Design of current communications systems and future trends

Dimitris Toumpakaris
Wireless Telecommunications Lab
Department of ECE
University of Patras

Erasmus Wi-CoNet 2009
July 22, 2009

Outline

- Introduction
  - Factors affecting communication
  - The reason for increasing design sophistication
- Historical review of some commercial wireline and wireless communications systems
- Current status and technology
- Future systems, requirements and trends
- Conclusion

Introduction

- Goal of communication:

  Convey information

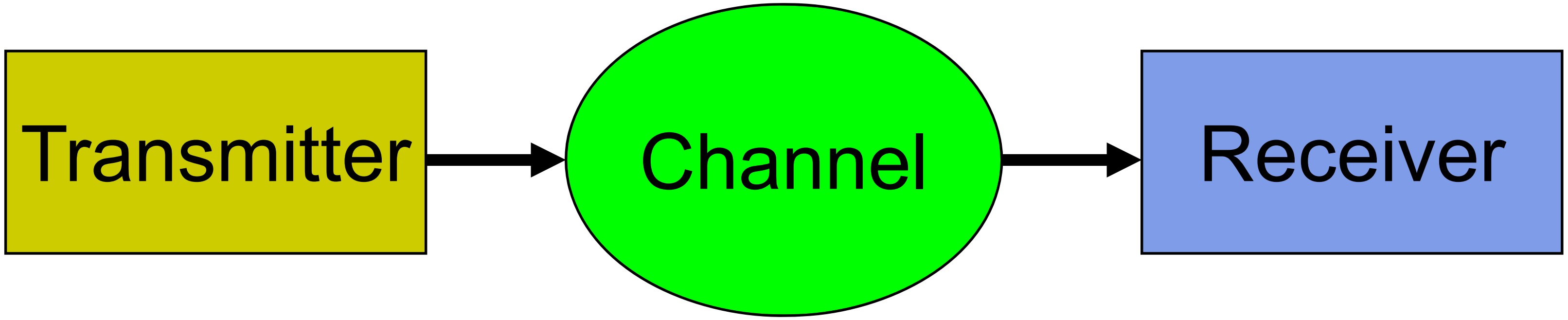
- Communication succeeds if receiver(s) can recover the information sent by the sender(s).
- In general, communication is *imperfect*
  - Imperfection quantified using *distortion measures* and/or *probability of error*.

Examples of communications systems

- Early humans: Cries, screams, drums
- Smoke/fire signals, pigeons
- Books, letters
- Tapes, records, CD, DVD, Hard disk etc.
- Telephone
- Internet
- Optical Fiber
- Nervous system
- etc…

Communications scenarios

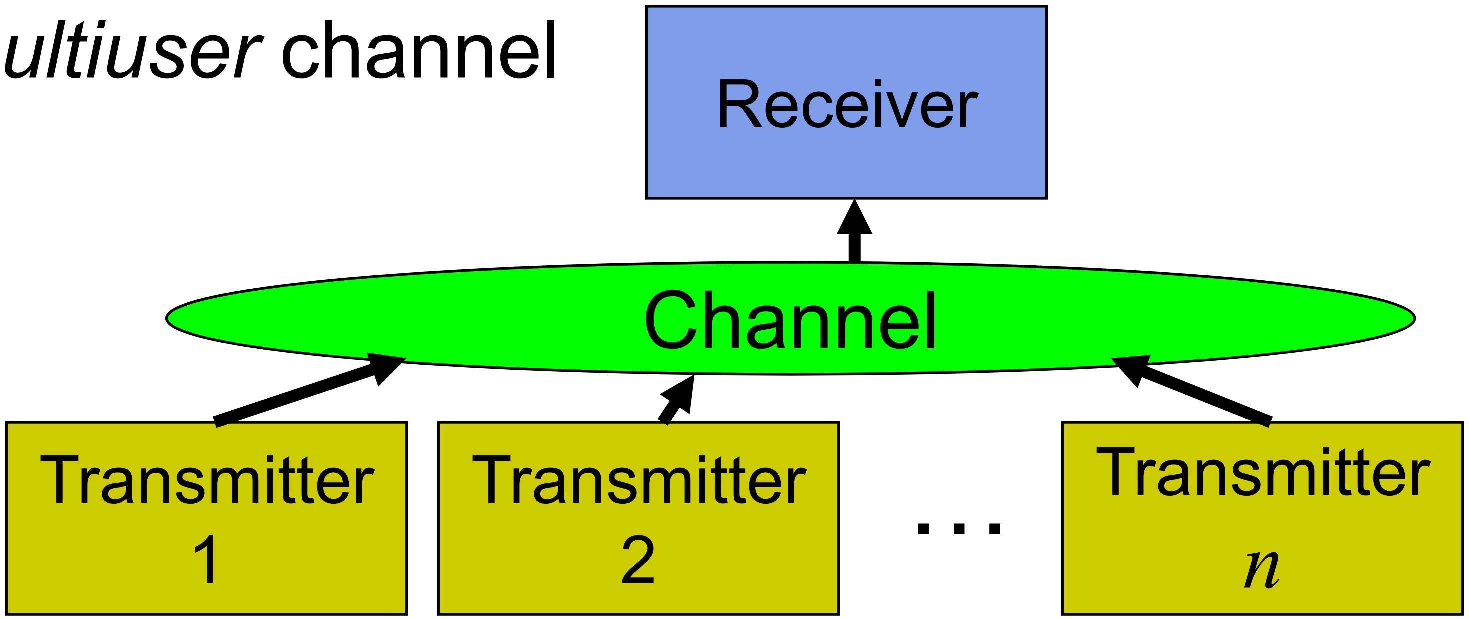
- Single-user: One transmitter (sender), one receiver.



- The most thoroughly analyzed and best understood scenario
- However, even this took years to understand theoretically and implement in practical systems.

