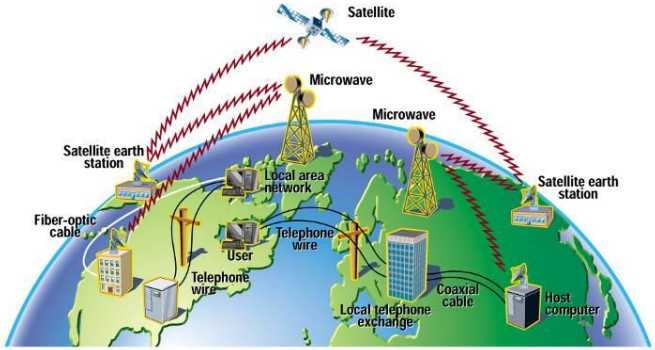
Wireless Networks



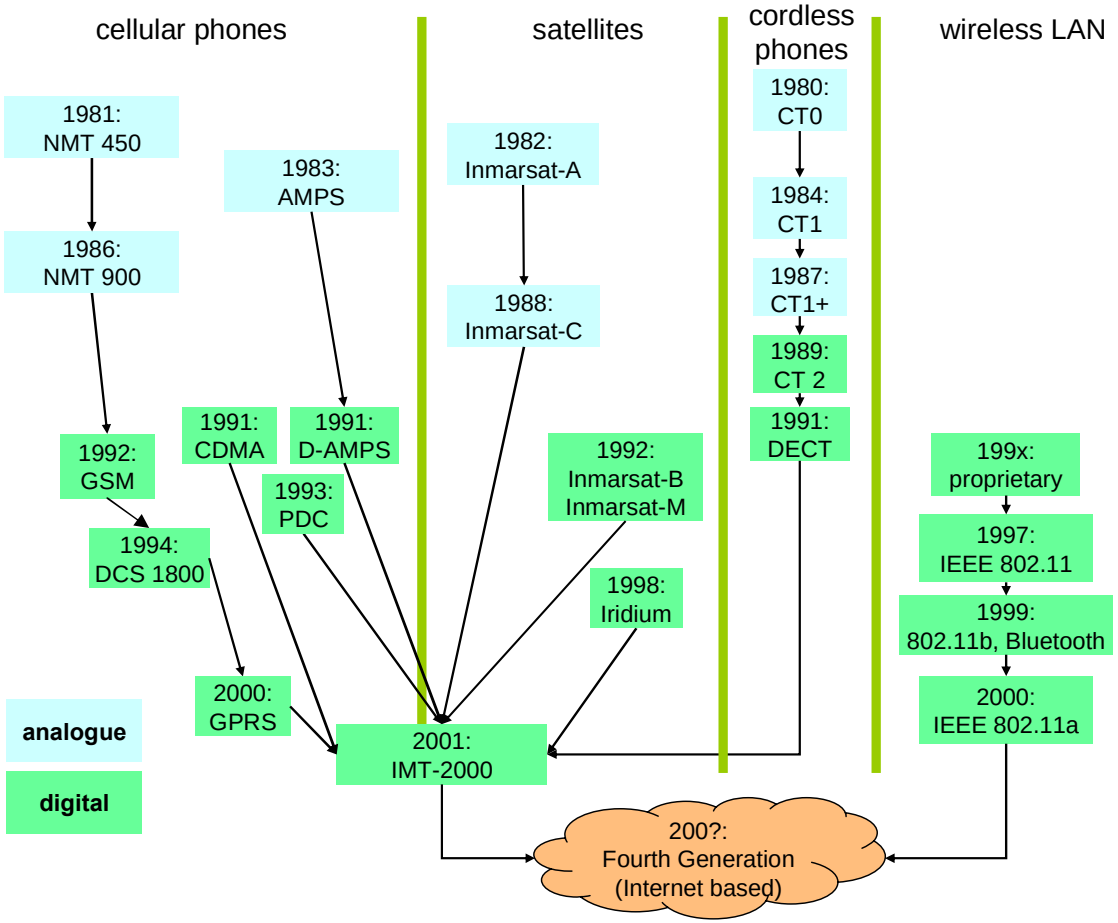
Wireless networks

TYPE OF NETWORK	COVERAGE AREA	FUNCTION	ASSOCIATED COST	TYPICAL THROUGHPUT	STANDARDS
Wireless personal area network (WPAN)	**Personal operating space;** **Typically 10 meters**	**Cable replacement technology, personal networks**	**Very low**	**01. – 4 Mbps**	**IrDA,** **Bluetooth.** **802.15**
Wireless local area network (WLAN)	**In buildings or campuses; Typically 100 meters**	**Extension or alternative to wired LAN**	**Low-medium**	**10-100 Mbps**	**IEEE 802.11a, b, g, n HIPERLAN/2**
Wireless metropolitan network (including mesh)	**Coverage on city basis;** **Typically 15 km**	**Extended WLAN coverage**	**Medium**	**10 - 75 Mbps**	**IEEE 802.16**

Types of wireless networks

TYPE OF NETWORK	COVERAGE AREA	FUNCTION	ASSOCIATED COST	TYPICAL THROUGHPUT	STANDARDS
Wireless wide area network (WWAN)	**Coverage provided on national basis from multiple carriers**	**Extension of WLAN and WMAN**	**Medium-high**	**8 kbps – 3Mbps**	**GSM, TDMA, CDMA, GPRS, EDGE, WCDMA**
Satellite networks	**Global coverage**	**Extension of LAN**	**Very high**	**2 kbps – 19.2 kbps**	**TDMA, CDMA, FDMA**

Types of wireless networks



WPAN:
Wireless Personal Area Networks

WPAN

- **A network using wireless connections to interconnect devices centred around a person.**
  - Enable people to connect to a variety of devices without having to use cables, e.g.,
    - wirelessly connecting your laptop to Internet, printer, PDA
    - hands-free mobile phone attachment
    - Transferring photos from your digital camera
- **Characteristics**
  - Short range communication
  - Low power consumption
  - Low cost
  - Small in size
  - Mostly ad hoc networks – self discovery

WPAN Standards

- **Three standards**
  - IrDA (Infrared Data Association)
  - Bluetooth
  - IEEE 802.15

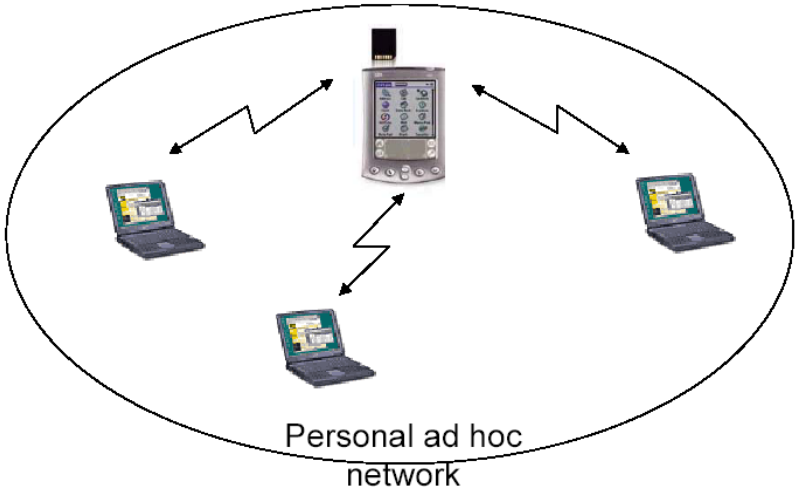
IrDA

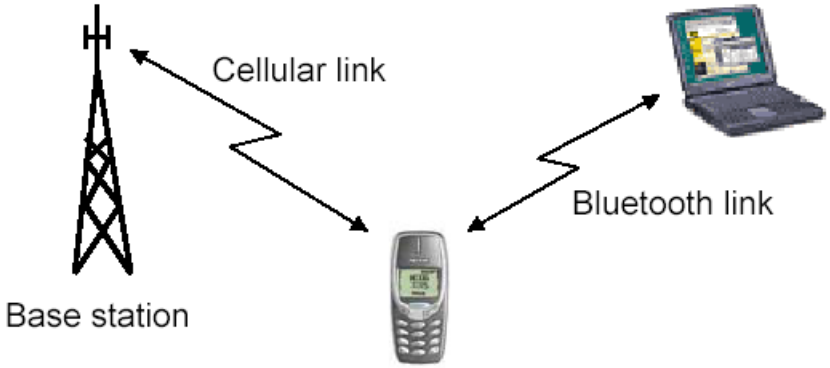
- **An industry sponsored organization set up in 1993**
  - Create international standards for the hardware & software used in ***infrared*** communication links
- **IrDA has a set of protocols:**
  - **IRDA DATA** – data delivery mechanism
  - **IRDA CONTROL** – controlling mechanism
- **Infrared features**
  - Communication range up to 1m (2m sometimes possible)
  - Not interfered by radio signal
  - Low power for communication up to 20 centimeters
  - Bidirectional communication (mostly point-to-point)
  - Data transmission rate from 9600 bps to 4 Mbps
  - Low cost
  - ***Line-of-sight*** light restriction – requires pointing at the device without physical barriers; also sensitive to fog and other atmospheric conditions.

Bluetooth

- **A computing and telecommunications industry specification**
  - Proposed in 1998 by Bluetooth SIG (>2000 companies, including Ericsson, Nokia, Intel, IBM, Toshiba, Microsoft, Motorola, etc)
- **Describes how devices can easily interconnect with each other using a short-range radio connection.**
  - Headsets, remote controls, wireless keyboards, hot syncing, etc.

Bluetooth applications





Bluetooth

Bluetooth features

- Worldwide vendor and product support
- Support for both voice and data communication
- Uses unlicensed 2.4 GHz spectrum, with peak throughput of ~720 Kbps (10 Mbps in future ?)
- Does not require line of sight – go through physical barriers (with a range up to 10m)
- Higher cost than infrared, but low cost compared with wireless LAN (~ US$ 15, targeted at $5 to $10).
- Uses frequency hopping spread spectrum

Bluetooth configuration

- **Use master/slave design – one of the devices acts as a master and others as slaves**
  - 1 master and up to 7 slaves - this network is called a *piconet*.
  - A single channel is shared among all devices which are synchronized to the same hopping sequence
    - hopping among 79 channels, each of 1Mhz bandwidth

Bluetooth configuration

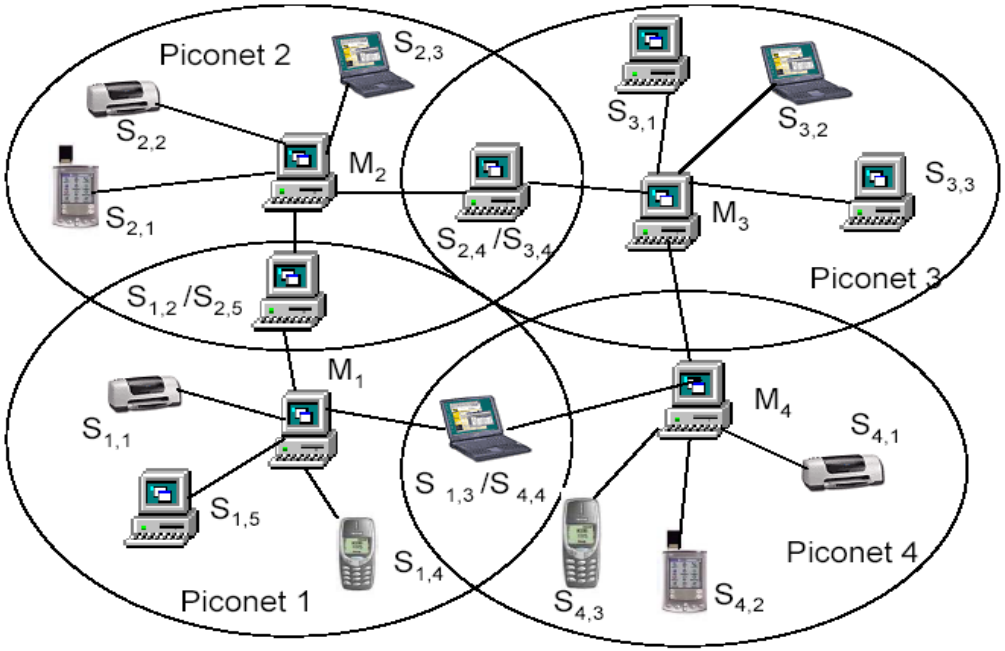
- **How does a piconet work?**
  - Initially all devices are stand-by.
  - The device establishing the piconet automatically becomes the master, all other devices will be slaves.
    - Master sends its device ID and clock to slaves.
      - Hopping pattern is determined by device ID (48 bit MAC address, unique worldwide)
      - The phase in the hopping pattern is determined by master's clock (28bit, frequency of 3.2 kHz, 24 hours per cycle).
    - After adjusting the internal clock according to the master, a device may participate in the piconet.
    - Master and a slave communicate by sending message alternatively. A slave can send message only after it receives a message from the master (i.e., the master allocated time slots to slaves using polling).
    - All active devices are assigned a 3-bit active member address (AMA).

Bluetooth configuration

- **Park devices**
  - can not actively participate in the piconet (i.e., they do not have a connection), but are known and can be reactivated
  - All parked devices use an 8-bit parked member address (PMA)
    - > 200 devices could be *parked*.
  - If a parked device wants to communicate and there are already 7 active slaves, one slave has to switch to park mode
- **Stand-by devices: don't participate**

Bluetooth configuration

- **Built upon *scattered net* with many piconets.**
  - If piconets are close to each other, they have overlapping areas
  - The scenario where the nodes of two or more piconets mingle is called **scatternet**.



Bluetooth device modes

- **Three device modes**
  - **Generally discoverable mode**
    - Allows a Bluetooth device to be detected by any other Bluetooth device within its proximity
  - **Limited discoverable mode**
    - Allows a Bluetooth device to be detected by only well-defined devices.
  - **Nondiscoverable mode**
    - Makes the device invisible to other devices so it can't be detected.

Bluetooth security

- **Security**
  - Provides security at the link level, leaving the developers to choose the application level security based on their applications.
  - *Device authentication* – built-in: each Bluetooth device has a unique ID
  - *Encryption*: for over-the-air communication between devices

IEEE 802.15

- **Proposed by IEEE 802.15 WPAN Working Group (1999)**
  - Develop consensus standards for PANs or short distance wireless networks.
- **Similar goals to Bluetooth:**
  - wireless networking of computing devices such as PCs, PDAs, peripherals, cell phones, pagers, and consumer electronics
  - aimed at standardizing MAC and Physical layers of Bluetooth
- **Also dealing with other issues – e.g. coexistence and interoperability within the networks**

IEEE 802.15

- Four task groups (work in progress)
  - 802.15 WPAN Task Group1: (802.15.1)
    - Based on Bluetooth and defining MAC and PHY layers specifications
  - 802.15 WPAN Task Group2: (802.15.2)
    - Coexistence of WPAN and WLAN operating in same 2.4 GHz band
  - 802.15 WPAN Task Group3: (802.15.3)
    - Publish new standard for high rate (≥ 20Mbps) WPANs, and
    - Provide a means for low-power and low-cost solutions for portable consumer electronics, multimedia applications, etc
  - 802.15 WPAN Task Group4: (802.15.4)
    - Low data rate (200kbps maximum) solutions with long battery life (months to years) and low complexity;
    - Targeted at sensors, interactive toys, smart badges, etc.

Comparison of WPAN Tech.

Standard	Frequency	Bandwidth	Optimum operating range	Points of interest
IrDA	**875 nm wavelength**	**9600 bps to 4 Mbps. Future of 15 Mbps**	**1-2 meters (3-6 feet)**	**Requires line of sight for communication**
Bluetooth	**2.4 GHZ**	**V1.1: 720 Kbps; V2.0: 10 Mbps**	**10 meters (30 feet) to 100 meters (300 feet)**	**Automatic device discovery; communicates through physical barriers**
IEEE 802.15	**2.4 GHZ**	**802.15.1: 1 Mbps 802.15.3: >20 Mbps 802.15.4: <200 Kbps**	**10 meters (30 feet) to 100 meters (300 feet)**	**Uses Bluetooth as the foundation; coexistence with 802.11 devices**

ZigBee

- **Specification for a suite of high level communication protocols based on the IEEE 802.15.4-2006 standard.**
  - Targeted at applications that require a low data rate, long battery life, and secure networking
  - Can send data at 128 kbps with 250ft range.
- **Intended to be simpler and less expensive than other WPANs, such as Bluetooth.**
- **ZigBee Alliance is a group of companies which maintain and publish the ZigBee standard**

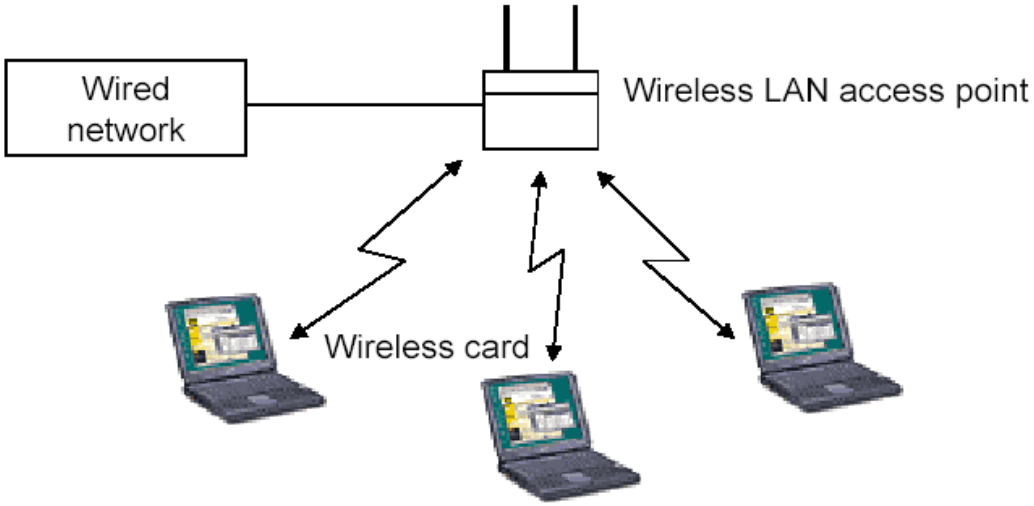
Other WPAN technologies

- **Ultra Wideband (UWB)**
  - Developed for military radar systems
  - Operates in 480 Mbps ranging up to 30 ft
  - Uses a low power source to send out millions of bursts of radio waves each second
  - 100 times as fast as Bluetooth
- **Wireless USB**
  - USB is the most used interface on PCs
  - The wireless version could be a hit
  - Range of 32 ft and maximum data rate of > 480 Mbps
- **Insteon (www.insteon.net)**
  - Combines electronic powerline and wireless technology for home automation
  - Can send data at 13.1 Kbps with 150 ft range
  - Replaces X10 (demo at http://www.youtube.com/watch?v=FMaargP_Meo)
- **Z-Wave (www.z-wave.com)**
  - Entirely wireless power-efficient technology for wireless remote control
  - Can send data at 127 Kbps to range of 100 ft
  - Allows you to remotely program your house!

