A Brief History of Cellular Communications

行動通訊發展史簡介

Wireless Information Transmission System Lab.
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遠古的通訊

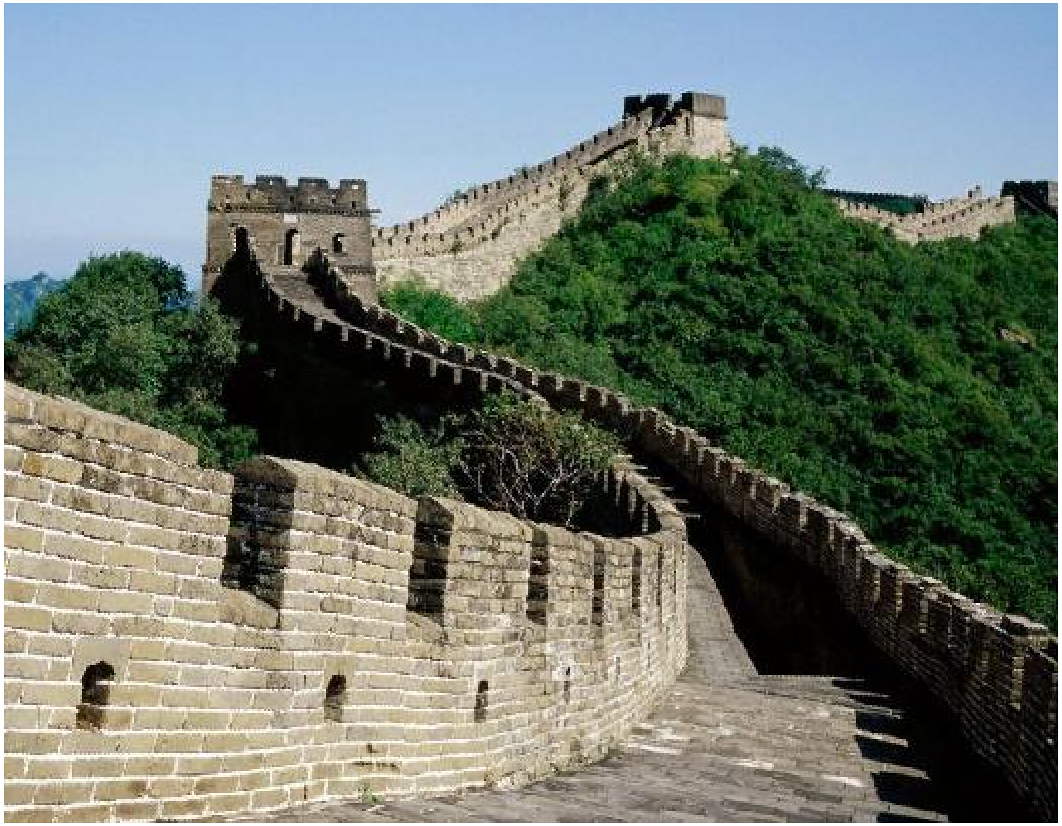
- 起源於人類自保的需要，用來互相通知獵物出現、警告危險的來臨。
  - 鼓聲
  - 銅鏡反射
  - 旗幟
  - 飛鴿傳書
  - 快馬及驛站
- 遠古的遠距通訊多僅限視力所及範圍





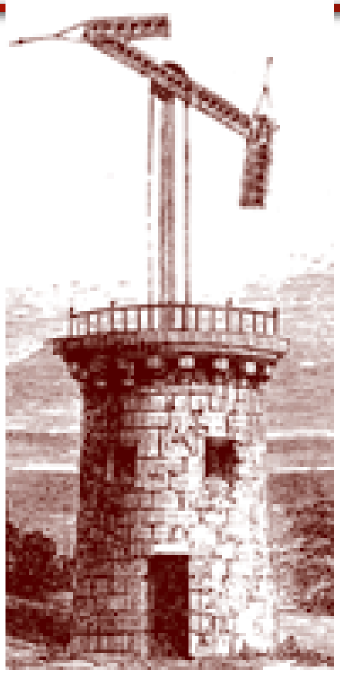
遠古的通訊

- 烽火臺：歷史記載中最早的長距離通報系統

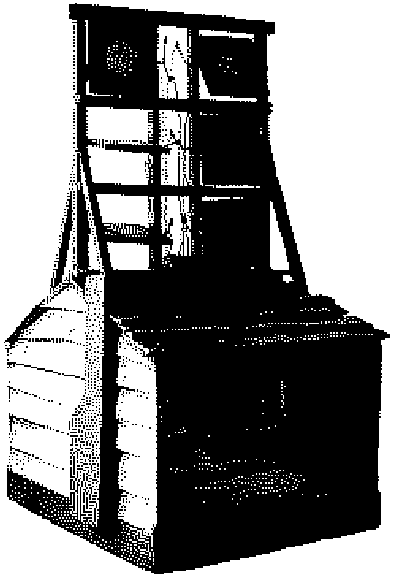


視報機 (Semaphores)

- 1793年，法國人查佩發明臂桿訊號通報機（Semaphores），是一套視覺訊號的系統。
  - 安裝在相距10至15公里的塔上，由一條橫桿連接著兩條活動木臂所組成，塔上的操作員轉動木臂及橫桿的位置和角度來顯示不同的字母和符號。下一站的操作員利用望遠鏡來觀看這些符號並為下一站做出同樣的符號。



- 1795年，英國人喬治慕雷藉轉動六塊活板往水平或垂直的位置，可組成64個不同字母及符號 。
- 視報會受天氣影響且無法在晚間使用
- 於19世紀中葉，被電報機所取代



視報機

第一條臂桿訊號線建於巴黎與里爾(Lille)之間(220公里)。於1794年8月，查佩的臂桿訊號系統在一小時內將有關從奧地利人手中俘虜素爾雷斯科伯爵的訊息傳至巴黎。這次成功促成更多臂桿訊號線的建立。當時法國所建立的臂桿訊號網絡成為歐洲的首個遠程通報網絡。

使用電傳遞通訊

- 1729年，英國格雷發現靜電可經導體傳導
- 1752年，美國富蘭克林證實了閃電是電的一種現象，又做實驗發現了電荷守恆定律。
- 1753年，一名英國人提出使用靜電來拍電報
- 1809年，德國賽謬爾發明電化學電報機
- 1820年，丹麥奧斯特發現電流的磁效應
- 1821年，法國安培以檢流計製成電報傳遞60m
- 1823年，英國羅納爾茲發明靜電電報機
- 1825年，英國特斯金發明電磁鐵
- 1831年，英國法拉地發現電磁感應定律
- 1832年，蘇聯希林發明電磁指針式電報機

使用電傳遞通訊

- 1833年，德國韋伯及高斯合作研究出電磁羅盤指針式電報機，可藉由電線傳遞1200m，1835年，高斯於慕尼黑佈建第一條沿鐵路電報線
- 1837年，英國庫克和惠斯登發明第一部商用的指針式電報機，並取得英國專利，1839年，沿著大西洋鐵路佈建21km長電報線，由英國鐵路公司開始營運
- 1837年，美國摩斯發明電報及電碼，在美國取得專利。

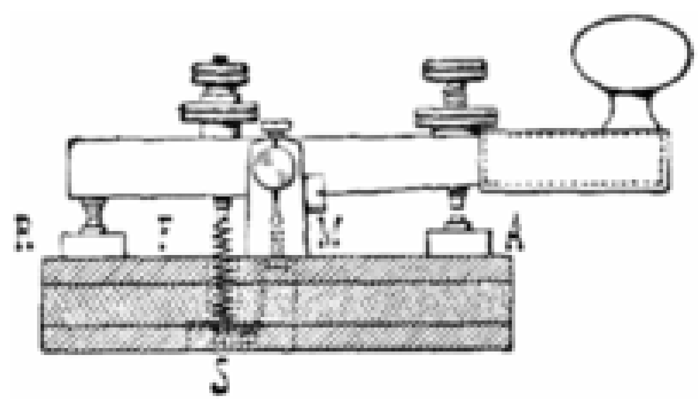


Fig. 6.

電報機與摩斯電碼

- 1832年，美國醫生傑克遜在郵船上，給旅客們講電磁鐵原理，旅客中美國畫家摩斯從在電線中流動的電流在電線突然截止時會迸出火花這一事實得到啟發。
- 將電流截止片刻發出火花作為一種信號，電流接通而沒有火花作為另一種信號，電流接通時間加長又作為一種信號，這三種信號組合起來，就可以代表全部的字母和數字，文字可通過電流傳到遠處。
- 1837年，摩斯發明**電報機**

摩斯電碼

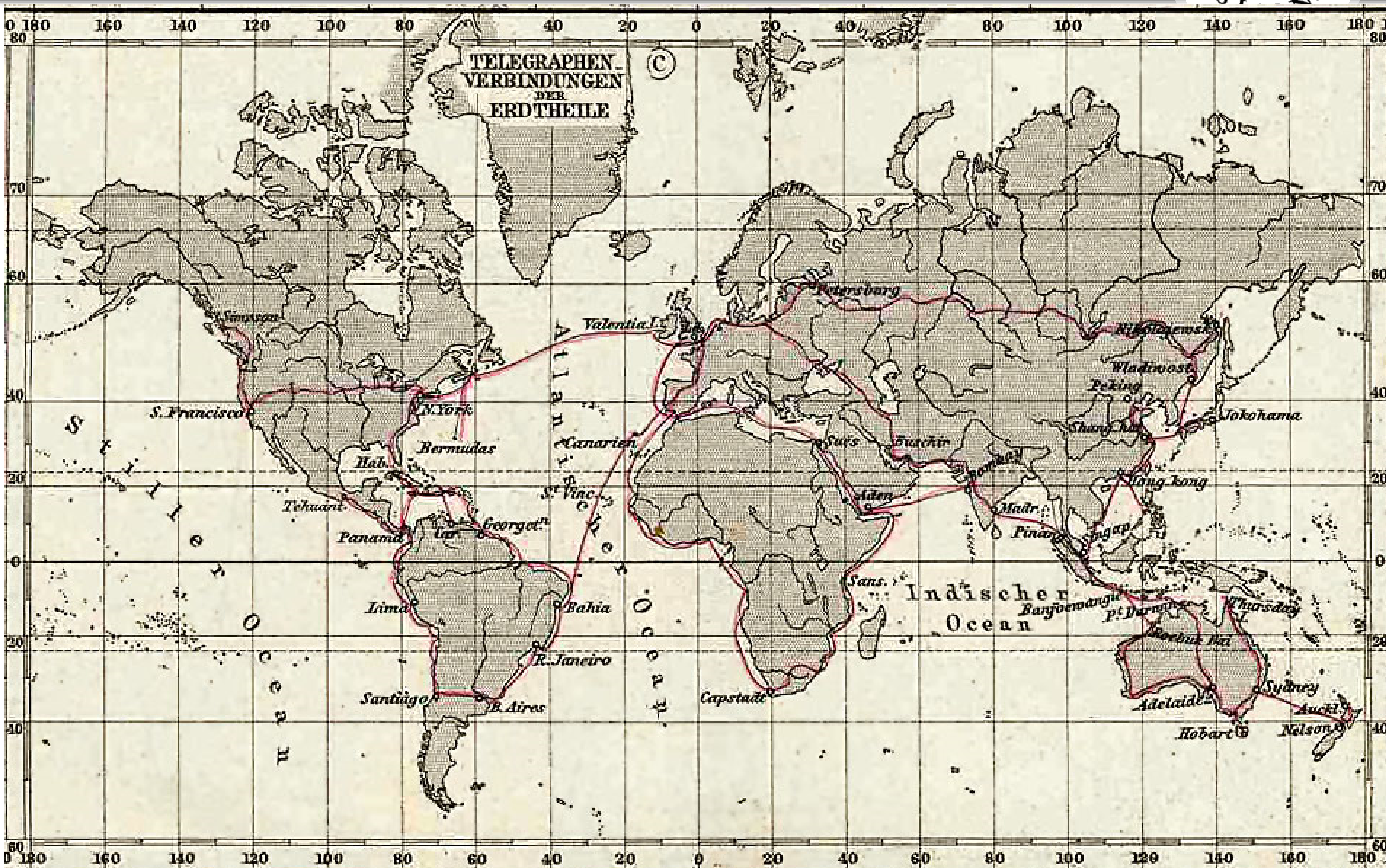
- 1837年，由摩斯設計
- 利用時通時斷的訊號代表“點”、“劃”和“間隔”，以不同組合來表示字母、數字、標點和符號。
- 1844年5月24日，摩斯在華盛頓國會大廈聯邦最高法院會議廳裡，親手操縱著電報機，遠在64公里外的巴爾的摩城收到世界上第一份電報。

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

跨洋電報電纜

- 1850年，首條海底電纜橫越英吉利海峽，連接英國及歐洲大陸。
- 1857年，橫越大西洋的電報電纜敷設完畢，但在1866年方才成功使用。
- 1870年，英國至印度海底電纜完工。
- 1872年，澳洲連外海底電纜陸續完工。
- 1902年，橫越太平洋的海底電纜完工。
- James Clerk Maxwell, "A Dynamical Theory of the Electromagnetic Field", *Philosophical Transactions of the Royal Society of London* **155**, 459–512 (1865). (This article accompanied a December 8, 1864 presentation by Maxwell to the Royal Society.)
  - A Dynamical Theory Of The Electromagnetic Field – 1865 Maxwell's 1865 paper describing his 20 Equations, link from Google Books.
- J. Clerk Maxwell (1873) A Treatise on Electricity and Magnetism
  - Maxwell, J.C., A Treatise on Electricity And Magnetism – Volume 1 – 1873 – Posner Memorial Collection – Carnegie Mellon University
  - Maxwell, J.C., A Treatise on Electricity And Magnetism – Volume 2 – 1873 – Posner Memorial Collection – Carnegie Mellon University

Major telegraph lines in 1891.



電報交換 (Telex)

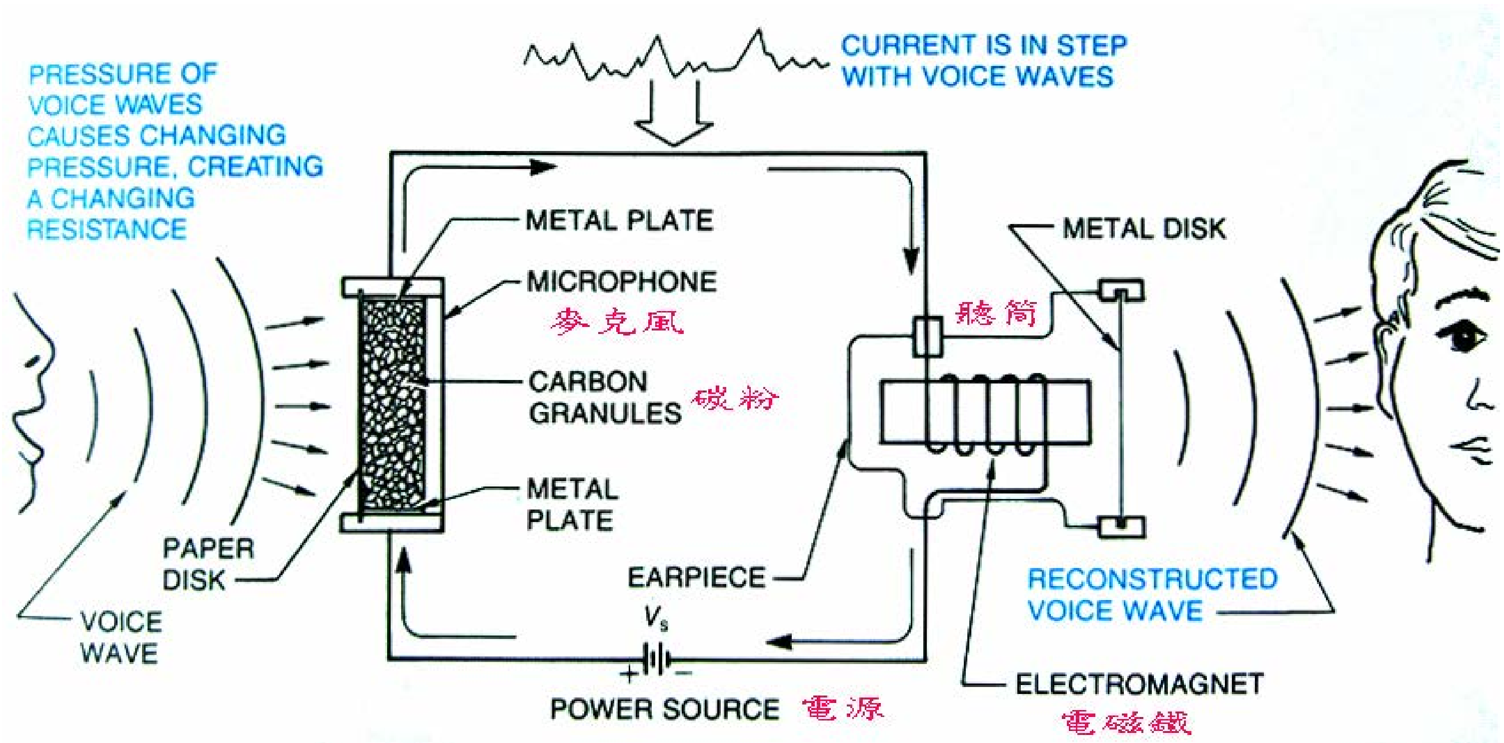
- 1920年代，電傳打字機(teleprinter)發明，加速拍電報
- 電傳打字機初期為點對點傳輸
- 1930之後，電傳打字機的交換網路(Telex)逐漸佈建
- 每一台Telex有其呼叫號碼，如果撥到此號碼，就會響鈴並開始打字，如需要亦可鑿出紙帶
- 1933年在德國正式啟用此服務，一分鐘可傳送66個字元
- 1945之後，Telex服務遍及歐洲
- 1958年，Western Union開始於美國佈建telex網路，於1966年，完成美國東西岸大城市之間的telex網路。

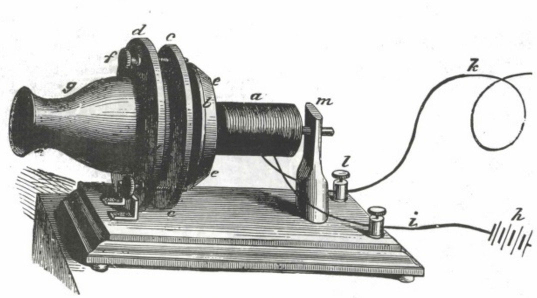
電話的發明

- 1875年，美國發名家貝爾做電報實驗時，發現電報機的螺絲拴得太緊，電流沒有像電報一樣斷續，反而形成通路傳來另一端的聲音，隔天造出斷頭臺電話，可惜之後半年實驗無進展。

- 1876年3月，貝爾及華生合作完成液態送話器及電磁式接收器
- 1876年3月，貝爾的電話發明獲得美國專利權，編號174465，是美國有史以來最值錢的專利

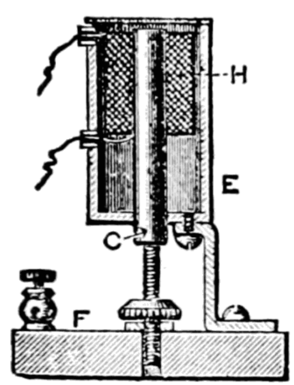
電話原理

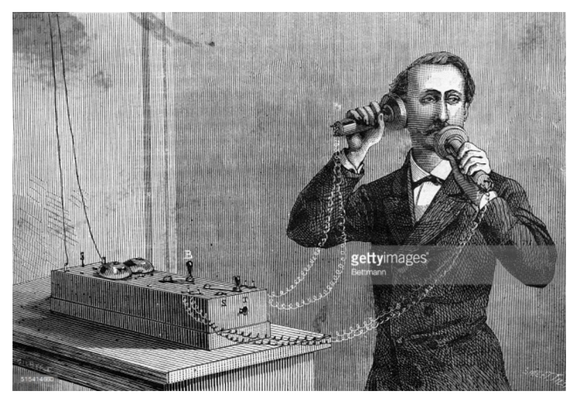




Bell's first Telephone (Transmitter).

a. Electro-magnet. b. Diaphragm. c. Collar. d. Collar and tube. f. Screw. g. Mouthpiece. h. Battery. i. Wire from battery to coil. k. Telegraph wire. l. Through binding screw. m. Pillar holding magnet.





話機的演進

牆上型磁石式電話機　桌上型磁石式電話機

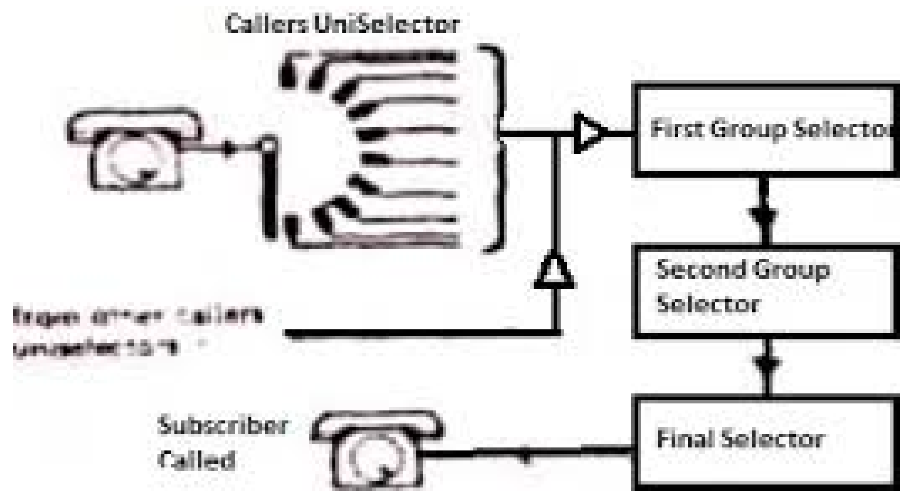
共電式電話機

撥號盤電話機

按鈕式電話機

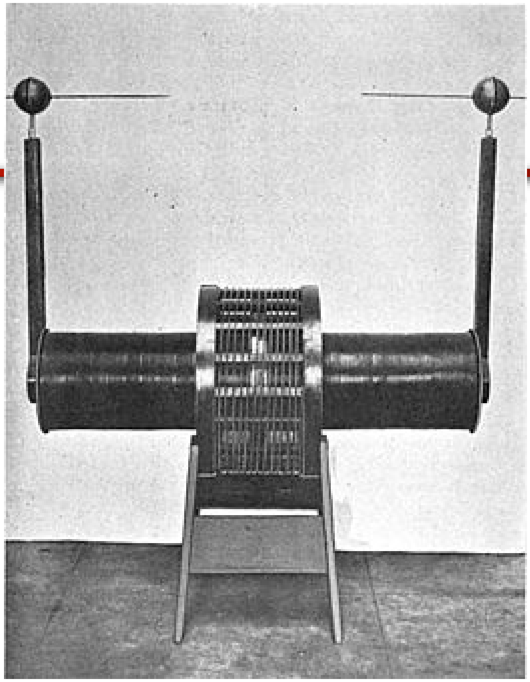
電話交換機

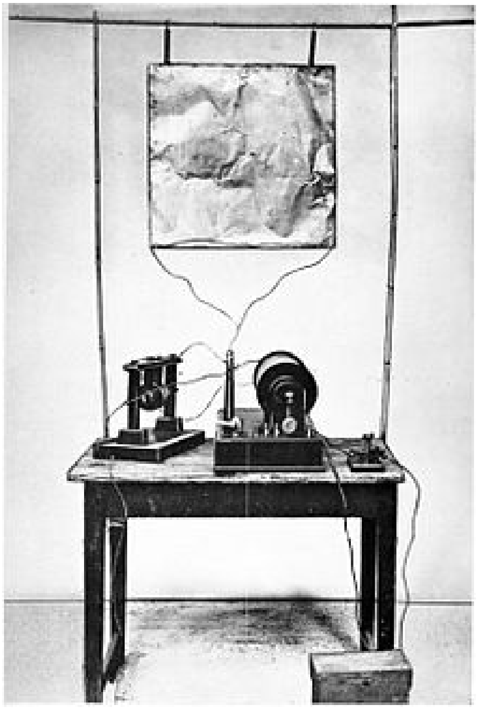
- 1877年，美國波士頓出現實驗性質的電話交換機系統
- 1878年，美國電話交化系統進入營運
- 早期的電話交換由人工服務
- 二十世紀初期，自動化的撥號交換機逐漸取代人工交換台



