# UNIT I
# INTRODUCTION AND OVERVIEW OF WIRELESS SENSOR NETWORK

# INTRODUCTION AND OVERVIEW OF WIRELESS SENSOR NETWORKS

# Introduction

## Sensor Network:

- It is an infrastructure comprised of sensing (measuring), computing, and communication elements that gives an administrator the ability to instrument, observe, and react to events and phenomena in a specified environment.

# Components in a Sensor Network

- An assembly of distributed or localized sensors.
- An interconnecting network (usually, but not always, wireless-based).
- A central point of information clustering.
- A set of computing resources at the central point (or beyond) to handle data correlation, event trending, status querying, and data mining.

# Background of Sensor Network Technology

## Wireless Sensor Networks(WSNs):

- WSNs- “Exciting emerging domain of deeply networked systems of low-power wireless motes2 with a tiny amount of CPU and memory, and large federated networks for high-resolution sensing of the environment”.
- Sensor networking is a multidisciplinary area.
- It involves, radio and networking, signal processing, artificial intelligence, database management, resource optimization, power management algorithms.

# Technology for Sensing and Control

- Electric and magnetic field sensors.
- Radio-wave frequency sensors.
- Optical-, Electro optic-, and Infrared sensors.
- Radars.
- Lasers.
- Location/navigation sensors.
- Seismic and pressure-wave sensors.
- Environmental parameter sensors (e.g., wind humidity, heat); and biochemical.
- National security–oriented sensors.

# Sensors

- Sensors can be described as “smart” inexpensive devices.
- They are low-cost low-power untethered multifunctional nodes.
- Sensor devices, or wireless nodes (WNs), are also called *motes*.
- Sensors are internetworked via a series of multi-hop short-distance low-power wireless links.
- *Micro sensors* are a subset of the general family of sensor networks.

# Sensor’s Size

| | |
|---|---|
| Nano-scopic (also known as nano-scale) | Objects or devices on the order of 1 to 100 nm in diameter. |
| Meso-scopic scale | Objects between 100 and 10,000 nm in diameter. |
| Micro-scopic scale | Ranges from 10 to 1000 mm. |
| Macro-scopic scale | Millimeter to Meter range. |

# Power efficiency in WSNs

It generally accomplished in three ways:

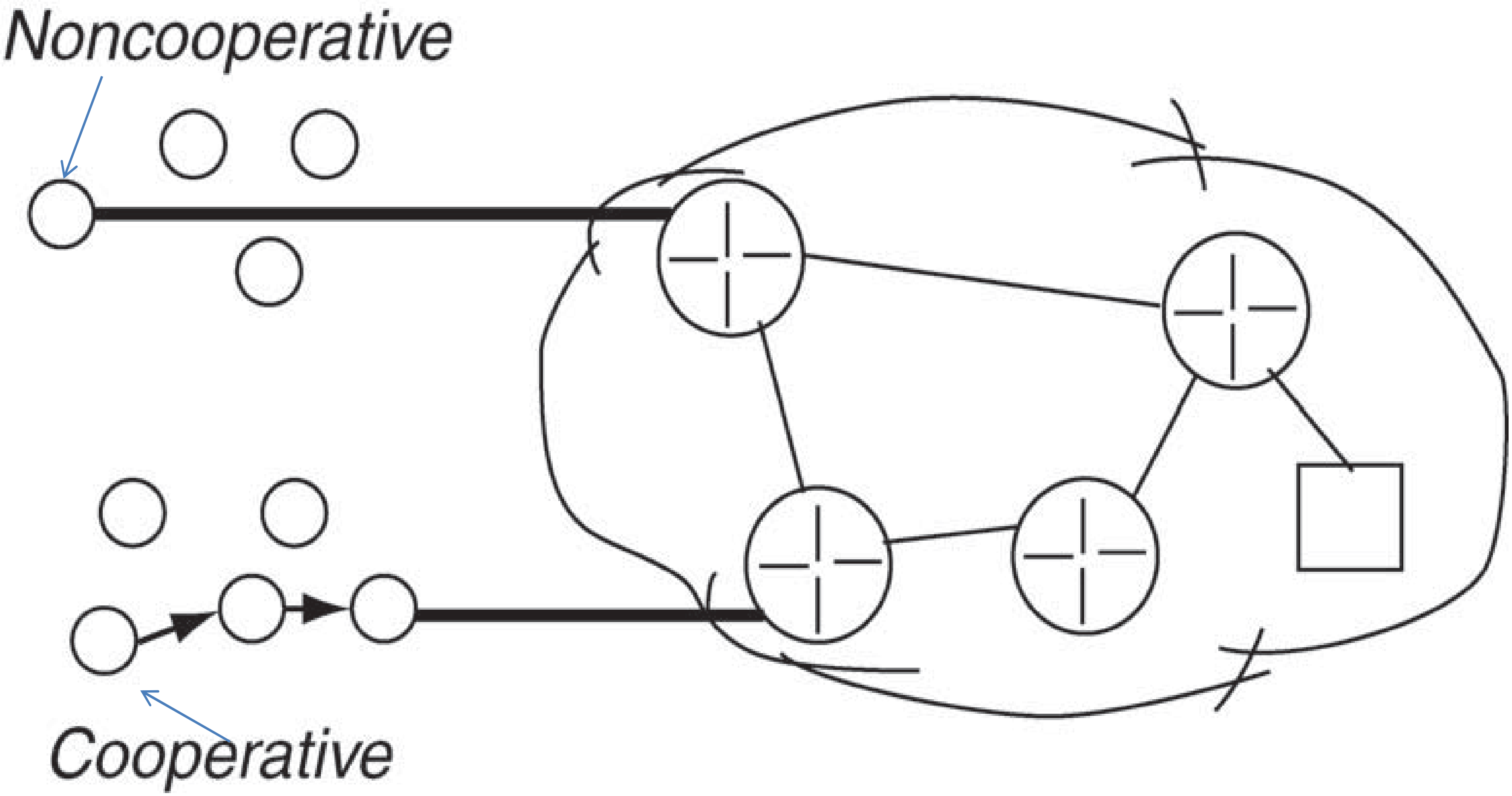
- Low-duty-cycle operation.
- Local/in-network processing.
- Multi hop networking reduces the requirement for long-range transmission since signal path loss is an inverse exponent with range or distance.

# TYPES OF WSN

Wireless Sensor Network can be classified into two types

- Mesh based system (non cooperative)
- Point to point system (cooperative)

# COOPERATIVE & NON COOPERATIVE NODES



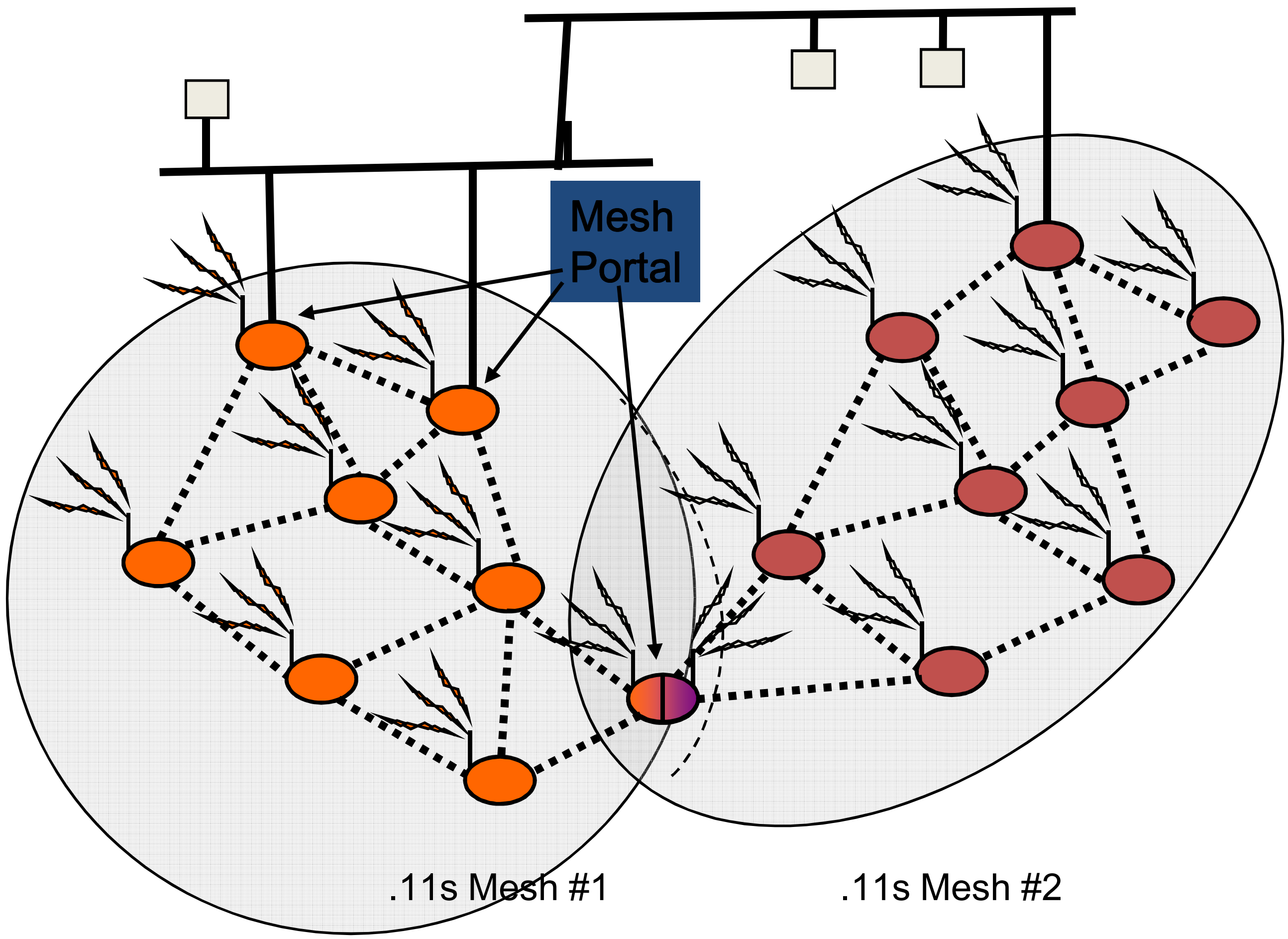
# MESH BASED WSN SYSTEM

- This is a system with multihop radio connectivity among or between WNs, utilizing dynamic routing in both the wireless and wire line portions of the network.
- These are networks in which sensors are permitted to be more than one radio hop away from a routing or forwarding node
- The forwarding node is a wireless router that has a mechanism that is used to find the best route to the destination out of a possible set of more than one route

# CHARECTERISTICS

- Sensor nodes can support communications on behalf of other sensor nodes by acting as repeaters
- The forwarding node can support data processing or reduction on behalf of the sensor nodes.
- The forwarding node supports dynamic routing and more than one physical link to the rest of the network is physically and logically present.
- The radio links are measured in thousands of meters

# WSN MESH BASED SYSTEM Infrastructure



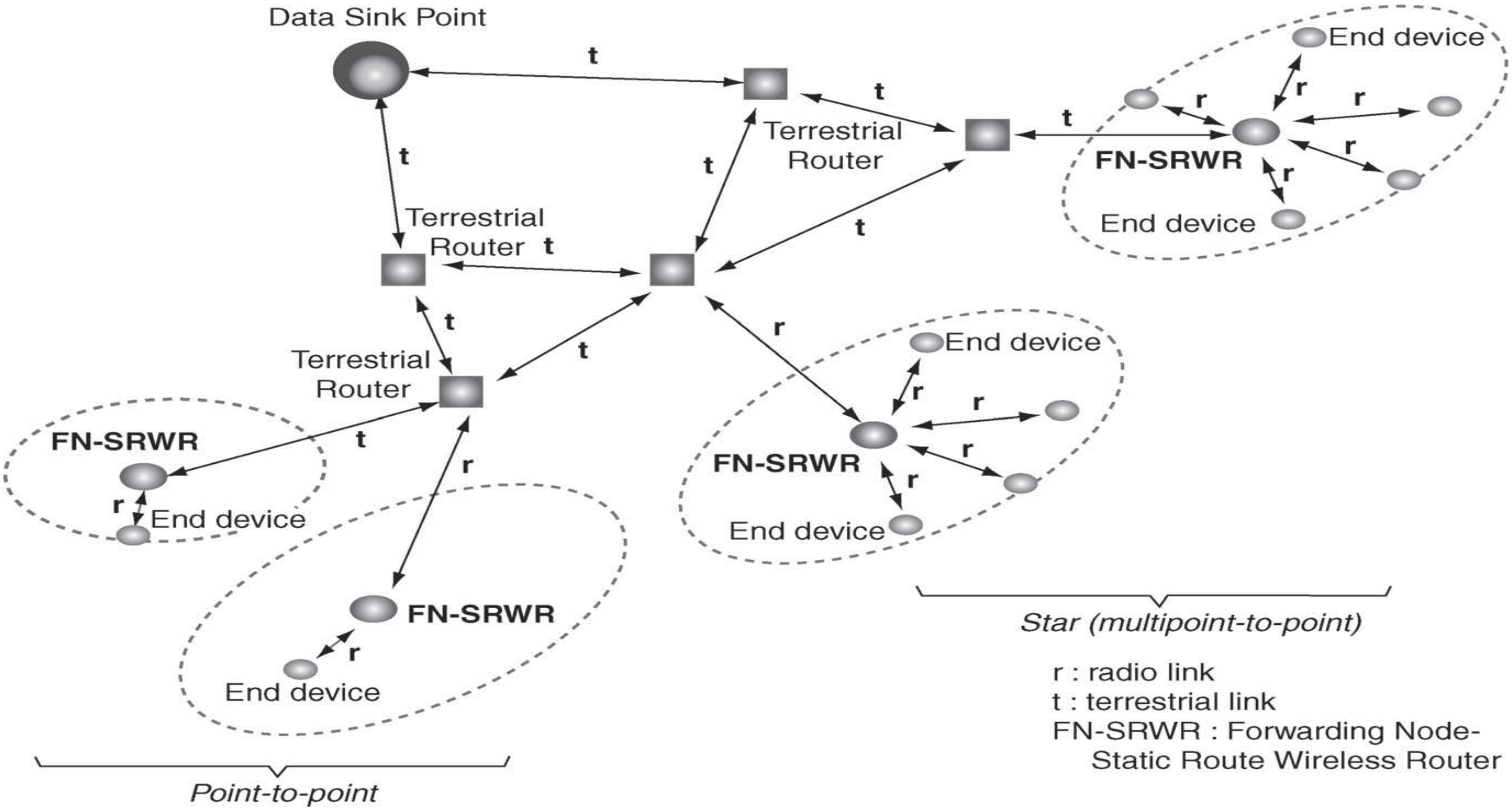
# POINT TO POINT SYSTEM

- This system has a single-hop radio connectivity to WNs, utilizing static routing over the wireless network. Typically, there will be only one route from the WNs to the companion terrestrial/wire line forwarding node.
- These are networks in which end devices (sensors) are one radio hop away from a terrestrially homed forwarding node
- The forwarding node/wireless router is connected to the terrestrial network via either a landline or a point-to-point wireless link

# CHARACTERISTICS

- Sensor nodes do not support communications on behalf of any other sensor nodes
- The forwarding node does not support data processing or reduction on behalf of the sensor nodes. In effect, these are relatively simple wireless systems
- The forwarding node supports only static routing to the terrestrial network and/or only one physical link to the terrestrial network is present
- The radio link is measured in hundreds of meters

# Point-to-point single-hop system utilizing static routing



# APPLICATIONS

- Applications range from environmental control (e.g., tracking soil contamination, habitat monitoring), warehouse inventory and health care at one end of the spectrum, to scientific and military
- WSN research promise to have a significant impact on a broad range of applications relating to national security, health care, the environment, energy, food safety, and manufacturing

- The range of potential applications include tracking wild fires; microclimate assessment; monitoring animal populations; defence systems; and allowing authorities to monitor for toxic chemicals, explosives, and biological agents
- WSNs using sensor and micro sensor technology are expected to enable a plethora of applications for sensing and controlling

# Categories of Sensor Networks

## Category 1 WSNs (C1WSNs):

- Invariably mesh-based systems with multi-hop radio connectivity among or between WNs.
- Military theater systems typically belong to this category.

## Category 2 WSNs (C2WSNs):

- Point-to-point or multipoint-to-point (star-based) systems generally with single-hop radio connectivity to WNs.
- Residential control systems typically belong to this category.

## C1WSN

- Support highly distributed high-node-count applications.
- Tend to deal with large-scale multipoint-to-point systems with massive data flows.

## C2WSN

- Support confined short-range spaces such as a home, a factory, a building, or the human body.
- Tend to focus on short-range point-to-point, source-to-sink applications.

# APPLICATIONS OF WIRELESS SENSOR NETWORKS

# Examples of category 2 WSN Application

- Point-to-Point (**star-based**) topologies, generally with **single-hop** radio connectivity utilizing **static** routing.
- C2WSN technology is being targeted for a gamut of building automation, industrial, medical, residential control and monitoring applications.
- **ZigBee** middleware provides interoperability and desirable RF performance characteristics, with chipsets implementing the standard-specified protocol stack being developed at press time.

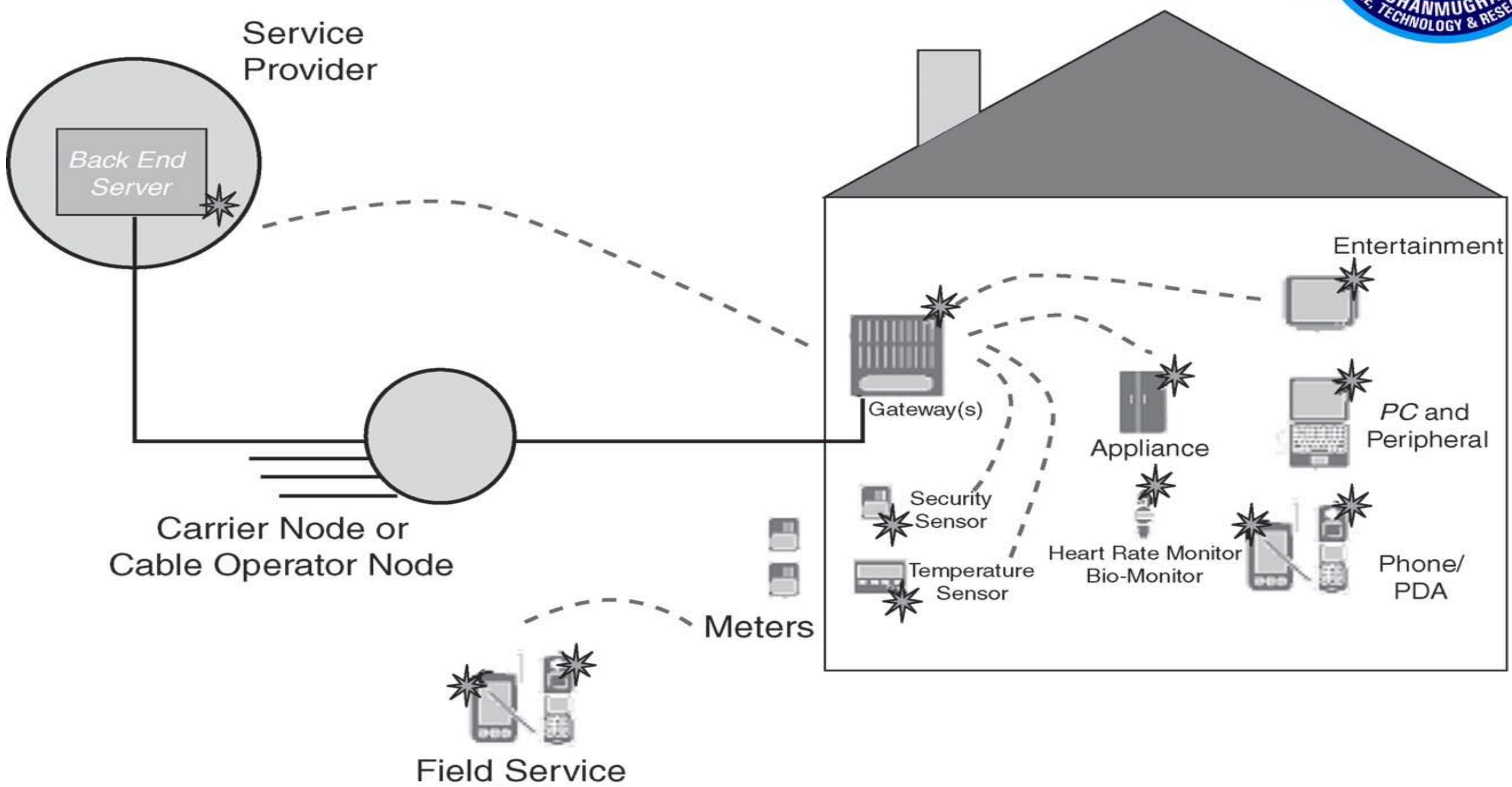
- **Examples** of applications include, lighting automatic meter reading, wireless smoke and CO detectors, HVAC control ,heating control , home security, environmental controls , medical sensing and monitoring.
- The sensor environment has some unique requirements:
  - The primary drivers for this environment are simplicity, long battery life, networking capabilities, reliability, and low cost.
- **ZigBee5** enables the broad-based deployment of wireless networks with lowcost, low-power solutions.

- **ZigBee** is designed for low-to very-low-duty-cycle static and dynamic environments with many active nodes.
- **Bluetooth** is designed for high QoS, a variety of duty cycles, and moderate data rates in networks with limited active nodes.

## Home Control

- provide control, conservation, convenience, and safety.
- Sensing applications facilitate flexible management of lighting, heating, and cooling systems .

# Home Control Application



- Sensing applications automates control of multiple home systems to improve conservation, convenience, and safety.
- captures highly detailed electric, water, and gas utility usage data.
- embeds intelligence to optimize consumption of natural resources.
- enables the installation, upgrading, and networking of a home control system without wires.
- enables one to configure and run multiple systems from a single remote control.

- It facilitates the reception of automatic notification upon detection of unusual events.
- **Body-worn medical sensors** (e.g., heartbeat sensors) are also emerging. These are battery-operated devices with network beacons occurring either every few seconds that could be worn by home-resident elderly or people with other medical conditions.
- These sensors have two ongoing processes: heartbeat time logging and transmission of heart rate and other information s are, instantaneous and average heart rate, body temperature, and battery voltage.

# Building Automation

- Building automation applications provide control, conservation, flexibility, and safety, as follows
- Sensing applications integrates and centralized management of lighting, heating, cooling, and security .
- It automates control of multiple systems to improve conservation, flexibility, and security.
- It reduces energy expenses through optimized HVAC management.
- It enables one to allocate utility costs equitably based on actual consumption.
- It enables the rapid reconfiguring of lighting systems to create adaptable workspaces.

- It enables the extension and upgrading of building infrastructure with minimal effort.
- It enables one to network and integrate data from multiple access control points.
- It enables one to deploy wireless monitoring networks to enhance perimeter protection.

To developing integrated sensor or wireless communication and energy source WNs that,

1. Support multiple sensing of temperature, light, sound, flow, and localization (called multimodal sensing)

2. Support a seamless wireless network interface

3. Support an integrated energy source that allows the node to be self-contained and to operate independently for at least 10 years

4. Support building control applications software

- Research on this at present is sponsored through the NSF program "XYZ on a Chip: Integrated Wireless Sensor Networks for the Control of the Indoor Environment in Buildings".