WLAN: Wireless Local Area Networks

Wireless Local Area Networks

- **A local area network (LAN) accessed through a wireless (radio) connection**
  - e.g, small office/home (SOHO), airports, hotels etc.
  - Save cost and avoid laying cables
  - Maybe the best option for providing high-speed wireless Internet access



WLANs

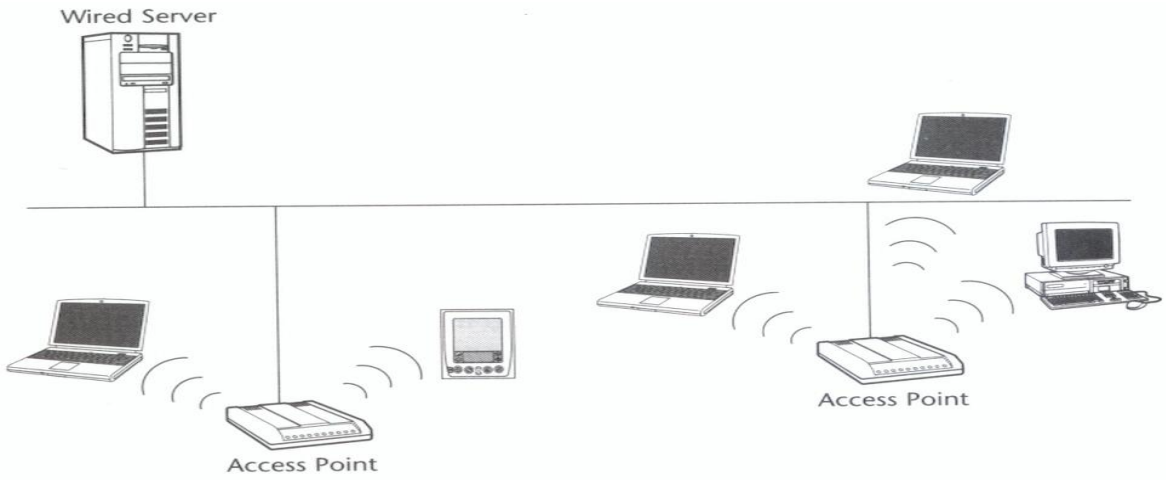
- **Evaluating factors for WLAN products**
  - Range/Coverage – 50 m to 150 m
  - Throughput – 1 Mbps to 54 Mbps
  - Interference – from household electronics
  - Power consumption – differs between wireless products
  - Cost – based on deployment and standards.

Wireless card operation mode

- **The keys behind WLANs are the *wireless cards* and *wireless APs*.**
- **The wireless cards can be operated in**
  - **continuous aware mode** (radio always on) and
  - **power-saving polling mode** (radio in sleep state to extend battery life).
  - In the latter mode, AP keeps data in its buffer for the users and sends a signal to wake them up.
- **Depends on whether to use APs, WLAN has 2 possible configurations.**

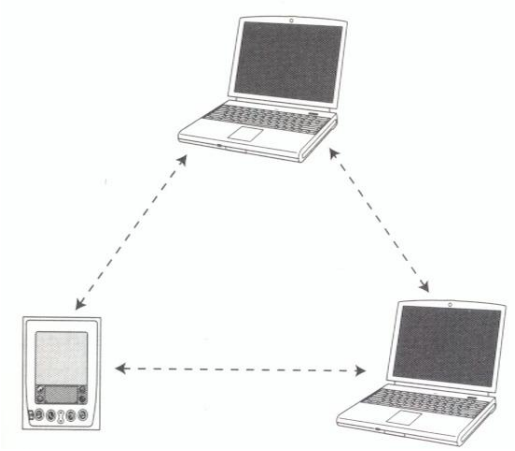
WLAN configurations

- **Configuration with Access Points (APs)**
  - Client server model - many PCs or laptops physically close to each other (20 – 500m) are linked to a central hub (AP).
    - AP controls the shared access of the channels, e.g., by selecting one of the hopping sequences, and the wireless cards tune in to the corresponding sequence.
    - The AP acts as a bridge between the wireless and wired network



WLAN configurations

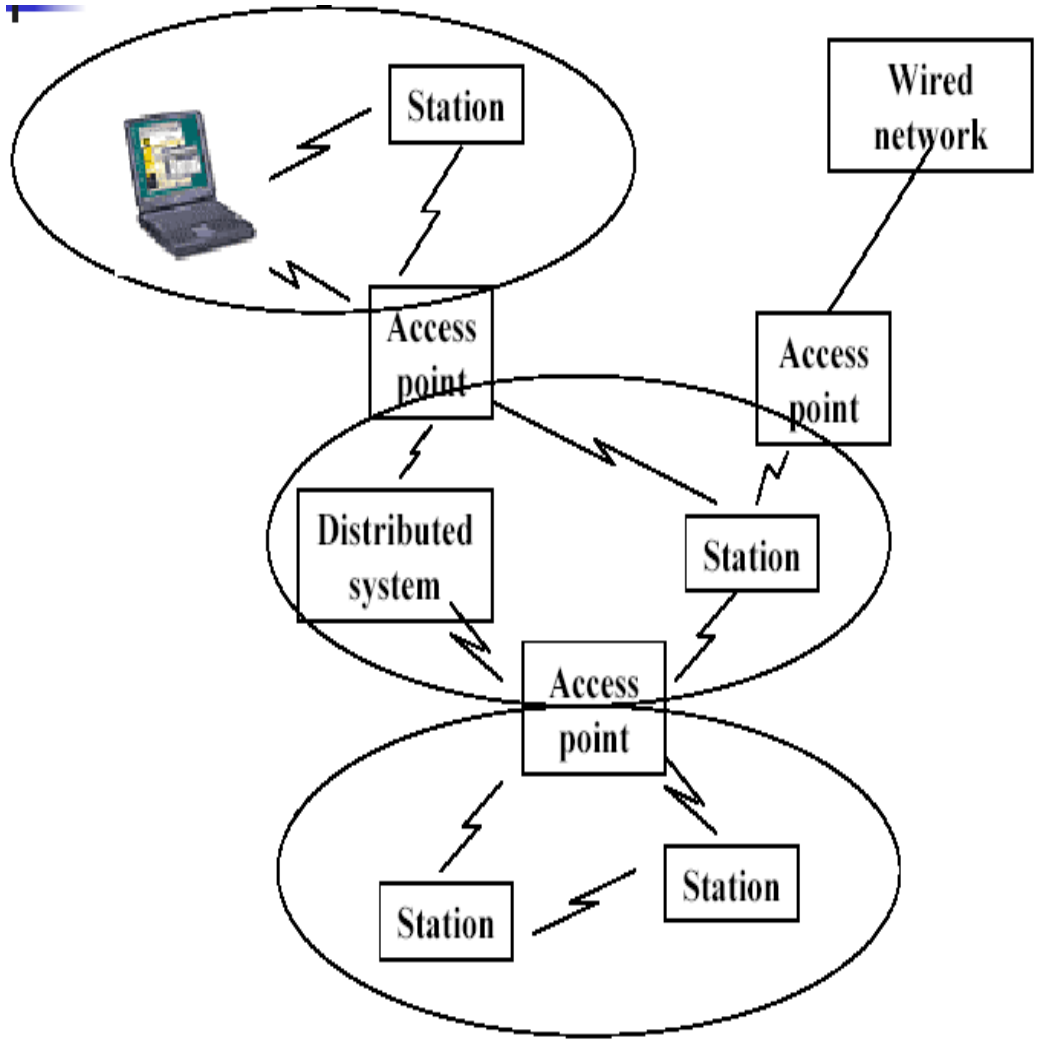
- **Peer-to-peer (ad hoc)**
  - Ad hoc network mode - there is no central controller; wireless access cards use MAC protocols (e.g., IEEE 802.11 uses CSMA/CA) to resolve shared access of the channel.



WLAN configurations

- **Several APs can work together to provide wider wireless coverage (e.g., for an entire building or campus.)**
  - *Microcell* – the coverage area of each AP
  - Microcells may overlap at their boundaries;
  - Roaming – movement of mobile devices between cluster of APs (made possible by a handoff mechanism – mobility management)
- **More advanced configurations**
  - EPs – extension points
  - Directional antenna

WLAN configurations



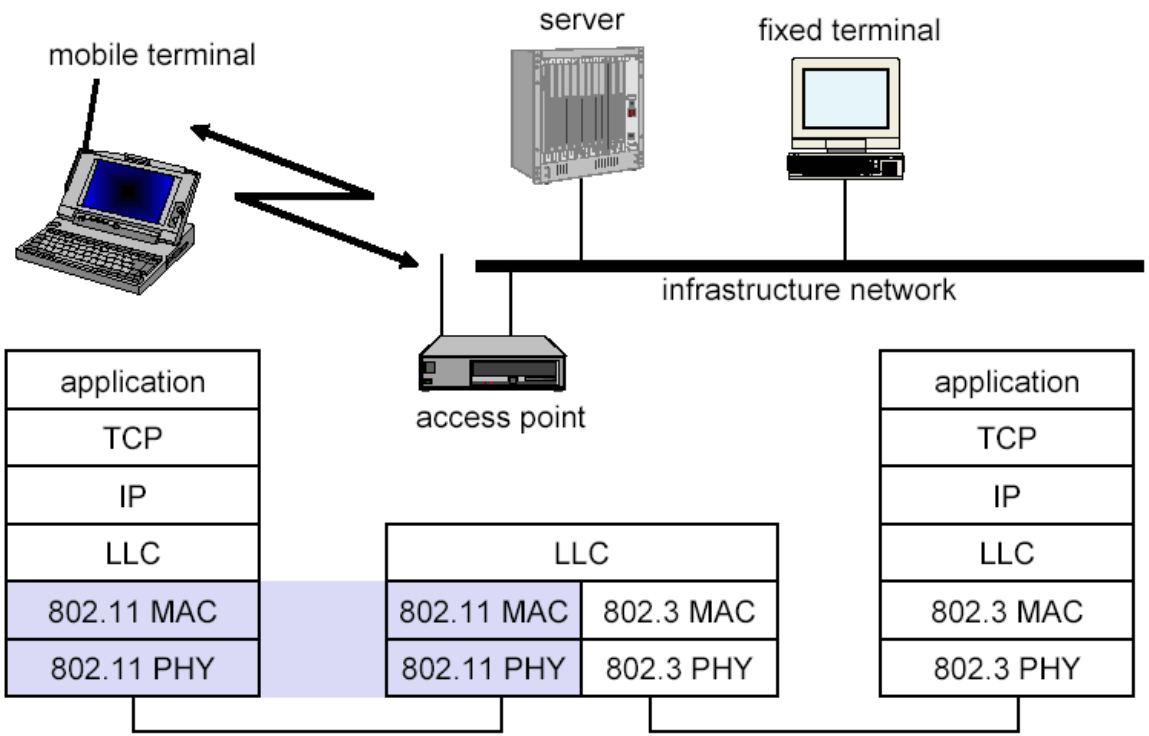
LANs interconnected using APs

WLAN standards

- **Parties that promote WLAN standards:**
  - IEEE
  - **E**uropean **T**elecommunications **S**tandards **I**nstitute (ETSI)
  - HomeRF (Home Radio Frequency Working Group)
- **Standards include:**
  - 802.11
  - HIPERLAN/1 (**HI**gh **PE**rformance **R**adio **L**ocal **A**rea **N**etwork) (For business workspace)
  - HIPERLAN/2

WLAN standards - IEEE

- **IEEE 802.11x are** Physical Layer **(PHY) and** Medium Access Control **(MAC) standards, specifying**
  - Carrier frequencies, data rate, protocols, power levels, modulation schemes, and so on.



WLAN standards - IEEE

- **802.11 (1997, outdated)**
  - 2.4 GHz range bandwidth with data rate of 1 or 2 Mbps
- **802.11b**
  - Higher bit rates and international availability of the 2.4 GHz ISM band
  - Specify a PHY layer providing a basic rate of 11 Mbps
- **802.11a**
  - Operate at higher frequencies and provide higher bit rate
  - 5.2 GHz band, utilizing OFDM to provide data rates up to 54 Mbps
- **802.11g – back-compatible with 802.11b, higher speed.**
- **802.11n**
  - 2.4 GHz range bandwidth; Backward compatible with 802.11b and g.
  - Theoretical data rate of 600 Mbps and transmission range of 50 meters.
  - Uses MIMO to improve its transmission speed and range.

WLAN standards - IEEE

- **Other 802.11 standards**
  - IEEE 802.11e – enhancing MAC to provide QoS for multimedia app.
  - IEEE 802.11f – Inter-AP protocol for inter-operability of different APs
  - IEEE 802.11h – enhancing PHY of 802.11a for compliant with Euro
  - IEEE 802.11i – enhancing MAC to increase security
  - IEEE 802.11k – for radio resource management

WLAN standards - IEEE

- **Wi-Fi (Wireless Fidelity? not really)**
  - Wi-Fi Alliance, founded in 1999
  - Comprising more than 300 companies whose products are certified by the Wi-Fi Alliance, based on the IEEE 802.11 standards
  - Covers IEEE 802.11 standards, including 802.11a, 802.11b, 802.11g, and 802.11n

WLAN standards - IEEE

- **802.11 specification implemented a feature called *Wired Equivalent Privacy (WEP)***
  - with the goal of providing an equivalent level of security as normally present in an unsecured wired LAN.
- **Provide basic levels of authentication and data encryption.**
  - *Authentication*: verifying client's identity using secret key.
  - *Encryption*: encrypting each data packet (need to distributed private key – not defined in 802.11).
- **WEP considered not secure enough – never designed to provide end-to-end security, and should be used with other existing security mechanisms.**

WLAN standards - HiperLAN

- **A High Performance Radio LAN.**
  - A standard for Radio LANs developed in Europe by ETSI
  - An interoperability standard which specifies a common air interface for MAC and PHY layers in OSI model
  - Operate in 5.15 GHz and 17.1 GHz bands
  - Coverage of 50 m
  - Mobility < 10 m/s
  - Specially designed for ad hoc computing
- **A family of standards**
  - HiperLAN/1 – Indoor LAN (~20 Mbps)
  - HiperLAN/2 – Indoor broadband multimedia (~50 Mbps)

Comparison of WLAN Tech.

Standard	Frequency	Bandwidth	Range	Points of interest
802.11	**2.4 GHZ**	**1-2 Mbps**	**100 meters (300 feet)**	**The first approved specification in the 802.11 family**
802.11a	**5 GHZ**	**54 Mbps**	**50 meters (150 feet)**	**Uses OFDM modulation to achieve high data rates; first commercial products became available in 2002**
802.11b	**2.4 GHZ**	**11 Mbps**	**100 meters (300 feet)**	**Largest market penetration of any WLAN standard, with commercial products available since 1999**
802.11g	**2.4 GHZ**	**54 Mbps**	**100 meters (300 feet)**	**Approved by the IEEE-SA in the fall of 2002. Backward compatible with 802.11b**

Comparison of WLAN Tech.

Standard	Frequency	Bandwidth	Range	Points of interest
HIPERLAN/1	**5 GHZ**	**20 Mbps**	**-**	**HIPERLAN/1 did not achieve commercial success**
HIPERLAN/2	**5 GHZ**	**54 Mbps**	**150 meters (450 feet)**	**Designed for integration with other networks, including wired LANs, IEEE 1394 (Firewire) and 3G mobile networks. Unlikely to achieve commercial success**

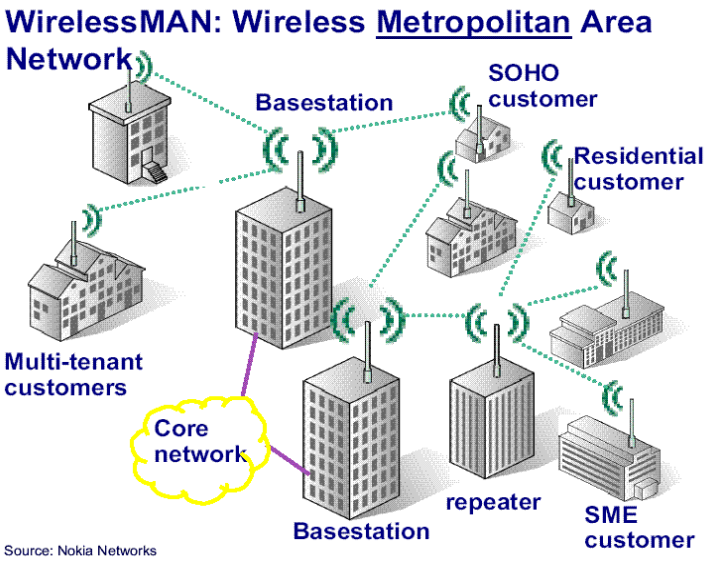
WMAN: Wireless Metropolitan Networks

Wireless MAN

- **Provide metropolitan level coverage**
- **With wireless network infrastructure provided by a wireless service carrier, mostly using *licensed* (for a monthly usage fee) / *regulated* frequencies.**

Wireless MANs

- **Broadband wireless access (BWA) networks – providing a wireless communication path between fixed subscribe sites and a core network (e.g., Telephone, Internet).**
  - The "last mile" to business and residential customers
- **Provide services in**
  - rural areas,
  - developing countries, and
  - underserved urban areas



Wireless MANs

- **IEEE 802.16: WirelessMAN**
- **Point-to-Multipoint (broadcasting)**
  - Base station (BS) connected to public netv
  - BSs serve Subscriber Stations (SSs)
  - SS typically serves a building
- **Compared to a WLAN**
  - Multimedia QoS – connection-oriented, not ony contentionless-based
  - Many more users
  - Much higher data rates (1.5 Mbps – 50 Mbps)
  - Much longer distances (~20 miles)

IEEE Std 802.16-2001®

IEEE Standard for
Local and metropolitan area networks

Part 16: Air Interface for Fixed Broadband Wireless Access Systems

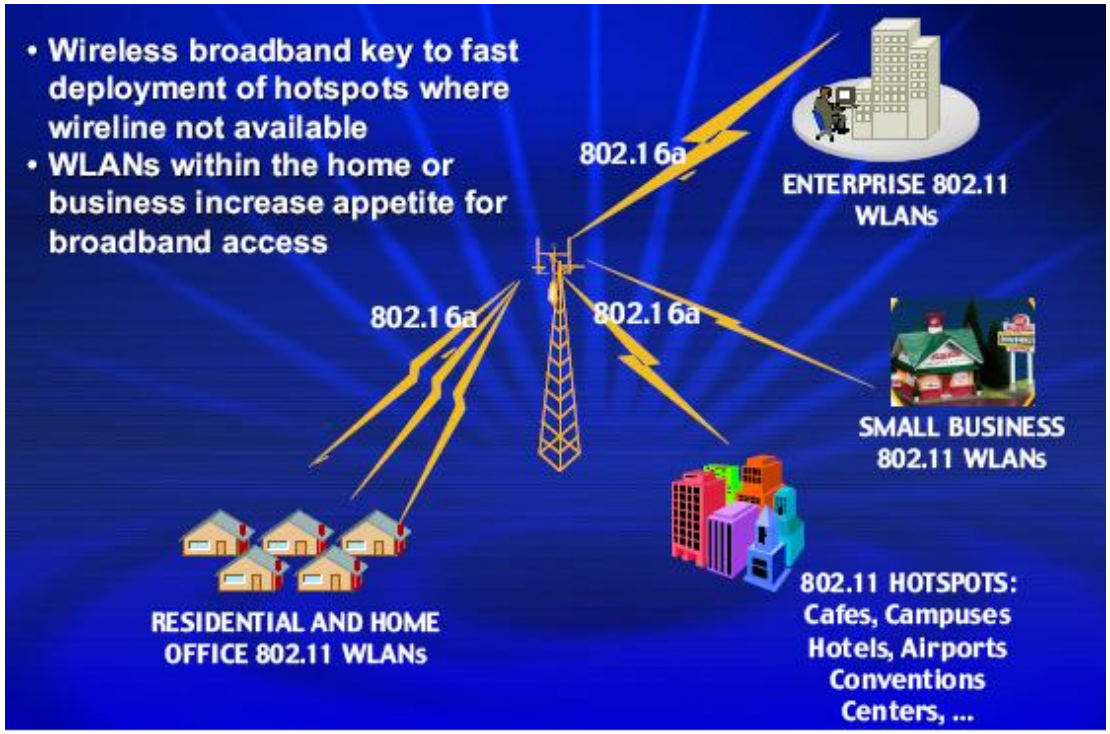
Sponsor
LAN/MAN Standards Committee
of the
IEEE Computer Society

and the
IEEE Microwave Theory and Techniques Society

Approved 6 December 2001
IEEE-SA Standards Board

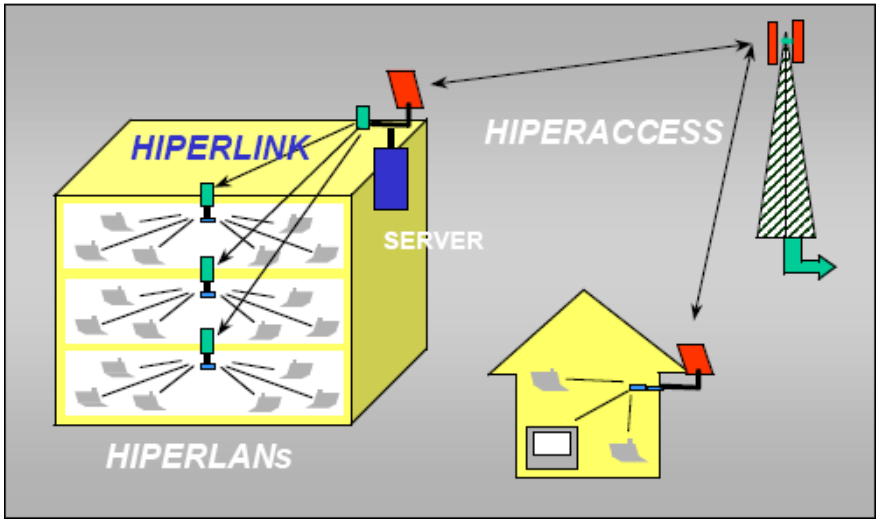
Wireless MANs

- Can also be used to inter-connect LANs in different buildings - IEEE 802.11 drives demand for 802.16