Multiple Access Channel

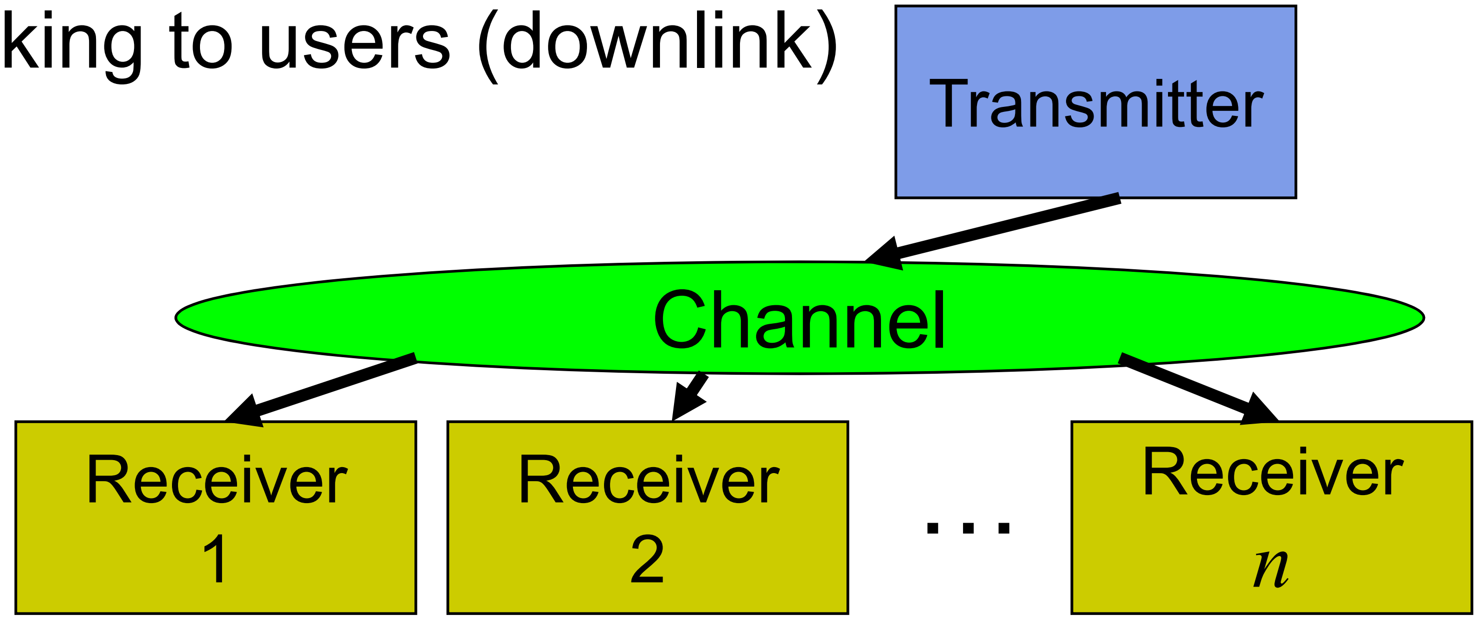
- Many transmitters, one receiver
- A *multiuser* channel



- Example: Many computers transmitting to a WiFi access point (uplink)
- More complicated; recently understanding has improved significantly

Broadcast Channel

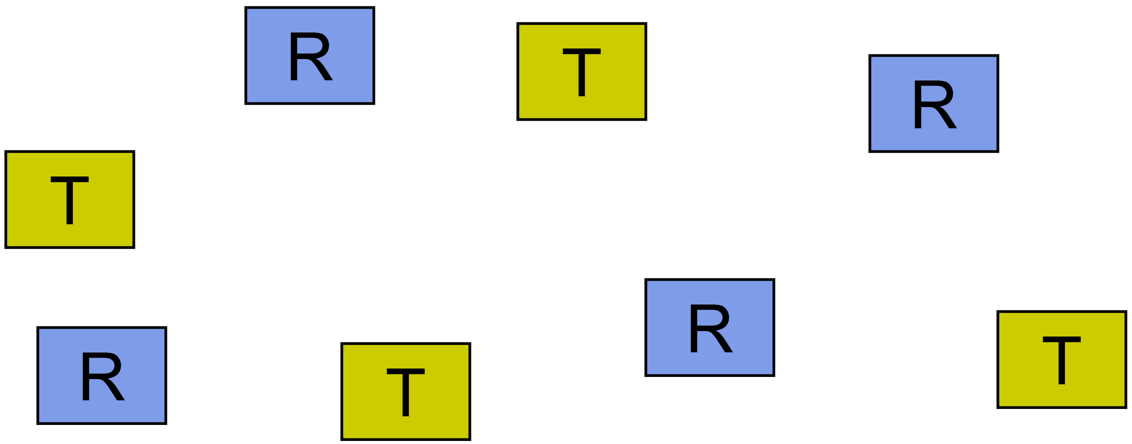
- Multiuser. One transmitter, many receivers.
- *Different* message to each receiver, in general
- Example: Cell phone network Base Station talking to users (downlink)



- Not as well understood as Multiple Access

The general multiuser scenario

- Many transmitters wishing to communicate with many receivers
- The most realistic scenario
- Example: Users of a cell phone network
- Very complicated to solve optimally! (solution still unknown)
- Do we need optimal solution? We will come back to this later.



Factors affecting communication

- The main factor affecting communication is the *channel*
  - The main problem is the combined effect of *attenuation* and *noise*.
    - Noise: an unknown signal.
  - Because of noise (and, usually, other factors as well), the signal “seen” by the receiver is different than the signal sent by the transmitter.
  - The noise and attenuation, coupled with the distortion (or probability of error) constraints, determine the *rate* of communication.
    - Rate: Transported information in the unit of time

Example: Noisy Typewriter

- Transmitter can send one of numbers 0, 1, 2 and 3.
- If message arrives at the receiver intact, we can send one of 4 messages/channel use ($\rightarrow$rate = 2 bits/channel use)
- Suppose, now, that the channel adds the value “1” to the transmitted signal with probability ½
- Can show that we can only send reliably one of 2 messages (1 bit)/channel use.
  - For example, by not allowing the transmitter to send “1” or “3”

Effect of channel on transmission

- In addition to noise and attenuation, the transmission may also be affected by
  - Distortion – major issue in wireline communication
  - Interference from other users (example: cell phones, DSL, WiFi)
  - Delay (example: inter-planetary communication)
  - Rain/Clouds/Buildings/Trees and other obstacles
  - Fading: Wireless channel varies with time and as we move – major impairment in wireless communications
  - etc…
  - The performance of a system depends on these factors even if the channel is perfectly known.

