Overview on Cellular and IoT Networks 蜂窝和物联网网络概述

Trends 趋势

- MBB Subscriptions by 2024: 8.9 billion
  2024 年 MBB 订阅量：89 亿
- Cellular IoT Devices by 2024: 4.5 billion
  2024 年蜂窝物联网设备：45 亿
- Non-Cellular IoT Devices by 2024: 17.8 billion
  2024 年非蜂窝物联网设备：178 亿
- Connected Devices by 2024: 33.9 billion
  2024 年连接设备：339 亿

Market Evolution 市场演变

- Mobile Network History (1973 - 2021)
  - Evolution of mobile network technologies over five generations
    移动网络技术在五代中的演变
  - Mobile market statistics including subscribers, ARPU, and churn rates
    移动市场统计数据，包括用户数、ARPU 和流失率

IoT Network: Main Characteristics 物联网网络主要特征

- Business Market: 商业市场：
  - Applications include smart cities, health, and car embedded systems.
    应用包括智慧城市、健康和车载系统。
- Consumer Market: 消费市场：
  - Applications include fitness bands, smart watches, and smart home devices.
    应用包括健身带、智能手表和智能家居设备。

IoT Architecture 物联网架构

- Connected Objects: 连接对象：
  - Devices with core features residing partially in the cloud.
    核心功能部分位于云中的设备。
  - Communication capabilities both ways: emission and reception.
    双向通信能力：发射和接收。

Network Topology 网络拓扑

- Indirect Network Topology:
  间接网络拓扑：
  - Communication through a gateway, using technologies like Bluetooth Low Energy and Zigbee. 通过网关进行通信，使用低功耗蓝牙和 Zigbee 等技术。
  - Gateways use compression techniques such as 6LoWPAN and CoAP protocols.
    网关使用压缩技术，如 6LoWPAN 和 CoAP 协议。
- Direct Connection:直接连接：
  - LPWAN technologies such as LoRa and Sigfox for direct connections.
    使用 LoRa 和 Sigfox 等 LPWAN 技术进行直接连接。

Short Range Communications 短程通信

- Wireless Local Area Networks (WLAN) 无线局域网
  - WiFi = IEEE 802.11
- Wireless Personal Area Network (WPAN) 无线个人区域网
  - Bluetooth IEEE 802.15.1
  - Bluetooth Low Energy (BLE)
- Zigbee IEEE 802.15.4
- Wireless Body Area Network (WBAN) 无线体域网
- Radio Frequency Identification 射频识别

Gateway Architecture 网关架构

- MQTT Protocol
  - Uses a publish/subscribe communication model 使用发布/订阅通信模型
  - A web service called a broker manages data flow 网络服务管理数据流

Connectivity Overview 连接概述

- Different Types of Connectivities
  - Internet, Mobile Network, Direct Connection 互联网、移动网络、直接连接

6LoWPAN Protocols

- IPv6 over Low power Wireless Personal Area Networks (6LoWPAN)
  低功耗无线个人区域网络上的 IPv6 (6LoWPAN)：
  - Provides header compression, fragmentation, and forwarding
    提供头压缩、分片和转发

CoAP Protocol

- Constrained Application Protocol (CoAP)
  受限应用协议 (CoAP)：
  - Enables low power devices to use REST architecture interactions
    使低功耗设备能够使用 REST 架构交互

Properties of the Radio Frequencies 无线电频率的特性

- Attenuation increases with frequency and distance 衰减随频率和距离增加
- Data rate is proportional to the bandwidth 数据速率与带宽成正比
- Antenna size is proportional to the wavelength 天线尺寸与波长成正比

Signal to Noise Plus Interference 信噪比加干扰

- SINR Calculation
  - SINR = Received Power / (Noise + Interference) = 接收功率 / （噪声 + 干扰）

Theoretical Data Rate 理论数据速率

- Shannon Capacity Formula 香农容量公式：
  - Capacity (b/s) = Bandwidth x log2(1 + SINR)
    容量（b/s） = 带宽 x log2(1 + SINR)

Network Engineering 网络工程

- Planification and Dimensioning 规划和尺寸调整
- Radio Propagation Models 无线电传播模型：
  - Okumura-Hata, Deygout, Walfish Ikegami for outdoor
    户外的 Okumura-Hata, Deygout, Walfish Ikegami 模型
  - Erceg, Wiart for indoor 室内的 Erceg, Wiart 模型

Radio Propagation 无线电传播

- Link Budget Calculation 链路预算计算
- Path Loss 路径损耗

Mobility Management 移动管理

- Handover Mechanism 切换机制：
  - Hard Handover and Soft Handover 硬切换和软切换
    - **连接数：**
    - Hard Handover: Only establishes a connection between one base station and the mobile terminal 硬切换：只在一个基站与移动终端之间建立连接
    - Soft Handover: Can simultaneously maintain connections between multiple base stations and the mobile terminal 软切换可以在多个基站与移动终端之间同时保持连接
    - **切换过程：**
    - Hard Handover: Instantaneous, may interrupt communication
      硬切换：瞬时的，可能会中断通信

        - Soft Handover: Smooth, will not interrupt communication
          软切换：平滑的，不会中断通信
        - **适用网络：**
        - Hard Handover: Mainly used in 2G networks 硬切换：主要用于 2G 网络
        - Soft Handover: Mainly used in 3G and later networks
          软切换：主要用于 3G 及以上的网络
        - **实现复杂度：**
        - Hard Handover: Relatively simple to implement 硬切换：实现较简单
        - Soft Handover: Relatively complex to implement 软切换：实现较复杂
        - **用户体验：**
        - Hard Handover: Users may experience brief communication interruptions
          硬切换：用户可能感受到短暂的通信中断
        - Soft Handover: Better user experience, no communication interruptions
          软切换：用户体验更好，不会中断通信

Summary of Digital Transmission Chain 数字传输链概述

Transmitter 发送器

- Components:组成部分：
    - Source, Sampling, Quantization, Compression, Redundancy
      源，采样，量化，压缩，冗余
    - Modulation, Line Coding, Carrier Transmission
      调制，线路编码，载波传输

Receiver 接收器

- Components:组成部分：
    - Baseband Restoration, Matched Filtering, ML Detection
      基带恢复，匹配滤波，最大似然检测
    - Demodulation, Low Pass Filtering, Complex Envelope Detection
      解调，低通滤波，复包络检测
    - Phase Path (Real), Quadrature Path (Imaginary)
      相位路径（实数），正交路径（虚数）
    - Error Detection, Source Decoding, Signal Reconstruction
      错误检测，源解码，信号重建

Digitization and Quantization 数字化和量化

- Sampling:采样：
    - Sampling an analog signal at regular intervals with period T_e or sampling frequency $F_e = \frac{1}{T_e}$.