Wireless MANs

- **ETSI wireless MAN standards**
  - ***HiperMAN*** : equivalent to 802.16a
    - Wireless access under 11GHz
  - ***HiperACCESS***
    - Above 11 GHz (mostly licensed users)

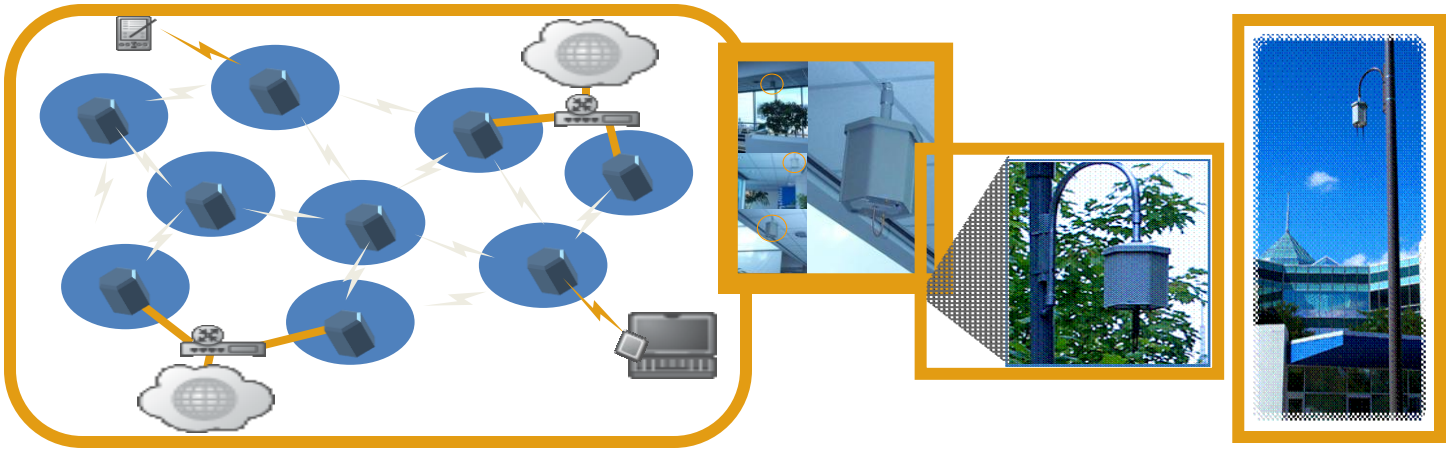


Wireless MANs

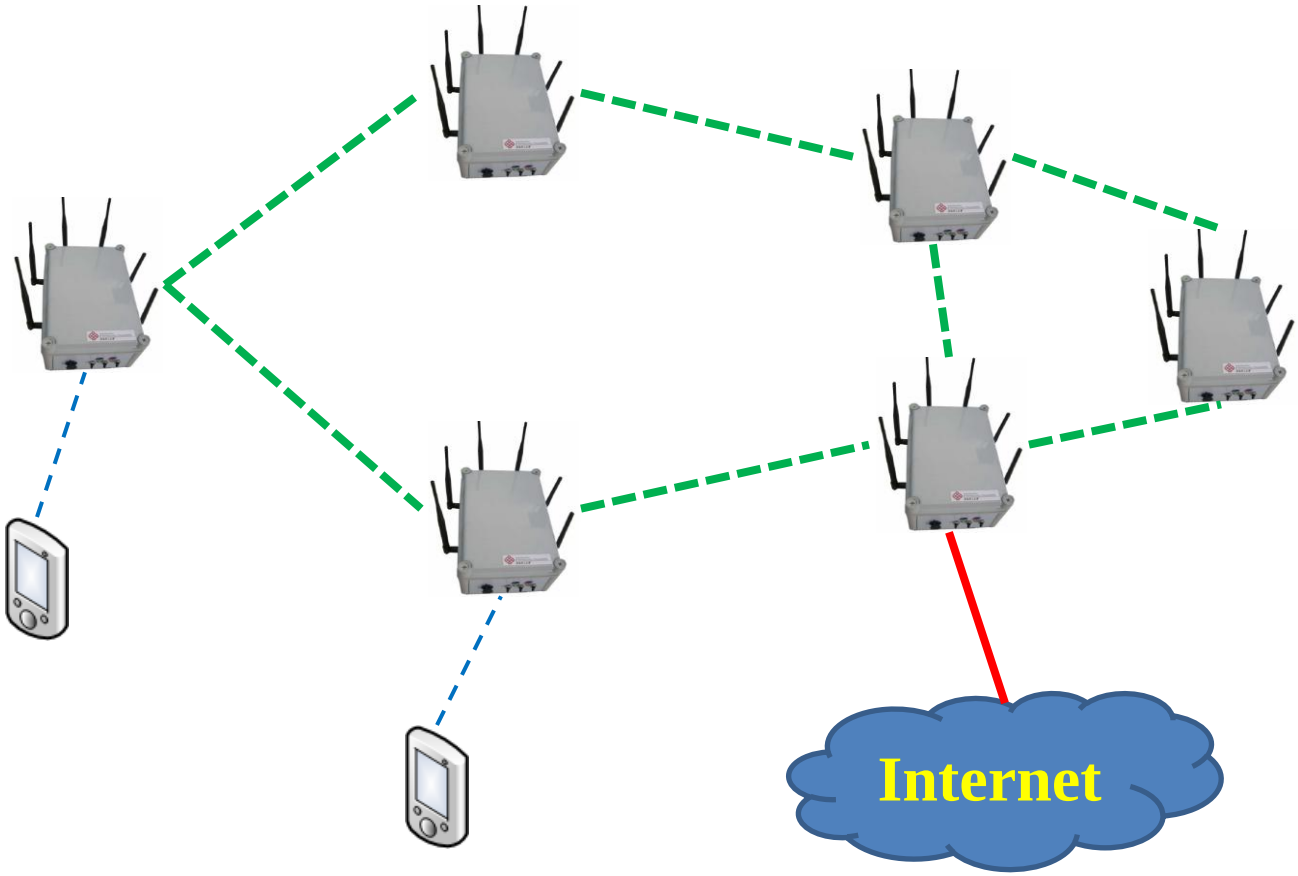
- ***WiMAX* Forum (Worldwide Interoperability for Microwave Access)**
  - Mission: promoting deployment of BWA by using a global standard and certifying interoperability of products and technologies
  - Support IEEE 802.16 (2 – 66 GHz)
  - Promote IEEE 802.16 standard to achieve global acceptance
  - Also make sure that 802.16a works with HiperMAN products

Wireless Mesh Network (WMN)

- **Wireless *ad hoc* networks consisting of BSs / APs inter-connected in mesh topology**
  - No need for wired backhaul connection to every AP - eg. reaching outdoor areas where wired infrastructure would not be feasible
- **Based on ad hoc 802.11 (11a, b, g SOHO APs)**



Wireless Mesh Network



Benefits:

Low cost;

Easy to maintain and extend;

Robust; ……

Applications:

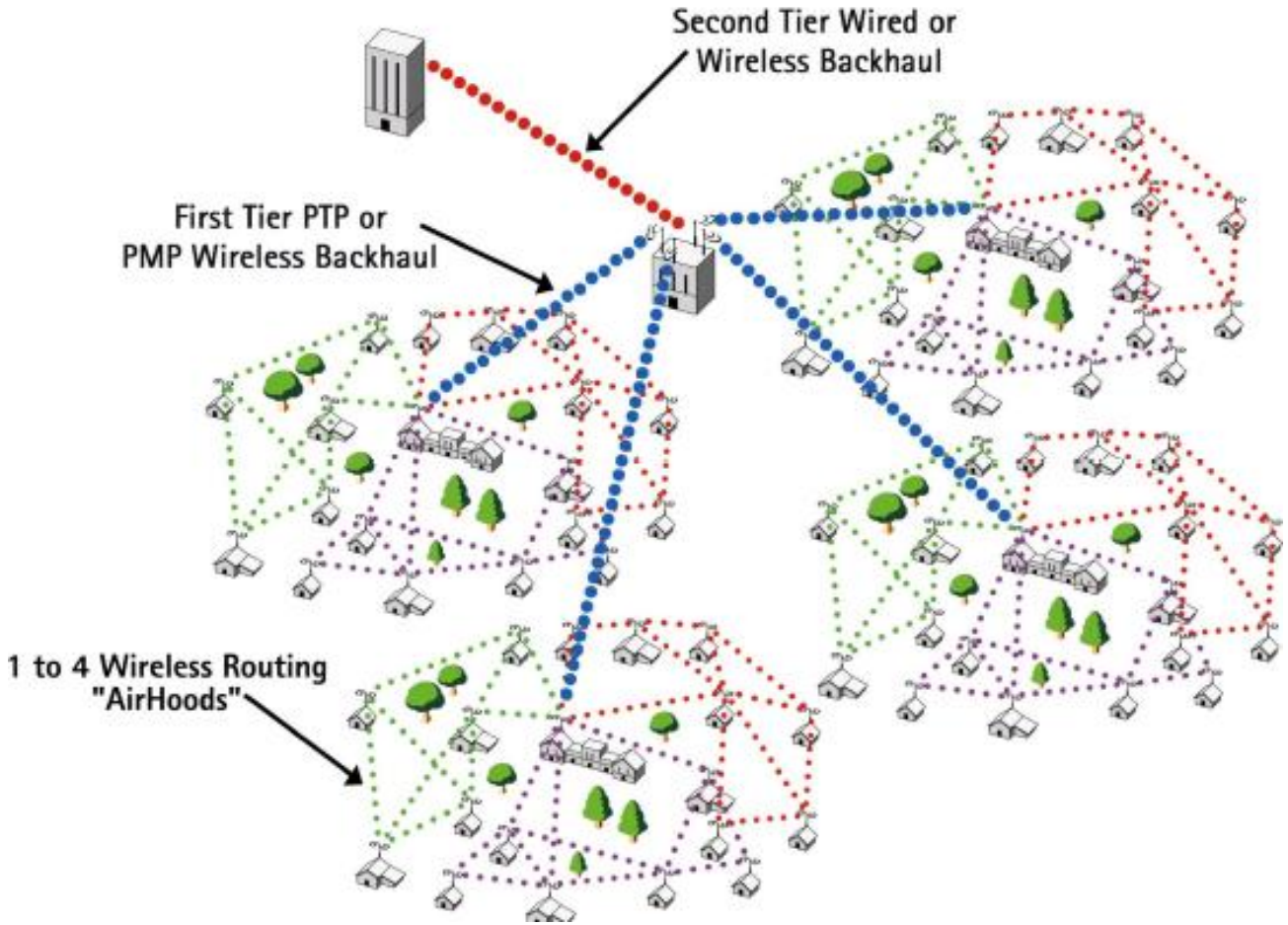
Emergency scenario;

Disaster rescue;

Internet Access Service;

Video surveillance;…

Mesh-based WilelessMAN



- Can be complimentary to future 802.16a WiMAX
- A promising option for equipping rural broadband networks

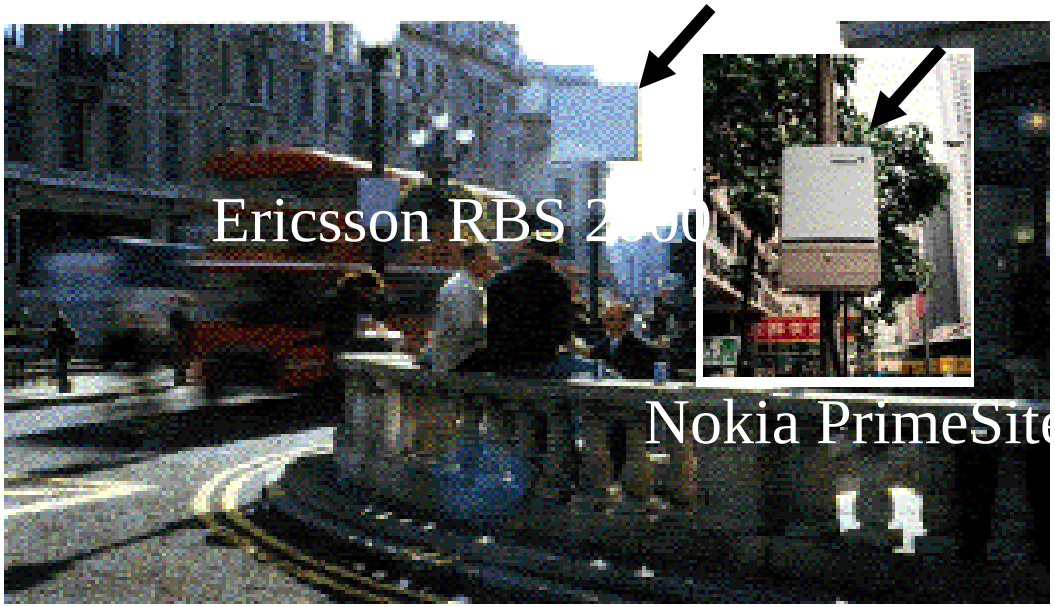
WWAN:
Wireless Wide Area Networks

WWAN

- **Provide national, and international coverage**
  - Cellular and Satellite networks
- **With wireless network infrastructure provided by a wireless service carrier, using licensed (for a monthly usage fee) / regulated frequencies.**

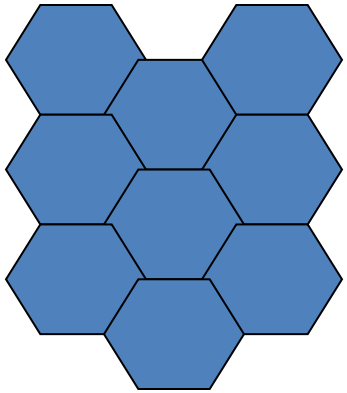
Cellular networks

- **Based on the concepts of *cells*, *base stations***
  - **Using a system of *hexagonal* ground-area cells around transmitter-receiver base stations**
  - ***Mobile Unit*** moves between ***cells,*** each is served by a ***base station***



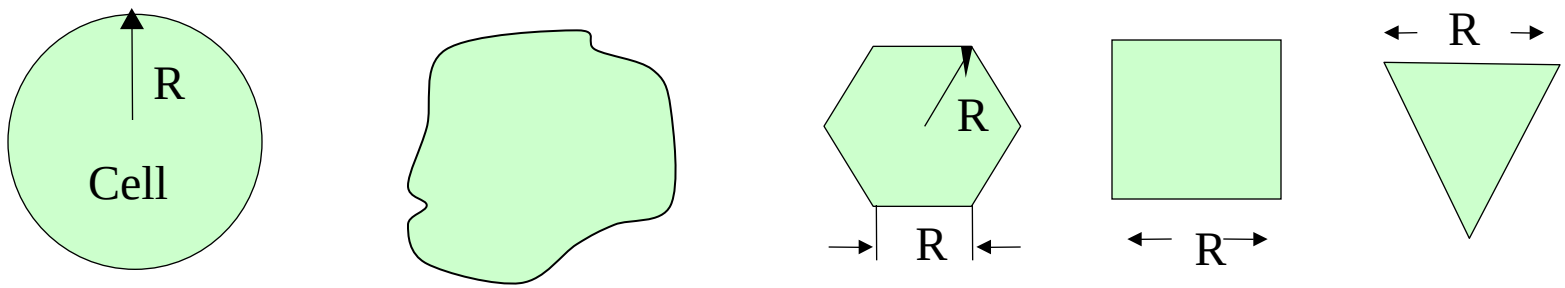
Cells

- ***Cell*** **: the region covered by each base station is known as its cell.**
  - Typical cell sizes: 1 – 40 Km in radius (decided by signal power, network protocols, etc)
  - ***Microcells*** are often used in highly populated areas, with base stations positioned closer to one another
    - Usually deployed in buildings
    - Coverage is much less (~ 100 m)



  - Multiple cells form a cluster covering over a larger area.

