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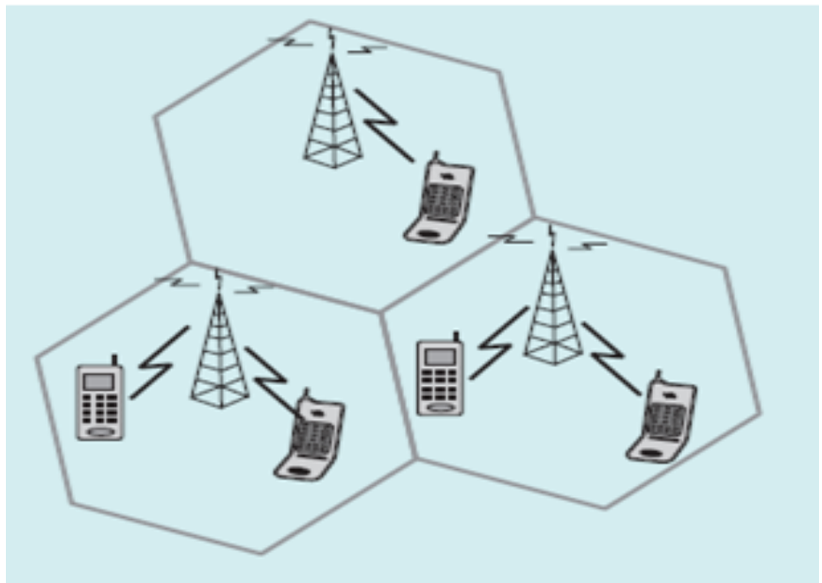
Introduction to Mobile Ad Hoc Networks

Wireless Ad hoc Networks

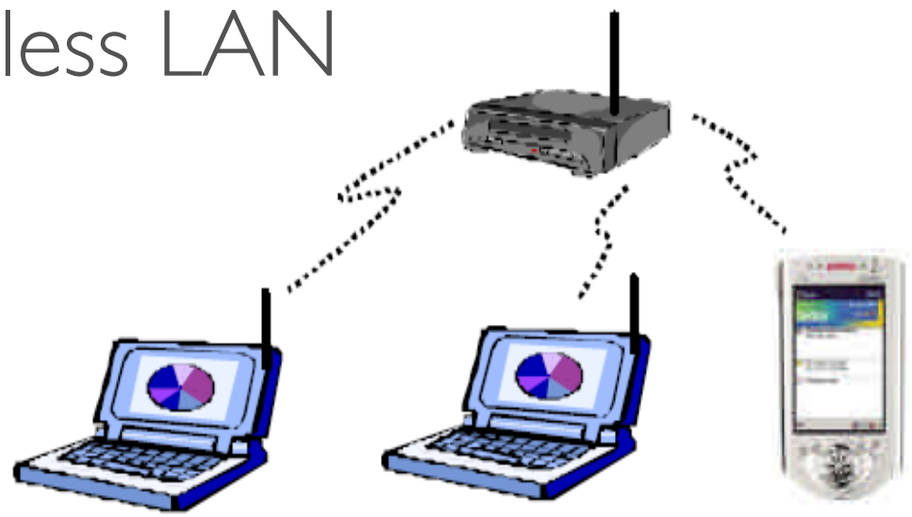
Wireless networks

- Any type of computer network that utilizes some form of wireless network connection
- Several types, all having similar architecture
  - Relies on a fixed infrastructure
  - Centralized base station or access point
  - All users within wireless range of it
  - Communicate with an access point or base station
  - Need planning, installation and management

