RF and MicrowavesS ystems

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RF and Microwave systems

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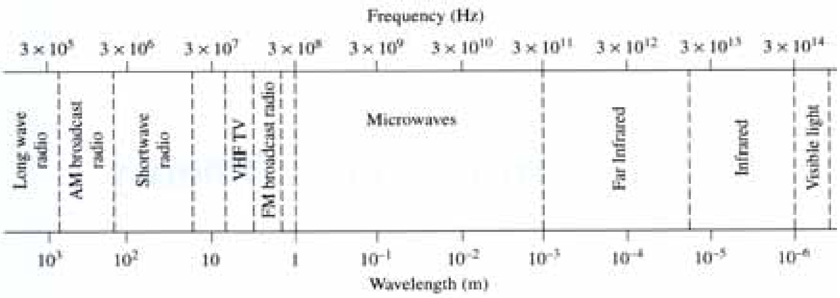
What does RF and Microwaves mean?

- Microwaves: Frequency between 300 MHz and 3 GHz. Since EM waves propagate at the speed of light, this equates to a wavelength between 1m and 1mm.
- RF (Radio Frequency): Refers more generally on any frequency within the electromagnetic spectrum normally associated with radio wave propagation.



Wireless systems

- **A wireless system allows communication of information between two points without a wired connection.** Theoretically one could use ultrasonic, infrared, optical or radio frequency energy but RF is usually preferred.
- ☞ **Do not confuse between wireless and mobile communications.**
  - ✓ Mobile means that communication is allowed everytime and everywhere. Handover (change of cell/antenna) and roaming (change of operator) must be supported dynamically.
  - ✓ Wireless: wireless is simply an alternative to wired communications. The fixed wireless user does not need mobility.

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Circuit versus Packet Switching

- **Circuit Switching**
  - ✓ Provides a physical connection between communicating parties for the duration of the call.
  - ✓ Very reliable, but inefficient since most communication (such as internet data) occurs in bursts.
- **Packet Switching**
  - ✓ Data is divided into fixed length packets that are independently routed through the network between sender and receiver.
  - ✓ The network provides multiple paths between the two parties and data can take any route.
  - ✓ Efficient and robust, but does not guarantee a minimum quality of service.

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Why using high frequencies?

- **Antenna gain is proportional to the electrical size of the antenna. At higher frequencies, more antenna gain is possible for a given antenna size. Easier implementation of miniaturized devices.**
- **More bandwidth (and thus more capacity) can be realized at higher frequencies. A 1% bandwidth at 600 MHz is 6 MHz (a single TV channel), and at 60 GHz it is 600 MHz (100 TV channels).**
- **Microwaves signal travel by line of sight and are not bent by the ionosphere as are lower frequency signals. Satellites and high capacities communication links are thus possible, with frequency reuse at minimally distant location.**
- **Radar cross section of a target varies according to the frequency. Most radars operate between 2GHz and 18 GHz.**
- **Various molecular, atomic, and nuclear resonances occur at microwaves frequencies, creating a variety of unique applications in the areas of basic sciences, remote sensing, medical diagnostics and treatments, and heating methods.**

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Choice of operating frequency

- Choice is never completely free. Governed to a large extent by regulatory allocation of the frequency spectrum.
- **1st choice: go high**
  - Noise power increases sharply below 100MHz and above 10GHz.
  - Data rates determined by bandwidth: high data rates will require high RF bandwidth, which is easier to obtain at high frequencies.
- **2nd choice: go low**
  - Component cost increases as operating frequency increases, esp. above 1GHz.
  - Lower frequencies give better propagation characteristics for radio-communication systems. They propagate better through or around obstacles (foliage, building, obstacles).