      以周期 T_e 或采样频率 $F_e = \frac{1}{T_e}$ 在规则间隔内采样模拟信号。
- Quantization: 量化：
    - Approximating each sample by a discrete value, encoded as an integer on b bits.
      将每个样本近似为离散值，并用 b 位整数编码。

Signal Reconstruction 信号重建

- Shannon's Theorem:香农定理：
    - A signal with no components at frequencies higher than f_{max} is fully determined by its values at intervals $T_e \leq \frac{1}{2f_{max}}$.

      不含高于 f_{max} 频率分量的信号完全由其在间隔 $T_e \leq \frac{1}{2f_{max}}$ 处的值确定。

Compression and Source Coding 压缩和源编码

- Purpose:目的：
  - Encode information using a minimal number of bits to reduce storage or bandwidth usage.
    使用最少的比特编码信息，以减少存储或带宽使用。
- Example Methods:示例方法：
  - Fano-Shannon, Huffman, Arithmetic, and Vector Coding
- Principle: 原理：
  - High probability values are encoded with fewer bits.高概率值用较少的比特编码。

Entropy 熵

- Definition:
  - Entropy measures the average uncertainty or surprise associated with a random variable's outcomes. 熵衡量与随机变量结果相关的平均不确定性或惊讶度。
- Formula:
  - $$H(X) = -\sum p(x) \log_2 p(x)$$

Coding Rate and Huffman Coding 编码率和霍夫曼编码

- Average Rate:平均率：
  - $$R = \sum p_i \ell_i$$
- Huffman Algorithm:霍夫曼算法：
  - Step-by-step process to build an optimal binary tree for encoding.
    构建最佳二叉树以进行编码的逐步过程。

Redundancy and Protection 冗余和保护

- Error Correction Codes:纠错码：
  - Repetition, Parity, Block, Convolutional, Turbo, and LDPC Codes
    重复码，奇偶校验码，块码，卷积码，涡轮码和低密度奇偶校验码
- Shannon's Theorem:香农定理：
  - Reliable transmission rate R<C using error correction codes.
    使用纠错码的可靠传输速率 R<C。

Channel Coding 信道编码

- Hamming Distance:汉明距离：
  - Minimum Hamming distance d_{min} determines error correction capability.

    最小汉明距离 d_{min} 决定了纠错能力。
- Capacity:容量：
  - Corrects t errors if $d_{min} \geq 2t + 1$.

    如果 $d_{min} \geq 2t + 1$，则纠正 t 个错误。

Modulation and Demodulation 调制和解调

- Types:类型：
  - Amplitude, Phase, Frequency, and Hybrid Modulations (BPSK, PAM, PSK, QAM)
    幅度，相位，频率和混合调制（BPSK，PAM，PSK，QAM）
- Objective:目标：
  - Map binary messages to continuous-time sinusoidal signals.
    将二进制消息映射到连续时间正弦信号。

Error Probability 错误概率

- Calculation:计算：

- Based on the modulation scheme and SNR (Signal-to-Noise Ratio).
  基于调制方案和信噪比（SNR）。

Summary of Internet of Things: Radio Frequency Identification (RFID)物联网：射频识别（RFID）总结

What is an RFID system? 什么是 RFID 系统?

- RFID (Radio Frequency Identification) is a means of identifying a person or object using a radio frequency transmission. RFID（射频识别） 是一种使用射频传输识别人员或物体的方法。
- The technology can be used to identify, track, sort, or detect a wide variety of objects.
  该技术可用于识别、跟踪、分类或检测各种物体。
- Communication takes place between a reader (interrogator) and a transponder (Silicon Chip connected to an antenna) often called a tag.
  通信发生在阅读器（询问器）和称为标签的应答器（连接到天线的硅芯片）之间。

Tags 标签

- Tags can either be active (powered by battery) or passive (powered by the reader field).
  标签可以是主动的（由电池供电）或被动的（由阅读器场供电）。
- Tags come in various forms including Smart cards, Tags, Labels, watches and even embedded in mobile phones.
  标签有多种形式，包括智能卡、标签、标签、手表，甚至嵌入手机中。
- The communication frequencies used depend largely on the application and range from 125KHz to 2.45 GHz.所用的通信频率在很大程度上取决于应用，范围从 125KHz 到 2.45GHz。

Commonly used RFID frequencies 常用 RFID 频率

Frequency	Range	Data rate	Tag	Tag size	Antenna	Field	Applications
125 kHz	< 0.5 m	< 1 kbps	Passive	Large	Spiral	Near Field, Inductive Couling	Access Control, Animal tagging
13.56 MHz	1 m	25 kbps	Passive	Medium	Spiral	Far Field, Electromagnetic Field	Smart Card, Payment, ID
860 MHz	4-5 m	30 kbps	Active and Passive	Small	Dipole	Far Field, Electromagnetic Field	Supply Chain, Baggage handling
2.45 GHz	600 m	> 100 kbps	Active and Passive	Small	Dipole	Far Field, Electromagnetic Field	Real Time location, Electronic toll

RFID System Components RFID 系统组件

- RFID Tag: Contains information about the object.
  RFID 标签：包含有关对象的信息。
- RFID Reader: Interacts with the tags to retrieve or update information.
  RFID 阅读器：与标签互动以检索或更新信息。