Example: Erasure Channel

- Suppose that a transmitter can send one of M different messages.
- If a message gets lost (erased) in the channel with probability α, the capacity of the channel equals to $M\alpha$ messages/channel use.
- Even though we know that the message has been lost (*i.e.*, we know the channel at the receiver), we cannot increase the capacity to M.

Effects of Transmitter/Receiver on Communication

- In addition to the channel, the design of the transmitter and the receiver may affect system performance
- Constraints affecting transmitter/receiver design
  - Cost
  - Power consumption/Heat generation
  - Technology (circuit speeds)
  - Operating Environment
  - Regulations
  - etc…

How “optimal” should a system be?

- An engineering decision needs to be made on how “optimal” a system design should be in terms of performance (achievable communication rates and/or number of users that can be supported)
- More optimal usually means more *complex* → more expensive, less robust, maybe more power “hungry”
- Thus, we may want to exchange performance for cost/energy efficiency/robustness
- The design of a communications system always involves such *tradeoffs*

Why worry about "optimal" designs?

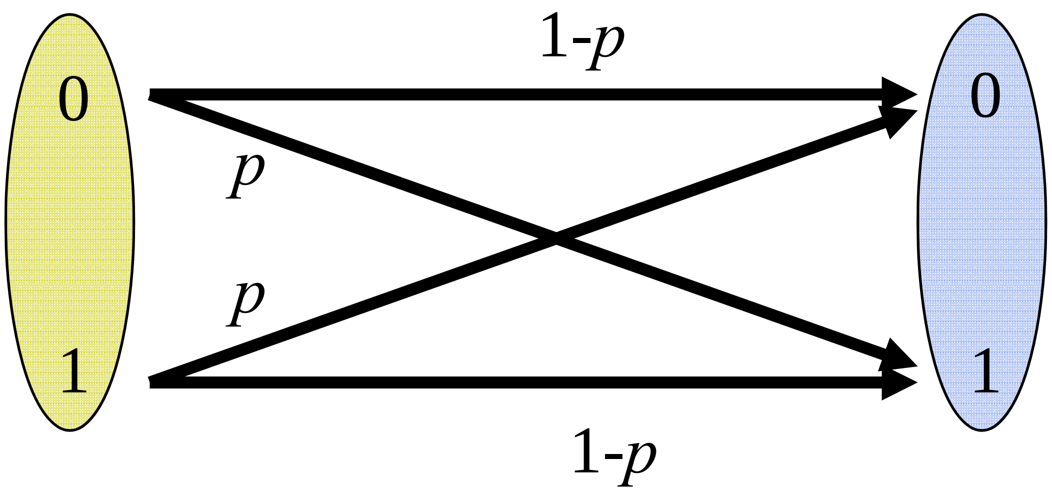
- Not solely an issue of scientific interest
- The main problem: The *resources* that can be used for communication are (*usually*) limited.
  - Limited power that we can use (battery, heat generation etc)
  - Limited channel bandwidth (*i.e.*, spectrum, frequencies that we can use)
  - Limited transmission interval (since other users may want to transmit, too)
  - Limited delay (message should reach recipient within prescribed time interval)
  - Limited space to put antennas
  - …and other limitations…

The need to use a more "optimal" design

- Because of resource limitations, in many cases we may be forced to design more optimally in order to make system more *efficient* and meet requirements
- This may come at a price (complexity, cost etc) → *tradeoff*. The more we know about how to design a system, the more favorable this tradeoff will be for us.
- Therefore, by better understanding a system we can find better designs *given* the constraints.
- The need for better designs is becoming increasingly relevant in current and new systems

Example: Binary Symmetric Channel

- A bit “flips” to the opposite value with probability p



- One possible solution: transmit bit n times. At the receiver decide based on the value that most received bits have (majority voting)
- Probability of error (for even n): $\sum_{k=0}^{n/2-1} \binom{n}{k} (1-p)^k p^{n-k}$

Binary Symmetric Channel (continued)

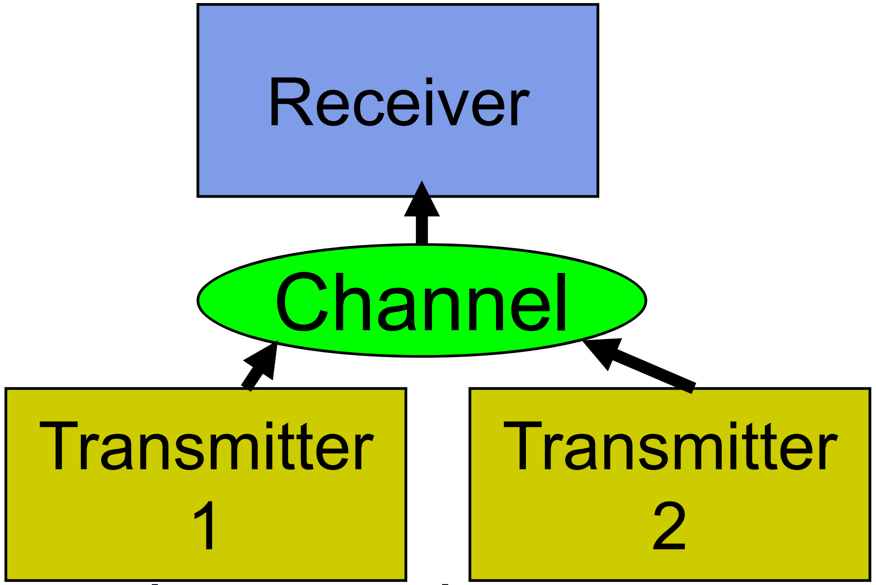
- As the number of retransmissions n increases, the probability of mis-decoding a bit approaches 0.
- However, the *rate*, *i.e.*, the number of bits that we can send in the unit of time also approaches 0!
- For exactly zero probability of error the rate is equal to 0.
- Can we do better? YES!

Binary Symmetric Channel: Capacity

- It has been shown [Shannon, 1948] that the maximum rate that can be sent through the Binary Symmetric Channel with probability of error → 0 is equal to $1\text{-}p\log_2 p\text{-}(1\text{-}p)\log_2(1\text{-}p)$
- Greater than 0! (except for $p=1/2$).
- However, this comes at a price
  - Complexity (need *coding*)
  - Delay (need long code)
- More on Information Theory classes/books.