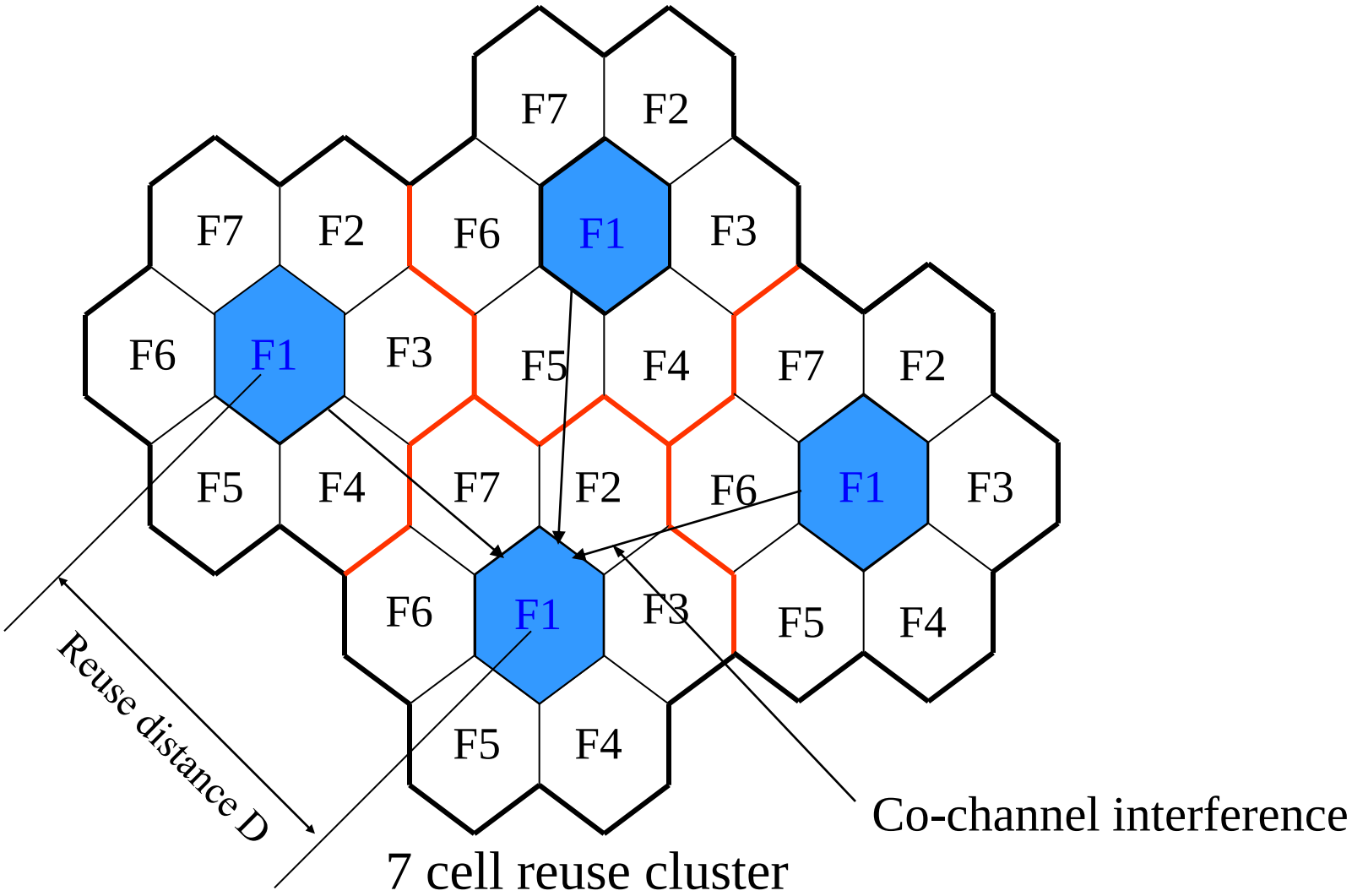
Cell Shapes



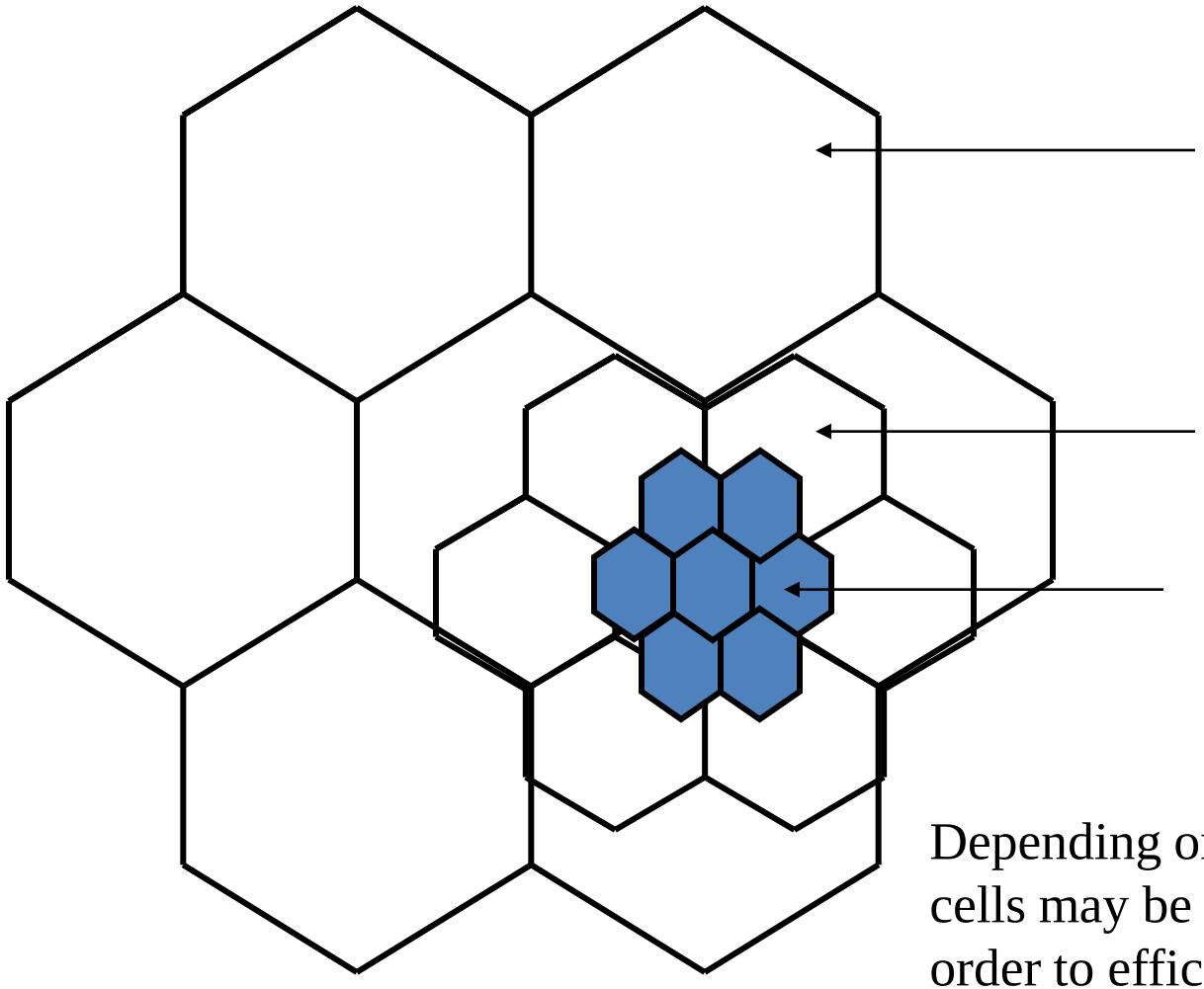
(a) Ideal cell (b) Actual cell (c) Different cell models

Shape of the Cell	Area	Boundary	Boundary Length/ Unit Area	Channels/Unit Area with N Channels/ Cells
Square cell (side $= R$)	R^2	$4R$	$\frac{4}{R}$	$\frac{N}{R^2}$
Hexagonal cell (side$=$ R)	$\frac{3\sqrt{3}}{2}R^2$	$6R$	$\frac{4}{\sqrt{3}R}$	$\frac{N}{1.5\sqrt{3}R^2}$
Circular cell (radius $=$ R)	πR^2	$2\pi R$	$\frac{2}{R}$	$\frac{N}{\pi R^2}$
Triangular cell (side $= R$)	$\frac{\sqrt{3}}{4}R^2$	$3R$	$\frac{4\sqrt{3}}{R}$	$\frac{4\sqrt{3}N}{3R^2}$

Frequency Reuse

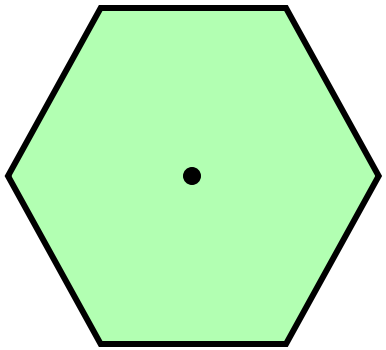


Cell Splitting

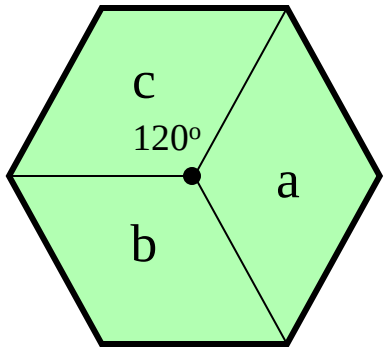


Depending on traffic patterns the smaller cells may be activated/deactivated in order to efficiently use cell resources.

Cell Sectoring



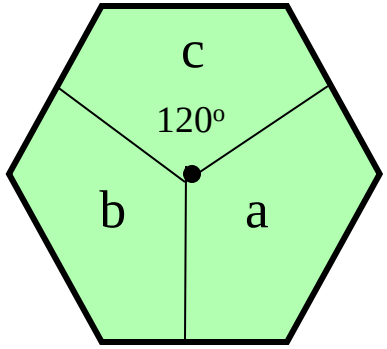
(a). Omni



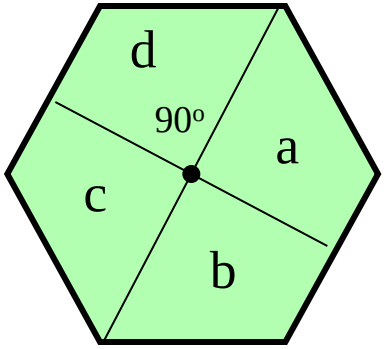
(b). 120° sector

By antennas design

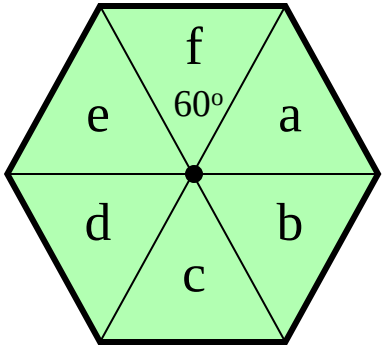
-increase signaling range
-reduce delay spread & flat fading
-suppress interference between users



(c). 120° sector (alternate)

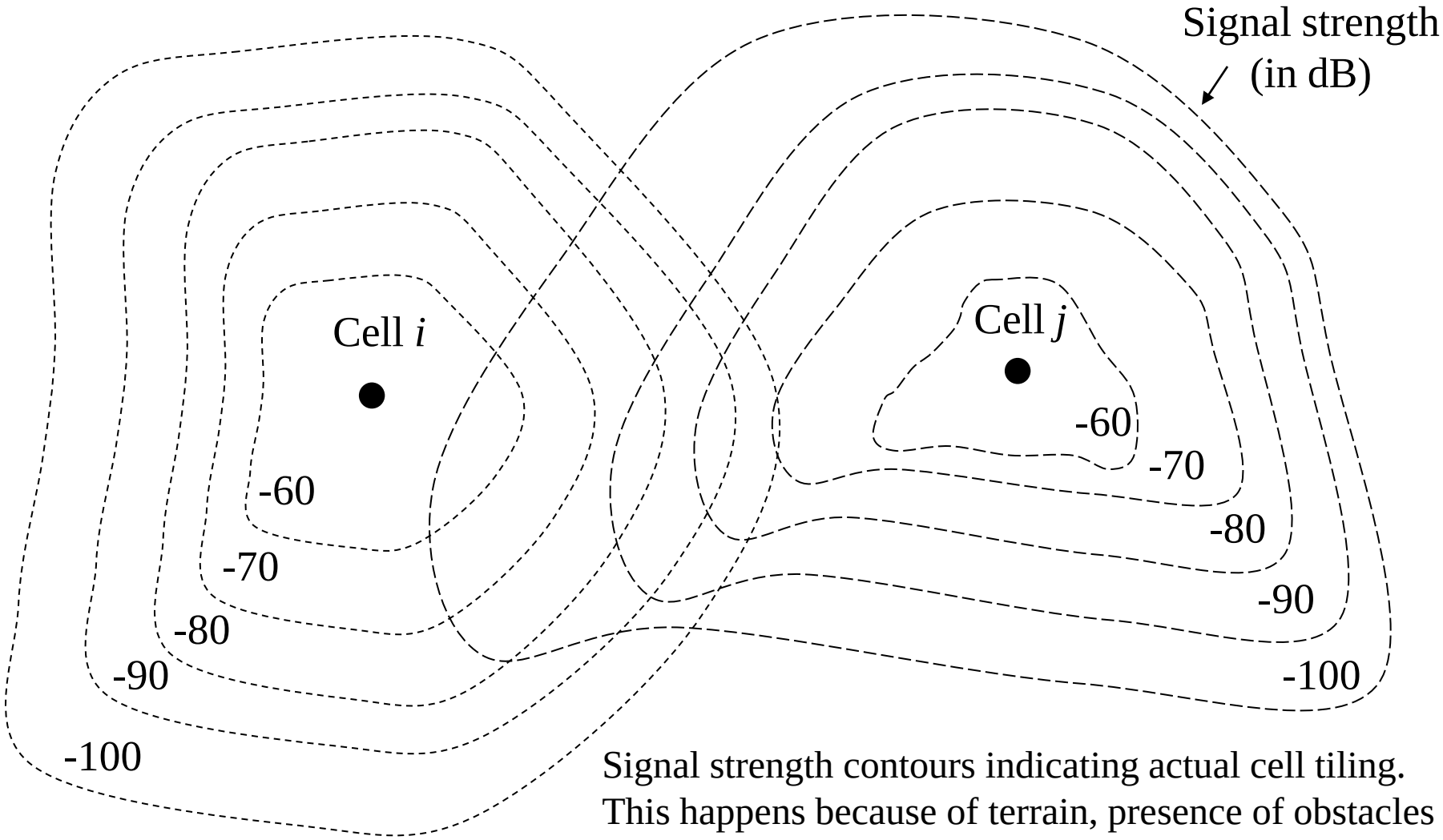


(d). 90° sector



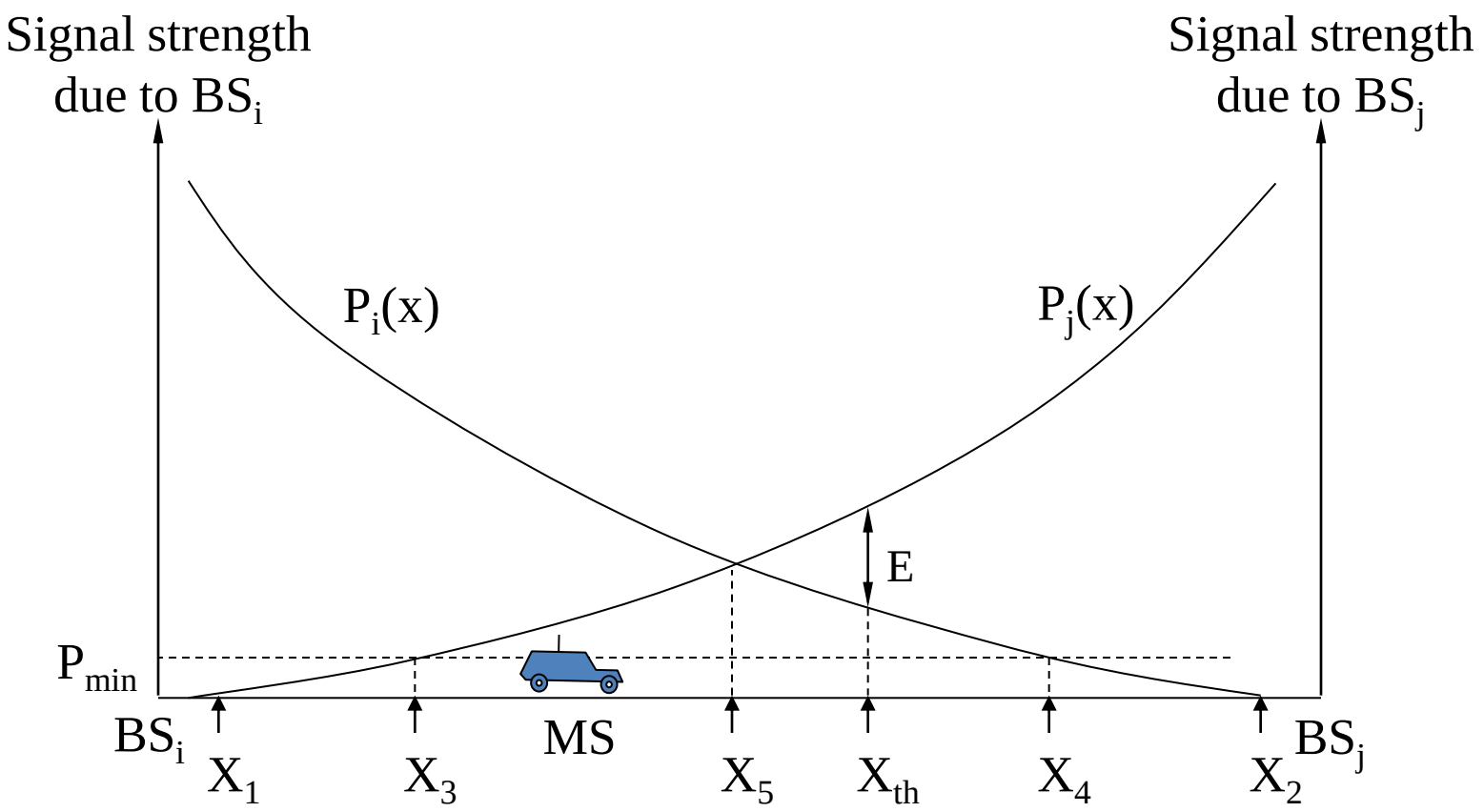
(e). 60° sector

Signal Strength



Signal strength contours indicating actual cell tiling. This happens because of terrain, presence of obstacles and signal attenuation in the atmosphere.

Handoff



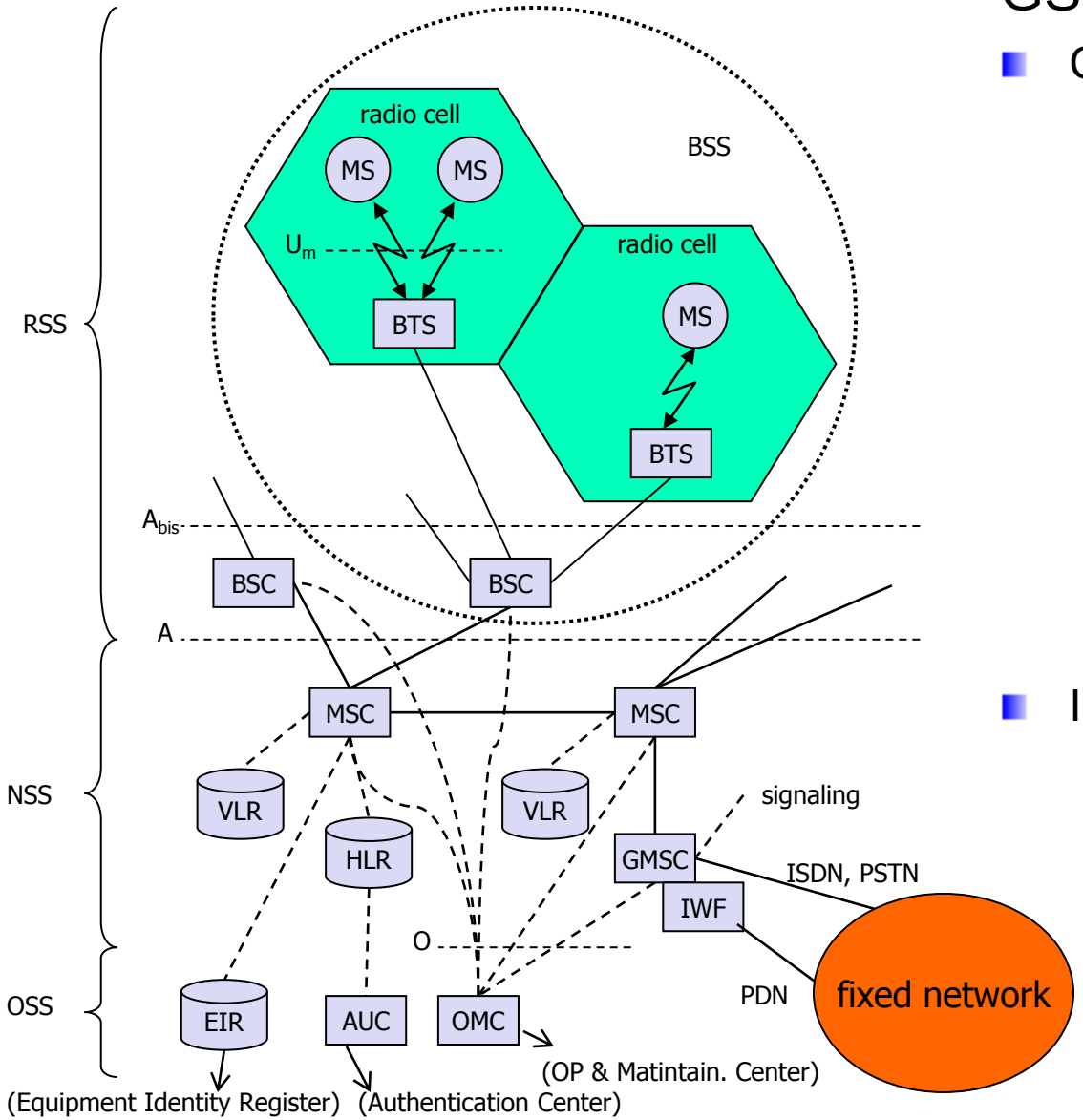
By looking at the variation of signal strength from either base station it is possible to decide on the optimum area where handoff can take place.