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Digital communication system

- **Today, communications are essentially digital, which means that**
  - ✓ Communication standards use digital modulation/demodulation (FSK, PSK, QAM, CDMA, OFDM,…)
    - More efficient use of the radio spectrum
    - Less transmitted power
    - noise immunity
    - Cost effective
  - ✓ Most of the processing is performed on digital platforms (FPGA, DSP, …)

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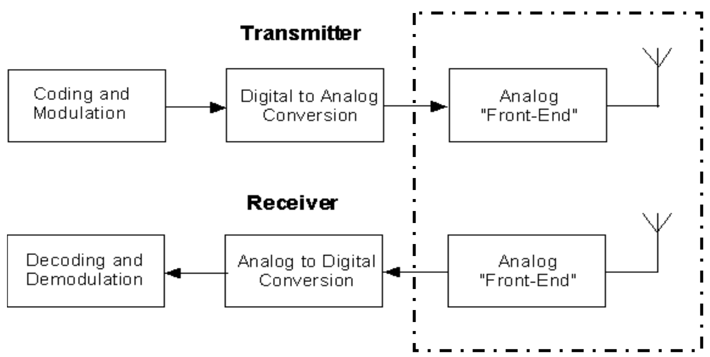
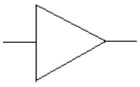
Transmitter / Receiver Design



- **In this course, we will focus on the analog part of both transmitters and receivers**
- **Because of high frequency, standard circuit theory is not adapted**

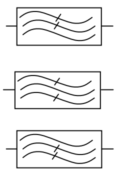
Why do we still need analog devices?

- **Amplifiers**



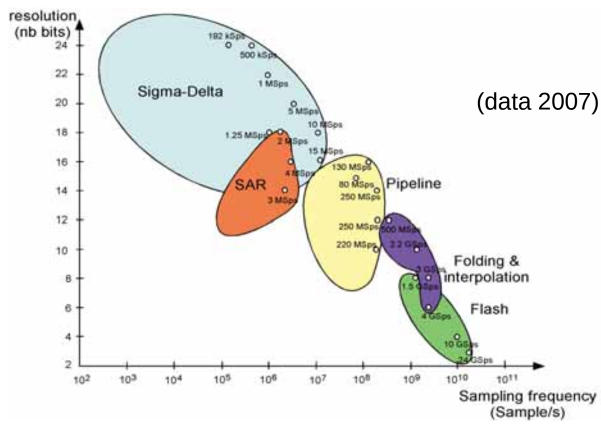
  - At the transmitter: a power amplifier is requested to amplify the signal before radiating it through the antenna.
  - At the receiver: a low noise amplifier is used at the input stage of the receiver.
  - IF amplifiers are used in IF stages of both transmitter and receiver.

- **Filters**



  - Selection of the operating frequency band and rejection of interfering signals.
  - Anti-aliasing filters to avoid higher frequencies or harmonics of the signal to be aliased before digitization.

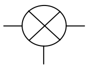
Analog to Digital Converters' limitations



- **Sampling frequency is limited for high resolution ADCs (>12 bits)**
- **At microwave frequencies, signal must be downconverted prior to digitization (or upconverted at the transmitter)**

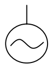
Mixers and oscillators

- **Mixers**



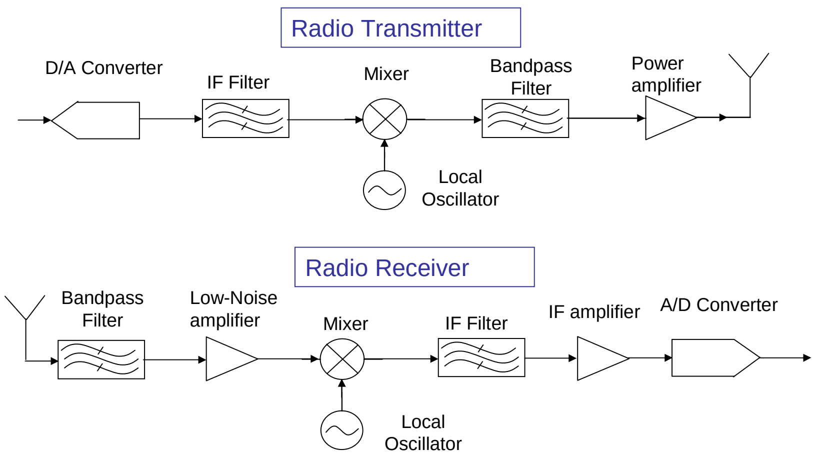
  - Three port component used for frequency conversion. Upconversion at the transmitter and downconversion at the receiver.
  - Perform the conversion by the mean of diodes and transistor, which creates harmonic frequencies and intermodulation products.