Communication Process 通信过程

- When the reader is switched on, it emits a signal at the selected frequency band.
  当阅读器打开时，它会在选定的频段发出信号。
- Tags in proximity detect the signal, wake up, and supply operating power to their internal circuits.
  附近的标签检测到信号，唤醒并为其内部电路提供工作电源。

- The tag replies to the reader by modulating the reader field.
  标签通过调制阅读器场向阅读器回复。

Anti-Collision 防碰撞

- If many tags are present, they all reply simultaneously, causing signal collision.
  如果有许多标签存在，它们都会同时回复，导致信号碰撞。
- The reader uses an anti-collision algorithm to sort and individually select tags.
  阅读器使用防碰撞算法对标签进行排序和单独选择。
- Algorithms include Binary Tree, Aloha, etc.
  算法包括二叉树、Aloha 等。

Tag Packaging 标签包装

- Tags are manufactured in various formats for different applications.
  标签以不同的格式制造，以适应不同的应用。
- Materials and assembly methods impact the cost and performance.
  材料和装配方法影响成本和性能。
- Assembly process includes substrate material, antenna, and protective overlay.
  装配过程包括基材、天线和保护覆盖层。

Tag Integrated Circuit (IC) 标签集成电路（IC）

- ICs are designed using advanced silicon processes, typically around 0.3 mm².
  IC 使用先进的硅工艺设计，通常约为 0.3 mm²。
- Challenges include low power consumption, managing noisy RF signals, and emission regulations.
  挑战包括低功耗、管理嘈杂的 RF 信号和发射规定。
- Data stored ranges from simple ID numbers to detailed product information.
  存储的数据从简单的 ID 号到详细的产品信息不等。

Tag Classes 标签类别

- Class 0: Read Only - Factory Programmed
  0 类：只读 - 工厂编程
- Class 1: Write once Read Only (WORM) - Factory or User programmed
  1 类：写一次只读（WORM） - 工厂或用户编程
- Class 2: Read Write
  2 类：读写
- Class 3: Read Write - with on-board sensors
  3 类：读写 - 带有板载传感器
- Class 4: Read Write - with integrated transmitters
  4 类：读写 - 带集成发射器

Active and Passive Tags 主动和被动标签

- Passive Tags: Use the reader field as a power source, with limited communication distance.
  被动标签：使用阅读器场作为电源，通信距离有限。
- Semi-Passive Tags: Have built-in batteries, enabling longer distances up to 100 meters.
  半被动标签：内置电池，可实现最长 100 米的距离。
- Active Tags: Battery-powered with an active transmitter, enabling long-range communication over several kilometers.
  主动标签：电池供电，具有主动发射器，可实现几公里的长距离通信。

Comparison of Passive and Active Tags 被动和主动标签的比较

Type	Advantages	Disadvantages	Remarks
Passive	Long lifetime, Low cost	Short range (4-5 m)	Widely used, LF, HF, or UHF
Semi-Passive	Long range, Can manage sensors	Expensive	Used for high value tracking, UHF
Active	Long range, Real-time systems	Expensive	Logistics tracking, UHF or Microwave

RFID Reader RFID 阅读器

- Known as an interrogator, it connects tag data to enterprise systems.
  称为询问器，它将标签数据连接到企业系统。
- Uses attached antennas to capture data from tags.
  使用连接的天线从标签捕获数据。
- Can be stationary or integrated into mobile devices.
  可以是固定的，也可以集成到移动设备中。

Reader Antennas 阅读器天线

- Convert electrical current into electromagnetic waves. 将电流转换为电磁波。
- Linear Antennas: Long ranges, sensitive to tag orientation.线性天线：长距离，对标签方向敏感。
- Circular Antennas: Less sensitive to orientation but have shorter ranges.
  圆极化天线：对方向不太敏感，但距离较短。
- Near-field antennas operate under 30 cm, far-field antennas can reach tens of meters.
  近场天线的工作范围在 30 cm 以内，远场天线可达数十米。

Near and Far Field Communication 近场和远场通信

- Near Field: Uses magnetic coupling, typically for LF and HF frequencies.
  近场：使用磁耦合，通常用于 LF 和 HF 频率。
- Far Field: Uses electromagnetic coupling, typically for UHF and Microwave frequencies.
  远场：使用电磁耦合，通常用于 UHF 和微波频率。

Load Modulation 负载调制

- Data from a passive target is transmitted back to the reader using load modulation.
  使用负载调制将被动目标的数据传输回阅读器。
- The target is powered by the magnetic field from the reader.
  目标由阅读器的磁场供电。
- Subcarrier load modulation uses a low-frequency subcarrier modulated by the baseband data signal.
  子载波负载调制使用由基带数据信号调制的低频子载波。

Wireless Local Area Network (WLAN) - IEEE 802.11 WiFi 无线局域网 (WLAN) - IEEE 802.11 WiFi

WiFi Overview WiFi 概述

- Wi-Fi (Wireless Fidelity) is a wireless technology based on the IEEE 802.11 series of standards, providing wireless connectivity to fixed or mobile user devices. Wi-Fi（无线保真） 是一种基于 IEEE 802.11 系列标准的无线技术，提供固定或移动用户设备的无线连接。
- The IEEE 802.11 series of standards have been developed over the last 25 years by the US-based IEEE standards body. IEEE 802.11 系列标准由美国的 IEEE 标准机构在过去 25 年中开发。
- CSMA-CA is a key feature of the 802.11 standards to facilitate equitable spectrum access between multiple Wi-Fi systems even in highly contended environments. CSMA-CA 是 802.11 标准的一项关键特性，即使在竞争激烈的环境中也能促进多个 Wi-Fi 系统之间的公平频谱访问。

