of Ray W. Nettleton and reproduced by permission of Formus Communications.)



- A voice channel occupies ≈ 10 kHz of spectrum.
- A TV channel occupies ≈ 5 MHz of spectrum.

Figure 2.6 Comparison of spectrum allocations for various US wireless communications services. The areas of the rectangles are proportional to the amount of bandwidth allocated for each service.

- The tremendous amount of spectrum in the 59-64 GHz range is earmarked for unlicensed WLAN use.
- One of the most promising applications for LMDS is in a local exchange carrier (LEC) network.

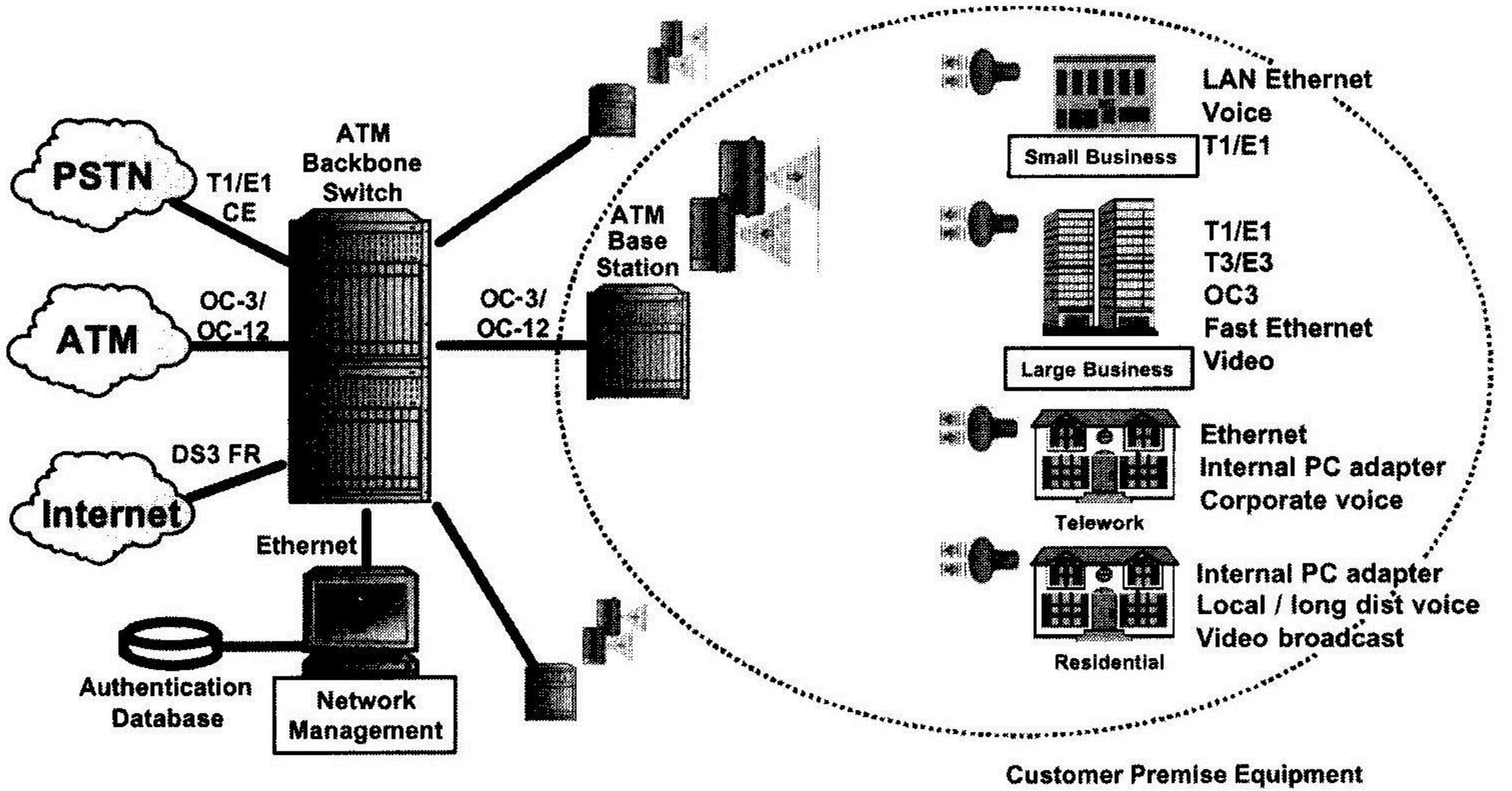
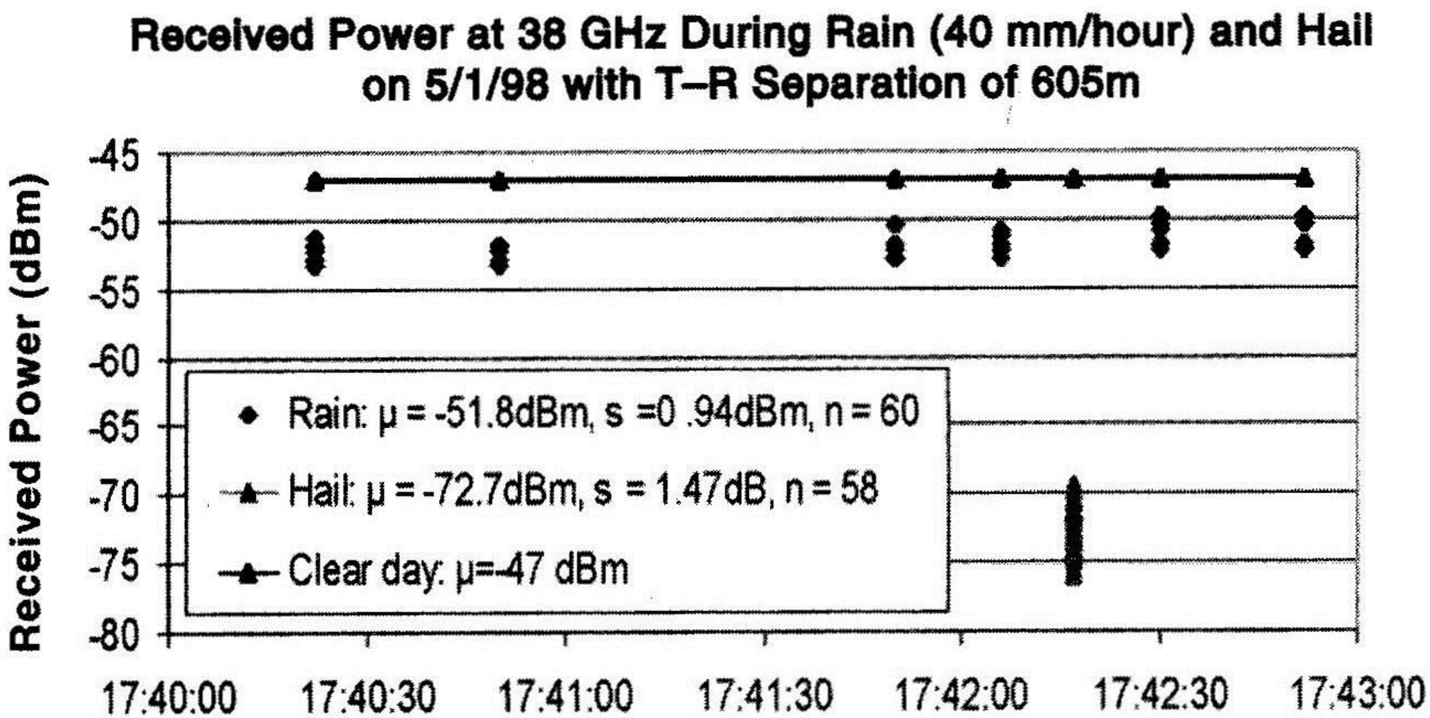