Handoff, Roaming

- ***Handoff*** **: Inter–base-station transition, as well as the switching process.**
  - Call still in progress so connection has to be passed from one cell to another.
  - No need to re-establish connection before continuing.
- ***Roaming*** **: allowing user to move to a cell owned by a different wireless operator.**
  - When you sign up with a cellular telephone service provider, you are given access to only their cell system.
  - When travelling out of the range of this cell system, the cell system can enable you to be transferred to another company's cell system without your being aware of it.

Cellular System: Architecture

- **A Cellular Network is a PLMN (Public Land Mobile Network)**
  - Several providers setup mobile networks following the same standard (e.g., GSM) within each country
  - Components
    - MS (mobile station)
    - BS (base station)
    - MSC (mobile switching center)
    - LR (location register)
  - Subsystems
    - RSS (radio subsystem): covers all radio aspects
    - NSS (network and switching subsystem): call forwarding, handover, switching
    - OSS (operation subsystem): management of the network



GSM

- Components
  - *MS* (Mobile Station)
  - *BSS* (Base Station Subsystem): consisting of
    - *BTS* (Base Transceiver Station): sender and receiver
    - *BSC* (Base Station Controller): controlling several transceivers
  - *MSC* (Mobile Services Switching Center): controlling several BSCs
    - switching, mobility, resources
  - *IWF* (Interworking Functions)
- Interfaces
  - U_m : radio interface
  - A_{bis} : standardized, open interface with 16 kbit/s user channels
  - *A*: standardized, open interface with 64 kbit/s user channels

First-generation (1G)

- **First constructed in the late 1970s in US (AMPS – Advanced Mobile Phone Service), early 1980's in Europe (TACS – Total Access Communication System, NMT – Nordic Mobile Telephony).**
- **They are *analog* networks and only provide voice communication service.**
- **Compared with today's wireless networks, they suffered lots of drawbacks.**
  - High level of interference, low call quality
  - Poor handoffs, often resulting in disconnections.
  - Low capacity
  - Almost no security
  - Large devices

Second-generation (2G)

- **2G networks appeared in the early 1990's.**
- **Introduced *digital* technologies, solving all the problems in 1G networks and provided many new services.**
  - Higher quality voice and basic data services, and other features (voicemail, call waiting, 3-way calling, etc)
  - Increase capacity
  - Strong security support
  - Basic data services: 9.6~19.2 Kbps (fast enough for simple applications based on WAP, or text messaging with SMS)

2G (Cont'd)

- **Four major 2G systems currently in use:**
  - **Digital AMPS** (DAMPS): known as **TDMA** in Americas, evolved from AMPS.
  - **CDMA** (CDMA IS-95 / cdmaOne): introduced by QUALCOMM in 1995
  - **GSM** (Global System for Mobile Communications): most popular of the 2G networks
  - **PDC** (Personal Digital Cellular): largely used in Japan, based on TDMA
- **Majority of 2G systems use TDMA.**
- **Based on different standards, incompatible with one another (even the same network may not be compatible due to frequency regulations.)**
  - e.g, in Europe, GSM networks operate on 900-MHz and 1800-MHz, while in North America GSM use the 1900-MHz.
  - that is why we have dual-band, and tri-band handsets.

2G (Cont'd)

- **Other features of 2G**
  - WAP browsers
  - Text messaging
  - Contact lists
  - Calendars
  - Games
  - Changeable ring tones

2G (Cont'd)

- **2G are the driving force for 3G – its capacity (data transfer rates) is still not adequate for data-driven applications.**
- **1G and 2G are circuit-switched, inefficient and expensive, with very limited data transfer rates.**
- **There were packet-switched options for *data* services**
  - CDPD (for AMPS) and DAMPS
  - Mobix
  - DataTAC (for TAC)
  - Packet PDC (for PDC)

However, they still use narrowband and old modulation / multiplexing technologies, with data rates similar to 1G / 2G networks

Second-and-a-Half-Generation (2.5G)

- **2.5G networks are a step toward 3G, but not quite there.**
- **Major difference from 2G: packet-switch systems**
  - High speed data transfer rate: up to 144 Kbps (theoretically).
- **5 important characteristics of 2.5G networks.**
  - Efficiency on spectrum utilization due to sharing connections
  - Speedup due to more efficient modulation algorithms and simultaneous use of multiple channels
  - ***Always-on*** capability without having to pay by-the-minutes charges
  - Upgrading to 2.5G from 2G only require software update.
  - Providing foundation of 3G infrastructure

2.5G (Cont'd)

- **Two leading 2.5G network protocols:**
  - GPRS (General Packet Radio Services)
  - CDMA2000 1x.

2.5G - GPRS

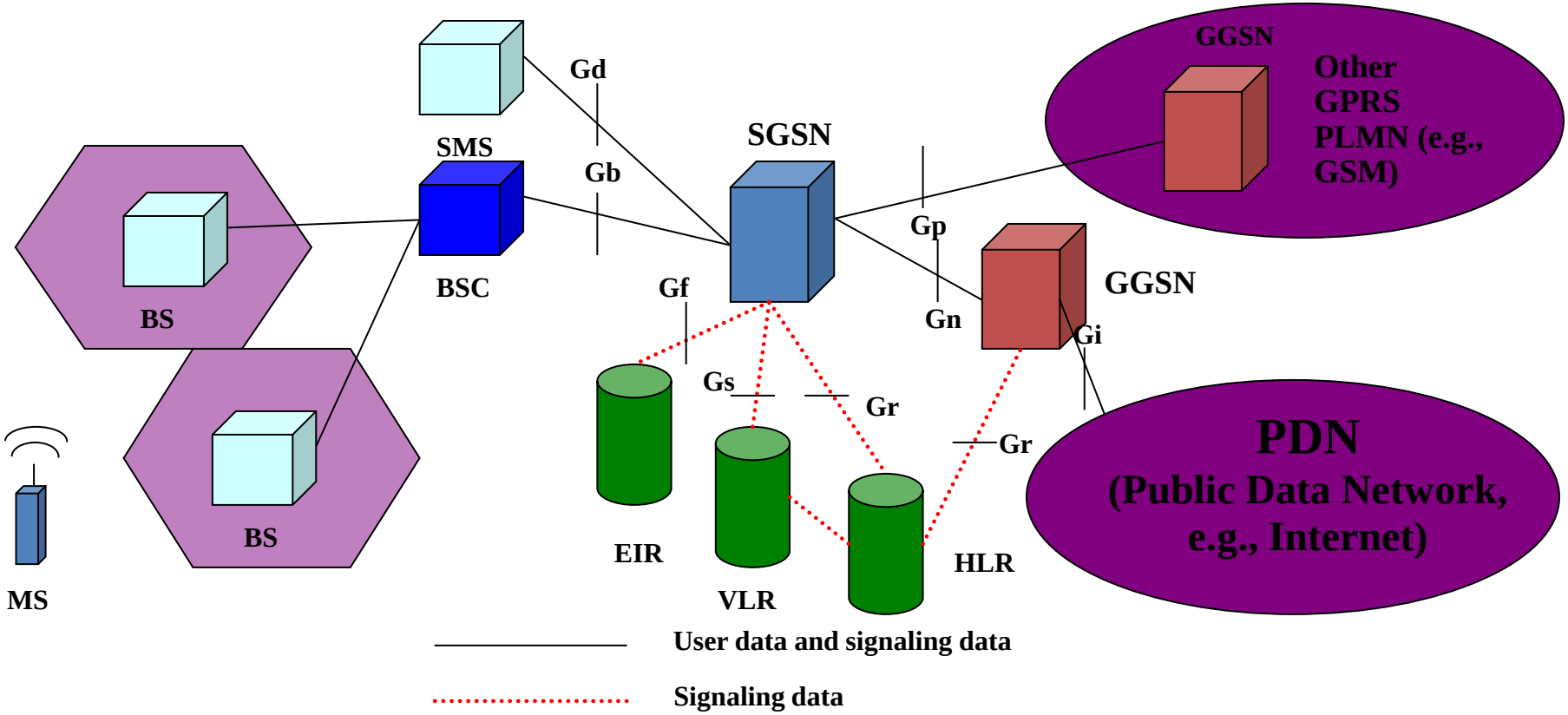
- A simple, cost-effective upgrade to GSM/TDMA to provide increased bit rates and many other new features, such as Always-On capabilities.
- Operate on 900/1800/1900MHz.
- Provide theoretical data transfer rate 115 Kbps (Practical rate is around 40 Kbps).
- Upgrade on existing networks, so it is a safe point between 2G and 3G.
  - new packet-switched core network
  - software upgrades only in radio access network

2.5G - GPRS

- New components
  - SGSN: Serving GPRS Support Node
  - GGSN: Gateway GPRS Support Node

GPRS backbone

- Based in IP
- Tunnels of data and signaling messages between GPRS support nodes



2.5G - GPRS

- **SGSN:**
  - Delivers data packets from and to mobile stations
  - Packet Routing and Transfer from MS to GGSN
  - Mobility Management
  - Logical Link Management
  - Authentication
  - Billing and maintaining user profiles
- **GGSN:**
  - Interfaces GPRS backbone network with external packet data networks (PDNs: Internet)
  - Translation between PDP (packet data protocol) addresses and GSM addresses
  - Authentication and billing

2.5G – CDMA2000 1x

- Officially classified to be 3G by ITU (Int'l Telecom. Union). But it does not meet the minimum speed requirements for 3G, and very similar to GPRS, so it is a 2.5G technology in practice.
- Each channel is 1.25 MHz. Theoretical data transfer rate is 144 Kbps (practical rate is 40~56 Kbps).
- Compatible with cdmaOne, but the capacity is double, and also provide Always-On capabilities.

2.5G - Devices

- **Often it is the device that limits the total data rates that 2.5G networks provide.**
- **Most devices do not provide the needed capability due to cost reasons.**
- **GPRS provide three classes of handsets / terminals:**
  - Class A: handle both voice and packet data at the same time
  - Class B: handle both voice and packet data, but not at the same time
  - Class C: handle either voice or data

2.5G - Applications

- Wireless Internet applications with full graphics and some multimedia capabilities
- Corporate email, calendar, contact lists
- Instant messaging
- Still and moving images
- Job dispatch
- Vehicle positioning using location-based services
- Remote LAN access
- File sharing applications

Third-Generation (3G)

- **Original motivation/goal is to develop a single global standard for high speed data and high quality voice services - allow for true global roaming.**
- **Unfortunately, companies and standards bodies from Europe, North America, and Japan could not agree on a single protocol for 3G.**

  After much negotiation, it was realized that a single 3G implementation is impossible.
  - This is because backward compatibility with 2G networks and frequency differences among countries were too difficult to overcome

3G (Cont'd)

- **3G networks' features**
  - Based on CDMA and IP technologies.
  - Higher data rates: ranging from 144 Kbps to 2 Mbps, depending on the level of mobility:
    - High mobility (speed >= 120 KM per hour) - 144Kbps
    - Full mobility (speed < 120 KM per hour) - 384Kbps
    - Limited mobility (speed < 10 KM per hour) - 2Mbps

    Data transfer rates also depend on user's distance from base station
  - Enhanced quality of services: QoS is supported from end to end.
    - Allow users to establish agreements with network operators for certain properties such as data transfer rate and network latency.

3G (Cont'd)

- **3G networks' features (cont'd)**
  - Global seamless operation in multi-cell environment (SAT, macro, micro, pico)
  - Global roaming: multi-mode, multi-band, low-cost terminal, portable services & QoS.

3G(Cont'd)

- **Three branches of 3G systems were created:**
  - EDGE (Enhanced Data Rates for Global Evolution)
  - CDMA2000 1x EV
  - WCDMA (referred as UMTS in Europe)

  ☞ **TD-SCDMA**

  All are based on CDMA except EDGE (TDMA)

- **In 1999, ITU approved an industry standard for 3G, called Int'l Mobile Telecom.-2000 (IMT 2000)**
  - With the goal to converge the three 3G standards into a single universally accepted standard.

3G (Cont'd)

EDGE

- Allow current GSM networks to offer 3G within existing frequencies.
- TDMA or GSM/GPRS can be upgraded to EDGE with minimum impact.
- Use narrowband technology, no need to obtain a 3G license. These make it a low-cost, fast solution.
- Peak data rate: **384K bps**, download rate: **75~150 Kbps**.
- Provide a seamless upgrade from 2G to 3G.

3G (Cont'd)

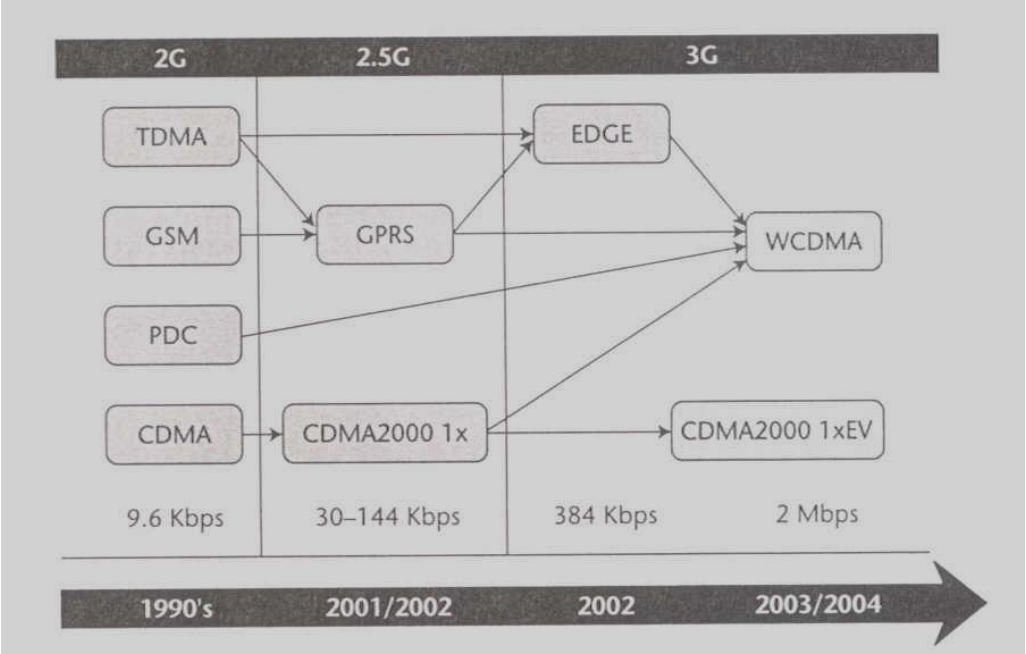
- CDMA2000 1x EV: **two members of the family:**
  - *CDMA2000 1x Evolution Data Optimized* (CDMA2000 1x EV-DO)
    - Provide **2.4 Mbps** peak data transfer rate. Support the complete range of available frequencies. Work on all IP networks.
  - *CDMA2000 1x Evolution Data and Voice* (CDMA2000 1x EV-DV)
    - Provide similar wireless data capabilities as CDMA2000 1x EV-DO, but with additional voice capabilities. The peak data transfer rate will be **3 Mbps**.

3G (Cont'd)

- WCDMA (UMTS)
  - Require 5MHz channel bandwidth.
  - Can provide 3 modes of mobility defined by IMT-2000 (**144 Kbps**, **384 Kbps**, **2M bps**)
  - Unlike the upgrade to GPRS and EDGE, WCDMA requires coverage to be built from scratch. This requires significant capital expenditures by carriers.
  - Fortunately, WCDMA is compatible with GSM/GPRS/EDGE, so user can roam between them.

Evolution to 3G

- **First 3G systems were implemented on a trial basis in Japan and Europe in late 2001.**
- **Worldwide commercial rollouts began in late 2002.**
  - In HK, 3G was launched in early 2004.



3G - Devices

- Support for multimedia
- Large, high-resolution screens
- Form factors similar to PDAs
- Integrated voice and data
- Mobile operating systems that allow for sophisticated client-side applications

3G - Applications

- **In addition to those similar to 2.5G applications, we have new ones:**
  - Streaming video applications
  - Downloadable audio such as MP3s
  - Over-the-air download of software programs
  - Workplace collaboration
  - Voice-over-IP
  - Location-based services
  - Multimedia messaging services
  - Corporate email and a full range of attachments

Comparison of cellular networks

Protocol	Frequencies	Data Transfer Rate	Coverage
Mobitex	**400 MHz, 800 MHz** **900 MHz**	**8 kbps**	**Widely available in North America; Coverage in 23 other countries**
CDPD	**800 – 900 MHz**	**19.2 kbps**	**Widely available in North America**
DataTAC	**800 MHz**	**19.2 kbps**	**North America, Asia Pacific, and Europe**

Comparison of cellular networks

Protocol	Frequencies	Data Transfer Rate	Coverage
TDMA	**800 MHz, 1900 MHz**	**19.2 kbps via CDPD**	**Widely used in Americas, with some deployment in Asia Pacific**
GSM	**900 MHz, 1800 MHz, 1900 MHz**	**9.6 kbps**	**Pervasive throughout Europe; deployed in ~170 countries**
CDMA	**800 MHz, 1900 MHz**	**14.4 kbps**	**Widely available in North America; Popular in Asia Pacific**
GPRS	**900 MHz, 1800 MHz, 1900 MHz**	**115 kbps**	**Logical upgrade to GSM and TDMA networks, deployed in the same region**
CDMA2000 1x	**800 MHz**	**144 kbps**	**Logical upgrade to CDMA networks, deployed in the same region**

Comparison of cellular networks

Protocol	Frequencies	Data Transfer Rate	Coverage
EDGE	**800 MHz, 900 MHz 1800 MHz, 1900 MHz**	**384 kbps**	**Upgrade to GPRS, GSM and TDMA, deployed in the same regions**
CDMA2000 1x EV-DO	**450 MHz, 700 MHz, 800 MHz, 1800 MHz, 1900 MHz, 2GHz**	**144 kbps – 2.4 Mbps**	**Upgrade to cdmaOne and CDMA2000 1X, deployed in the same region**
WCDMA	**2 GHz**	**144 kbps – 2 Mbps**	**Upgrade to PDC, EDGE, and CDMA, resulting in potential worldwide deployments**

4G Technologies

- **Wireless broadband infrastructure to support multimedia information society**
- **Expectations include**
  - High bandwidth of 50 - 100 Mbps (even for high mobility)
  - Low system cost
  - Ubiquitous connection (not only with people but environ.)
  - Seamless integration with wired network and the support of IPv6
  - Adaptive resource and spectrum management with proper QoS
  - High quality multimedia

3GPP Long-term Evolution (LTE)

- **LTE is the latest 3GPP standard in the mobile network technology, representing a major advance in cellular technology**
  - Offers high speed , reduced latency, and cost efficiency – in both the uplink and downlink
- **3GPP Evolution**
  - Release 99 (2000): UMTS/WCDMA
  - Release 5 (2002): HSDPA
  - Release 6 (2005): HSUPA, MBMS(Multimedia Broadcast/Multicast Services)
  - Release 7 (2007): DL MIMO, IMS (IP Multimedia Subsystem), optimized real-time services (VoIP, gaming, push-to-talk).
  - Release 8(2009): LTE (Long Term Evolution)