Different IEEE 802.11 Protocols 不同的 IEEE 802.11 协议

- 802.11a: Released in 1999, operates at 5 GHz, typical data rate 1 Mb/s, max data rate 2 Mb/s.
  1999 年发布，工作在 5 GHz，典型数据速率 1 Mb/s，最大数据速率 2 Mb/s。
- 802.11b: Released in 1999, operates at 2.4 GHz, typical data rate 6.5 Mb/s, max data rate 11 Mb/s.
  1999 年发布，工作在 2.4 GHz，典型数据速率 6.5 Mb/s，最大数据速率 11 Mb/s。
- 802.11g: Released in 2003, operates at 2.4 GHz, typical data rate 25 Mb/s, max data rate 54 Mb/s.
  2003 年发布，工作在 2.4 GHz，典型数据速率 25 Mb/s，最大数据速率 54 Mb/s。
- 802.11n: Released in 2009, operates at 2.4 GHz and/or 5 GHz, typical data rate 200 Mb/s, max data rate 450 Mb/s.
  2009 年发布，工作在 2.4 GHz 和/或 5 GHz，典型数据速率 200 Mb/s，最大数据速率 450 Mb/s。
- 802.11ac: Released in 2014, operates at 5 GHz, typical data rate 433 Mb/s, max data rate 1300 Mb/s. 2014 年发布，工作在 5 GHz，典型数据速率 433 Mb/s，最大数据速率 1300 Mb/s。

Network Architecture 网络架构

- Ad hoc Architecture: Independent Basic Service Set (IBSS)
  自组织架构：独立基本服务集 (IBSS)
- Infra-structured Architecture: Infra-structured BSS via an Access Point (AP).
  基础设施架构：通过接入点 (AP) 构建的基础设施 BSS。
- Extended Basic Service Set (EBSS): Distribution System (DS) connecting multiple APs via wired or wireless connection.
  扩展基本服务集 (EBSS)：分布系统 (DS) 通过有线或无线连接多个 AP。

Wireless Personal Area Network (WPAN) - Bluetooth 无线个人区域网 (WPAN) - 蓝牙

Bluetooth Overview 蓝牙概述

- Bluetooth technology is named after the 10th-century Danish King Harald Bluetooth who united Scandinavian Europe. 蓝牙 技术以 10 世纪丹麦国王哈拉尔德·蓝牙命名.
- It unites various industries under a common, simple wireless communication protocol.
  它将各个行业统一在一个共同的、简单的无线通信协议下。

Bluetooth Versions 蓝牙版本

- V1.2 (BDR): Released in 2003, data rate 732 kb/s, range 10 - 100 m.
  V1.2 (BDR)：2003 年发布，数据速率 732 kb/s，范围 10 - 100 米。
- V2.1 (EDR): Released in 2007, data rate 2.1 Mb/s, range 10 - 100 m.
  V2.1 (EDR)：2007 年发布，数据速率 2.1 Mb/s，范围 10 - 100 米。
- V3.0 (HS): Released in 2009, data rate 25 Mb/s, range 10 - 100 m.
  V3.0 (HS)：2009 年发布，数据速率 25 Mb/s，范围 10 - 100 米。
- V4.0 (BLE): Released in 2010, data rate 0.3 Mb/s, range 10 - 100 m.
  V4.0 (BLE)：2010 年发布，数据速率 0.3 Mb/s，范围 10 - 100 米。

Network Topology 网络拓扑

- Piconet: Consists of 1 master and up to 8 slaves. 微微网：由 1 个主设备和最多 8 个从设备组成。
- Scatternet: Consists of up to 10 interconnected piconets. 散射网：由最多 10 个互联的微微网组成。

Basic Operations in Bluetooth 蓝牙的基本操作

- When powered on, a Bluetooth device tries to operate as a slave device and listens for a master's inquiry. 打开电源时，蓝牙设备尝试作为从设备运行并监听主设备的查询。
- The inquiry phase lets the master know the address of the slave; this phase is not necessary for already paired devices. 查询阶段使主设备知道从设备的地址,对于已经配对的设备此阶段不是必需的
- Once a master knows the address of a slave, it may open a connection if the slave is listening for paging requests.一旦主设备知道从设备的地址，如果从设备正在监听寻呼请求，它可以打开连接。

Frequency Hopping Spread Spectrum (FHSS)频率跳变扩频 (FHSS)

- FHSS involves accessing different radio channels according to a pseudo-random sequence.
  FHSS 涉及根据伪随机序列访问不同的无线电信道。

- The hopping sequence is generated from the master station's address and clock.
  跳变序列由主站的地址和时钟生成。

Wireless Personal Area Network (WPAN) - IEEE 802.15.4 无线个人区域网 (WPAN) - IEEE 802.15.4

IEEE 802.15.4 Overview

- Developed to address the need for low-power, low-cost wireless networking in residential and industrial environments. 为了满足住宅和工业环境中低功耗、低成本无线网络的需求而开发。
- Properties:
  - Raw data rate: 20 kb/s (868 MHz), 40 kb/s (915 MHz), 250 kb/s (2.4 GHz).
  - Range: 10 - 20 m.
  - Latency: Down to 15 ms.
  - Channels: 11 channels (868/915 MHz), 16 channels (2.4 GHz).
  - Frequency band: 868 MHz/915 MHz and 2.4 GHz.
  - Addressing: Short 8-bit or 64-bit IEEE addresses.
  - Channel access: CSMA-CA and slotted CSMA-CA.

Network Topology 网络拓扑

- Supports multiple topologies, including star and peer-to-peer networks.
  支持多种拓扑结构，包括星型和对等网络。
- Full-Function Device (FFD) can serve as the coordinator of a PAN and communicate with any other device. 全功能设备 (FFD) 可以作为 PAN 的协调器，并与任何其他设备通信。
- Reduced-Function Devices (RFD) are simple devices that can only communicate with FFDs and cannot act as coordinators.
  简化功能设备 (RFD) 是只能与 FFD 通信且不能作为协调器的简单设备。

Beacon and Non-Beacon Enabled Networks 启用信标和不启用信标的网络

- Beacon Enabled Network:
  - The PAN coordinator transmits periodic beacons. 节点在接收到信标时才活动。
- Non-Beacon Enabled Network:
  - The PAN coordinator has its receiver on all the time and waits for transmissions from remote units/clients. 节点定期唤醒以宣布其存在，并在事件发生时立即传输警报。