- **Oscillators**



  - Set the frequency for the conversion.
  - Quartz oscillators provide accurate output frequency but are not easily tunable.
  - Phase locked loop provide accurate and tunable frequency and thus can be used as frequency synthesizers
  - Create phase noise in the transmitter/receiver chain.

Basic radio system



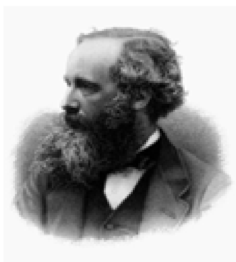
- **Proper design of the whole chain is one of the objective of the course.**

Historical Perspectives

- Fundamental concepts of electromagnetism were developed over 100 years ago.
- Microwave technology was intensively developed during World war 2 for radar applications.
- Still significant developments today in microwaves integrated circuits (MMIC) and in high frequency solid state devices + current trend towards wireless systems keep the field active and vibrant.
- New applications to address current problems often use old ideas, so it is important to have some knowledge of the history of the field.

James Clerk Maxwell (1831-1879)

- **In 1873, Maxwell hypothesized, solely from mathematical considerations, EM wave propagation and the idea that light is a form of EM energy.**
- **He extended and unified the earlier work of Ampere and Faraday and produced a coherent unified theory of electromagnetism referred to today as Maxwell's Equations.**
- **From these equations, he predicted that EM fields propagate as waves and that light propagates as an EM wave.**



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James Clerk Maxwell (1831-1879)

- Maxwell's formulation was cast in its modern form by Olivier Heaviside, during the period from 1885 to 1887.
- Richard P. Feynman referred to this discovery as the most important of the 19th century.
- Maxwell did however incorrectly hypothesize the existence of "luminiferous aether", a medium through which light supposedly propagates.
- This idea was later rejected by Einstein when developing the theory of special relativity.

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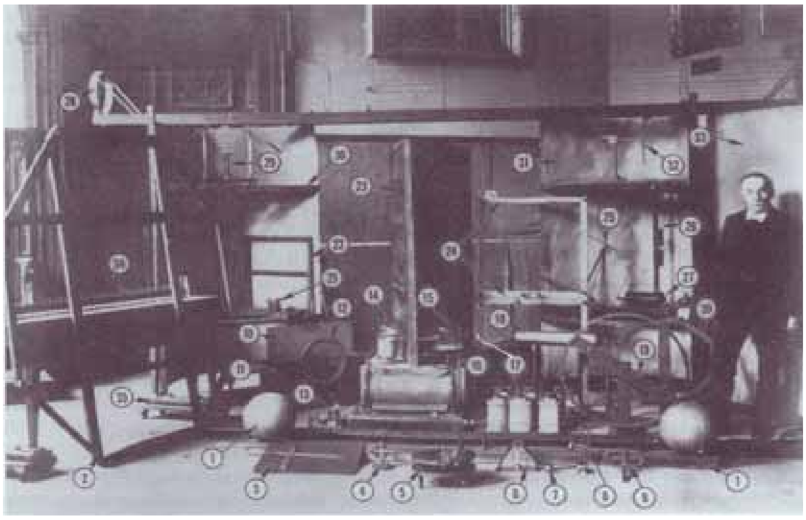
Heinrich Hertz (1857-1894)

- In 1888, Hertz experimentally confirmed the presence of EM waves by building a device to generate and receive UHF waves.
- Note that EM waves were first theorized and then experimentally verified!
- Hertz developed a dipole antenna in 1886 that he would use in these experiments.
- He was able to demonstrate the reflection, refraction, polarization, interference, and velocity of EM waves
- Hertz also found that radio waves could be transmitted through different types of materials, and were reflected by others.
- Hertz famously stated: ``I do not think that the wireless waves I have discovered will have any practical application."

Heinrich Hertz in his lab



Guglielmo Marconi (1874-1937)

- **Marconi took the work of Hertz and essentially industrialised it to provide wireless communications.**
- **He built the first working wireless telegraph.**
- **His company was the first to offer such a service, early in the 20th century.**
- **In 1901, he announced the first wireless transatlantic transmission, sent from a high power transmitter in Cornwall to a 122m receiver antenna in Newfoundland, Canada - A distance of 3500km**

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Main inventions

- **Radar**
  - ✓ The idea of detecting remote metallic objects using radiowaves was first demonstrated by Christian Hulsmeyer in 1904.
  - ✓ The first real radar was developed in 1935 by the british.
  - ✓ Development of radar accelerated during WW2, when the US government funded research due to its importance as a defense tool.
  - ✓ They brought some of the best physics minds together to at MIT's Radiation Laboratory to rapidly advance the field. Applications of microwave technology developed then were later incorporated in communications systems.