# Industrial Automation

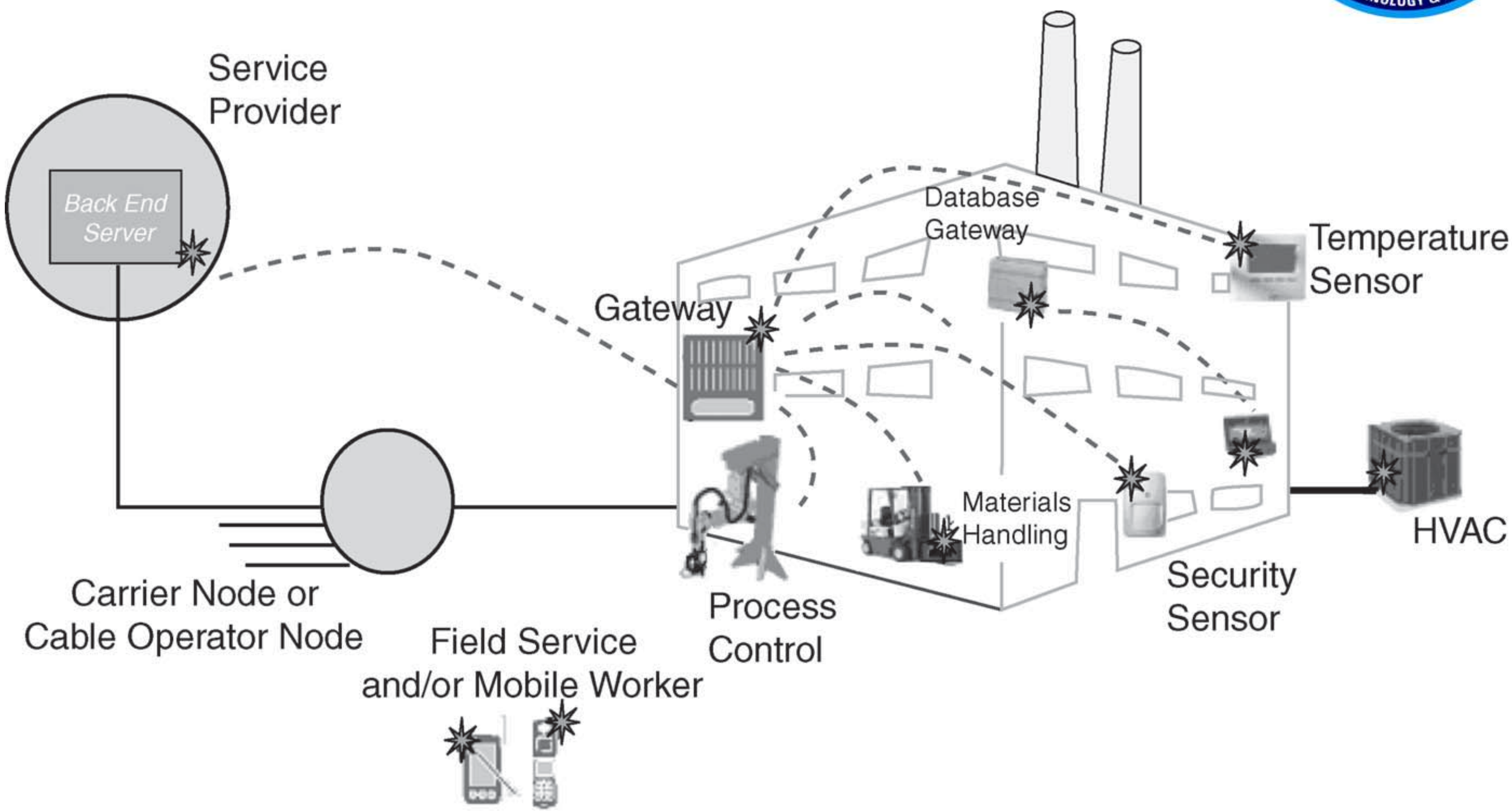
- Industrial automation applications provide control, conservation, efficiency, and safety, as follows (see Figure 2.7)
- Sensing applications extends existing manufacturing and process control systems reliably.
- Sensing applications improves asset management by continuous monitoring of critical equipment.
- Sensing applications reduces the energy costs through optimized manufacturing processes.

- It helps to identify inefficient operation or poorly performing equipment.
- It helps to automate data acquisition from remote sensors to reduce user intervention.
- It provides the detailed data to improve preventive maintenance programs.
- It helps to deploy monitoring networks to enhance employee and public safety.
- It helps to streamlining data collection for improved compliance reporting.

# Applications for Industrial and Commercial Spaces

- Warehouses, fleet management, factories, supermarkets, office complexes
- Gas, water, and electric meters
- Smoke, CO, and H2O detectors
- Refrigeration cage or appliance
- Equipment management services and preventive maintenance
- Security services
- Lighting control
- Assembly line and workflow and inventor
- Materials processing systems

# Industrial Control Applications



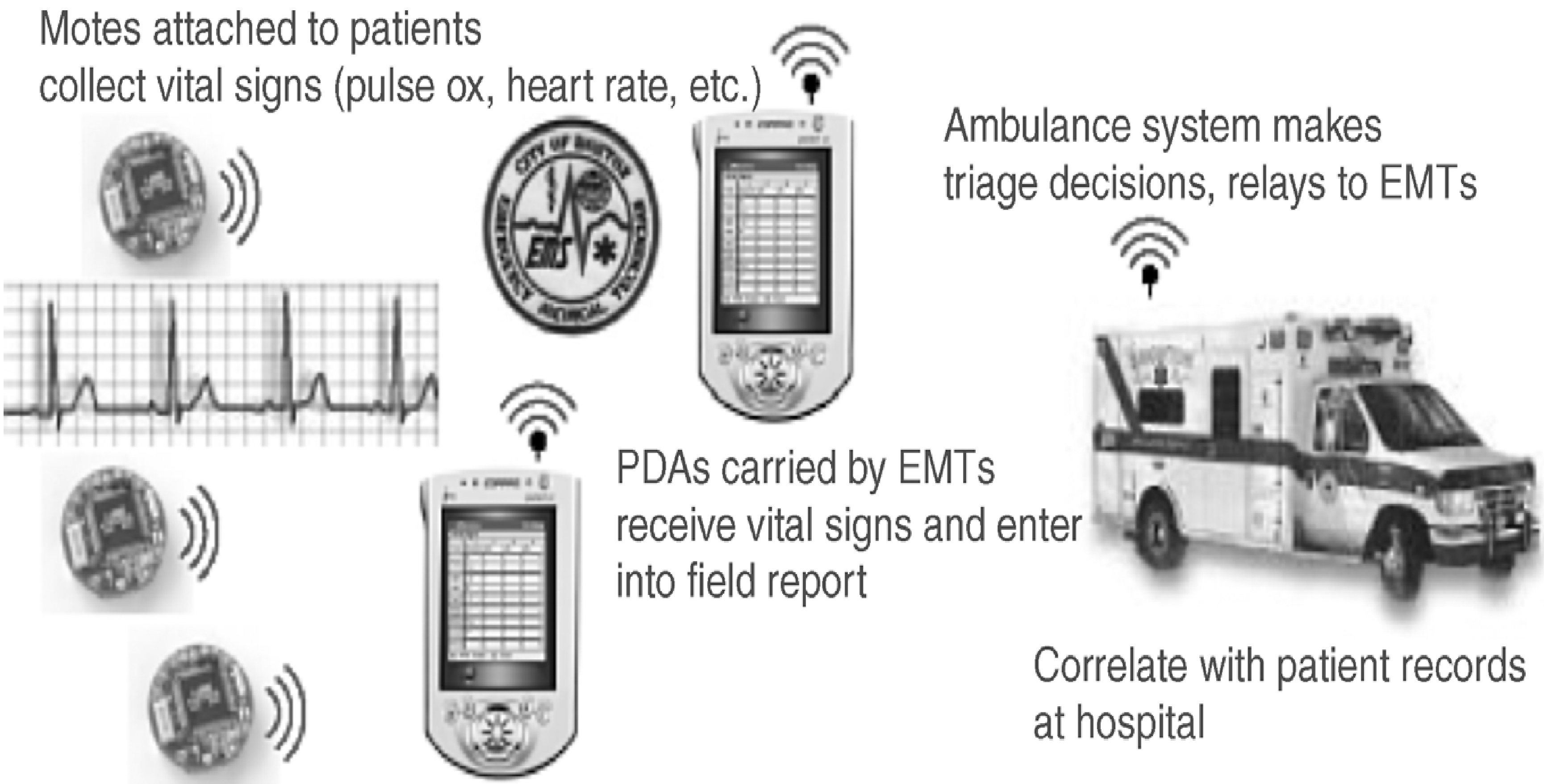
# Medical Applications

- A number of hospitals and medical centers are exploring applications of WSN technology to a range of medical applications, including pre-hospital and in-hospital emergency care, disaster response, and stroke patient rehabilitation.
- WSNs have the potential to affect the delivery and study of resuscitative care by allowing vital signs to be collected and integrated automatically into the patient care record and used for real-time triage, correlation with hospital records, and long-term observation.

- WSNs permits home monitoring for chronic and elderly patients, facilitating long-term care and trend analysis; this in turn can sometimes reduce the length of hospital stays.
- WSNs  permits collection of long-term medical information that populates databases of clinical data; this enables longitudinal studies across populations
- These devices, consisting of three-axis accelerometer, gyroscope, and electro myogram sensors, allow researchers to capture a rich data set of motion data for studying the effect of various rehabilitation exercises on this patient population.

- In addition to the hardware platform, Harvard University developed a scalable
- software infrastructure called **CodeBlue**, for wireless medical devices.
- designed to provide routing, naming, discovery, and security for wireless medical sensors, PDAs, PCs, and other devices that may be used to monitor and treat patients in a number of medical settings .
- designed to scale across a different network densities, ranging from sparse clinic and hospital deployments to very dense ad hoc deployments at a mass casualty site.
- includes a system for tracking the location of individual patient devices indoors and outdoors using radio signal information.

# Medical Applications



# Examples of category 2 WSN Application

Centre Based (**Mesh-based**) topologies, generally with **Multi-hop** radio connectivity utilizing **dynamic** routing.C2WSN technology is being targeted for a gamut of applications such as,

1. Military sensor networks to detect and gain as much information as possible about enemy movements, explosions, and other phenomena of interest

2. Law enforcement and national security applications for inimical agent tracking or nefarious substance monitoring

3. Sensor networks to detect and characterize chemical, biological, radiological, nuclear, and explosive (CBRNE) attacks and material.
4. Sensor networks to detect and monitor environmental changes in plains, forests, oceans, and so on
5. Wireless traffic sensor networks to monitor vehicle traffic on highways or in congested parts of a city
6. Wireless surveillance sensor networks for providing security in shopping malls, parking garages, and other facilities

# Sensor and Robots

- Two technologies appear poised for a degree of convergence:
  - **Mobile robotics**
  - **Wireless sensor networks.**
- For example, Intel envisions mobile robots acting as gateways into wireless sensor networks, such as into the Smart Dust networks of wireless motes.
- These robots embody sensing, actuation, and basic (miniaturized) robotics functions.

- The field of mobile robotics deals with mechanical aspects (the wheels, motors, grasping arms, or physical layout) as well as with the logic aspects (the microprocessors, the software, and the telemetry)
- One major issue with a mobile robot acting as a gateway is the communication between the robot and the sensor network.
- Some propose that a sensor network can be equipped with IEEE 802.11 capabilities to bridge the gap between robotics and wireless networks.

# Reconfigurable Sensor networks

- Military applications require support for tactical and surveillance arrangements that employ reconfigurable sensor WNs that are cap assembling themselves without central control, and being deployed incrementally.
- Reconfigurable “smart” WNs are self-aware, self-configurable, and autonomous.
- Self-organizing WSNs utilize mechanisms that allow newly deployed WNs to establish connectivity (to build up a network topology) spontaneously.

# Highway Monitoring

- Transportation (traffic flow) is a sector that is expected to benefit from increased monitoring and surveillance.
- **Traffic Pulse Technology** is an example of a WSN developed by Traffic.com.
- The goal of this system is to collect data through a sensor network, process and store the data in a data center, and distribute those data through a variety of applications.
- Traffic Pulse is targeted for open-air environments; it provides real-time collection of data .

- These basic data elements make it possible to calculate average speeds and travel times.
- The data are then transmitted to the data center for reformatting.

Applications:

1. Private traffic information providers in the United States: The company's realtime and archived data offer valuable tools for a variety of commercial and governmental applications.
2. Telematics: For mobile professionals and others, the company's traffic information complements in-vehicle navigation devices, informing drivers not only how to get from point A to point B but how long it will take to get there, or even direct them to an alternative route.

## Military Applications:

- A number of companies have developed WS include customizable, sensor-laden, networked nodes and both mobile and Internet-hosted user interfaces
- For example, Rockwell Scientific's wireless sensing network development system allows examination of issues relative to design, deployment, and use of micro-sensor networks.
- Each node incorporates

  (1) one or more sensors for measuring the environment,

  (2) computing capability to process sensor data into "high-value" information and to accomplish local control.

(3) a radio to communicate information to and from neighboring nodes and eventually to external users.

- The baseline prototype wireless sensing unit is based on an open, modular design using widely available commercial-off-the-shelf (COTS) technology.
- These nodes combine sensors (such as mechanical vibration, acoustic, and magnetic) with a commercial digital cordless telephone radio and an embedded commercial RISC micro processor in a small package.

# Condition-Based Monitoring

- The economic trade-off is between the cost of the CBM equipment and the staffing resources expended to determine the machine’s health and the cost of unexpected, as opposed to scheduled, repair and process downtime.
- The costs associated with CBM can be allocated into equipment, installation, and labor costs in collecting and analyzing the machine health data.
- WSNs are positioned to minimize all three costs and, in particular, to eliminate the staffing costs, which often are the largest.

# Military Surveillance

- WSNs can replace single high-cost sensor assets with large arrays of distributed sensors for both security and surveillance applications.
- The WSN nodes are smaller and more capable than sensor assets presently in the inventory; the added feature of robust, self-organizing networking makes WSNs deployable by untrained troops in essentially any situation.
- WSNs can be used in traditional sensor network applications for large-area and perimeter monitoring and will ultimately enable every platoon, squad, and soldier to deploy WSNs to accomplish a number of mission and self-protection goals.

# Borders Monitoring

- At press time Boeing Co. had secured a contract from the Department of Homeland Security to implement SBInet, the Secure Borders Initiative, along the northern and southern U.S. borders.
- The SBInet portion of the Secure Borders Initiative is the development of a technological infrastructure that facilitates the use of a variety of sensors and detection devices, and which enables that data to be forwarded to remote operations centers via Ku-band satellite uplinks.

# Civil and Environmental Applications

- Sensors can be used for civil engineering applications. Research has been under way in recent years to develop sensor technology that is applicable for buildings, bridges, and other structures.
- The goal is to develop "smart structures" that are able to self-diagnose potential problems and self-prioritize requisite repairs .
- This technology is attractive for earthquake-active zones. Although routine mild tremors may not cause visible damage, they can give rise to hidden cracks that could eventually fail during a higher-magnitude quake.

- Up to the present, wired seismic accelerometers (devices able to measure movement) have been used; however, these devices are expensive (several thousands of dollars each) and are difficult to install.
- This predicament limits the density of sensor deployment, which in turn limits the planner’s view of a building’s structural integrity.
- As a result, a safety-impacting structural problem does not become visible until the entire building is affected.

# Habitat Monitoring

- As an example, in the recent past, the Intel Research Laboratory at Berkeley undertook a project with the College of the Atlantic in Bar Harbor and UC–Berkeley to deploy wireless sensor networks on Great Duck Island in Maine.
- The goal was to develop a habitat-monitoring kit that enables researchers worldwide to engage in nonintrusive and non disruptive monitoring of sensitive wildlife and habitats.
- For habitat monitoring the planner needed sensors that can take readings for temperature, humidity, barometric pressure, and midrange infrared. Motes sample and relay their sensor readings periodically to computer base stations on the island.

# Wildfire Instrumentation

- Collecting real-time data from wildfires is important for life safety considerations and allows predictive analysis of evolving fire behavior.
- FireBugs are small wireless sensors (motes) based on Tiny OS that self-organize into networks for collecting real-time data in wildfire environments.
- The FireBug system combines state-of-the-art sensor hardware running TinyOS with standard off-the-shelf World Wide Web and database technology, allowing rapid deployment of sensors and behavior monitoring.

# Nanoscopic Sensor Applications

- There is in WSNs for biological sensing. In particular, there is interest in the "labs on a chip" concept, including new methodology.
- In particular, a nanoscopic, microscale confocal imaging array (micro-CIA) is a device that merges MEMSs (micro electromechanical systems), ultrasmall lasers, lenses, and plumbing.
- A single nanoscopic micro-CIA is essentially a massively scaled-down confocal microscope. Confocal microscopes work by shining a laser at a molecule that has been tagged with a fluorescent die.ies supported by nanotechniques.

# Another Taxonomy Of WSN Technology

- The taxonomy is based on physical placement of the various sensors and the connectivity of these nodes to nodes in the wired infrastructure; the network configuration determines the amount of routing intelligence that needs to be supported in the sensor nodes.
- Specifically, key factors used in the classification process under discussion are the size of the system, the number of sensors used, the average (and/or maximum) distance (in hops) of the sensors to the wired infrastructure, and the distribution of the sensor nodes.

- Three types of WSN system (technology) that have been described in are:
    1. Non propagating WSN systems
  2. Deterministic routing WSN systems
    a. Aggregating
    b. Non aggregating systems
  3. Self-configurable and self-organizing WSN systems
    a. Aggregating
    b. Non aggregating systems

# Definition

" A wireless sensor network (WSN) is a wireless network consisting of spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion pollutants, at different locations."

- WSNs are collections of compact-size, relatively inexpensive computational nodes that measure local environmental conditions (parameters)
- WSN forward such information to a central point for appropriate processing.
- WSNs typically consist of hundreds (even thousands) of inexpensive WNs

## Existing and potential applications of Sensor networks:

- Military sensing
- Physical security
- Air traffic control, traffic surveillance, video surveillance, industrial and manufacturing.
- Automation, process control, inventory management, distributed robotics.
- Weather sensing, environment monitoring, national border monitoring, and building and structures monitoring.

## Military applications

- Monitoring inimical forces
- Monitoring friendly forces and equipment
- Military-theater or battlefield surveillance
- Nuclear, biological, and chemical attack detection

## Environmental applications

- Microclimates
- Forest fire detection and Flood detection
- Precision agriculture

## Health applications

- Remote monitoring of physiological data
- Tracking and monitoring doctors and patients inside a hospital

## Home applications

- Home automation
- Instrumented environment
- Automated meter reading

## Commercial applications

- Vehicle tracking and detection
- Traffic flow surveillance
- Chemical-, physical-, acoustic-, and image-based sensors can be utilized to study ecosystems.
- Defense applications have fostered research and development in sensor networks during the past half-century.
- Process control and Home automation

# BASIC OVERVIEW OF THE TECHNOLOGY

- Sensor networks deal with space and time: location, coverage, and data synchronization.
- Data are the intrinsic "currency" of a sensor network.
- There will be a large amount of time-stamped time-dependent data.
- Sensor networks often support in-network computation.
- Some sensor networks use source-node processing; others use a hierarchical processing architecture.

## Sensor Processing:

- Nodes often use their processing abilities locally to carry out basic computations.
- Then transmit only a subset of the data and/or partially processed data.
- In a hierarchical processing architecture, processing occurs at consecutive tiers until the information reaches the appropriate decision-making.
- Sensor nodes are almost invariably constrained in energy supply and radio channel transmission bandwidth.

## Key technology and standards elements of sensor networks:

- Sensors
  - Intrinsic functionality
  - Signal processing
  - Compression, forward error correction, encryption
  - Control/actuation
  - Clustering and in-network computation
  - Self-assembly
- Wireless radio technologies
  - Software-defined radios
  - Transmission range
  - Transmission impairments
  - Modulation techniques
  - Network topologies

## Standards

- IEEE 802.11a/b/g together with ancillary security protocols
- IEEE 802.15.1 PAN/Bluetooth
- IEEE 802.15.3 ultrawideband (UWB)
- IEEE 802.15.4/ZigBee
- IEEE 802.16 WiMax
- IEEE 1451.5 (Wireless Sensor Working Group)
- Mobile IP

- **Tiny OS** is being developed by the University of California–Berkeley as an open-source software platform; the work is funded by DARPA.
- **Tiny DB** is a query-processing system for extracting information from a network of Tiny OS sensors.

Software applications

- Operating systems
- Network software
- Direct database connectivity software
- Middleware software
- Data management software

# Basic Sensor Network Architectural Elements

Elements and design principles are characterized by many of the following factors:

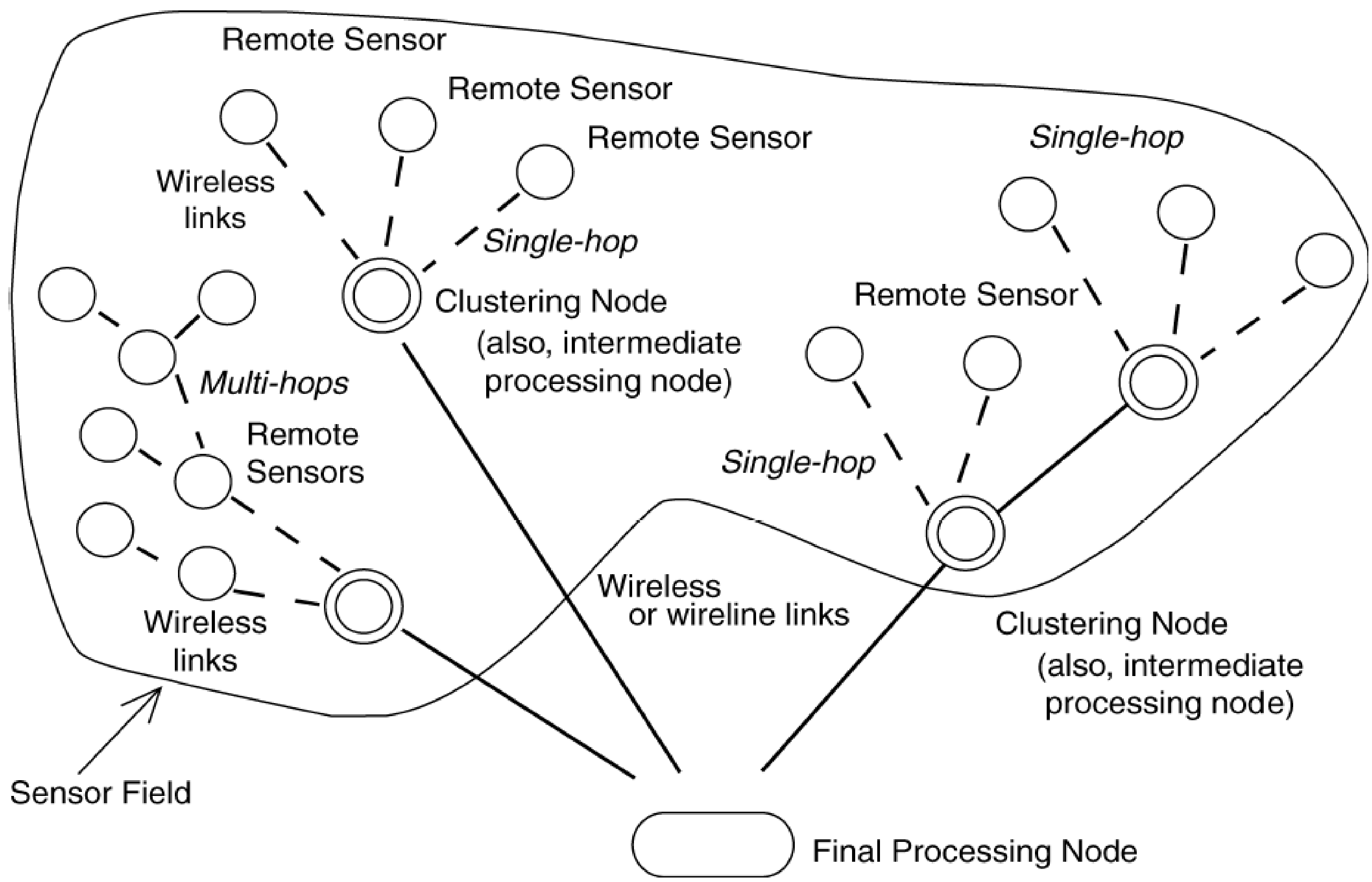
- Large sensor population
- Large streams of data
- Incomplete/uncertain data
- High potential node failure
- Electrical and processing power limitations
- Multi-hop topology

➢ Routing protocols for WSNs need to be energy-aware.

