北京郵電大學
Beijing University of Posts and Telecommunications

2021春季　　电子工程学院

《通信网技术基础》

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主要内容

- 1：通信网概述及导论
- 2：通信业务特征与网络分层模型
- 3：传送与交换

网络基础知识

- 4：排队论基础与应用
- 5：网络规划设计理论基础

相关数学理论

- 6：典型网络及应用

扩展应用

课程大纲

- 第一章：通信网概论与课程导论
  - 开课背景介绍
  - 通信与网络技术发展史
  - 通信与网络的发展与演变
    - 模拟通信到数字通信的转变
    - 电路交换向分组交换的演变
    - 语音通信向多媒体通信的演变
    - 固定通信向移动通信的演变
  - 网络互联的新需求
    - 异构网络互联
    - 网络可扩展性
    - 网络可靠性
    - 网络安全性
  - 通信网基本概念

长距离传输：从模拟到数字

物理发现

20世纪50年代发明半导体

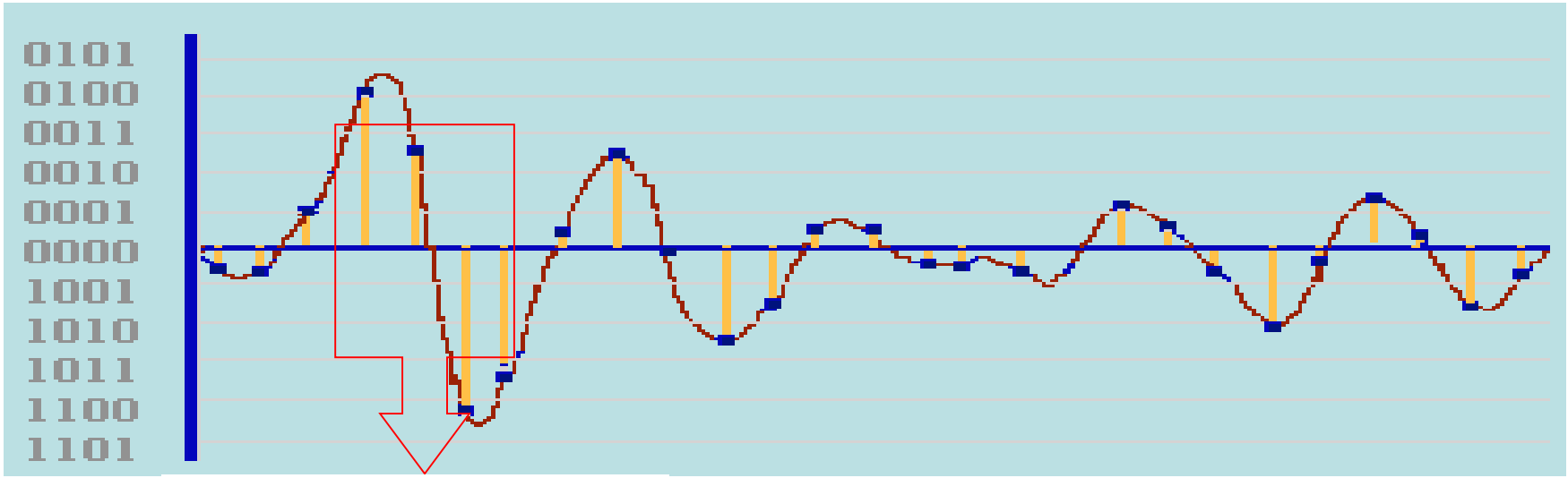
20世纪60年代发明集成电路

通信技术发展

1928年奈奎斯特准则和取样定理

1948年仙农定理

抽样　量化　编码



1001 1001 0001 0100 0011

数字技术的威力

- 长距离传输
  - 数字化传输有更好的抗干扰性能
- 多媒体通信
  - 多媒体融合与通信变为可能
- 保密通信
  - 数字化传输有更好的保密性能
- 大容量存储与通信
  - 借助计算机和大规模集成电路的高速大容量处理能力，数字信号处理提供更高的信息压缩

电话网经历了从模拟到数字的漫长演变

模拟信号
模拟手动电路交换
模拟传输

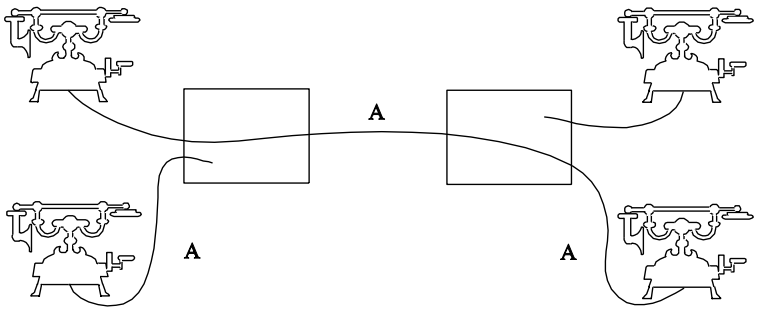


Fig.1.1 Telephone NW around 1890

模拟信号
模拟自动电路交换
数字传输

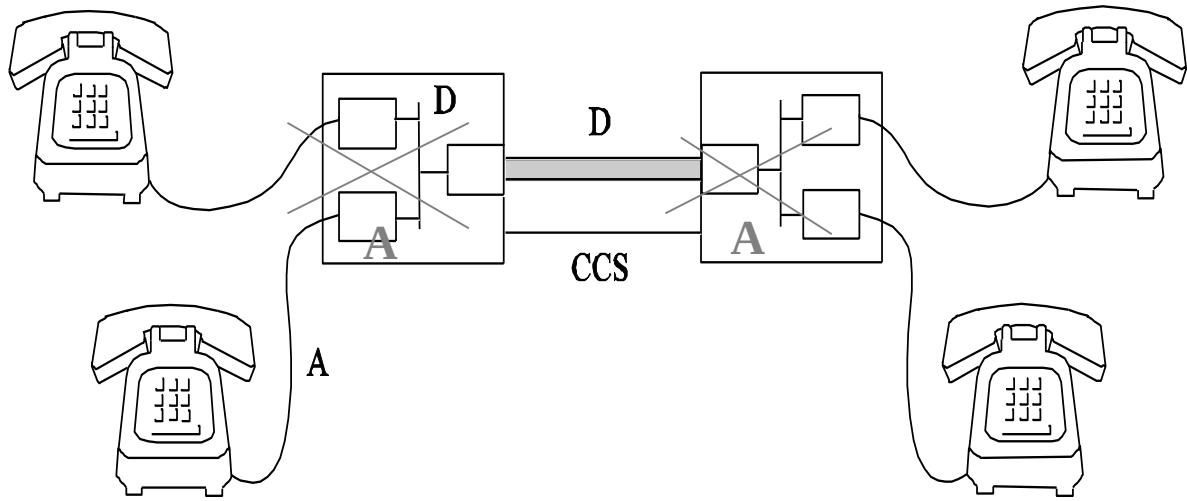


Fig.1.2 Telephone NW until 1970s

全数字综合业务网（ISDN）的出现

模拟信号
数字程控电路交换
数字传输

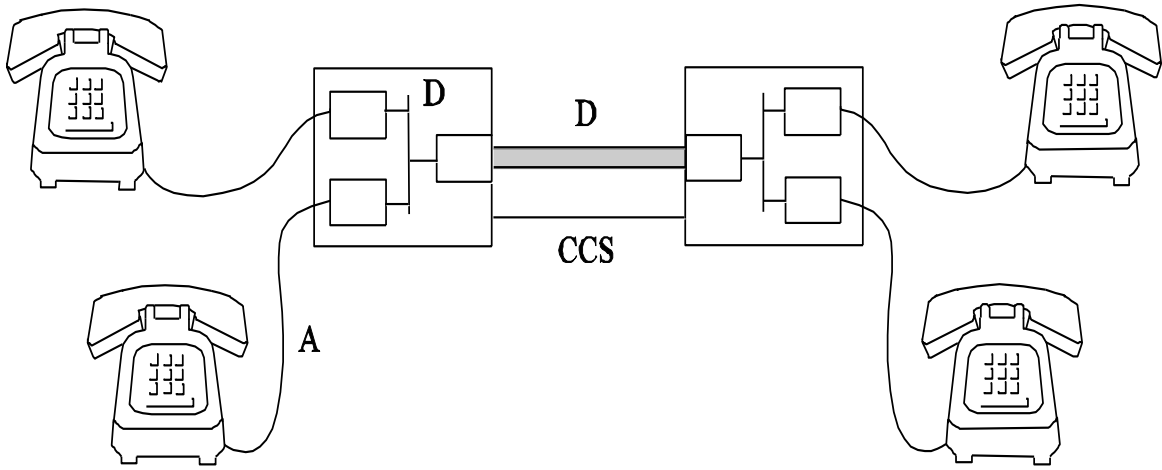


Fig.1.3 Telephone NWs until 1980s

数字信号
数字程控电路交换
数字传输

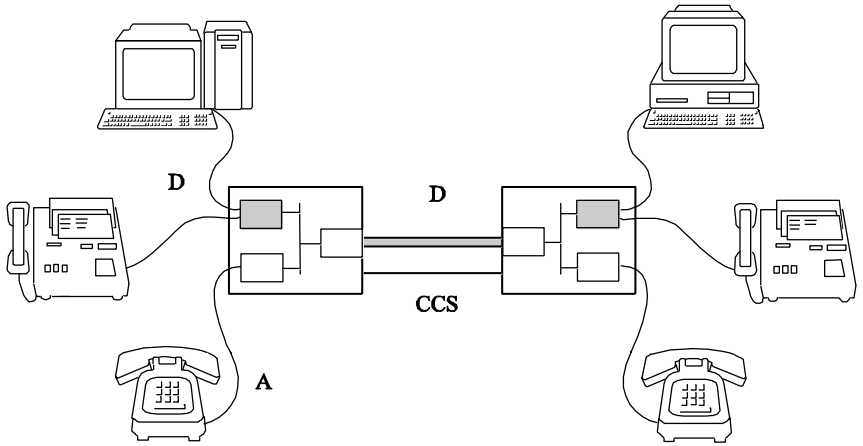
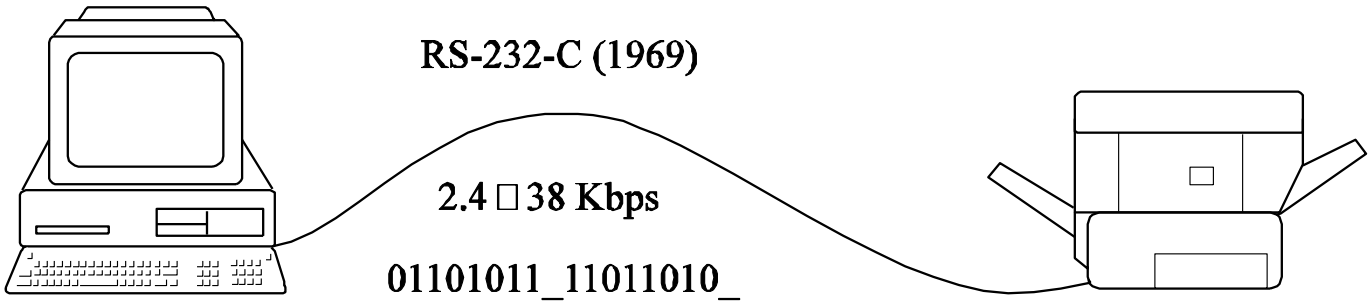


