1. Introduction

- 1.1 The Crowded Spectrum
- 1.2 Need for High Data Rates
- 1.3 Multiple-Input Multiple-Output Systems
- 1.4 Internet Protocol
- 1.5 Wireless Internet Protocol
- References

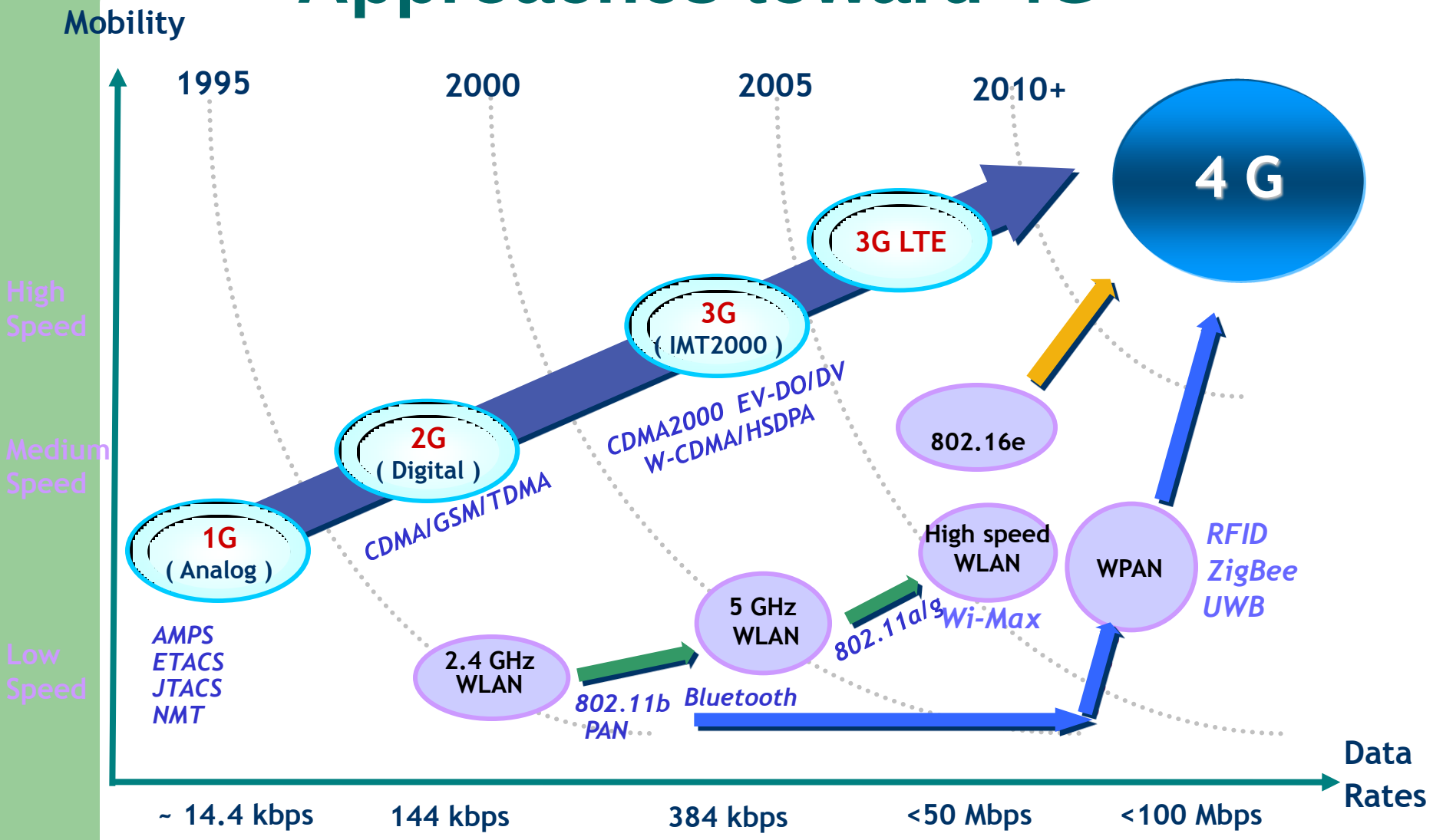
1.1 The Crowded Spectrum

- The demands on bandwidth and spectral availability are endless.
  - Currently wireless finds its widest expression in fixed and mobile roles. In the fixed role, wireless is used extensively for data transfer, especially from desktop computers and laptops. In the mobile role, wireless networks provide mobility for use from fast vehicles for both voice and data.
  - Consequently wireless designers face an uphill task of limited availability of radio frequency spectrum and complex time varying problems in the wireless channel,such as fading and multipath, as well as meeting the demand for high data rates. Simultaneously, there is an urgent need for better quality of service (QoS), compared with that obtained from DSL and cable.

1.2 Need for High Data Rates

- The gradual evolution of mobile communication systems follows the quest for high data rates, measured in bits/sec (bps) and with a high spectral efficiency, measured in bps/Hz.

Approaches toward 4G



- 2G
  - Global system for mobile communications (GSM): 22.8 kb/s
  - CDMA1.x
- 2.5G
  - High-speed circuit switched data (HSCSD): 38.4 kb/s
  - General packet radio service (GPRS): 172.2 kb/s
  - Enhanced data rates for GSM evolution (EDGE)
  - Enhanced circuit switched data (ECSD)
  - Enhanced general packet radio service (EGPRS): 473.6 kb/s
- 3G: 384 kb/s for mobile and 2 Mb/s for indoors
  - UMTS (universal mobile telephone system) / Wideband code-division multiplex (WCDMA)
  - CDMA2000 1.x
  - TD-SCDMA
- E3G/B3G
  - LTE

- WPAN
  - IEEE 802.15
  - Bluetooth: < 1 Mb/s
- WLAN
  - IEEE 802.11: 1, 2 Mb/s
  - IEEE 802.11a: 6, 9, 12, 18, 24, 36, 48, 54 Mb/s
  - IEEE 802.11b: 1, 2, 5.5, 11 Mb/s
  - IEEE 802.11g: 6, 9, 12, 18, 24, 36, 48, 54 Mb/s