Summary of 2G and 2.5G Technology (GSM, GPRS, and EDGE)

2G (GSM) Overview 2G（GSM）概述

- History and Development:历史和发展：
  - GSM (Global System for Mobile communications) was developed by the Groupe Spécial Mobile. GSM（全球移动通信系统）由特别移动小组开发。
  - It was designed by public R&D labs in France and Germany and standardized by ETSI (1987-1995). 它由法国和德国的公共研发实验室设计，并由 ETSI 在 1987-1995 年标准化。
  - The system uses circuit-switched technology and robust radio modulation, enabling features like automatic roaming and communication encryption.
    该系统使用电路交换技术和强大的无线调制，支持自动漫游和通信加密等功能。
  - Initial deployments began in 1992 with operators like Orange France and SFR.
    最初的部署始于 1992 年，由 Orange France 和 SFR 等运营商进行。
  - The system included innovations like separating the mobile phone function from the identification function, which was placed on a SIM card.
    该系统包括将手机功能与识别功能分离的创新，后者被放置在 SIM 卡上。
  - By the end of 2006, the penetration rate in France reached 82.5%.
    到 2006 年底，法国的普及率达到了 82.5%。
- Frequency Bands: 频率频段：
  - Operates in 900 MHz and 1800 MHz bands, with each band having a bandwidth of 200 kHz.

在 900 MHz 和 1800 MHz 频段上运行，每个频段的带宽为 200 kHz。
    - In France, operators have sub-bands within these bands: 10 MHz in the 900 MHz band and around 25 MHz in the 1800 MHz band. 在法国，运营商在这些频段内有子频段：在 900 MHz 频段内有 10 MHz，在 1800 MHz 频段内约有 25 MHz。
- Network Architecture: 网络架构：
    - Includes components such as BTS (Base Transceiver Station), BSC (Base Station Controller), MSC (Mobile Switching Center), and G-MSC (Gateway MSC).
      包括 BTS（基站收发信台）、BSC（基站控制器）、MSC（移动交换中心）和 G-MSC（网关 MSC）等组件。
    - The architecture involves the Public Switched Telephone Network (PSTN), Home Location Register (HLR), Visitor Location Register (VLR), and others. 该架构涉及公共交换电话网络（PSTN）、归属位置寄存器（HLR）、访客位置寄存器（VLR）等。
    - Mobile stations transmit with a maximum power of 1 W (2 W).
      移动台以最大 1 W（2 W）的功率发射。
    - The network access part includes BTS as access points and BSC for BTS control.
      网络接入部分包括作为接入点的 BTS 和用于 BTS 控制的 BSC。
    - The core network includes MSC for switching and G-MSC for interfacing with other networks. 核心网络包括用于交换的 MSC 和用于与其他网络接口的 G-MSC。
- User Multiplexing: 用户复用：
    - Utilizes Frequency/Time Division Multiple Access (F/TDMA) with radio channel bandwidth of 200 kHz and frame duration of 4.615 ms.
      利用频分/时分多址（F/TDMA），无线信道带宽为 200 kHz，帧持续时间为 4.615 ms。
    - Each frame consists of 8 timeslots, with each slot lasting 577 µs.
      每个帧由 8 个时隙组成，每个时隙持续 577 µs。
- Duplexing: 双工：
    - Uses Frequency Division Duplex (FDD) with duplex spacing of 45 MHz in the 900 MHz band and 95 MHz in the 1800 MHz band. 使用频分双工（FDD），在 900 MHz 频段的双工间隔为 45 MHz，在 1800 MHz 频段的双工间隔为 95 MHz。
- Radio Resource Management: 无线资源管理：
    - A GSM cell can handle a certain number of TRXs (transceivers) based on the adopted frequency reuse pattern.
      根据采用的频率复用模式，GSM 小区可以处理一定数量的 TRX（收发器）。
    - Each TRX operates on a duplex frequency band of 200 kHz.
      每个 TRX 在 200 kHz 的双工频段上运行。
- Security: 安全性：
    - Authentication protects the network from fraudulent use and subscribers from fraudulent access. 认证保护网络免受欺诈性使用，并保护订户免受欺诈性访问。
    - The A5 encryption algorithm was broken in 1999. 1999 年 A5 加密算法被破解。
- Short Message Services (SMS): 短消息服务（SMS）：
    - SMS messages are 160 characters long and transmitted on signaling channels like SACCH and SDCCH. SMS 消息长度为 160 字符，并通过 SACCH 和 SDCCH 等信令信道传输。
    - In 2012, 40 billion SMS were sent per quarter in France, with an average of 242 SMS per subscriber per month.
      2012 年，法国每季度发送 400 亿条短信，平均每个用户每月发送 242 条短信。

2.5G (GPRS/EDGE) Overview 2.5G（GPRS/EDGE）概述

- General Packet Radio Services (GPRS): 通用分组无线服务（GPRS）：
    - Introduced packet switching to GSM networks, allowing for better data transmission.
      将分组交换引入 GSM 网络，允许更好的数据传输。

    - GPRS architecture includes components like SGSN (Serving GPRS Support Node) and GGSN (Gateway GPRS Support Node). GPRS 架构包括 SGSN（服务 GPRS 支持节点）和 GGSN（网关 GPRS 支持节点）等组件。
    - SGSN handles services within a geographical area, providing security, mobility management, and billing. SGSN 在地理区域内处理服务，提供安全、移动管理和计费。
    - GGSN acts as a gateway to other data networks and manages IP address allocation. GGSN 作为通向其他数据网络的网关，并管理 IP 地址分配。
    - Packet Control Unit (PCU) in BSC handles packet segmentation and reassembly. BSC 中的分组控制单元（PCU）处理分组分段和重组。
- Enhanced Data rates for GSM Evolution (EDGE): 增强数据速率的 GSM 演进（EDGE）：
    - EDGE uses 8PSK modulation, increasing data rates by a factor of three compared to GPRS. EDGE 使用 8PSK 调制，使数据速率比 GPRS 提高了三倍。
    - Supports both circuit-switched and packet-switched data services. 支持电路交换和分组交换的数据服务。
    - Throughputs for EDGE range from 8.8 kbits/s to 59.2 kbits/s depending on the modulation and coding scheme. EDGE 的吞吐量范围从 8.8 kbits/s 到 59.2 kbits/s，具体取决于调制和编码方案。
    - Dynamic link adaptation adjusts the modulation and coding scheme based on channel quality during the session. 动态链路自适应在会话期间根据信道质量调整调制和编码方案。
    - Automatic Repeat reQuest (ARQ) mechanisms retransmit corrupted blocks using the same or a more robust modulation scheme. 自动重传请求（ARQ）机制使用相同或更稳健的调制方案重传损坏的块。