Fig.1.4 Telephone NWs since 1990s

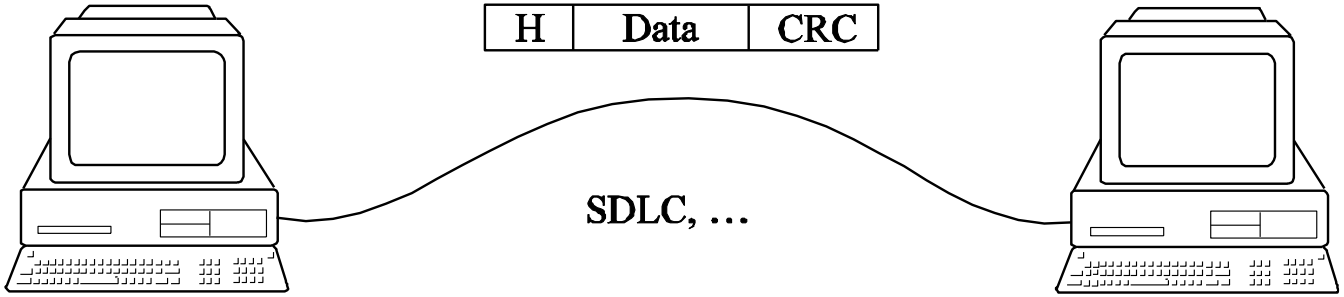
计算机通信从开始就是全数字的

低速串行数字通信



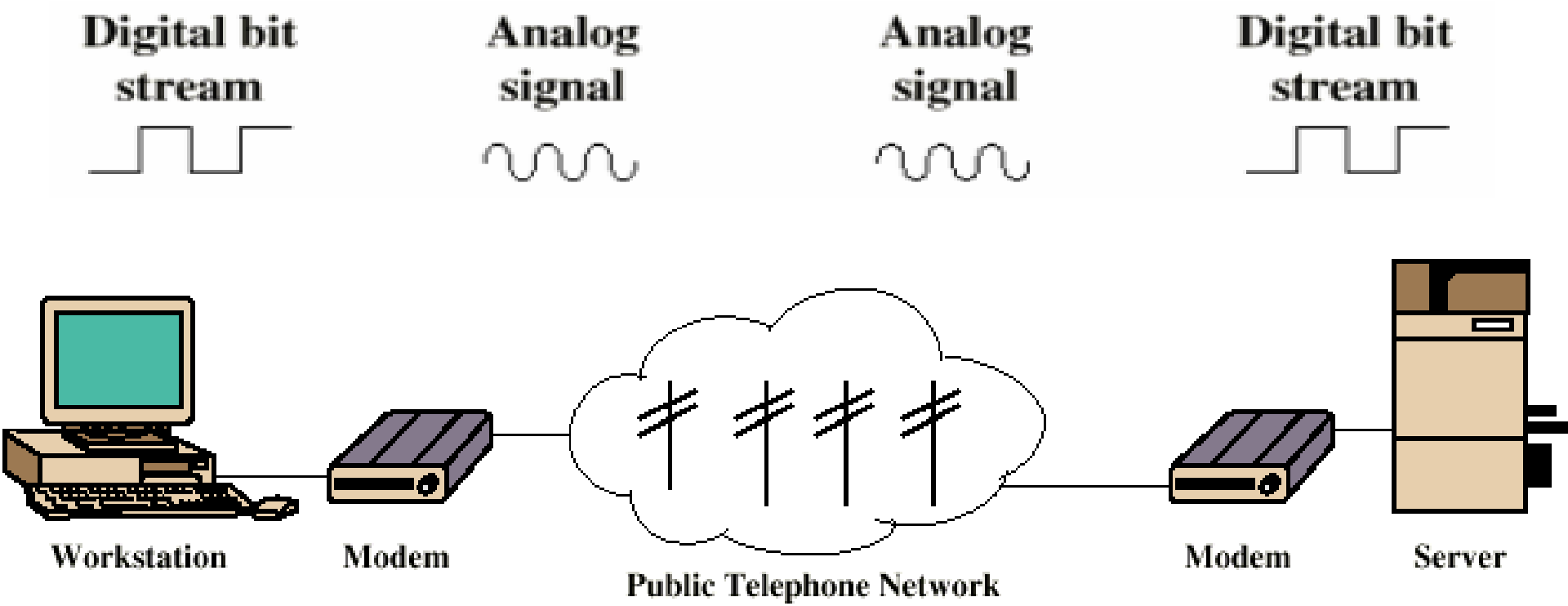
最早的RS232c串行传输协议每次只能传送8bits，因此速率和传输距离都受到极大的限制

高速并行数据通信



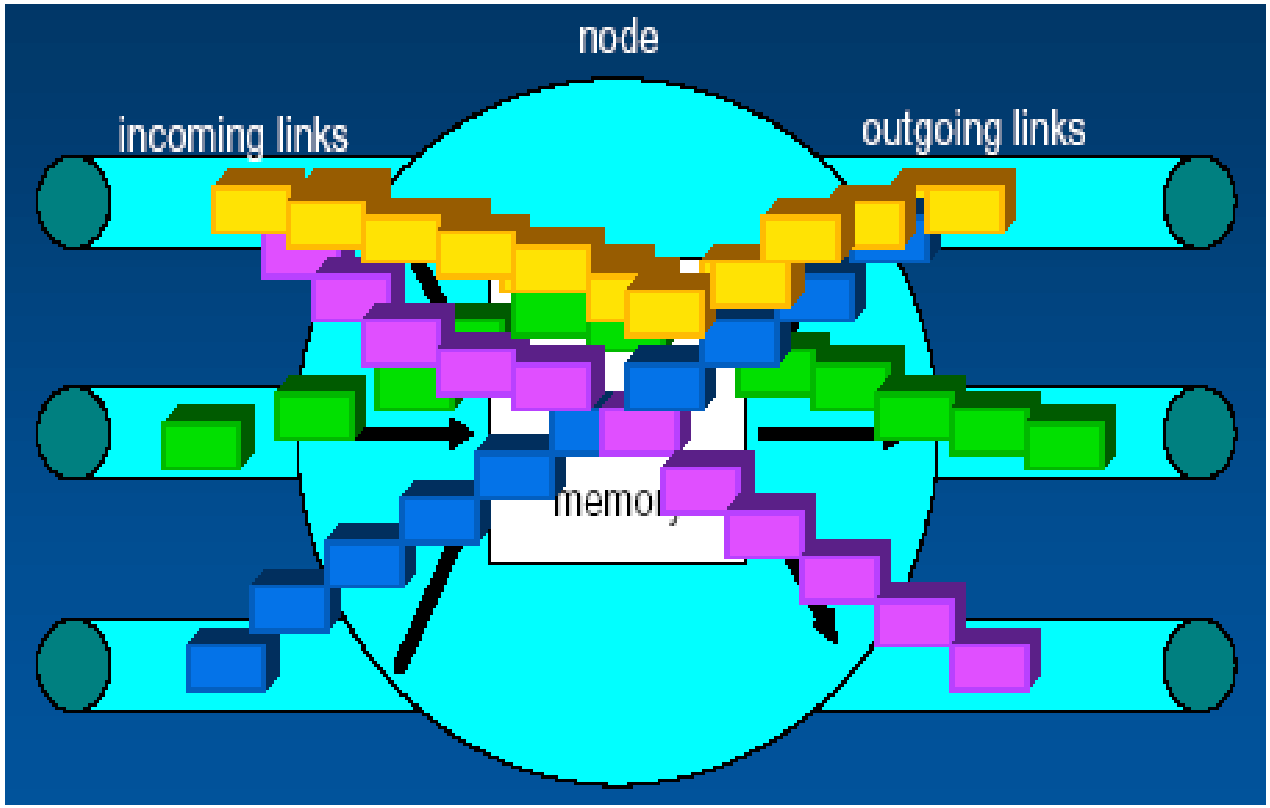
高速并行数据传输协议SDLC (Synchronous Data Link Control)允许并行传输长包，通过包头(H)和循环校验(CRC)比特实现同步和校验

早期计算机广域通信仍需借助电话网



受限于接入线路的带宽和模拟信道的抗干扰能力，通信速率难以提升(e.g., 56Kbps)