3GPP LTE: Key Features

- **OFDM technology for the downlink**
  - Increased spectrum efficiency for larger carriers and therefore increase capacity
  - lower cost per bit and lower prices for end-users
- **Adaptive modulation and coding**
- **Multiple Antenna (MIMO) technology for enhanced data rate and performance**
- **Power control and link adaptation**
- **Simplified protocol stack & all-IP network arch.**
  - reduced latency
  - easier network management
- **Flexibilities and scalability in deployment depending on spectrum availability**
  - operating in various frequency bands from 1.4 to 20MHz and therefore can be deployed in lower frequencies
  - operators can start with smaller deployment and increase bandwidth as users increase

3GPP LTE: Performance

- **Data rate**
  - Instantaneous downlink peak data rate of 100Mbit/s in a 20MHz downlink spectrum (i.e. 5 bit/s/Hz)
  - Instantaneous uplink peak data rate of 50Mbit/s in a 20MHz uplink spectrum (i.e. 2.5 bit/s/Hz)
- **Cell range**
  - 5 km - optimal size
  - 30km sizes with reasonable performance
  - up to 100 km cell sizes supported with acceptable performance
- **Cell capacity**
  - up to 200 active users per cell (5 MHz) (i.e., 200 active data clients)
- **Mobility**
  - Optimized for low mobility (0-15km/h) but supports high speed
- **Latency**
  - User plane < 5ms
  - Control plane < 50 ms

Satellites

- **Provide a wireless network with the coverage for the entire planet, without the need for multiple mobile phones or to roam between many carrier's networks.**
- **Satellites act as transponder for signal and data transfer (broadcast).**
  - a satellite is in effect a microwave relay station - used to link two or more ground-based microwave transmitter/receivers known as *ground stations*
  - receives transmissions on one frequency band, amplifies or repeats the signal, and transmits it on another frequency

Satellites

- **Applications**
  - Television distribution
  - Long-distance telephone transmission
  - Private business networks

Satellites

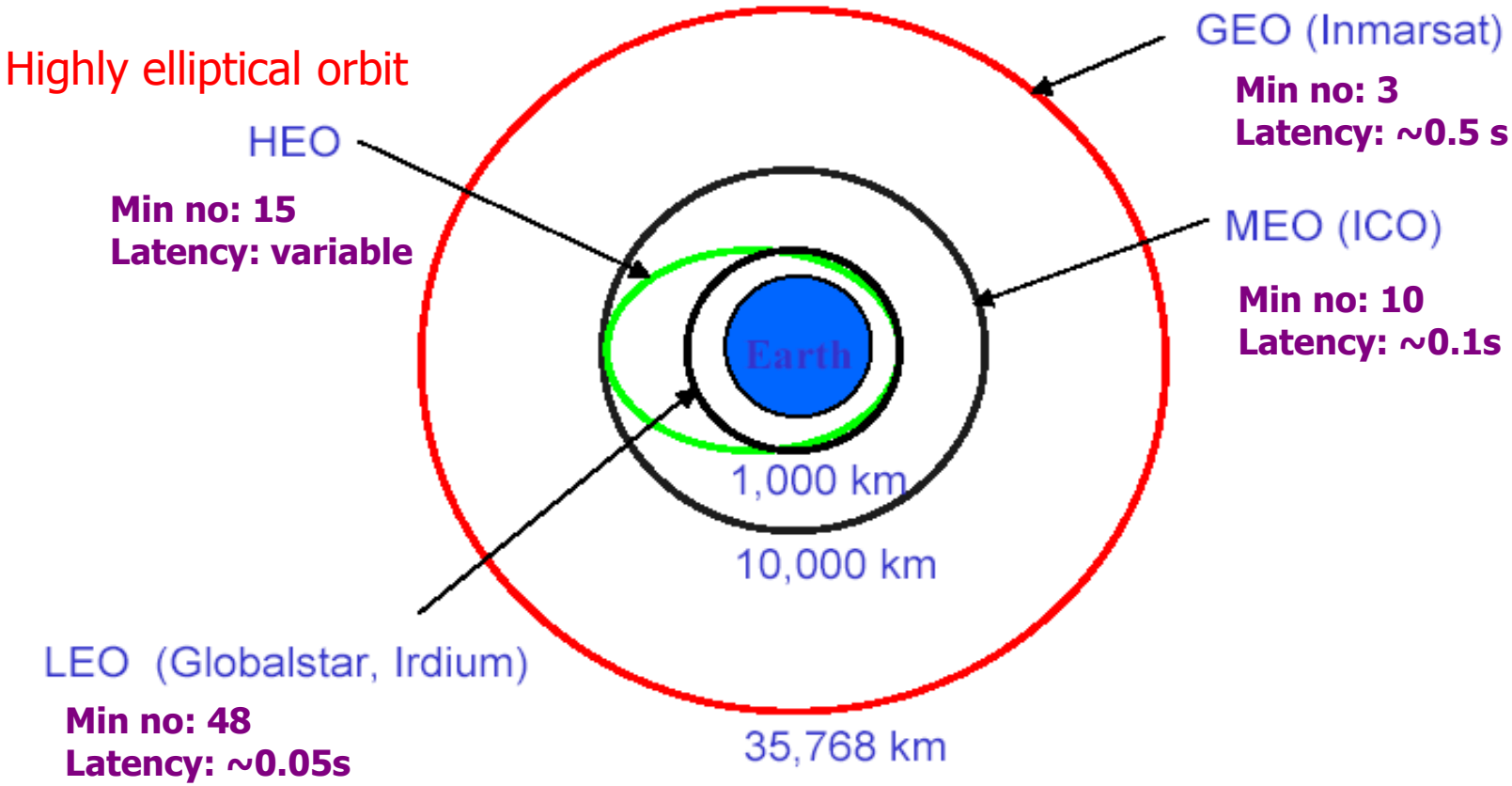
- **Types of satellites**
  - Geostationary Earth Orbit (GEO)
    - 22,282 miles above the Earth's surface.
  - Medium Earth Orbit (MEO)
    - 6000 to 12000 miles.
  - Low Earth Orbit (LEO)
    - 200 - 400 miles

Data transmission speeds range from

2.4 kbps to 2 Mbps

- Multiple MEOs and LEOs are needed to complete communicat.
- LEOs must be replaced every few years - Earth's gravitational pull drags the satellites down from their original orbit.
- GEOs need to be replaced less often than LEOs or MEOs, but they encounter problems with certain areas of Earth's surface such as near the equator.

Satellites



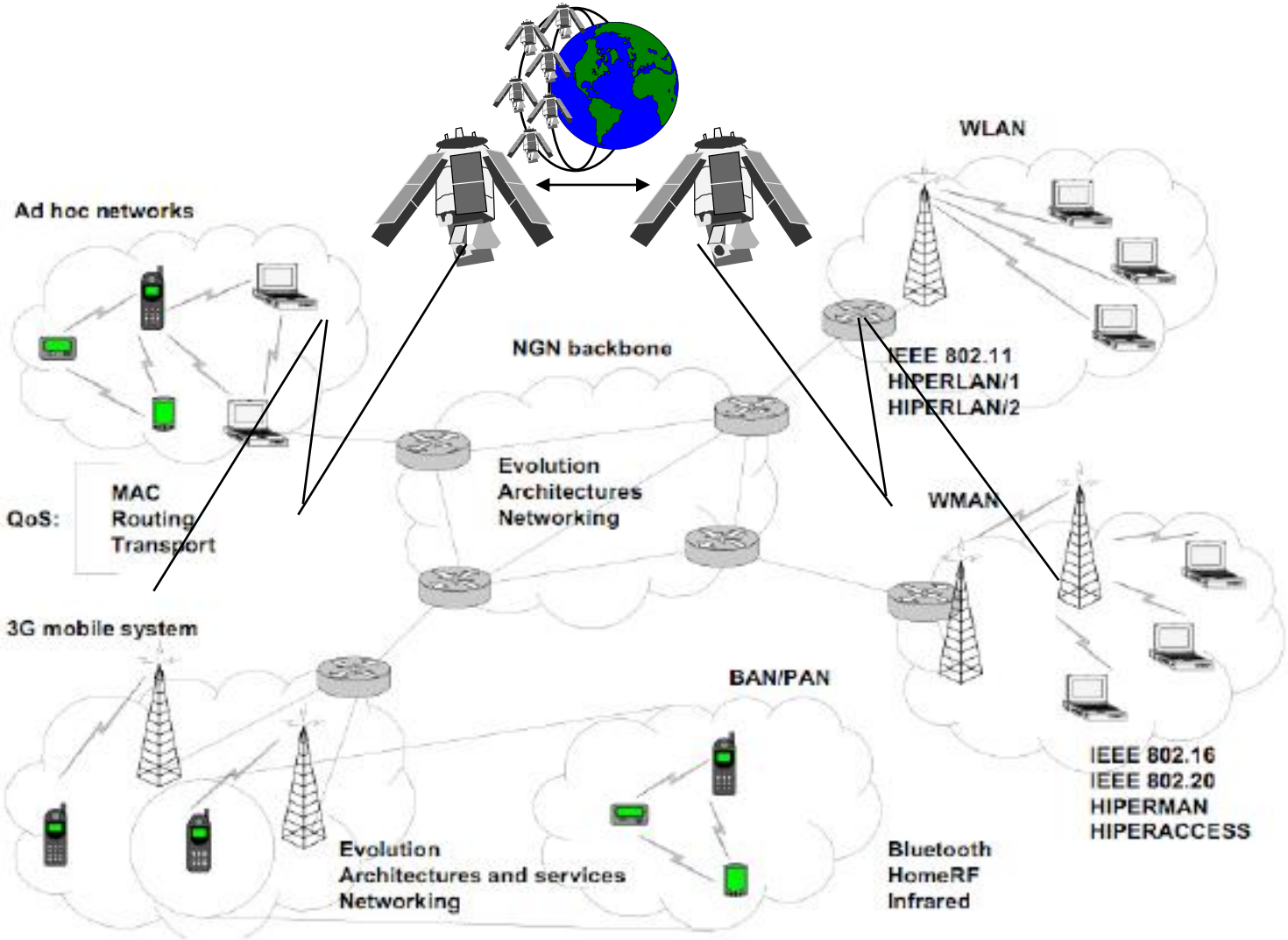
Orbits of different satellites

Satellites

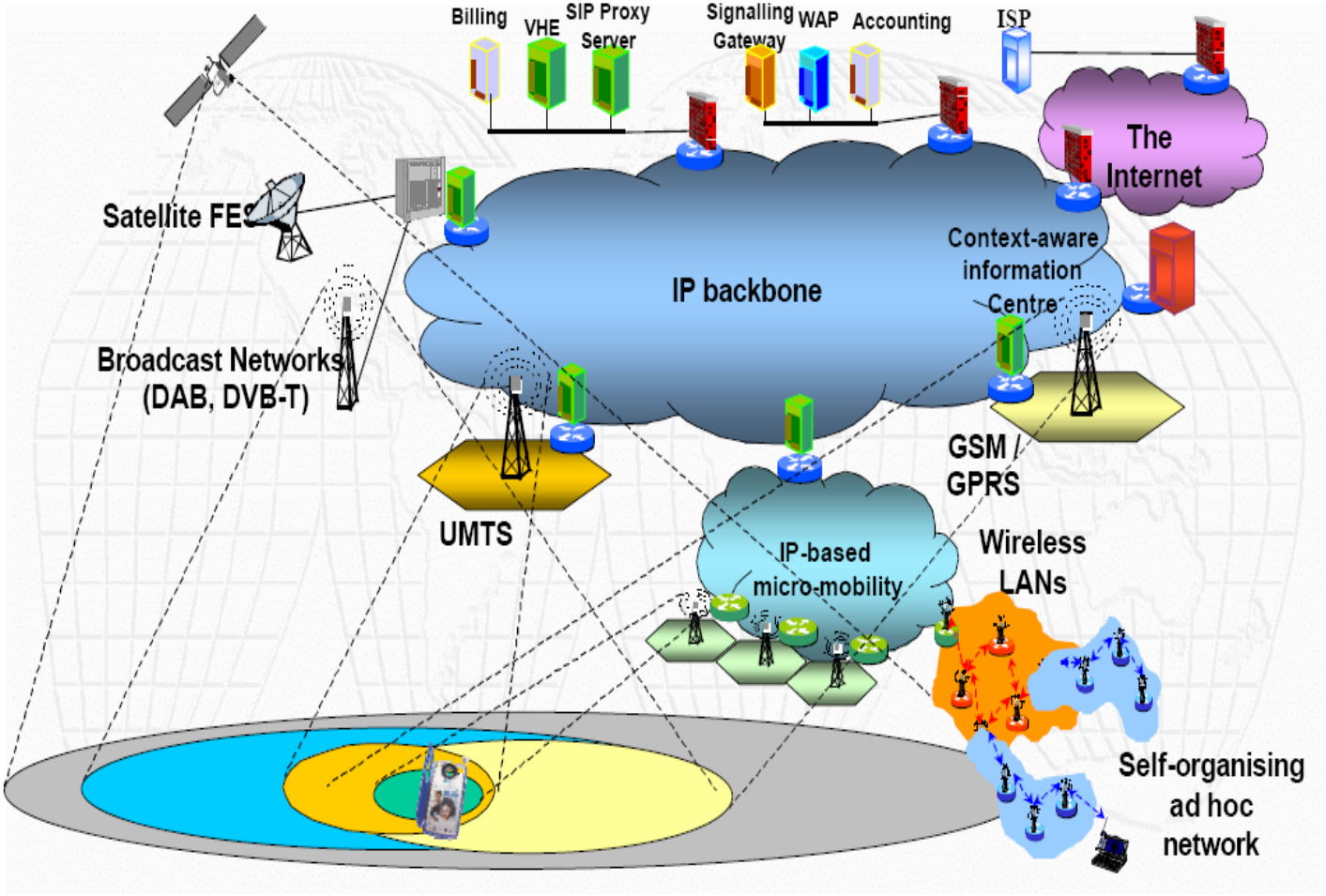
- **Overtaken by cellular system for *mobile services***
  - Satellite phone is bulky, expensive.
  - It is too costly to use a satellite phone.
- **But satellite technology is still helpful**
  - Fixed locations: in the area that other system not cover. E.g.,
    - Industries such as oil and gas
    - Military establishments
  - Portable communication: Field activities. E.g.,
    - Search-and-rescue
    - Corporate travelers in remote locations
  - Vehicle: Communication no matter what the location is. E.g.,
    - Air plane
    - Delivery personnel
    - Law enforcement

Positioning & Navigation

Future wireless network architecture



4G – Next Generation Network



IP-based

Mobile Ad Hoc Networks (MANETs)

MANET and WSN

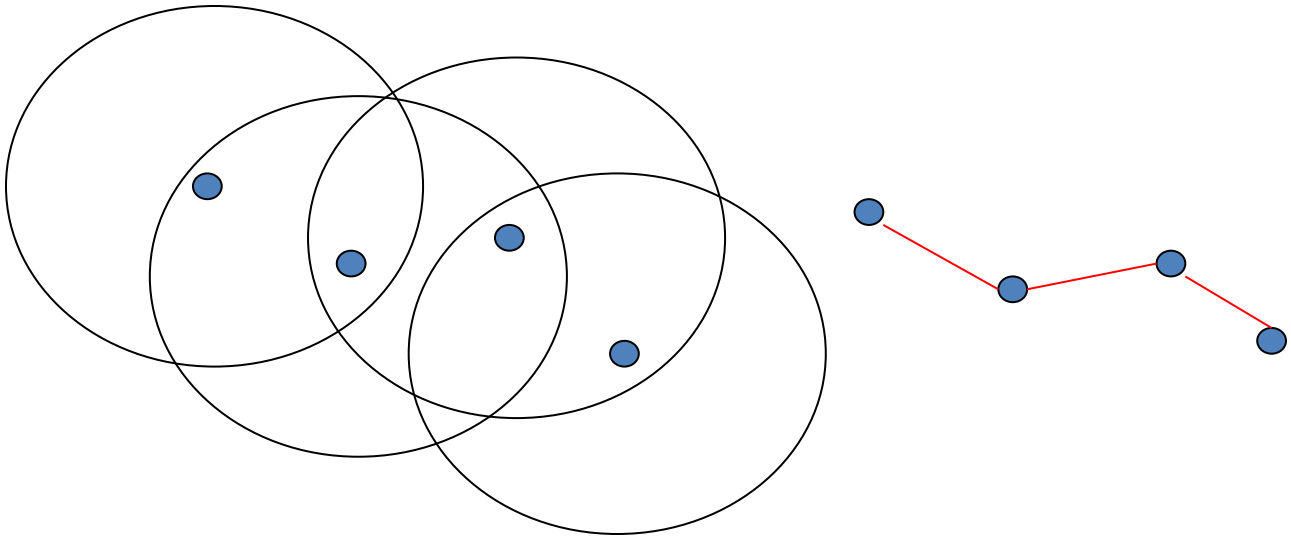
- Introduction to MANET
  - What is MANET?
  - Characteristics of MANET
- Wireless sensor networks

Infrastructured wireless network

- **Cellular Network / WLAN:**
  - Having infrastructure support – wired backbone
  - High setup costs
  - Large setup time
  - Reliable
  - Not suitable for some applications:
    - Casual conferencing
      - low set-up time, cost preferred
    - Battlefield operations/disaster relief
      - infrastructure unavailable
    - Personal area networking
      - Pairwise connection of devices around the home/office

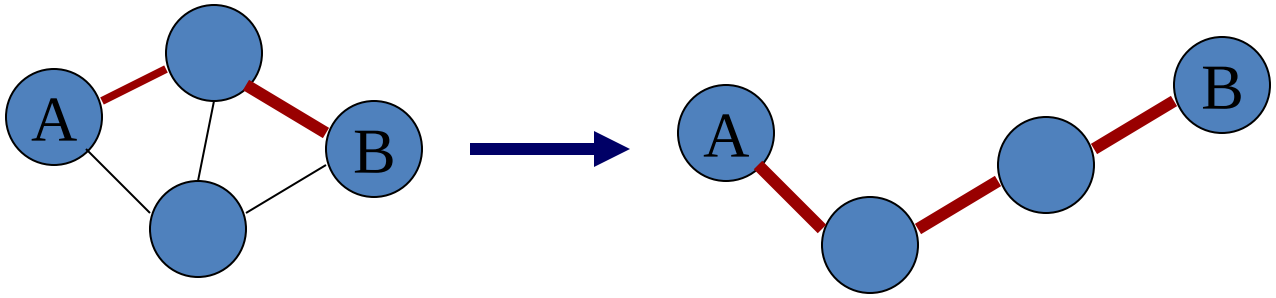
Wireless ad hoc network

- No fixed/static network infrastructure
- Nodes provide network functionality
  - Highly co-operative, each host is an independent router
- Multi-hop peer-to-peer mobile wireless communications



Mobile ad hoc network (MANET)

- **Wireless ad hoc network where nodes can move.**
- **MANET characteristics**
  - Lack of a centralized entity
  - Network topology changes frequently and unpredictably
    - links formed and broken with mobility

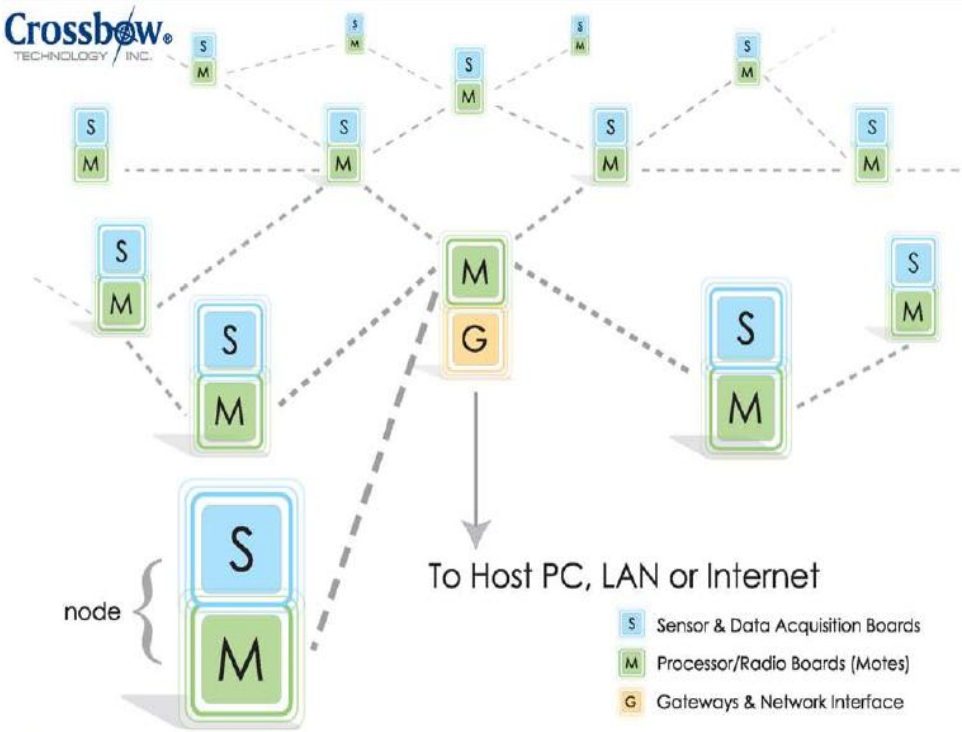


Mobile ad hoc network (MANET)

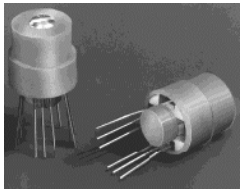
- **MANET characteristics (cont'd)**
  - Channel access / bandwidth constrained variable capacity links
    - Congestion is the norm
    - Lack of symmetrical links – possibly uni-directional links
  - Energy-constrained operation

Wireless sensor networks (WSN)

- A special kind of MANET - composed of a large number of sensor nodes
  - Nodes are constantly mobile or in fixed positions
- Sensor nodes communicate through wireless connections
- There is no fixed infrastructure
  - Sensor nodes can be deployed randomly over the designated site or very close to it.