cellular network

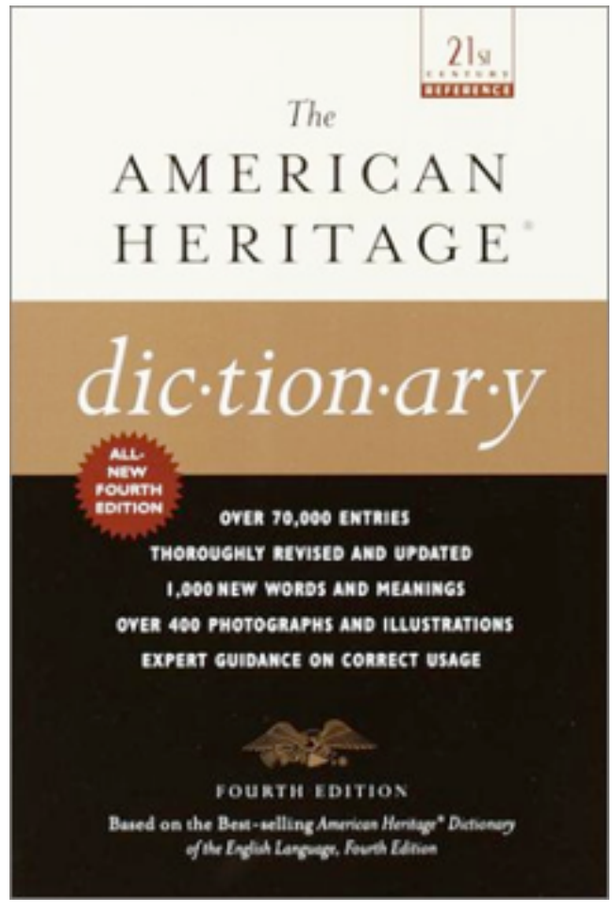


wireless LAN



Ad hoc networks

- Ad hoc (American heritage dictionary of english language)
  - form for or concerned with one specific purpose
  - improvised and often impromptu



- Ad hoc network [DRD14]
  - It is a decentralized and self-configuring network spontaneously created between neighboring devices with communication capabilities, without relying on any existing infrastructure.

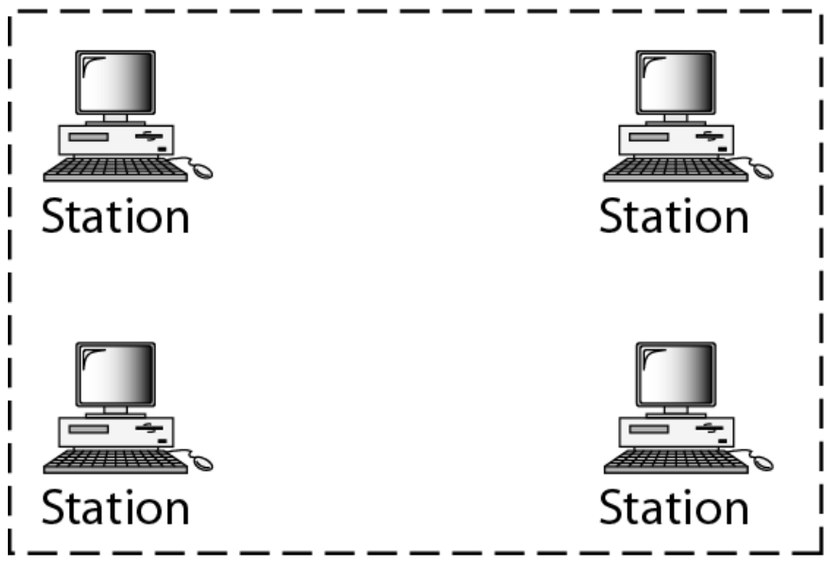
[DRD14] B. Dorronsoro, P. Ruiz, G. Danoy, Y. Pigné, P. Bouvry, Evolutionary Algorithms for Mobile Ad Hoc Networks, Wiley/IEEE Computer Society, Nature-Inspired Computing series, 2014. ISBN 978-1-118-34113-1.

Ad hoc networks

- Origin: 1970 by Norman Abramson, University of Hawaii
  - AlohaNet
    - Wireless communication between computers distributed over four islands
    - Communication with a central node in Oahu
    - Development of random access protocol ALOHA
      - Used in most major cellular networks (2G & 3G) and two-way satellite data networks
- PRNET (1973-1987): Included repeaters, authentication and coexistence with other possible systems
- Quick extension thanks to the reduction in cost and size of hardware needed

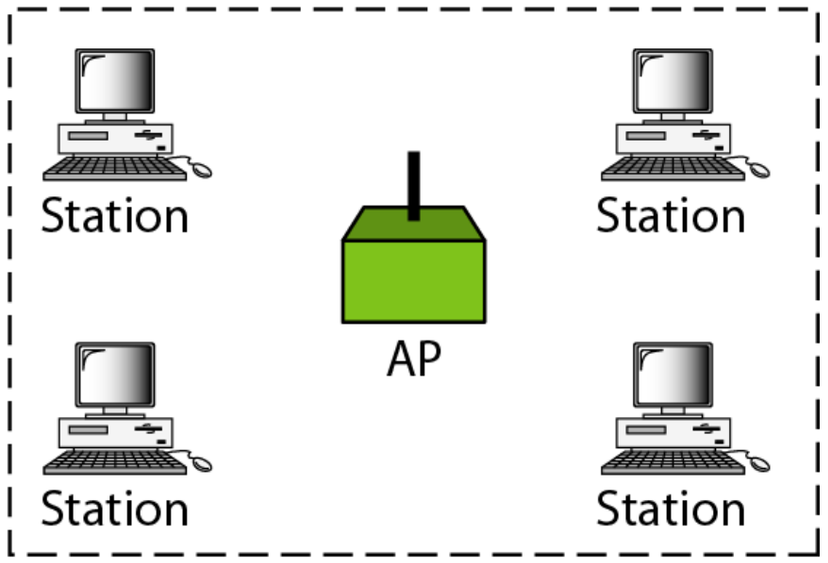
The topology of AlohaNet

Ad hoc networks



Ad hoc network

(no infrastructure)