Example:
2-user Multiple Access Channel

- 2 users that want to send (different) messages to 1 receiver
- What can we do?
- Simple solution:
  Orthogonalize users
- TDMA: Split time in *slots*.
  Only one user transmits in each slot.



- FDMA: Assign *different frequencies* to each user
- CDMA: Assign *orthogonal signatures* (codes) to users
- SDMA: Use more than one antennas to create different *spatial streams*
- GSM uses a combination of TDMA and FDMA.

2-user Multiple Access Channel: Capacity Region

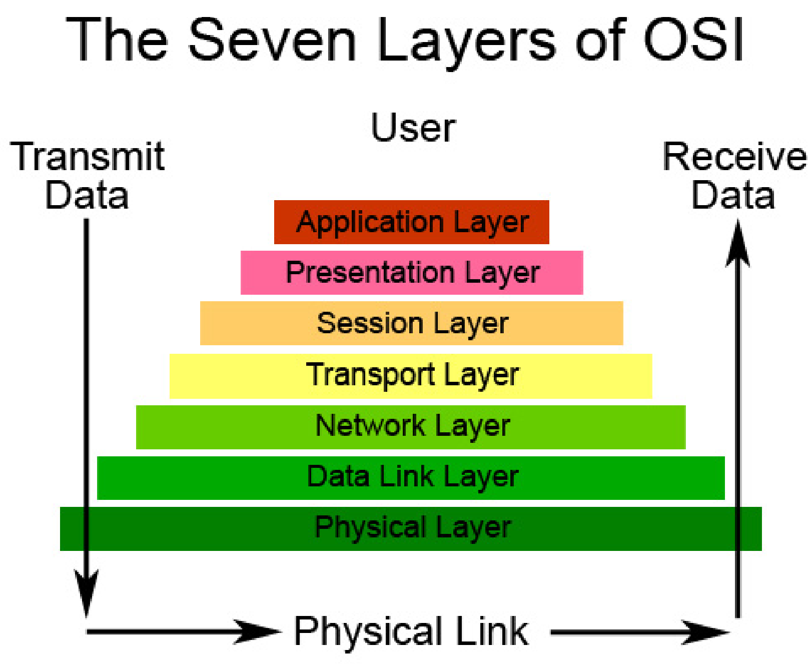
- Rate of user 1 depends on rate of user 2 (and vice-versa)
- Have to decide how to split rates between users
- Optimal tradeoff curve: Capacity Region
- It has been shown that TDMA and FDMA are *suboptimal*, in general
- The capacity region for single-antenna systems can be achieved using CDMA <u>and</u> Interference Cancellation at the receiver.

2-user Multiple Access Channel: No centralized control

- Alternative approach (used in networks where traffic is bursty)
- No central coordinator
- Users "compete" for access to the channel
- CSMA family of protocols (used in Ethernet, WiFi)
- Advantage: Simple, distributed, good for bursty traffic
- Drawback: Less efficient channel use for high loads → inferior performance in terms of rates/number of users
  - Does not achieve capacity

OSI Model

- To standardize design of networks, their architecture is divided into 7 layers
- Not all systems have all layers (e.g. Internet)
- However, most networks follow layered design philosophy
- Design of layers may not be completely independent (especially recently)



Modulation

- In order to transmit information, the signals need to be brought in a form appropriate for the physical transmission medium → *Modulation*
- Analog modulation: Transmitted signal is continuous function of continuous information signal.
- Digital modulation: Information signal is converted to a set of messages that are sent through the channel using a set of waveforms
  - The signals sent to the channel are still analog!

Why Digital Modulation?

- Older systems used Analog Modulation
  - Reason: Lack of processing power/fast circuits/memory, knowledge gaps in communication and coding theory
- Digital Modulation is better
  - More *efficient* channel usage → improved rates/robustness
  - Combined with coding can get very close to channel capacity
  - Easier to adapt to changing channel conditions
  - Easier encryption
  - Once we have the processing power and we know what algorithms to use it is easier to make system *reliable*
- All high-capacity systems currently use digital modulation

Circuit and Packet switching

- Assume that many users want to share the same medium
- Circuit switching
  - Establish fixed channel(s) for each session involving a pair (or group) of communicating users
  - Channel(s) allocated to pair (group) during entire session
  - Example: Plain Old Telephone Service (POTS)
- Packet switching
  - Packets are sent over shared links
  - Packets queued at network nodes at link edges
  - Example: Postal Service, Internet

Circuit and Packet switching (continued)

- Circuit switching
  - Guarantees fixed Quality of Service
  - Good when traffic is regular (e.g. voice)
  - However, inefficient when channel is not used continuously (when traffic is bursty)
- Packet switching
  - Makes good use of links when traffic is bursty
  - However, need to employ additional mechanisms in order to guarantee Quality of Service
- Latest trend: Packet Switching at Network Layer (all-IP networks)

Historical Review

- Introduction
- Historical review of some commercial wireline and wireless communications systems
  - Telegraph and Telephony
  - Cellular Networks
  - Wireless Local Area Networks (WLANs)
- Current status and technology
- Future systems, requirements and trends
- Conclusion

Historical Review (continued)

- By no means an exhaustive list
- We will just refer to some of the systems to show the evolution of the design as the requirements become stricter and put a strain on available resources
- Will focus on wireline and wireless systems
- Many other systems are not covered (satellite, broadcast audio/video, storage, optical, radar, underwater etc).
- However, several of the technologies and design approaches are used in such systems, too.