Summary of 3G and 3.5G Technologies (UMTS and HSPA) 3G 和 3.5G 技术总结（UMTS 和 HSPA）

3G (UMTS) Overview 3G（UMTS）概述

- Development and Standardization: 开发和标准化：
    - UMTS (Universal Mobile Telecommunications System) was standardized by 3GPP (3rd Generation Partnership Project) from 1998 to 2001. UMTS（通用移动通信系统）由 3GPP（第三代合作伙伴计划）在 1998 年至 2001 年期间标准化。
    - First commercial launches were in Japan (October 2001 by NTT DoCoMo) and France (September/October 2004). 首次商业发布是在日本（2001 年 10 月由 NTT DoCoMo）和法国（2004 年 9 月/10 月）。

Penetration and Subscribers 渗透率和用户数

- Global Penetration: 全球渗透率：
    - By the end of 2009, there were 485 million UMTS subscribers, including 180 million using HSPA. 到 2009 年底，UMTS 用户数达到 4.85 亿，其中包括 1.8 亿 HSPA 用户。
    - By the end of 2011, the number increased to 800 million, including 500 million HSPA users. 到 2011 年底，用户数增加到 8 亿，其中包括 5 亿 HSPA 用户。
    - Around 400 networks in 170 countries, with over 3000 devices available. 约 170 个国家的 400 个网络，超过 3000 种设备。
- French Market:法国市场：
    - By the end of 2009, there were 15 million subscribers (25% of the mobile market). 到 2009 年底，用户数为 1500 万（占移动市场的 25%）。
    - By the end of 2012, this number increased to 33 million (45% of the mobile market). 到 2012 年底，用户数增加到 3300 万（占移动市场的 45%）。

IMT2000 Context IMT2000 背景

- Objectives: 目标：
    - One single phone, usable everywhere in the world, creating a global network. 一部手机，全球通用，创建一个全球网络。

    - Data services integrated into the terminal, representing IT and Telecom convergence.
      数据服务集成到终端中，代表 IT 和电信的融合。
- Quality of Service (QoS): 服务质量（QoS）：
    - Voice quality, global coverage (global roaming), enhanced transmission delays.
      语音质量、全球覆盖（全球漫游）、增强的传输延迟。
    - Higher spectral efficiency (higher capacity) and cost efficiency.
      更高的频谱效率（更高的容量）和成本效率。

UMTS Frequencies and Services UMTS 频段和服务

- Frequencies:频段：
    - 2000 MHz band: W-CDMA for FDD mode, TD-CDMA for TDD mode.
      2000 MHz 频段：FDD 模式使用 W-CDMA，TDD 模式使用 TD-CDMA。
    - 900 MHz band: Reuse of GSM band.
      900 MHz 频段：重用 GSM 频段。
- Services:服务：
    - Mobile video calling and conferencing, teleworking, internet access, remote monitoring, and news reporting. 移动视频通话和会议、远程办公、互联网接入、远程监控和新闻报道。
    - Throughputs range from 144 kbits/s (rural outdoor) to 2 Mbit/s (stationary).
      吞吐量从 144 kbits/s（农村户外）到 2 Mbit/s（静止状态）。

UMTS Architecture UMTS 架构

- Components: 组件：
    - Core network: Includes MSC (Mobile Switching Center), VLR (Visitor Location Register), SGSN (Serving GPRS Support Node), and GGSN (Gateway GPRS Support Node).
      核心网络：包括 MSC（移动交换中心）、VLR（访问位置寄存器）、SGSN（服务 GPRS 支持节点）和 GGSN（网关 GPRS 支持节点）。
    - Access network: Includes UTRAN (UMTS Terrestrial Radio Access Network) with NodeB (base stations) and RNC (Radio Network Controller).
      接入网络：包括 UTRAN（UMTS 地面无线接入网络）和 NodeB（基站）及 RNC（无线网络控制器）。

HSPA Overview HSPA 概述

- HSPA (High-Speed Packet Access): HSPA（高速分组接入）：
    - An enhancement to UMTS, providing higher data rates and improved performance.
      对 UMTS 的增强，提供更高的数据速率和改进的性能。
    - HSDPA (High-Speed Downlink Packet Access) and HSUPA (High-Speed Uplink Packet Access) as key technologies.
      HSDPA（高速下行分组接入）和 HSUPA（高速上行分组接入）作为关键技术。
    - Typical data rates: HSDPA up to 14.4 Mbps, HSUPA up to 5.76 Mbps.
      典型数据速率：HSDPA 高达 14.4 Mbps，HSUPA 高达 5.76 Mbps。

Summary of 4G Technology (LTE and LTE-A) 4G 技术总结（LTE 和 LTE-A）

LTE Context LTE 背景

- Worldwide Mobile Networks:全球移动网络：
    - As of 2020, there are 5.08 billion unique mobile subscribers globally.
      截至 2020 年，全球共有 50.8 亿独立移动用户。
- LTE Services:LTE 服务：
    - Provides services like surfing, HD streaming, videophony, music, mobile cloud, and games.
      提供如上网、高清视频流、视频通话、音乐、移动云和游戏等服务。

LTE Standardization LTE 标准化

- Long Term Evolution (LTE): 长期演进（LTE）：
    - Standardized by 3GPP with LTE Release 8 finalized in 2008.