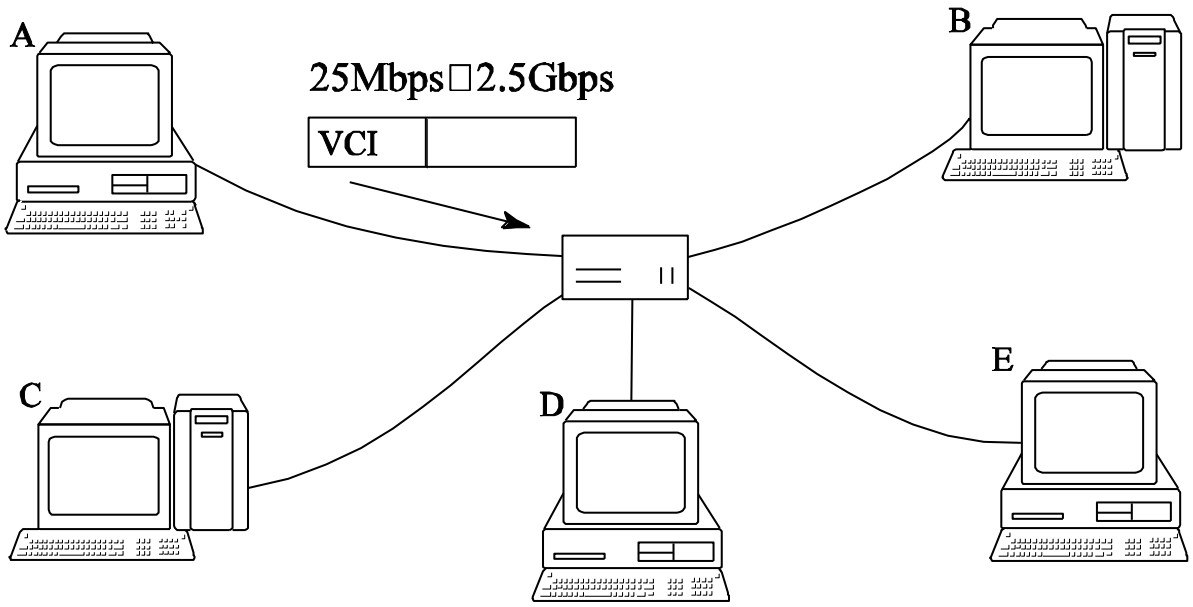
数据通信的第二次大飞跃：分组交换的出现



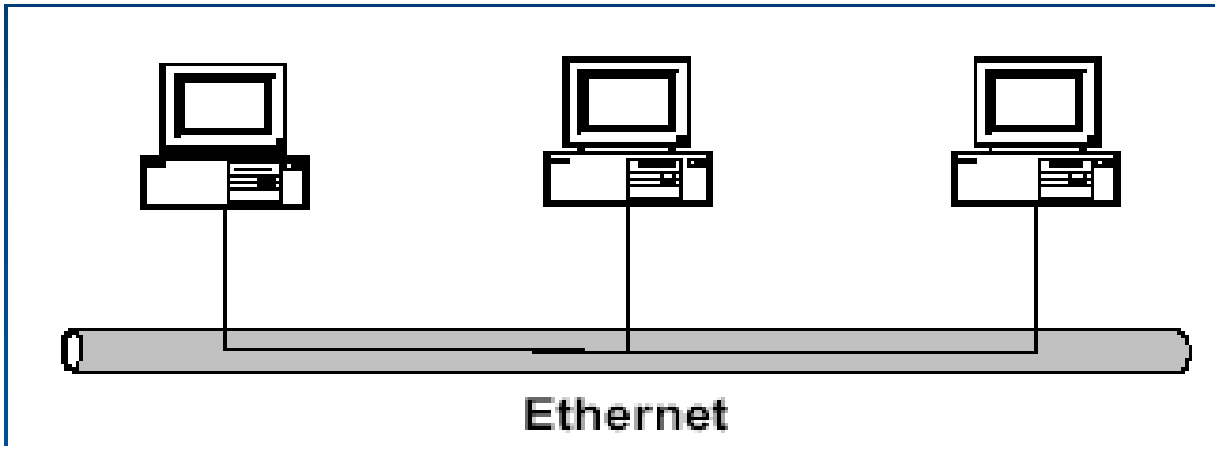
1. 但繁琐的存储转发协议（Store-and-forward，X.25）以及**逐段的纠错检错ARQ**机制大大限制了端对端速率的提高。
2. 随着传输链路质量的不断提高，转发协议的简化势在必行，因此出现了**快速分组交换**技术（帧中继、ATM等）

快速分组交换的发展－ATM的出现

- **快速分组交换的出现－多媒体网络！**
  - 使用短的、固定长度的分组（信元）
  - 导入硬件交换的概念

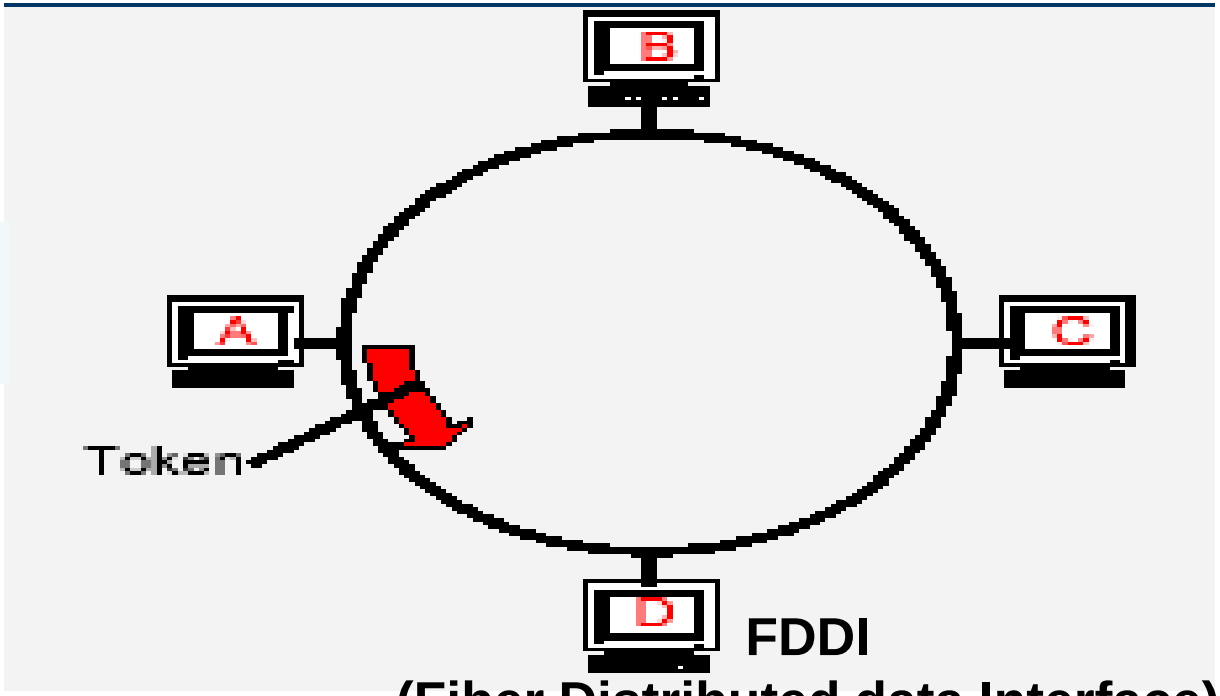


计算机局域网：以太网与FDDI



总线式(Bus)
(CSMA/CD)

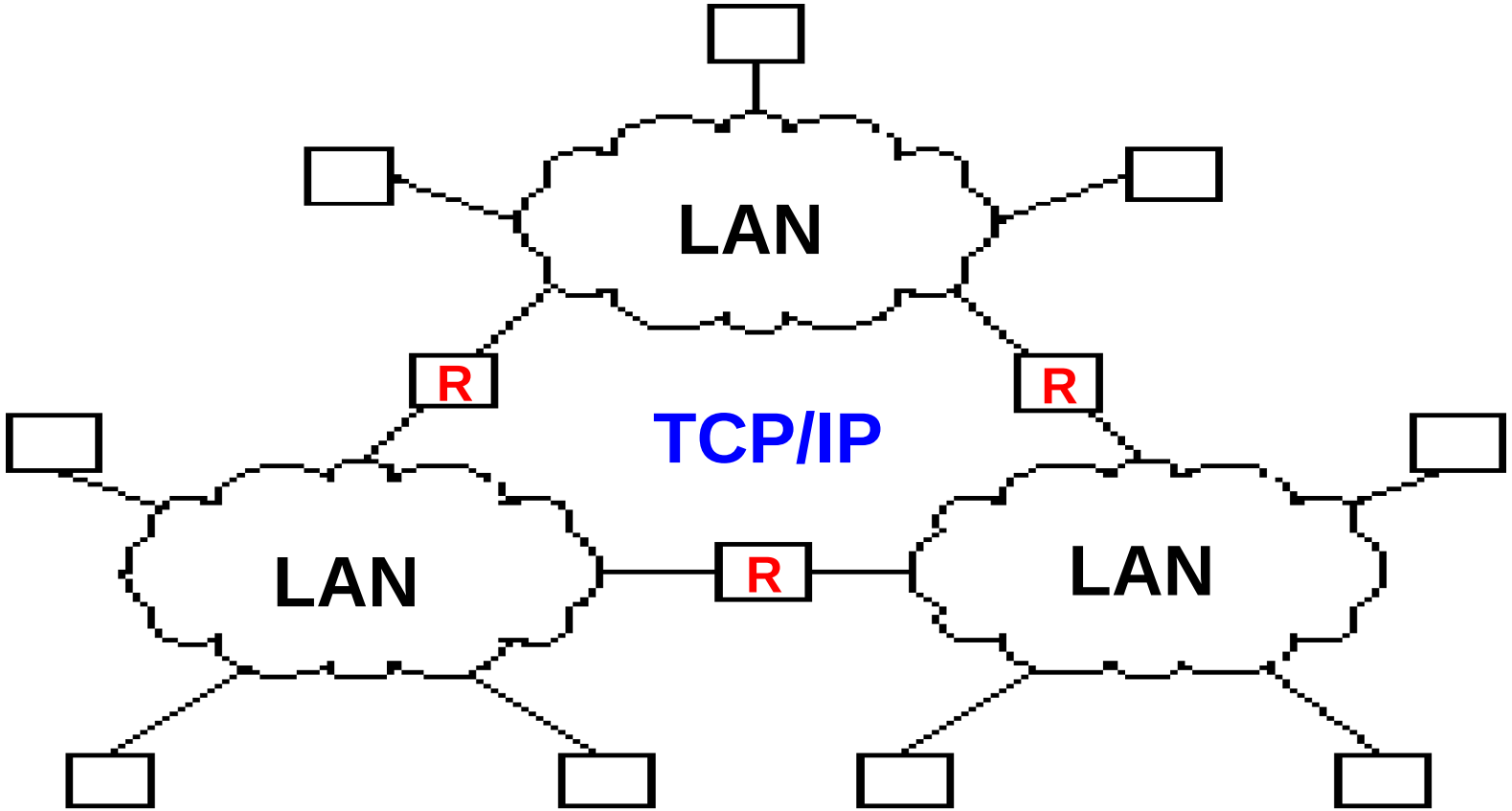
令牌环(Token Ring)
(Polling, Round-Robin)