Wireline systems
Telegraph

- (Electrical) Telegraph: Used copper wires
- A digital system!
- First commercial systems: 1838. First transatlantic cable: 1866
- Rate: 8 words/minute!
- Problem: Channel distortion (due to imbalance) that limited the rates.
- Led to first studies of transmission lines
- Eventually, 120 words/minute

Telephone network

- Improvements to telegraphy: Telex and facsimile (over the telephone network)
- Public Switched Telephone Network (PSTN) or Plain Old Telephone Service (POTS)
  - Originally, analog and wireline
  - March 10, 1876: “Mr. Watson, come here, I want to see you.”
- Problem: Attenuation, Crosstalk (interference from wires of other users)
  - Crosstalk alleviated using twisted pairs to reach end user

Telephone network (continued)

- Until recently telephone network used *circuit switching*
- Digital telephony was introduced in the late 1960s. However, subscriber loop remained analog until very recently.
- Still, maximum achievable rates did not exceed 56 kbits/s
- Reason: Limited bandwidth: 300-3400 kHz

Digital Subscriber Loop (DSL)

- First efforts to increase rates of telephone network
  - ISDN: Integrated Services *Digital* Network
    - Digital transmission
    - Larger bandwidth (~100 kHz)
    - Larger rates (up to 144 kbits/s, up to 15,000 feet)
    - Supports packet-switched data transmission (but is a circuit-switched system in the Physical Layer)
  - Other DSL system: HDSL (1992)
    - replacement for T1/E1, up to 2 Mbits/s

Asymmetric DSL (ADSL)

- First ITU standard in 1999 (G.992.1)
- Original ADSL used frequencies up to 1.1 MHz
- Rates up to 8 Mbits/s downstream, 1 Mbits/s upstream over distances up to 15,000 feet and over copper cables (twisted pairs).
- Latest standard (ADSL2+) uses 2.2 MHz of bandwidth and supports up to 24 Mbits/s downstream
- Sophisticated digital modulation is used (Discrete Multi Tone – a variant of OFDM)

Very High Speed DSL (VDSL)

- Latest standard (VDSL2) uses bandwidth of up to 30 MHz
- Can achieve high data rates (of the order of 100 Mbits/s both downstream and upstream) but for short loops (~300 m)
- Uses DMT, similar to ADSL
- Is offered in several countries, and may eventually replace ADSL if fiber gets closer to end users (Fiber To The Curb – FTTC).

Wireless Mobile Phone Systems

- 1st Generation (1G) systems appeared in the 1980s
  - NMT (Scandinavia, 1981)
  - AMPS (USA, 1983). FDMA, 800 MHz band, ~800 channels
  - TACS (UK)
- Used Analog Modulation between Base Stations and Mobile Stations (users)
- Inefficient use of spectrum → limited number of users

2G Wireless Systems

- First commercial 2G standard: GSM (1991)
- Fully digital
- Designed for voice, but also supports data services
- Speech coding advances a major contributor in improving capacity
- Two main approaches:
  - Time Division Multiple Access (TDMA): GSM,IS-136
  - Code Division Multiple Access (CDMA): IS-95
- Uses two 25 MHz bands in 900 MHz, 1.8 GHz and 1.9 GHz areas
- Compared to 1G, improved capacity in terms of number of users and communication rates

2.5G and 2.75G

- Enhancements to 2G systems to support better data rates
- General Packet Radio Service (GPRS): Data rates up to 114 kbits/s
  - Packet-switched
  - No fundamental changes in modulation scheme.
- Enhanced Data rates for GSM Evolution (EDGE): Up to 236.8 kbits/s
  - Extends modulation scheme of 2G (in Physical Layer).

3G: UMTS (3GSM)

- First launched in Japan (2001)
- Design for high data rates
- In most systems, W-CDMA is used (in contrast to TDMA used for GSM)
  - New hardware is required
- Theoretically, up to 14 Mbits/s (with 3.5G enhancements such as HSDPA)
  - Competes with fixed broadband access
- Typically, frequencies in the 2 GHz area are used

3G: CDMA2000

- Evolved from the 1G CDMA standard
- Incompatible with UMTS
- Up to 3.1 Mbits/s
- Currently deployed in many countries

Wireless LANs

- Wireless Networks that link two or more computers
- Relatively small (local) range (~100 m)
- Nowadays their main purpose is to access the internet (Wireless Local Loop)
- Although transmission takes place through a challenging medium (wireless channel in free ISM bands) very high rates can be achieved
  - Small distance between computers
  - Relatively small number of users
  - Sophisticated algorithms
  - Improvements in circuit speeds

First WLANs

- ALOHAnet in Hawaii (1970). Fixed star topology, packet-switched, no central coordination.
  - Not really “local” by today’s definition
  - Ideas used for ALOHAnet have evolved into protocols used in current networks (such as CSMA/CD and CSMA/CA).
- Several wireless modems appeared in the 1980s (data rates up to 1 Mbits/s)
- Central ideas
  - Packet switching
  - Medium sharing without centralized control (in contrast to fixed telephony and cellular systems)

The 802.11 family of standards

- 1991: Launch of IEEE 802.11 with goal to develop standard for WLANs
- First standard: 802.11, released in 1997. Up to 2 Mbits/s, at 2.4 GHz carrier frequency. CDMA-like modulation. CSMA/CA medium access protocol.
- Range: ~20m indoors, ~100m outdoors
- 802.11b (1999): Extension to 11 Mbits/s. Small range extension. Widely popular.

802.11a and 802.11g

- 802.11a (1999). First use of OFDM in WLAN
- Transmission in the 5 GHz area, up to 54 Mbits/s. Range similar to 802.11b
- 802.11a was not very successful
  - Chips appeared later than 802.11b
  - Lack of OFDM design expertise (at the time)
- 802.11g (2003). Uses OFDM at 2.4 GHz. Same rates/range as 802.11a. Can fall back to 802.11b for backwards compatibility.
  - Widespread success and adoption proved suitability and maturity of OFDM for wireless communication systems

802.11n

- The newest standard of the 802.11 family.
- Not ratified yet (expected 11/2009), but many products (pre-n or draft-n) already in the market.
- Data rates up to 300 Mbits/s
- Main enhancement: Multiple antennas at transmitter and receiver (MIMO)
  - Achievable rate depends on transmission environment
- Also, more sophisticated channel bandwidth management
  - Cognitive radio elements

Clarification: WiFi = 802.11?

- A WiFi system is certified by the WiFi Alliance
  - WiFi Alliance: a non-profit industry association
  - WiFi logo permitted only if system passes performance, compliance and interoperability tests
- Mandatory: MAC/PHY interoperability at least with one of 802.11a, b, g, or n draft 2.0 + WPA2

Current status and technology

- Introduction
- Historical review of some common wireline and wireless communications systems
- Current status and technology
  - Evolution in design philosophy and approaches used in current systems
- Future systems, requirements and trends
- Conclusion

Evolution in the design philosophy and goals

- Older systems: Emphasis on voice traffic
  - Requirements: low latency, reliable link, no interruptions, relatively low bandwidth
  - Circuit-switched
  - Assign channels to users and protect from interference and channel fluctuations
    - Interference/channel fluctuations viewed as *nuisance*
- Newer systems: Emphasis on data traffic
  - Need high rates (spectral efficiency) under adverse conditions (interference, limited power, mobility)
  - Traffic is usually very bursty, so each user needs high rates, but typically for a relatively short time interval
  - However, also need to provide Quality-of-Service and *fairness* guarantees, depending on type of data

What resources can we use to design new systems?