Figure 2.7 A wireless Competitive Local Exchange Carrier (CLEC) using Asynchronous Transfer Mode (ATM) distribution.

- Unfortunately, finding a line-of-sight path is not the only requirement for maintaining a suitable fixed wireless connection for millimeter wave fixed wireless links. Rain, snow, and hail can create large changes in the millimeter wave channel gain.



Attenuation due to hail: 25.7 dB.
Hail size: 0.5-1.5 cm in diameter.

Figure 2.8 Measured received power levels over a 605 m 38 GHz fixed wireless link in clear sky, rain, and hail [from [Xu00], ©IEEE].

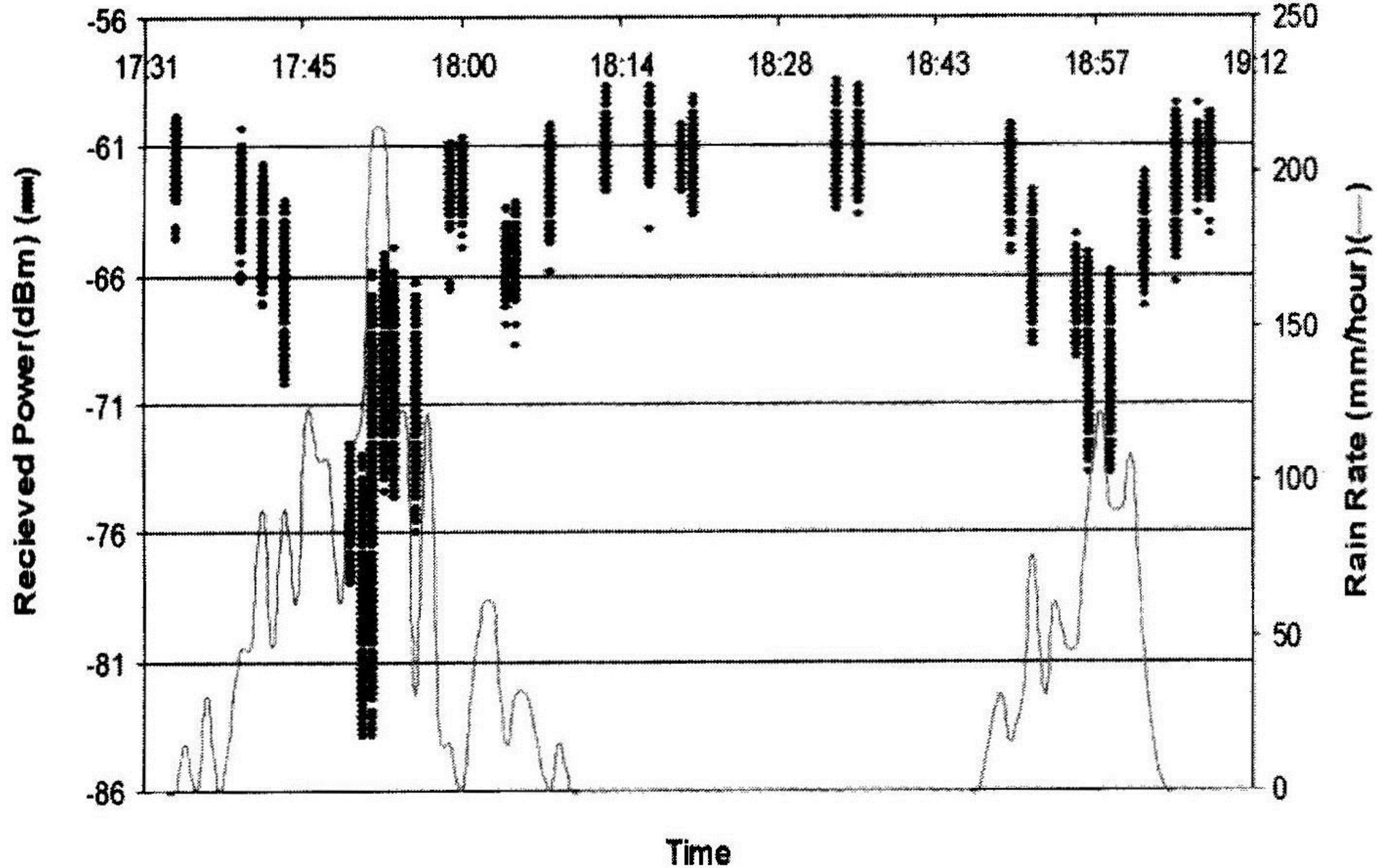


Figure 2.9 Measured received power during rain storm at 38 GHz [from [Xu00], ©IEEE].

2.4 Wireless Local Area Networks (WLANs)

- In 1997, the FCC allocated 300 MHz of unlicensed spectrum in the Industrial Scientific and Medical (ISM) bands of 5.150-5.350 GHz and 5.725-5.825 GHz.
- This allocation is called the Unlicensed National Information Infrastructure (UNII) band.