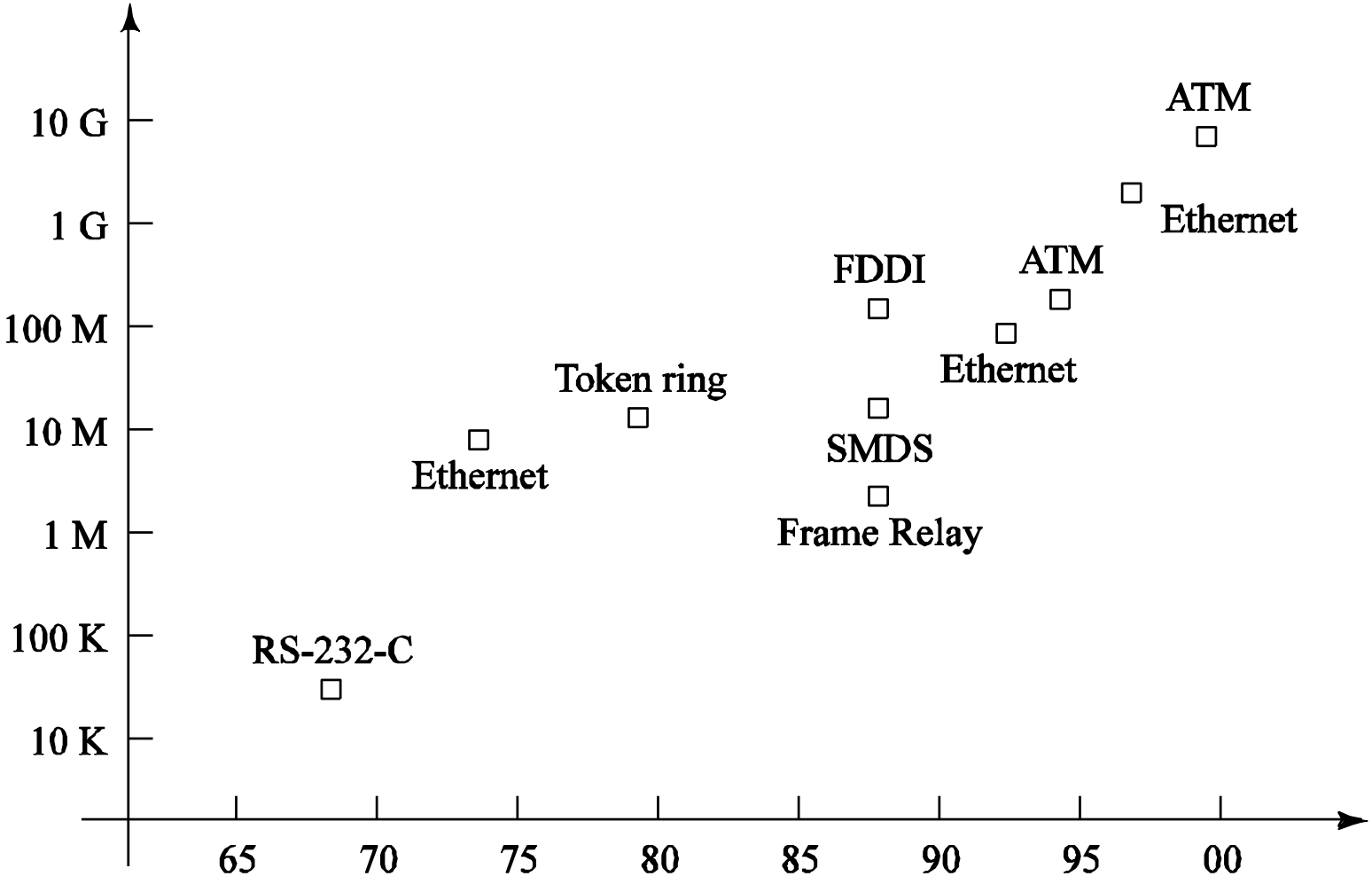
FDDI
(Fiber Distributed data Interface)

局域网互联—Internet的出现

当时的广域分组交换网难以支撑高速局域网的互联需求

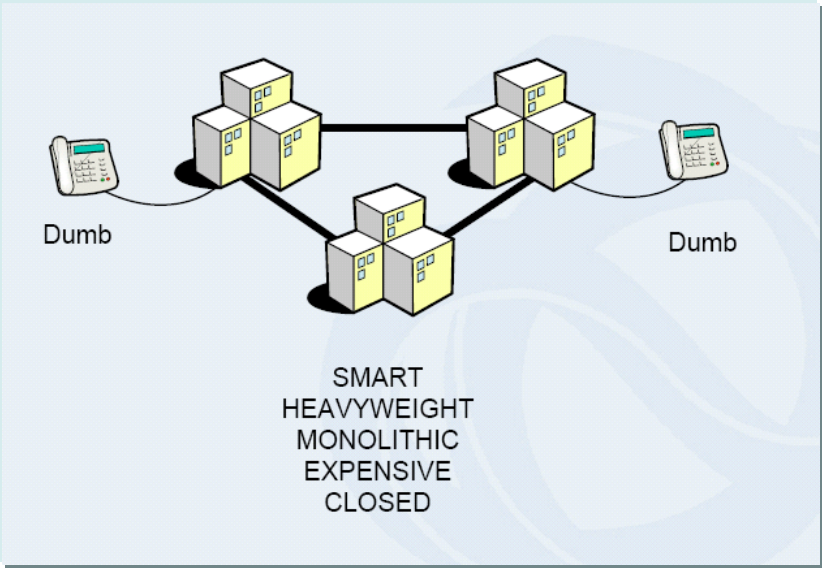


数据通信的发展历程

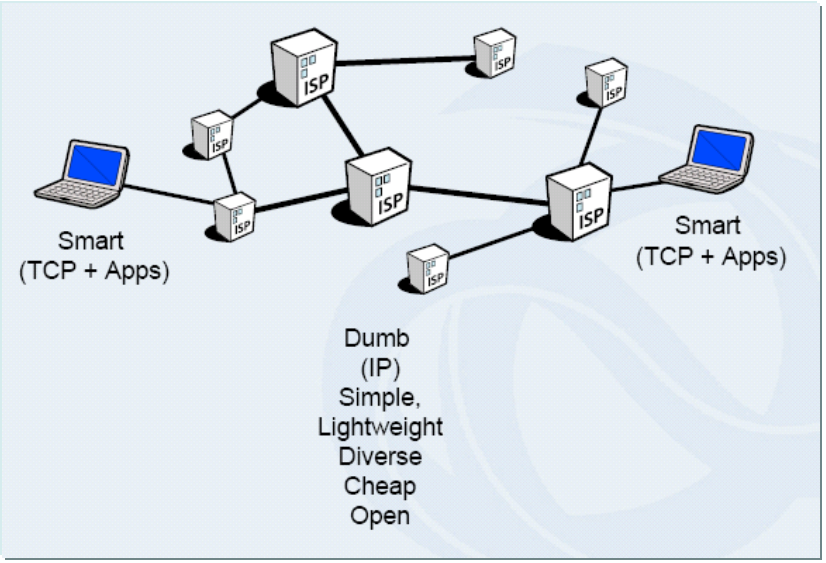

10 G
1 G
100 M
10 M
1 M
100 K
10 K
65
70
75
80
85
90
95
00
ATM
Ethernet
FDDI
ATM
Ethernet
Token ring
SMDS
Ethernet
Frame Relay
RS-232-C

电信网与互联网的架构区别

- 电信网(Telecom)
  - 集中式、层次化架构
  - 智能网络、简单终端
  - 限制接入、统一标准

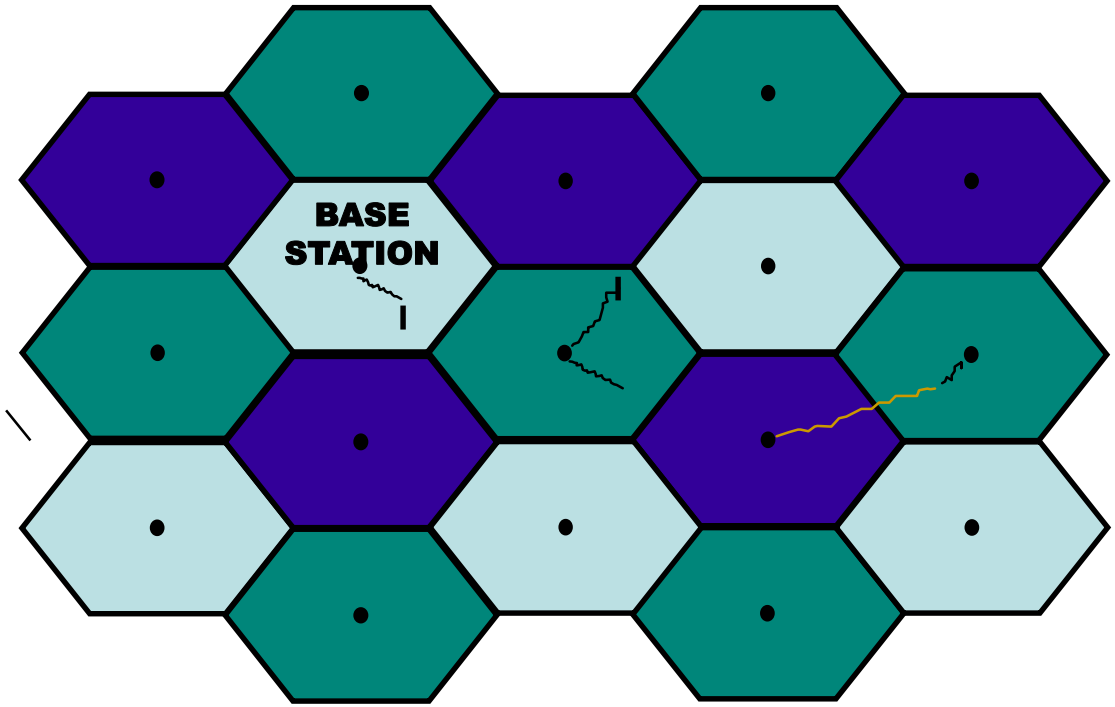


- 互联网(Internet)
  - 分布式、扁平化架构
  - 简单网络、智能终端
  - 开放接入、异构互联



无线通信发展的一次飞跃：蜂窝网络

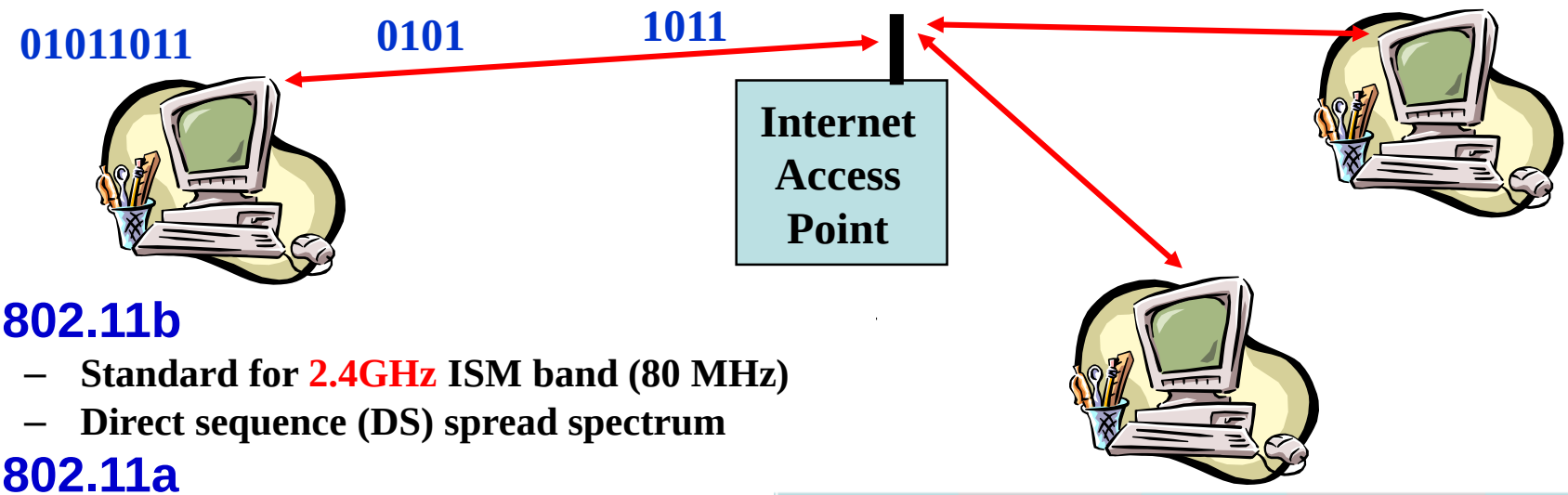
- 通过限制电波的传播范围重复利用宝贵的频谱资源（空间重用）
- 网络覆盖通过蜂窝小区的无缝衔接实现
- 为了减少同频干扰，蜂窝小区间频谱重用遵循一定的规则
- 通过信号（RSSI）检测及信道切换支持小区间的越区切换
- 小区内部频谱可再通过频分/时分/码分等方式实现频率复用