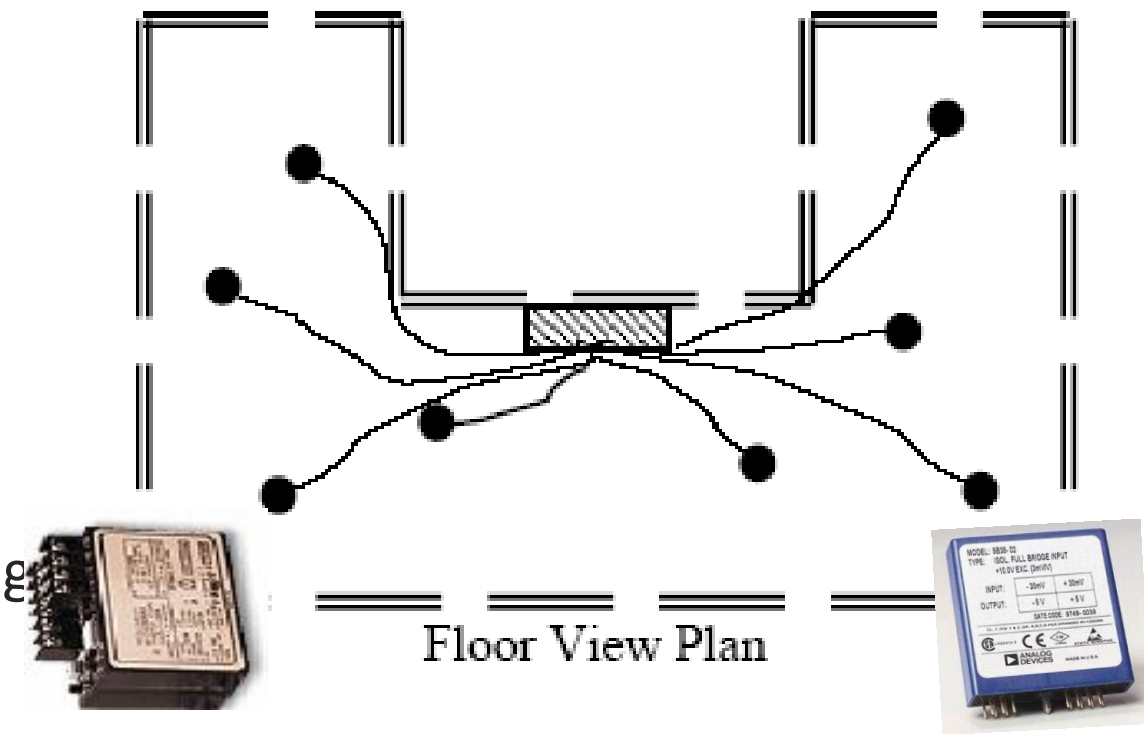
Sensors



- **What is a sensor?**
  - A device that measures or detects a real-world conditi such as heat and light, and converts the condition into an analog or digital representation.
- **Various types of sensors**
  - Thermal, infrared, acoustics, radar, optical, etc.
- **Sensing various kinds of data**
  - temperature, humidity, pressure, noise level, and speed/size of an object, etc.

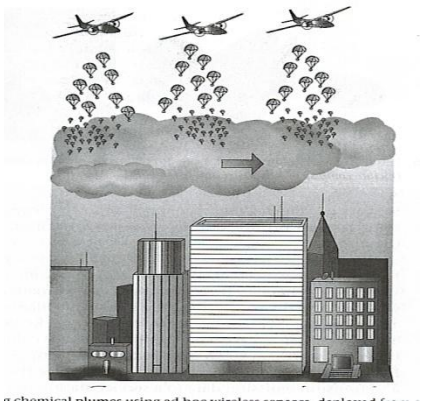
Traditional sensor systems

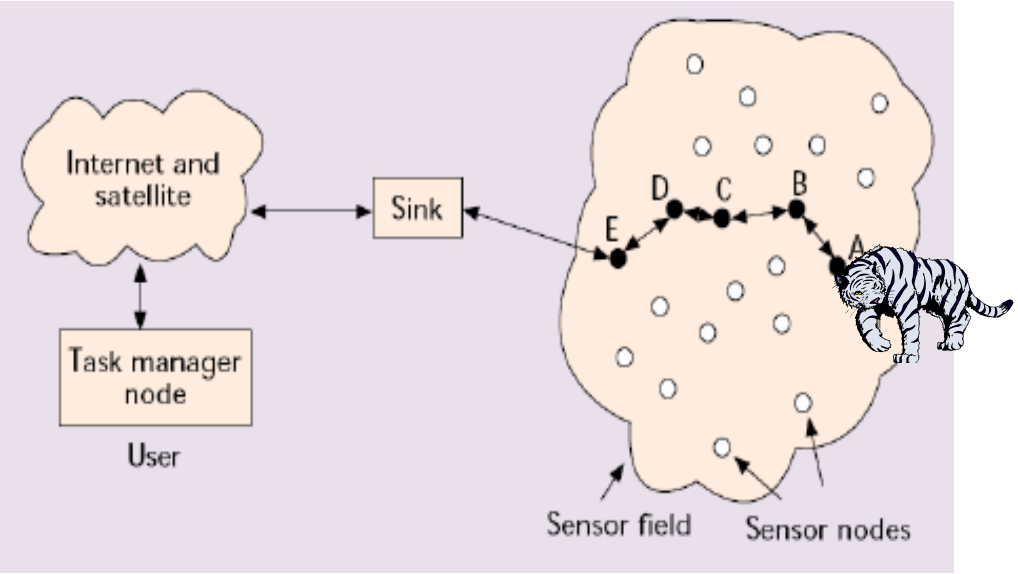
- Sensor has no computing power
- Sensors are *wired* to the control station
  - Difficult to deploy
  - Difficult to maintain
  - Low mobility
  - Centralized processing



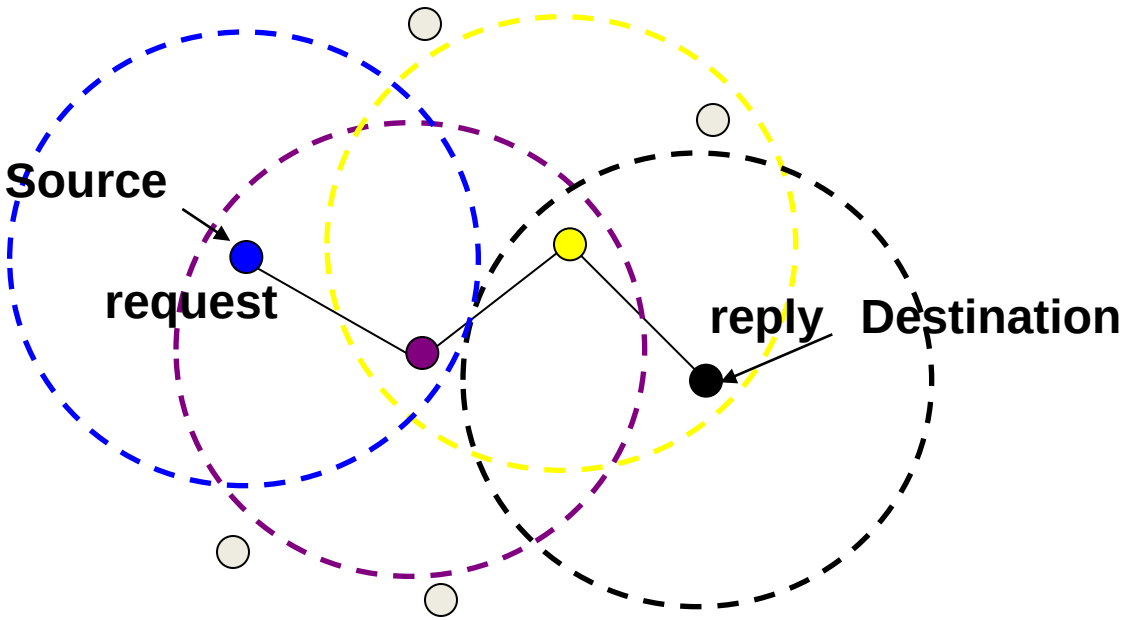
Wireless sensor networks

- Sensor nodes have processing power, communicate wirelessly, and cooperate with each other to perform some tasks.
- Sensor nodes may communicate with a *sink* node that can connect to application-specific server with user interface.





How does WSN Work?
-Multi-hop ad hoc routing



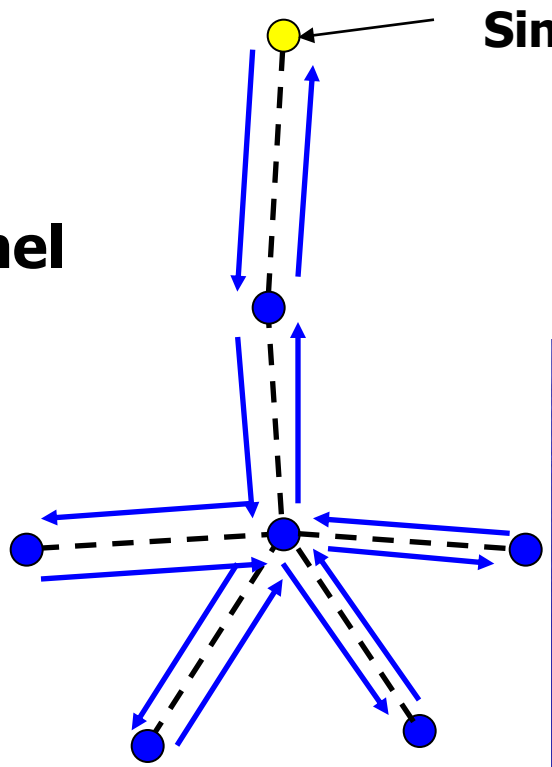
How does WSN Work?
-Multi-hop ad hoc routing

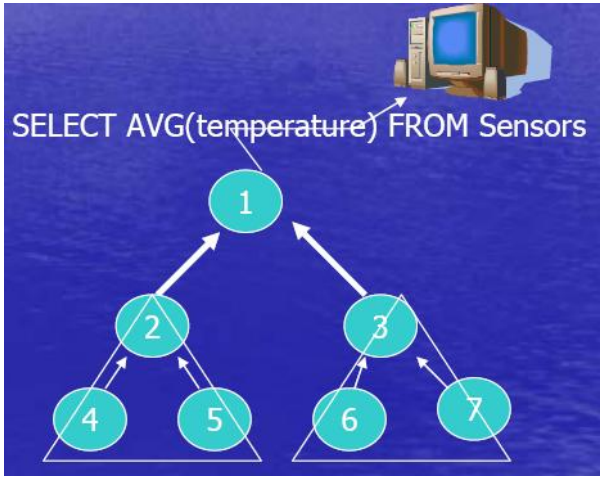
Sensor node

Wireless channel

Data query

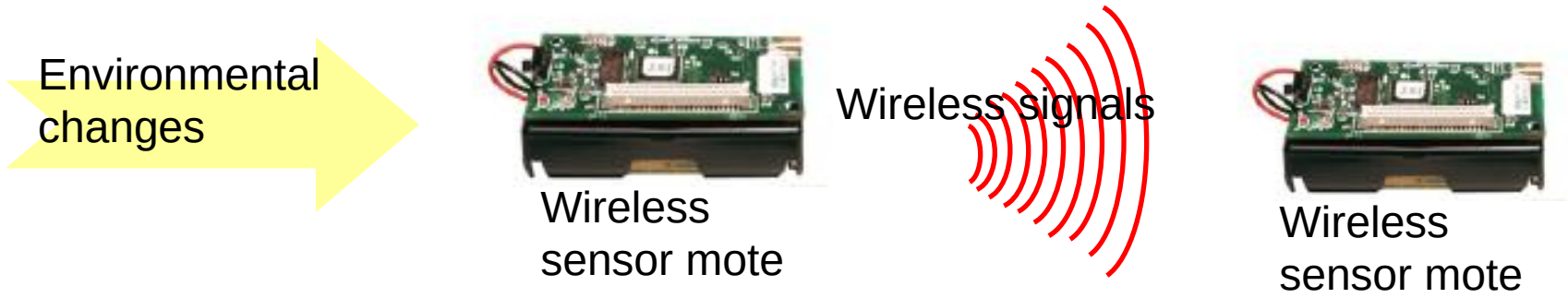
Data report





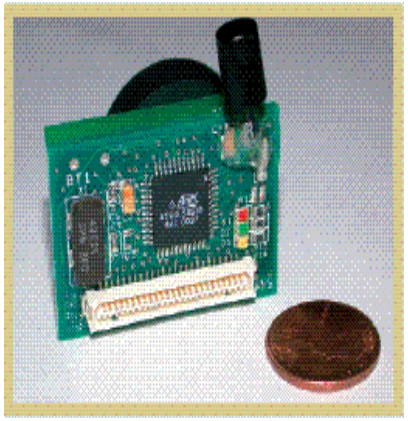
WSN sensor nodes

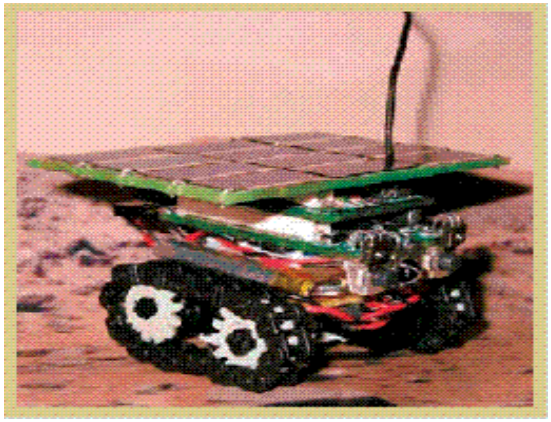
- Can detect & process various environmental data. (e.g. weight, light, temperature, sound, etc).
- Can also communicate with each other by using wireless channels

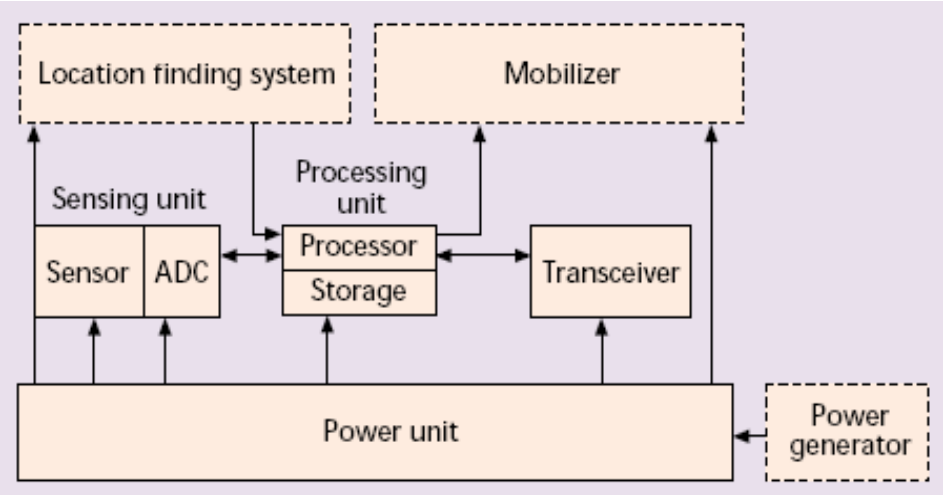


WSN sensor nodes

- **Basic components:**
  - Power Unit
  - Sensing Unit
  - Processing Unit
  - Transceiver Unit – connects to the network
- **Additional components (optional):**
  - A location finding system
  - A power generator
  - A c – to move sensor nodes if required

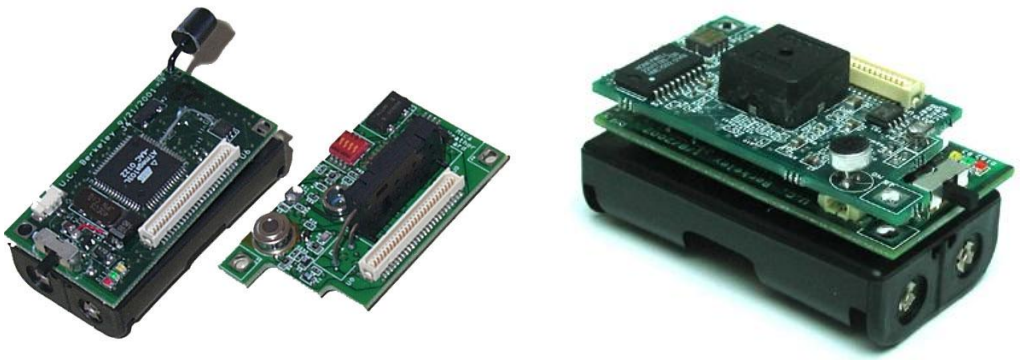






WSN sensor nodes

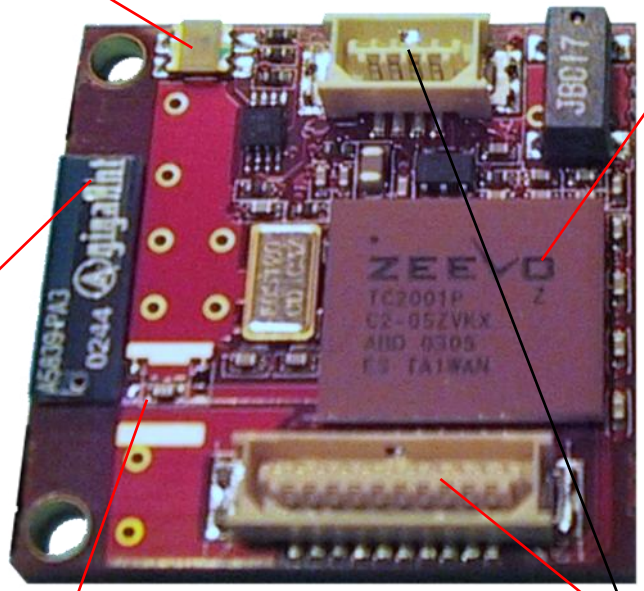
- Berkeley's MICA Mote Hardware



Plug-in sensor boards
Atmel 128L Micro
RF transceiver
2 x AA Battery pack
Size 55mm x 30 mm x h mm

WSN sensor nodes

- Intel's Mote Hardware



Multicolor status LED

2.4 GHz antenna

Optional external antenna connector

Optional voltage regulator (bottom)

ARM* core
SRAM
FLASH
BT radio

Stackable connectors (top and bottom)

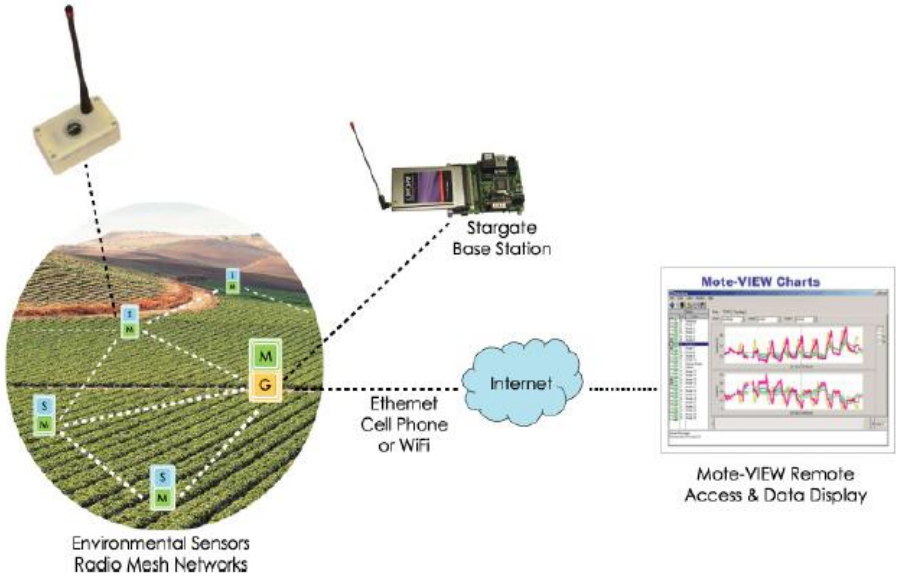
WSN sensor networks

- **Advantages over wired sensor systems:**
  - Up to 90% lower install costs
  - Rapid installation = less on-site time
  - Monitor and control in harsh environments and in "wire unfriendly" installations
  - Location flexibility – permits mobile equipment and easy optimization of sensor position
  - Multiple sensor types with standard wireless nodes on a single network.