由 3GPP 标准化，LTE R8 于 2008 年完成。
    - System Architecture Evolution (SAE) finalized in 2009.
      系统架构演进（SAE）于 2009 年完成。
- IMT-Advanced Specifications: IMT-Advanced 规格：
    - Target speeds of 100 Mbps downlink and 50 Mbps uplink.
      下行速率目标 100 Mbps，上行速率 50 Mbps。
    - Supports web browsing, FTP, video streaming, and VoIP with quality comparable to 2G/3G networks. 支持网页浏览、FTP、视频流和与 2G/3G 网络相媲美的 VoIP。
- Commercial Launches: 商业发布：
    - First launches in 2009 by Telia Sonera in Stockholm and Oslo.
      2009 年由 Telia Sonera 在斯德哥尔摩和奥斯陆首次发布。
    - Notable launches by NTT Docomo (December 2010) and Verizon (December 2010).
      由 NTT Docomo（2010 年 12 月）和 Verizon（2010 年 12 月）发布。
    - By the end of 2012, 146 networks; by November 2013, 245 networks in 92 countries.
      到 2012 年底有 146 个网络；到 2013 年 11 月有 92 个国家的 245 个网络。

LTE Carrier Frequency Bands LTE 载波频段

- Licensed Frequency Bands: 授权频段：
    - 700-800 MHz, 2.3 GHz, 2.5-2.6 GHz, and more than 40 available bands.
      700-800 MHz，2.3 GHz，2.5-2.6 GHz 等超过 40 个可用频段。
    - Reuse of existing systems' bands: 900 MHz, 1800 MHz, 2100 MHz.
      重用现有系统的频段：900 MHz，1800 MHz，2100 MHz。
- Duplexing:双工：
    - FDD (Frequency Division Duplex) and TDD (Time Division Duplex).
      频分双工（FDD）和时分双工（TDD）。

LTE Network ArchitectureLTE 网络架构

- Core Network:核心网络：
    - Packet data only; no more circuit services.仅分组数据，不再有电路服务。
    - Maximum device transmission power: 0.25 W (24 dBm).
      设备最大传输功率：0.25 W（24 dBm）。
- Access Network:接入网络：
    - Connected eNodeB without controllers. 连接 eNodeB，无控制器。
    - SAE (System Architecture Evolution) defines an entirely new core network (EPC - Evolved Packet Core). SAE 定义了一个全新的核心网络（EPC - 演进分组核心）。
- EPC (Evolved Packet Core): EPC（演进分组核心）：
    - Higher data rate, lower latency, optimized for packet-switched system supporting multiple radio-access technologies.
      更高的数据速率，更低的延迟，优化的分组交换系统，支持多种无线接入技术。
    - Key components: Serving-GW, P-GW, HSS, MME, PCRF.
      关键组件：Serving-GW，P-GW，HSS，MME，PCRF。

Multiple Access in LTE: OFDMA　LTE 中的多址接入：OFDMA

- Pros:优点：
    - High flexibility in subcarrier allocation, addressing users' QoS constraints.
      子载波分配的高灵活性，满足用户的 QoS 约束。
    - No intra-cell interference, efficiency for frequency-selective channels.
      无小区内干扰，频率选择性信道的效率。
- Cons: 缺点：
    - Bandwidth loss due to guard band (cyclic prefix). 由于保护带（循环前缀）导致带宽损失。

- High Peak-to-Average Power Ratio (PAPR), requiring expensive power amplifiers at transmission. 高峰均比（PAPR）高，需要昂贵的功率放大器。

Radio Frame Structure 无线帧结构

- Structure: 结构：
  - A radio frame has a duration of 10 ms, divided into 20 slots with 1 ms TTI (Transmission Time Interval). 无线帧持续时间为 10 ms，分为 20 个时隙，TTI（传输时间间隔）为 1 ms。
  - A resource block spans 12 subcarriers, each with a 15 kHz bandwidth.
    一个资源块跨越 12 个子载波，每个子载波带宽为 15 kHz。

LTE Markets and Deployment LTE 市场和部署

- Global Penetration: 全球渗透率：
  - By December 2013, 500 operators in 143 countries invested in LTE with 200 million subscribers. 到 2013 年 12 月，143 个国家的 500 个运营商投资于 LTE，用户数达到 2 亿。
  - By December 2016, 540 networks in 170 countries with 1.6 billion subscribers.
    到 2016 年 12 月，170 个国家的 540 个网络，用户数达 16 亿。
- French Market:法国市场：
  - Operators like Orange, SFR, Bouygues Telecom, and Free Mobile launched LTE services between 2012 and 2013.
    Orange，SFR，Bouygues Telecom 和 Free Mobile 等运营商在 2012 年至 2013 年间推出了 LTE 服务。

LTE-Advanced (LTE-A)

- Enhancements: 增强：
  - Maximum throughputs: 300 Mbps downlink, 150 Mbps uplink.
    最大吞吐量：下行 300 Mbps，上行 150 Mbps。
  - Carrier aggregation to extend bandwidth to 100 MHz.
    载波聚合将带宽扩展至 100 MHz。
  - Introduction of relays to enhance coverage and performance.
    引入中继以增强覆盖和性能。
- Market Growth: 市场增长：
  - As of 2017, 8.3 billion mobile subscriptions including M2M (Machine to Machine).
    截至 2017 年，全球移动用户达 83 亿，包括 M2M（机器对机器）。

Summary of 5G Technology 5G 技术总结

The Market Trend 市场趋势

- Data Growth: 数据增长：
  - In Q3 2019, mobile data traffic grew 68% year-on-year.
    2019 年第三季度，移动数据流量同比增长 68%。
- Internet of Things (IoT): 物联网（IoT）：
  - Forecast of 29 billion connected devices by 2022, with 18 billion related to IoT.
    预计到 2022 年，将有 290 亿台连接设备，其中 180 亿台与物联网相关。
  - 1.5 billion IoT devices with cellular connections by 2022.
    到 2022 年，将有 15 亿物联网设备通过蜂窝连接。

The Technology Evolution 技术演变

- 5G Subscriptions: 5G 用户：
  - By 2025, 2.6 billion 5G subscriptions, accounting for 29% of mobile subscriptions.
    到 2025 年，5G 用户将达到 26 亿，占移动用户的 29%。
- 5G Launches: 5G 发布：
  - Launched in 2018 in Asia and the USA.
    2018 年在亚洲和美国发布。
  - Launched in Europe in 2020, with rapid migration expected from 4G to 5G.