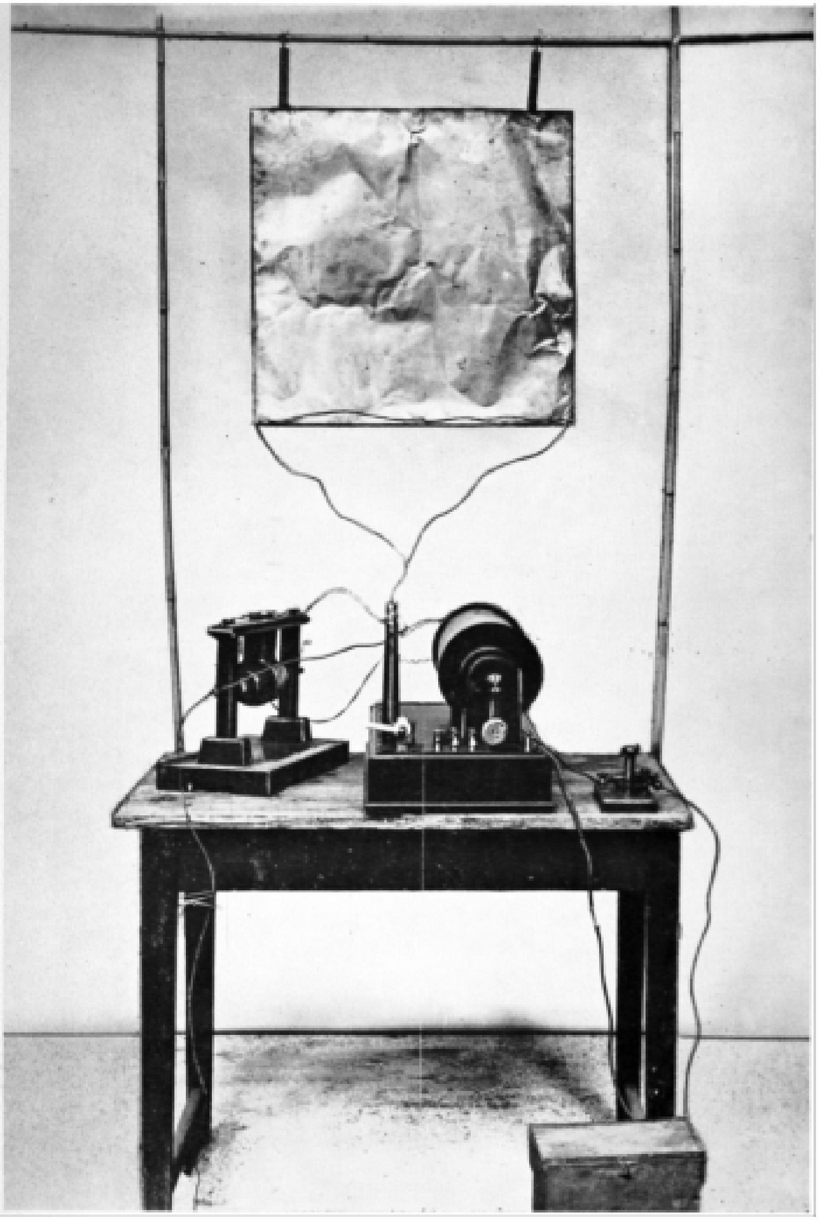
無線電

- 1882年，美國特斯拉發明感應馬達，並於1889年發明特斯拉線圈，將高壓電轉換為無線電
- 1895年，義大利馬可尼發明無線電報機。1897年，馬可尼成功發出海對地的無線電報。1901年，馬可尼實現橫越大西洋的無線電通訊。
- 無線電的最早應用於航海中 ，配備無線電的遠洋船隻，就算在海洋上仍然與陸地保持通訊，更能在需要時發出求救訊號 。





1909 Nobel Prize
Guglielmo Marconi & Karl Braun

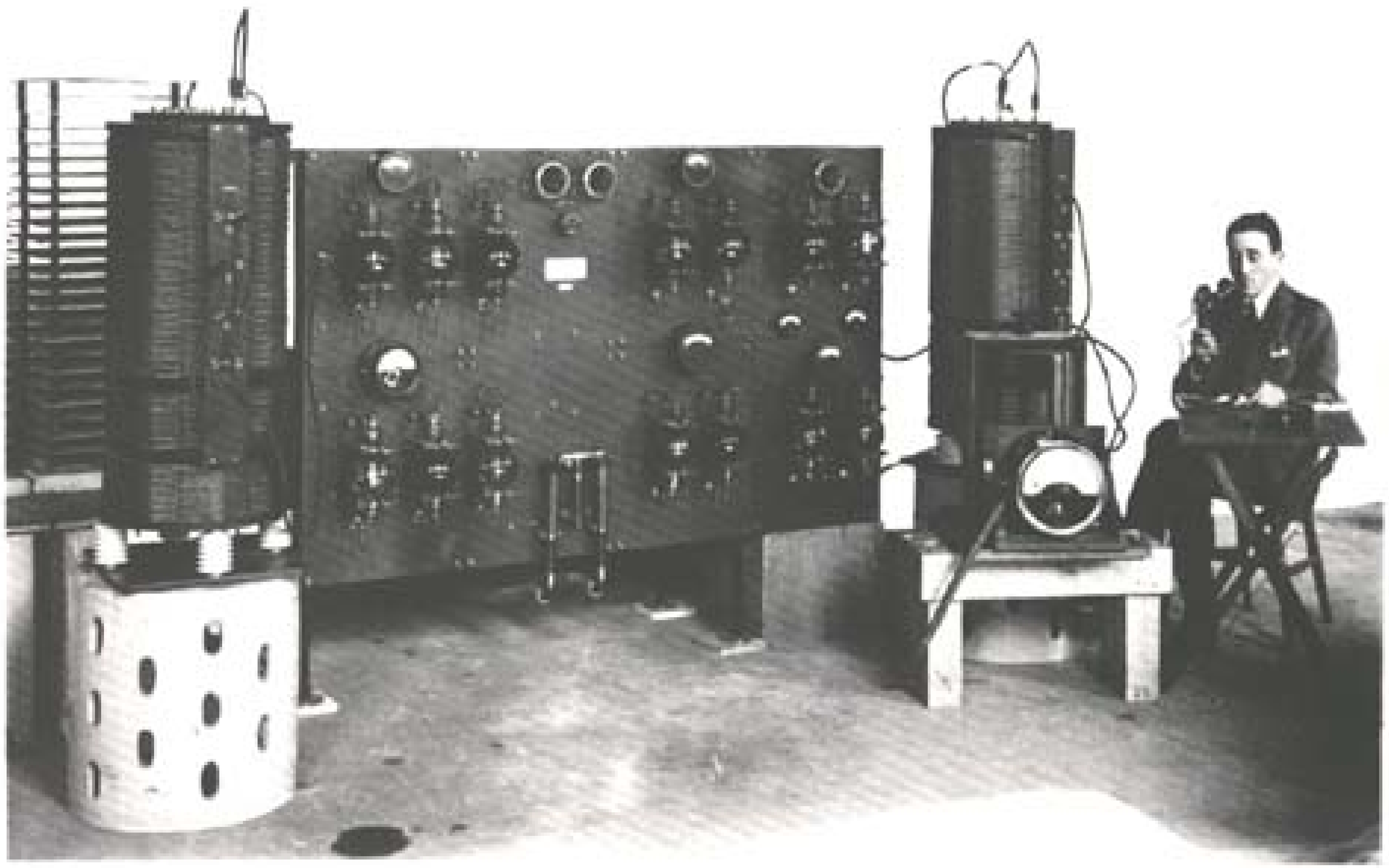


馬可尼的第一台無線電報發射器，能夠以摩斯密碼傳送訊息。

- ✓ 義大利工程師Marconi在 1890 年代初開始發展無線電技術，希望能以無線電報作為通訊工具。
- ✓ 1897年5月13日，Marconi成功發送人類首個跨越Bristol Channel的電報Are you ready？
- ✓ 1899年，Braun成功發送電報跨越英倫海峽。
- ✓ 1901 年，Marconi使用Braun設計的發射和接收器由英國發送電報至加拿大，完成史上第一次跨大西洋電報通訊。
- ✓ 在1912年Titanic沉沒期間，在接到Titanic的緊急呼叫後，有703人獲救。電話是用馬可尼的設備發出的。這場災難的直接後果是所有船隻都被迫安裝無線電發射機。

1909 Nobel Prize – Guglielmo Marconi

無線電之父馬可尼在英國表演他的無線電發射機



Cellular Communications

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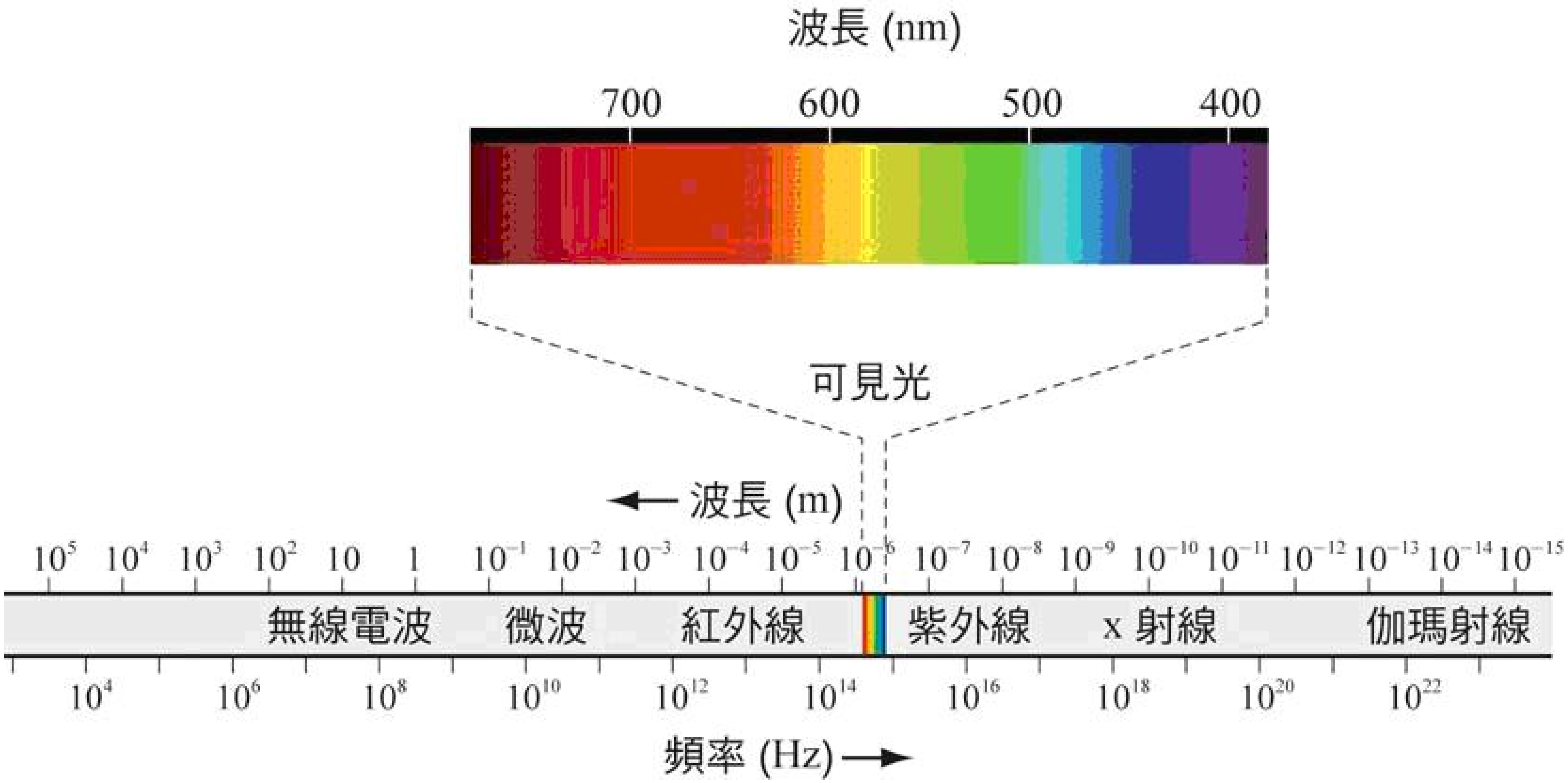
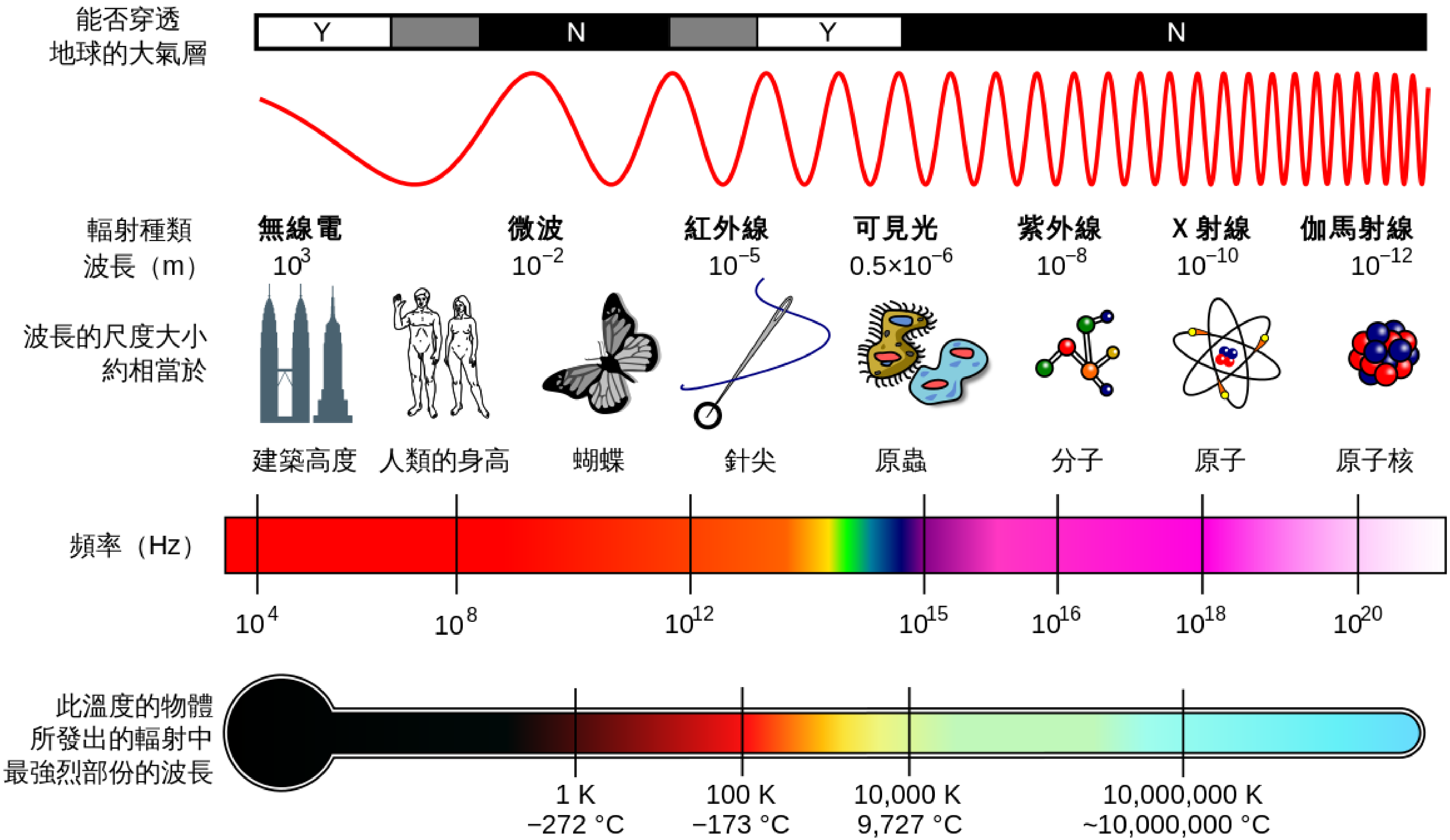
電磁波光譜圖

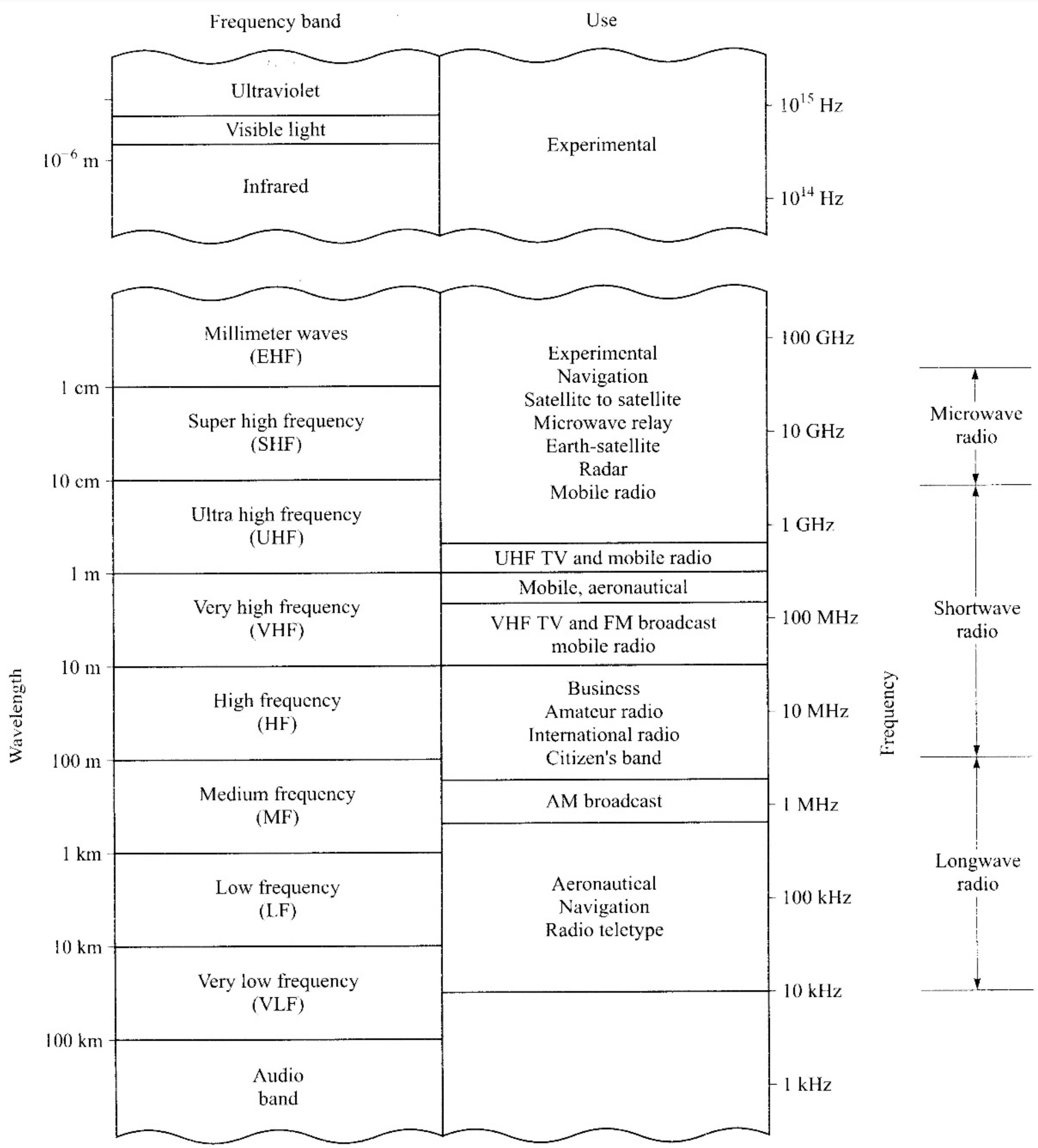


波長 (nm)
700
600
500
400
可見光
波長 (m)
10⁵ 10⁴ 10³ 10² 10 1 10⁻¹ 10⁻² 10⁻³ 10⁻⁴ 10⁻⁵ 10⁻⁶ 10⁻⁷ 10⁻⁸ 10⁻⁹ 10⁻¹⁰ 10⁻¹¹ 10⁻¹² 10⁻¹³ 10⁻¹⁴ 10⁻¹⁵
無線電波
微波
紅外線
紫外線
x 射線
伽瑪射線
10⁴ 10⁶ 10⁸ 10¹⁰ 10¹² 10¹⁴ 10¹⁶ 10¹⁸ 10²⁰ 10²²
頻率 (Hz)

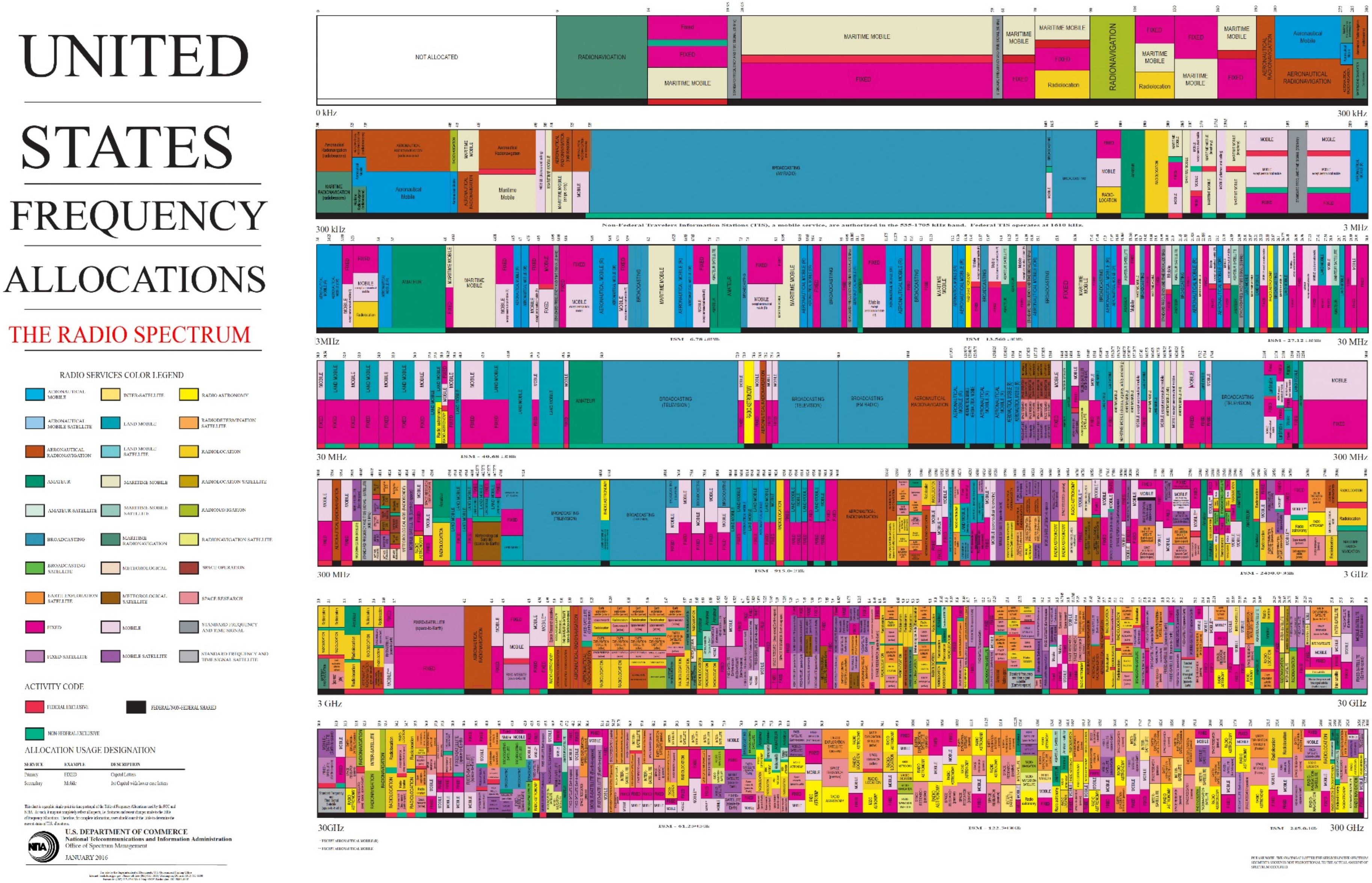
電磁波光譜圖


能否穿透
地球的大氣層
Y
N
Y
N
輻射種類
波長（m）
無線電
10^{3}
微波
10^{-2}
紅外線
10^{-5}
可見光
0.5×10^{-6}
紫外線
10^{-8}
X 射線
10^{-10}
伽馬射線
10^{-12}
波長的尺度大小
約相當於
建築高度
人類的身高
蝴蝶
針尖
原蟲
分子
原子
原子核
頻率（Hz）
10^{4}
10^{8}
10^{12}
10^{15}
10^{16}
10^{18}
10^{20}
此溫度的物體
所發出的輻射中
最強烈部份的波長
1 K
−272 °C
100 K
−173 °C
10,000 K
9,727 °C
10,000,000 K
~10,000,000 °C