- In the late 1980s, the FCC first provided license free bands under Part 15 of the FCC regulations, for the spectrum in the 902-928 MHz, 2400-2483.5 MHz, and 5.725-5.825 MHz ISM bands.
- The IEEE 802.11 Wireless LAN working group was founded in 1987 to begin standardization of spread spectrum WLANs for use in the ISM bands.

- Until the late 1990s, WLANs became a important and rapidly growing marketplace.
- IEEE 802.11a, 802.11b, 802.11g – Wi-Fi

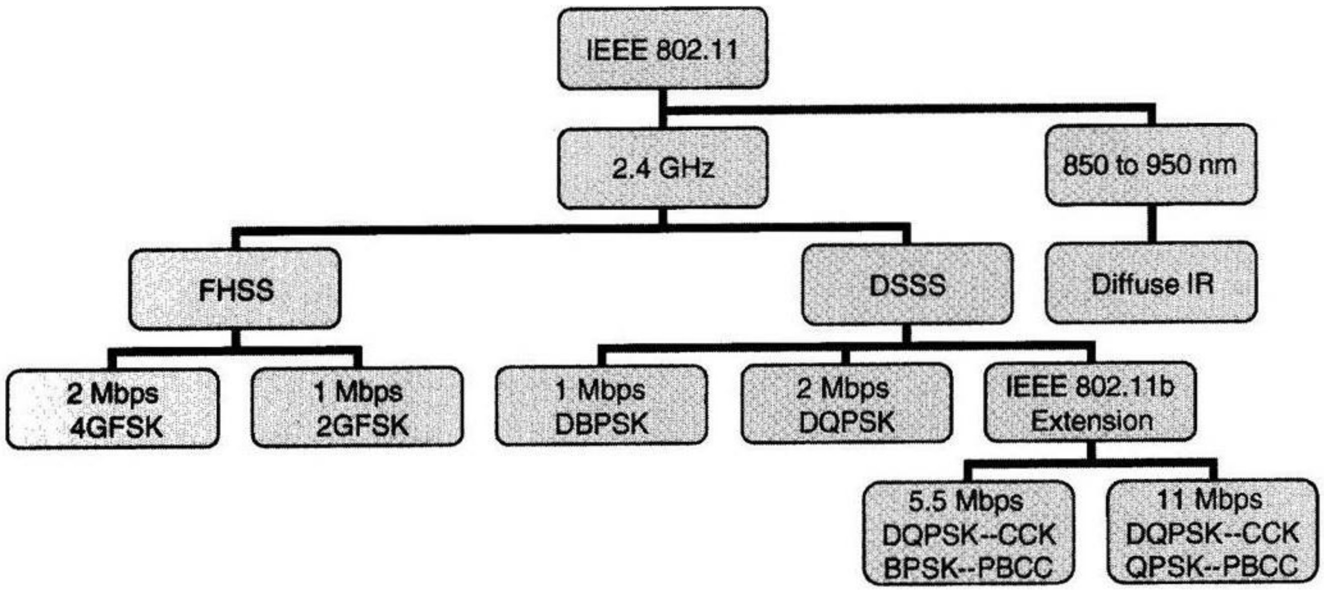


Figure 2.10 Overview of the IEEE 802.11 Wireless LAN standard.

- International channel allocations for DS and FH WLANs in the 2.4 GHz band.