- In order to provide high data rates with Quality-of-Service guarantees we need large system capacity (in terms of total rate and users)
- Need more bandwidth!
- However, we have almost run out…
- Need to exploit other resources, devise new algorithms and increase sophistication of designs.

Wireline (DSL)
What resources can we use?

- Signal in copper twisted pair attenuates significantly as distance increases
- Right now it seems that we cannot use spectrum above 30 MHz even for short distances
- It may take some time (and $$$) before Fiber-to-the-Home becomes a reality.
- What can we do in the near future?

Increasing DSL rates

- Replace wires with better ones (CAT6 etc) → *expensive*
- Use more than 1 twisted pairs, if available (MIMO) → *some efforts here*
- Employ active crosstalk reduction techniques → *Dynamic Spectrum Management (DSM)*
  - Especially attractive if we can control centrally many DSL lines → *Vectored DSL*
- So, stop designing for single-user and move to multi-user scenario
  - Several theoretical challenges here (including the notorious "interference channel")

Wireless systems
What resources can we use?

- Bandwidth is limited and/or expensive!
- 2 types of bandwidth
  - Free (ISM bands). Used by cordless phones, WLANs.
    - Problem: Interference and power constraints. Have to be able to co-exist with others, and, in the same time, “compete” for the channel
    - Also, free spectrum is limited
  - Licensed (auctioned by governments). Operators pay $$$, so they want *efficiency*
- What can we do?

Using space to increase rates

- Use of *multiple* antennas at the transmitter and the receiver can increase capacity and improve reliability under certain conditions → *MIMO systems*
- Resource used by MIMO (and also MISO and SIMO) systems is *space*
- MIMO communication has been a major research and implementation topic for the last 10 years

Incorporating MIMO to wireless systems

- Issues with MIMO
  - Capacity increase depends on environment
  - Need more processing power
  - Need more circuitry
  - Need space to put antennas
- These issues are being addressed, and MIMO has already appeared in wireless systems: IEEE802.11n, IEEE802.16e (Mobile WiMAX), 3GPP-LTE (3.75G)

Using opportunistic transmission

- Traditional systems: Assign resources to communicating user pair (or group) and try to provide fixed Quality of Service (fixed "bit pipe")
  - Need to shield from channel fluctuations, interference
  - Suitable for voice where latency requirement is stringent, traffic is regular and required rate is relatively low
- *Opportunistic* approach: Use channel when good, avoid when bad
  - Cannot always do that (for example if very constrained by delay)
  - Need to put mechanisms into place that guarantee Quality of Service
  - Need efficient channel monitoring/estimation schemes, also at the transmitter! (difficult, especially when channel changes fast)

Using multiuser diversity

- Traditional systems: Pairs (or groups) of communicating users are assigned system resources (time slots/frequency bands) for the entire session
- Opportunistic approach: At any point in time, give the channel to the users that can make good use of it → *multiuser diversity*
  - Again, multiuser diversity gain and usefulness depends on delay requirements, position, rates and other requirements
  - Also need mechanisms for *fairness*
  - Complicates system design

Other system enhancements

- In addition to exploiting all available resources, latest systems use algorithms that use available resources more efficiently
  - Heavy coding (Turbo, LDPC)
  - Channel sensing (cognitive radio): Give more bandwidth to a session if bandwidth not used by others (e.g. IEEE802.11n)
  - Hybrid ARQ

Example: IEEE802.11n

- Can create 40 MHz channel by combining two 20 MHz channels when available (bonding)
- Supports MIMO transmission: 2 spatial streams (so need at least 2x2 antennas – 802.11n systems may be up to 4x4)

Example:
CDMA 2000 EV-DO (I-856)

- EV-DO: Enhanced Version-Data Optimized
- Uplink: Similar to 2G CDMA (I-95)
- Downlink
  - TDMA instead of CDMA
  - Base Station transmits with *same* power to all users → what varies is the *rate*
  - Opportunistic scheme: We do not "waste" power when channel is not good.
  - Multiuser diversity exploited through *Proportional Fair Scheduling* algorithm

Example: IEEE802.16e (mobile WiMAX)

- Variable channel bandwidth depending on needs (1.25 – 20 MHz)
- Supports MIMO transmission
- Departure from WiFi logic. Connection oriented: Mobile Stations need permission from Base Station in order to transmit.
  - Reason: Need increased efficiency
- Uses OFDMA (Orthogonal Frequency Division Multiple Access)
  - OFDMA can accommodate opportunistic transmission schemes and multiuser scheduling

Some current trends

- OFDMA used for physical layer of new systems
  - Actually for uplink of 3GPP-LTE, slightly different modulation scheme
- Convergence of design philosophy between cell phone systems and WLANs
  - Similar Physical Layer
  - In higher layers, everything treated as packets requiring different QoS
- Base Station runs sophisticated algorithms and controls Mobile Stations
  - Complex, but necessary evil in order to use resources efficiently
- System re-allocates channel resources according to needs in real time (cognitive radio).
- MIMO everywhere

Future systems, requirements and trends

- Introduction
- Historical review of some common wireline and wireless communications systems
- Current status and technology
- Future systems, requirements and trends
  - Design for multiuser scenario
  - Towards relay and ad-hoc networks
- Conclusion