Wireless network

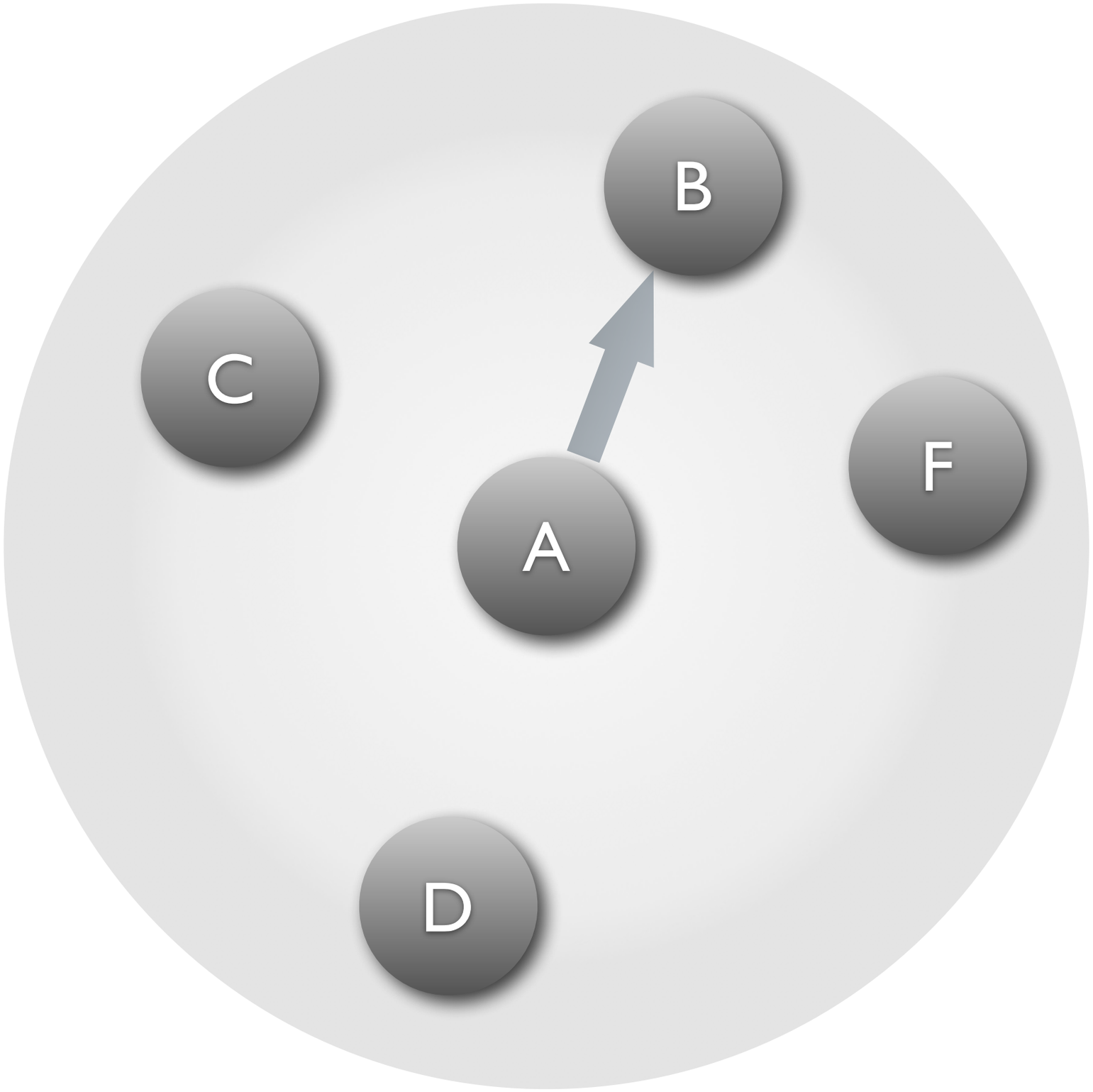
(with an access point)