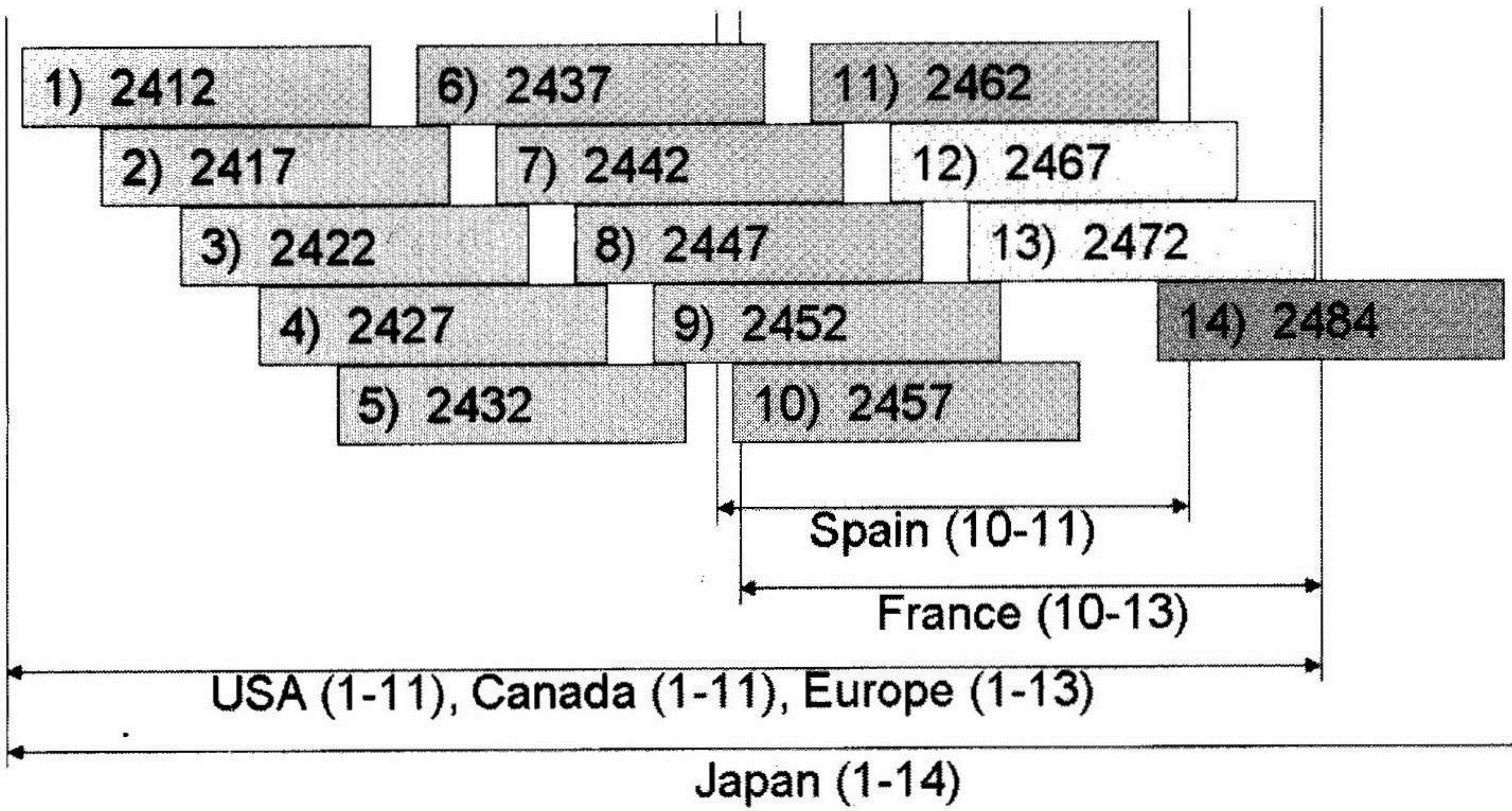


Figure 2.12 Channelization scheme for IEEE 802.11b throughout the world.

Table 2.4 IEEE 802.11b Channels for Both DS-SS and FH-SS WLAN Standards

Country	Frequency Range Available	DSSS Channels Available	FHSS Channels Available
United States	2.4 to 2.4835 GHz	1 through 11	2 through 80
Canada	2.4 to 2.4835 GHz	1 through 11	2 through 80
Japan	2.4 to 2.497 GHz	1 through 14	2 through 95
France	2.4465 to 2.4835 GHz	10 through 13	48 through 82
Spain	2.445 to 2.4835 GHz	10 through 11	47 through 73
Remainder of Europe	2.4 to 2.4835	1 through 13	2 through 80

2.5 Bluetooth and Personal Area Networks

- There is huge consumer appreciation for "removing the wire".
- Bluetooth is an open standard that has been embraced by over 1,000 manufacturers of electronic appliances.
- It provides an ad-hoc approach for enabling various devices to communicate with one another within a nominal 10 meter range.