Frequency Range for Wireless Electromagnetic Channels

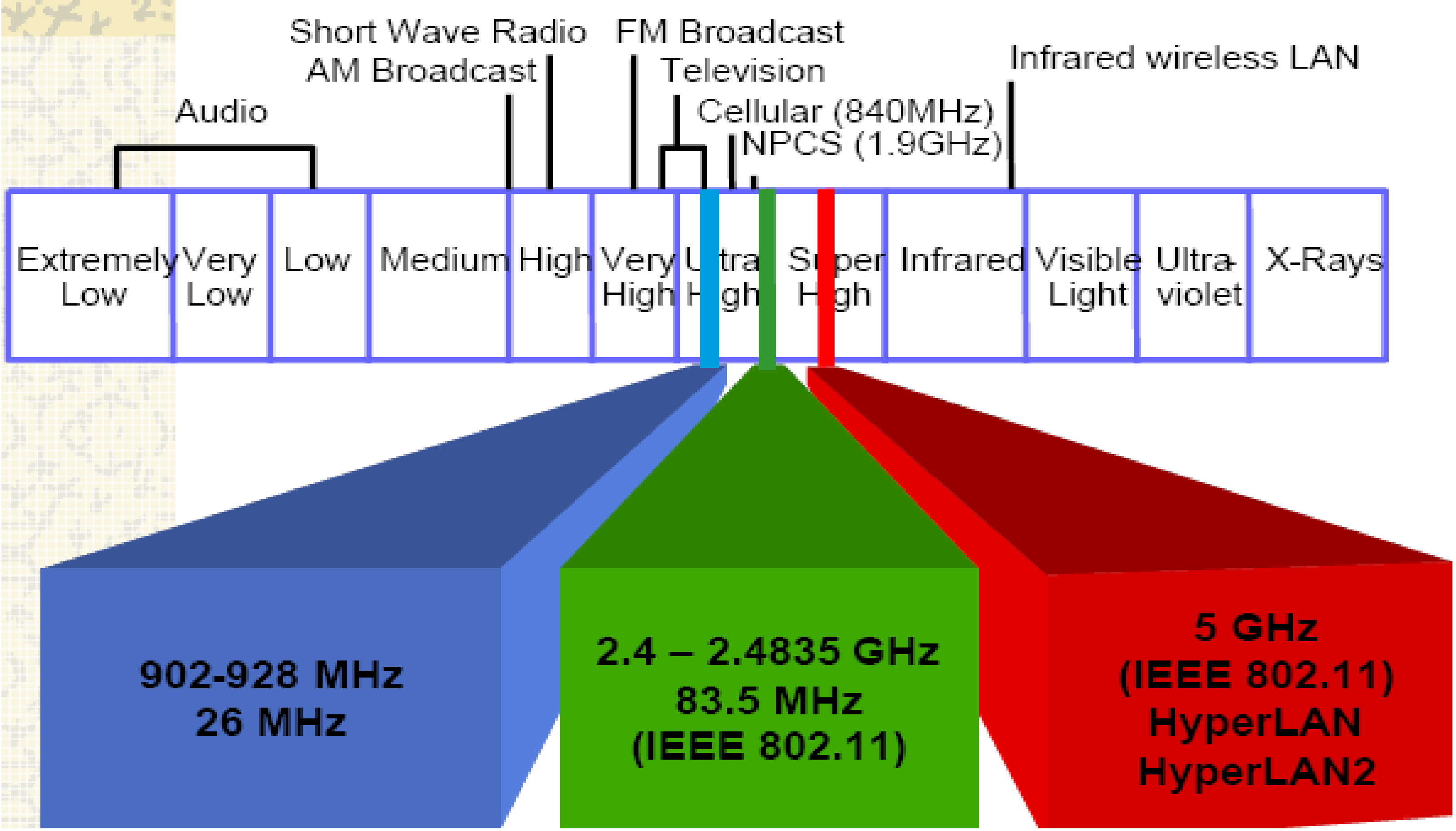


擁擠的電波頻道


UNITED
STATES
FREQUENCY
ALLOCATIONS
THE RADIO SPECTRUM
RADIO SERVICES COLOR LEGEND
ACTIVITY CODE
ALLOCATION USAGE DESIGNATION
U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Office of Spectrum Management
JANUARY 2016
0 kHz
300 kHz
3 MHz
3 MHz
30 MHz
30 MHz
300 MHz
300 MHz
3 GHz
3 GHz
30 GHz
30 GHz
300 GHz
NOT ALLOCATED
RADIONAVIGATION
MARITIME MOBILE
FIXED
BROADCASTING (AM RADIO)

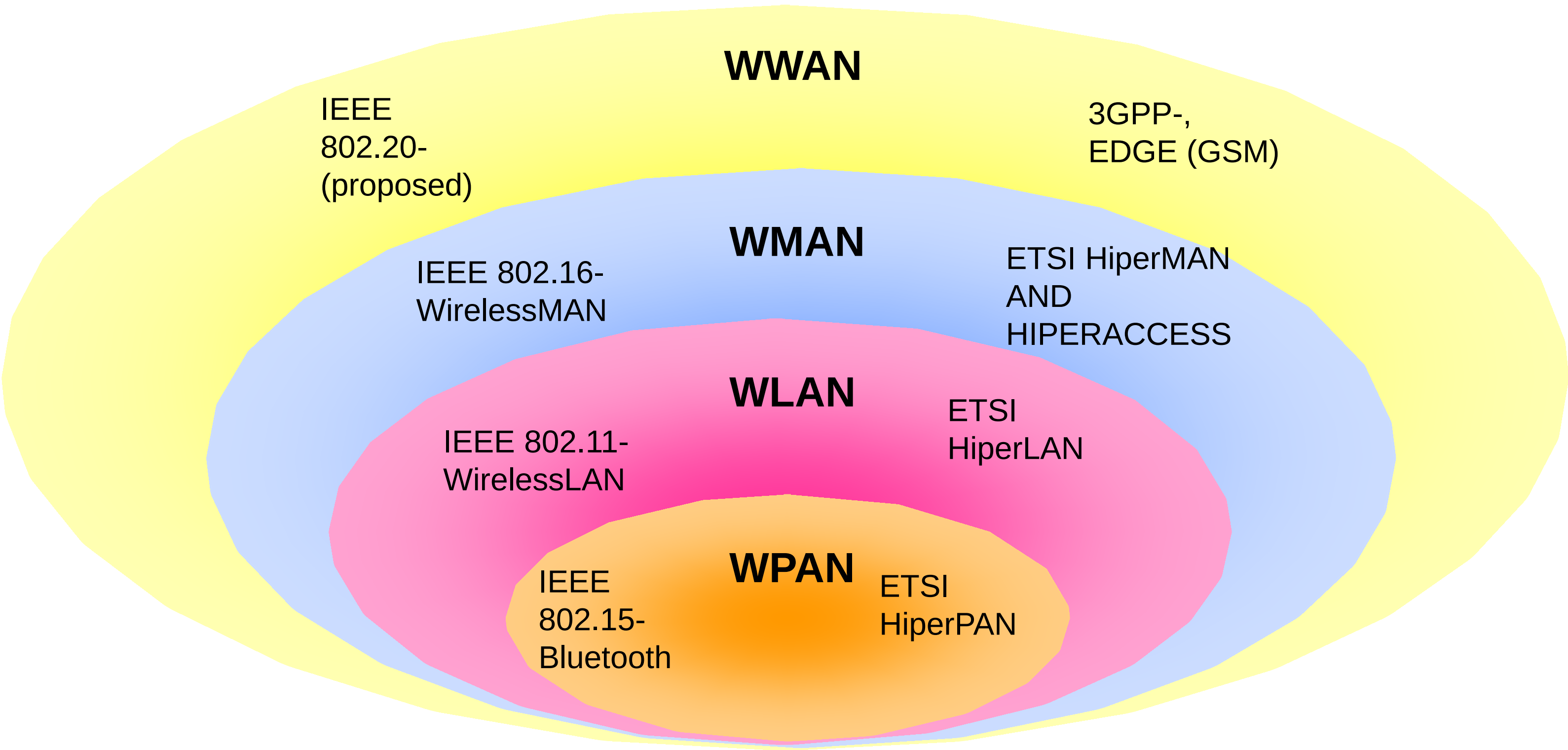
ISM頻帶

- ISM頻帶：專供工業(Industrial)、科學(Scientific)及醫療(Medical)使用的頻帶，主要在900MHz、2.4GHz、5GHz
- 使用這些頻段無需許可或費用，只需遵守一定的發射功率



無線通訊系統（依涵蓋範圍）

- 依通訊傳送距離範圍大小，一般將行動通訊系統劃分為
  - 無線廣域網路(wireless wide area networks, WWAN)、
  - 無線都會區域網路(wireless metropolitan area networks, WMAN)、
  - 無線區域網路(wireless local area networks, WLAN)、
  - 無線個人區域網路(wireless personal area networks, WPAN)



Early Wireless Systems

- The first successful use of mobile radio dates from the late 1800s, when M. G. Marconi established a radio link between a land-based station and a boat sailing the English channel, over an 18-miles path.
- In 1934, 194 municipal police radio systems and 58 state police stations had adopted amplitude modulation (AM) mobile communication systems for public safety in the U.S.
- In 1935, Edwin Armstrong demonstrated frequency modulation (FM) for the first time. Since late 1930s, FM has been the primary modulation technique used for mobile communication systems throughput the world.

Early Wireless Systems

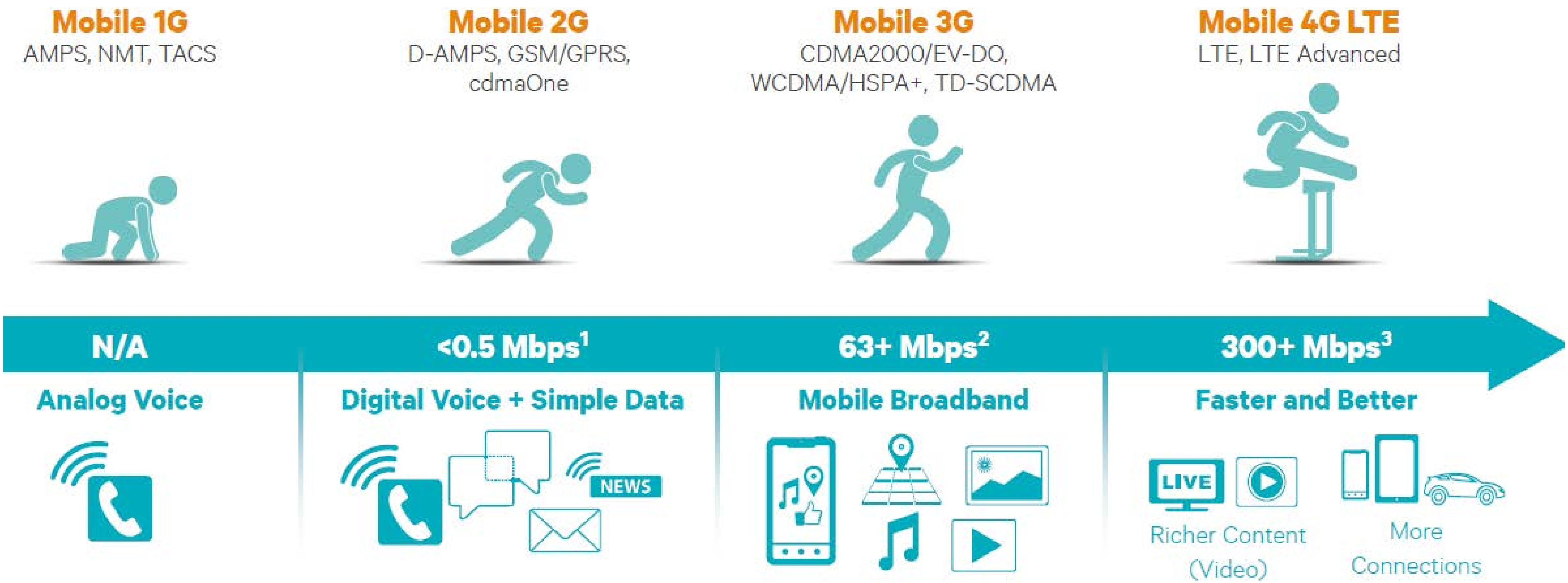
- The first public mobile phone service was the Mobile Telephone System (MTS) introduced in the United States in 1946, when FCC granted a licence to AT&T.
  - Operation was half duplex.
  - Call placement was manual operation.
  - Cover distances over 50Km.
  - Modulation was FM (frequency modulation).
  - 120KHz per channel.
- In 1950, the FCC doubled the number of mobile telephone channels, but with no new spectrum allocation.
  - 60 KHz per channel.
- By mid 1960s, the FM bandwidth of voice transmission was cut to 30 KHz.

Early Wireless Systems

- Improved Mobile Telephone System (IMTS) was introduced in 1969.
  - Full Duplex.
  - Automatic switching.
  - 450 MHz band.
- The cellular concept began to appear in Bell Laboratories proposals during the late 1940s.
  - Cellular concept is introduced because of limited spectrum.
  - Channels are reused when there is sufficient distance between the transmitters to prevent interference.
- AT&T proposed the concept of a cellular mobile system to the FCC in 1968.
- Cellular technology wasn't available to implement cellular telephony until the late 1970s.

1956年
5MB IBM 硬碟正被裝上飛機
其重量超過1000公斤

行動通訊演進

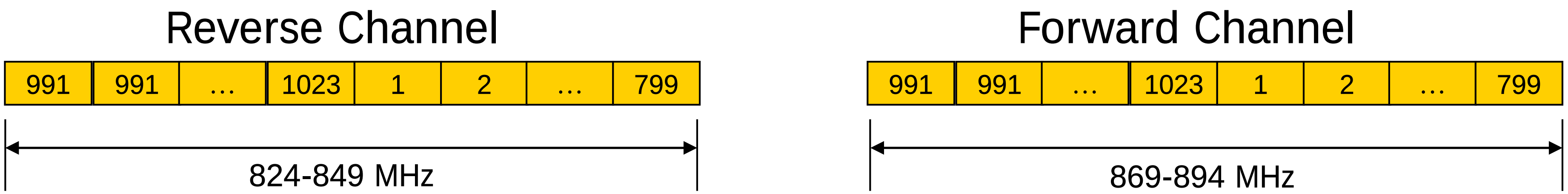

Mobile 1G
AMPS, NMT, TACS
Mobile 2G
D-AMPS, GSM/GPRS, cdmaOne
Mobile 3G
CDMA2000/EV-DO, WCDMA/HSPA+, TD-SCDMA
Mobile 4G LTE
LTE, LTE Advanced
N/A
<0.5 Mbps[1]
63+ Mbps[2]
300+ Mbps[3]
Analog Voice
Digital Voice + Simple Data
Mobile Broadband
Faster and Better
NEWS
LIVE
Richer Content (Video)
More Connections

First Generation Cellular Systems

- Analog Voice Technology

- AMPS (advanced mobile phone service), introduced in 1983 in the USA.
  - 666 duplex channel.
  - 40 MHz of spectrum in the 800 MHz band.
  - 30 KHz for one way bandwidth.
  - In 1989, the FCC granted an additional 166 channels (10 MHz) to U.S. cellular service providers.
  - The forward and reverse channels in each pair are separated by 45 MHz.

AMPS Frequency Allocation



	Channel Number	Center Frequency (MHz)
Reverse Channel	1 <= N <= 799	0.03N+825.0
	990 <= N <= 1023	0.03(N-1023)+825.0
Forward Channel	1 <= N <= 799	0.03N+870.0
	990 <= N <= 1023	0.03(N-1023)+870.0
Channels 800 – 990 are unused.		

First Generation Cellular Systems

- NMT-450 (Nordic Mobile Telephone), introduced in 1981, was adopted by European states. (25KHz)

- TACS (Total Access Communication System) was a very successful system in Great Britain. (25KHz)

- NTT (Nippon Telephone and Telegraph) was introduced in 1979. (25KHz)

1G的特色

1

Licensed Spectrum

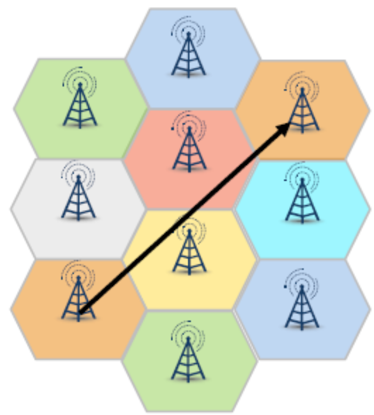
Cleared spectrum for exclusive use by mobile technologies

Operator-deployed **base stations** provide access for subscribers

2

Frequency Reuse

Reusing frequencies without interference through geographical separation

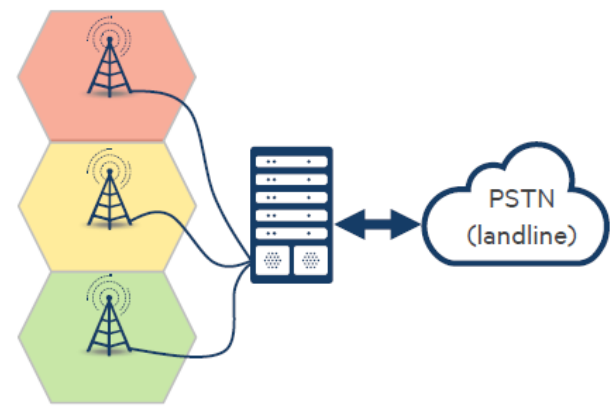


Neighboring **cells** operate on different frequencies to avoid interference

3

Mobile Network

Coordinated network for seamless access and seamless mobility

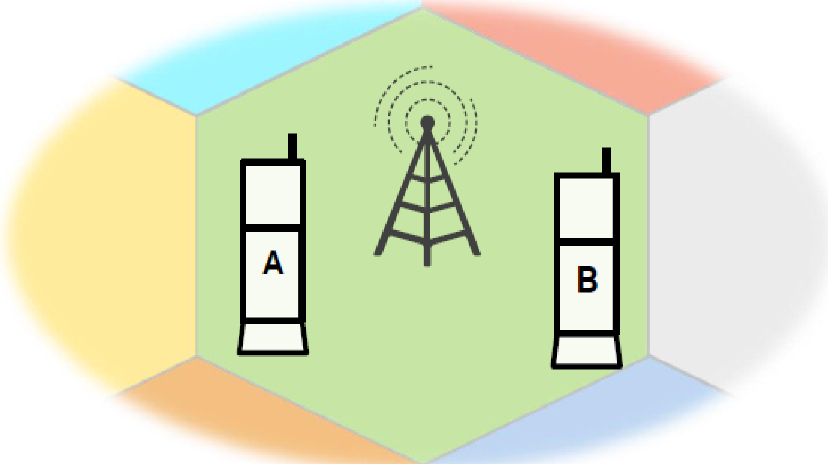


Integrated, transparent **backhaul network** provides seamless access

1G的限制

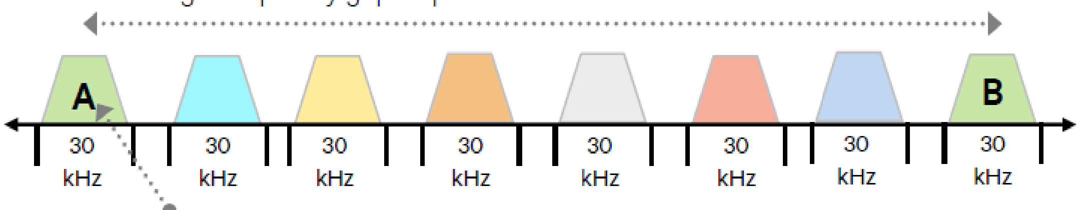
Limited Capacity

Analog transmissions are inefficient at using limited spectrum



Frequency Division Multiple Access (FDMA)*

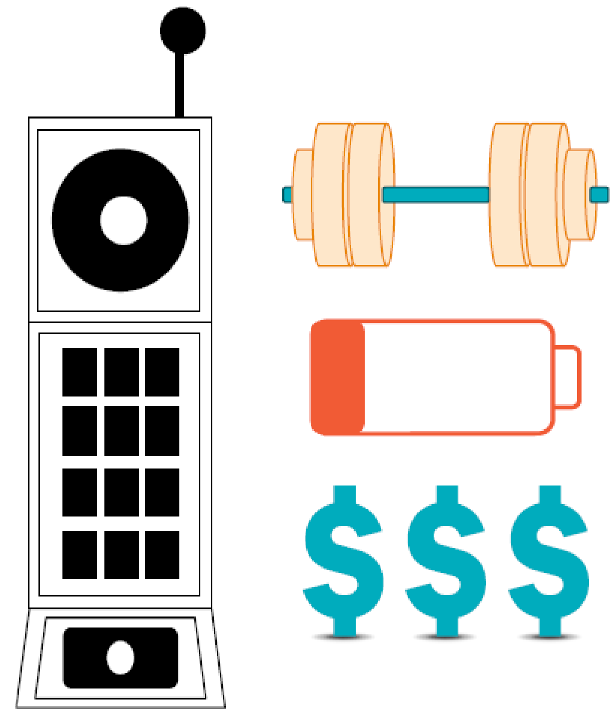
Large frequency gap required between users to avoid interference



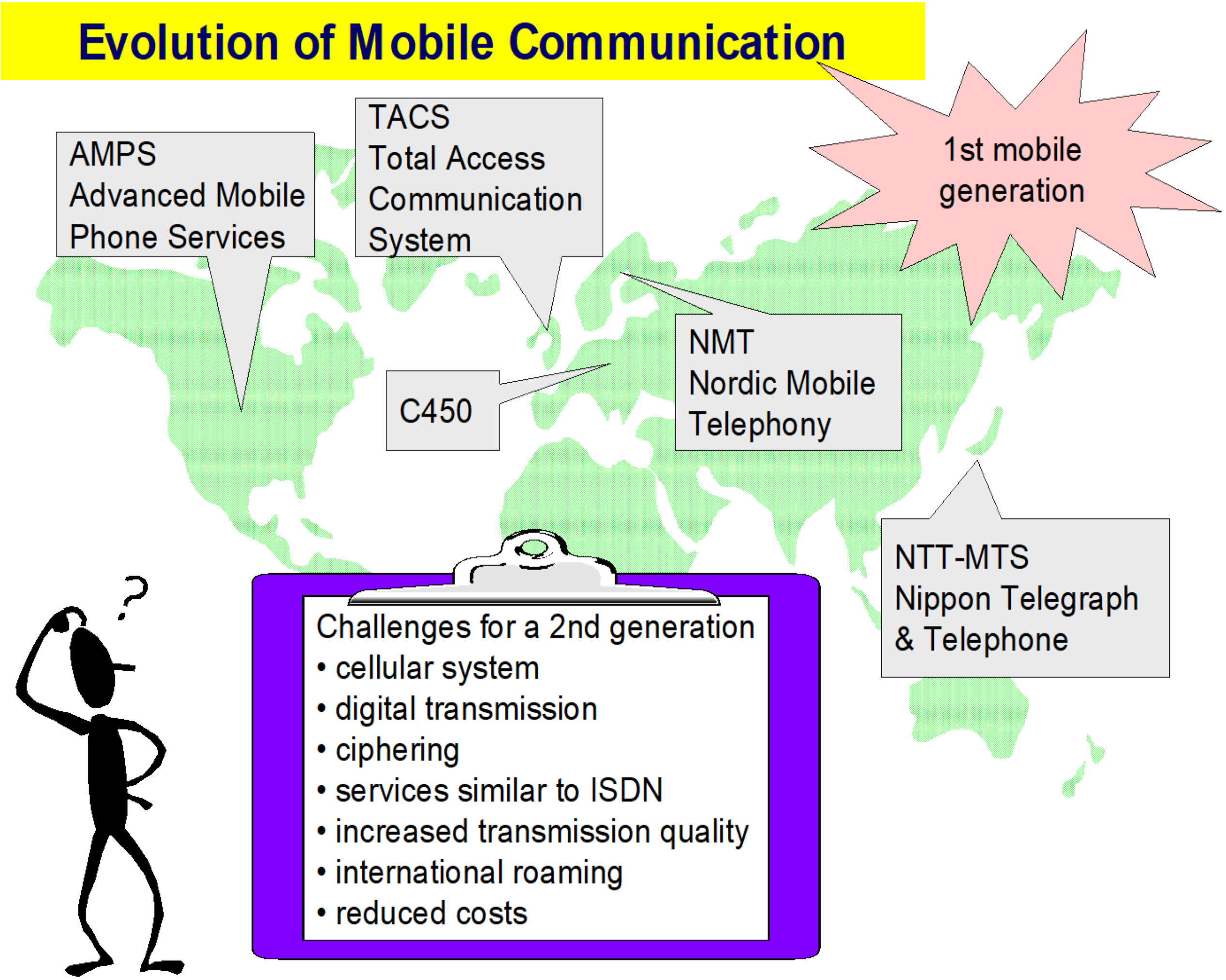
Support for only 1 user (analog phone call) per channel

Limited Scalability

Analog devices are large/heavy, power inefficient, and high cost



First Generation Cellular Systems



Second Generation Cellular Systems

- Digital Technology
- US
  - A: USDC (IS-54/136), DCS1900, IS-95 (CDMA)
  - B: PACS
- Europe
  - A: GSM, DCS1800
  - B: CT2 (TDD), DECT(TDD)
- Japan
  - A: PDC
  - B: PHS (TDD)

- A: high speed, high BS power, low traffic density, few BSs.
- B: low speed, low BS power, high traffic density, many BSs.