Ad hoc networks

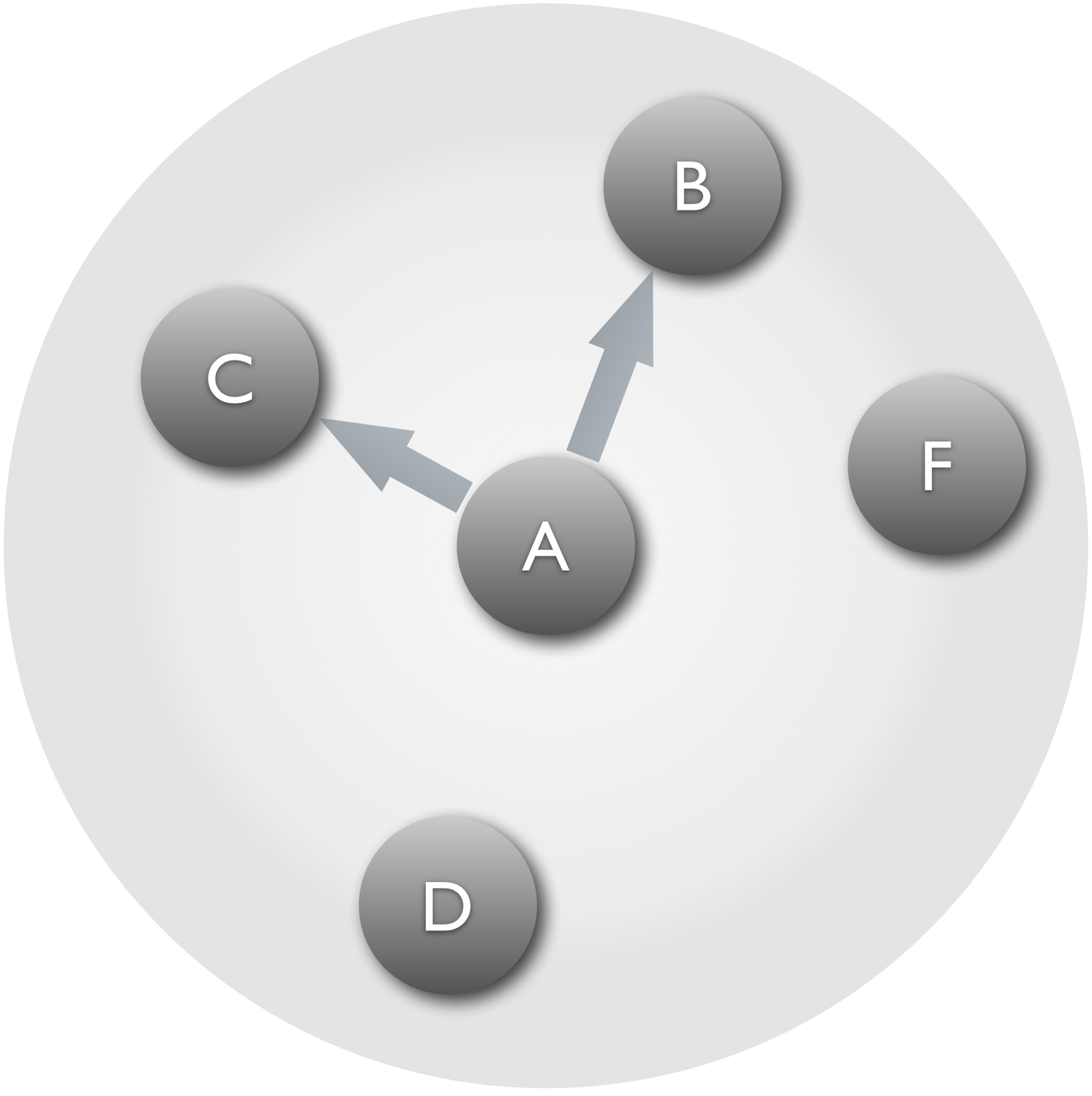
- A collection of two or more devices equipped with wireless communications and networking capability
- No infrastructure
- Devices can communicate with others
  - within their radio range (one-hop)
  - or outside their radio range (multi-hop)
- Nodes act as routers for multi-hop communication
- Challenging features
  - Suffer the drawbacks of wireless networks
    - interferences, time varying channels, low reliability, limited tx range, …
  - But they also have many other specific characteristics…