# Sensor Types and Technology
# Deployment of Sensor Network:

- A sensor network is composed of a large number of sensor nodes that are *densely deployed*.
- Sensor nodes may be deployed
  - in an open space
  - on a battlefield in front of, or beyond, enemy lines
  - in the interior of industrial machinery
  - at the bottom of a body of water;
  - in a commercial building
  - in a home
  - on a human body

# Typical WSN Arrangement



## Important issues pertaining to WSNs are:

- Sensor type and placement
- Sensor power consumption
- Operating environment and Connectivity
- Computational/sensing capabilities and signal processing
- Telemetry or control of remote devices

## Characteristic features of sensor networks:

- Sensor nodes are densely deployed.
- Sensor nodes are prone to failures.
- Sensor nodes are limited in power, computational capacities, and memory.
- Sensors are either passive or active devices.

## Components of Sensing Node:

- A sensing and actuation unit (single element or array)
- A processing unit
- A communication unit
- A power unit
- Other application-dependent units

➢ In addition to sensing there is a desire to build, deploy, and manage unattended or untethered embedded control and actuation systems called *control networks*.

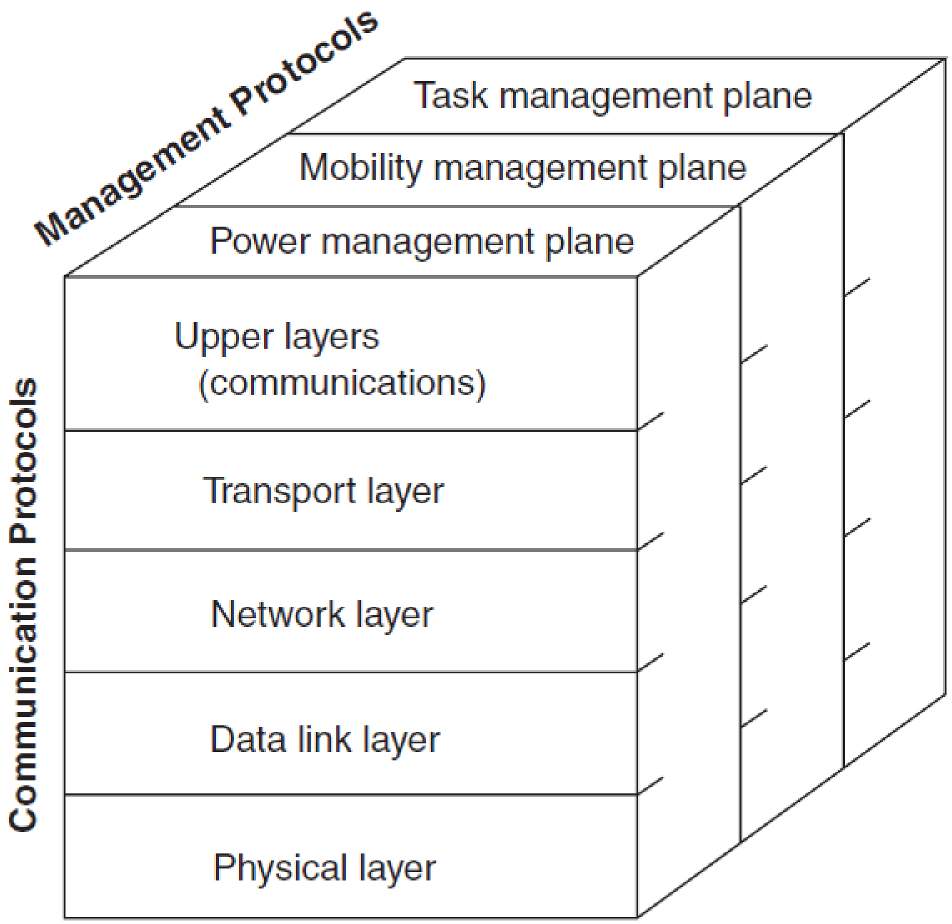
## Software (Operating Systems and Middleware):

- To support the node operation, it is important to have open-source operating systems designed specifically for WSNs.
- Such operating systems typically utilize a component-based architecture. One such Example is Tiny OS.
- Tiny OS's component library includes network protocols, distributed services, sensor drivers, and data acquisition tools.

## Standards for Transport Protocols:

- The goal of WSN is to develop a cost-effective standards-based wireless networking solution.
- That supports low-to-medium data rates, has low power consumption, and guarantees security and reliability.
- The position of sensor nodes does not have be predetermined, allowing random deployment in inaccessible terrains or dynamic situations.
- Sensor network protocols and algorithms must possess self-organizing capabilities.

# Generic protocol stack for sensor networks



# WSN Protocol Stack

| | |
|---|---|
| **Upper layers** | **In-network applications -** including application processing, data aggregation, external querying query processing, and external database. |
| **Layer 4** | **Transport -** including data dissemination and accumulation, caching, and storage. |
| **Layer 3** | **Networking -** including adaptive topology management and topological routing. |
| **Layer 2** | **Link layer (contention) -** channel sharing (MAC), timing, and locality. |
| **Layer 1** | **Physical medium -** communication channel, sensing, actuation, and signal processing. |

## Routing and Data Dissemination:

- It deals with **data dissemination** mechanisms for large-scale wireless networks, adaptive routing, and other specialized routing mechanism.
- **Routing protocols** for WSNs generally fall into three groups: data-centric, hierarchical, and location-based.
- Data aggregation is used to combine the data arriving from different sources along the way.
- This routing approach shifts the emphasis from address-centric approaches to a data-centric approach.

## Sensor Network Organization and Tracking:

- Network organization and tracking include the fo areas:
  - Distributed group management
  - Self-organization: authentication, registration, and session establishment
  - Entity tracking: target detection, classification, and tracking
  - Dynamic sensor allocation
  - Area of coverage

## Computation:

- Computation deals with
  - Data aggregation
  - Data fusion and Data analysis
  - Grid computing (utility-based decision making in wireless sensor networks)
  - Signal processing

## Data Management:

- Data management deals with data architectures; database management, including querying mechanisms; and data storage and warehousing.
- Traditionally, data are collected to a centralized server for storage, against which queries are issued.
- Multi tire solution/multi-tiered data storage and retrieval is more interested.
- True-real-time data querying is a mechanism that can be deployed to support distributed data storage and to support distributed data querying.

## Security:

- Security deals with
  - Confidentiality (Encryption)
  - Integrity (E.g., Identity management, Digital signatures)
  - Availability (Protection from denial of service)

## Network Design Issues:

- Issues in Sensor networks relate to
  - Reliable transport (possibly including encryption)
  - Bandwidth-and power limited transmission
  - Data-centric routing
  - In-network processing
  - Self-configuration

# Challenges and Hurdles

- Challenges and limitations of wireless sensor networks include the following:
  - Limited functional capabilities, problems of size
  - Power factors
  - Transmission channel factors
  - Topology management complexity ,node distribution
  - Standards versus proprietary solutions
  - Scalability concerns

## Hardware Constraints:

- A sensor node is typically comprised of *four key* components and *four optional* components.
- The **key components** include
  - Power unit (batteries and/or solar cells)
  - Sensing unit (sensors and analog-to-digital converters),
  - Processing unit (along with storage)
  - Transceiver unit (connects the node to the network)
- The **optional components** include
  - Location-finding system
  - Power generator
  - Control actuator
  - Other application-dependent elements
  - **Analog -to-digital converters**

# Power Consumption:

- The sensor node lifetime typically exhibits a strong dependency on battery life.
- Battery operation for sensors used in commercial applications is typically based on *two AA alkaline cells* or *one Li-AA cell*.
- Power management and power conservation are critical functions for sensor networks. Need to design power-aware protocols and algorithms.
- *Power consumption* can therefore be allocated to three functional domains: *sensing, communication, and data processing*, each of which requires optimization.

## Node Unit Costs:

- A sensor network consists of a large set of sensor nodes.
- The cost of an individual node is critical to the overall financial metric of the sensor network.
- The cost of each sensor node has to be kept low for the global metrics to be acceptable.
- Current sensor systems based on Bluetooth technology cost about $10.
- The cost of a sensor node is generally targeted to be less than $1, which is lower than the current state-of-the-art technology.

## Environment:

- Sensor networks often are expected to operate in an unattended fashion in dispersed and/or remote geographic locations.
- Nodes may be deployed in harsh, hostile, or widely scattered environments.
- Sensor nodes are occasionally deployed densely either in close proximity with or directly inside the environment to be observed.

## Transmission Channels:

- Sensor networks operate in a bandwidth- and performance-constrained multi-hop wireless communications medium.
- Wireless communications links operate in the radio, infrared, or optical range.
- Low power radio-based sensor devices use a single-channel RF transceiver operating at 916 MHz .
- Some sensor systems use a Bluetooth-compatible 2.4-GHz transceiver with an integrated frequency synthesizer.

## Connectivity and Topology:

- Hundreds to thousands of sensors may be deployed in a sensor field. The density of sensors may be as high as 27 nodes/m3.
- Sensor network applications require ad hoc networking techniques.
- Any time after deployment, topology changes due to changes in
  - Sensor node position
  - Power availability
  - Dropouts, or brownouts
  - Malfunctioning
  - Jamming

# Standards:

- ➢ IEEE-based wireless LAN standards have been giv
  consideration.
- ➢ IEEE 802.11
  - Supports *1- or 2-Mbps* transmission in the *2.4-GHz band* using either *frequency hopping* spread spectrum *or direct-sequence* spread spectrum.
- ➢ IEEE 802.11a
  - It is an *extension of 802.11* that provides up to *54 Mbps* in the *5-GHz band* and uses orthogonal frequency-division multiplexing*(OFDM)* encoding.
- ➢ IEEE 802.11b
  - It is an *extension to 802.11* that provides *11-Mbps* transmission in *the 2.4-GHz* band using *DSSS.*

# WIRELESS NETWORK

- WSNs nodes (WNs) can sense the environment, can communicate with neighbouring nodes, and can, in many cases, perform basic computations on the data being collected
- The WNs have computational power and sensing capabilities and typically operate in an unattended mode
- WN gets power from battery, piezo electric or solar power source

# BASIC WIRELESS SENSOR TECHNOLOGY

# Introduction

- We are going to look about basic sensor node technologies at varying levels.
- First we concentrate on sensor node technology and categories devices into families.
- Second, we look at fundamental networking and topology issues.
- Sensor node/Wireless node/Smart dust/Mote/COTS are interchangeable.

# Sensor Node Technology

The typical requirements of WN are as follows

1. Determine the value of the parameter at a given location.
2. Determine the occurrence of event of interest and estimate the parameters of the events.
3. Classify the object that has been detected.
4. Track an object.

# Continues..

- Sensing principle include, but are not limited to, mechanical, chemical, thermal, electrical, chromatographic, magnetic, biological, optical and mass sensing.
- Typical sensor parameters (measurands) includes:

  Physical measurements

  Chemical and biological measurements

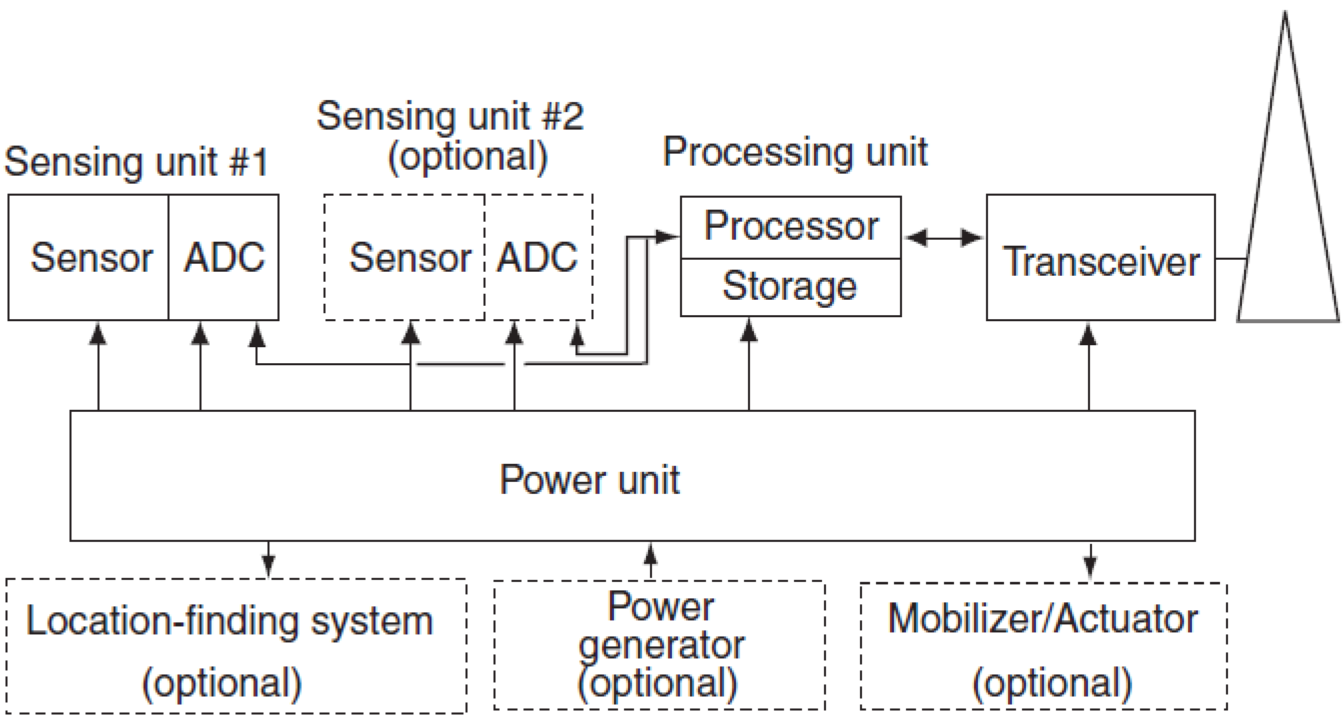
  Event measurements

# Hardware and Software

Sensors have four basic hardware subsystems

1. Power : Energy infrastructure.
2. Computational logic and storage : Used to handle onboard data.
3. Sensor Transducer(s) : Interface between environment and WNs.
4. Communication : WNs must have the ability to communicate

# Hardware

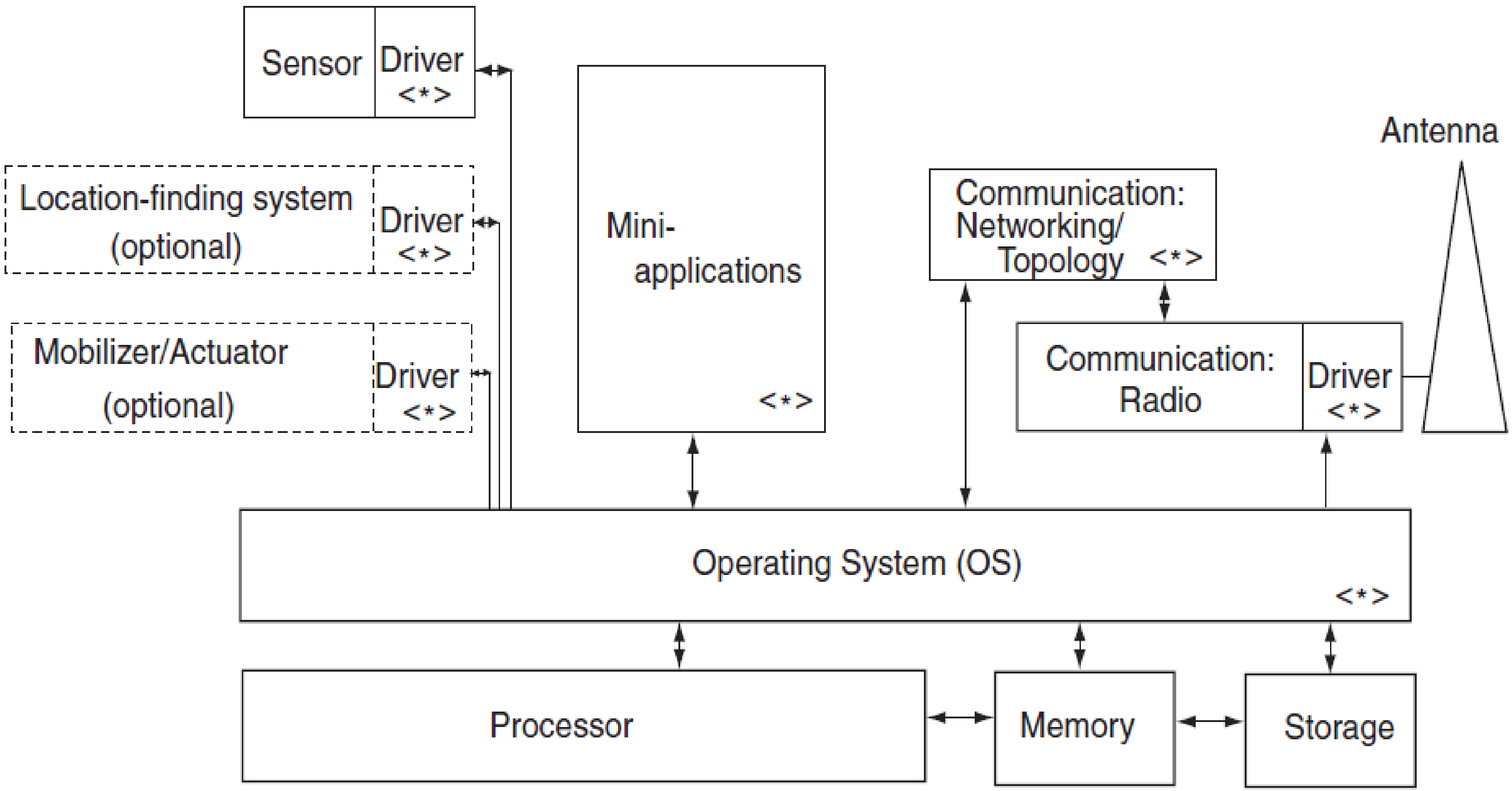



ADC = Analog-to-Digital Converter

Sensors have five basic software subsystems

1. Operating system(OS) or microcode (also known as middleware).
2. Sensor Drivers.
3. Communication processors.
4. Communication drivers.
5. Data processing mini-apps.

**Software**




<*> Software

# Sensor Taxonomy

- As we have a variety of sensor types, the taxonomy is useful.
- Taxonomy is some what daunting since there are 9*9*9*8*7*10*5=2,041,200 cases or combination.
- To reduce the scope of taxonomy, we suggest the modified table 3.2 as 4*4*4*3*2*2=768 cases or combinations.

# Some of the networking protocols supported by WNs

Communication Protocols

| | |
|---|---|
| Upper layers (communications) | In-network applications including application processing, data aggregation, external querying query processing, external database |
| Transport layer | Transport, including data dissemination/accumulation, caching, storage |
| Network layer | Networking, including adaptive topology management, topological routing |
| Data link layer | Channel Sharing (MAC), timing, locality |
| Physical layer | Communication channel, sensing, actuation, signal processing |

Network layer protocols:

Data-centric
- Sensor Protocols for Information vis Negotiation (SPIN)
- Directed Diffusion Rumor Routing Gradient-based routing (GBR)
- Constrained anisotropic diffusion routing (CADR)
- COUGAR

Hierarchical
- Energy Adaptive Clustering Hierarchy (LEACH)
- Threshold sensitive Energy Efficient sensor Network protocol (TEEN) and Adaptive Threshold sensitive Energy Efficient sensor Network protocol (APTEEN)
- Power-Efficient GAthering in Sensor Information Systems (PEGASIS)

Location-based
- Minimum Energy Communication Network (MECN) and Small Minimum Energy Communication Network (SMECN)
- Geographic Adaptive Fidelity (GAF) Geograhic and Energy
- Aware Routing (GEAR)

QoS-oriented
- Sequential Assignment Routing (SAR)
- Stateless Protocol for end-to-end delay (SPEED)

Physical layer:
- IEEE 802.11b/g Wi-Fi™
- IEEE 802.15.1 Bluetooth™
- IEEE 802.15.4 ZigBee™

*Networking Driver* | *Other Drivers*

***OPERATING SYSTEM*** *(e.g., TinyOS)*

# Basic Taxonomy Of Sensor Nodes

| Size of Sensor | Mobility of Sensor | Power of Sensor | Computation logic; Storage | Sensor Mode | Communication apparatus; Lower layer protocol | Communication apparatus; Higher layer protocol |
|---|---|---|---|---|---|---|
| Very large | FM at deployment; FM at post deployment | Self replenishable; Continuous | High-end processor; High-end Storage | High-end multimodal; Physics | Multi-Hop/Mesh; IEEE/MAC | Dynamic Routing; Data-centric |
| Large | FM at deployment; SM at post deployment | Self replenishable; Sporadic | Mid-range processor; High-end Storage | HE MM; Chemistry, Biology | Multi-Hop/Mesh; IEEE/MAC | Dynamic Routing; Hierarchical |
| Medium | FM at deployment; IM at post deployment | Battery 10 power 1 hours | Low-end processor; High-end Storage | HE MM; P,C,B | Multi-Hop/Mesh; IEEE MAC | Dynamic Routing; location based |

# Reduced Complexity Of Sensor Node

| Size of Sensor, s | Mobility of Sensor, m | Power of Sensor, p | Computation Logic and Storage Capability of Sensor, cp | Sensor Mode, md | Communication Apparatus or Protocols of Sensor, cm |
|---|---|---|---|---|---|
| 1 Large | 1 Mobile | 1 Self-replenishable | 1 High-end processor and storage | 1 Multimodal, physics | 1 Multihop/mesh with dynamic routing |
| 2 Small | 2 Static | 2 Battery, hours–days | 2 Midrange processor and storage | 2 Multimodal, chemistry/biology | 2 Single hop with static routing |
| 3 Microscopic | | 3 Battery, weeks–months | 3 Low-end processor and storage | 3 Single function, physics | |
| 4 Nanoscopic | | 4 Battery, years | | 4 Single function, chemistry–biology | |

# WN operating environment

Sensor nodes have to deal with the following resource constraints:

1.Power consumption: Energy conservation.