Requirements for new systems

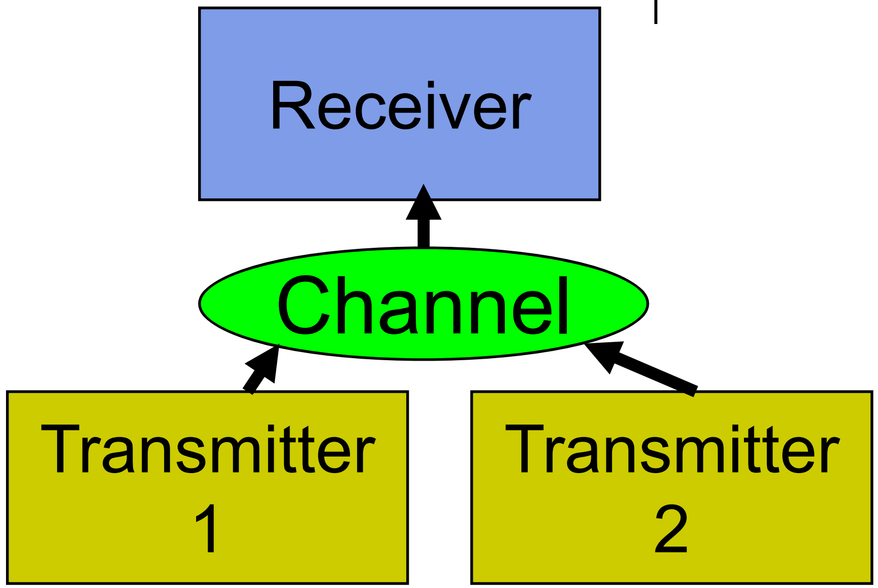
- Scalability
  - Should be able to increase coverage, number of users, bandwidth without redesigning the system
- Affordability
  - Should reduce deployment cost as much as possible, guarantee widespread adoption
  - Make design that will last for (relatively) long time
- Attractiveness to users
  - Should provide Quality-of-Service guarantees, seamless service, flexible interface

So, what is next?

- Up to now, design was mostly based on single-user scenario
  - Philosophy: Give sufficient resources to a transmitter-receiver pair, protect from interference
    - TDMA: each user pair has own slot
    - CDMA: interferers are assigned orthogonal codes
  - Treat residual interference as unknown signal (noise)
  - Frequency reuse: Different parts of spectrum manually allocated to neighboring cells (network planning)
- We can do better if we design for multiuser
- Of course, complexity goes up!

Multiple Access Channel

- Traditional system: Transmitter 2 interferes to 1's transmission
  - Orthogonalize
- But, Information Theory tells us that optimal is overlap of transmissions ("CDMA") with successive interference cancellation
- Need sophisticated design and more processing in order to make this work properly
- Similarly for the downlink (Broadcast Channel)



Multiuser MIMO

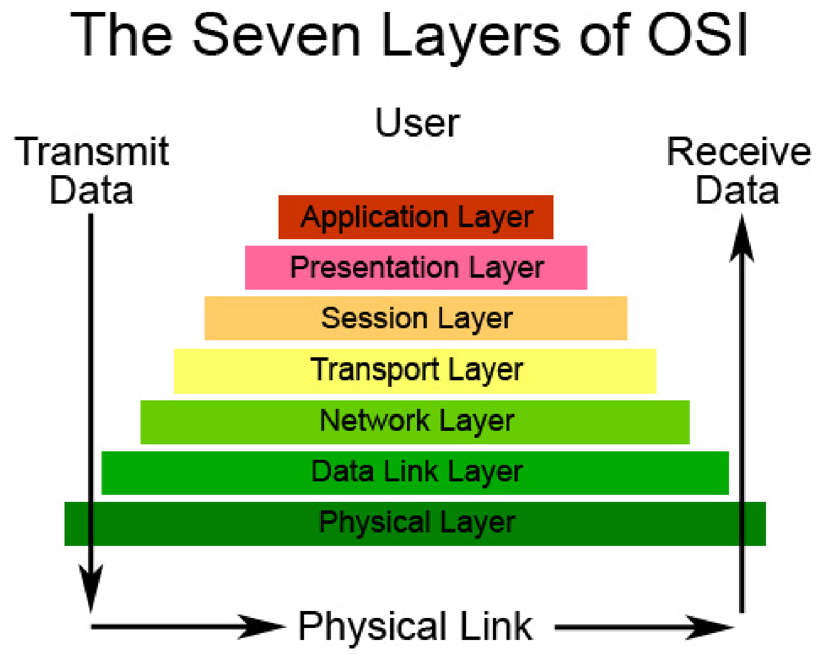
- Can do even better by using multiple antennas
- More than one users can be transmitting simultaneously and orthogonally in the same frequency band during the same time (Space Division Multiple Access - SDMA)
- Again, need work to incorporate in practical systems
  - Need good channel estimation, feedback, adaptation
  - Requires significant processing power
  - Have to develop reliable, fair, real-time Resource Allocation algorithms

Virtual MIMO and multi-cell coordination

- Up to now, Frequency Reuse among cells
  - Neighboring cells use different frequencies
  - Exception: CDMA
- Universal Frequency Reuse: All cells have access to the entire spectrum
  - Can reallocate spectrum in real time
  - Can “see” Mobile station from more than one Base Stations
    - Handoff (Soft/softer handoff already in IS-95)
- If Base Stations can exchange signals, Virtual MIMO (multiple antennas, but not in the same location)

