Προηγμένες Δικτυακές Τεχνολογίες

εαρινό εξάμηνο 2024

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Σκοπός μαθήματος

- Παρουσίαση επιλεγμένων θεμάτων με διαχρονική αξία και δυνητικά ευρεία εφαρμογή.
  - Έμφαση στις αρχές, τη βαθύτερη κατανόηση και μεθοδολογία
- Στόχος η παρουσίαση τρόπων διερεύνησης / προσέγγισης που οδηγούν σε πρωτότυπες προσεγγίσεις και καινοτομία και βαθύτερη κατανόηση.
- Παρουσίαση ερευνητικών άρθρων από φοιτητές.

Υλικό μαθήματος

- **Διαλέξεις**
  - .ppt διαφάνειες, επιπλέον papers συνοδευτικά
  - Πρόσθετο υλικό που παρουσιάζεται στον πίνακα

- **E-class link**
  - http://eclass.uoa.gr/courses/D208/index.php
    - γραφτείτε αν δεν το έχετε κάνει ήδη!

Εξέταση/αξιολόγηση

- **Ερευνητικές εργασίες – παρουσίαση άρθρων (30%)**

- **Γραπτές εξετάσεις (70%)**
  - στο τέλος του εξαμήνου. Κατά κανόνα, γίνονται με κλειστά βιβλία.

Course Outline

- **Device-to-Device (D2D)/ Ad-Hoc ασύρματα δίκτυα:** Εισαγωγή (1)
- **Δρομολόγηση σε Ad-hoc / D2D δίκτυα:** Proactive – Reactive, Destination Sequenced Distance Vector Routing (DSDV), Optimized Link State Routing (OLSR), Dynamic Source Routing (DSR), Ad-Hoc On Demand Distance Vector (AODV), Geographic and Energy-Aware routing, κλπ (2-3)
- **Κλιμάκωση (scalability) ad hoc δικτύων / πρωτοκόλλων δρομολόγησης** : Ιδιότητες κλιμάκωσης γνωστών πρωτοκόλλων (επιπέδων, ιεραρχικών και υβριδικών) και ανάλυση επιπέδου (flat) πρωτοκόλλου δρομολόγησης με βέλτιστες ιδιότητες κλιμάκωσης. (2-3)
- **Δίκτυα Ανεκτικά σε Καθυστέρηση (Delay Tolerant Networks - DTNs):** Αποδοτική διάχυση / δρομολόγηση μηνυμάτων. (1)

Course Outline

- **Μηχανισμοί πρόσβασης σε κατανεμημένους δικτυακούς (και όχι μόνο) πόρους:** Μηχανισμοί απόφασης / επιλογής πόρων σε συνθήκες ανταγωνισμού / συμφόρησης. Θεώρηση του τιμήματος της έλλειψης συντονισμού (αναρχίας). Μοντέλα αποφάσεων επηρεασμένα από τον ανθρώπινο παράγοντα. Εναλλακτικές προσεγγίσεις βασισμένες σε μερικό συντονισμό και τις τεχνολογίες ΤΠΕ (ICT). (3)
- **Τοποθέτηση Υπηρεσιών / Περιεχομένου στο Δίκτυο** (Network Service/Content Placement): Μηχανισμοί προσδιορισμού θέσης τοποθέτησης περιεχομένου/υπηρεσιών σε δικτυακές δομές μεγάλης κλίμακας με περιορισμένη (τοπική μόνο) γνώση της δικτυακής τοπολογίας και της ζήτησης (1)
- **Κατανεμημένοι μηχανισμοί προσωρινής αποθήκευσης περιεχομένου (caching).** Τοποθέτηση πόρων σε 5G (1-2)
- **Connected Cars:** Network supported driving, etc (1-2)
- **Sensor Network Connectivity and Topology Routing** (1-2)

Ad Hoc / D2D Networks

- “ad hoc” in Latin literally means "for this purpose only”
- It can be seen as a “spontaneous network,” i.e., automatically “emerging” when nodes gather together
- Ad-hoc networks include today **machine-to-machine (M2M) or Device-to-Device (D2D) networks, Vehicular Networks (VANETS), Sensor Networks,** etc.
- Communication is wireless and frequently mobility is present
- Energy is frequently limited (battery-powered)
- A D2D network may be:
  - Pure D2D: autonomous system of nodes connected by wireless links forming an arbitrary graph (stand-alone fashion), or
  - Hybrid: connected to a fixed infrastructure