GSM (Global System for Mobile Communication)

- 提供短訊服務的數位通訊系統
- 使用TDMA與FDD。
- 下行頻率範圍為935-960MHz（25MHz）
- 上行頻率範圍為890-915MHz（25MHz）
- 每一頻道占200kHz，兩個頻帶各有124組頻道可供使用。
- 每組頻道再以時間劃分成為8個時槽。
- 每個行動通訊用戶在其所屬的時槽傳送與接受資訊，而該時槽稱為通訊的通道（channel）。

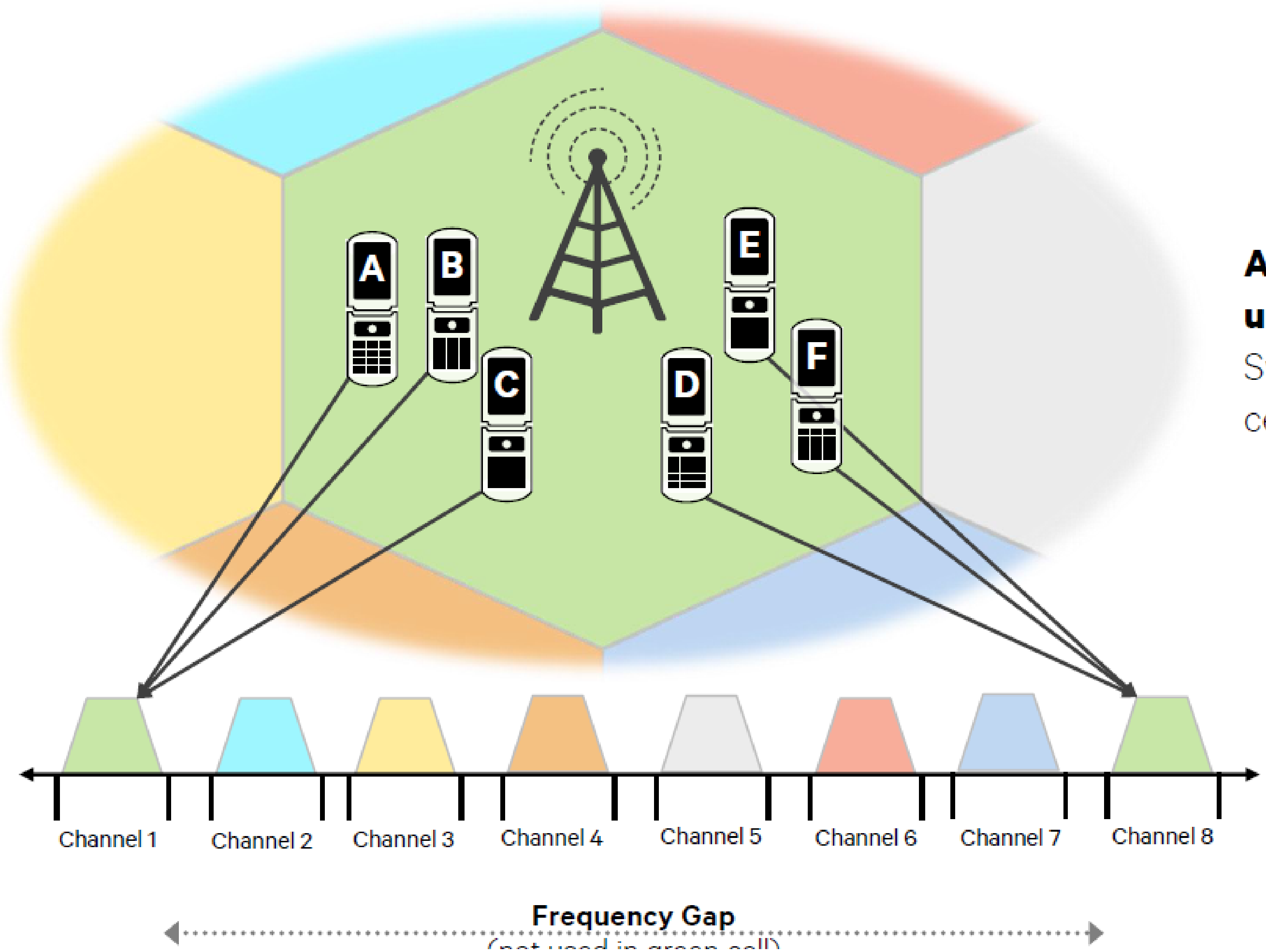
Second Generation Cellular Systems

GSM - The Standard

Parameter	(E-)GSM-900	GSM-1800 (DCS, PCN)	GSM-1900 (PCS)	GSM-R
Frequency Range (Uplink)	890 - 915 MHz E-GSM: 880 - 890 Mhz	1710 - 1785 MHz	1850 - 1910 MHz	876 - 880 MHz
Carrier Spacing	200 kHz	200 kHz	200 kHz	200 kHz
Duplex Spacing	45 MHz	95 MHz	80 MHz	45 MHz

2G的限制

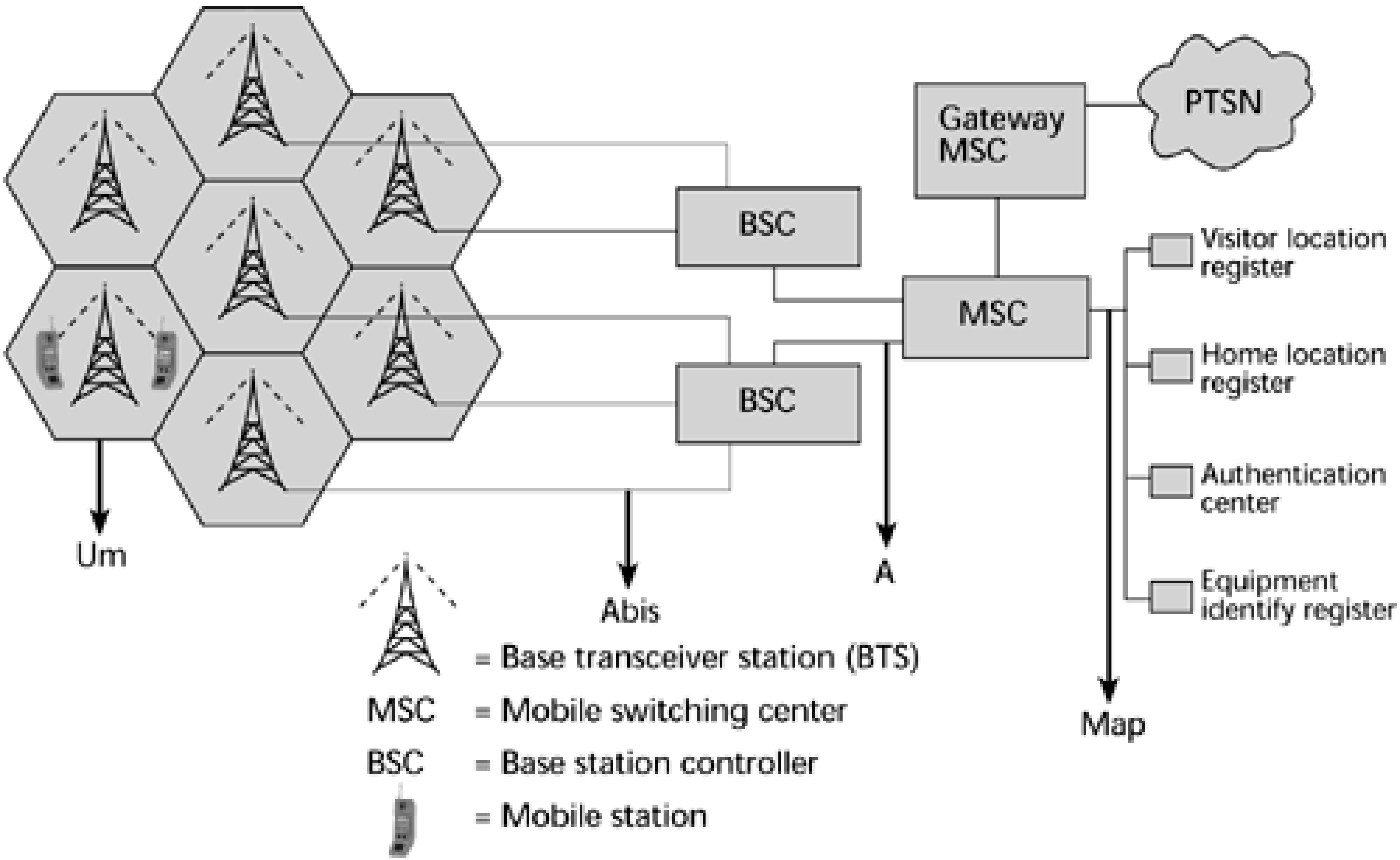
- TDMA系統需要guard band來避免干擾



Also required potentially unreliable "hard" handoffs

Switch channels between adjacent cells – potential for dropped calls

行動通訊架構 (GSM)



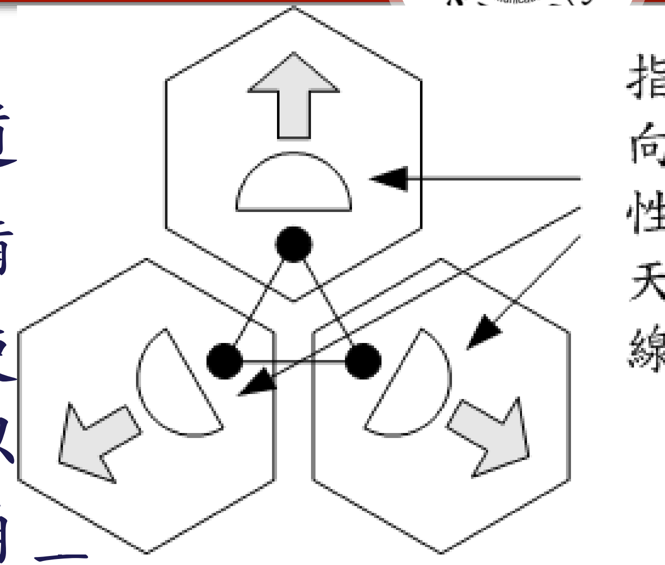
PTSN
Gateway MSC
BSC
BSC
MSC
Visitor location register
Home location register
Authentication center
Equipment identify register
Um
Abis
A
Map
= Base transceiver station (BTS)
MSC = Mobile switching center
BSC = Base station controller
= Mobile station

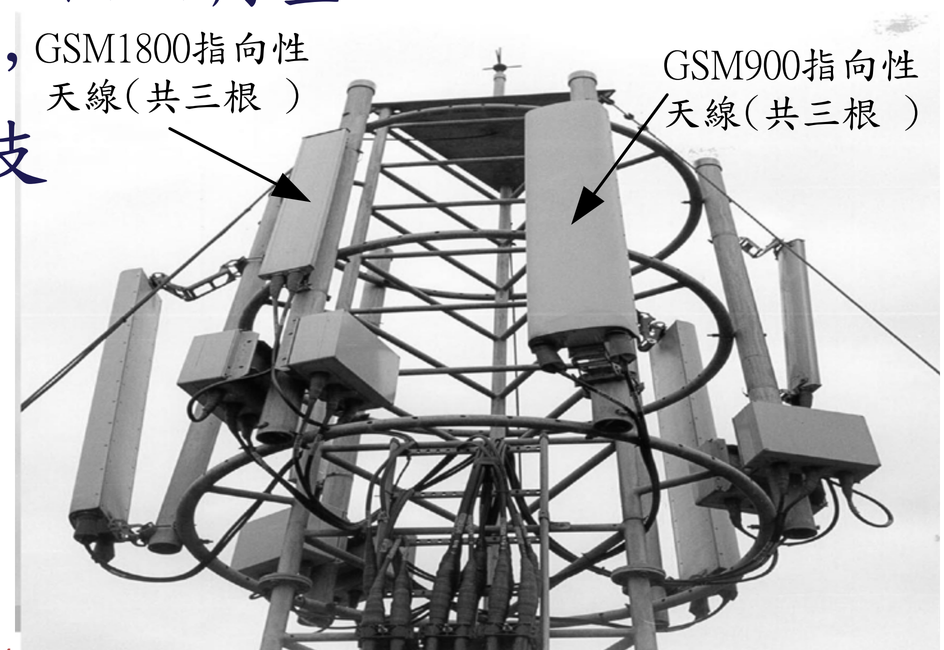
行動通訊架構 (GSM)

- Base transceiver station (BTS): 基地台，負責與手機連線
- Base station controller (BSC):基地台控制站，控制數個基地台，分配各基地台使用的頻帶及傳送功率，協助群組內基地台進行Handover
- Mobile switching center (MSC):行動交換中心，行動網路核心，負責call的傳遞路徑，將通話切換至其他MSC或BSC，負責不同BSC之間的Handoff，連接PSTN及以下資料庫:
  - Home location register (HLR):本籍位址記錄器，記錄行動用戶位置
  - Visitor location register (VLR):訪客位址記錄器，記錄漫遊用戶位置
  - Authentication Center (AUC):驗證中心，記錄並核對用戶sim卡密碼
  - Equipment Identity Register (EIR): 裝置ID記錄器，記錄話機ID，可於話機被盜竊時使用
- Public switched telephone network (PSTN):公共交換電話網

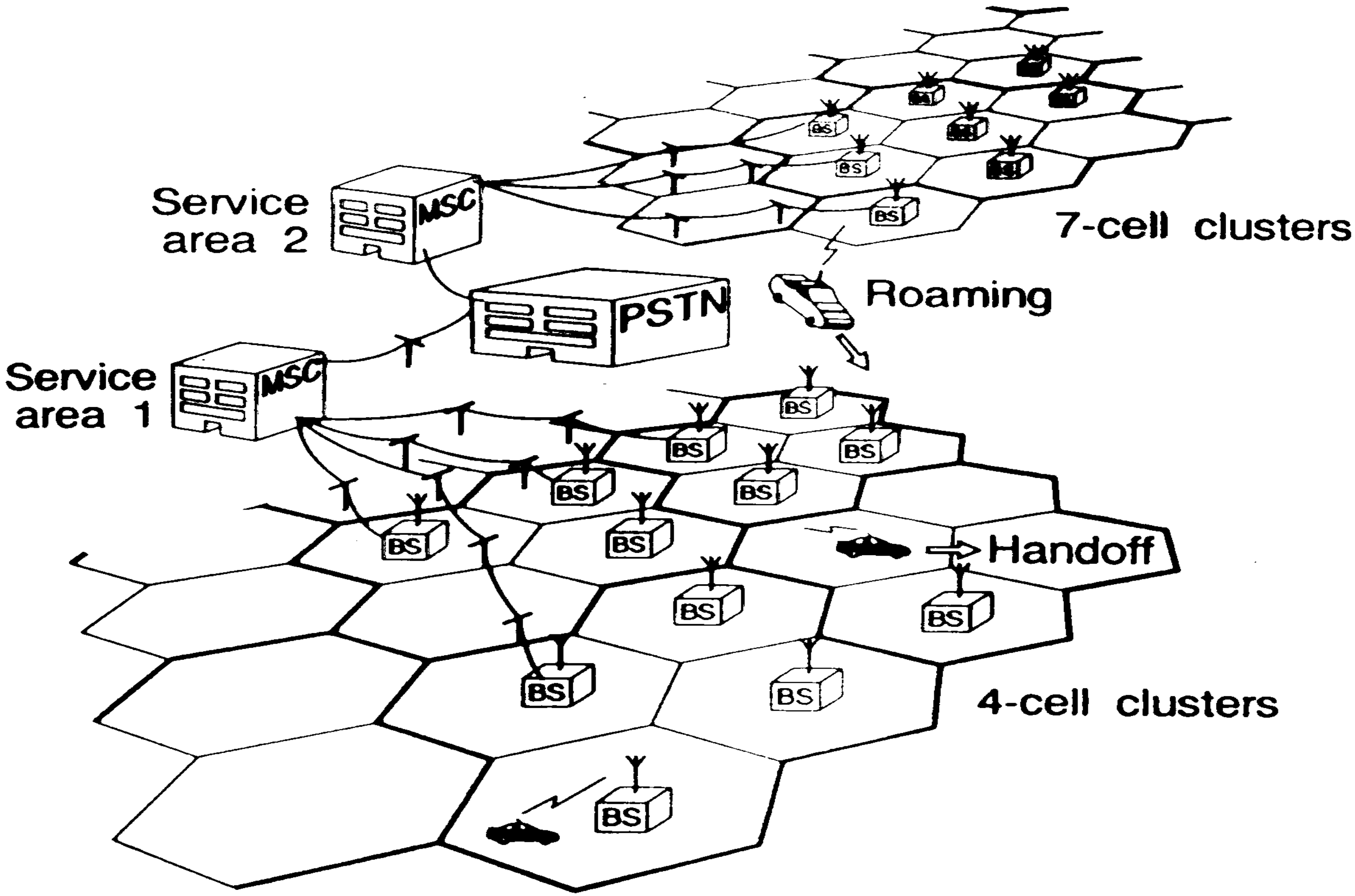
基地台

- 網路與使用者手機間的溝通管道
- 包含無線電收發機及天線等設備
- 不過實際上為了讓頻率的重覆使率盡可能的高，基地台多半是以形的型式存在，像是在一個六角的中心點架設三隻天線，各朝向不同的方向，每支天線負責120度的區域。





Traditional Cellular Networks (1G & 2G)



Third Generation Cellular Systems

- High Speed Data Service

- Three major standards:
  - UMTS (Universal Mobile Telecommunication Standard)
    - In Japan – WCDMA.
  - cdma2000 (IS-95 successor)
  - TD-SCDMA: Time-Division Synchronous CDMA

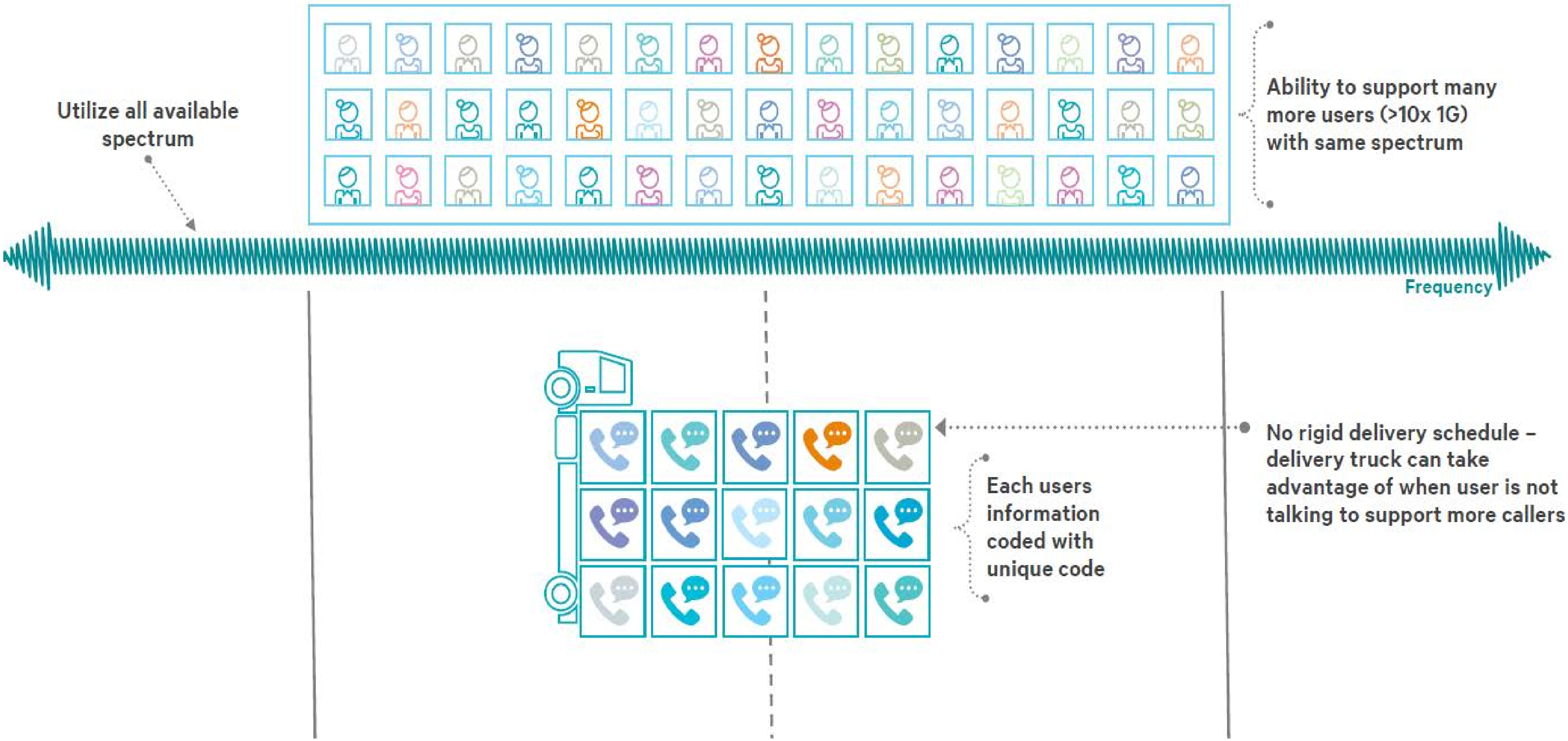
Third Generation Cellular Systems

- IMT-2000 Services
  - Indoor office: 2M bps
  - Pedestrian: 384 kbps
  - Vehicular: 144 kbps
  - Satellite: 9.6 kbps

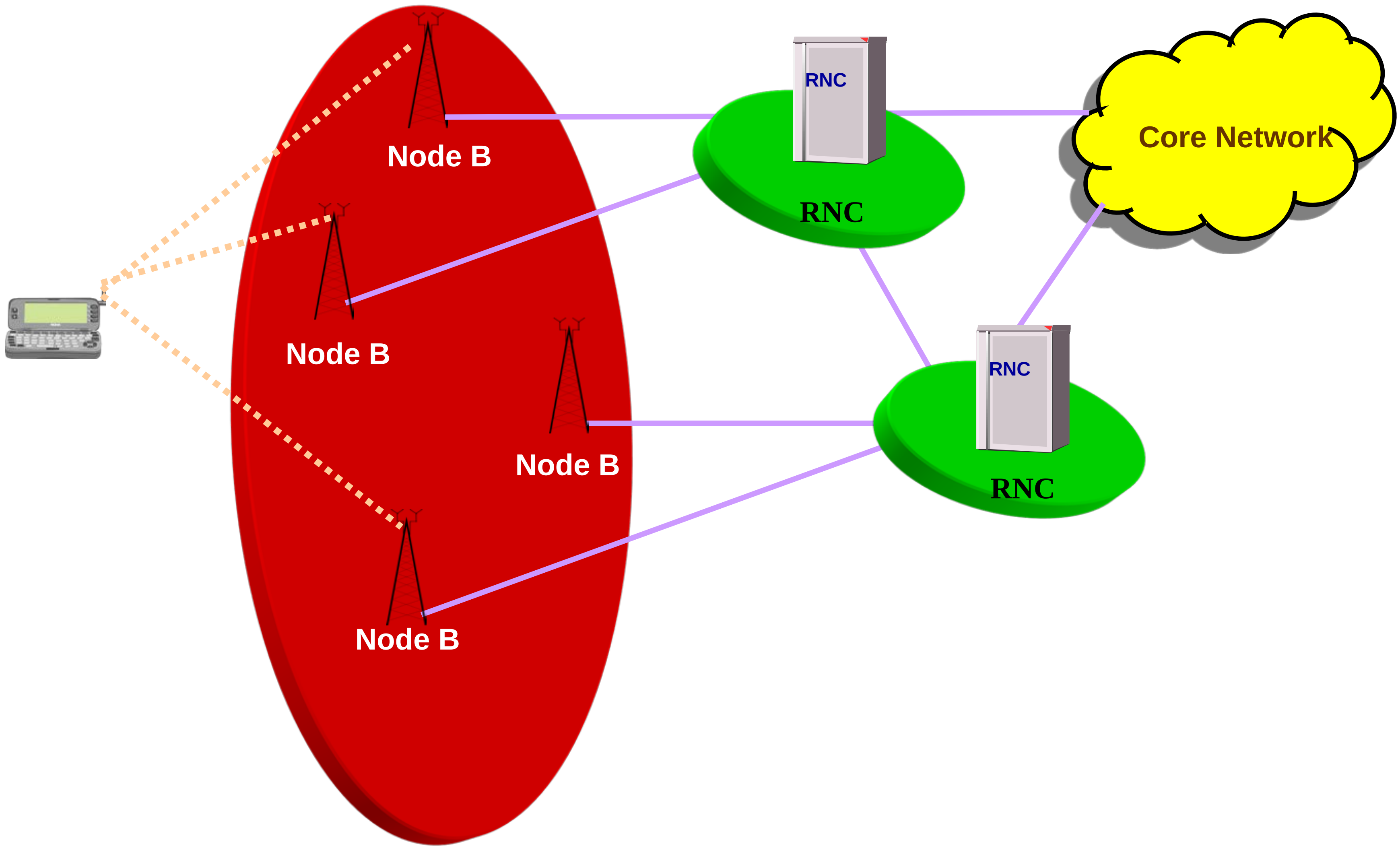
- Multi-environment operations
  - Mega-cell (100-500 km)
  - Macro-cell (<=35 km)
  - Micro-cell (<=1km)
  - Pico-cell (<=50m)