蜂窝通信经历了几代的变革

Introduced	Generation	Traffic support	Peak data rate
Pre-1990	1G	Analog voice	N/A
1991	2G (GSM, IS-95)	Digital voice, SMS, Circuit data	9.6–14.4 kb/s
1999	2.5G (GPRS, cdmaOne)	Improved voice, circuit, and packet data	115 kb/s
2002	3G (WCDMA, EDGE, CDMA2000 1xRTT)	Improved voice, packet data, multimedia	384 kb/s–2 Mb/s
2003	3.5G (UMTS, EV-DO)	Voice over IP, packet data, MMS, multimedia	2–3 Mb/s
2010	4G (HSDPA, HSUPA, EV-DO Rev. B, LTE)	All-IP, Internet Multimedia Subsystem (IMS)	10–100 Mb/s
2020	**5G？(HCN)**	**All-IP, U-shape traffic**	100-1000Mb/s

无线局域网的演变



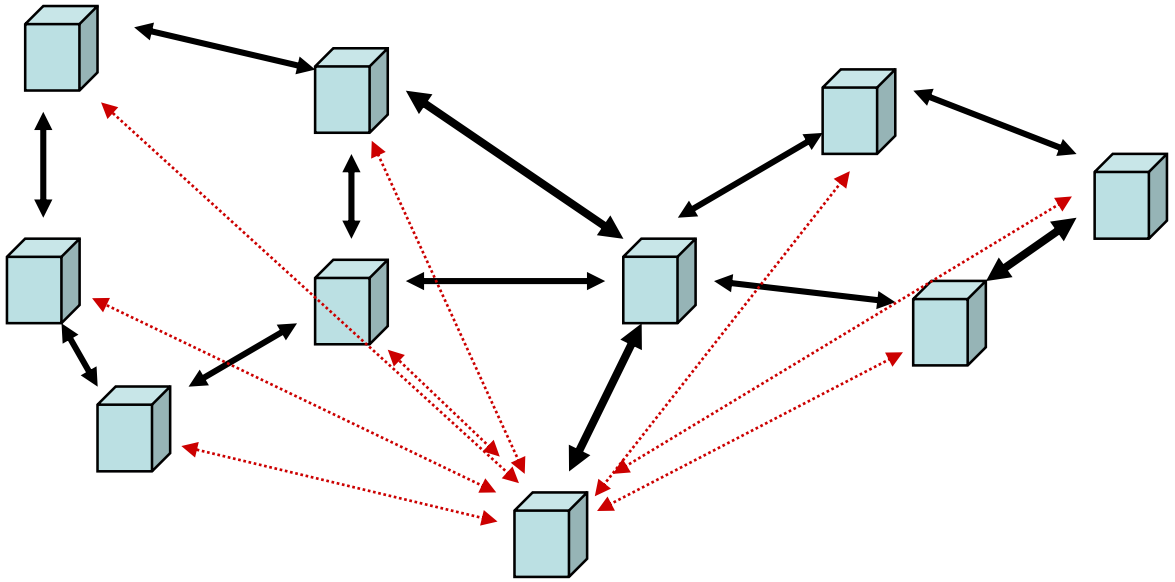
- **802.11b**
  - Standard for 2.4GHz ISM band (80 MHz)
  - Direct sequence (DS) spread spectrum
- **802.11a**
  - Standard for 5GHz NII band (300 MHz)
  - OFDM with time division
  - Similar to HiperLAN in Europe
- **802.11g**
  - Standard in 2.4 GHz band with 54Mbps
  - OFDM
- **802.11n**
  - Standard in 2.4 GHz or 5GHz band
  - OFDM + MIMO
  - Speeds up to 250 Mb/s (110 Mb/s in practice) and about twice the range

WiFi protocol	Year ratified	Freq. (GHz)	Max. rate (Mb/s)	Max. range (m)
802.11	1997	2.4	1, 2	~100
802.11a	1999	5	54	~100
802.11b	1999	2.4	11	~130
802.11g	2003	2.4	54	~130
802.11n	2009 est.	2.4, 5	248	~250

无线个域网的演变

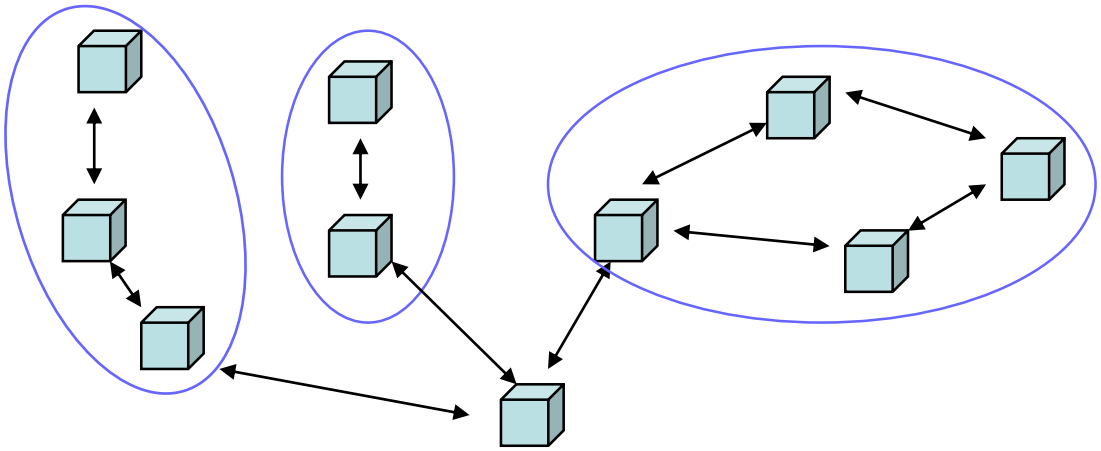
- Bluetooth
  - Short range connection (10-100 m)
  - 1 data (721 Kbps) and 3 voice (56 Kbps) channels
  - Bluetooth 2.0/3.0 for higher data rate
- ZigBee
  - Low-Rate WPAN (20, 40, 250 Kbps)
  - Very low power consumption
  - Frequency of operation in ISM bands
- Ultra WideBand (UWB)
  - Impulse radio: sends pulses of tens of picoseconds to nanoseconds (Low probability of detection)
  - Uses a lot of bandwidth (GHz) to achieve very high data rates (~100 Mbps)
  - Low range, 10m or less, due to power restriction

无线自组织(Ad-Hoc)网络



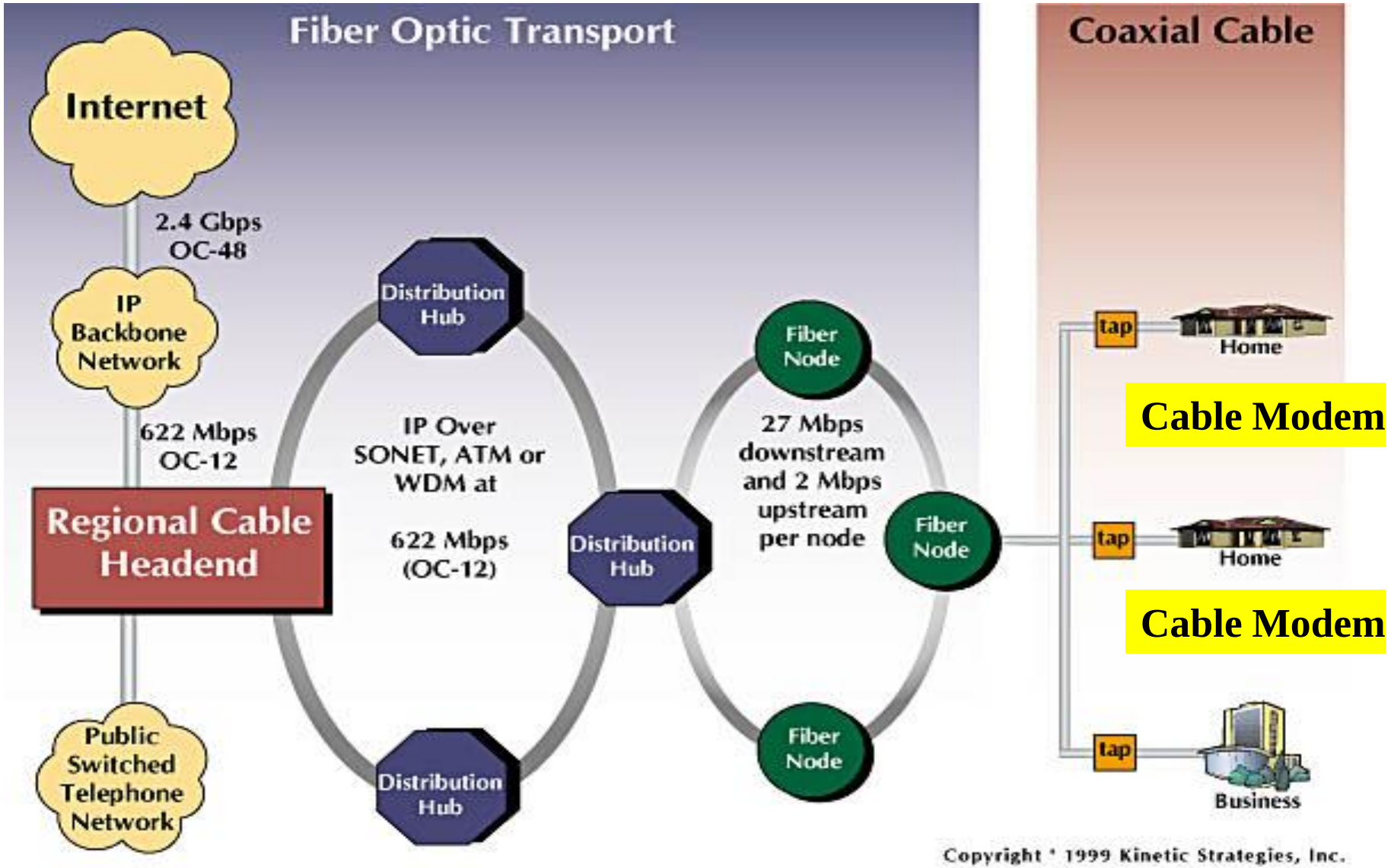
- Peer-to-peer communications.
- No backbone infrastructure.
- Routing can be multihop.
- Network topology is dynamic.