Applications

- **Personal communications**
  - ☐ smartphones, laptops, tablets
- **Internet of Things**
  - ☐ sensors (also smartphones), RFIDs for smart cities
- **Cooperative environments**
  - ☐ taxi cab network
  - ☐ meeting rooms
- **Emergency operations**
  - ☐ Policing, fire fighting and disaster situations
- **Military environments**
  - ☐ battlefield

Ad-Hoc / D2D Network Advantages

- Ease and speed of deployment
- Decreased dependence on infrastructure: content sharing and distribution within a community, e.g campus, concert, emergency situations -> traffic offloading
- Independent of network operators: safe, private, fast

Typical Scenarios

Distributed environment:

- ❑ Fully symmetric environment: nodes have identical capabilities and responsibilities
- ❑ Asymmetric capabilities: transmission ranges may differ, battery life at different nodes may differ, processing capacities may differ
- ❑ Asymmetric responsibilities: some nodes may act as leaders of nearby nodes

Typical Scenarios

Traffic characteristics may differ:

- ❑ bit rate
- ❑ time constraints
- ❑ reliability requirements
- ❑ unicast / broadcast / multicast / geocast / anycast

Typical Scenarios

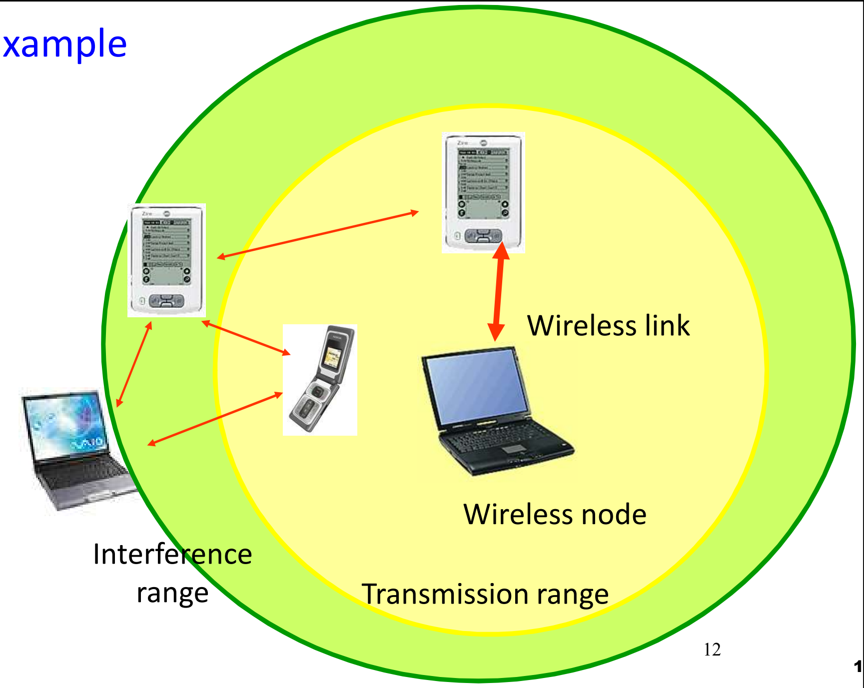
Mobility patterns may differ:

- ❑ people sitting at an airport lounge
- ❑ taxi cabs
- ❑ kids playing
- ❑ military squads
- ❑ work / home environments

Mobility Characteristics:

- ❑ speed

Example



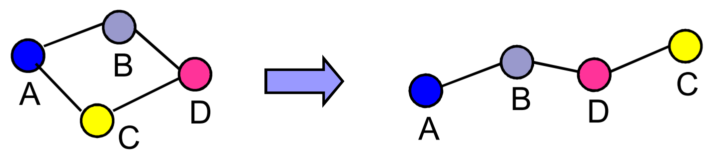
Typical Scenarios

Most wireless communication devices are half-duplex:

- They include one transceiver only
- Hence, they can either transmit or receive (not both at the same time)
- It might change in the future into full duplex