3G的特性

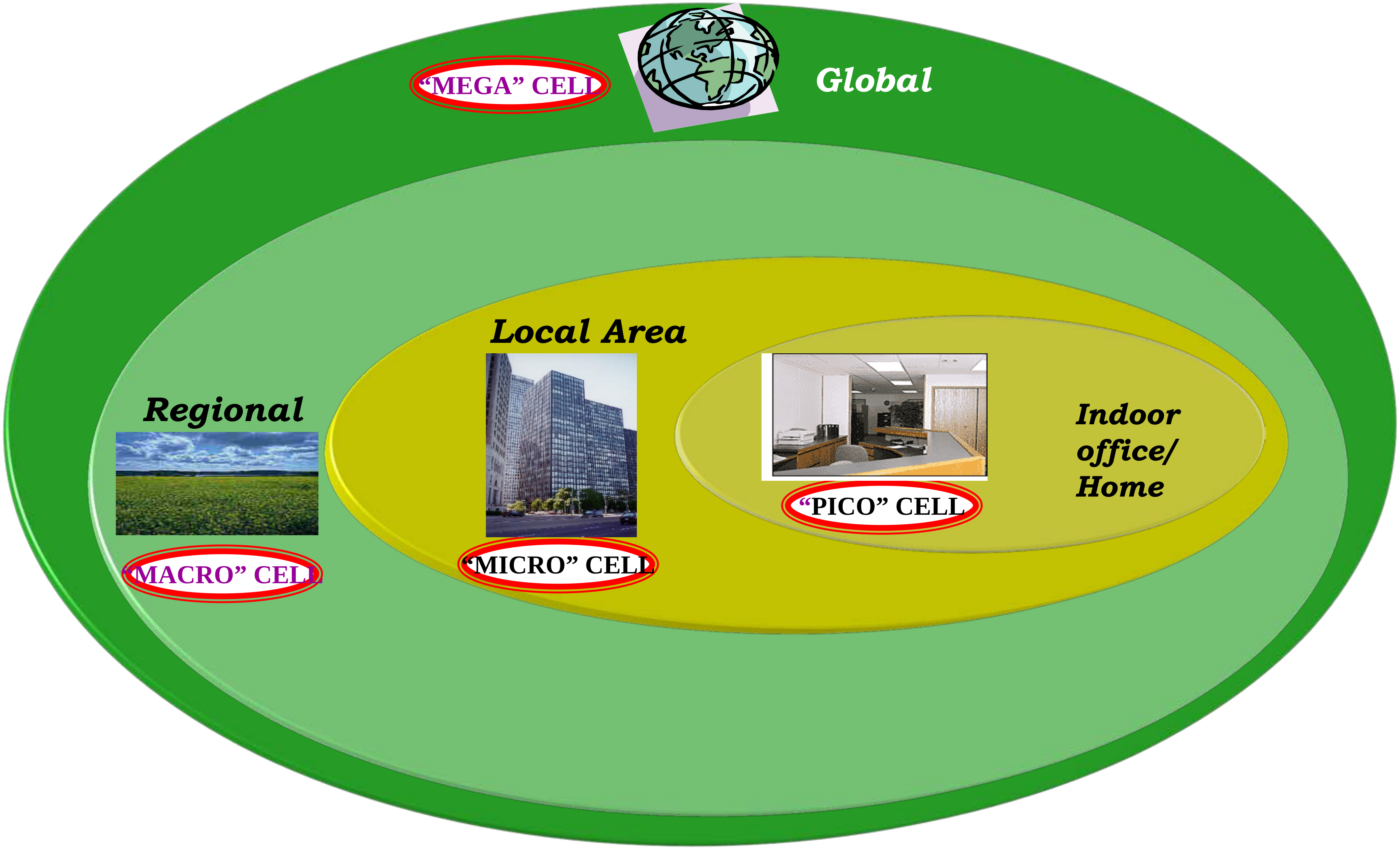
- CDMA使用可用的載波頻寬來支援更多用戶的傳輸



3G Cellular Network - WCDMA

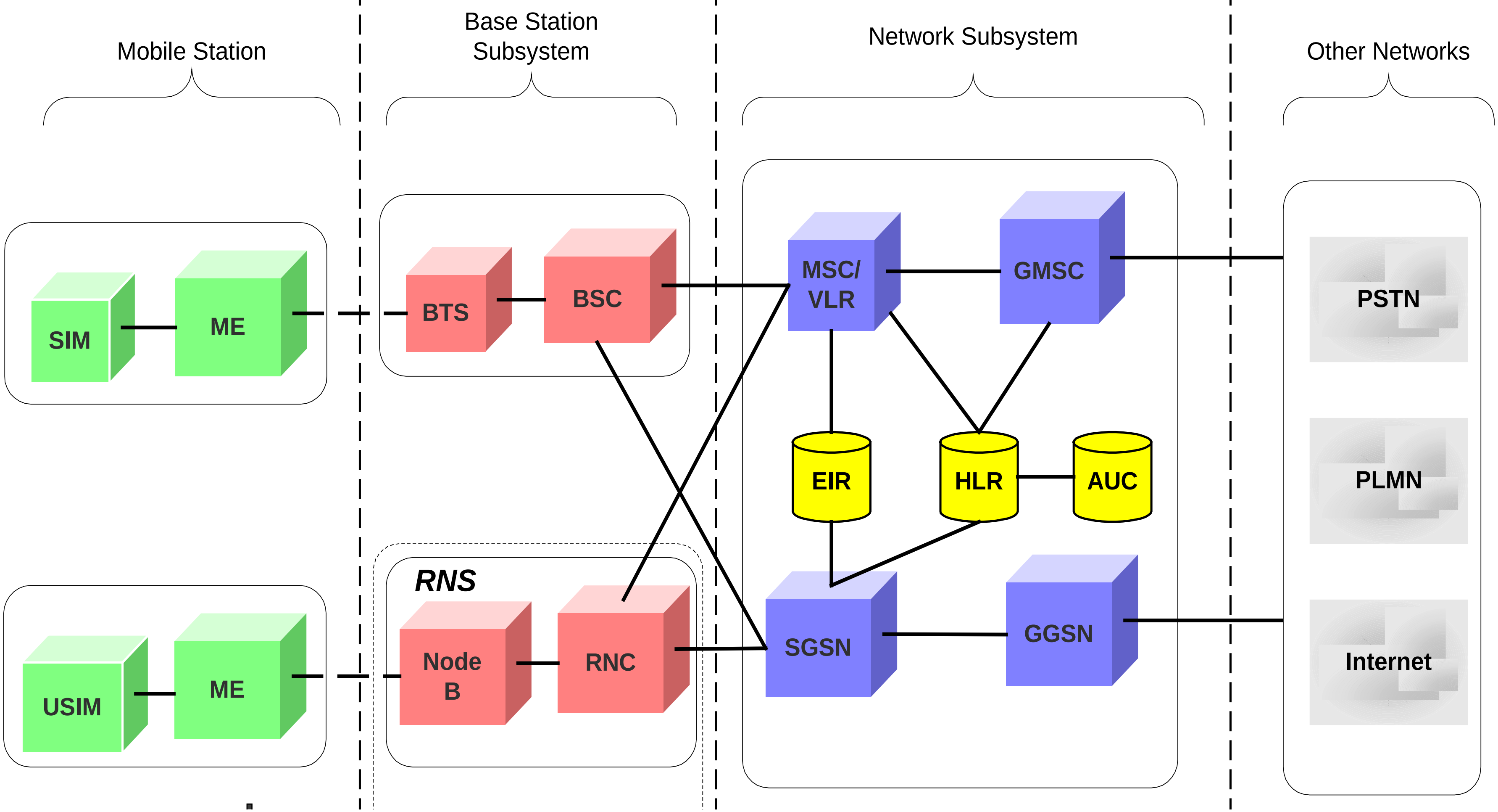


Hierarchical Cellular Networks



通用行動通訊系統 (UMTS)

- 由 GSM 系統演進的3G通用行動通訊系統（Universal Mobile Telecommunications System，UMTS）



UMTS架構

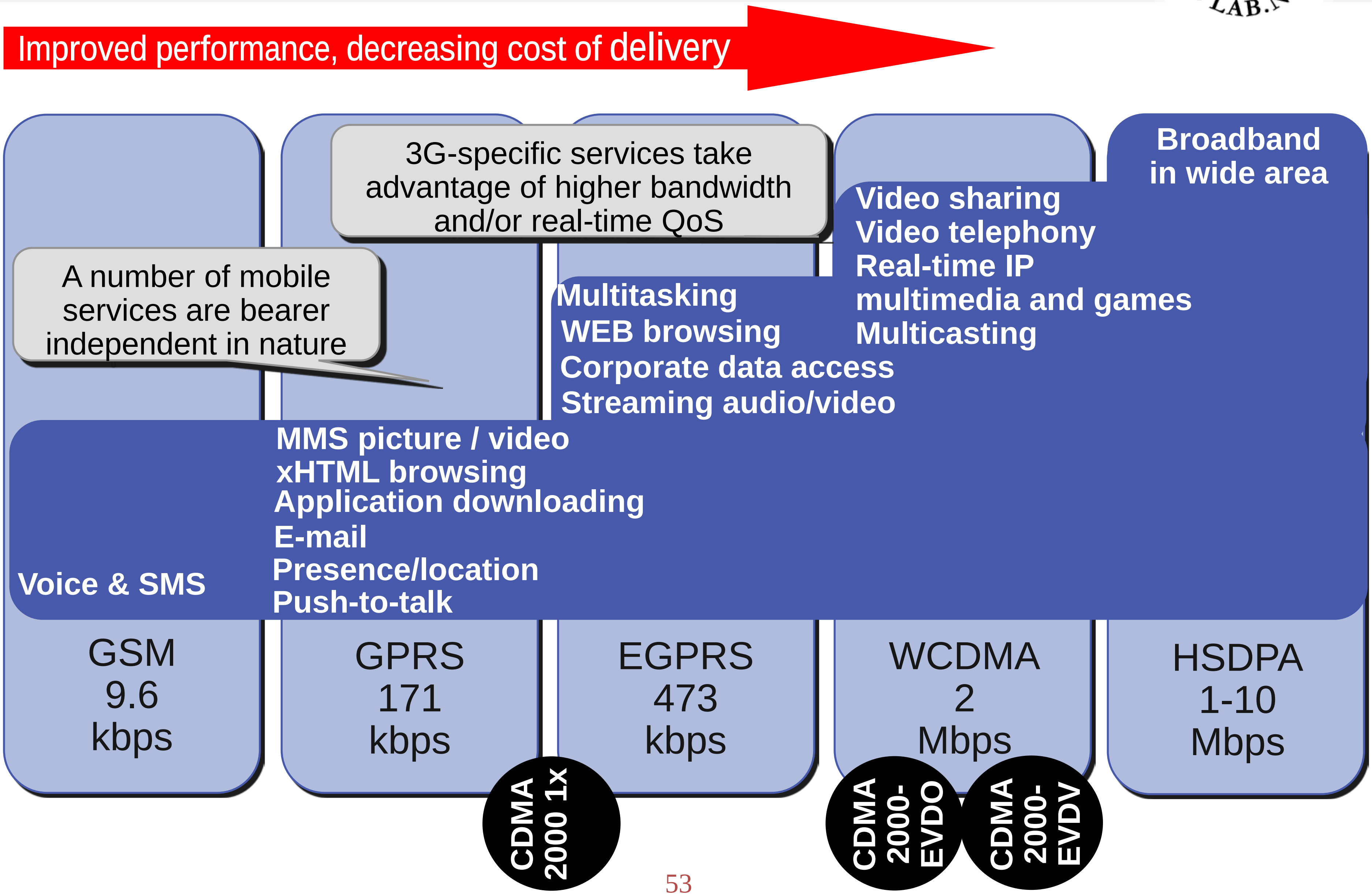
無線電網路子系統（Radio Network Subsystem，RNS）

- Node B:基地台
- Radio Network Controller (RNC) 無線電網路控制器

核心網路:

- 負責傳遞語音的網路元件包括 MSC/VLR、HLR 和 GMSC ，沿襲GSM架構
- 負責傳遞數據資料的網路元件包括 SGSN 和 GGSN ，沿襲GSM架構
  - Serving GPR Support Node (SGSN):GPRS服務節點，把用戶的資料，轉送到GPRS網路中，以及負責把外部網路送給GGSN的資料，轉到無線網路介面傳送給使用者。
  - Gateway GPRS Support Node (GGSN): GPRS閘道節點，結網際網路及行動網路的橋樑

2G到3.5G的演進

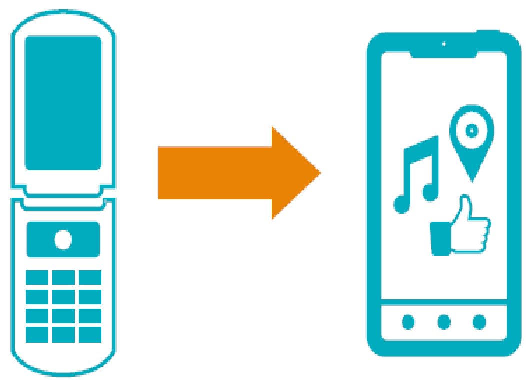

Improved performance, decreasing cost of delivery
3G-specific services take advantage of higher bandwidth and/or real-time QoS
A number of mobile services are bearer independent in nature
Broadband in wide area
Video sharing
Video telephony
Real-time IP multimedia and games
Multicasting
Multitasking
WEB browsing
Corporate data access
Streaming audio/video
MMS picture / video
xHTML browsing
Application downloading
E-mail
Presence/location
Push-to-talk
Voice & SMS
GSM 9.6 kbps
GPRS 171 kbps
EGPRS 473 kbps
WCDMA 2 Mbps
HSDPA 1-10 Mbps
CDMA 2000 1x
CDMA 2000-EVDO
CDMA 2000-EVDV

However….

Broadband Internet

Consumers introduced to broadband internet access in the home/office

The Smartphone



Amazing innovations in device technology resulted in the era of the smartphone

Mobile Everywhere

2 → 39 → 92

1990 2000 2010

Average mobile subscriptions per 100 people[1]

Thanks to 2G technologies, more and more people had a mobile subscription

The Economist(經濟學人), April 26th, 2007.
When everything connects

iPhone是蘋果公司推出的第一代智慧型手機，該款智慧型手機於2007年1月9日正式發布，並於同年6月29日正式發售。

為提供讀者更寬廣的國際視野，與世界經濟脈動同步，本刊與《經濟學人》簽約，取得台灣地區獨家授權報導，呈現給讀者最新、最快的世界政經脈動。

未來五十年 無線通訊將掀起生活革命

無線電裝置曾經是放在客廳角落、微微發熱的木框機器，時至今日，已經是能夠輕巧放在口袋的時髦行動電話。未來幾年，隨著通訊晶片內建於許多日常生活用品，無線設備可能完全從眼前消失。這些通訊晶片以及連結晶片的網路，終將證實它們的最大影響力。

就像過去幾十年，每樣東西都找得到微處理器一樣，無線通訊晶片將來也會成為大小物品的一部分。此預言的可能性非常高。小玩意和小東西將和其他裝置對話，從遠端提供服務；農場的無線系統將測量溫度與濕度，控制灌溉設備；標籤將驗證食物的來源與通路，證實藥物的真偽；位於人們體表或體內的微晶片，將傳送生命跡象訊號到診所，協助監控身體健康。

擺脫電纜線束縛 資訊傳遞更快更便宜

電腦革命與資訊有關：將文件、照片等紀錄數位化，使資訊運用起來更簡便；無線通訊革命則是使數位資訊傳送至任何地方，而且幾乎毋須花費任何成本。不再受到有形的電纜線束縛以後，資訊將傳送到最有價值的目的地。

就現階段而言，大出風頭的是行動電話。從簡單的電話功能，逐步進化成電子錢包、鑰匙圈、健康監測器及導航裝置。

此成就得歸功於通訊公司馬可尼（Marconi）的無線電發報裝置及微處理器之間的整合與發展。無線電功能鑲嵌在矽晶片之後，尺寸與成本大幅減少，而運算性能大幅提升。今天的衛星導航晶片每片只需要一美元（約合新台幣三十三元），而無線射頻識別系統（Radio Frequency Identification，RFID）的標籤尺寸則可以小到放進指紋縫隙之間。當我們能以無線方式將電力傳送至這些裝置時（不久的將來就能實現），所有東西將能一切就緒。

無線通訊應如同資訊科技一般，能夠推升生產力。想想無線通訊將如何改變汽車產業。汽車製造商開始監督車輛，根據震動或溫度的變化，在損壞之前知道何時該更換零件。

即時監控，故障前換掉零件 小晶片改變汽車產業

如果發生車禍，無線晶片可以告訴緊急服務人員地點在哪裡、發生的事件以及是否有人受傷。交通資訊可以立即反映，而且完全正確。依據精確的路線收取過路費。英國保險商以駕駛人精確的時間與地點為基礎，提供不同保費的保單。

當然，在無線通訊有能力實現承諾的願景之前，還有許多工作待完成。第一大障礙是新奇性。如一般新產業發展初期常見的，市場充滿各式各樣專利系統，其中許多是從零開始，不像一九七〇年代的早期電腦駭客，是以他們的Altair電腦（編按：第一台個人電腦，但功能極為簡單）招搖撞騙。目前還不清楚能夠拔得頭籌設定準則的會是誰。行動電話產業兩大巨擘——索尼愛立信（Sony Ericsson）與諾基亞（Nokia）最近幾年已經賣掉機器通訊部門。此舉為來自電腦產業、捷足先登的公司開啟大門，諸如三星（Samsung）、飛利浦（Philips）、霍尼威爾（Honeywell）與日立（Hitachi）。四月底，奇異（General Electric）的感應部門表示，將在製藥與石油化學產業使用無線感應器。

> **擺脫有形的電纜線束縛，無線通訊可應用在任何物品上，並能夠推升生產力。**

政府將扮演關鍵角色，不只是因為無線電頻寬供給不足。除了頻寬可能因為新興技術缺乏財力或政治力而被棄置一旁外，政界與商界人士也可能緊盯電磁波對人體造成的影響。

就長期而言，另一項重大考量為隱私權問題。今天的法律通常假定隱私權受到消費者與公司，或民眾與政府之間的約定所保障。但在一個許多網路在空中相互連接、資訊廣泛共享的世界，無線網路應使消費者知道，他們何時受到監督。

政府應扮演關鍵角色 避免太多政策干預及管制

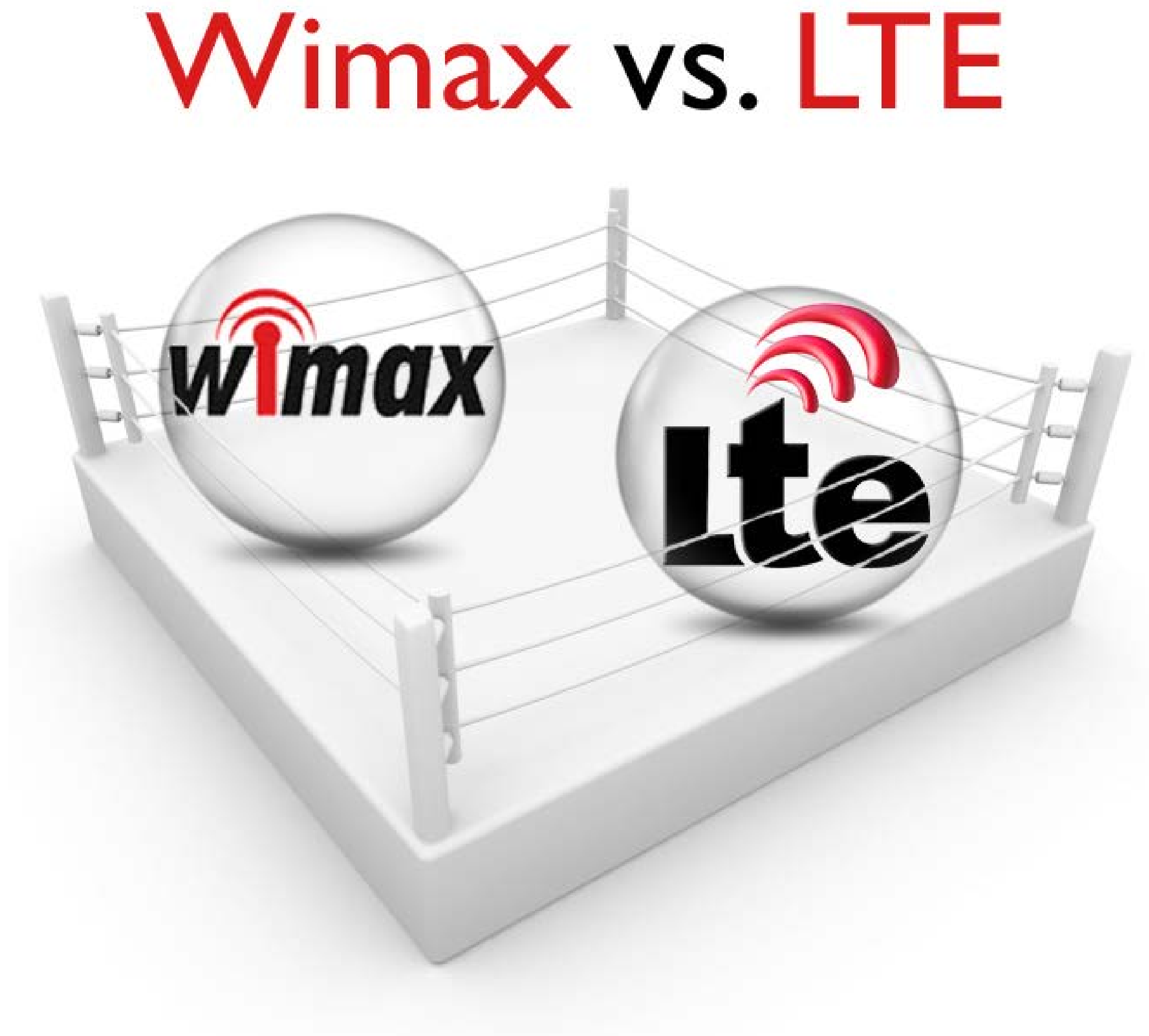
但就現階段而言，危險是來自於太多規範，而非太少管制。對於任何人（其中大多是政治人物）而言，描繪無線技術遠景的藍圖十分困難，就像電動馬達和微處理器的情況一樣。

未來五十年，無線技術無所不在的情形，不僅會像二十世紀前半期的電動馬達，出現在從打蛋機到電梯等每樣東西，也會像二十世紀後半期的電腦化操作模式，占據從汽車到咖啡機的各式各樣機器。儘管結果有可能令人恐懼，但大部分情況下，它們將帶來超乎想像的助益。