无线传感器网络

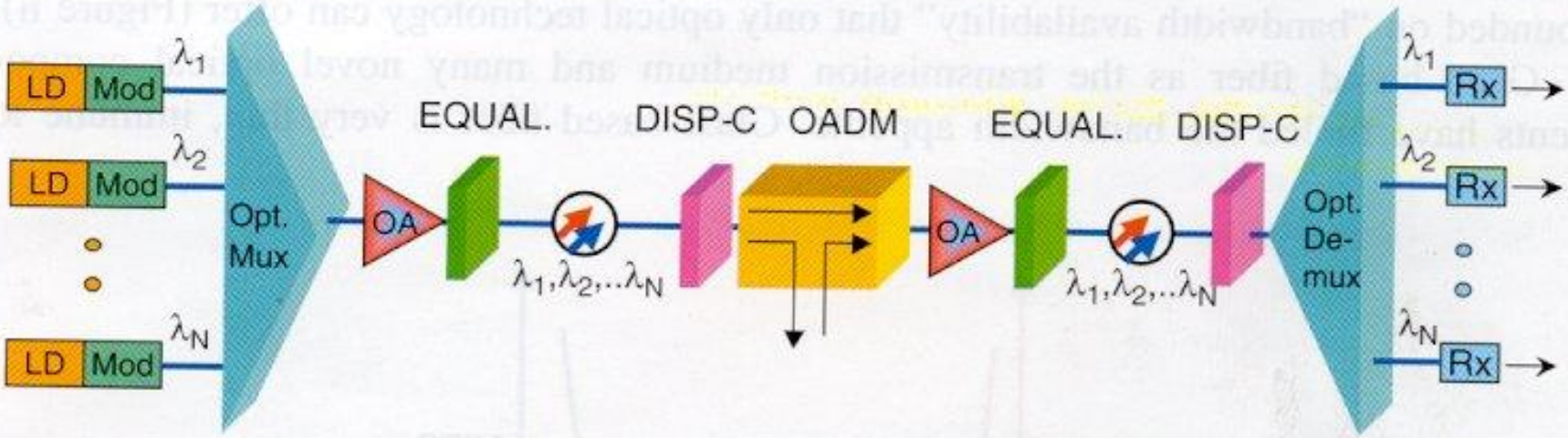


- Nodes powered by non-rechargeable batteries
- Data flows to centralized location.
- Low per-node rates but up to 100,000 nodes.
- Data highly correlated in time and space.
- Nodes can cooperate in transmission, reception, compression, and signal processing.

CATV Networks for Communications



Optical Communications



LD Mod = Laser Diode + Modulator

Rx = Receiver

OA = WDM Optical amplifier

DISP-C = WDM Dispersion compensation
EQUAL. = WDM Equalization
OADM = Optical Add-Drop Multiplexer

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    - 网络可靠性
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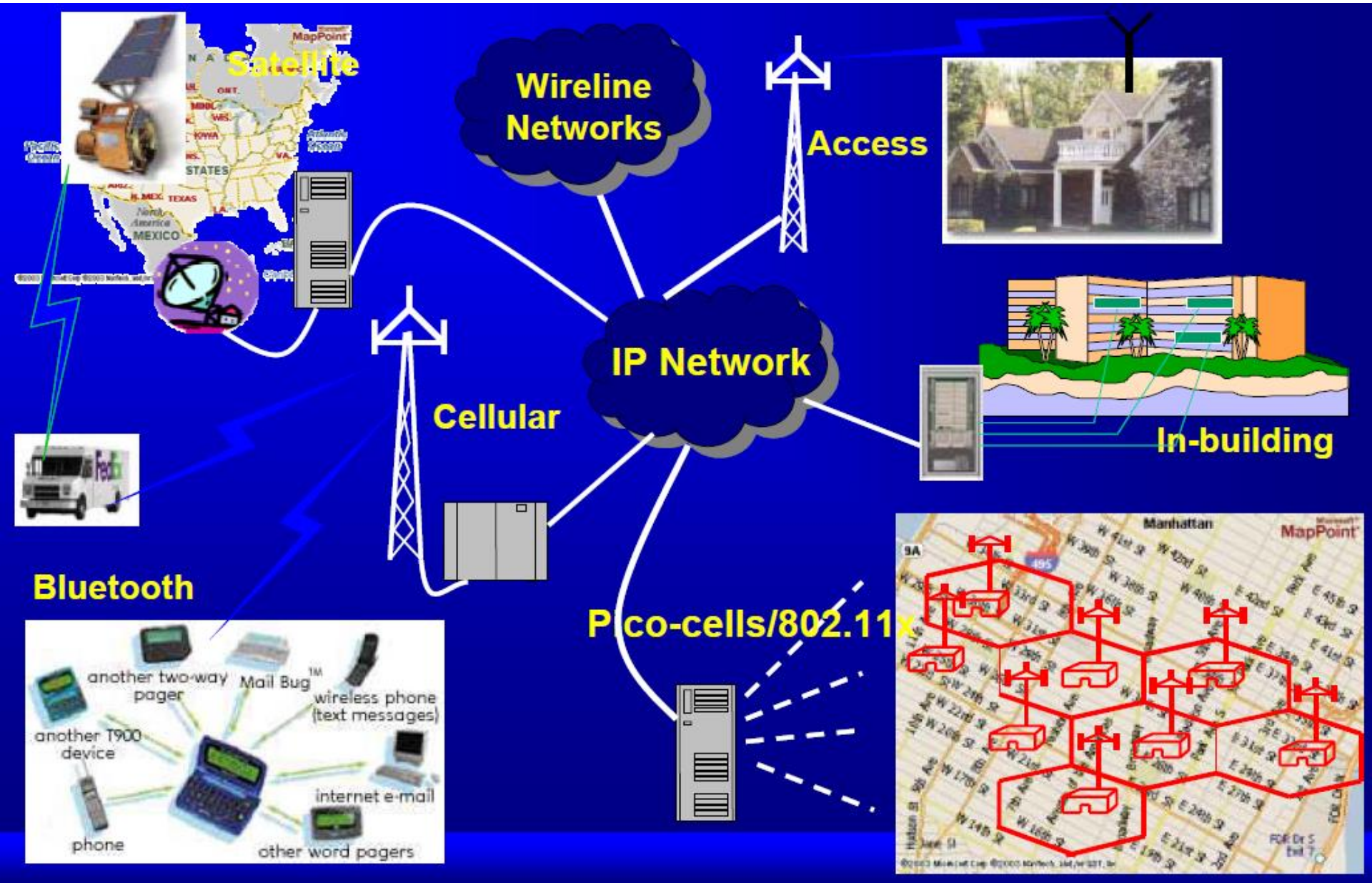
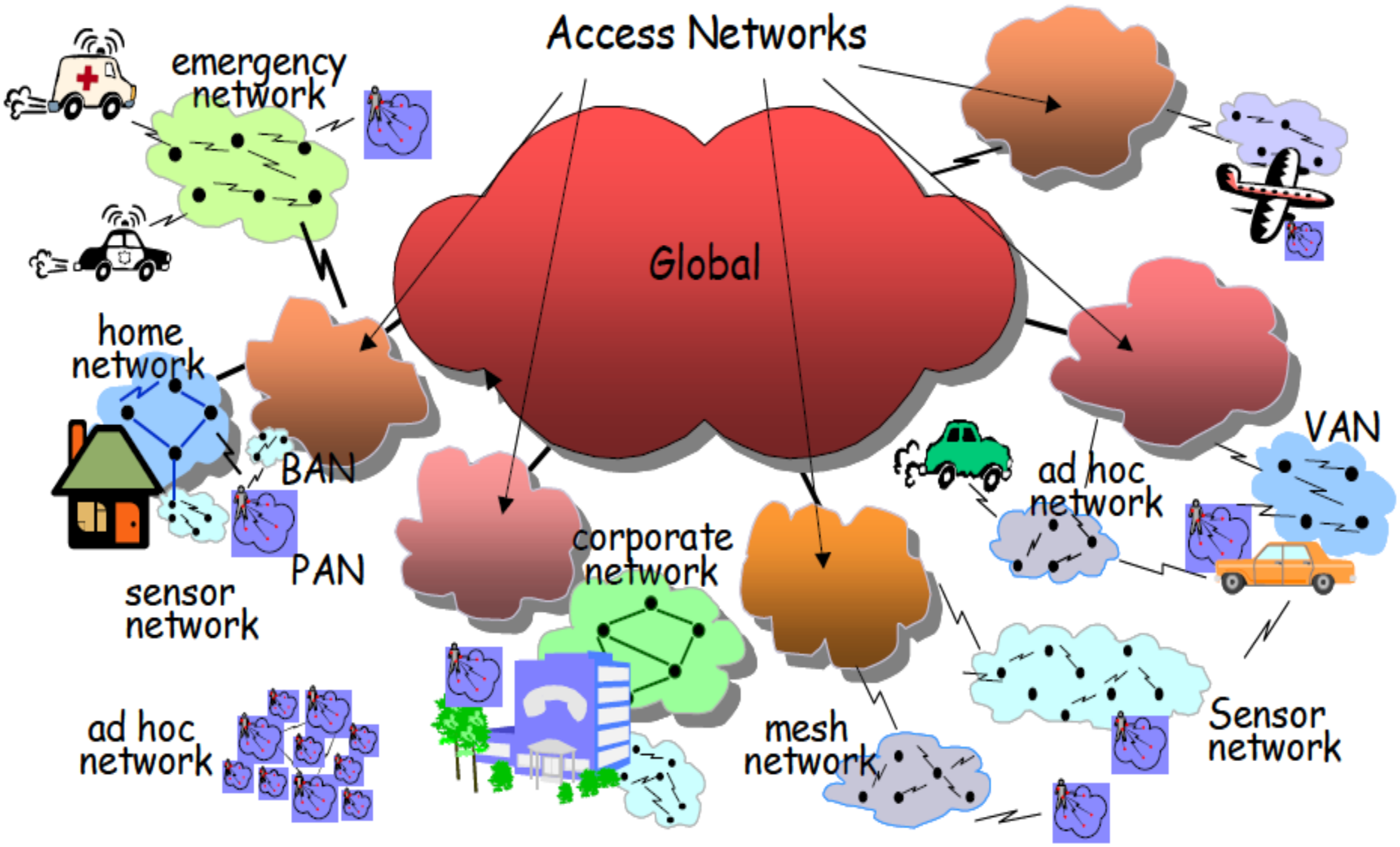
网络已经无处不在、且花样繁多



网络（基本上）无所不能、相互依赖



但对网络的需求仍将进一步扩大

RFID Applications

Communication Anywhere and Everywhere

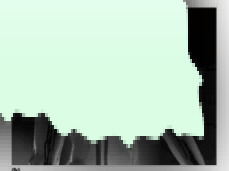
Moving Towards *Trillions* of Wireless Devices

(Machine-to-Machine (M2M) Communication)