2.Communication: Limited bandwidth, noisy channel, security exposure.

3.Computation: Limited computing power and memory resources.

4.Uncertainity in measured parameters: Due to interference in the environment

# Design constraints or requirements for WNs

- Collaborative data processing
- Constrained energy use
- Large topology support
- Querying capabilitie
- Self-organization

Some of the intrinsic factors in design constraints:

- WNs may be deployed in a dense manner.
- Need to support in ad hoc fashion, highly dynamic.
- WNs are prone to failure
- Communication circuit and antennas are primary element.
- WNs does not have a global address.
- Require special routing and data dissemination mechanism.

# WN Trends

- For WSNs to achieve wide-scale deployment, the size, cost, and power consumption of the nodes must decrease considerably and the intelligence of the WNs must increase.
- Miniaturization, manufacturability, and cost are also critical issues. Integration of sensors, processors, energy sources, and the communications network interface on a chip would facilitate the exchange of sensor data and critical information with the outside world.

Evolving requirements for new WSNs and WNs include, among others:

(1) The ability to respond to new toxic chemicals, explosives, and biological agents.

(2) enhanced sensitivity, selectivity, speed, robustness, and fewer false alarms.

(3) the ability to function, perhaps autonomously, in unusual, extreme, and complex environments.

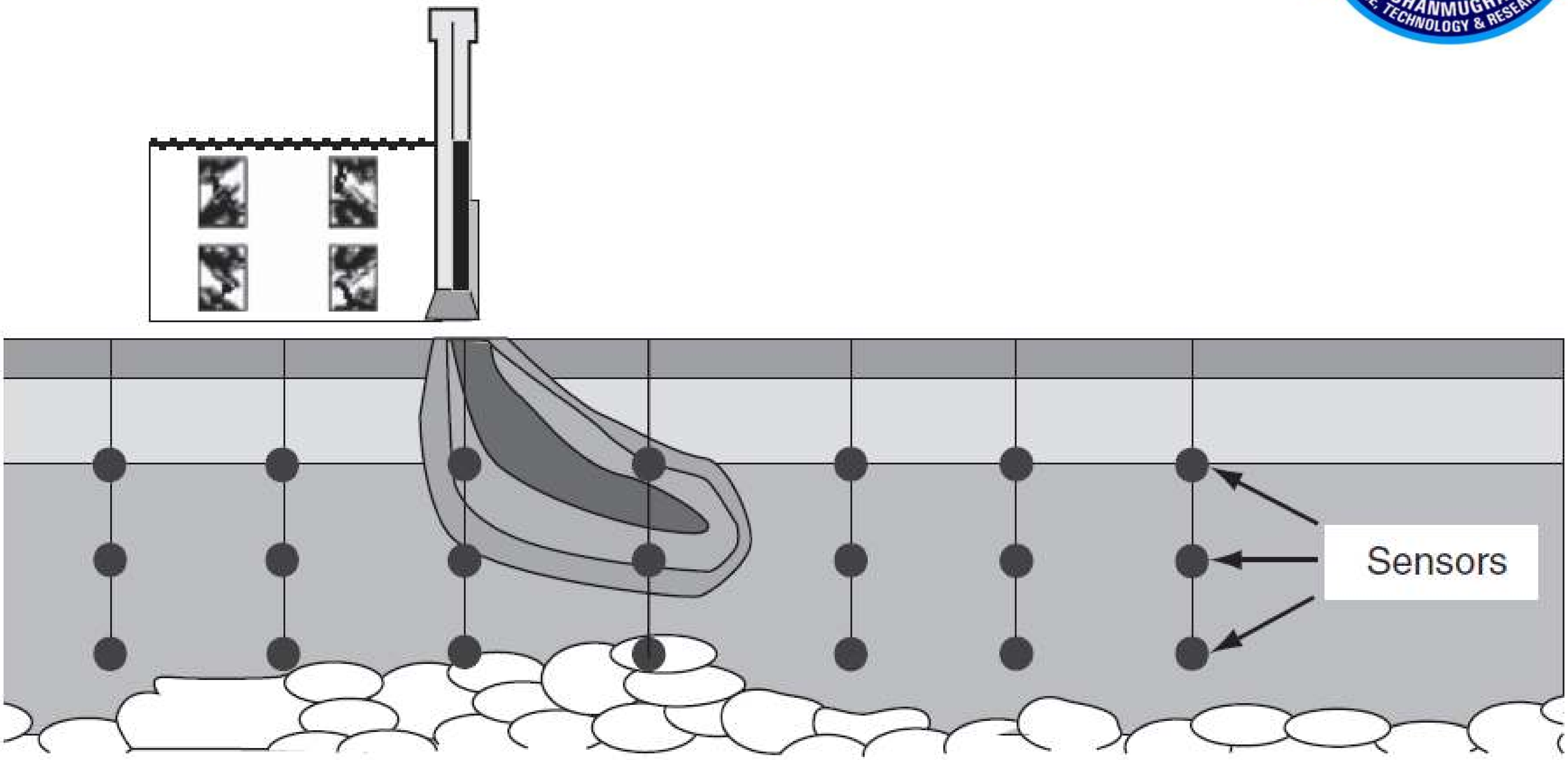
# Partial List of Near-Term Research Efforts as Sponsored by U.S. Government Agencies

- Designs, materials, and concept for new sensors and sensing system - (Ex) biometric sensors, including hybrids consisting of proteins.
- Arrayed sensor networks and networking – (Ex) Scalable and robust architectures ,Design, Automated tasking , Querying techniques.
- Interpretation, decision and action based on sensor data – (Ex) concepts for optimal sensor locations for effective process and system control.

# Sensor array for chemical contamination analysis

- Sandia has been testing handheld sensors designed to detect chemical-weapons agents on the battlefield with high sensitivity; the detection window is 2 minutes or less.
- The lab has been asked to explore adding networking and GPS capability to those sensors so that they could be mounted on military vehicles, creating a mobile battlefield sensor network.
- The expectation is that by the turn of the present decade, a bio smoke alarm detector will be ready for commercial deployment

# Sensor array for chemical contamination analysis



# Conclusion

In this chapter we looked at basic sensor node technology along with a taxonomy of sensor types. Some current trends were also discussed.

# WIRELESS TRANSMISSION TECHNOLGY AND SYSTEMS

# INTRODUCTION

- Radio channel related issues
- Make use of emerging Commercial off-the-self(COTS)
- COTS technologies(PANs,WLAN,WiMax,3G)
- Plug –and-play system integration
- Macro-level issues

# Radio Technology Primer

- Electromagnetic spectrum provides a channel for broadcast radio transmission
- Analog bandwidth determines how much information can be transmitted over the channel
- A transmission channel is never perfect due to external noise sources
- Radio transmission engineering deal with noise problem
  - Optimize the signal-to-noise ratio with constraints(cost ,reliability, power consumption etc.)

# Propagation and Propagation Impairments

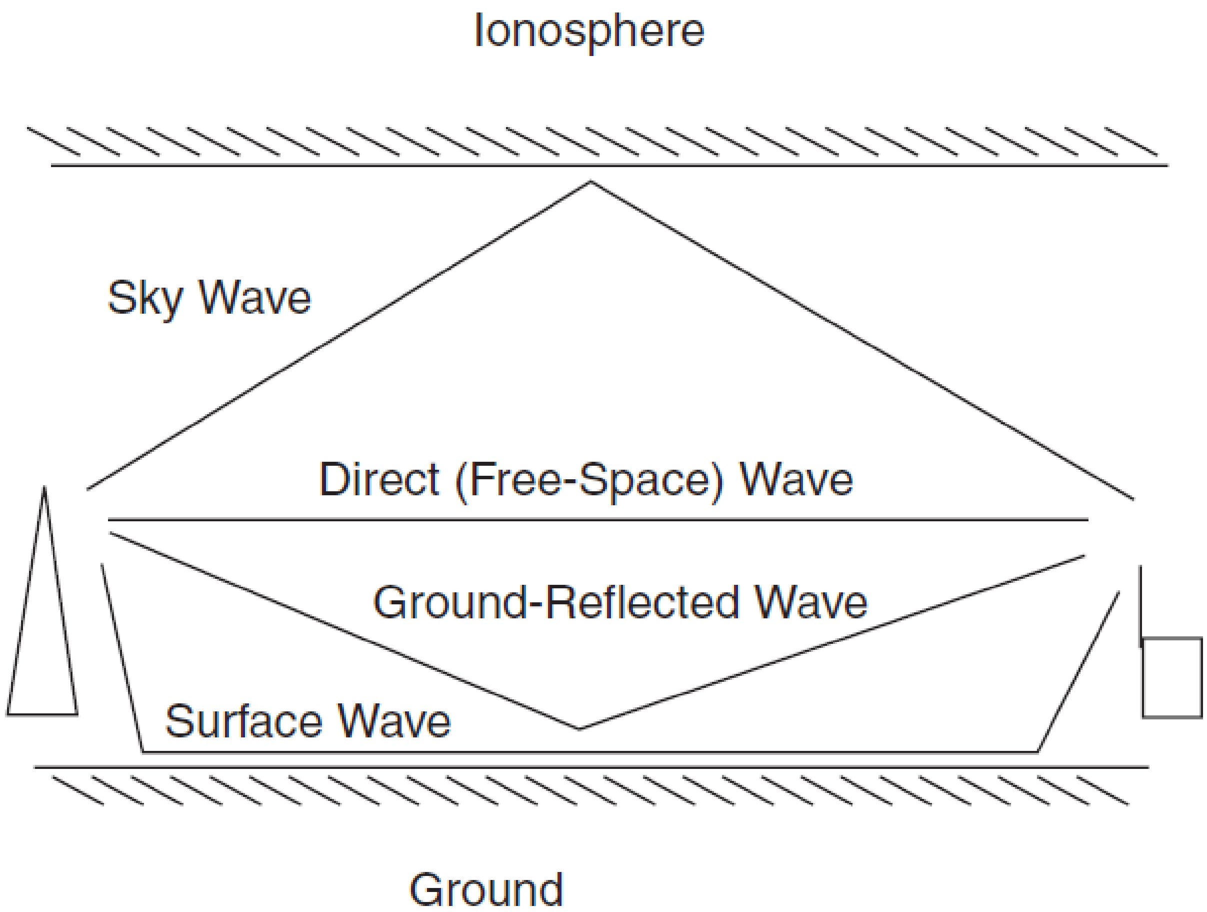
- Radio design includes propagation, impairments, sensitivity, antenna design, bandwidth etc.
- These design factors related to frequency band in use
- Higher frequency bands if  bandwidth increases
- Basic model of radio wave propagation - ***direct or free-space wave***

# Direct or free-space wave model

Radio waves emanate, travel in all directions in straight line ,filling entire space with radio energy

Strength=I/(Distance)$^2$

# Diagram


Ionosphere
Sky Wave
Direct (Free-Space) Wave
Ground-Reflected Wave
Surface Wave
Ground

# Physical Mechanism affect radio Propagation

- Reflection
- Diffraction
- Scattering

These phenomena cause radio signal distortions and signal fading as described in table,

# Phenomena Affecting Signals

| Phenomenon | Description |
|---|---|
| Reflection | Occurs when a propagating electromagnetic wave impinges upon an object that is large compared to the wavelength of the propagation wave. |
| Diffraction | Occurs when the radio path between the transmitter and receiver is obstructed by a surface that has  sharp irregularities. |
| Scattering | Occurs when the medium through which the wave travels consists of objects with dimensions that are small compared to the wavelength and where the number of obstacles per unit volume is large. |

- The intrinsic electromagnetic signal strength attenuation caused by this phenomenon is called ***large-scale effect.***
- Signal-strength fluctuation related with the motion of the broadcasting or receiving antenna are called ***small-scale effect.***
- When multiple signal path exist ,the actual signal level received is the vector sum of all the signals incident from any direction.

# Multipath Types

| Type | Description |
|---|---|
| Specular Multipath | Arises from discrete ,coherent reflections from smooth metal surfaces. The problem is especially difficult in underpasses, tunnels, stairwells and small enclosed room. |
| Diffuse Multipath | Arises from diffuse scatters and sources of diffraction. It gives rise to a background noise level of interference. |

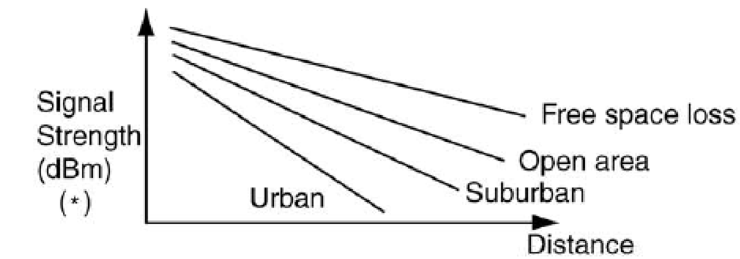
# Fade Factors

- Large-scale fades :
  - Attenuation: in free space, power decreases as a function of 1/d^2 (d  distance from the transmitting antenna)
  - Shadows: signals blocked by obstructing structures

# Fade Factors

- Small-scale fades :
  - Rapid changes in signal strength over a small area or time
  - Random frequency modulation due to varying Doppler
  - shifts on different multipath signals
  - Time dispersion (echoes) caused by multipath propagation delays
  - Multipath propagation yields signal paths of different paths with different times of arrival at the receiver

# Outdoor Propagation

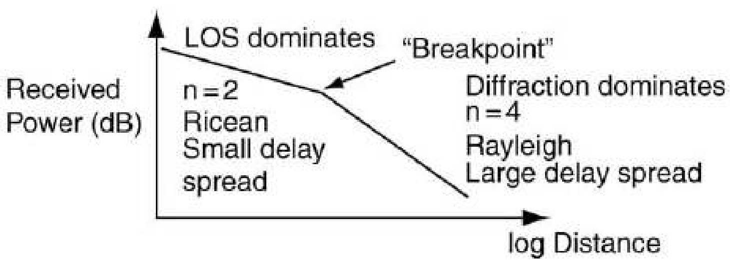



(*) Relative power of received signal compared to power at ref. distance from transmitter

Received Power $P_r = Kd^{-n}$, n = 2 in free space, $3 \le n \le 4$ typically

BER = $f$(signal stength)

Error rates increase as SNR decreases




| Item | Macrocell | Microcell |
|---|---|---|
| Cell Radius | 1 to 20 km | 0.1 to 1 km |
| Tx Power | 1 to 10 W | 0.1 to 1 W |
| Fading | Rayleigh | Ricean |
| RMS Delay Spread | 0.1 to 10 µs | 10 to 100 ns |
| Max. Bit Rate | 0.3 mbps | 1 mbps |

**Figure 4.2** Outdoor radio propagation. (Based in part on [4.2].)

# Indoor propagation

Path loss=unit loss+10nlog(d) = kF+ IW

where ,

unit loss = power loss (dB) at a 1m distance (30 dB)

n = power-delay index

d = distance between transmitter and receiver

k = number of floors that the signal traverses

F = loss per floor

I = number of walls that the signal traverses

W = loss per wall

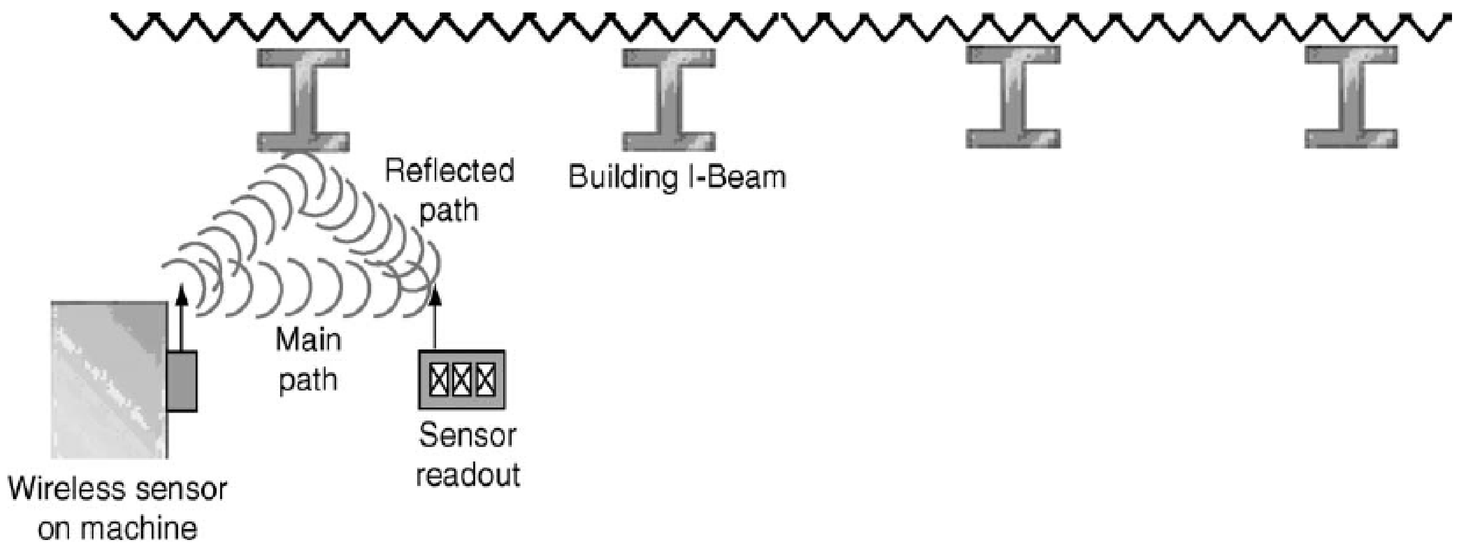
- Indoor signal depends on office plan ,construction materials
- A drawback of higher frequency bands compared to low frequency bands is the shorter the wavelength of the signal at the higher band

# Signal Attenuation Due To Typical Obstacles

| Wall type | Frequency | Transmission loss |
|---|---|---|
| Exterior wood frame wall | 800 MHZ<br>5-6 GHZ | 4-7<br>9-18 |
| Brick Exterior | 4-6 GHZ | 14 |
| Concrete block, interior | 2-4 GHZ<br>5 GHZ | 5<br>5-10 |
| Gypsum board interior | 2-4 GHZ<br>5 GHZ | 3<br>5 |
| Wooden Floors | 5 GHZ | 9 |
| Concrete Floors | 900 MHZ | 13 |

- Few “RF-friendly” buildings that are free of multipath reflections
- Radio wave propagation inside smooth-walled metal buildings can be so problematic that radio dead spots can exist to the point where the signal is virtually nonexistent.
- The dead spots arise because of almost perfect, lossless reflections from smooth metal walls, ceilings, or fixtures that interfere with signals radiated directly
- Proper functioning of the radio communication link requires that multipath be minimized or eliminated

# Indoor Interference



- Error bursts are an outcome of fades in radio channels.
- The typical acceptable BER for data communications is $10^{6.}$
- Strategies for overcoming errors include antenna diversity, forward error correction techniques, and traditional automatic repeat request.
- In an industrial environment, sensors are placed in order to minimize interference.

- Sensors that must be located near such devices should connect to transmitter via a short piece of shielded cable.
- multipath propagation occurs when nearby metal reflects the radio signal in the same way that a mirror reflects light.
- The receiver detects multiple signals simultaneously -the original and the reflections -and cannot decode any of them.
- Moving the receiving or transmitting antenna just a few inches fix this problem

# Multipath Problems

- Radio system design
- Antenna system design
- Signal/waveform design
- Building/environment design

- Interference can also be caused by other legitimate or illegitimate users of a given frequency band.
- Occur when a user starts to broadcast signal in a band while in proximity to other transmitters and/or receivers.

# Modulation

- Overlay of an intelligent signal over an underlying carrying signal, which is then transmitted over the medium
- Baseband applications are applications where the coded signal is carried directly over a medium without having to overlay it onto a carrier signal.
- Baseband systems usually are limited to the carriage of information over a fraction of a mile.
- Non-baseband systems use modulation
- Analog radio and TV transmission use modulation.

# Types Of Modulation

- Amplitude Modulation (AM)

  amplitude of the carrying signal is modulated by the incoming intelligence-bearing signal.
- Frequency Modulation (FM)

  frequency of the carrying signal is modulated by the incoming intelligence-bearing signal.
- Phase Modulation(PM)

  phase of the carrying signal is modulated by the incoming intelligence-bearing signal.

- AM ,when the incoming intelligence-bearing signal – is digital [seq 0,1]the modulation process is called amplitude shift keying(ASK).
- FM , when the incoming intelligence-bearing signal is digital, the modulation process is called frequency shift keying (FSK).
- PM, when the incoming intelligence-bearing signal is digital, the modulation process is called phase shift keying (PSK).