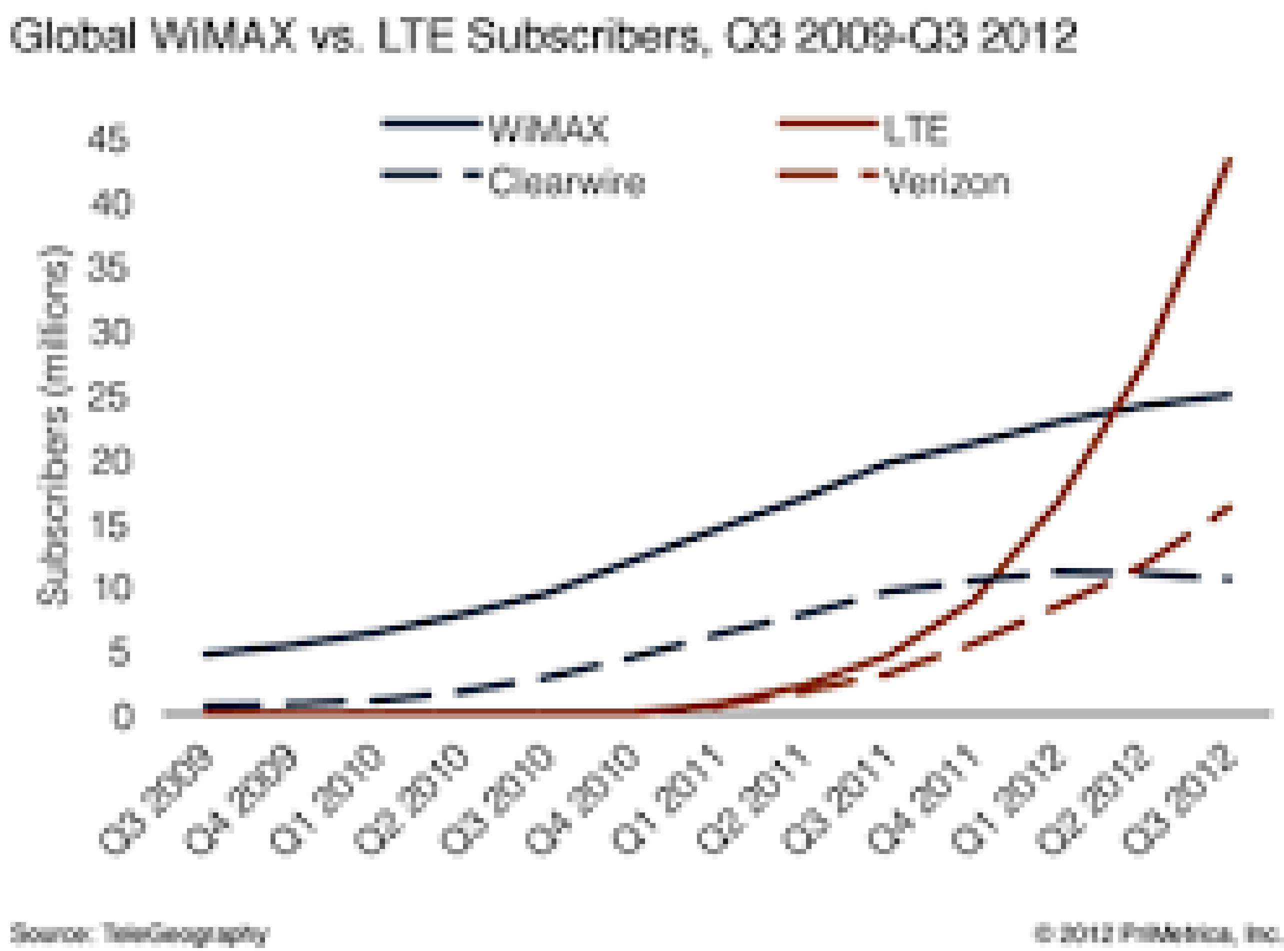
（譯●賴　美）

（本文譯自《經濟學人》When everything connects Apr. 26th, 2007.）

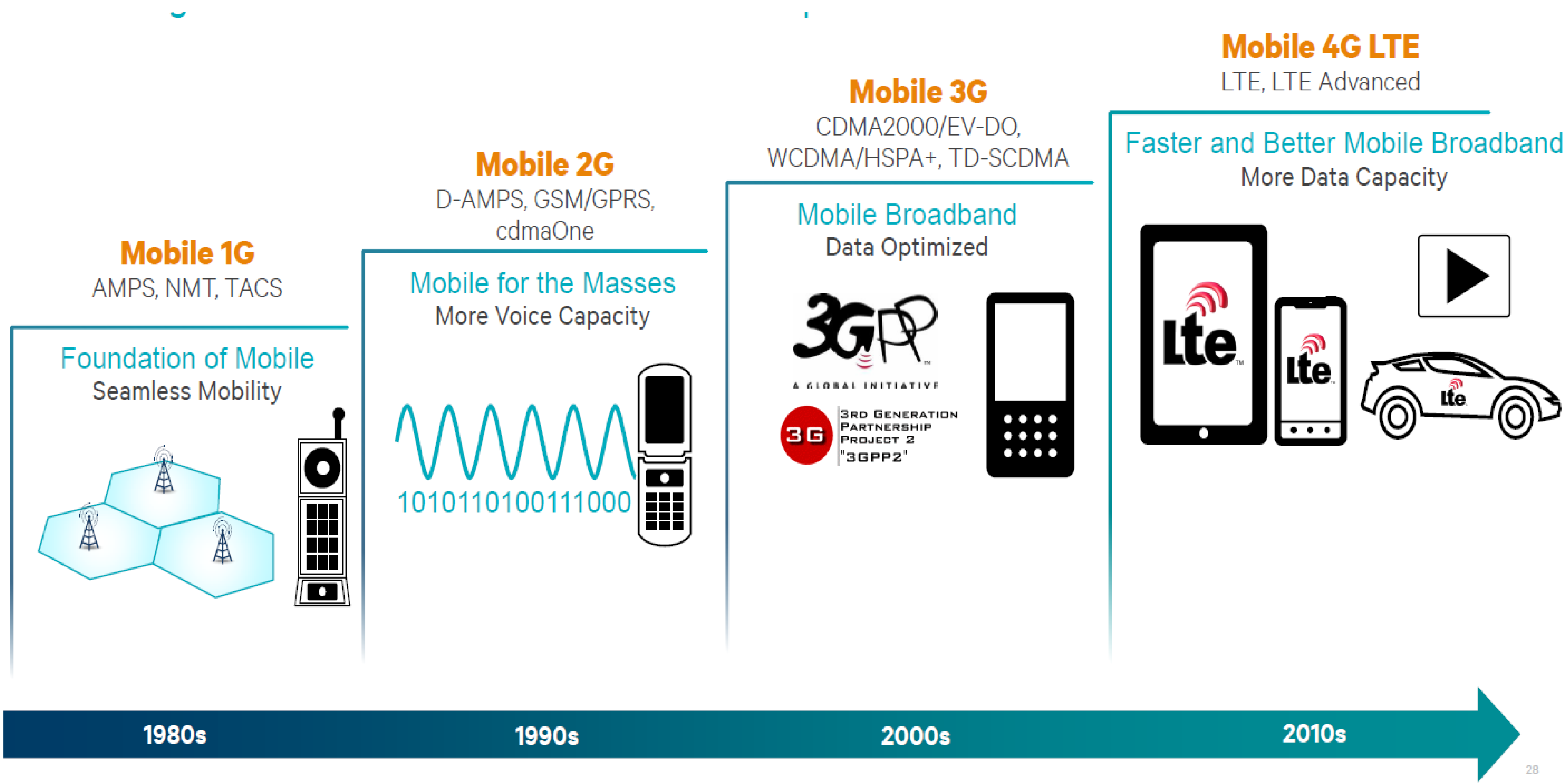
WiMAX與LTE之爭



WiMAX與LTE之爭

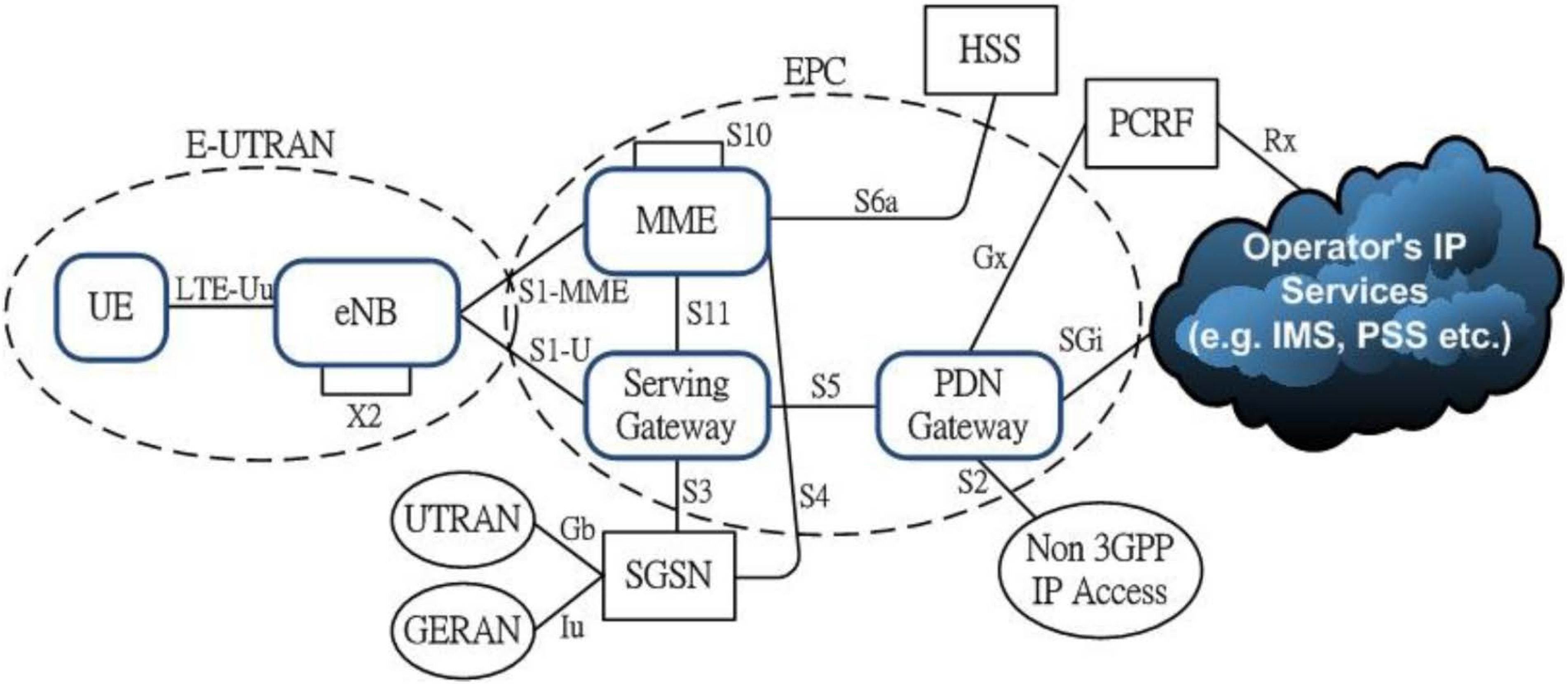


4G的演進



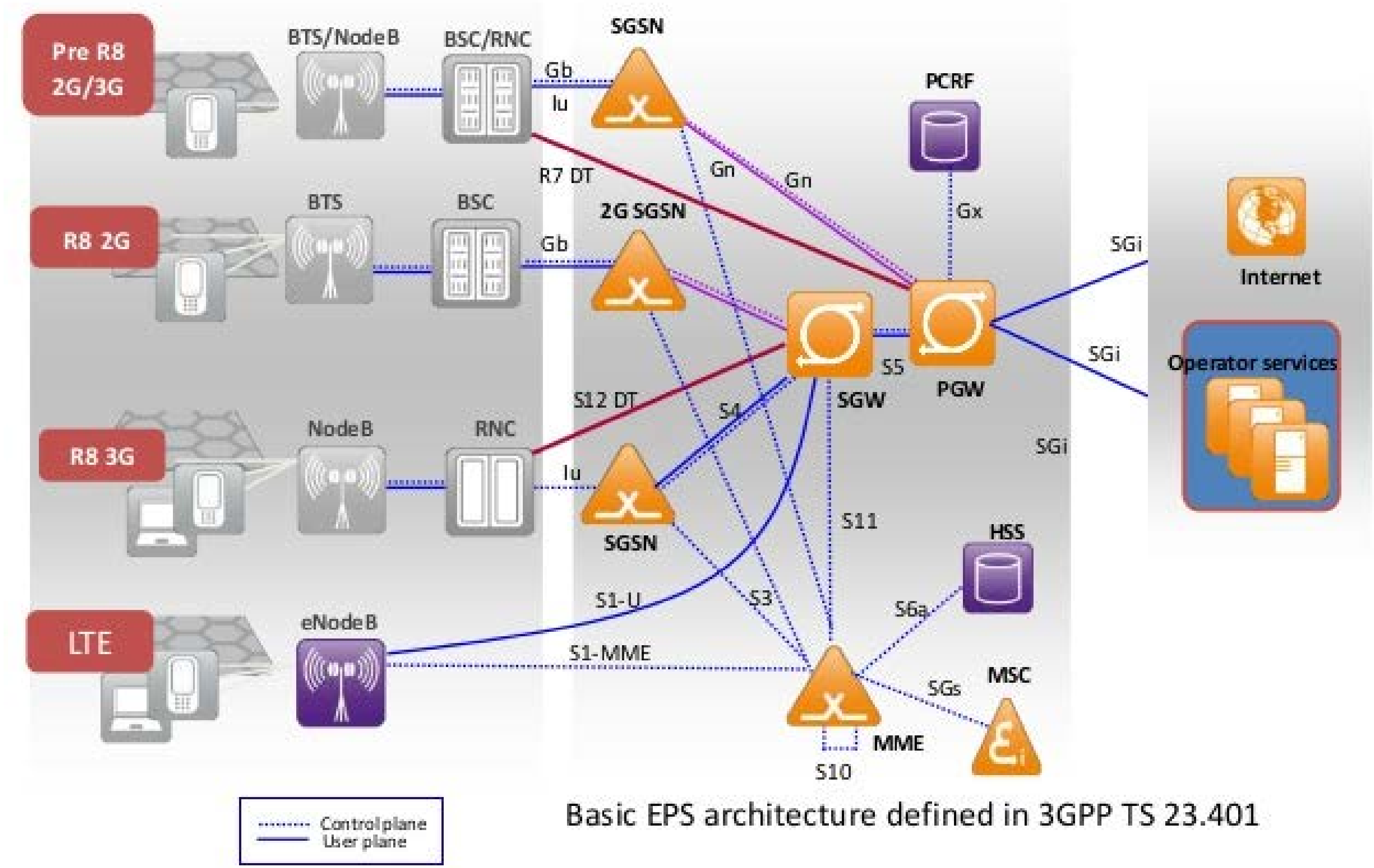
Mobile 1G
AMPS, NMT, TACS
Foundation of Mobile
Seamless Mobility
Mobile 2G
D-AMPS, GSM/GPRS, cdmaOne
Mobile for the Masses
More Voice Capacity
1010110100111000
Mobile 3G
CDMA2000/EV-DO, WCDMA/HSPA+, TD-SCDMA
Mobile Broadband
Data Optimized
3GPP
A GLOBAL INITIATIVE
3G
3rd Generation Partnership Project 2 "3GPP2"
Mobile 4G LTE
LTE, LTE Advanced
Faster and Better Mobile Broadband
More Data Capacity
lte
1980s
1990s
2000s
2010s
28

4G LTE Architecture



4G LTE Architecture

General LTE Architecture

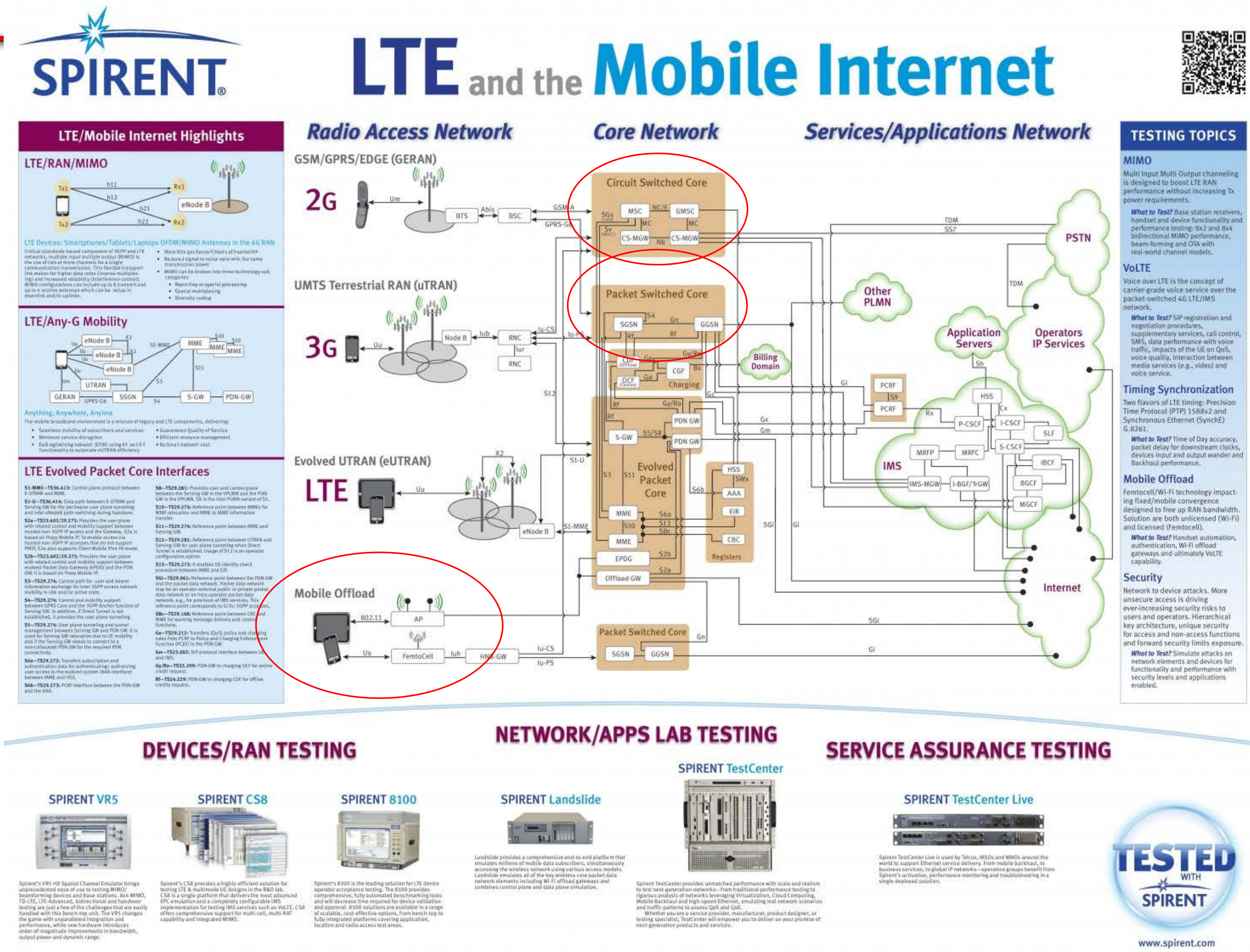


Basic EPS architecture defined in 3GPP TS 23.401

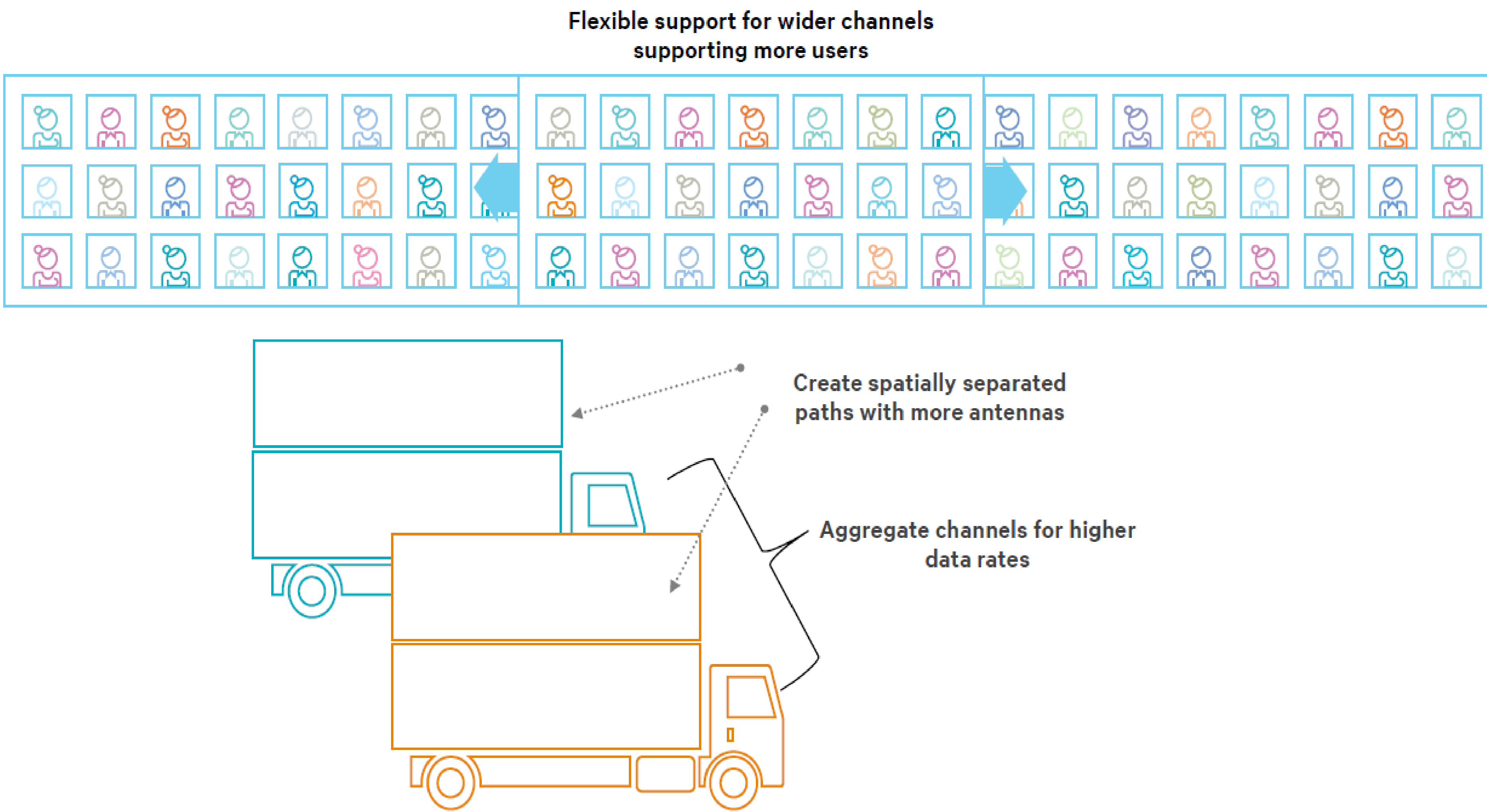
Abbreviations

- GPRS: General Packet Radio Service (2.5G)
- EDGE: Enhanced Data Rates for GSM Evolution (2.75G)
- GGSN: Gateway GPRS Support Node
- SGSN: Serving GPRS Support Node
- MME: Mobility Management Entity
- PGW: Packet Data Network (PDN) Gateway
- SGW: Serving Gateway
- HSS: Home Subscriber Server
- PCRF: Policy and Charging Rules Function
- RNC: Radio Network Controller
- BTS: Base Transceiver Station
- BSC: Base Station Controller
- GERAN: GSM EDGE Radio Access Network
- RRC: Radio Resource Control

LTE & Mobile Internet



LTE的特性

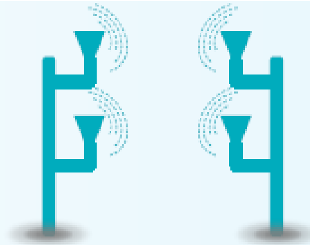


Flexible support for wider channels supporting more users
Create spatially separated paths with more antennas
Aggregate channels for higher data rates

Connect faster ! Connect real-time !