Video

Mobile TV

Sensor Applications

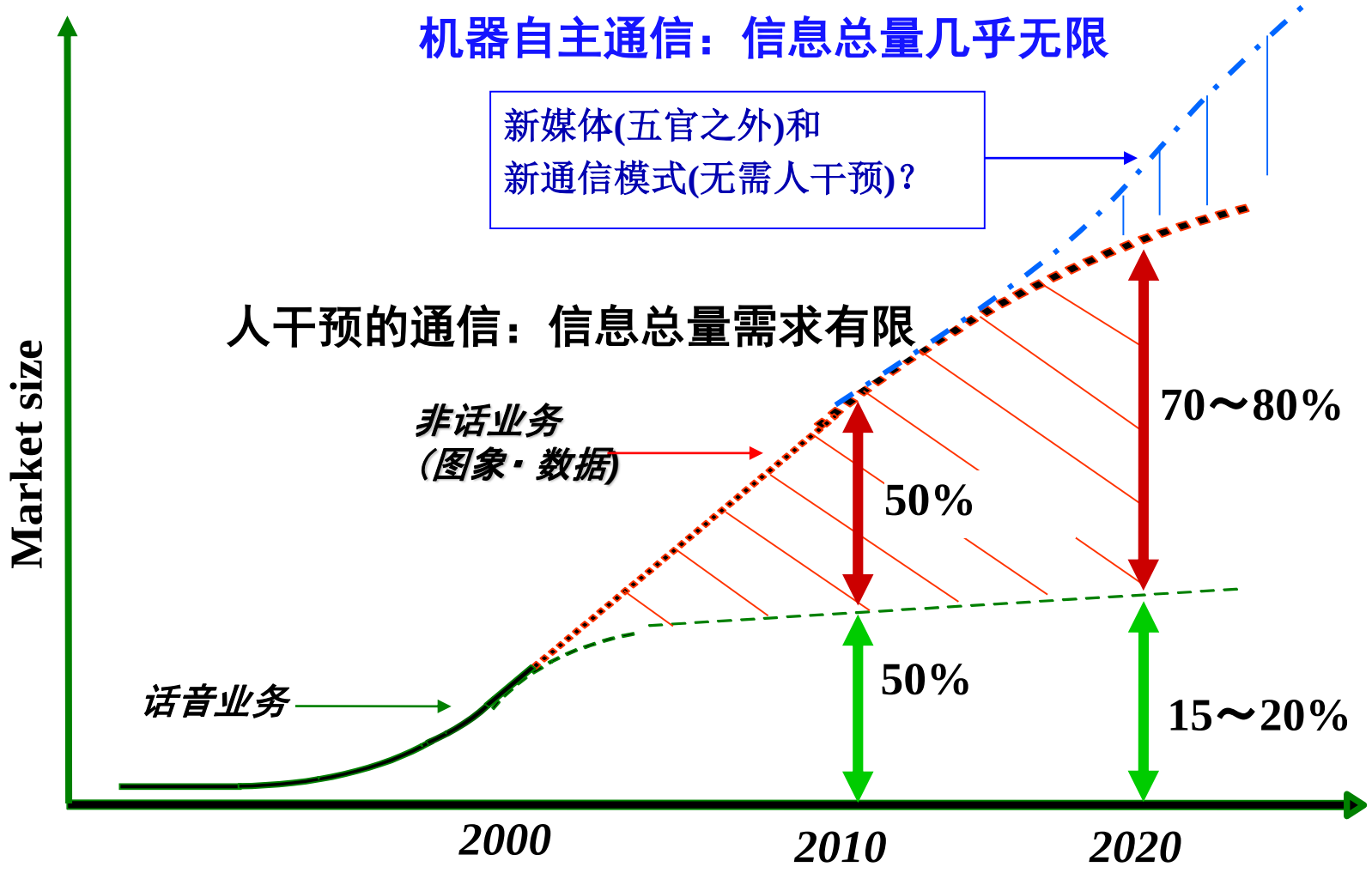


1997
0.20 Billion
Mobile devices

2007
1.8 Billion
Mobile devices

Future
Trillion's Wireless devices

网络流量也将继续快速增长



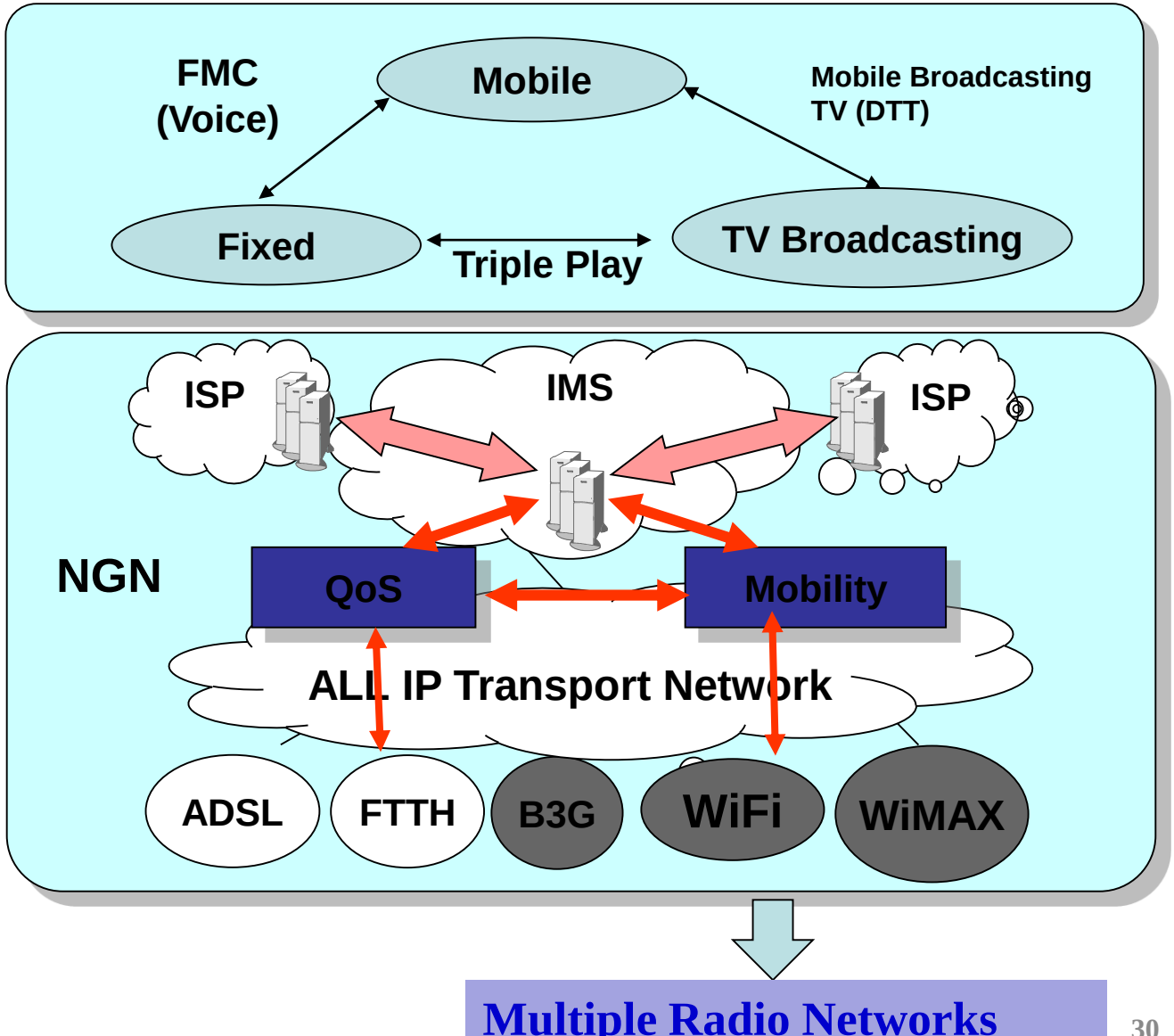
网络的可持续发展（可扩性、可控性、可靠性）至关重要

因此网络将逐步走向融合与多样化接入

- **Convergence** Between Fixed/ Mobile Services

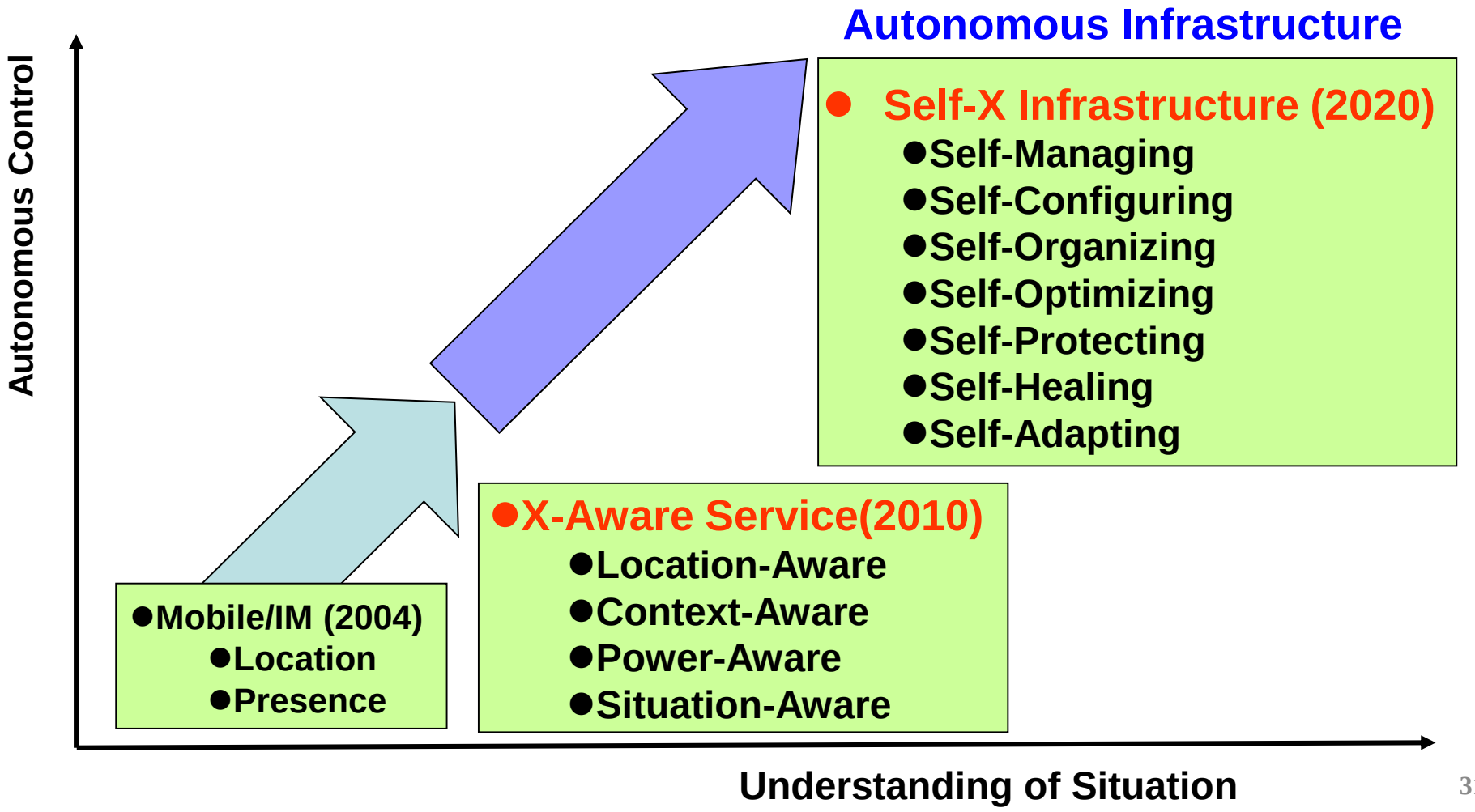
- **Convergence** Between IP Transport Technologies (NGN)