Main Issue A: Network Topology

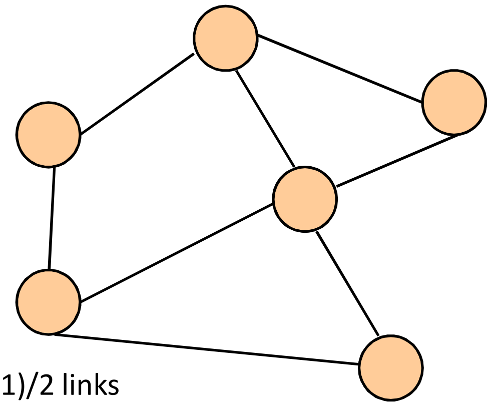
- The network topology is the set of nodes and links
- It may change rapidly and unpredictably because of
  - node movement
  - node failure
  - link failure



Most Common Network Topologies

- **Flat:** All nodes are at the same hierarchical level
- **Tree:** Hierarchical architecture, easily extendible but not suitable for fault-tolerant networks
- **Cluster-Based:**
  - Nodes grouped into different sets (clusters)
  - Nodes identified as cluster-heads or ordinary
    - cluster-head: central controller that coordinates communications within the cluster
  - There may be several hierarchical layers

Example: Flat

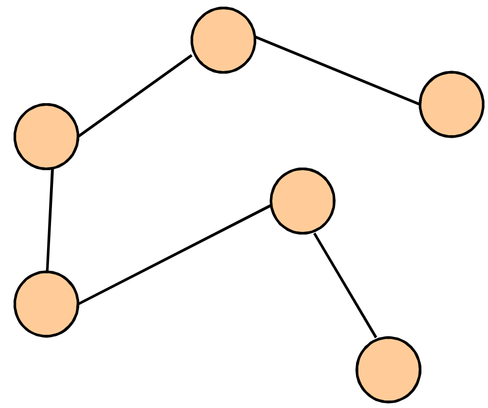


N nodes

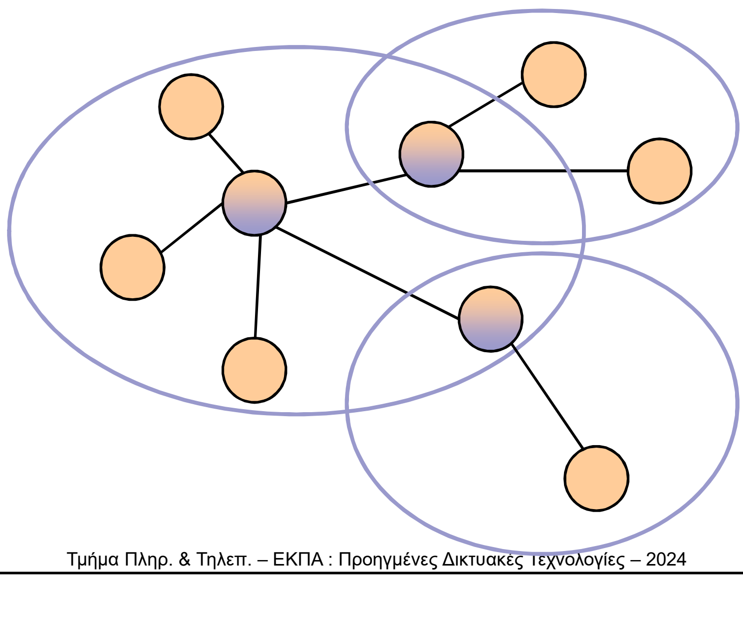
At most Nx(N-1)/2 links

Example: Tree

- N nodes + (N-1) links with no cycles (or connected), or
- Any two nodes connected by exactly one path



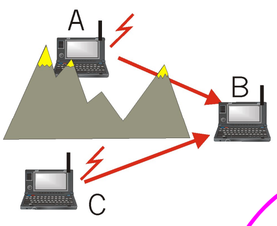
Example: Cluster-Based

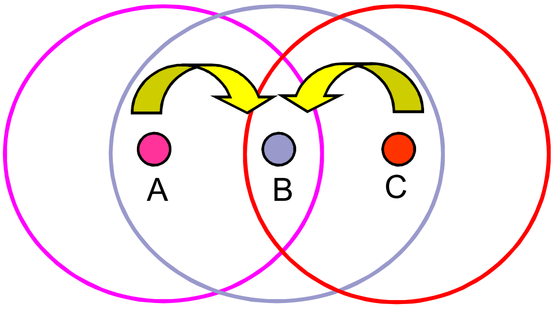


Main Issue B: Channel Access

- Broadcast nature of the wireless medium
- Limited wireless transmission range
- Packet losses due to transmission errors
- Typically, CSMA/CA-based schemes
  - Listen before transmit
  - Back-off and retransmit if a collision is detected
  - Problem of: **Hidden and Exposed terminals**