  - IEEE 802.11n: 100 Mb/s
  - High Performance Radio Local Area Network (HIPERLAN) Type 1
  - HIPERLAN Type 2
- WMAN
  - IEEE 802.16x
  - WiMAX
- WWAN
  - IEEE 802.20

- 4G
  - The first 4G systems are likely to be an integration of 3G systems and WLAN systems. By this means, considerable data rates can be granted at hot spots. On the other hand, the interworking of WLAN and 3G systems will provide a good degree of mobility, given that seamless handover is accomplished between several heterogeneous systems.

- Possible candidates for 4G systems
  - BWIF (Broadband Wireless Internet Forum)
    - VOFDM (vector orthogonal frequency division multiplexing)
    - DOCSIS (data over cable service interface specification)
  - IEEE-ISTO (IEEE Industry Standards and Technology Organization)
  - TD-SCDMA (time-division synchronous CDMA)
  - HSDPA (high-speed downlink packet access)
  - CDMA2000 1xEV
  - …

- The BWIF is the principal organization chartered with creating and developing next generation fixed wireless standards. BWIF was formed to address the needs of the quickly emerging wireless broadband market. Further, through BWIF, members establish product road maps that lower product costs, simplify deployment of advanced services, and ensure the availability of interoperable solutions. BWIF extends the partnership model to all companies offering expanded broadband wireless technology to multiple markets. At the core of the partnerships, membership includes:
  - ASIC semiconductor companies, which develop new ASICs based on VOFDM technology;
  - Customer premise equipment (CPE) companies, which use the chips to build new subscriber equipment;
  - Systems integrators, which design and deploy the networks based on these products;
  - Service providers, which incorporate VOFDM products and technology into their network infrastructure to offer to new services customers;
  - RF/ODU manufacturers, which supply subsystems to the total wireless solution offering.