Operational Modes in Wireless Networks

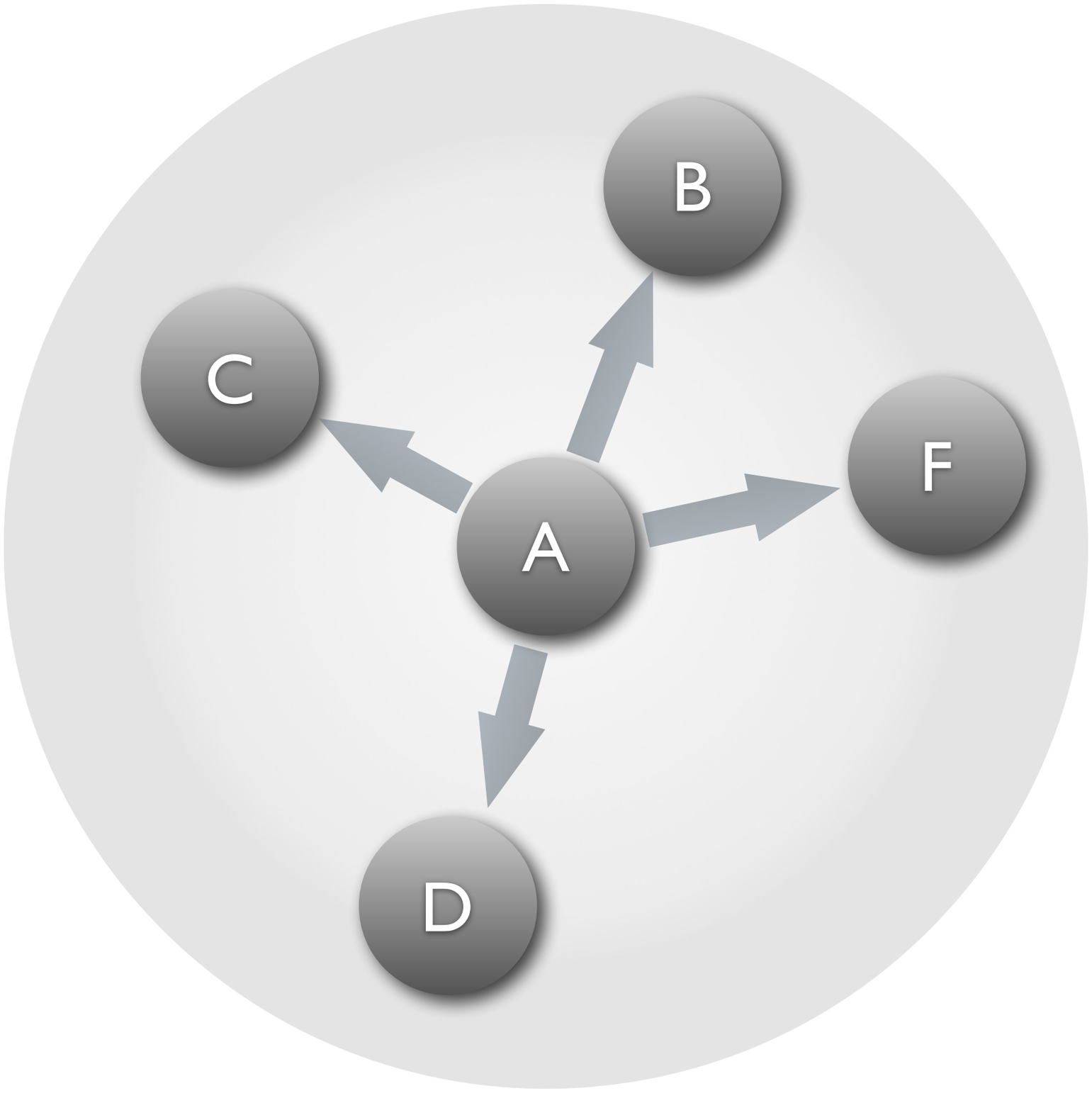
Unicast operation



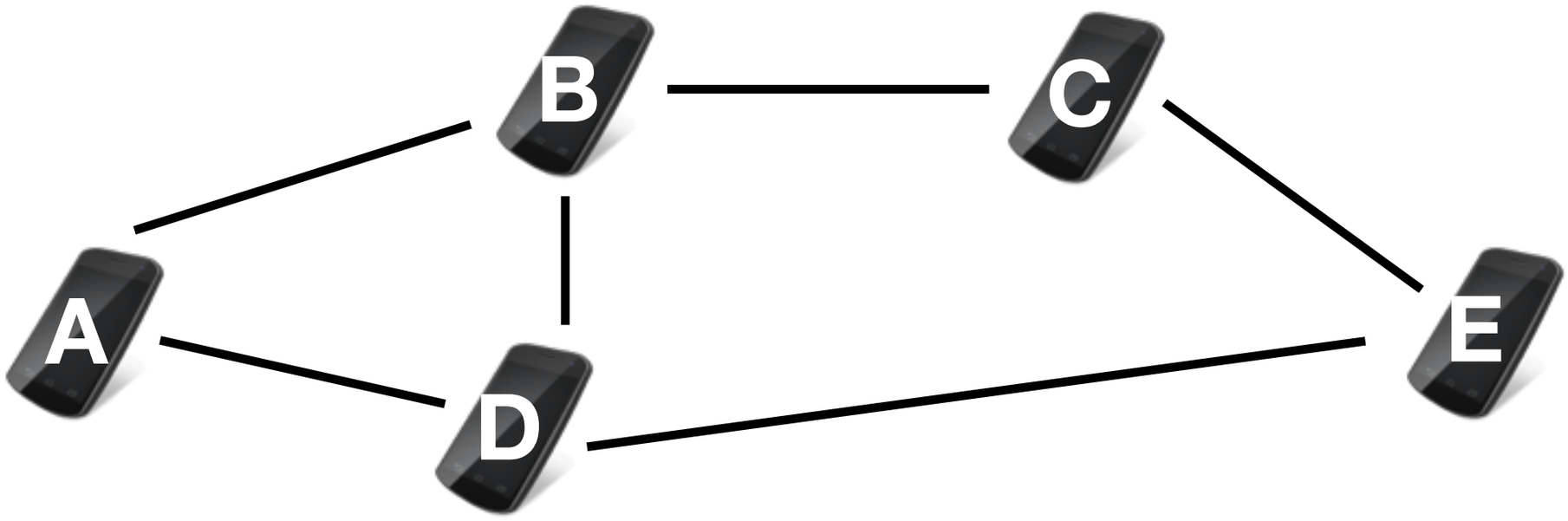
Multicast operation



Broadcast operation



Ad hoc networks: summary