Wider Channels

Flexible support for channels up to 20 MHz enabled with OFDMA

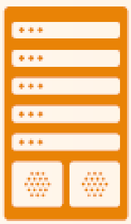


More Antennas

Advanced MIMO techniques to create spatially separated paths; 2x2 MIMO mainstream

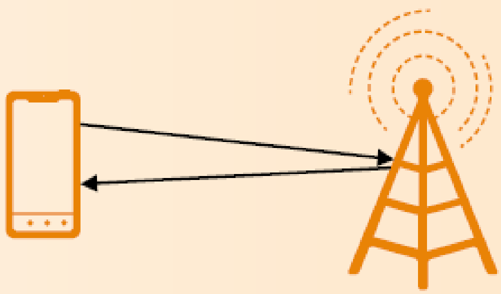
Carrier Aggregation

Aggregate up to 100 MHz for higher data rates – 2 carrier (2C) commercial; 3C announced[1]



Simplified Core Network

All IP network with flattened architecture resulting in less equipment per transmission



Low Latencies

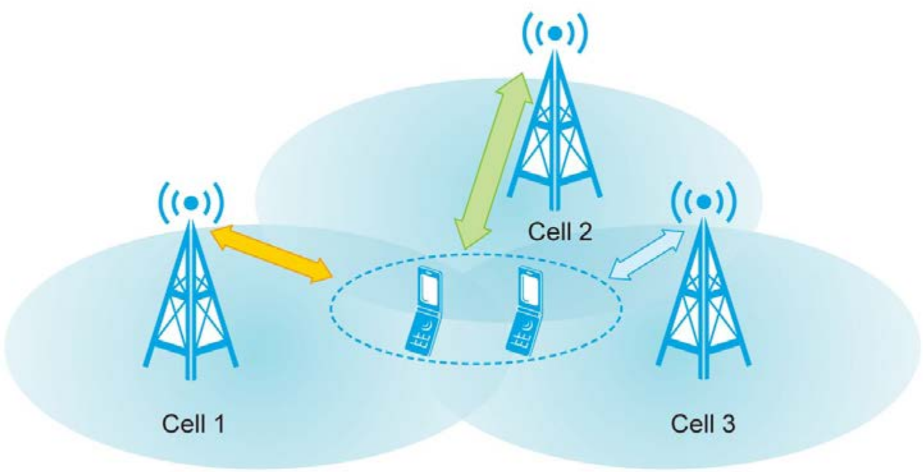
Optimized response times for both user and control plane improves user experience

LTE-Advanced

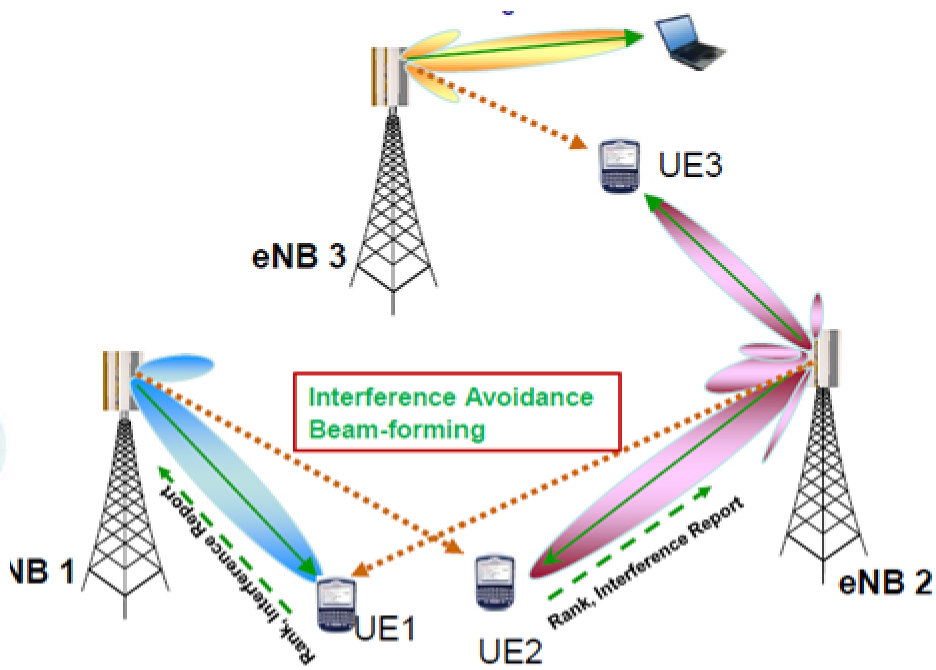
System aspect			E-UTRA/LTE (3GPP Rel-8)	IMT-Advanced requirements	LTE-Advanced (3GPP Rel-10)	
(Peak) data rates		DL	327.6 Mbps (4x4 MMO, 64QAM)	1 Gbps (high mobility) 100 Mbps (low mobility)	1 Gbps	Carrier aggregation, MIMO
		UL	86.4 Mbps (64QAM)		500 Mbps	
Supportable bandwidth			up to 20MHz	40 MHz, up to 100 MHz	up to 100MHz	Carrier aggregation
Spectral efficiency	Peak	DL	15 bps/Hz (UE category 5)	15 bps/Hz (4x4 MIMO)	30 bps/Hz	8x8 DL MIMO
		UL	3.75 bps/Hz (UE category 5)	6.75 bps/Hz (2x4 MIMO)	15 bps/Hz	4x4 UL MIMO
	Average	DL	1.87 bps/Hz	2.2 bps/Hz	3.7 bps/Hz (4x4 MIMO)	CoMP, MIMO
		UL		1.4 bps/Hz	2.0 bps/Hz (2x4 MIMO)	CoMP, MIMO
	Cell edge	DL	0.06 bps/Hz (4x2 MIMO)	0.06 bps/Hz (4x2 MIMO)	0.12 bps/Hz (4x4 MIMO)	CoMP, MIMO
		UL	0.03 bps/Hz (2x4 MIMO)	0.03 bps/Hz (2x4 MIMO)	0.07 bps/Hz (2x4 MIMO)	CoMP, MIMO
U-plane latency			less than 30 ms	less than 10 ms	less than 10 ms	
C-plane latency			less than 100 ms	less than 100 ms	less than 50 ms	

Coordinated Muilti-Point (CoMP)

Joint Processing



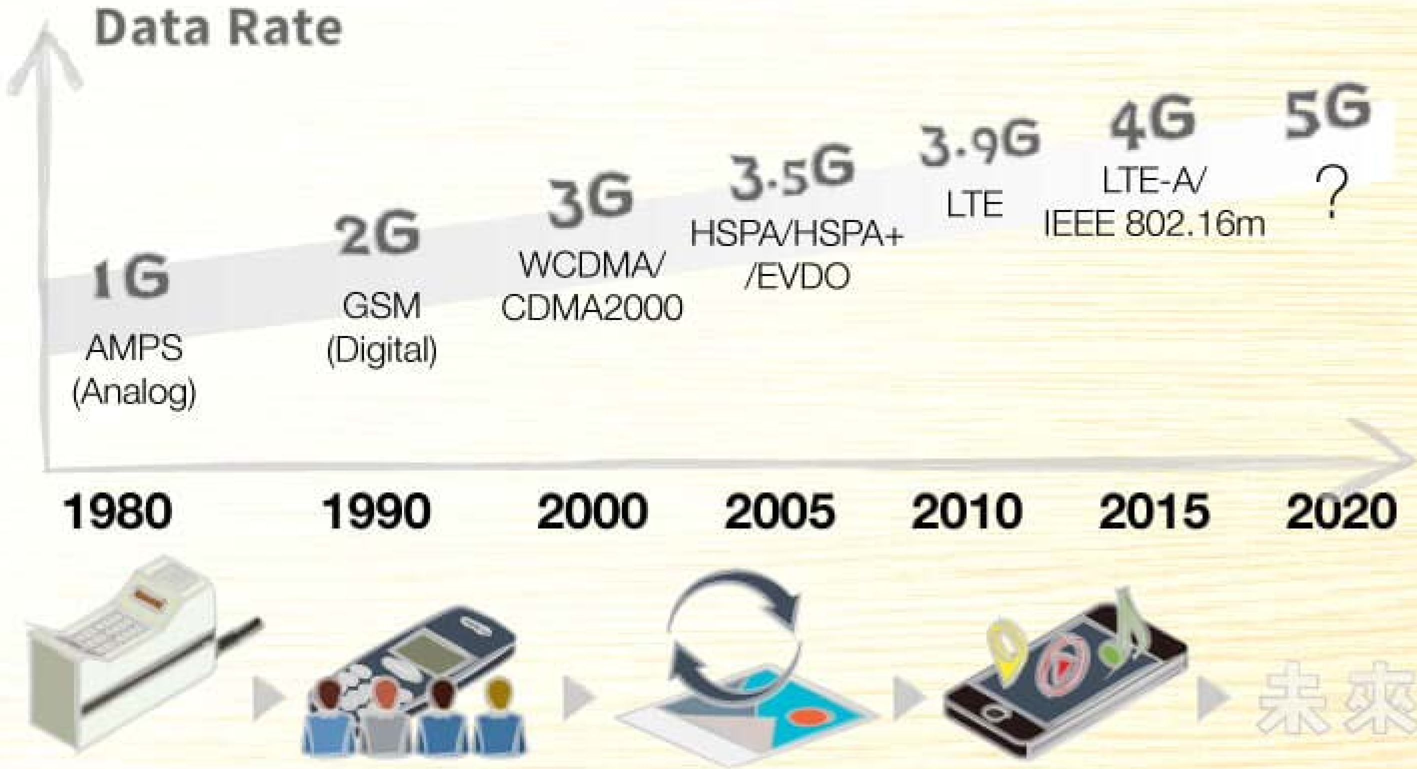
Coordinated Beamforming



傳輸速率比較

世代	系統名稱	多工方式	調變方式	通道頻寬	資料傳輸率 上傳/下載 (bps)	頻譜效率 上傳/下載 (bps/Hz)
2G	GSM	FDMA TDMA	GMSK	200KHz	9.6K/14.4K	0.05/0.07
2.5G	GPRS		GMSK	200KHz	9.6K/115K	0.05/0.58
2.75G	EDGE		8PSK	200KHz	384K/384K	1.92/1.92
3G	WCDMA	FDMA CDMA	QPSK	5MHz	64K/2M	0.01/0.40
3.5G	HSDPA		16QAM	5MHz	384K/14.4M	0.08/2.88
3.75G	HSUPA		QPSK	5MHz	5.76M/14.4M	1.15/2.88
4G	LTE	FDMA OFDM	64QAM	20MHz	50M/100M	2.5/5
4G	LTE-A		64QAM	100MHz	500M/1G	5/10

行動通信技術演進歷程



行動電話問世

實現行動通話

行動電話普及

具收發簡訊、語音通話等功能

行動數據傳輸

拓展到了圖片等移動互聯網路

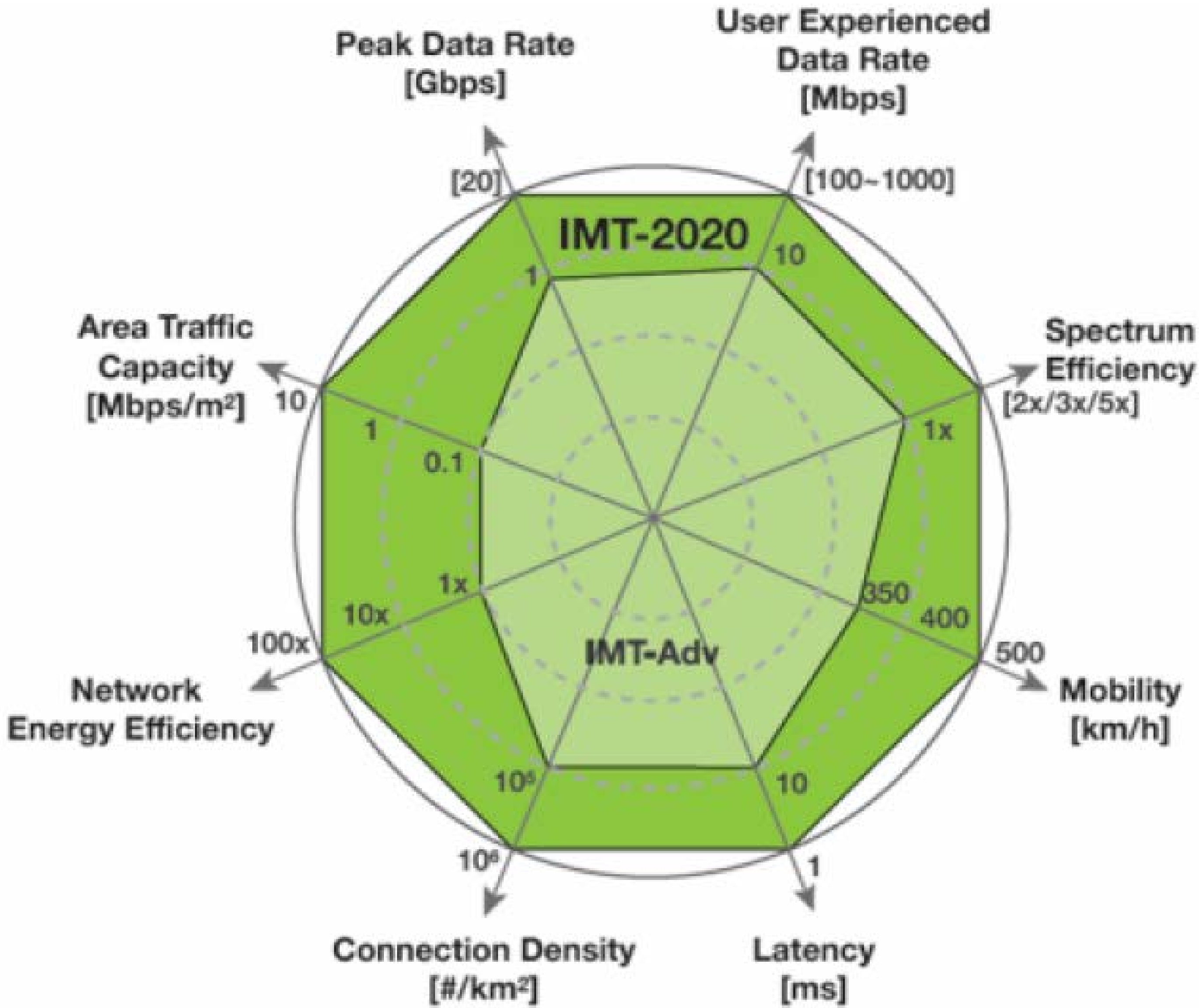
行動寬頻上網

延伸為以即時影片交互為主的網路時代

萬物互聯

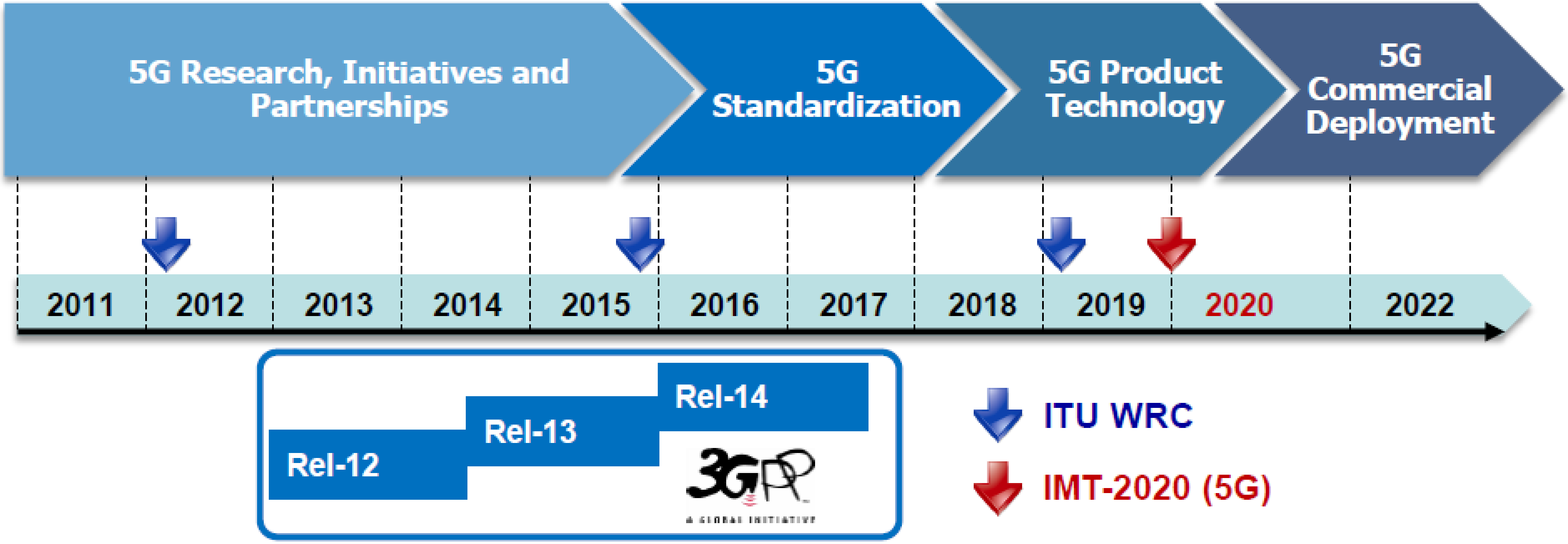
將支援更多無線設備和龐大的數據

第五代行動通訊 (5G)



Peak Data Rate
[Gbps]
User Experienced
Data Rate
[Mbps]
[20]
[100~1000]
IMT-2020
1
10
Area Traffic
Capacity
[Mbps/m²]
10
Spectrum
Efficiency
[2x/3x/5x]
1
0.1
1x
1x
10x
350
400
100x
500
IMT-Adv
Network
Energy Efficiency
Mobility
[km/h]
10
1
Connection Density
[#/km²]
Latency
[ms]

5G的時程


5G Research, Initiatives and Partnerships
5G Standardization
5G Product Technology
5G Commercial Deployment
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2022
Rel-12
Rel-13
Rel-14
ITU WRC
IMT-2020 (5G)

5G關鍵技術的趨勢

Multi-Gbps Transmission Rate

- Massive MIMO
- Millimeter Waves
- New Waveforms

Highly Dense Networks

- Advanced Small Cells
- Advanced Inter-node Coordination
- Self Organizing Networks
- Wireless Backhaul/Access Integration

Higher Spectrum Usage

- Carrier Aggregation
- Operation on Unlicensed Bands
- Operation on Millimeter Wave Bands
- Cognitive Radio

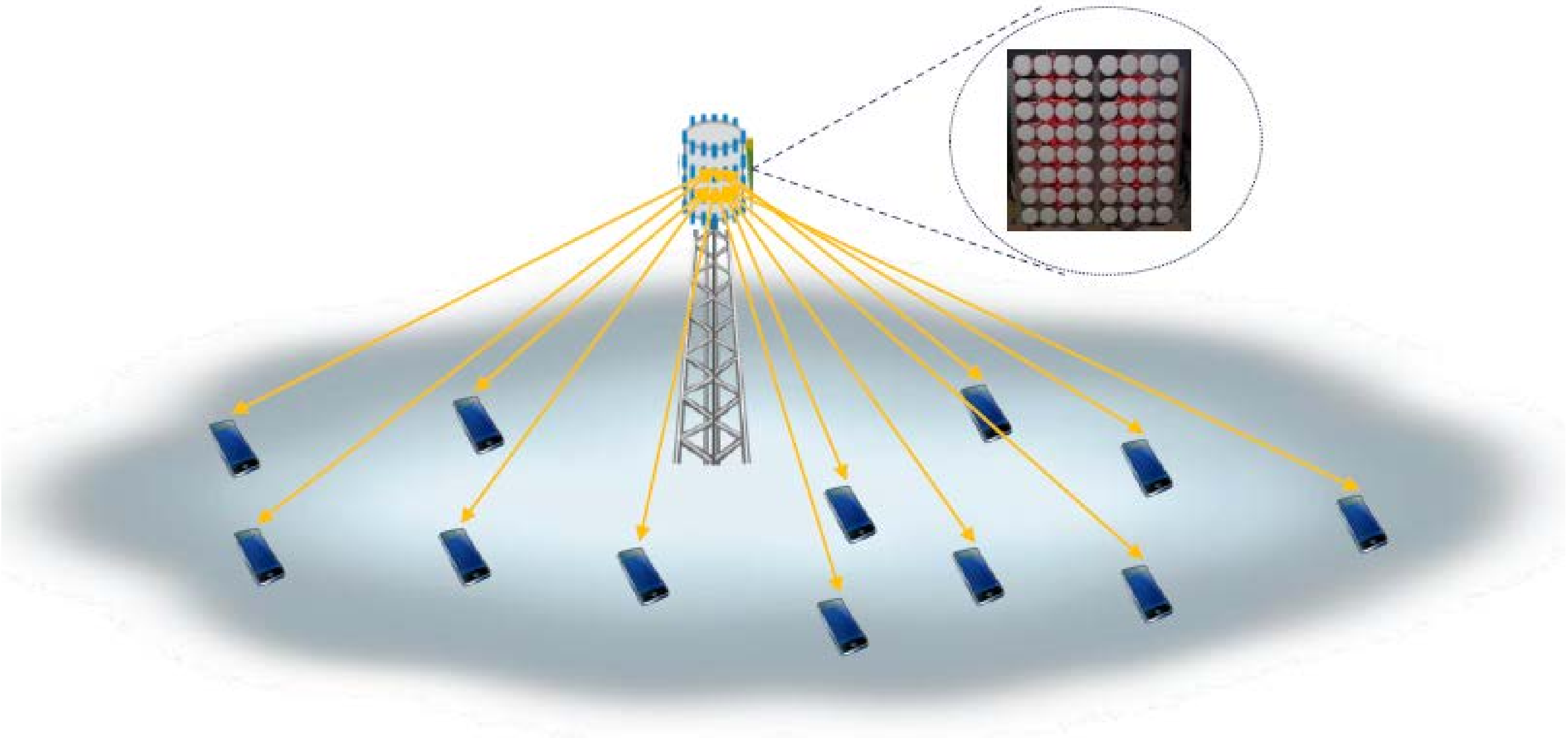
Large Scale MTC

- Device-to-Device Communication (D2D)
- Very low power consumption operation modes
- Multi-RAT Integration and Management
- Advanced Multiple Access Schemes
- Optimized operation in lower bands (sub-1GHz)

Highly Flexible Architecture

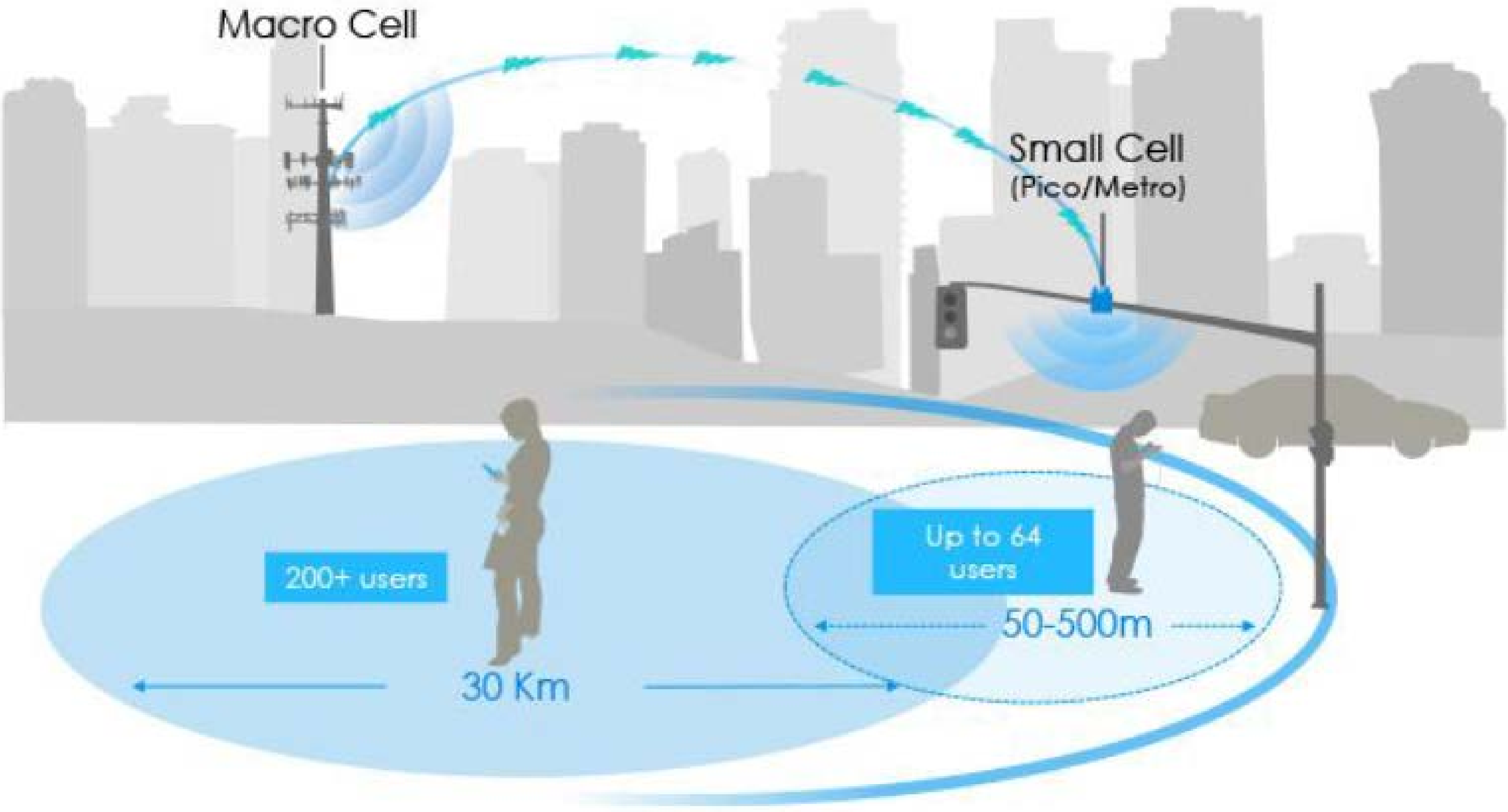
- Context Aware Networking
- Software Defined Networks
- Network Function Virtualization
- Moving Networks