- BWIF is organized as a program of the IEEE-ISTO, which acts as the managing body for this forum.
- TD-SCDMA is the Chinese contribution to the ITU's IMT-2000 specification for 3G wireless mobile services.
- HSDPA is a packet-based data service in WCDMA downlink with data transmission up to 8-10 Mb/s and 20 Mb/s for MIMO systems over a 5 MHz bandwidth in WCDMA downlink. HSDPA implementations include adaptive modulation and coding (AMC), MIMO, hybrid automatic request (HARQ), fast cell search, and advanced receiver design. In third generation partnership project (3GPP) standards, Release 4 specifications provide efficient IP support, enabling provision of services through an all-IP core network, and Release 5 specifications focus on HSDPA to provide data rates up to approximately 10 Mb/s to support packet-based multimedia services. MIMO systems are the work item in Release 6 specifications, which will support even higher data transmission rates up to 20 Mb/s.

- There are many approaches toward 4G. The final standard has not been defined as yet. The common theme in all these proposals is increasing spectrum efficiency using OFDM-MIMO techniques.

1.3 Multiple-Input Multiple-Output Systems

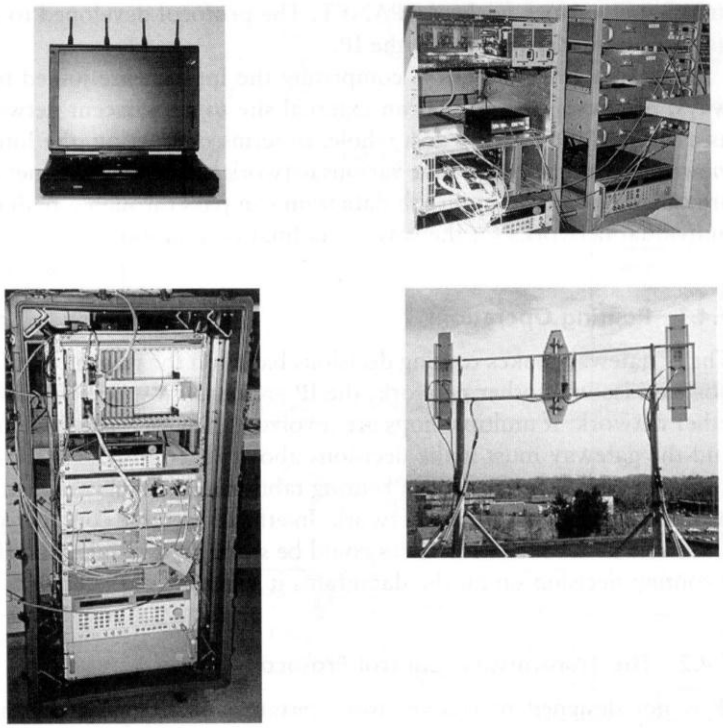
- This technique is mainly based on the theoretical work developed by Teletar and Foschini. The core of this idea is to use multiple antennas both for transmission and reception. This increases the capacity of the wireless channel.
  - Capacity is expressed as the maximum achievable data rate for an arbitrarily low probability of error. Hence, the thrust has been toward the development of codes and schemes that would enable systems to approach their Shannon capacity limit.

- This technology received a fillip when Tarokh et al. introduced their space-time trellis coding techniques and Alamouti introduced his space-time block coding techniques to improve link-level performance based on diversity.
- It received another boost when Bell Laboratories introduced its Bell Laboratories Layered Space-Time coding technique, demonstrating spectral efficiencies as high as 42 b/s/Hz. This represents a tremendous boost in spectral efficiency compared with the current 2-3 b/s/Hz achieved in cellular mobile and WLAN systems.

- We will now discuss a MIMO system pioneered by AT&T Labs-Research in Middletown, New Jersey.
  - It conducted field tests to characterize the mobile MIMO radio channel.
  - The company measured the capacity of a system with four antennas on a laptop computer and four antennas on a rooftop base station.
  - The field test showed that close to the theoretical fourfold increase in capacity over a single antenna system can be supported in a 30 KHz channel with dual polarized spatially separated base station and mobile terminal antennas.