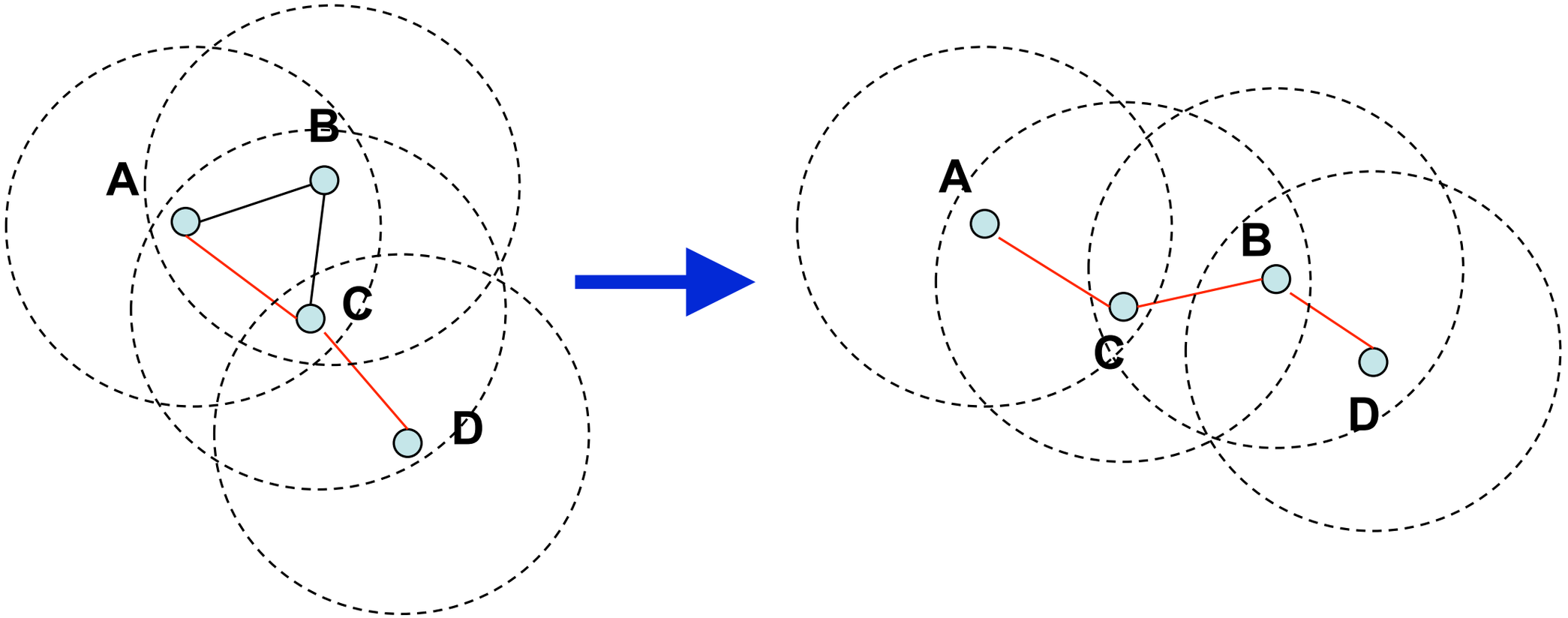


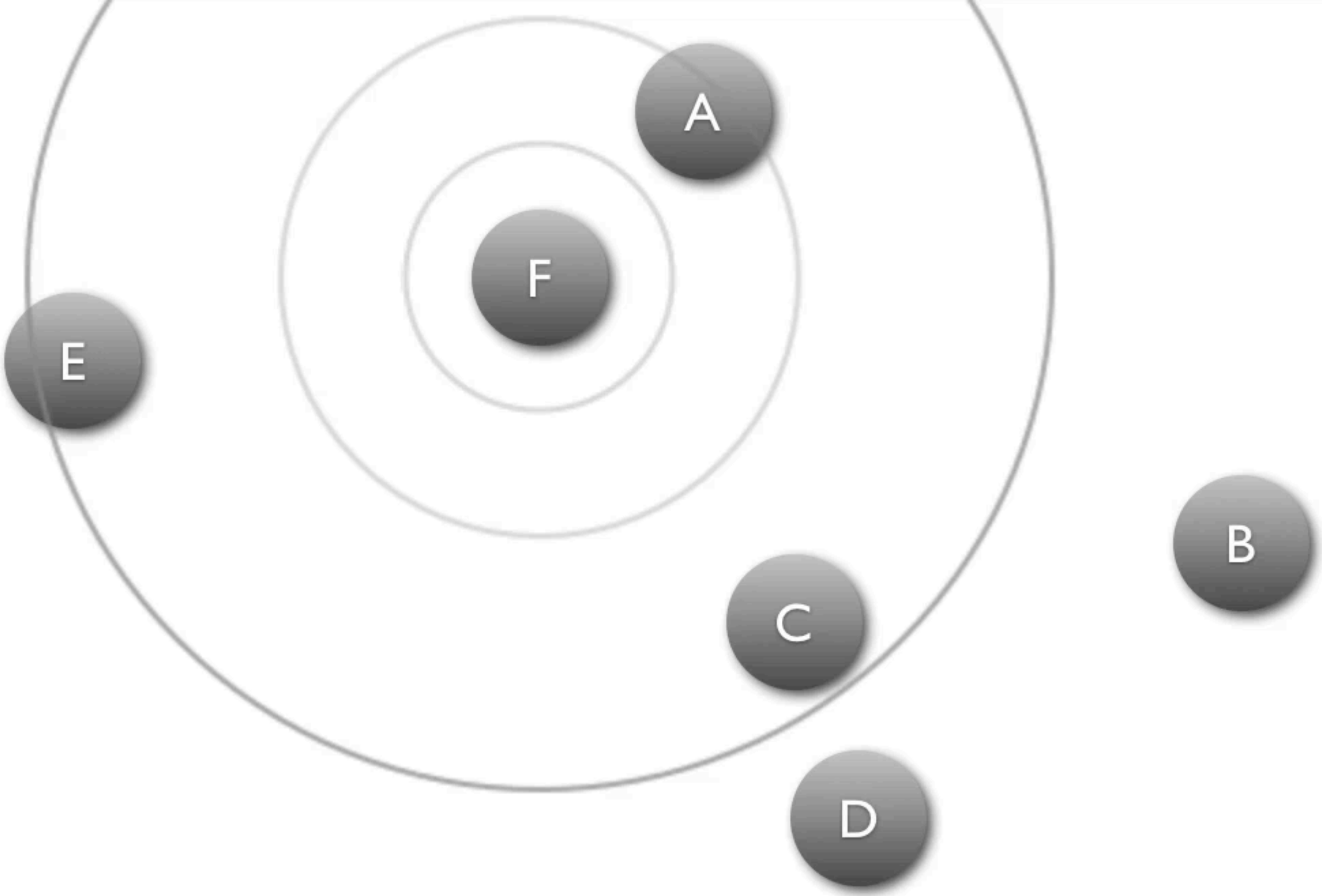
- Fig. depicts a peer-to-peer multihop ad hoc network
- Mobile node A communicates directly with B (single hop) when in range
- Not in range: multi-hop communication (A➜D➜E)
- Multi-hop communication: intermediate nodes must route the packet
- Example: For A to communicate C, B, or D & E, should act as routers