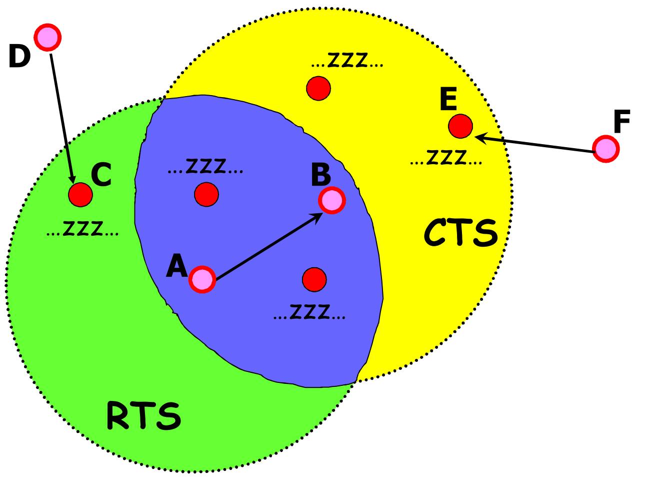
The Problem of Hidden Terminals





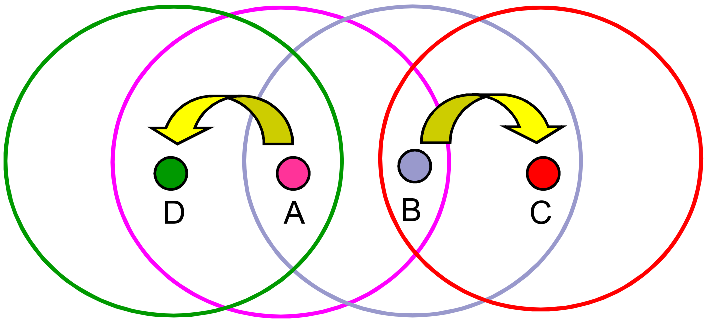
CSMA/CA with RTS/CTS

(mitigates the hidden terminal problem)



The Problem of Exposed Terminals

A → D and B is “exposed” to A’s transmission to D.
(but B could transmit to C without causing collision)

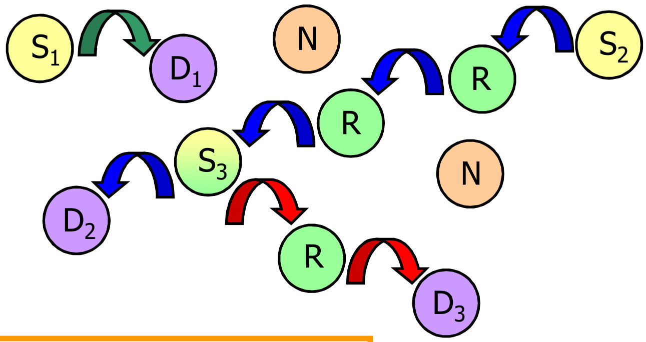


CSMA/CA with RTS/CTS mitigates the hidden terminal problem)

A → D: RTS / D → A: CTS ;
B hears RTS from A but doeas not hear CTS from D, thus B is free to transmit to C (without causing collision at D)

Main Issue C: Multi-hop Communications

S=Source; D=Destination; R=Relay; N=Not participating



Each node is a router !!!

Multi-hop Communications

- **Advantages:**
  - ☐ Reduced transmit energy at the source
  - ☐ Reduced interference, thus
  - ☐ Increased network capacity since the spatial domain can be reused for concurrent communications

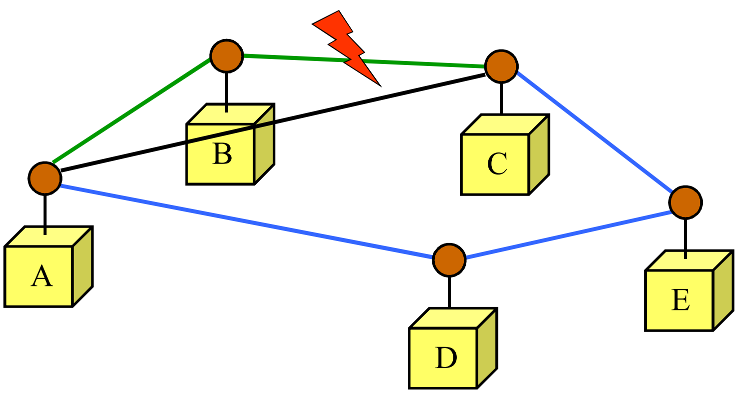
- **Disadvantages:**
  - Increased network traffic load!
  - Increased traffic delivery delay
  - Increased network energy expenditure