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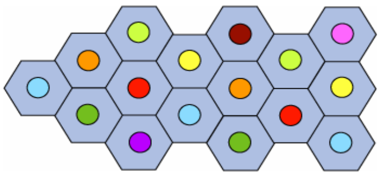
Main inventions

- **Television**
  - ✓ The 20-year old German university student Paul Nipkow developed a rotating-disc technology to transmit pictures over wire in 1884 called the Nipkow disk. This was the very first electromechanical TV scanning system.
  - ✓ Development of the **Cathode Ray Tube** by Ferdinand Braun in 1897
  - ✓ On March 25, 1925, Scottish inventor John Logie Baird gave a demonstration of televised silhouette images in motion at Selfridge's Department Store in London.

- **Radio**
  - ✓ Radio technology began as "wireless telegraphy".
  - ✓ 1897: First patent registered by Nikola Tesla on radio communication
  - ✓ In 1933, FM radio was patented by inventor Edwin H. Armstrong . The inception of an FM broadcast service in South Africa, began on September 1, 1961 from the Brixton Tower (now the Sentech Tower).

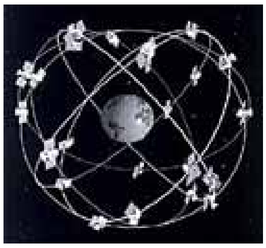
Main inventions

- **Cellular phones systems**
  - ✓ Largest commercial application today with almost 3 billion users worldwide (200 million in 1997)
  - ✓ Divide a geographic area into a set of non overlapping cells.
  - ✓ No adjacent cell has the same frequency, but frequencies are reused over the network.
  - ✓ Each cell has its own transmitter and receiver (base station).
  - ✓ Users in the cell communicate with this base station.
  - ✓ Base stations are connected to each other by a fixed line network.



Main inventions

- **Global Positioning System (GPS)**
  - ✓ Uses 24 Navstar satellites in medium earth orbits (20,2 km) to provide accurate position of the location (lattitude, longitude and elevation)
  - ✓ Military and commercial applications
  - ✓ Operates by using triangulation with a minimum of 4 satellites
  - ✓ Distances are found by timing the propagation delay between satellites and receiver.
  - ✓ Need to know the position of every satellites accuracy and accurate clock for timing signals.
  - ✓ Received signal is low, under the level of noise. Use of spread spectrum techniques to improve SNR.



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Current Wireless Systems

- **Cellular Systems**
- **Wireless LANs**
- **WIMAX**
- **Satellite Systems**
- **Digital TV systems**
- **Bluetooth**

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Current Wireless Systems

- **Cellular Systems**
  - ✓ **2G: GSM (*Global System for Mobile communications*)** is the most widespread system. Can carry data at a maximum throughput of 9,6 kbps, which makes it possible to transmit voice and short text messages (SMS)
  - ✓ **2.5G: GPRS (*General Packet Radio Service).*** Evolution of the GSM standard to allow a max throughput of 171,2 kbit/s (114 kbit/s in practice). Packet switched rather than circuit switched.
  - ✓ **3G: UMTS (Universal Mobile Telecommunications system).** Provide high bit rate services that enable transmission and reception of high quality images and vide. Max Throughput of 144 Kbps (mobile), 384 Kbps (pedestrian) and 2Mb/s (motionless). Improvement with HSDPA (*High-Speed Downlink Packet Acces*): up to 10 Mbits/s.