- **Divergences** of Access Media



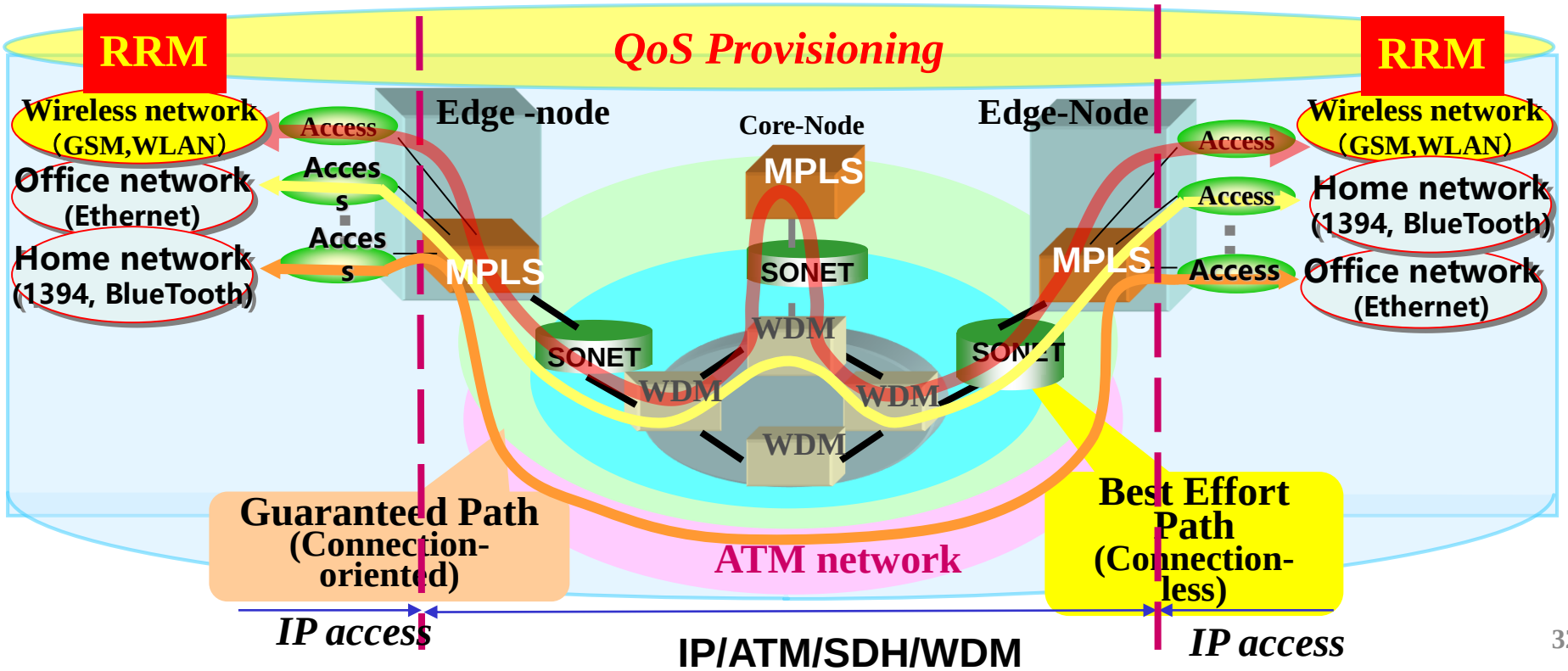
且网络本身也将进一步智能化

- A network that understands situation and controls itself autonomously according to changes in situation to guarantee quality of communication



新一代网络的基本构成及其需求

- Key Requirements to NGN
  - *Mobility* → *Ubiquitous connectivity*
  - *Capacity* → *Multi-dimensional Diversities & Cooperative RRM*
  - *Scalability* → *Adaptability and Robustness*
  - ***Smart*** → *Intelligent*
  - ***Green*** → *Energy-efficient and sustainable*



通信网的发展方向

- 信息：多媒体化、移动化
- 交换：高速化、柔性化
- 传输：数字化、高速化
- 网络：综合化、智能化、个人化

未来网络环境的新变化

- Rise of visual communications *(from P2P to Video Streaming)*
  - *At the end of 2011, YouTube was receiving 10 new videos each second—the equivalent of a half hour of new content* （每半小时内容就更新一半）
  - 视频通话更加普遍 *(fueled by smart phones, tablets, and always-on connectivity)*
  - 用户成为视频内容的提供主体（不再是广播业务提供商），因此上行带宽需要大大拓宽（FTTH变得越来越重要）
- Rise of social networks *(e.g., Facebook, MySpace, Twitter, WeChat)*
  - 未来网络的业务将出现明显的两极分化 *(**U-shape traffic**: capacity-hungry video streams and always-on-line short messages)*
- Growth of “over the top” (OTT) or Mobile Virtual Network Operators (MVNOs) *(e.g., Skype, Viber)*
  - *Network reconfigurability is key (SDN)*
- Terminal leads the shift of paradigm, not network elements
- Mobile payment became more prevalent *(security and privacy are key)*

2020年的通信网络

- "The 2020 network: How communications infrastructure will evolve" *(Vish Nandlall, Ericsson CTO for North America)*
  - How 50 billion connected devices and 6 billion people change the industry?
- Some likely truths about the telecom industry, which may shape decisions about the future
  - **The $1 ARPU** (average revenue per user) **economy**: *This "few" to "many" application economy drives pricing pressure. Whether serving human or machine, the value of a service is being driving down to $1*
  - **Telecom data center:** *To compete at cost, cloud data center must be more efficient*
  - **Software-defined network:** *make the network more flexible by network function virtualization (NFV) such that the operator can program services instead of creating static network overlays for every new service* ***(All network services are moved from network to data centers such that time to market can be reduced from years to hours)***
  - **Internet of things:** *The network needs to be transformed from a black box of static resources to a marketplace of services, for which the choice of web interfaces and crowdsourcing is crucial.*
  - **5G: Choice and flexibility:** *5G will not just be about speed. The explosion and diversity of machine-connected end points will define use cases for low bandwidth, low latency and energy-efficient connections.* ***5G will likely require similar abstraction requirements as in software-defined networks*** *to provide loosely coupled and coarsely grained integration with end-point and network-side services.*

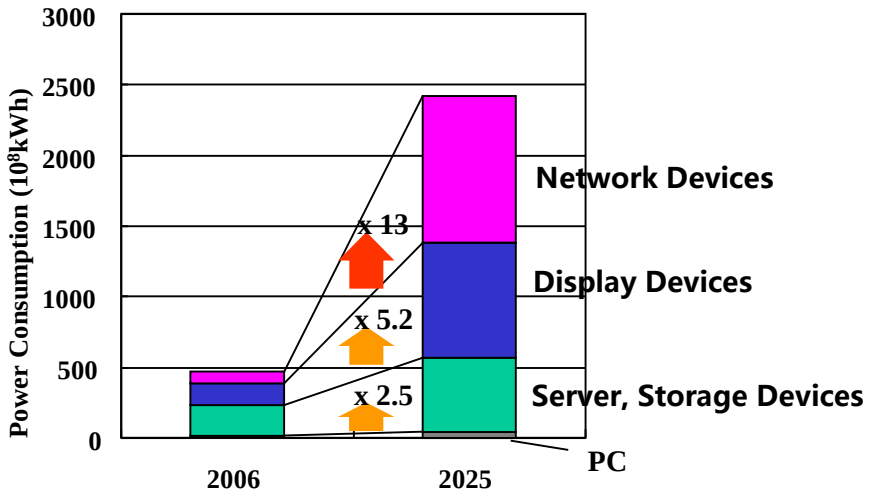
The 2020 telecom network will enable SPs (OTTs) to create a network marketplace of services and deliver the vision of a networked society

但进一步的发展受到能耗的约束 - 绿色通信

- **One Google Search排放7g的二氧化碳，等效于烧开一壶水**
- **网络容量的进一步提高越来越受到能耗的约束**
  - **更高的载频可以增加带宽，但伴随更大的路径损耗，增加覆盖成本**
  - **高阶调制可以提高频谱效率，但大都以增加能耗为代价**
  - **微蜂窝化可以提高频谱效率，但会增加覆盖成本和小区间干扰**
  - **基站数快速增长，且功能趋于复杂，需要消耗更大的能量**
    - ✓ 基站能耗占移动网整体能耗的**60-80%**，且在不断增长（中移动基站数：**46万'09→ 60万'10**）
    - ✓ 空调耗电占到基站能耗的**50%**以上，如果无法将基站关掉，难以大幅度降低功耗

中国移动能源消耗情况

	2006	2007	2008
总用电量（亿度）	63.8	80.9	93.3
总局房用电（亿度）	15.7	20.3	36.0
传输及基站用电（亿度）	48.1	60.6	57.3
公务用车的汽油油耗（百万升）	52.1	56.3	53.7
公务用车的柴油油耗（百万升）	8.9	9.7	6.9
发电机汽油油耗（百万升）	7.4	8.2	12.7
发电机柴油油耗（百万升）	11.8	12.7	11.2
天然气用量（百万立方米）	3.5	3.8	3.5
液化石油气用量（百吨）	1.0	1.4	1.5
人工煤气用量（百万立方米）	0.3	0.3	0.5
煤碳用量（万吨）	2.1	2.4	2.3
二氧化碳排放（百万吨）	5.4	6.9	7.9



Power Consumption by IT Devices in Japan

关注通信网络最新进展

- IEEE International Conference on Communication (ICC)
  - ✓ 每年5月份，约2500人参会，基本上在美国以外，ICC2008在北京、ICC2009在德国、ICC2010在南非、ICC2011在日本、悉尼、英国、…2019在上海
- IEEE Global Telecommunication Conference (Globecom)
  - 每年12月份，约2500人参会，基本上在美国，GC19在夏威夷
- IEEE Infocom
  - ✓ 每年3/4月份，约500人参会，2019在巴黎
- IEEE Wireless Communication and Networking Conference (WCNC)
  - ✓ 每年3/4月份，约600人参会，
- IEEE International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)
  - ✓ 每年3/4月份，约600人参会，
- Asia Conference on Communication (APCC)
  - ✓ 每年9/10月份，约300人参会，
- OFC、ECOC、APOC、VTC

课程大纲

- 第一章：通信网概论与课程导论
  - 开课背景介绍
  - 通信与网络技术发展史
  - 通信与网络的发展与演变
    - 模拟通信到数字通信的转变
    - 电路交换向分组交换的演变
    - 语音通信向多媒体通信的演变
    - 固定通信向移动通信的演变
  - 网络互联的新需求
    - 异构网络互联
    - 网络可扩展性
    - 网络可靠性
    - 网络安全性
  - 通信网基本概念

谢谢！祝同学们新学期学习顺利！