2020 年在欧洲发布，预计将快速从 4G 迁移到 5G。
    - By 2025, Asia will account for 58% (950 million) of subscriptions, Europe 17% (274 million).
      到 2025 年，亚洲将占用户的 58%（9.5 亿），欧洲占 17%（2.74 亿）。

5G Requirements 5G 要求

- Key Requirements: 关键要求：
    - 10 to 100 times higher user rates. 用户速率提高 10 到 100 倍。
    - 5 times reduced end-to-end latency. 端到端延迟减少 5 倍。
    - 10 to 100 times higher number of connected devices. 连接设备数量增加 10 到 100 倍。
    - 1000 times higher user data volume per area. 每单位面积的用户数据量增加 1000 倍。
    - 10 times longer battery life for low power devices. 低功耗设备的电池寿命延长 10 倍。
- Consensus: 共识：
    - The next network must support high data rates, low latency, massive number of connected devices, low energy consumption, and high reliability.
      下一代网络必须支持高数据速率、低延迟、大量连接设备、低能耗和高可靠性。

5G Architecture 5G 架构

- Core Components: 核心组件：
    - New Radio (NR) for 5G, supporting both NR and E-UTRA ("LTE") radio access.
      5G 的新无线电（NR），支持 NR 和 E-UTRA（“LTE”）无线接入。
    - NG-RAN node as gNB (5G base station) or ng-eNB (enhanced 4G base station).
      NG-RAN 节点为 gNB（5G 基站）或 ng-eNB（增强型 4G 基站）。
- 5G Core (5GC): 5G 核心（5GC）：
    - Does not support 2G (GERAN) or 3G (UTRAN); no circuit domain, only VoIP for voice.
      不支持 2G（GERAN）或 3G（UTRAN）；无电路域，仅通过 VoIP 进行语音通信。
    - Supports multiple radio-access technologies and all services through an all-IP architecture.
      通过全 IP 架构支持多种无线接入技术和所有服务。

5G New Radio 5G 新无线电

- Features: 特性：
    - Millimeter waves, full duplex, beamforming, and massive MIMO.
      毫米波，全双工，波束成形，大规模 MIMO。
- Propagation Characteristics: 传播特性：
    - Different characteristics depending on the frequency band.
      根据频段的不同，具有不同的特性。
    - OFDMA-based access up to ~10 GHz; new access design for higher frequencies.
      基于 OFDMA 的访问可达~10 GHz；更高频率需要新的访问设计。
- Spectrum: 频谱：
    - From below 1 GHz to 100 GHz, requiring additional spectrum for increased traffic.
      从 1 GHz 以下到 100 GHz，需要额外的频谱来应对增加的流量。

5G Core Network (5GC) 5G 核心网络（5GC）

- Entities: 实体：
    - AMF (Access and Mobility management Function): Handles access control, registration, and mobility management. AMF（接入和移动管理功能）：处理接入控制、注册和移动管理。
    - SMF (Session Management Function): Manages session control, IP address allocation, and user plane selection. SMF（会话管理功能）：管理会话控制、IP 地址分配和用户面选择。
    - UPF (User Plane Function): Handles user data, packet routing, and QoS.
      UPF（用户面功能）：处理用户数据、数据包路由和 QoS。
    - Other functions include NRF (Network Repository Functions), NEF (Network Exposure Function), NSSF (Network Slice Selection Function), UDM (Unified Data Management), PCF (Policy Control Function), and AUSF (Authentication Server Function).

其他功能包括 NRF（网络存储功能）、NEF（网络暴露功能）、NSSF（网络切片选择功能）、UDM（统一数据管理）、PCF（策略控制功能）和 AUSF（认证服务器功能）。

- Service Based Architecture (SBA): 基于服务的架构（SBA）：
  - Network functions provide services to other network functions via common service-based interfaces.网络功能通过通用服务接口向其他网络功能提供服务。

Enabler for 5G 5G 的推动因素

- Virtualization:虚拟化：
  - Ability to run network functions on standard servers, sharing resources among applications.
    能够在标准服务器上运行网络功能，应用程序之间共享资源。
  - Network slicing allows for multiple virtual networks on the same physical infrastructure.
    网络切片允许在同一物理基础设施上运行多个虚拟网络。
- Edge Computing: 边缘计算：
  - Hosting applications at the edge to reduce latency compared to centralized models.
    在边缘托管应用程序，以减少与集中模型相比的延迟。

5G Roll-out Scenarios 5G 部署场景

- Non-Standalone (NSA): 非独立组网（NSA）：
  - Initial roll-out supported by existing 4G infrastructure.
    初始部署由现有 4G 基础设施支持。
  - 5G-enabled smartphones connect to 5G for data but use 4G for other functions.
    5G 智能手机连接到 5G 用于数据传输，但使用 4G 进行其他功能。
- Standalone (SA): 独立组网（SA）：
  - Full standalone 5G network with new 5G services.
    全面独立的 5G 网络，提供新的 5G 服务。
  - Supports new use cases like ultra-reliable low latency communications (URLLC).
    支持新的用例，如超可靠低延迟通信（URLLC）。

Conclusion 结论

- Coexistence with LTE: 与 LTE 共存：
  - 5G will not replace LTE but will complement it for a significant period.
    5G 不会取代 LTE，而是将在很长一段时间内补充它。
  - LTE will continue to evolve. LTE 将继续发展。
- Challenges: 挑战：
  - Confirming use cases for industry and vertical networks using network slicing.
    确认使用网络切片的行业和垂直网络的用例。
  - Availability of new frequencies and terminals. 新频段和终端的可用性。