- Incoming signal  interpreted as a sequence of n bits at a time (e.g., 00, 01, 10, 11; or 000, 001,010, 011) and a combination of PSK and ASK techniques are used, the modulation process is called quadrature amplitude modulation (QAM).
- The maximum digital capacity C of a single-carrier system with spectral bandwidth W is defined by Shannon's equation

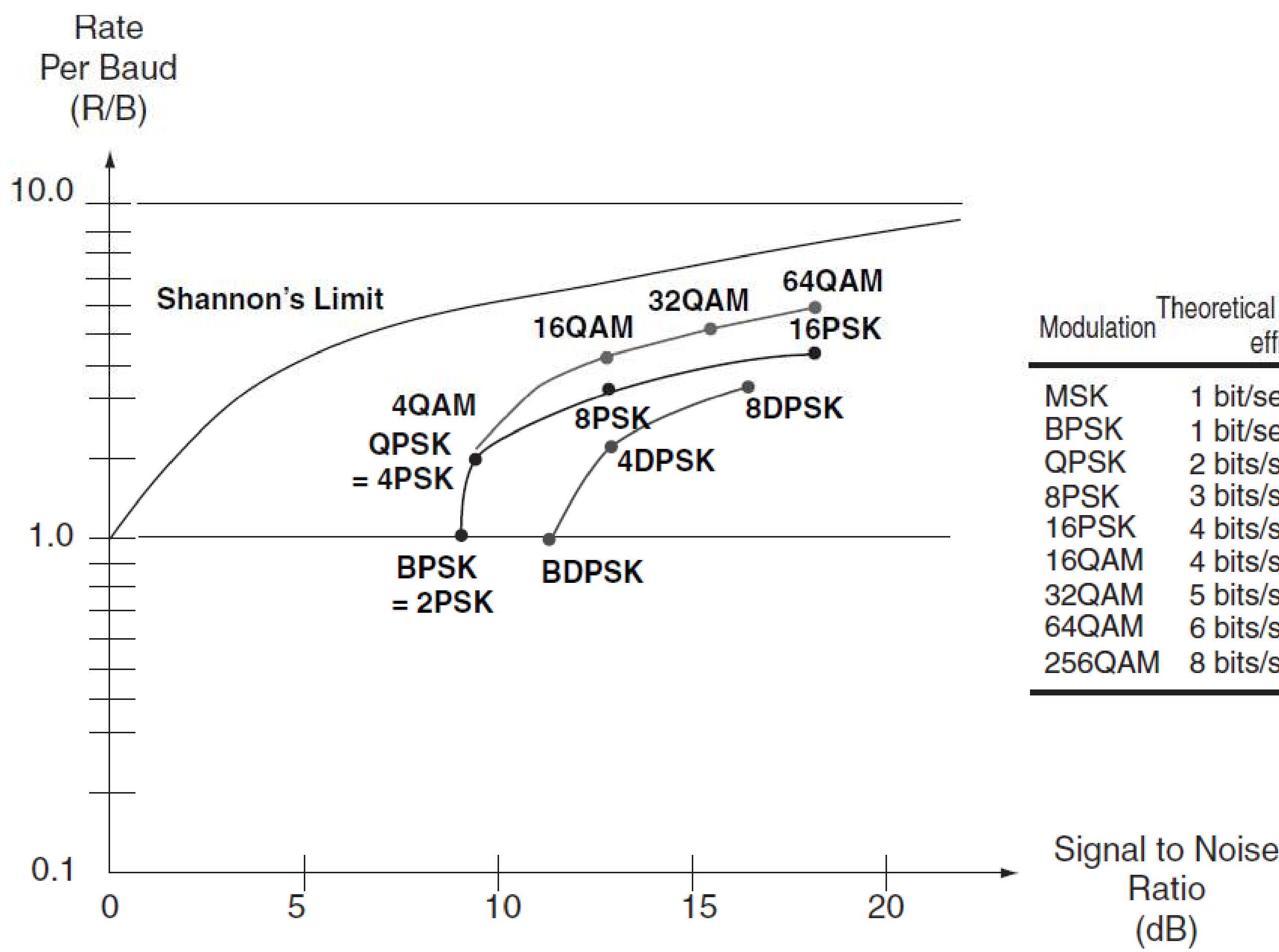
$$C=W \log_2(1+S/N)$$

Where,

S is the signal power received

N is the noise power

log term usually ranges from 1 to 10, depending on the modulation technique.




| Modulation | Theoretical bandwidth efficiency |
|---|---|
| MSK | 1 bit/second/Hz |
| BPSK | 1 bit/second/Hz |
| QPSK | 2 bits/second/Hz |
| 8PSK | 3 bits/second/Hz |
| 16PSK | 4 bits/second/Hz |
| 16QAM | 4 bits/second/Hz |
| 32QAM | 5 bits/second/Hz |
| 64QAM | 6 bits/second/Hz |
| 256QAM | 8 bits/second/Hz |

- Spread-spectrum modulation techniques have a higher effective signal-to-noise ratio than narrowband techniques, but require more channel bandwidth.
- Direct sequence spread spectrum (DSSS) is one of the two common spread-spectrum techniques(ZigBee)
  - the incoming  data stream is hashed by a pseudorandom sequence that generates a sequence of output micro bits or chips that are distributed across the underlying broadband channel.

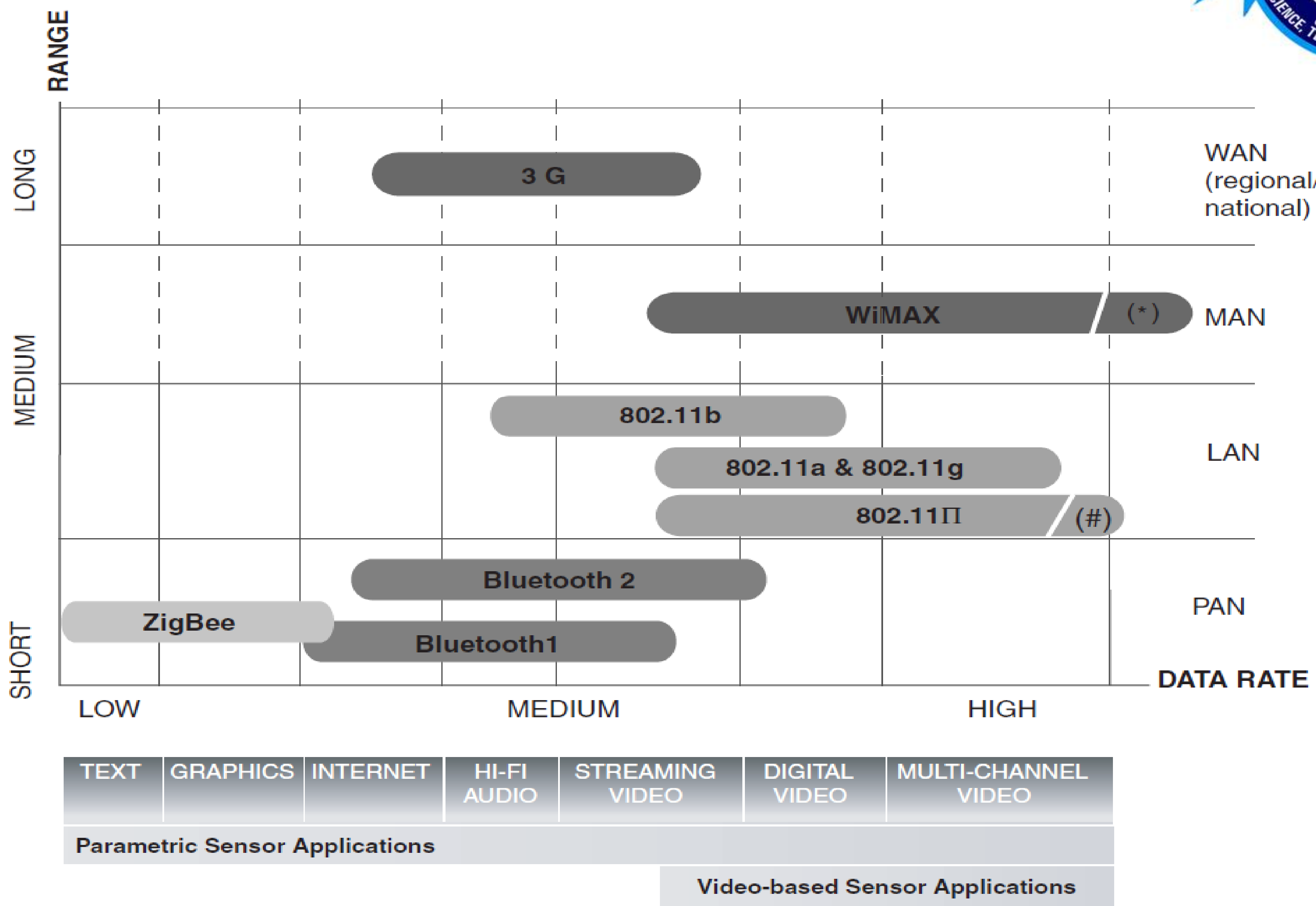
- Frequency hopping spread spectrum (FHSS) is the other technique (Bluetooth environment for PANs).
- Fairly complex digital signal processing functions needed.
- Compared to DSSS systems, FHSS uses relatively low complexity baseband hardware.
- Synchronization mechanism is also less complex
- Frequency hopping requires fast signalling settling.

- FHSS for WSNs (e.g., improved multipath performance can be achieved with FHSS)
- However, the requirement for low-power operation and the wide band nature of operation gives rise to practical engineering challenges

# AVAILABLE WIRELESS TECHNOLOGIES

- IEEE PAN/LAN/MAN technologies are broadly implemented technologies .
- The widely used wireless protocols are
  - (1) the IEEE 802.15.1 (Bluetooth);
  - (2) the IEEE 802.11a/b/g/n series of wireless LANs;
  - (3) the IEEE 802.15.4 (ZigBee);
  - (4) the MAN-scope IEEE 802.16(WiMax); and
  - (5) radio-frequency identification (RFID) tagging.

# Graphical comparison of available protocols.




(*) Up to 268 Mbps
( # ) Up to 108 Mbps

# Wireless Protocol Comparison

| | IEEE Standard | | |
|---|---|---|---|
| Property | 802.11 | 802.15.1/Bluetooth | 802.15.4/ZigBee |
| Range (m) | ~100 | ~10 to 100 | ~10 |
| Data throughput (Mbps) | ~2 to 54 | ~1 to 3 | ~0.25 |
| Power consumption | Medium | Low | Ultralow |
| Battery life measured in: | Minutes to hours | Hours to days | Days to years |
| Size relationship | Large | Smaller | Smallest |
| Cost/complexity ratio | >6 | 1 | 0.2 |

- The IEEE 802.15.4 standard supports a maximum data rate of 250 kbps, with rates as low as 20 kbps ; it has the lowest power requirement of the group.
- **ZigBee** devices are designed to run several years on a single set of batteries, making them ideal candidates for unattended or difficult-to reach locations.
- **Bluetooth** is a short-range communication protocol widely used in cellular-type phones and PDAs.
- **RFID** is the one form of wireless sensing that requires no power in the tag; it is a passive technology used for labeling and tracking.

# Campus Applications

- Campus sensor communications can occur over Bluetooth, wireless LAN (WLAN), ZigBee, or WiMax/hotspot systems.

# Bluetooth

- A specification for short-range RF-based connectivity for portable personal devices. a short-range wireless data exchange.
- A Protocol designed for a small variety of tasks, such as synchronization, voice headsets, cell modem calls, and mouse and keyboard input.
- IEEE Project 802.15.1 developed a wireless PAN standard based on the Bluetooth v1.1 Foundation Specifications.
- The system uses omnidirectional radio waves that can transmit through walls and other nonmetal barriers.

# Bluetooth

- The Bluetooth specification defines a low-power, low-cost technology that provides a standardized platform for eliminating cables between mobile devices and facilitating connections between products.
- The Bluetooth wireless specification includes both link layer and application layer definitions for product developers.
- Bluetooth radios use a spread-spectrum, frequency-hopping, full-duplex signal.

# Bluetooth

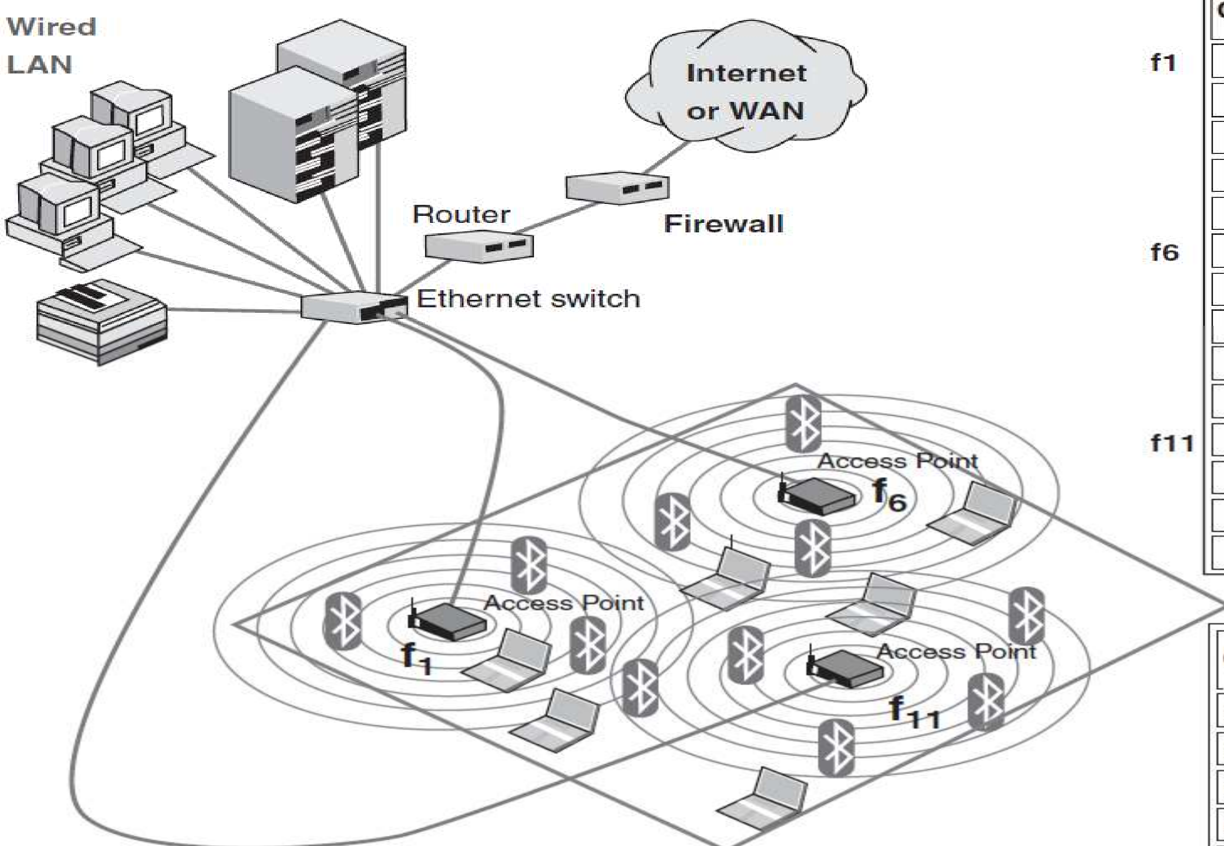
- Noteworthy features of Bluetooth core specification version 2.0 þ EDR include:
  - Three times faster transmission speed than that of preexisting technology
  - Lower power consumption through a reduced duty cycle
  - Simplification of multilink applications due to increased available bandwidth
  - Backwardly compatible to earlier versions
  - Improved bit-error-rate performance

# Bluetooth

- A Bluetooth device playing the role of "master" can communicate with up to seven devices playing the role of "slave" (groups of up to eight devices are called piconets).
- At any given instant in time, data can be transferred between the master and one slave; but the master switches rapidly from slave to slave in a round-robin fashion.

# WLAN

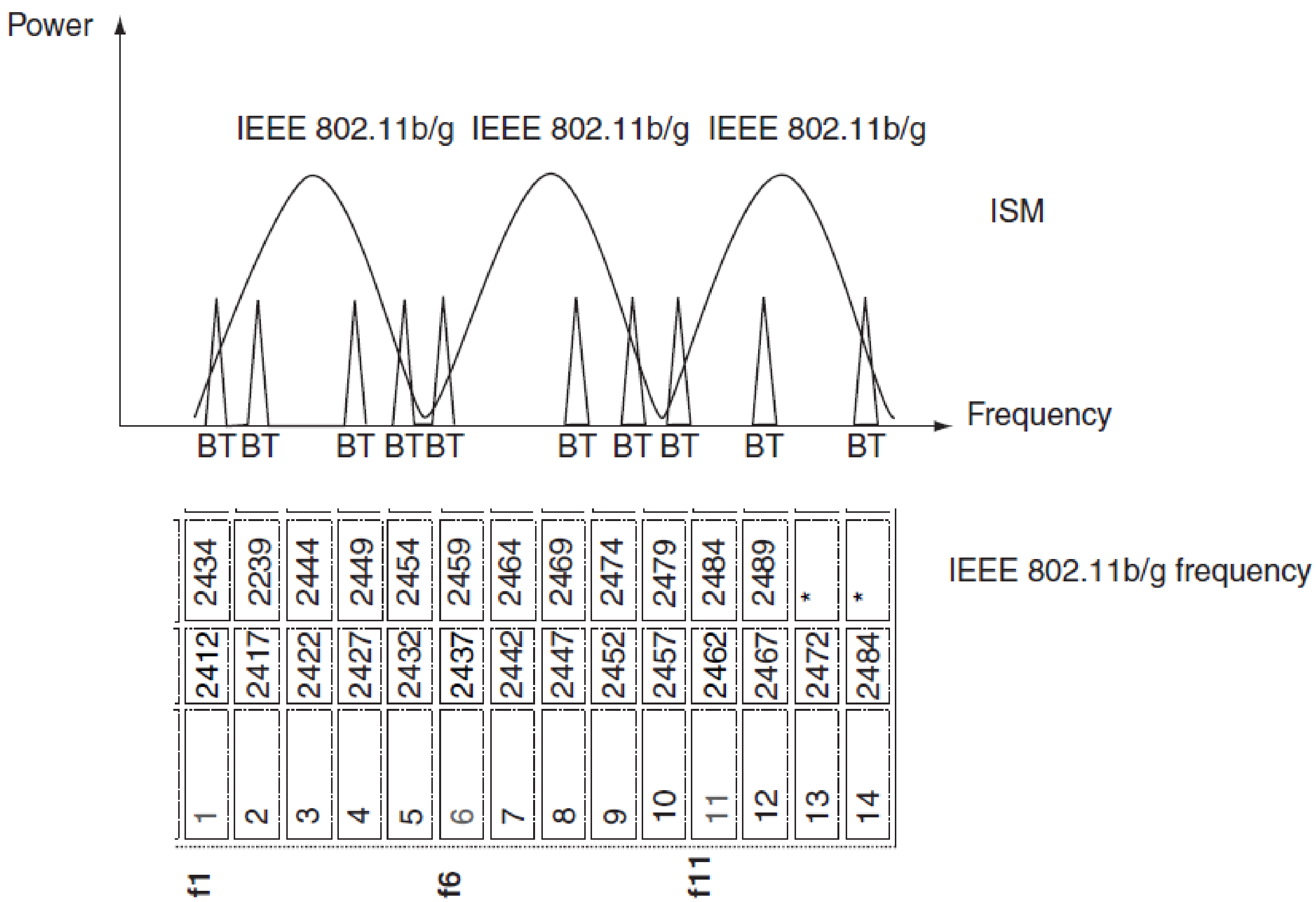
- Higher WLAN speeds to support an adequate number of users in high-density environments and also voice over IP (VoIP) users.
- Support of QoS over the wireless (and also core intranet) infrastructure.
- Secure communications is highly desirable. Roaming between access points, floors, and subnets is needed.




| | Channel | MHz | |
|---|---|---|---|
| f1 | 1 | 2412 | 2434 |
| | 2 | 2417 | 2239 |
| | 3 | 2422 | 2444 |
| | 4 | 2427 | 2449 |
| | 5 | 2432 | 2454 |
| f6 | 6 | 2437 | 2459 |
| | 7 | 2442 | 2464 |
| | 8 | 2447 | 2469 |
| | 9 | 2452 | 2474 |
| | 10 | 2457 | 2479 |
| f11 | 11 | 2462 | 2484 |
| | 12 | 2467 | 2489 |
| | 13 | 2472 | |
| | 14 | 2484 | |

| Channel | MHz | |
|---|---|---|
| i | 2412 | 2413 |
| ii | 2413 | 2414 |
| iii | 2414 | 2415 |
| iv | 2415 | |
| v | | |

# IEEE 802.11b/g Frequency Bands, Typical Topology, Bluetooth Interaction



# WLAN

- The 802.11a standard uses 300 MHz of bandwidth; the spectrum is divided into *three domains*, each having restrictions imposed on the maximum output allowed.
- The *first 100 MHz* in the lower-frequency portion is restricted to a maximum power output of 50mW;
- The *second 100 MHz* has a higher maximum, 250mW; and
- The *third 100 MHz*, intended primarily for outdoor applications, has a maximum power output of 1.0W.

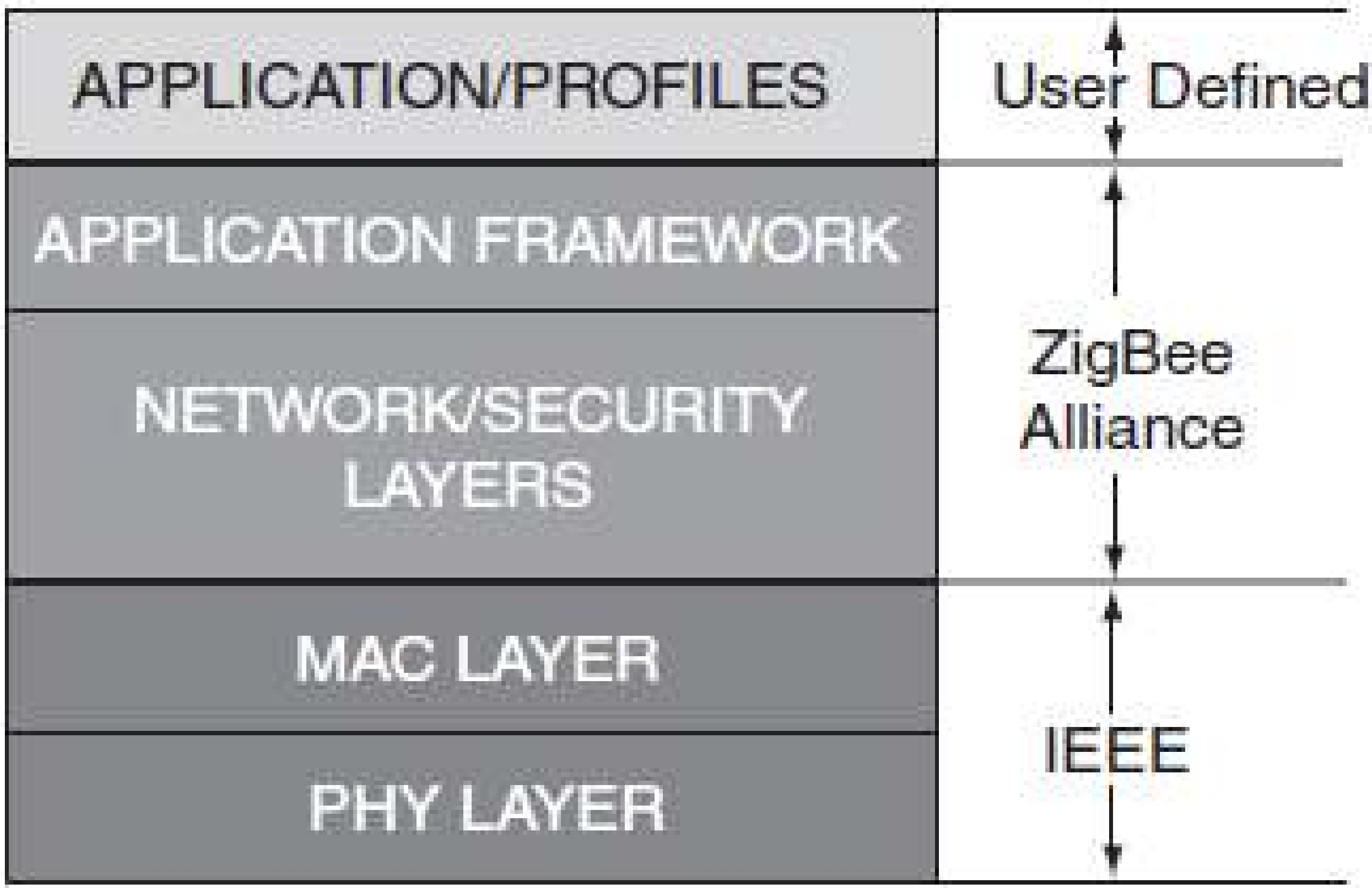
# A Comparison of IEEE 802.11b/g and IEEE 802.11a

| | 802.11b/802.11g | 802.11a |
|---|---|---|
| Available bandwidth | 83.5 MHz | 300 MHz |
| Unlicensed frequencies of operation | 2.4–2.4835 GHz | 5.15–5.35 GHz, 5.725–5.825 GHz |
| Number of non-overlapping channels | 3 (indoor–outdoor) | 4 (indoor–outdoor) |
| Data rate per channel | 1, 2, 5.5, 11, 54 Mbps | 6, 9, 12, 18, 24, 36, 48, 54 Mbps |
| Modulation | DSSS | OFDM |

# ZigBee

- ZigBee is the only standards-based technology designed to address the unique needs of low-cost, low-power WSNs for remote monitoring, home control, and building automation network applications in the industrial and consumer markets.
- Functionality defined by the ZigBee Alliance is used at the upper layers.
- The ZigBee Alliance ratified the first ZigBee specification in 2004, making the development and deployment of power-efficient, cost-effective, low-data-rate monitoring, control, and sensing networks a reality.