- The base station rooftop antenna array used dual-polarized antennas separated by 11.3 feet, which is approximately 20 wavelengths apart and a multibeam antenna.
- The laptop-mounted antennas included a vertically polarized array and a dual-polarized array with elements spaced half a wavelength apart.
- Different signals were transmitted out of each antennas simultaneously in the same bandwidth and then separated at the receiver. With four antennas at the transmitter and receiver, this has the potential to provide four times the data rate of a single antenna system without an increase in transmit power or bandwidth, provided the multipath environment is rich enough.
- This means that high capacities are theoretically possible unless there is a direct line of sight between transmitter and receiver.

Figure 1.3 Upper: Transmitter with four antennas on a laptop and the 1,900-MHz coherent transmitter. Lower: The four receivers with real-time baseband processing and rooftop antennas.

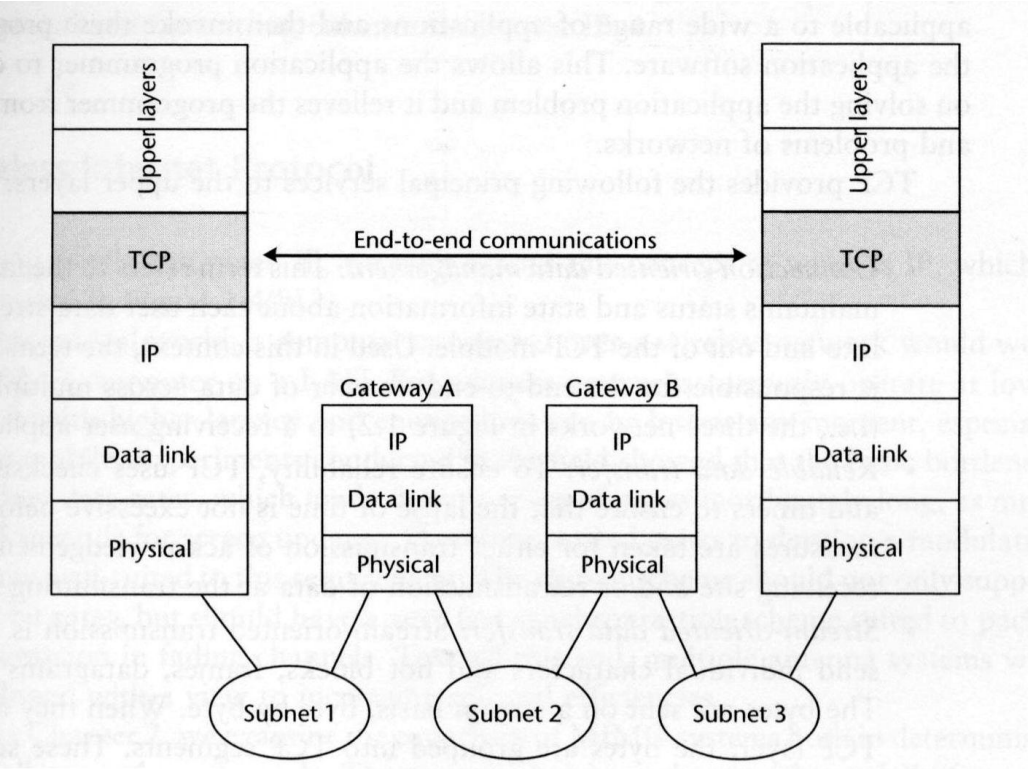


1.4 Internet Protocol

- 1.4.1 Routing Operations
- 1.4.2 The Transmission Control Protocol
  - Connection-oriented data management
  - Reliable data transfer
  - Stream-oriented data transfer
  - Flow control
  - Full-duplex transmission
  - Multiplexing
  - Precedence and security
  - Graceful close

- The Internet is a collection of thousands of networks interconnected by gateways. The protocol developed to interconnect the various networks was called the IP. A gateway appears as an external site to an adjacent network, but appears as a node to the Internet as a whole. In terms of layering, the Internet sublayer is viewed as sitting on top of the various network layers. The Internet sublayer packets are called datagrams and each datagram can pass through a path of gateways and individual networks on the way to its final destination. The IP gateway make routing decisions based on the routing list.
- TCP resides in the transport layer of the layered model. It is suited above IP and below the upper layers.