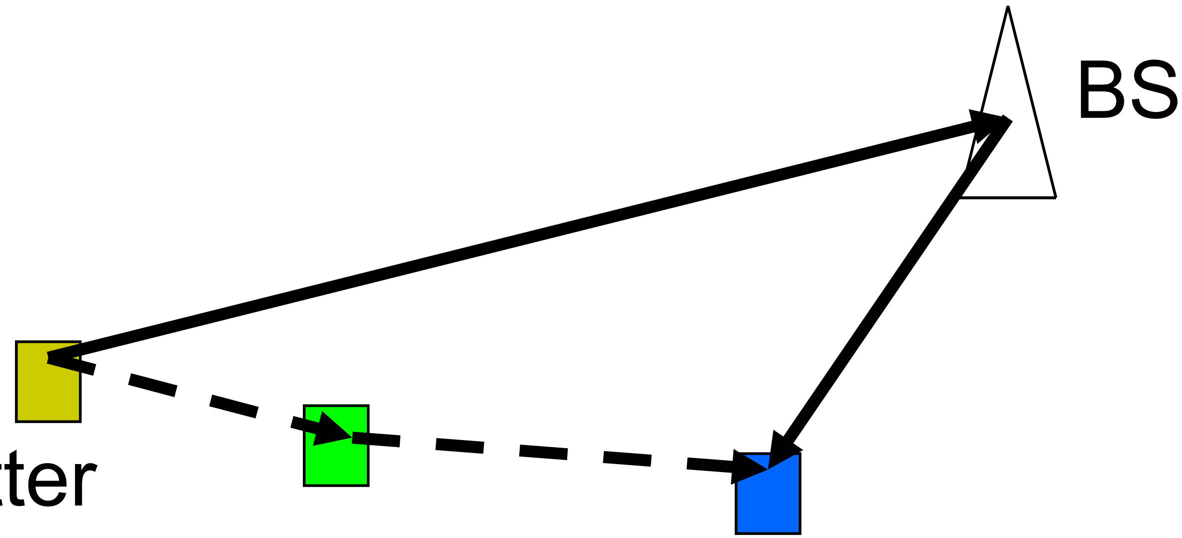
Cross-layer design

- Layered OSI model simplifies design, but is not optimal
- Physical Layer no longer a constant, circuit-switched "bit pipe"
- Channel awareness in higher layers can improve performance
  - Channel-aware admission and rate allocation algorithms



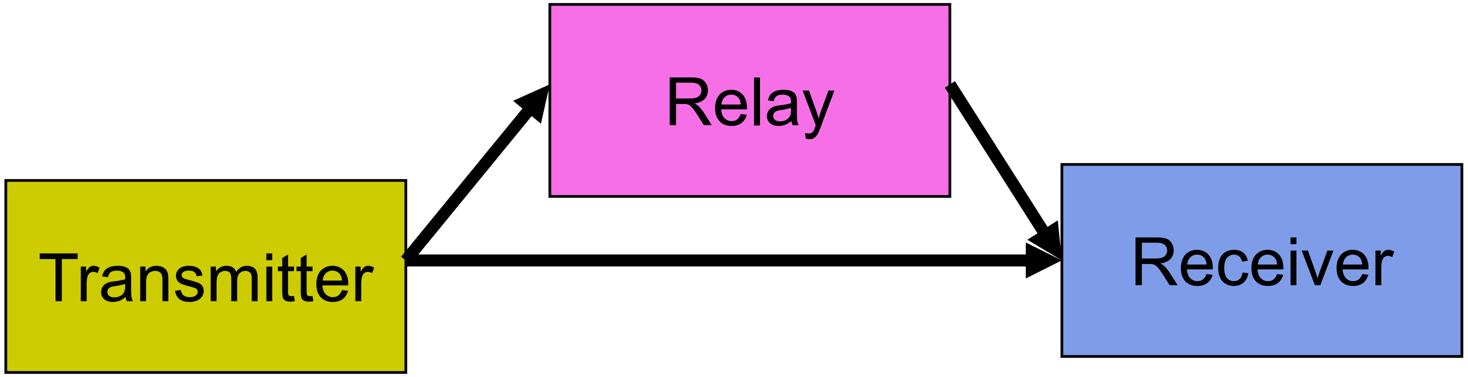
Using Relays

- Cellular networks use centralized approach
  - A Mobile Station always connects directly to a Base Station
  - Two Mobile Stations always communicate through a Base Station, even if they are located in the same cell



Can we do better with relaying?

Relay Channel



- Smart relays decode and re-encode data
  - Not simple retransmission
- Exact capacity of relay channel not yet known even for one relay (except for special cases)
- Using relays requires more complex Mobile Stations.
- Also need to evaluate effect on power consumption

Network Coding

- In a packet-switched network, each packet contains data belonging to only one communication pair (or group)
- Network coding: Combine packets of different sessions at network nodes
  - Each packet has data from more than one sessions, in general
  - Need encoding and decoding capabilities at nodes
- Relatively new field.
- Promises of capacity increase

Some trends for the near future

- Traditional cell phone and computer networks converge
  - Physical Layer of WiMAX very similar to 3GPP-LTE (3.75G). Both OFDMA
  - Packet switching, VoIP, all-IP based networks
- Smart Mobile Stations, but significant portion of control emanates centrally from Base Stations in order to improve efficiency
  - Centralized Scheduling
  - Resource Allocation

Some trends for the near future (continued)

- OFDMA used in the foreseeable future in the Physical Layer
- Dynamic and real-time resource allocation
  - Cooperation between neighboring cells
  - Use of cross-layer algorithms
- Use of many antennas to increase available degrees of freedom (exploit spatial diversity)

Further ahead in the future

- Development of practical algorithms that approach the capacity of the MIMO Multiple Access and Broadcast Channel
- Increasing use of relays, departure from fully centralized model
  - Need good algorithms for distributed control
- Use of network coding
- Eventually, ad-hoc networks that self-organize and operate without centralized control

Example:
3GPP-LTE (3.75G)

- Improvement of UMTS
- Functional freeze in March 2008. Ratification expected.
- Peak rates of 326.4 Mbits/s for 4x4 antennas
- Supports multiuser MIMO
- Can use different size of frequency bands
- All-IP

Conclusion

- Introduction
- Historical review of some common wireline and wireless communications systems
- Current status and technology
- Future systems, requirements and trends
- Conclusion

A lot of progress has been made during the last 20 years

- 20 years ago:
  - POTS, very limited data services, expensive long distance calls
- Today:
  - ~€20/month for 8 Mbits/s DSL connection
  - WiFi Access Points everywhere, integrated chips in laptops
  - Cheap cell phone service with MMS and, lately, broadband access capability

The driving factors

- Advances in circuits and Moore's law
- Advances in speech and image coding
- Success of Internet and GSM led to demand for high rates, services
- Advances in Communication and Information Theory

Some “traditional” paradigms are changing considerably

- Before:
  - Local loop wireline, long-distance connections mainly wireless (microwave/satellite)
- Nowadays:
  - Local loop increasingly wireless, fiber used for long-distance connections
- Before:
  - Circuit switching and centralized control for voice, packet switching and CSMA for data. Separate voice/data networks
- Nowadays:
  - Common network and packet switching for voice and data, but a trend for centralized control (for now) in the physical layer

The future is exciting

- Several theoretical and technical challenges to be addressed
  - Interference Channel
  - Relay Channel
  - General Network Information Theory
  - Practical coding schemes and estimation algorithms that make it possible to approach theoretical limits
- Need contributions from other disciplines
  - Materials science and Physics → *circuits*
  - Chemical engineering → *batteries*
  - Finance, marketing