# ZigBee-Protocol Stack




**IEEE 802.15.4 Stack**

# Hotspot/WiMax

- In recent years service providers have deployed IEEE 802.11b/11g-based hotspot services to support Internet access and VoIP applications.
- Metro-wide Internet/VoIP services are delivered using WiMax (IEEE 802.16-based) connectivity.

# WiMax

- The IEEE 802.16 Working Group has developed a point-to-multipoint (PMP)broadband wireless access standard for systems in the frequency ranges 10 to66 GHz and sub-11 GHz. This technology is targeted to metropolitan area environments.
- The IEEE 802.16 standard covers both the MAC and PHY layers.
- A typical WiMax network consists of a base station supported by a tower- or building-mounted antenna.

# WiMax

- The base station connects to the appropriate terrestrial network (PSTN, Internet, etc.)
- Applications include
  - point-to-point communication between stations,
  - point-to-multipoint communication between the base station and clients,
  - backhaul services for Wi-Fi (802.11) hotspots,
  - broadband Internet services to home users,
  - private-line services for users in remote locations,
  - metro-wide WSN applications.

# MAN/WAN Applications

- MAN/WAN sensor communications can occur over
  - WiMax/hotspots or
  - 3G systems.

# Cognitive Radios and IEEE 802.22

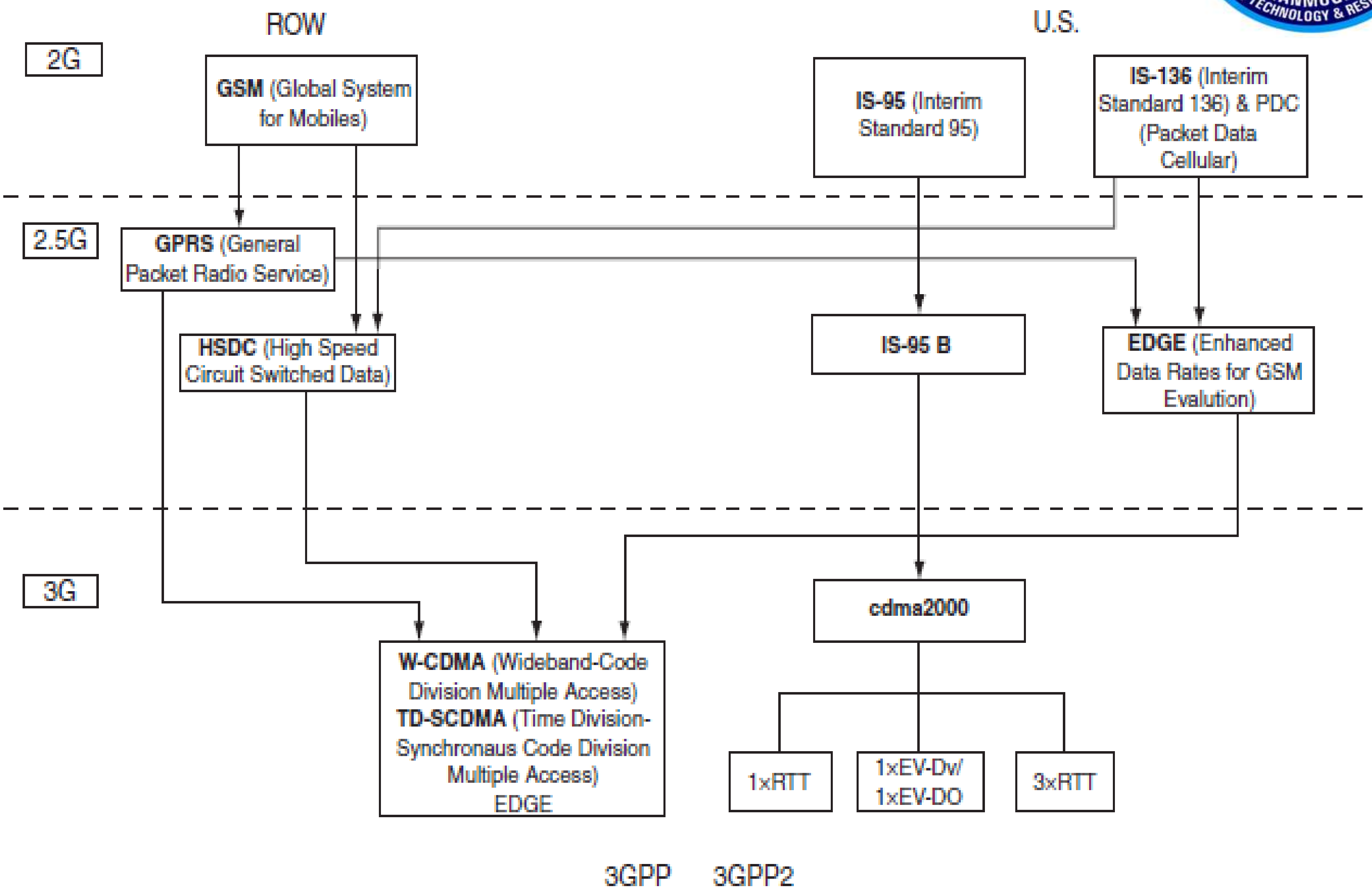
- The IEEE 802.22 wireless regional area network (WRAN) standard is the first worldwide project to employ CR concepts for dynamically sharing spectrum with television broadcast signals. IEEE 802.22 seeks to develop a standard for a cognitive radio-based PHY–MAC–air interface

- *Cognitive radio*—where a device can sense its environment and location and then alter its power, frequency, modulation, and other parameters so as to dynamically reuse available spectrum—is now just emerging.
- CR can allow multidimensional reuse of spectrum in space, frequency, and time.
- This new technology is in a way similar to software-defined radio (SDR).

# 3G Cellular Networks

- Third Generation Partnership Project (3GPP)
- The American National Standards Institute (ANSI) decided to establish the Third Generation Partnership Project 2 (3GPP2), a 3G partnership initiative for evolved ANSI/TIA/Electronics IndustryAssociation (EIA) networks .
- The establishment of a strategic group called International Mobile Telecommunications-2000 (IMT-2000) within the International Telecommunication Union (ITU)

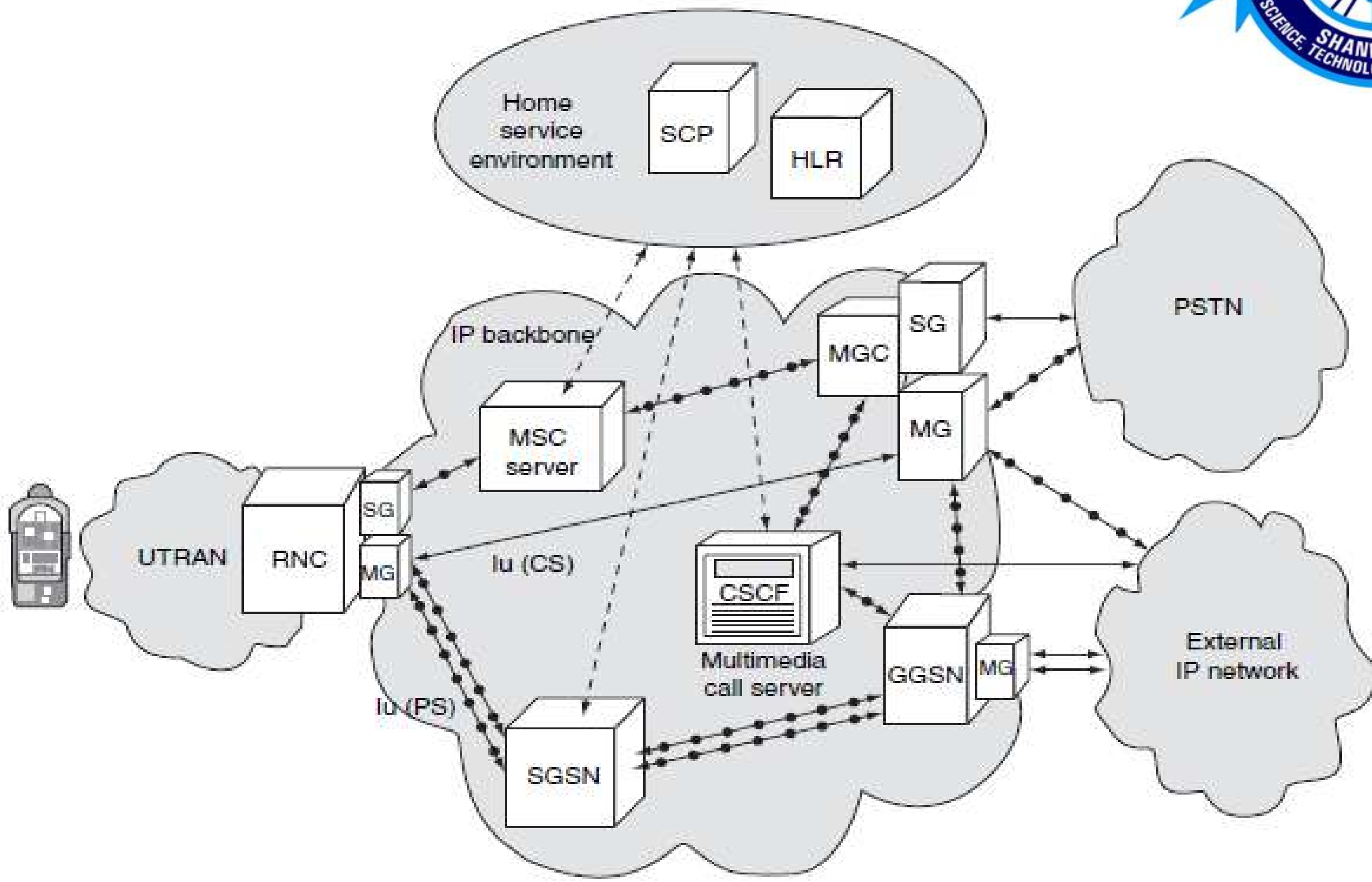
# Migration path(s) to 3G wireless networks.



# 3GPP

- 3GPP uses only SIP(Session Initiation Protocol) as the call control protocol between terminals and the mobile network. Interworking with other H.323 terminals (e.g., fixed H.323 hosts) is performed by a dedicated server in the network.

# All-IP 3G cellular service.



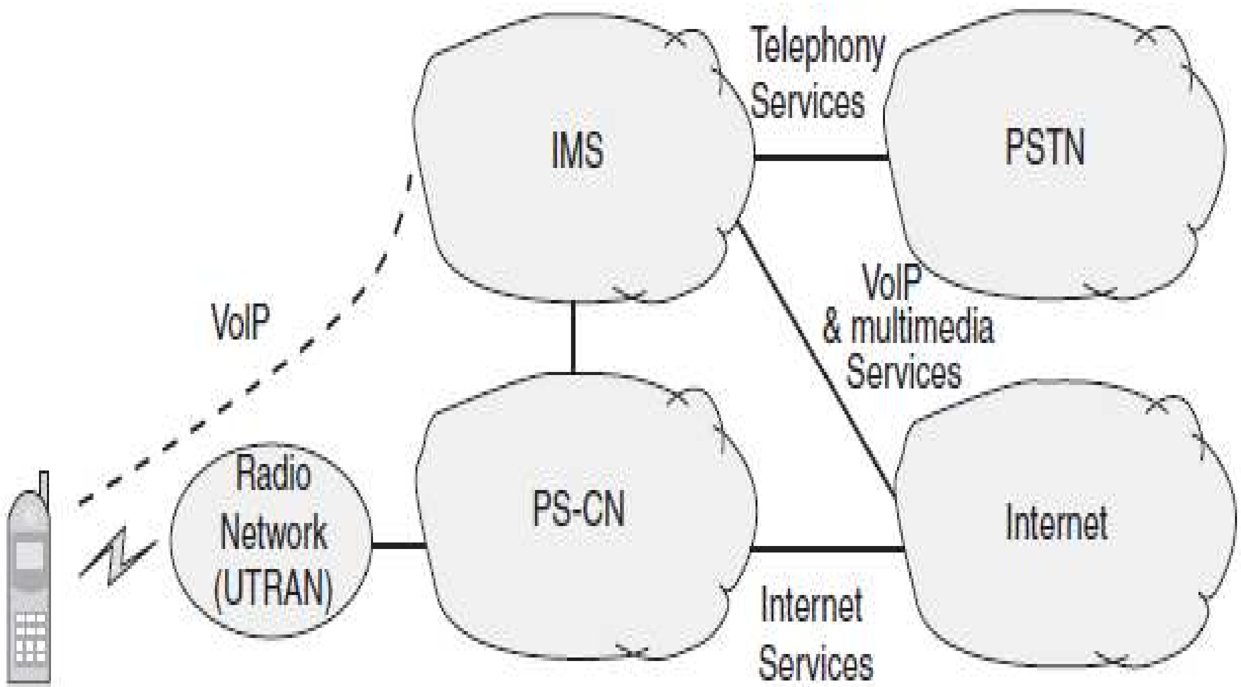

UTRAN = Universal Terrestrial Access Network
RNC = Radio Network Controller
CSCF = Call State Control Function
SG = Signaling Gateway
MG = Media Gateway
MSC = Mobile Switching Center

SGSN = Serving GPRS Support Node
SCP = Service Control Point
HLR = Home Location Register
MGC = Media Gateway Controller
GGSN = Gateway GPRS Support Node
GPRS = General Packet Radio Service

Signaling interfaces
Data transfer interfaces
Interfaces to the service environment

1. Mobile switching center (MSC) server.
2. Call state control function (CSCF).
3. MG at the Universal Terrestrial Access Network (UTRAN) side.
4. MG at the PSTN side.
5. Signaling gateway (SG).
6. MGCF.
7. Home subscriber server (HSS).

# UMTS Release 5 Basic Architecture.




UTRAN = UMTS Terrestrial Access Network
PS-CN = Packet Switched Core Network
IMS = IP Multimedia Subsystem

# 3GP22

- 3GPP2 has created a new packet data architecture building on the CDMA 2G and 3G air interface data services.
- ADVANTAGES
  - using IETF protocols is ease in interworking and roaming with other IP networks.
  - it can provide private network access (virtual private networking) via a MIP tunnel with IP security

# 3GP22

- In the 3GPP2 architecture, IP connectivity reaches all the way to the base station transceiver (BTS). Both the base station controller (BSC) and BTS are contained in the  IP-based radio access network node.
- In the 3GPP2 architecture, the mobile terminal uses mobile-Ipbased protocols to identify itself.

# Comparison of Services

- 3GPP
  - GPRS-based mobility was already defined, so the IP network enhancements were considered on top of GPRS.
- 3GPP2
  - needed to develop a mobility mechanism for packet data since one did not exist previously.
- 3 Types of Mobility:
  - Air-interface mobility
  - Link-level mobility
  - Network-level mobility.

## 3G Operators

- 3G operators may initially limit data access to their own branded data services or at least price open Internet access significantly higher than access to their own traditional data services.

# Hotspot/WiMax Operators

- For operators considering deployment of broadband wireless access technologies (e.g., WiMax), being able to offer VoIP could strengthen the business case for investing in such networks by moving operators beyond a focus on low-margin Internet access.

# Fixed-Mobile Convergence

- Mobile network operators plan to leverage emerging IMS service platforms to deliver "one phone, one number" telephony over both fixed and mobile infrastructure.
- This means that a mobile handset will use 2G/3G mobile infrastructure when the user is outdoors and VoIP over Wi-Fi when the user is at work or at home.

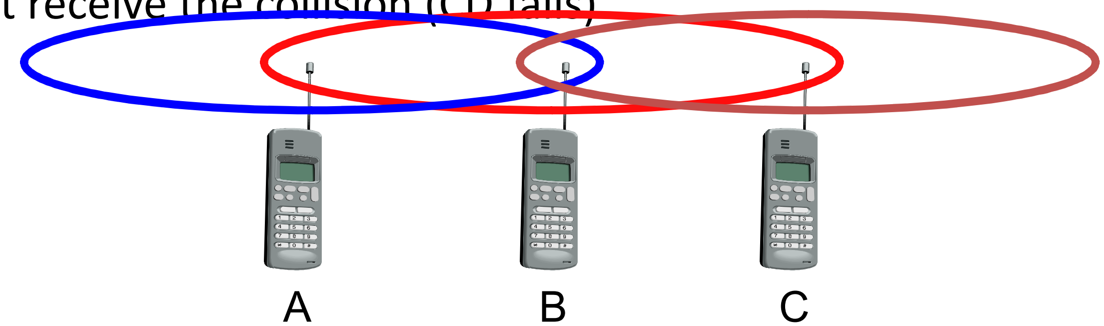
# Motivation

- Can we apply media access methods from fixed networks?

- Example CSMA/CD
  - **C**arrier **S**ense **M**ultiple **A**ccess with **C**ollision **D**etection
  - send as soon as the medium is free, listen into the medium if a collision occurs (legacy method in IEEE 802.3)
- Problems in wireless networks
  - signal strength decreases proportional to the square of the distance
  - the sender would apply CS and CD, but the collisions happen at the receiver
  - it might be the case that a sender cannot “hear” the collision, i.e., CD does not work
  - furthermore, CS might not work if, e.g., a terminal is “hidden”

# Motivation - hidden and exposed terminals

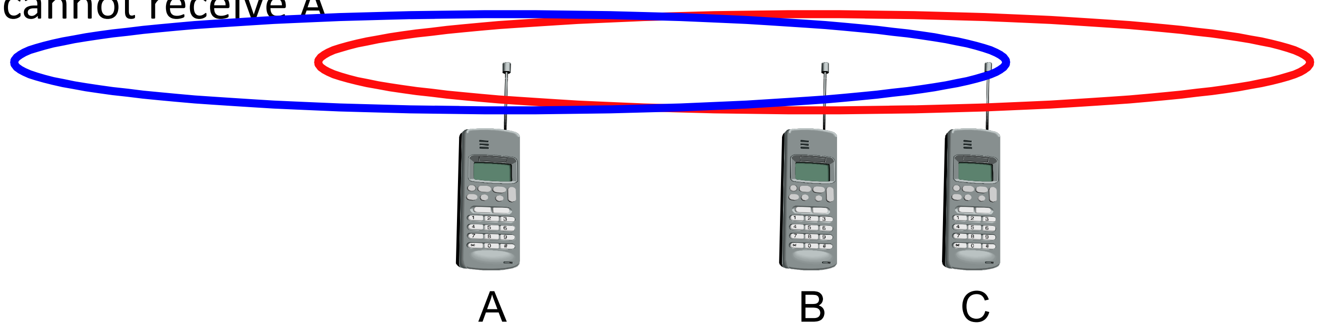
- Hidden terminals
  - A sends to B, C cannot receive A
  - C wants to send to B, C senses a “free” medium (CS fails)
  - collision at B, A cannot receive the collision (CD fails)
  - A is “hidden” for C




- Exposed terminals
  - B sends to A, C wants to send to another terminal (not A or B)
  - C has to wait, CS signals a medium in use
  - but A is outside the radio range of C, therefore waiting is not necessary
  - C is “exposed” to B

# Motivation - near and far terminals

- Terminals A and B send, C receives
  - signal strength decreases proportional to the square of the distance
  - the signal of terminal B therefore drowns out A’s signal
  - C cannot receive A



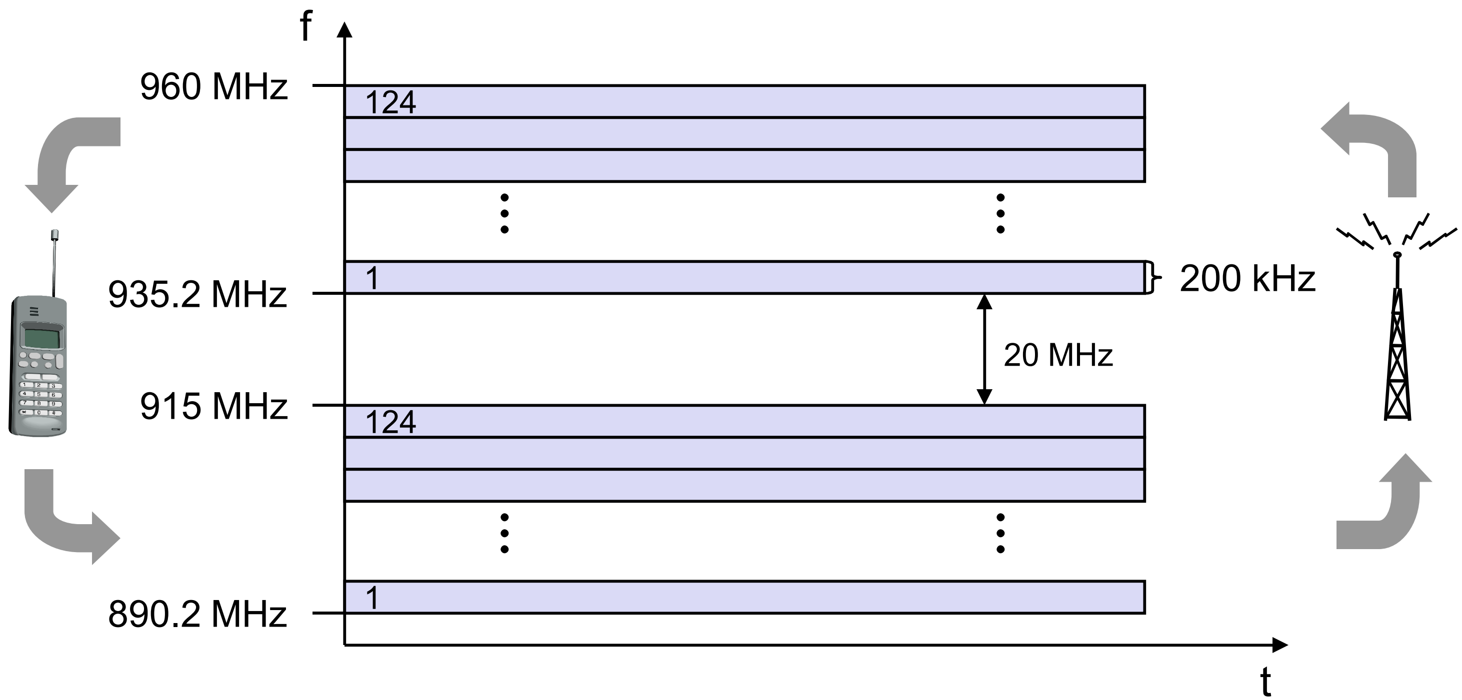

- If C for example was an arbiter for sending rights, terminal B would drown out terminal A already on the physical layer
- Also severe problem for CDMA-networks - precise power control needed!