Multi-hop Communications

Need for coordination among the nodes

- Easy in military environment; difficult for civil applications (users are naturally selfish)
- Algorithm to favor cooperation (e.g., based on monetary penalization of the user denying service or on users' reputation)

Traffic Routing



Main Issue D: Energy Consumption

- Mobility, battery powered devices
- Devices runtime depends on the amount of available energy and advances in battery technology are slow
- On top of it, increasing attention to energy consumption -> green networks
- Efficient energy management is crucial
  - Energy aware link, routing, transport protocols
  - Architectures, sleep modes

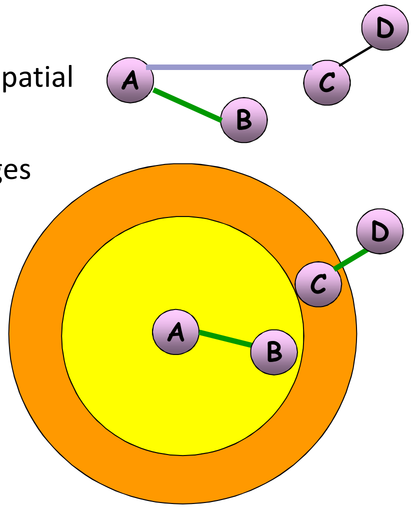
Design energy-efficient protocols and energy-efficient circuitries

User Device Energy Consumption

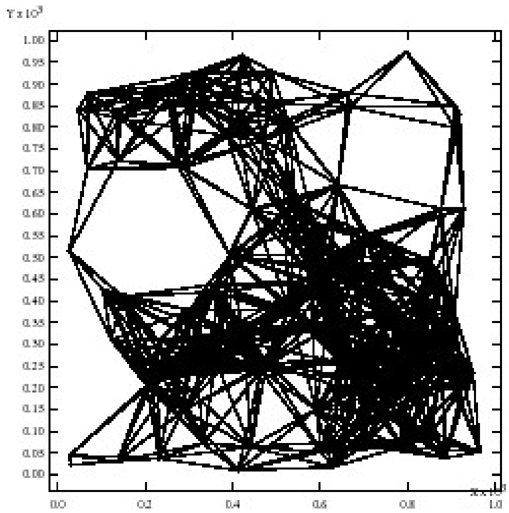
- Contributors to power consumption:
  - DSP
  - Transceiver (Tx/Rx)
  - Output transmit power (1mW-1W)
- Basic Solutions
  1. **Power control:** Reduce transmit power
  2. **Energy saving:** Enter low-power operational modes when idle

Power Control

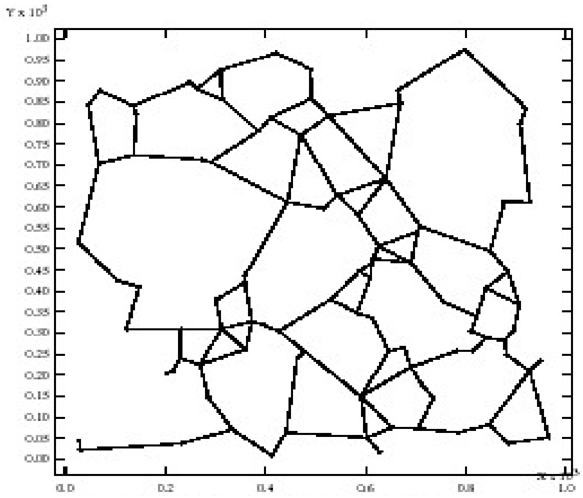
- Lower output transmit power
  - Received power level is proportional to $1/d^\alpha$, $\alpha \geq 2$
- Reduced interference, increased spatial reuse
- However, network topology changes (connectivity)



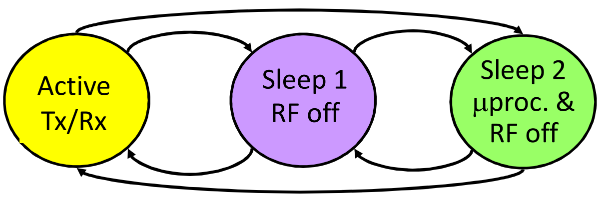
Using Max Transmission Power

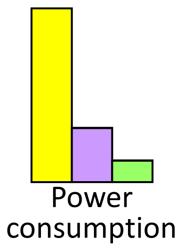


Reducing the Transmission Power



Energy Saving





- Enter low-power state when idle
- Wake-up schedule :
  - Synchronous
  - Asynchronous

