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：
  + 文本

    中度可信度描述已自动生成
* 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：
  + 文本

    描述已自动生成

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:
  + 卡通人物

    中度可信度描述已自动生成

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

* Average Rate:平均率：
  + 卡通人物

    描述已自动生成
* 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：
  + 文本

    描述已自动生成
* Capacity:容量：
  + 图示, 示意图

    描述已自动生成

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

表格

描述已自动生成

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

表格

描述已自动生成

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。