# Access methods SDMA/FDMA/TDMA

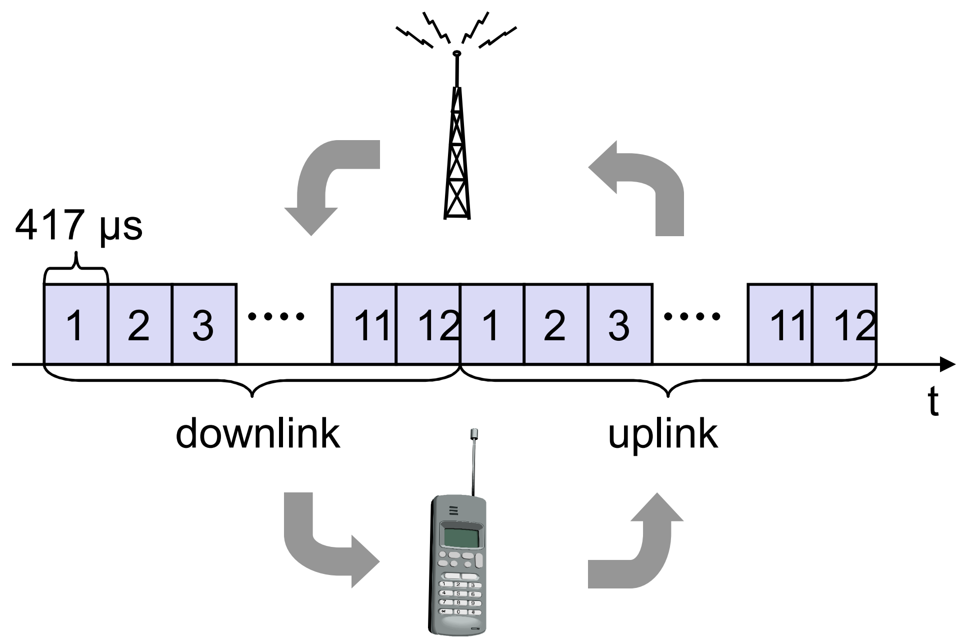
- SDMA (Space Division Multiple Access)
  - segment space into sectors, use directed antennas
  - cell structure
- FDMA (Frequency Division Multiple Access)
  - assign a certain frequency to a transmission channel between a sender and a receiver
  - permanent (e.g., radio broadcast), slow hopping (e.g., GSM), fast hopping (FHSS, Frequency Hopping Spread Spectrum)
- TDMA (Time Division Multiple Access)
  - assign the fixed sending frequency to a transmission channel between a sender and a receiver for a certain amount of time

- The multiplexing schemes presented in chapter 2 are now used to control medium access!

# FDD/FDMA - general scheme, example GSM

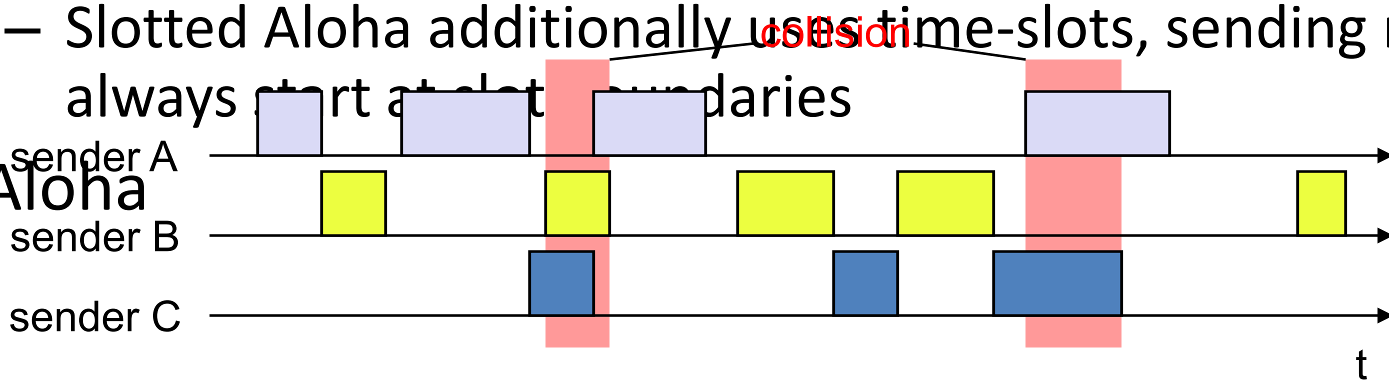


# TDD/TDMA - general scheme, example DECT

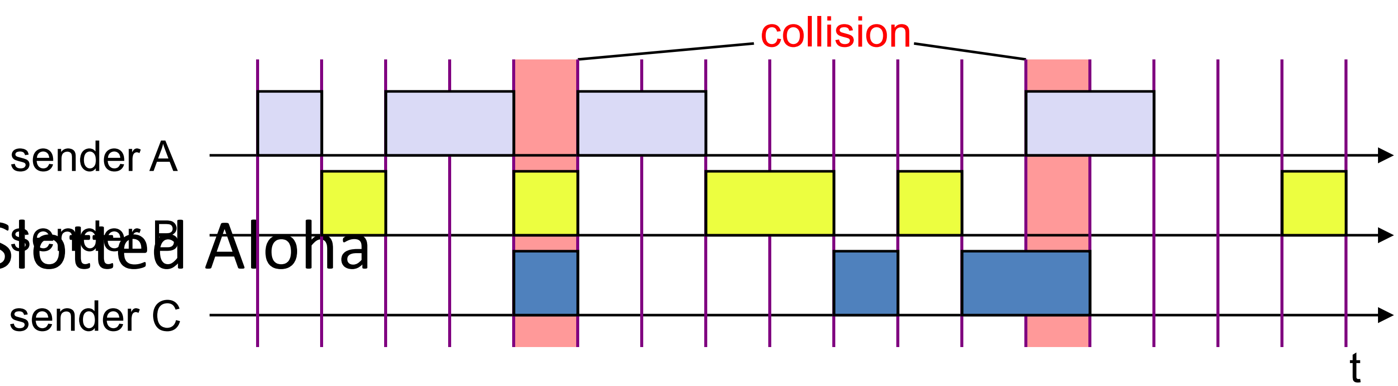


# Aloha/slotted aloha

- Mechanism
  - random, distributed (no central arbiter), time-multiplex
  - Slotted Aloha additionally uses time-slots, sending must always start at slot boundaries
- Aloha




- Slotted Aloha

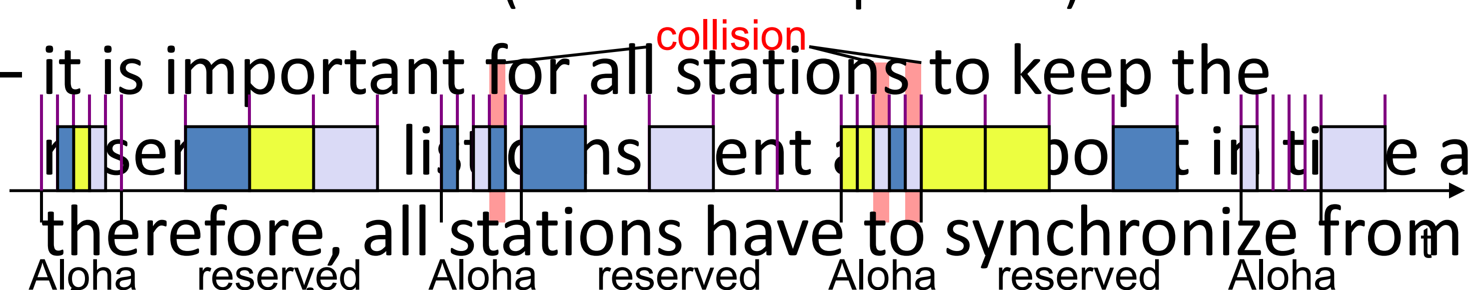


# DAMA - Demand Assigned Multiple Access

- Channel efficiency only 18% for Aloha, 36% for Slotted Aloha (assuming Poisson distribution for packet arrival and packet length)
- Reservation can increase efficiency to 80%
  - a sender *reserves* a future time-slot
  - sending within this reserved time-slot is possible without collision
  - reservation also causes higher delays
  - typical scheme for satellite links
- Examples for reservation algorithms:
  - *Explicit Reservation according to Roberts (Reservation-ALOHA)*
  - *Implicit Reservation (PRMA)*
  - *Reservation-TDMA*

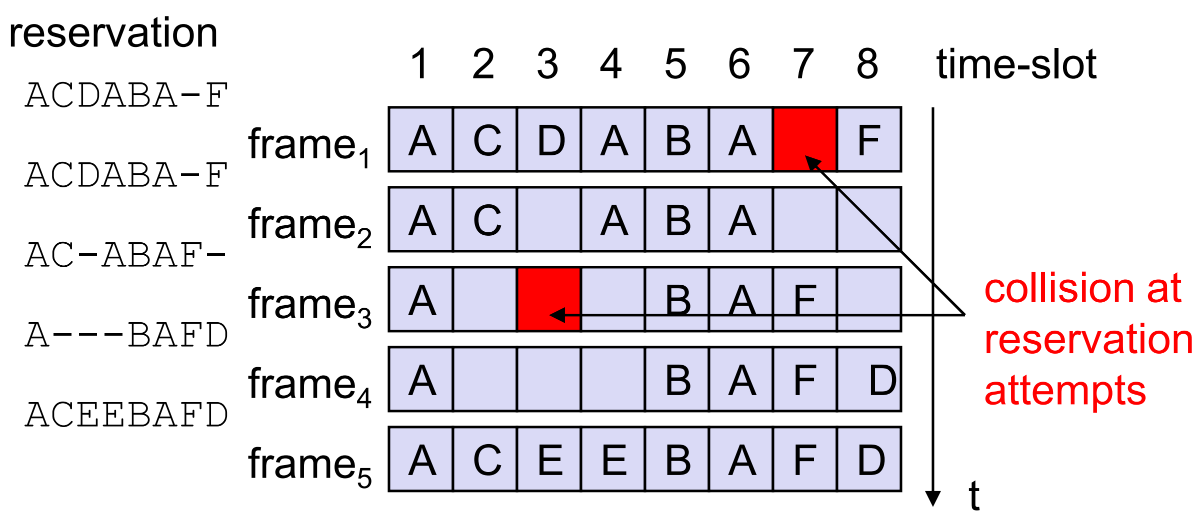
# Access method DAMA: Explicit Reservation

- Explicit Reservation (Reservation Aloha):
  - two modes:
    - ALOHA mode for reservation:
      competition for small reservation slots, collisions possible
    - reserved mode for data transmission within successful reserved slots (no collisions possible)
  - it is important for all stations to keep the reservation list consistent at any point in time and, therefore, all stations have to synchronize from time to time



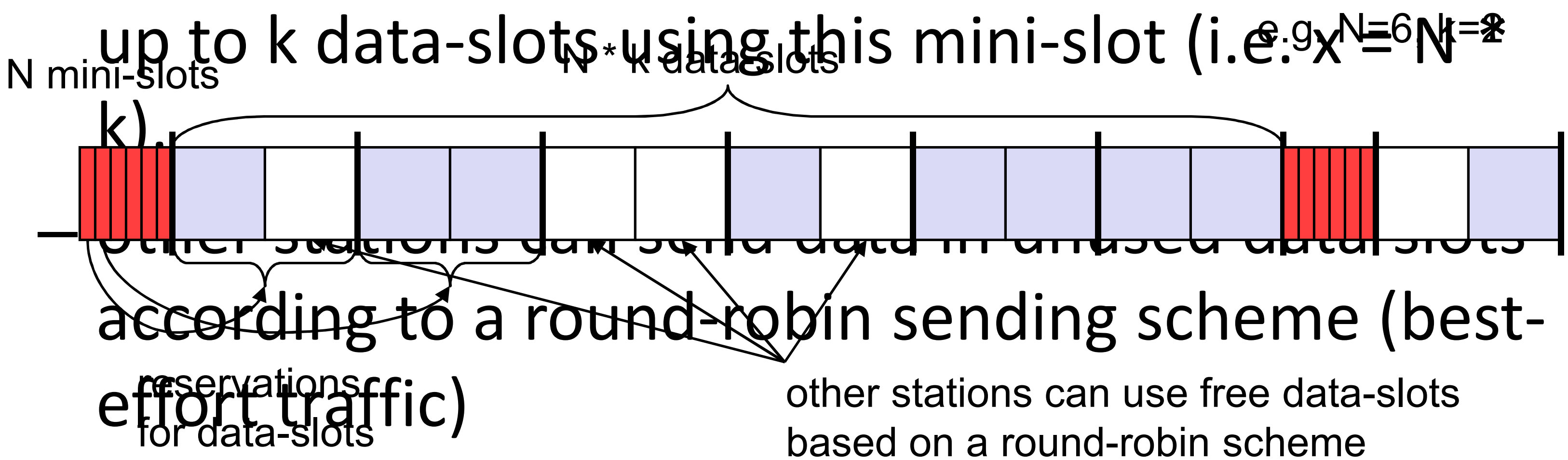
# Access method DAMA: PRMA

- Implicit reservation (PRMA - Packet Reservation MA):
  - a certain number of slots form a frame, frames are repeated
  - stations compete for empty slots according to the slotted aloha principle
  - once a station reserves a slot successfully, this slot is automatically assigned to this station in all following frames as long as the station has data to send
  - competition for this slots starts again as soon as the slot was empty in the last frame



# Access method DAMA: Reservation-TDMA

- Reservation Time Division Multiple Access
  - every frame consists of N mini-slots and x data-slots
  - every station has its own mini-slot and can reserve up to k data-slots using this mini-slot (i.e. x = N * k).
  - other stations can send data in unused data-slots according to a round-robin sending scheme (best-effort traffic)

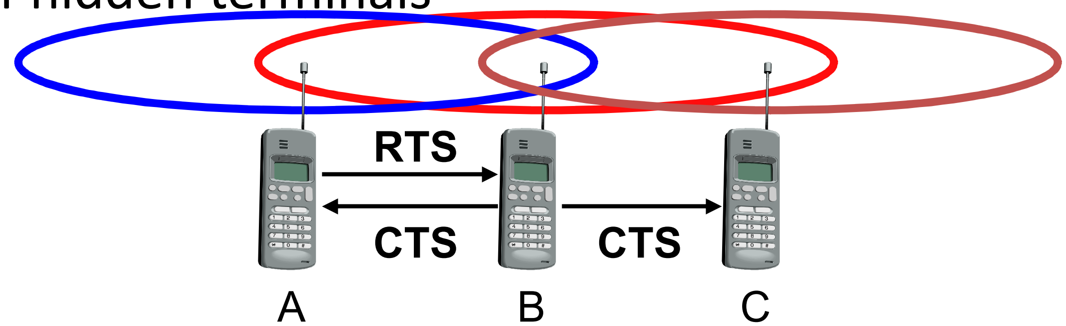


# MACA - collision avoidance

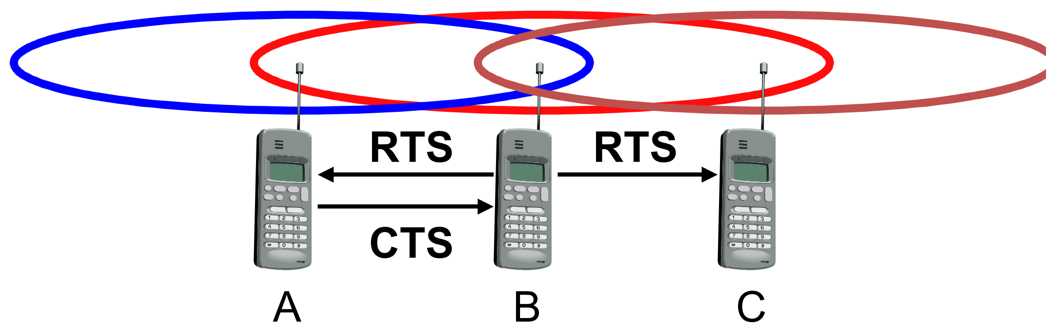
- MACA (Multiple Access with Collision Avoidance) uses short signaling packets for collision avoidance
  - RTS (request to send): a sender request the right to send from a receiver with a short RTS packet before it sends a data packet
  - CTS (clear to send): the receiver grants the right to send as soon as it is ready to receive
- Signaling packets contain
  - sender address
  - receiver address
  - packet size
- Variants of this method can be found in IEEE802.11 as DFWMAC (Distributed Foundation Wireless MAC)

# MACA examples

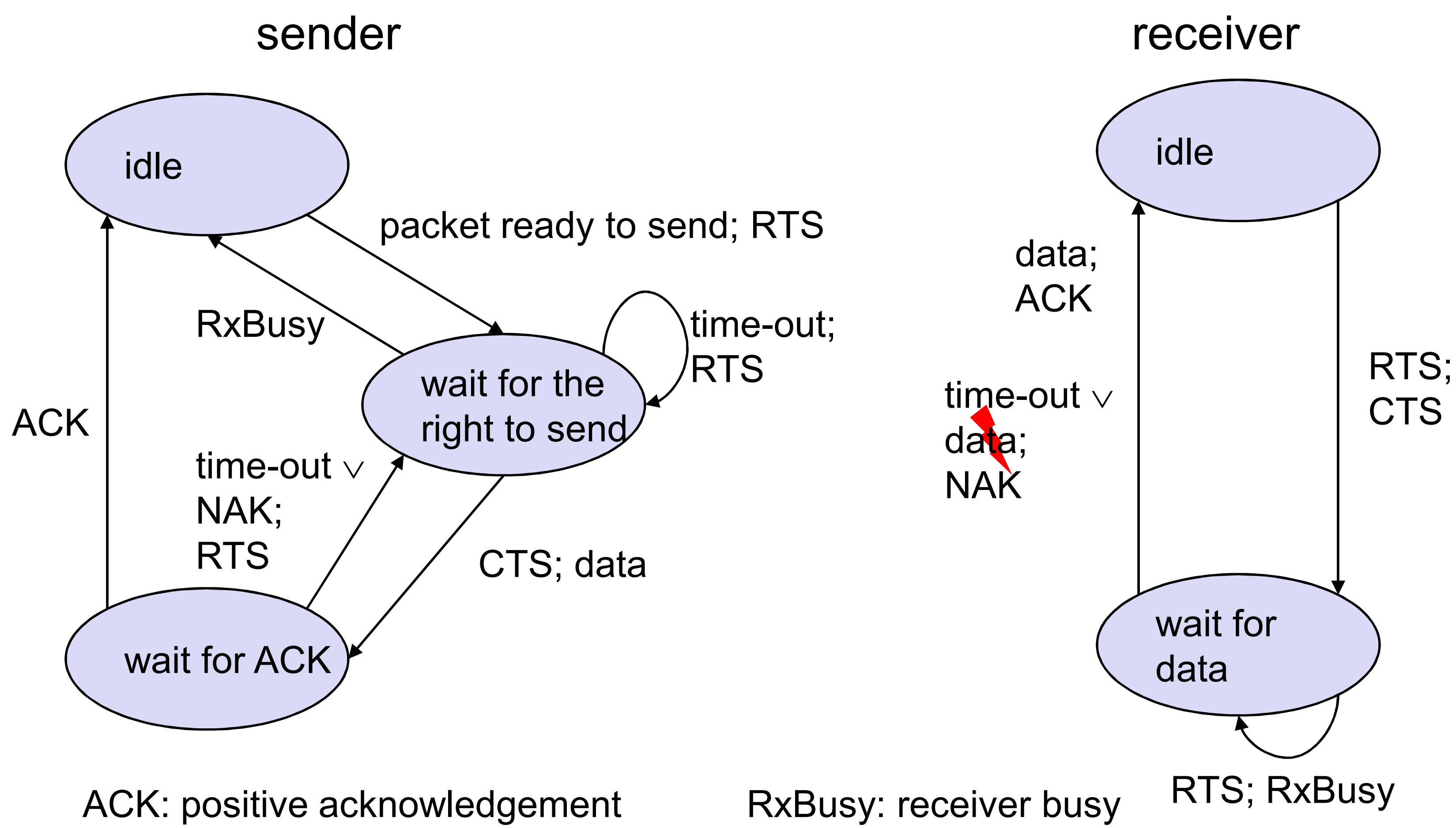
- MACA avoids the problem of hidden terminals
  - A and C want to send to B
  - A sends RTS first
  - C waits after receiving CTS from B




- MACA avoids the problem of exposed terminals
  - B wants to send to A, C to another terminal
  - now C does not have to wait for it cannot receive CTS from A



# MACA variant: DFWMAC in IEEE802.11




ACK: positive acknowledgement
NAK: negative acknowledgement

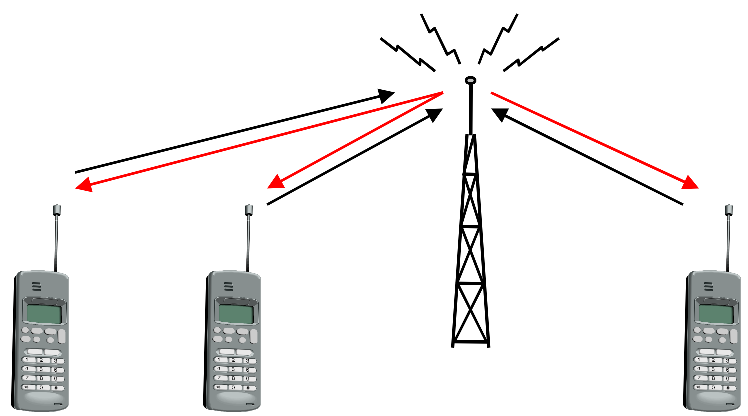
RxBusy: receiver busy

# Polling mechanisms

- If one terminal can be heard by all others, this “central” terminal (a.k.a. base station) can poll all other terminals according to a certain scheme
  - now all schemes known from fixed networks can be used (typical mainframe - terminal scenario)
- Example: Randomly Addressed Polling
  - base station signals readiness to all mobile terminals
  - terminals ready to send can now transmit a random number without collision with the help of CDMA or FDMA (the random number can be seen as dynamic address)
  - the base station now chooses one address for polling from the list of all random numbers (collision if two terminals choose the same address)
  - the base station acknowledges correct packets and continues polling the next terminal
  - this cycle starts again after polling all terminals of the list

# ISMA (Inhibit Sense Multiple Access)

- Current state of the medium is signaled via a “busy tone”
  - the base station signals on the downlink (base station to terminals) if the medium is free or not
  - terminals must not send if the medium is busy
  - terminals can access the medium as soon as the busy tone stops
  - the base station signals collisions and successful transmissions via the busy tone and acknowledgements, respectively (media access is not coordinated within this approach)
  - mechanism used, e.g., for CDPD (USA, integrated into AMPS)