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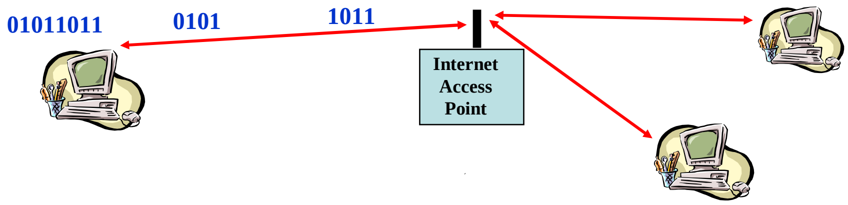
Current Wireless Systems

Wireless Local Area Networks (WLAN)

- ✓ Connect “local” computers (100m range).
- ✓ Breaks data into packets
- ✓ Channel access is shared (random access)



Current Wireless Systems

WLAN standards

- ✓ WIFI (IEEE 802.11)
  - 802.11b
    - Standard for 2.4GHz ISM band (80 MHz)
    - Direct sequence spread spectrum (DSSS)
    - Speeds of 11 Mbps, approx. 500 ft range
  - 802.11a/g
    - Standard for 5GHz NII band (300 MHz)
    - OFDM in 20 MHz with adaptive rate/codes
    - Speeds of 54 Mbps, approx. 100-200 ft range
  - 802.11n
    - Standard in 2.4 GHz and 5 GHz band
    - Adaptive OFDM /MIMO in 20/40 MHz (2-4 antennas)
    - Speeds up to 600Mbps, approx. 200 ft range
- ✓ Hyperlan (ETSI standard)
  - European competitor against Wifi
  - Speeds of 54 Mbps, same range than Wifi for Hiperlan 2
  - Better compatibility with cellular system, but dominated by Wifi today

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Current Wireless Systems

- **WimaX (**IEEE 802.16)
  - ✓ Wide area wireless network standard
    - System architecture similar to cellular systems
    - Hopes to compete with cellular
  - ✓ OFDM/MIMO is core link technology
  - ✓ Operates in 2.5 and 3.5 MHz bands
    - Different for different countries, 5.8 also used.
    - Bandwidth is 3.5-10 MHz
  - ✓ Fixed (802.16d) vs. Mobile (802.16e) Wimax
    - Fixed: 75 Mbps max, up to 50 mile cell radius
    - Mobile: 15 Mbps max, up to 1-2 mile cell radius

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Current Wireless Systems

- **Digital TV**
  - ✓ Governments around the world are switching from analog broadcast TV to digital broadcasts.
  - ✓ Analog TV encodes the image using PAL, NTSC or SECAM and then uses methods such as amplitude or frequency modulation to modulate the signal onto a VHF or UHF carrier.
  - ✓ Digital tv uses digital modulation techniques instead.
  - ✓ There are currently 3 different standards: the European DVB system, the U.S. ATSC system and the Japanese system ISDB.
  - ✓ DVB typically encodes the picture in MPEG2 format and modulates the data onto the carrier signal using QPSK.
  - ✓ Need to use set-top boxes, which convert the transmitted digital signal to analogue, in order to continue viewing TV using the current analogue TV sets

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Current Wireless Systems

Digital TV in South Africa

- South Africa will use the European DVB system.
- Sentech has announced plans for the rollout of Digital Television services in South Africa. The existing network infrastructure is being replaced and 184 analogue sites will be upgraded to digital.
- The planned DTT population coverage is as follows (from 2006 data):
  - **56% in 2008**
  - **78% in 2009**
  - **92% in 2010**
- Analogue switch off will be around 2015
- HDTV after analog switch off.

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Current Wireless Systems

Satellite communication systems

- **Used for transmitting voice and data**.
- **Advantage:** Cover very large areas. As few as 3 geosynchronous satellites can provide global coverage.
- **Disadvantage:** High altitude of satellites leads to very low signal strength.
- Satellite telephony has a relatively small market.
- Satellite TV, however, has a large market, especially in countries like SA, where cable TV is non existent.
- Allows one to broadcast to locations with little or no infrastructure. All that is needed is a dish and receiver.

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Current Wireless Systems

- **Bluetooth (IEEE 802.15)**
  - ✓ Bluetooth is a WPAN (Wireless Personal Area Network) technology.
  - ✓ Named from Harald Blaatand (910-986), king of Denmark (and called Bluetooth) who unified Denmark and Norway
  - ✓ Operates on the 2.45 GHz frequency band. Data rates up to 1 Mbit/s at 100m.
  - ✓ Small, inexpensive radio chip, which can be used in mobile computers, printers, mobile phones…, to transmit data between these devices.
  - ✓ Low power transmission to optimise battery life.