Summary
Important Issues & Requirements

Autonomous and spontaneous nature of nodes

- ➔ Distributed algorithms
- ➔ Decisions based on local knowledge

Main issues:

1) Time-varying network topology

   - ➔ Scalable mobility management techniques to face network dynamics

Summary
Important Issues & Requirements

2) Channel access

   - ➔ Enhanced functionalities to improve link-layer performance and QoS network support, in spite of fluctuating link capacity

3) Multihop communication

   - ➔ When is it convenient?
   - ➔ How to make nodes relay traffic for others?
   - ➔ What is the best route?

4) Low-power devices

   - ➔ Energy saving techniques at all layers

Examples of Technologies

- WLAN/Cellular based
- VANETs or connected cars
- WPANs
- BANs
- Sensor networks

WLAN/Cellular based

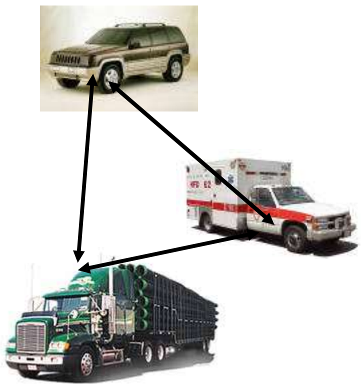
- Several new technologies are available that allow D2D communications
- Examples:
  - WiFi Direct
  - LTE Direct
  - ....

Wireless Local Area Networks (WLANs)

- Networks with limited geographical extension
  - Radio Frequency (RF)
  - Transmission power: ~10-100 mW (10-20 dBm)
- Created as extension of wired LANs, it provides high speed wireless communications
  - Data traffic (e.g., file transfer)
  - Real-time traffic (e.g., voice and video)

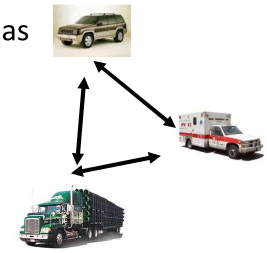
Mobile Ad hoc NETworks (MANETs)

- Autonomous system of **mobile** routers connected by wireless links, forming an arbitrary graph
- Developed within the IETF (Internet Engineering Task Force) to extend the Internet technology to mobile networks



Vehicular Networks (Connected cars)

Wireless ad hoc networks with mobile nodes (as MANETs) but:



- **Mobility:** higher speed and predicatble movements, macro and micro mobility
- **Network topology:** frequent network partitions, low connectivity level, highly dynamic topology
- **Resources:** not limited by energy, memory, computation capabilities
- **Localization:** equipped with satellite positioning systems such as GPS

Wireless Personal Area Networks (WPANs)

- Created when people meet for some collaborative activity (e.g., information exchange or relay)
- Limited extent in space (and possibly in time)
- Authentication and trust based on first-person interaction, no administrative services
- Hosts not preconfigured
- Low power: ~1 mW; Data rates: 1-10 Mbps
- Examples of used technology: Bluetooth

Body Area Networks (BANs)

- Wireless communication between various components (earphones, microphones, sensors) attached to human body
- Possible Applications:

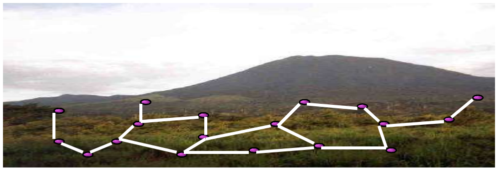
  - transmission of body parameters (blood pressure, pulse rate, body temperature)
  - music entertainment
  - help for disabled people

Body Area Networks (BANs)