- Named after king Harald Bluetooth, the 10^{th} century Viking who united Denmark and Norway.
- The Bluetooth standard aims to unify the connectivity chores of appliances within the personal workspace of an individual.
- Bluetooth operates in the 2.4 GHz ISM Band and uses a frequency hopping TDD scheme for each radio channel.

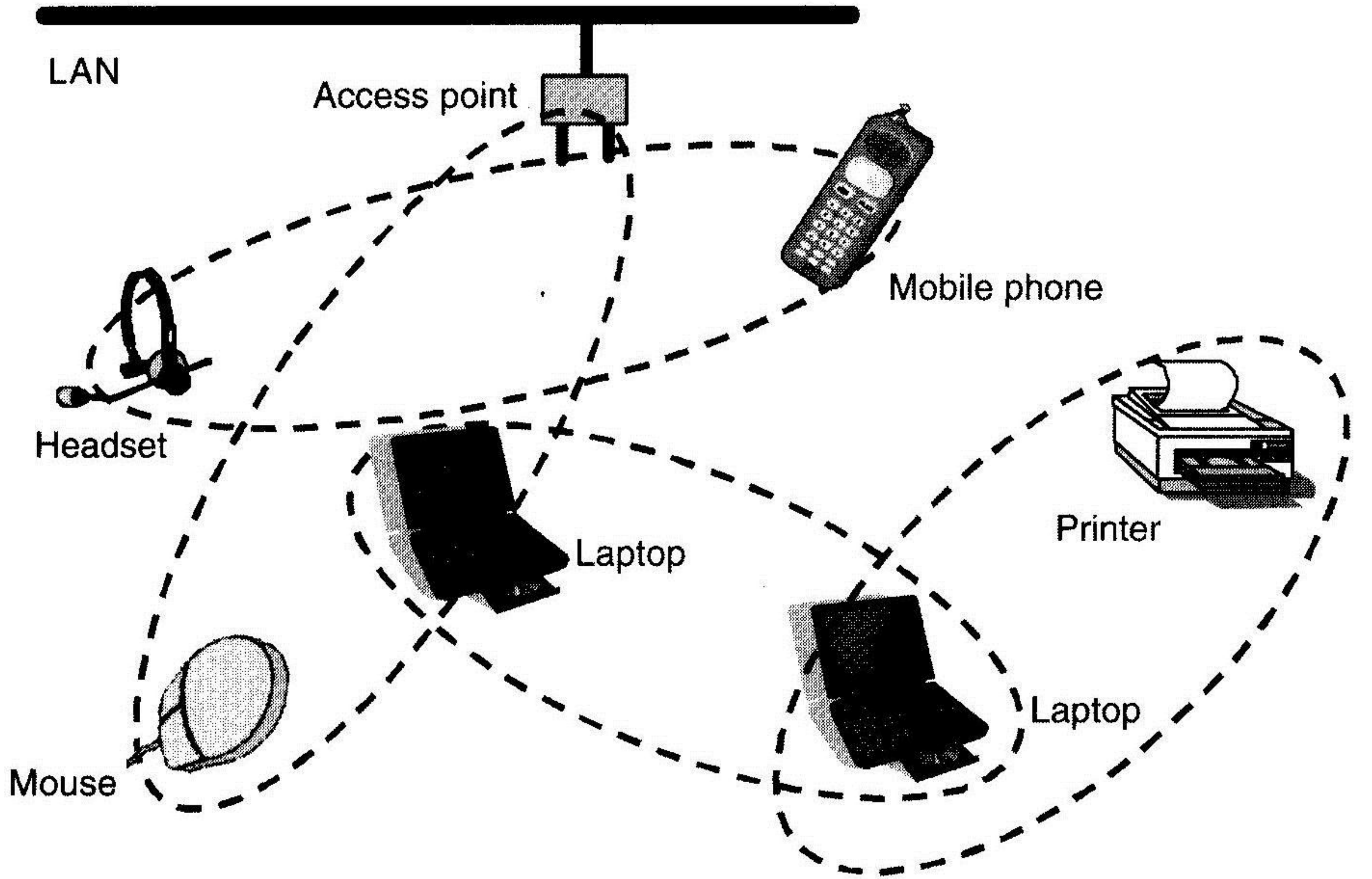


Figure 2.17 Example of a Personal Area Network (PAN) as provided by the Bluetooth standard.