Massive MIMO

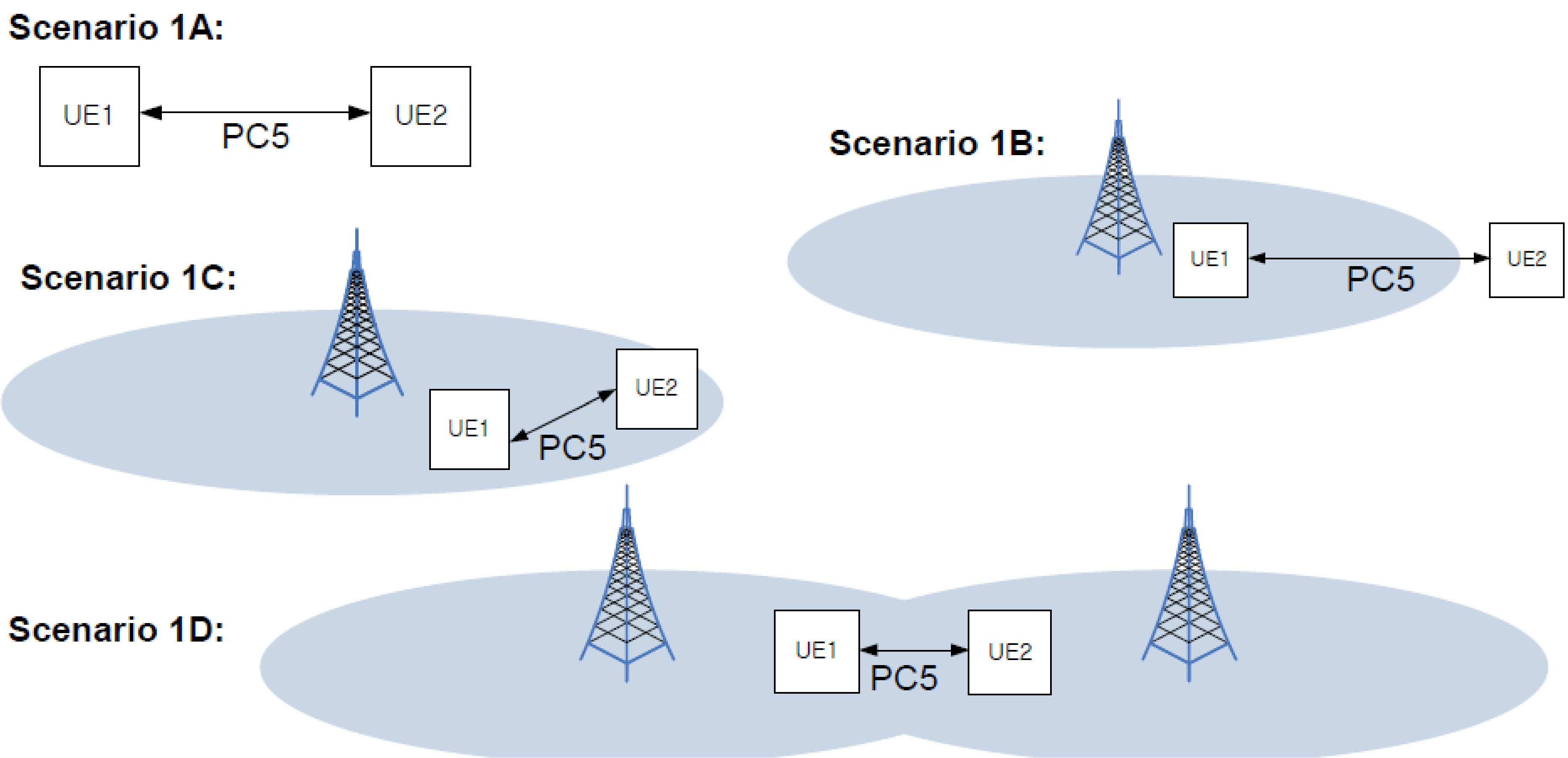


- ✓ Arrays with up to hundreds of elements
- ✓ Typical operation in higher frequencies (>10 GHz)
- ✓ Higher capacity can be achieved with enough elements

Heterogeneous Networks (HetNets)



Device-to-Device (D2D)



Bell Labs Museum

Wireless Information Transmission System Lab.
Institute of Communications Engineering
National Sun Yat-sen University

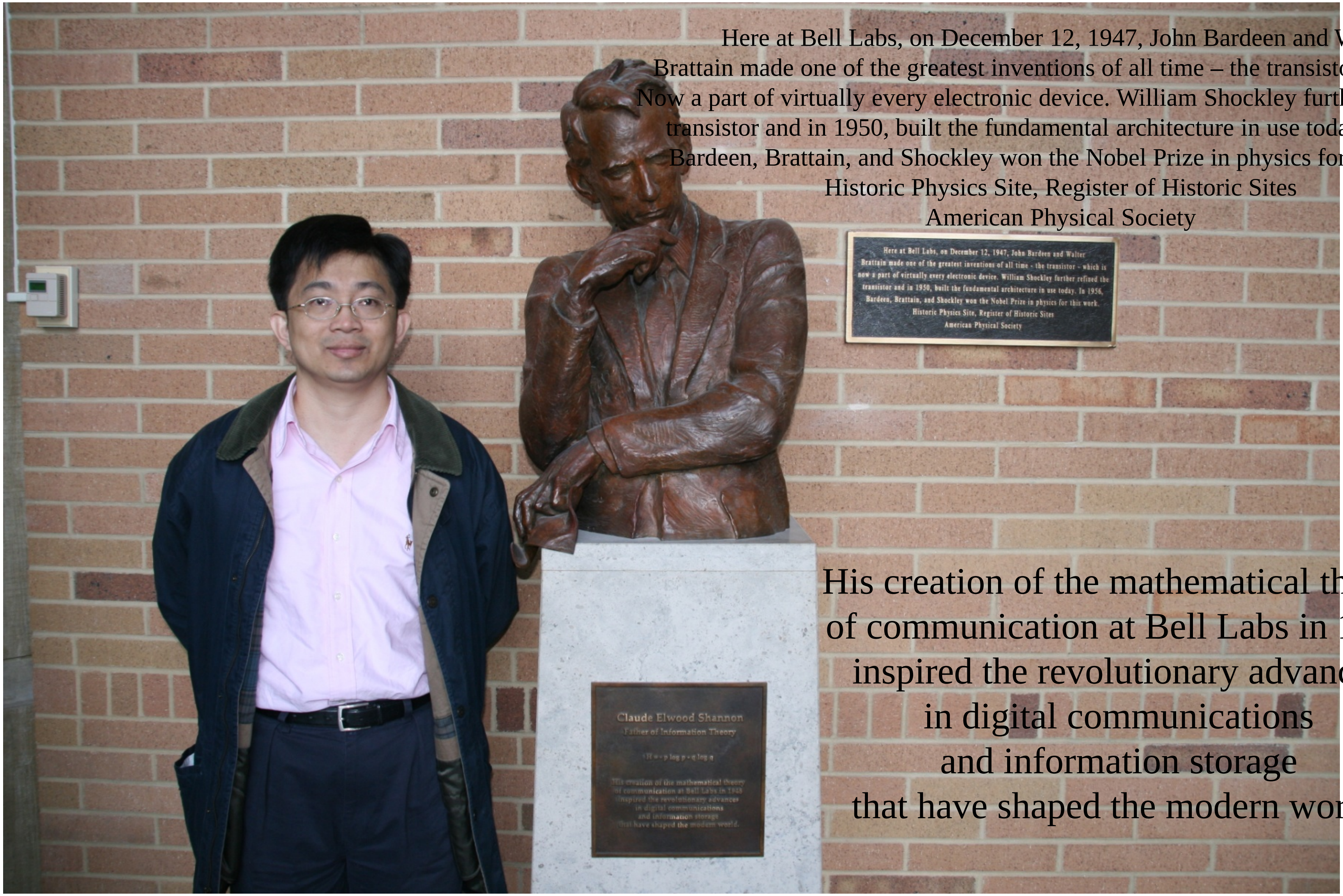
Alcatel-Lucent 大門 (Murray Hill, NJ)
5 December 2008

電話發明人
Alexander Graham Bell (1847~1947)

LEAVE THE BEATEN TRACK OCCASSIONALLY AND DIVE INTO THE WOODS. YOU WILL BE CERTAIN TO FIND SOMETHING THAT YOU HAVE NEVER SEEN BEFORE.

IN HONOR OF THE INVENTOR OF THE TELEPHONE ON THE CENTENNIAL OF HIS BIRTH

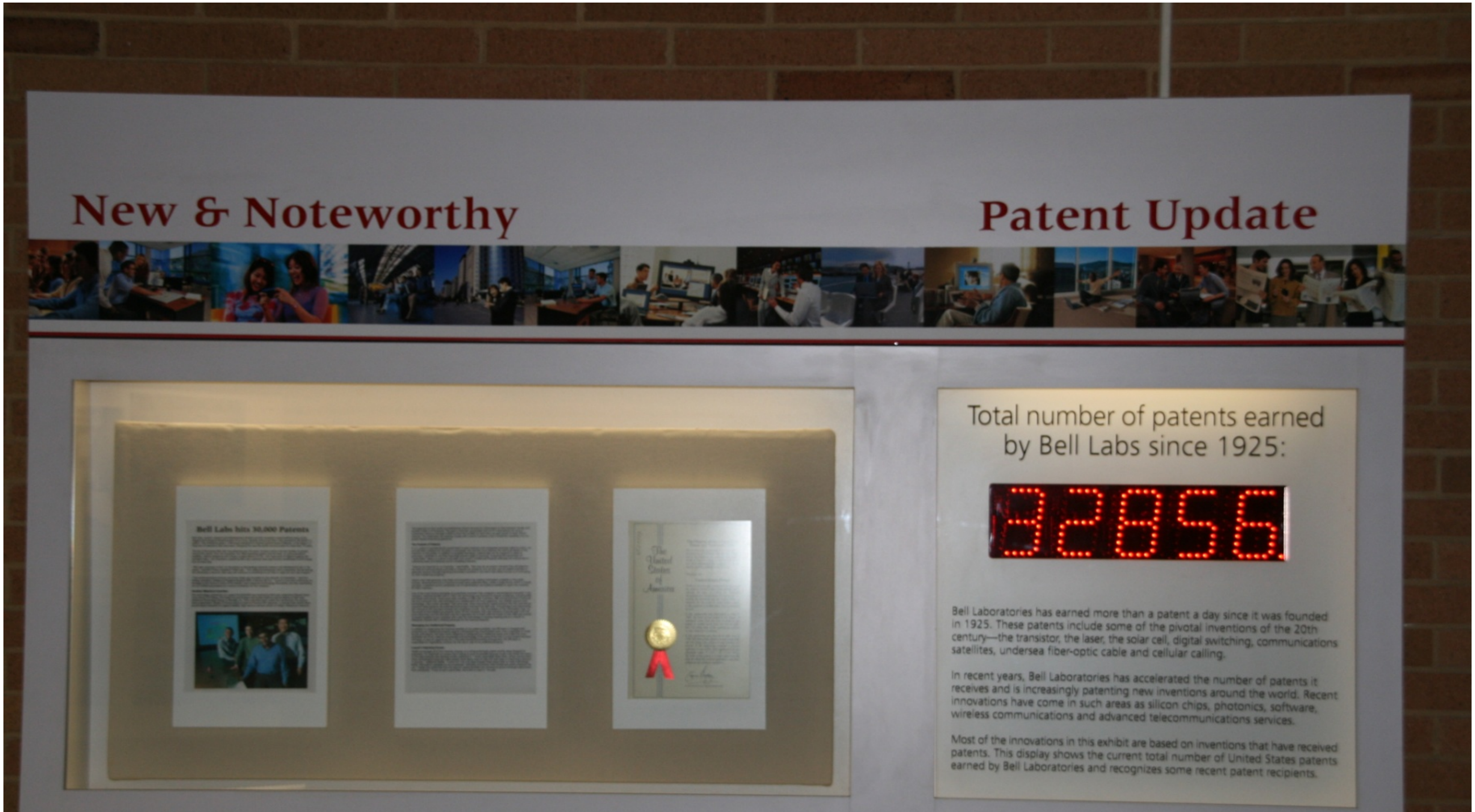
Claude Elwood Shannon
Father of Information Theory



Here at Bell Labs, on December 12, 1947, John Bardeen and Walter Brattain made one of the greatest inventions of all time – the transistor – which is Now a part of virtually every electronic device. William Shockley further refined the transistor and in 1950, built the fundamental architecture in use today. In 1956, Bardeen, Brattain, and Shockley won the Nobel Prize in physics for this work.
Historic Physics Site, Register of Historic Sites
American Physical Society

His creation of the mathematical theory
of communication at Bell Labs in 1948
inspired the revolutionary advances
in digital communications
and information storage
that have shaped the modern world.

Bell Labs Patents



Bell Laboratories has earned more than a patent a day since it was founded in 1925. These patents include some of the pivotal inventions of the 20th century – the transistor, the laser, the solar cell, digital switching, communications satellites, undersea fiber-optic cable and cellular calling.

Awards

6 Nobel Prizes in Physics shared by 11 scientists
9 U.S. Medals of Science
7 U.S. Medals of Technology
1 Draper Prize
6 Marconi International Fellowship Awards
7 C&C Prizes shared by 12 scientists and engineers
27 IEEE Medal of Honor winners

Nobel Prizes

Nobel Prizes

- 1937 Clinton Joseph Davisson, New York, "for their experimental discovery of the diffraction of electrons by crystals"
- 1956 John Bardeen, Walter Houser Brattain, William Bradford Shockley, Murray Hill, "for their researches on semiconductors and their discovery of the transistor effect"
- 1977 Phillip Warren Anderson, Murray Hill, "for their fundamental theoretical investigations of the electronic structure of magnetic and disordered systems"
- 1978 Arno Allan Penzias and Robert Woodrow Wilson, Holmdel, "for their discovery of cosmic microwave background radiation“
- 1997 Steven Chu, "for development of methods to cool and trap atoms with laser light"
- 1998 Robert B. Laughlin, Horst L. Stormer, Daniel C. Tsui, "for their discovery of a new form of quantum fluid with fractionally charged excitations"

Innovation Timeline 1869~1930s

- In 1864, James Clerk Maxwell has formulated the electromagnetic theory of light and predicted the existence of radio waves.
- The existence of radio waves was established experimentally in 1887 by Heinrich Hertz.
- The first successful use of mobile radio dates from the 27 March 1899, when M. G. Marconi established a radio link between a land based station and a boat sailing the English channel.

1869 Gray & Barton
(becomes Western Electric in 1872)

1876 First Telephone

"Mr. Watson, come here, I want you!" The Telecommunications revolution begins when Alexander Graham Bell speaks these words into his prototype telephone on March 10, 1876.

1914 Vacuum Tubes

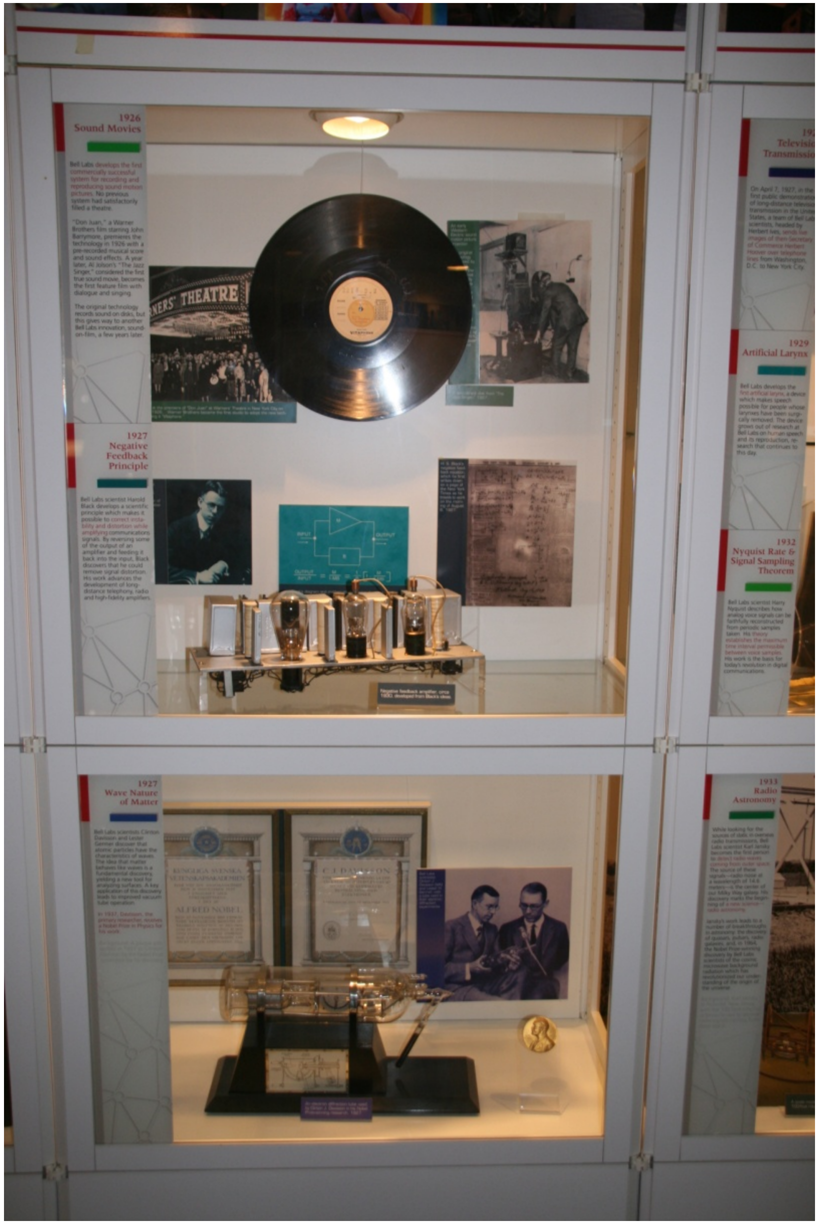
1916 Condenser Microphone

1916 Two-Way Radio Telephony

1917 Electric Wave Filter

1924 Statistical Process Control Charts

1924 Facsimile Services



1926 Sound Movies

1927 Negative Feedback Principle

1927 Wave Nature of Matter

1927 Television Transmission

1929 Artificial Larynx (喉嚨)

1932 Nyquist Rate & Signal Sampling Theorem

1933 Radio Astronomy

1933 Stereo Recording

1936 Speech Coding & Synthesis

1939 Electrical Digital Computer

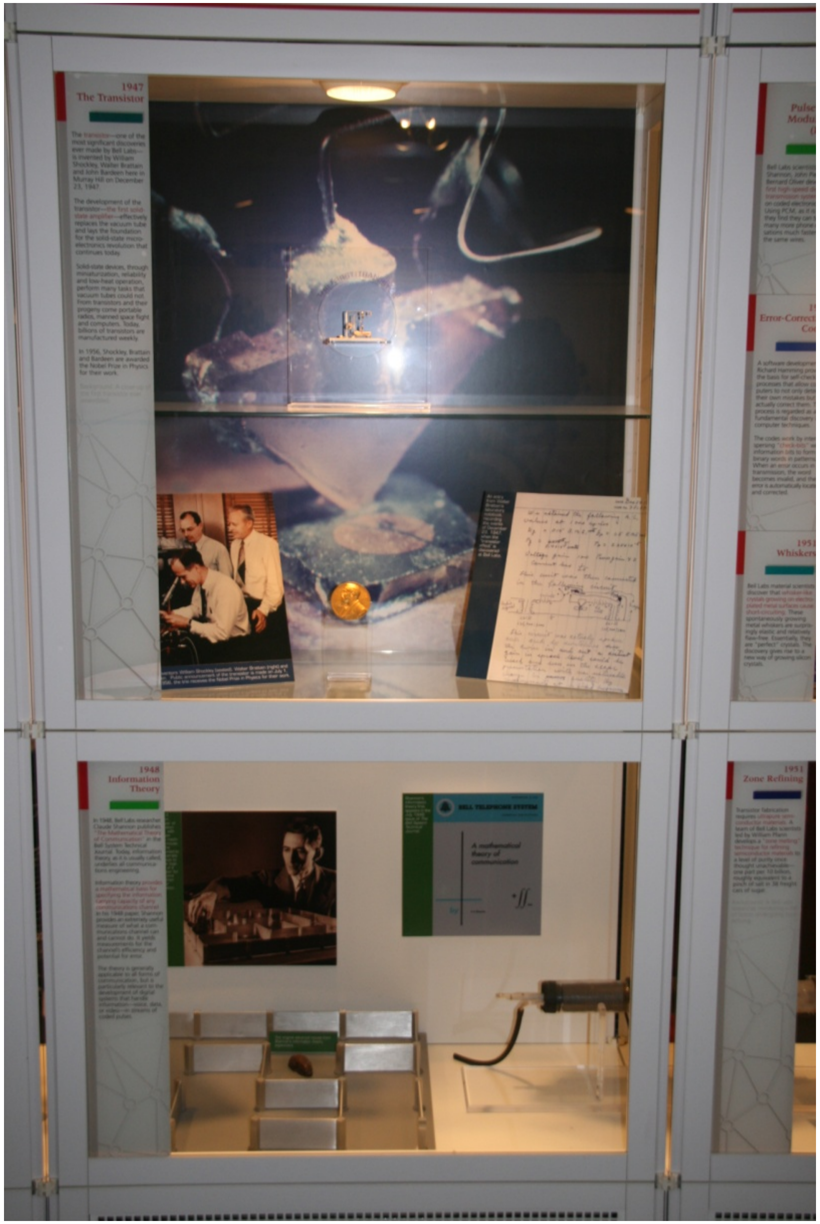
Innovation Timeline 1930s~1950s

1939 Radar Research

1936 Closed-Spaced Triode

1939 Traveling Wave Tube Amplification

1947 Cellular Concept



1947 The Transistor

1948 Information Theory

1948 Pulse Code Modulation (PCM)

1948 Error-Correcting Codes

1951 Whiskers

1951 Zone Refining

1954 Solar Cell

1954 Superconductors

1954 Oxide Masking

1956 Polyethylene Coating

1956 Submarine Telephone Cable

1957~58 Masers & Lasers

Innovation Timeline 1950s~1970s

1958 Physics of Imperfect Crystals

1959 MOSFETs

1959 Artificial Neuron (神經元)

1959 Time Assignment Speech Interpolation

1959 Macros

1960 Epitaxial Film Transistors

1960 Random Dot Stereogram
(立體照相)

1960 Computer Generated Music

1962 Foil-Electret Microphone

1962 Telstar (AT&T發射的通訊衛星)

1963 Touchtone Telephone

1964 Support for the Big Bang Theory

1964 Picturephone

1965 Echo Canceller

1965 IESS Switch

1966 Magnetic Bubbles

1967 Linear Predictive Coding (LPC)

1968 Molecular Beam Epitaxy (MBE)

1969 Charged Coupled Device (CCD)

1969 UNIX System

1970~71 Heterostructure & Distributed Feedback Lasers

Innovation Timeline 1970s~1990s

1973 C Language

1974 Computerized Axial Tomography (CAT) Algorithm

1974 Lithium Niobate for Lightwave Modulation

1974 Modified Chemical Vapor Deposition (MCVD)

1975 Speaker-Independent Voice Recognition

1977 Commercial Lightwave System

1978 Cellular Trials

1980 Solitons

1979 Text-to-Speech Voice System

1981 S Language

1980 Master-Rated Chess Machine

1982 Fractional Quantum Hall Effect

1983 Hidden Markov Models

1983 C++ Language

1984 Karmarkar Algorithm

1985 Atom Trapping

1986 SEEDs

1986 High-Temperature Superconductors

1986 Erbium-Doped Fiber Amplifiers

1988 Digital Cellular

1988 Undersea Fiber Optic Cable

1989 High Definition Television (HDTV)

1991 Microdisk Laser

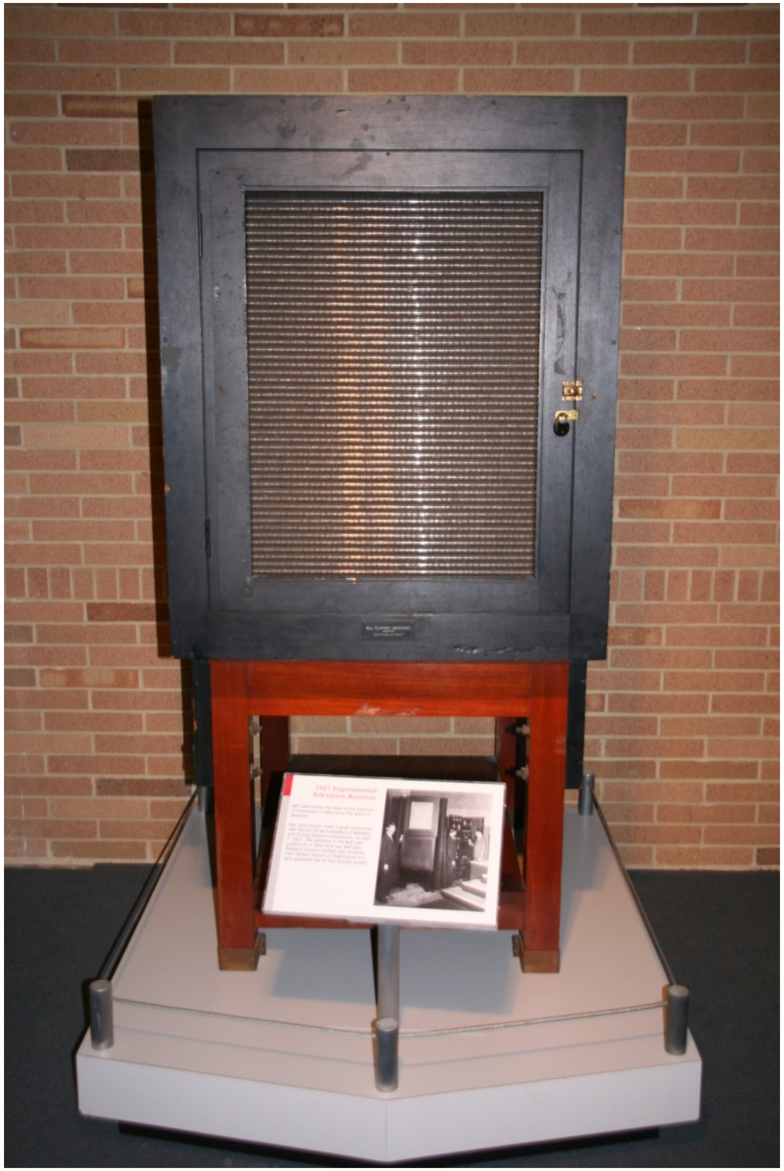
1992 Magneto-Optic Data Storage

1992 Video Codec Chip Set

1994 Quantum Cascade Laser

1996 360-Degree Camera

1927 Experimental Television Receiver



1926 Sound Motion Picture Projector