WSN applications

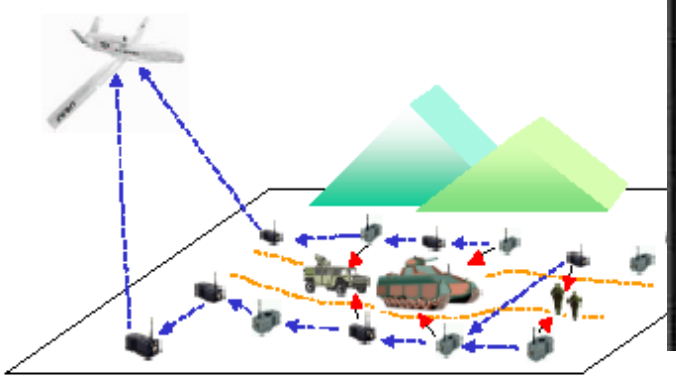
- **Environmental**
  - Forest fire detection, bio-complexity mapping of the environment, flood detection, precision agriculture

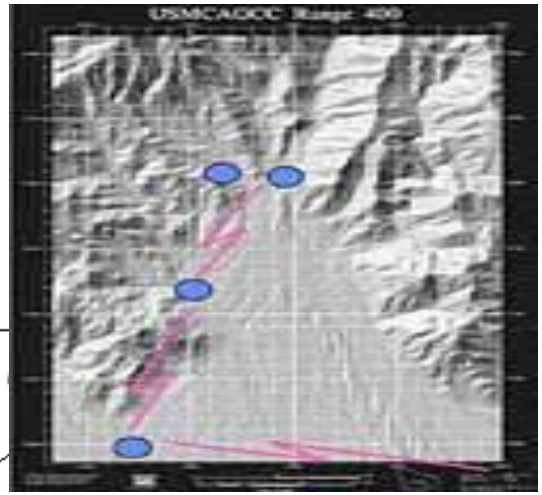
- **Healthy**
  - Tele-monitoring of human physiological data, tracking and monitoring doctors and patients inside a hospital, drug administration in hospitals



WSN applications

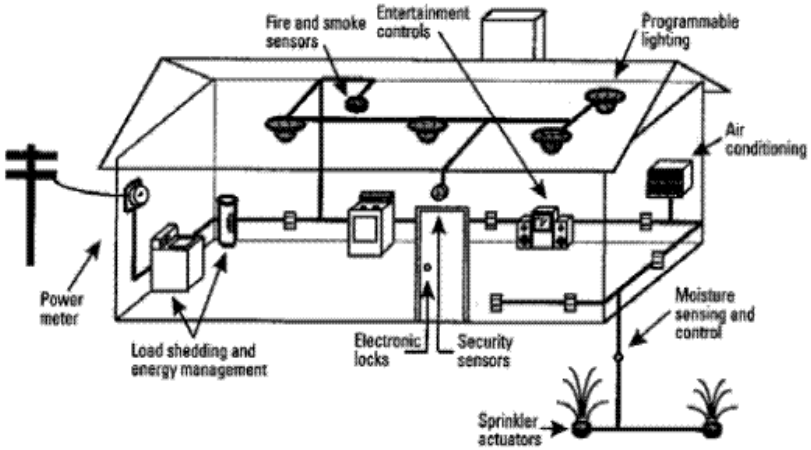
- **Military:**
  - Monitoring friendly forces, equipment and ammunition; battlefield surveillance; reconnaissance of opposing forces and terrain; targeting; battle damage assessment; nuclear, biological and chemical attack detection and reconnaissance





WSN applications

- **Home**
  - Home automation
  - Smart environment



- **Commercial**
  - Environmental control in office buildings
  - Interactive museums
  - Detecting and monitoring car thefts
  - Managing inventory control
  - Vehicle tracking and detection
  - Monitoring product quality
  - Monitoring disaster areas

Difference from MANET

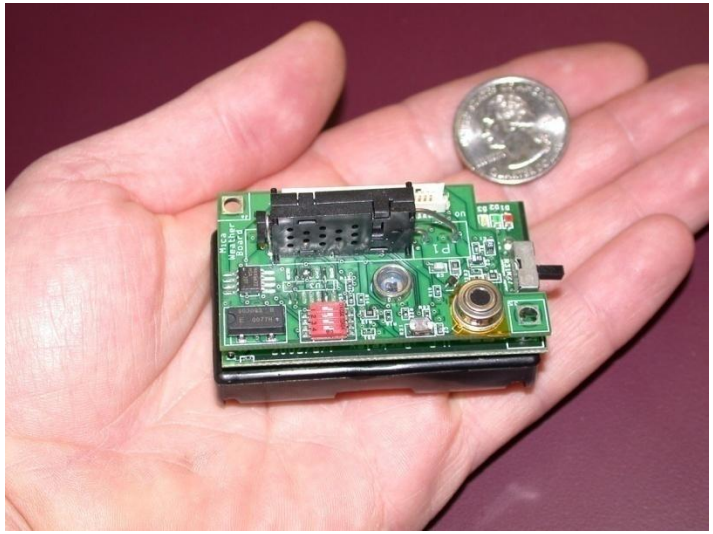
- **# sensor nodes >> # nodes in an MANET.**
  - Sensor nodes are densely deployed.
- **Senor nodes are likely to failure (due to power lost or damaged).**
- **Sensor nodes are much more limited in power, memory, and computational capacities.**
- **Senor nodes mainly use controlled broadcast communication (or flooding)**
  - Localized, multihop communication is being a more flavor approach.
- **Sensor nodes may not have global ID because of the large amount of overhead and large number of sensors involved.**
  - Content based naming – tasks are named (attribute-value pairs)
  - Name of sensors are irrelevant

Differences from MANET

- **Data centric: data is requested based on certain attributes**
  - Sensors net is queried for specific data
  - Source of data is irrelevant
  - No sensor-specific query
- **Application specific**
  - In-sensor processing to reduce data transmitted
  - In-network processing (data aggregation / data fusion)
  - In-sensor caching
  - Privacy and security

Characteristics of sensor node

- Powered by battery
- Limited in memory & CPU power
- Wireless communication



Power

- Most research has focused on power issues
  - Energy efficiency is the foremost concern in WSN

Radio States	Transmission	Reception	Idle	Sleeping
Power consumption (mw)	21.2~106.8	32	32	0.001

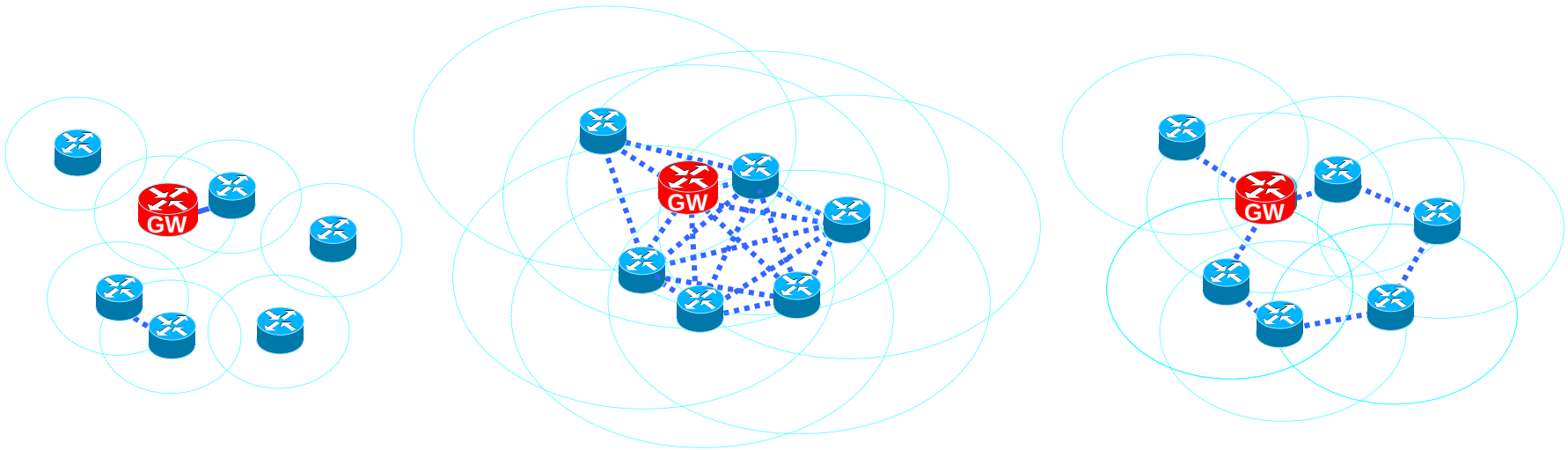
- Sleeping consumes much less power than idle listening
  - Motivate sleep scheduling
- Transmission consumes most power
  - Motivate power-aware routing and transmission power control

Power

- **Power saving**
  - How to schedule data transmission among neighboring nodes, with low complexity
  - How to pick minimal sets of nodes that cover the target area to cycle between
  - Topology optimization
    - How to control the topology to extend the lifetime of the network
    - Adjust transmission power of nodes or determine logical neighbors of nodes
    - Achieving desirable connectivity / reducing interferences / increasing throughput

Power control

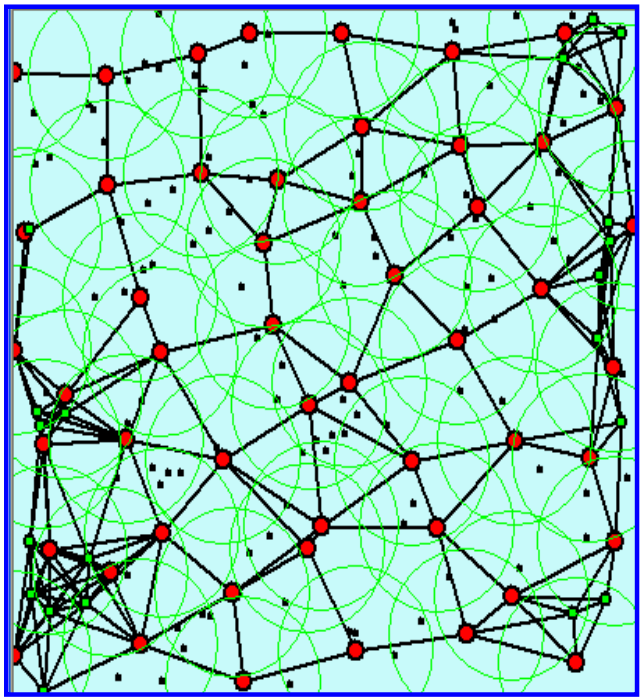
- **Physical level issue.**

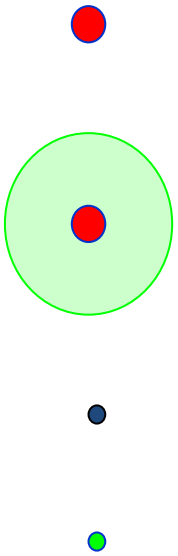


Too low Too high Just right

- Optimization Criteria
  - Network capacity
  - Delay
  - Error rates
  - Power consumption
- Ideal solution depends on
  - Network topology
  - Traffic load

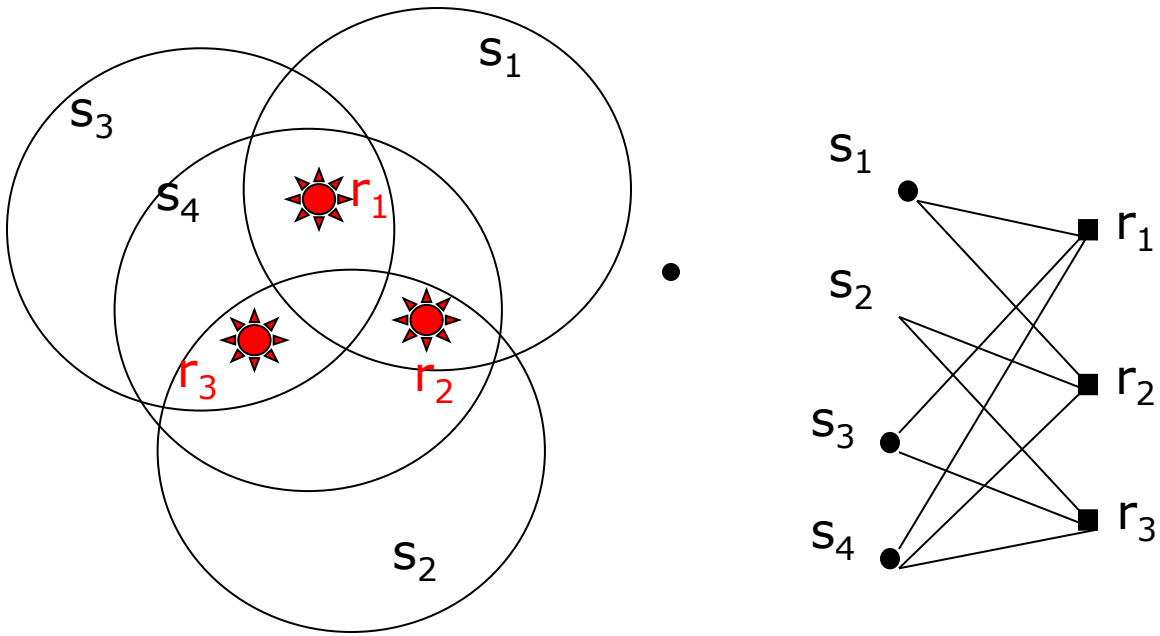
Coverage and connectivity





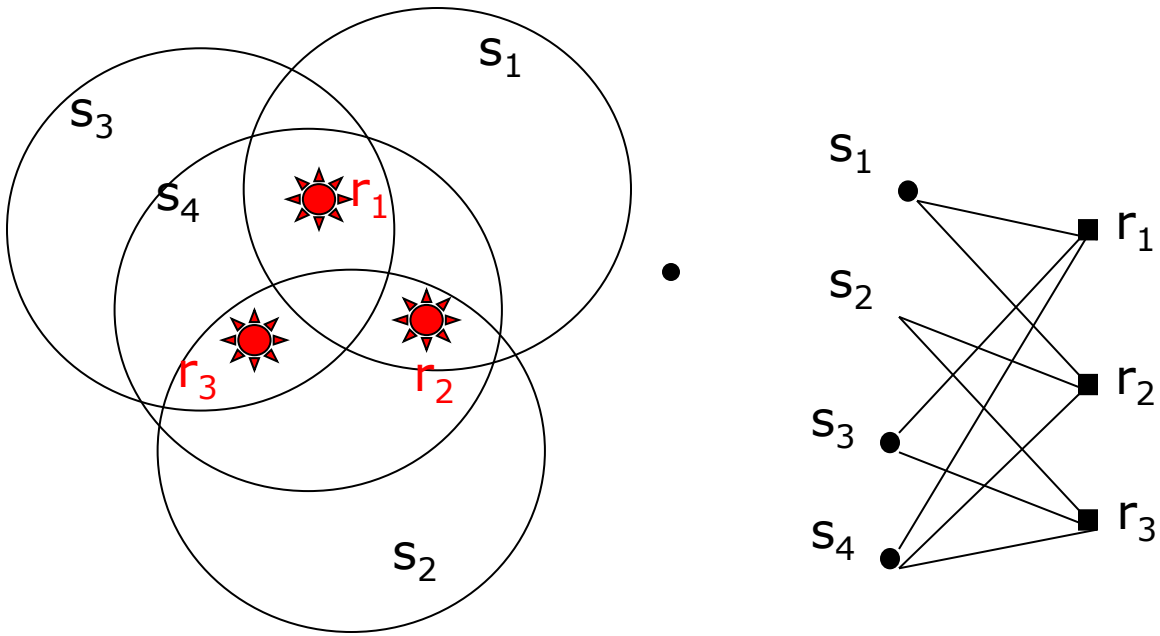
A network with 1-coverage and 1-connectivity

Coverage and connectivity



- If all sensor nodes are active, network lifetime is 1
- The optimal network lifetime is 2.5
- What is the technique?

Coverage and connectivity



Disjoint sets:

$C_1 = \{s_1, s_2\}$

$C_2 = \{s_3, s_4\}$

Lifetime G = 2

Approach:

$C_1 = \{s_1, s_2\}$ with $t_1 = .5$; $C_2 = \{s_2, s_3\}$ with $t_2 = .5$

$C_3 = \{s_1, s_3\}$ with $t_3 = .5$; $C_4 = \{s_4\}$ with $t_4 = 1$

Lifetime G = 2.5

R&D issues in WSN

- **Building the network**
  - Techniques for deploying and establishing WSN
  - Coverage, connectivity, MAC, routing, clustering, mobility, localization, time synchronization
- **Managing the network**
  - Techniques for monitoring and controlling WSN
  - Energy management, topology control, fault detection and recovery
- **Using the network**
  - Techniques for developing and supporting execution of applications
  - Programming, runtime, data collection and processing (aggregation, fusion, mining), event detection, object tracking
- **Orthogonal issues**
  - Energy efficiency, network lifetime, resource and capability constraints, fault tolerance, scalability, security, accuracy and timeliness

END
Lecture-P2