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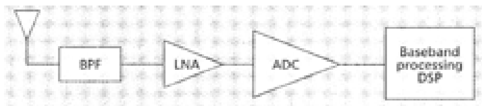
Future wireless systems

- **4G systems**
- **Galileo**
- **Software radio**
- **Ultra Wide Band radio**

Future wireless systems

- **Software radio**
  - ✓ Uses software to perform many of the signal processing tasks that analog circuits traditionally handle
  - ✓ Put many traditionally hard functions in digital modules whose characteristics can be changed while the radio is running.
  - ✓ Can handle several communication standards (WLAN, Bluetooth, cellular systems, TV, …) with the same hardware platform



Ideal SW receiver

Future wireless systems

- **Ultra Wide Band Systems**
  - ✓ UWB is an impulse radio: sends pulses of tens of picoseconds(10^{-12}) to nanoseconds (10^{-9})
  - ✓ A carrier is not necessarily needed
  - ✓ Uses a lot of bandwidth (7.5 GHz in the U.S)
  - ✓ Excellent ranging capability: 1 cm accuracy possible for location and positioning
  - ✓ Low power transmissions: 100 times lower than Bluetooth for same range/data rate
  - ✓ Very high data rates possible 500 Mbps at ~10 feet under current regulations

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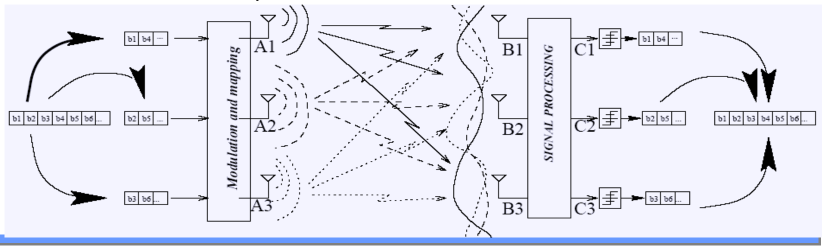
Promising technologies

- **MIMO systems (Multiple Input Multiple Outputs)**
  - ✓ MIMO was originally conceived in the early 1970s by Bell Labs engineers trying to address the bandwidth limitations that signal interference caused in large, high-capacity cables
  - ✓ Information is divided in several streams (one per antenna)
  - ✓ Throughput increase is proportional to the number of transmission antennas
  - ✓ Spatiotemporal decoding at the receiver (at least as many antennas as the transmitter)



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MIMO systems

- **Array gain:** Due to the use of multiple antennas, the antenna gain is increased and this leads to an increased range and coverage.

- **Interference suppression:** By using the spatial dimension provided by multiple antenna elements, it is possible to suppress interfering signals in a way that is not possible with a single antenna.

- **Spatial diversity** Multiple antennas can also be used to counteract the channel fading due to multipath propagation. Sufficiently spaced multiple antennas at the receiver gives copies of the transmitted signal that has propagated through channels with different fading and the probability that all signal copies are in a deep fade simultaneously is small.

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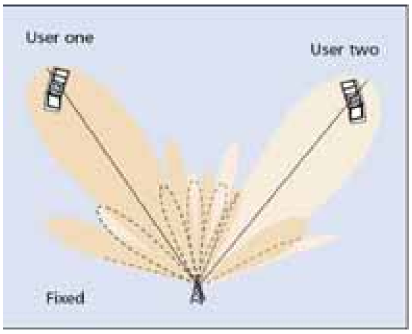
Smart antennas

- In the mid-1990s, the terms “smart antennas” and “adaptive antennas” were introduced since through signal processing, the array can be made adaptive, and in a smart manner change its transmission or reception characteristics when the radio environment changes



Ad Hoc/ Mesh Networks

- Peer-to-peer communications, where wireless nodes communicate directly with each other and create ad hoc mesh networks independently of the presence of any wireless infrastructure.
- Different from traditional wireless networks where an infrastructure provides wireless access for network connectivity to wireless terminals.

- Provide a flexible network infrastructure for many emerging applications.
- Energy constraints impose interesting design tradeoffs for communication and networking
- Mesh networking techniques using WLAN are being standardized in IEEE 802.11s.