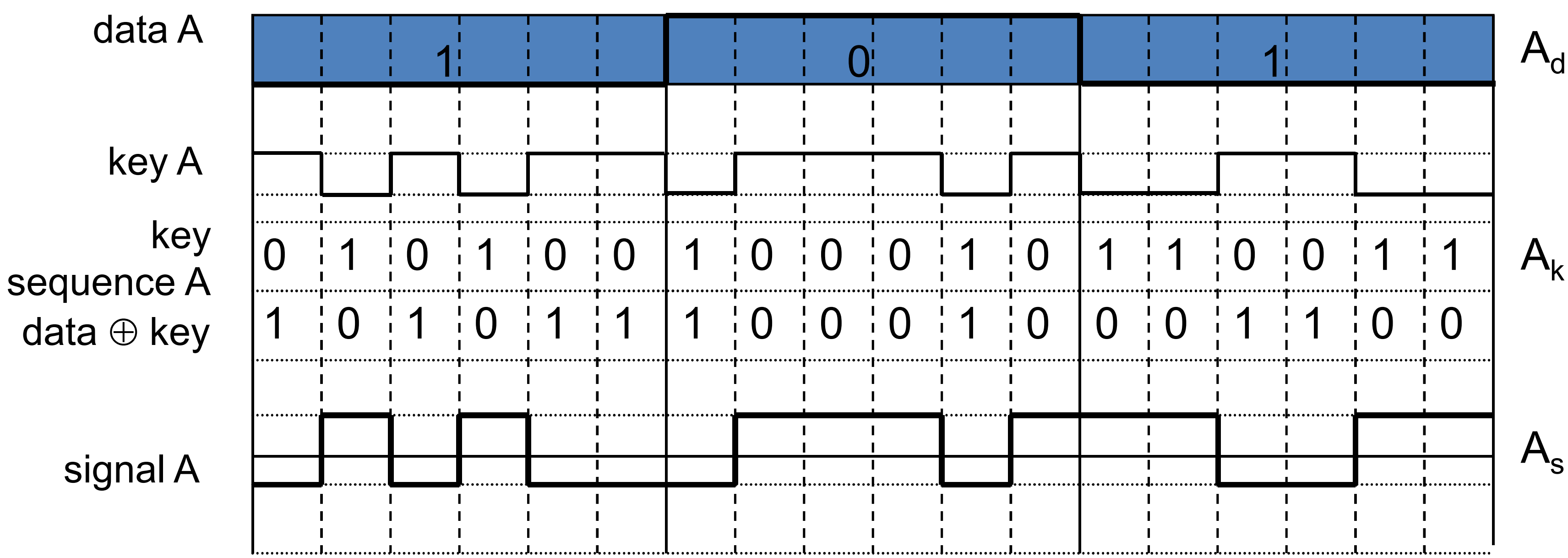
# Access method CDMA

- CDMA (Code Division Multiple Access)
  - all terminals send on the same frequency probably at the same time and can use the whole bandwidth of the transmission channel
  - each sender has a unique random number, the sender XORs the signal with this random number
  - the receiver can "tune" into this signal if it knows the pseudo random number, tuning is done via a correlation function
- Disadvantages:
  - higher complexity of a receiver (receiver cannot just listen into the medium and start receiving if there is a signal)
  - all signals should have the same strength at a receiver
- Advantages:
  - all terminals can use the same frequency, no planning needed
  - huge code space (e.g. $2^{32}$) compared to frequency space
  - interferences (e.g. white noise) is not coded
  - forward error correction and encryption can be easily integrated

# CDMA in theory

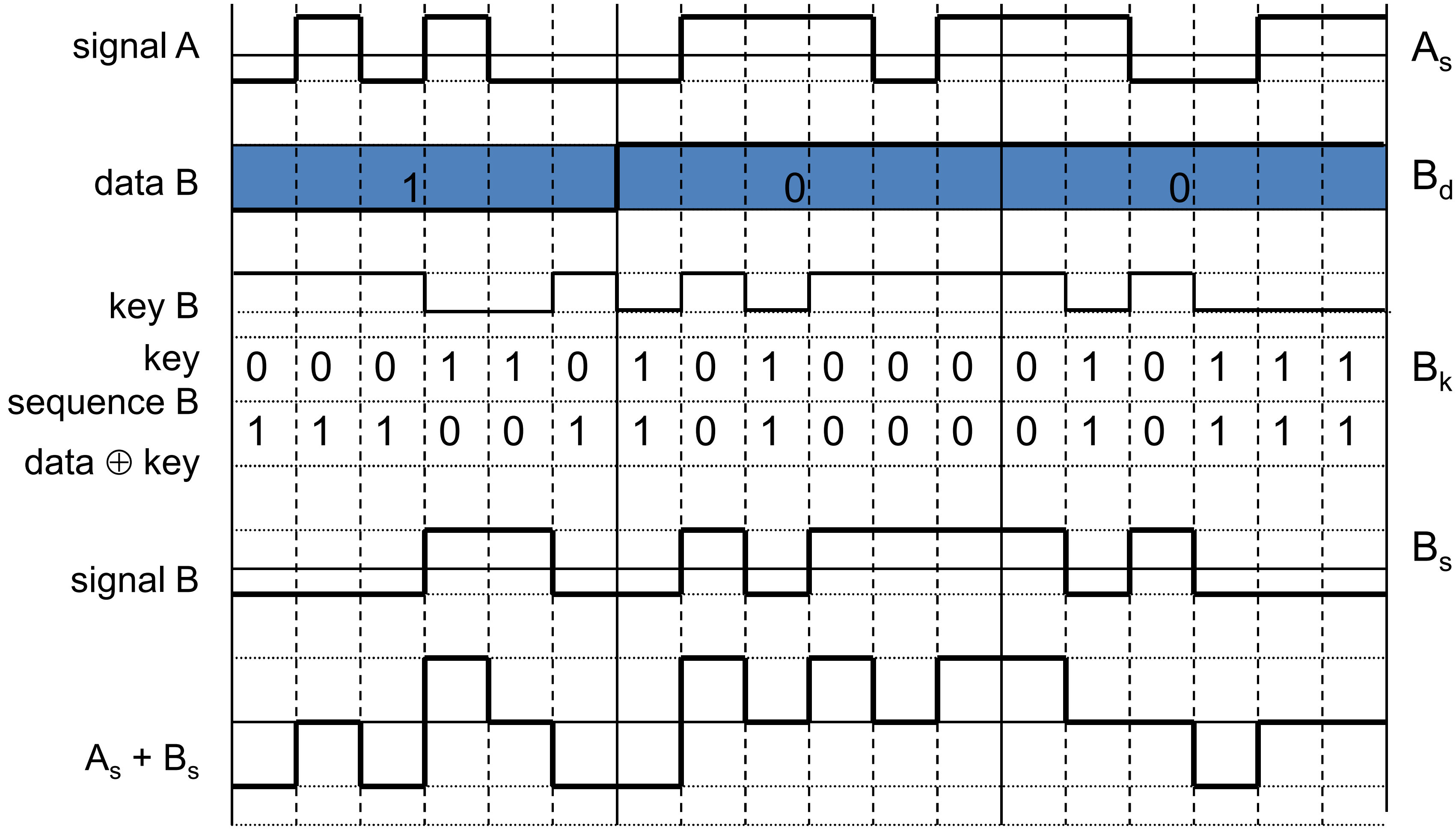
- Sender A
  - sends $A_d = 1$, key $A_k = 010011$ (assign: "0"= -1, "1"= +1)
  - sending signal $A_s = A_d * A_k = (-1, +1, -1, -1, +1, +1)$
- Sender B
  - sends $B_d = 0$, key $B_k = 110101$ (assign: "0"= -1, "1"= +1)
  - sending signal $B_s = B_d * B_k = (-1, -1, +1, -1, +1, -1)$
- Both signals superimpose in space
  - interference neglected (noise etc.)
  - $A_s + B_s = (-2, 0, 0, -2, +2, 0)$
- Receiver wants to receive signal from sender A
  - apply key $A_k$ bitwise (inner product)
    - $A_e = (-2, 0, 0, -2, +2, 0) \bullet A_k = 2 + 0 + 0 + 2 + 2 + 0 = 6$
    - result greater than 0, therefore, original bit was "1"
  - receiving B
    - $B_e = (-2, 0, 0, -2, +2, 0) \bullet B_k = -2 + 0 + 0 - 2 - 2 + 0 = -6$, i.e. "0"

# CDMA on signal level I

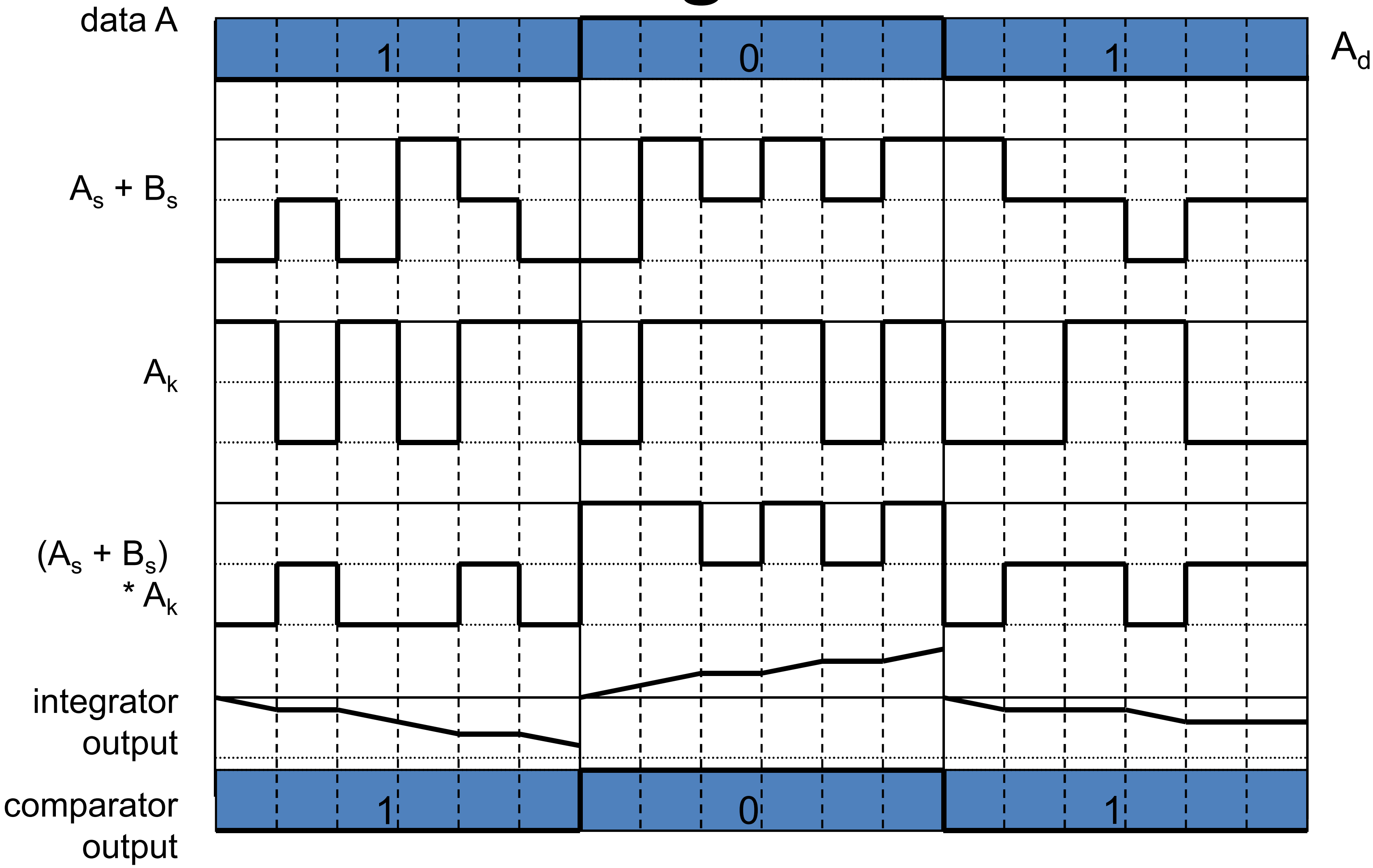



Real systems use much longer keys resulting in a larger distance between single code words in code space.

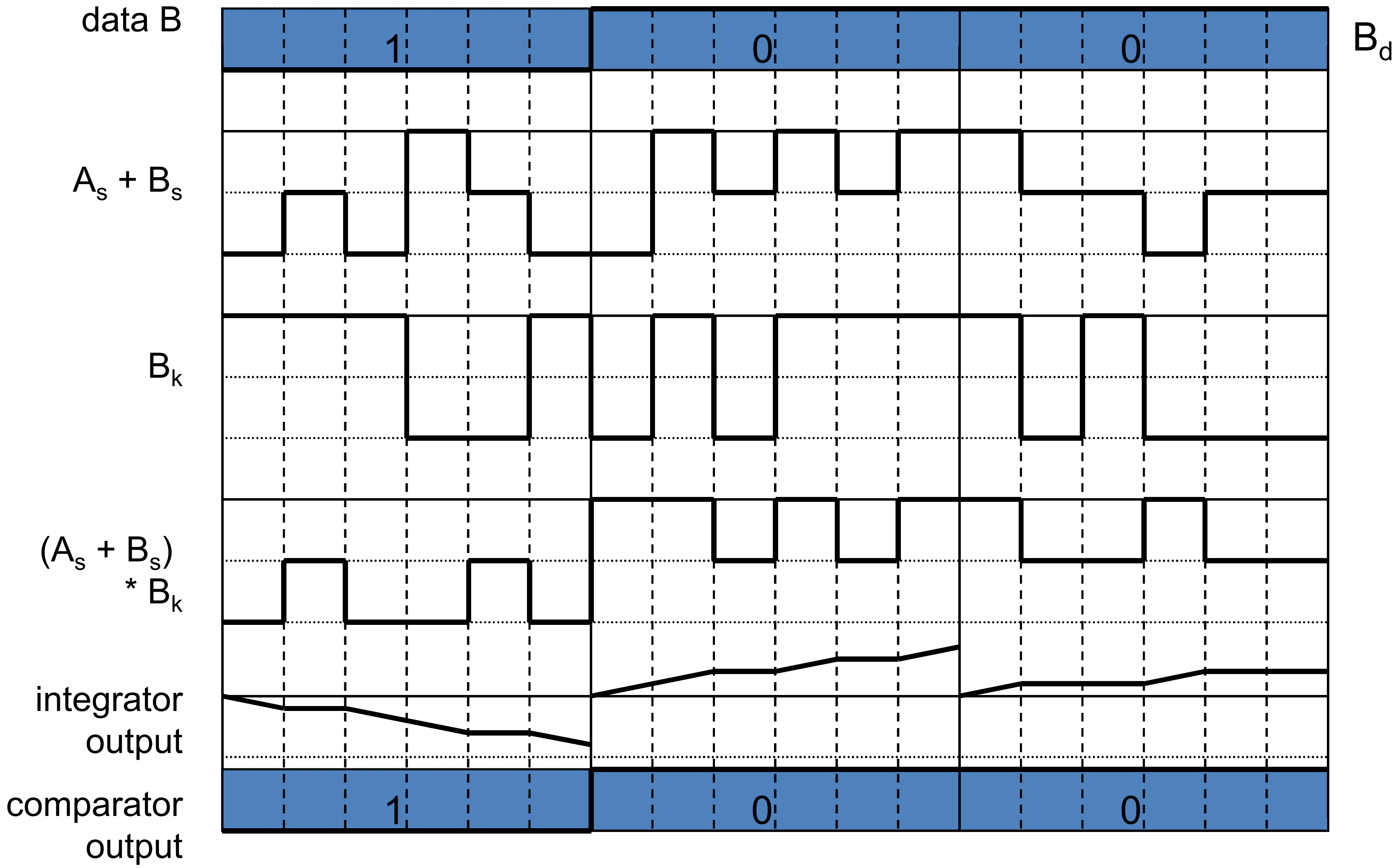
# CDMA on signal level II



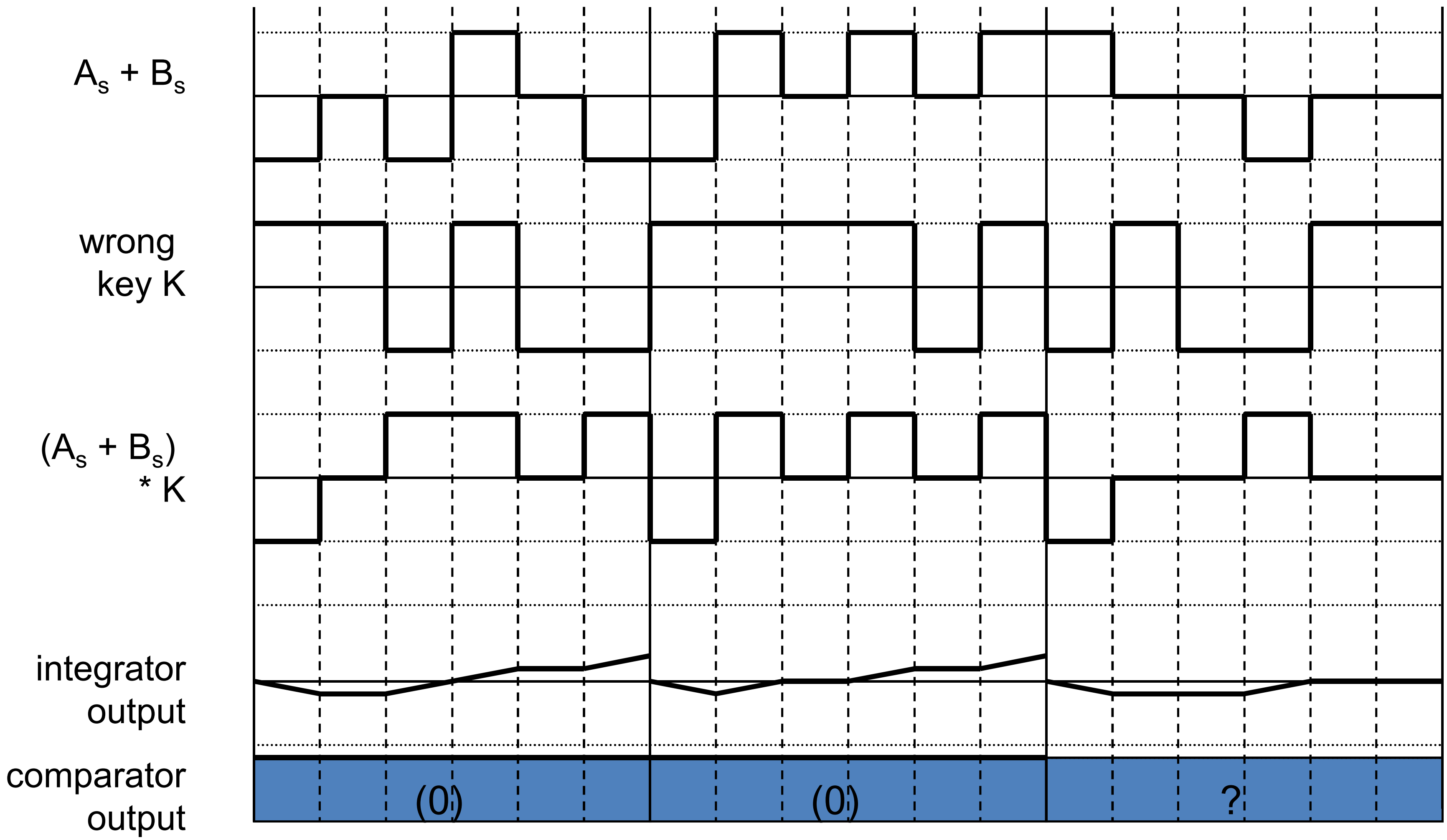
# CDMA on signal level III



# CDMA on signal level IV

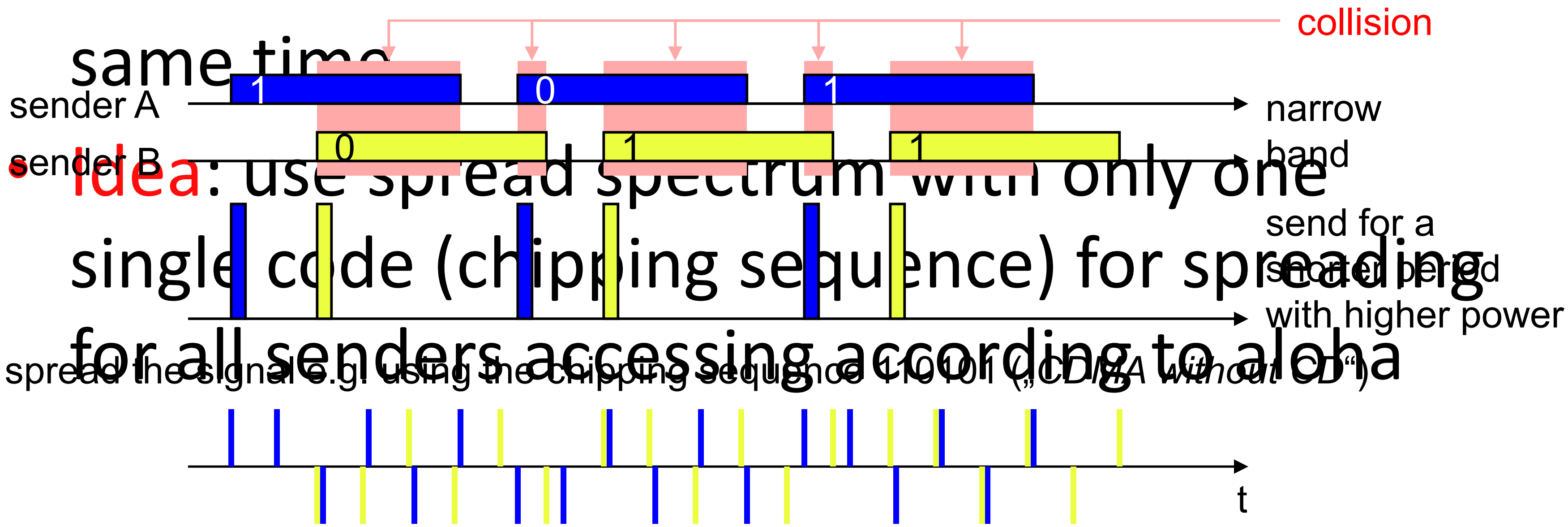


# CDMA on signal level V



# SAMA - Spread Aloha Multiple Access

- Aloha has only a very low efficiency, CDMA needs complex receivers to be able to receive different senders with individual codes at the same time
- Idea: use spread spectrum with only one single code (chipping sequence) for spreading for all senders accessing according to aloha




Problem: find a chipping sequence with good characteristics

# Comparison SDMA/TDMA/FDMA/CDMA

| Approach | SDMA | TDMA | FDMA | CDMA |
|---|---|---|---|---|
| Idea | segment space into cells/sectors | segment sending time into disjoint time-slots, demand driven or fixed patterns | segment the frequency band into disjoint sub-bands | spread the spectrum using orthogonal codes |
| Terminals | only one terminal can be active in one cell/one sector | all terminals are active for short periods of time on the same frequency | every terminal has its own frequency, uninterrupted | all terminals can be active at the same place at the same moment, uninterrupted |
| Signal separation | cell structure, directed antennas | synchronization in the time domain | filtering in the frequency domain | code plus special receivers |
| Advantages | very simple, increases capacity per km² | established, fully digital, flexible | simple, established, robust | flexible, less frequency planning needed, soft handover |
| Dis-advantages | inflexible, antennas typically fixed | guard space needed (multipath propagation), synchronization difficult | inflexible, frequencies are a scarce resource | complex receivers, needs more complicated power control for senders |
| Comment | only in combination with TDMA, FDMA or CDMA useful | standard in fixed networks, together with FDMA/SDMA used in many mobile networks | typically combined with TDMA (frequency hopping patterns) and SDMA (frequency reuse) | still faces some problems, higher complexity, lowered expectations; will be integrated with TDMA/FDMA |