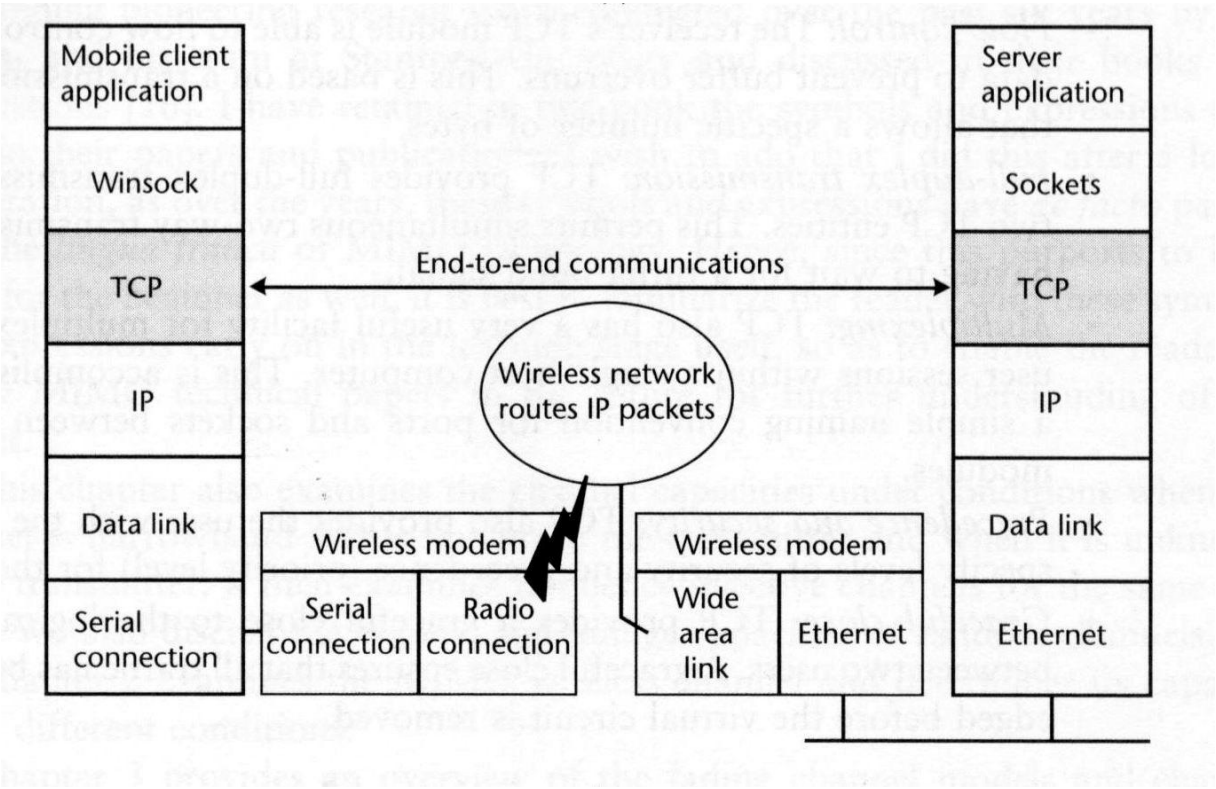
Figure 1.4(a) TCP structure



1.5 Wireless Internet Protocol

- In an ideal world, a computer connected over a wireless network would work just like a computer on a LAN. But wireless networks currently operate at lower speeds with higher latency and connections can be lost at any moment, especially when mobile. Therefore, a need exists to develop a modulation scheme well-suited to this requirement. The chosen scheme should not only support high bit rates, but should have a very fast synchronization scheme suited to packet transmission in fading channels. Toward this end, multiple antenna systems were developed with a view to increasing spectral efficiencies.

Figure 1.4 (b) Wireless network IP that is packet-based



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