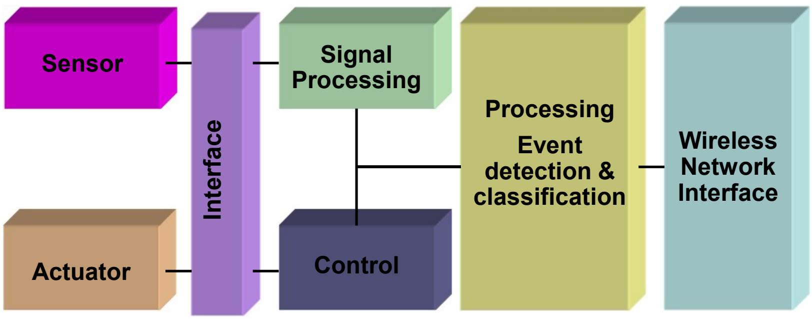
- Features
  - transmission without interference
  - licence free
  - low transmission power
  - cheap, tiny and light-weight hardware
- Data rates up to 250 Kbps
- Candidate technology: Bluetooth

Sensor Networks

- Self-configurable networks made of sensors linked by a wireless medium
- Sensors perform distributed sensing tasks
- IEEE Standard: Wireless Personal Area Network Low Rate (WPAN-LR) 802.15.4 (Zigbee).
- Other net protocols: Bluetooth Low Energy (BLE), 6LoWPAN (ipv6 capable), etc
- Integrated sensing and communication designs / protocols emerging

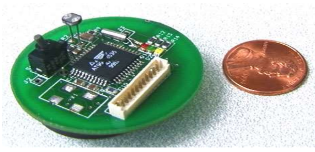


Sensor Architecture



Requirements

- ❑ Small, simple and cheap
- ❑ Low power consumption, batteries lasting multiple months to multiple years (e.g., < 0.5 Ah, 1.2V)
- ❑ Poor memory resources and processing capabilities

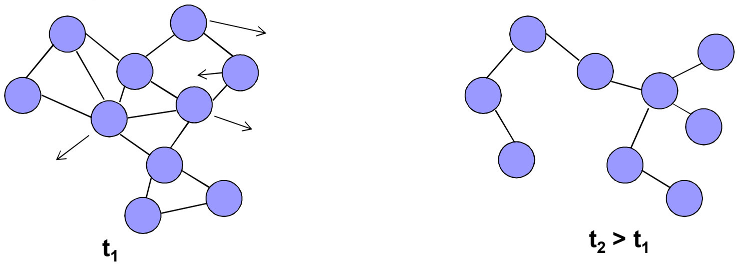


Sensor Network Characteristics

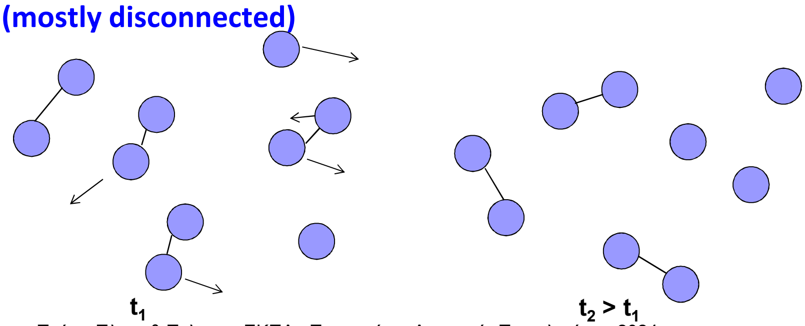
1. Sensors are typically deployed in large numbers
2. Presence of a gateway node or a central controller where information is collected (sink)
3. Asymmetric traffic mostly in the uplink direction
4. Addressing done by data and area, no global ids
5. Synchronization and localization are often required but difficult to achieve
6. Sink battery depletion and node battery recharging challenges.

Mobile Networks: MANET – DTN (Delay-Tolerant Nets)

MANET(mostly connected)

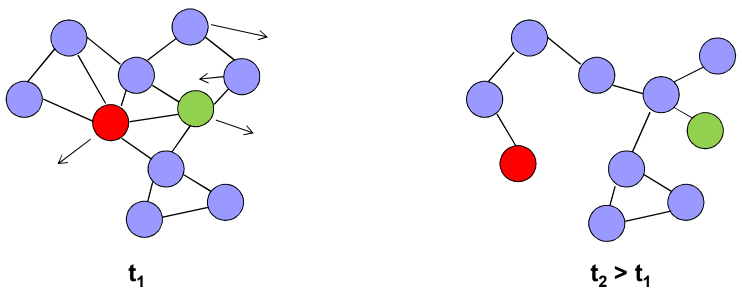


DTN (mostly disconnected)



Mobile Networks: MANET – DTN (Delay-Tolerant Nets)

MANET (info moved mostly via transmissions)



DTN (info moved mostly physically)