Mobile Ad hoc Networks

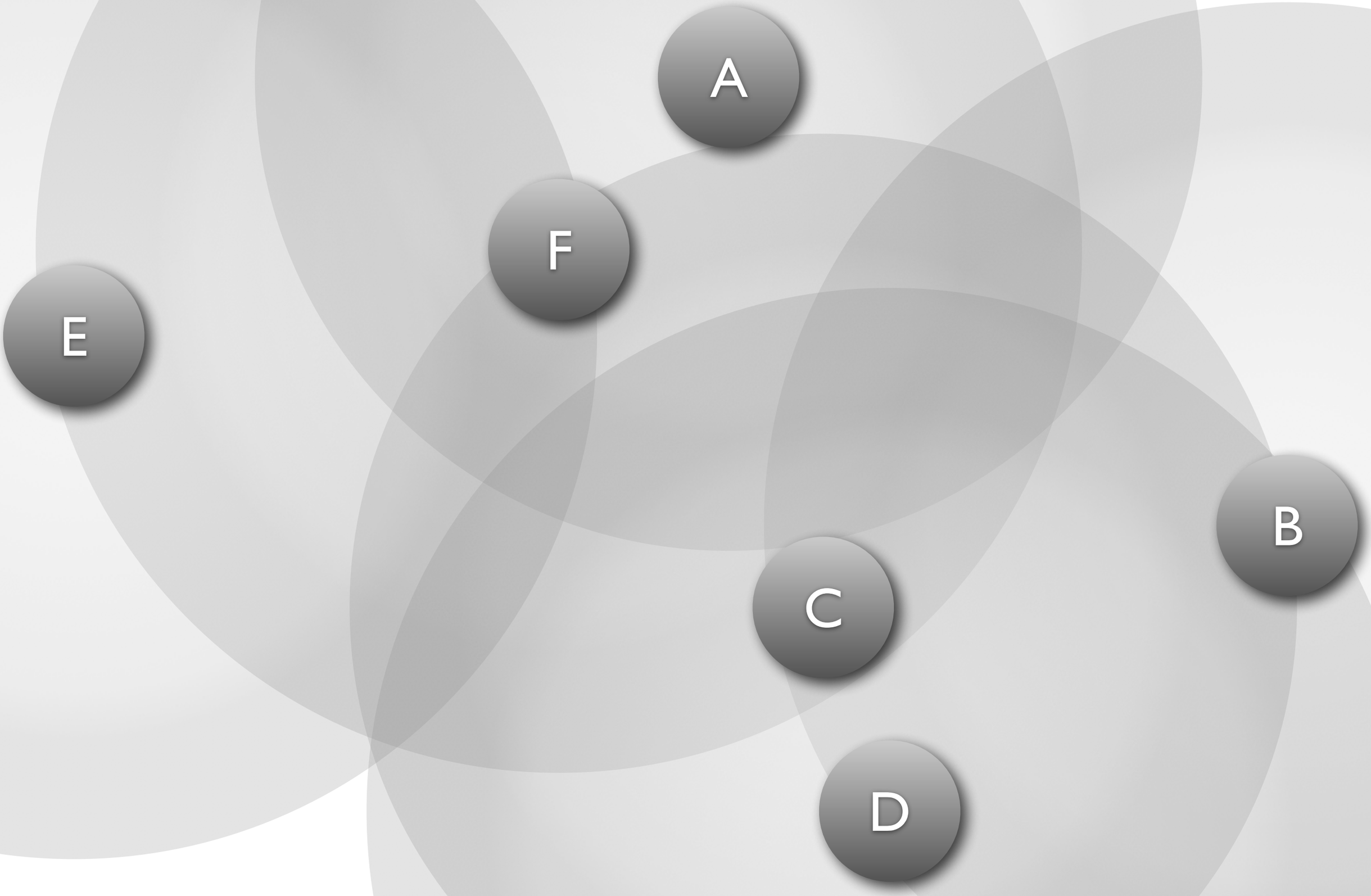
Mobile ad hoc networks

- Ad hoc networks…
  … but formed by wireless hosts which may be mobile
  - No pre-existing infrastructure
  - Routes between nodes may potentially contain multiple hops
    - Nodes act as routers to forward packets for each other
    - The network topology changes quickly

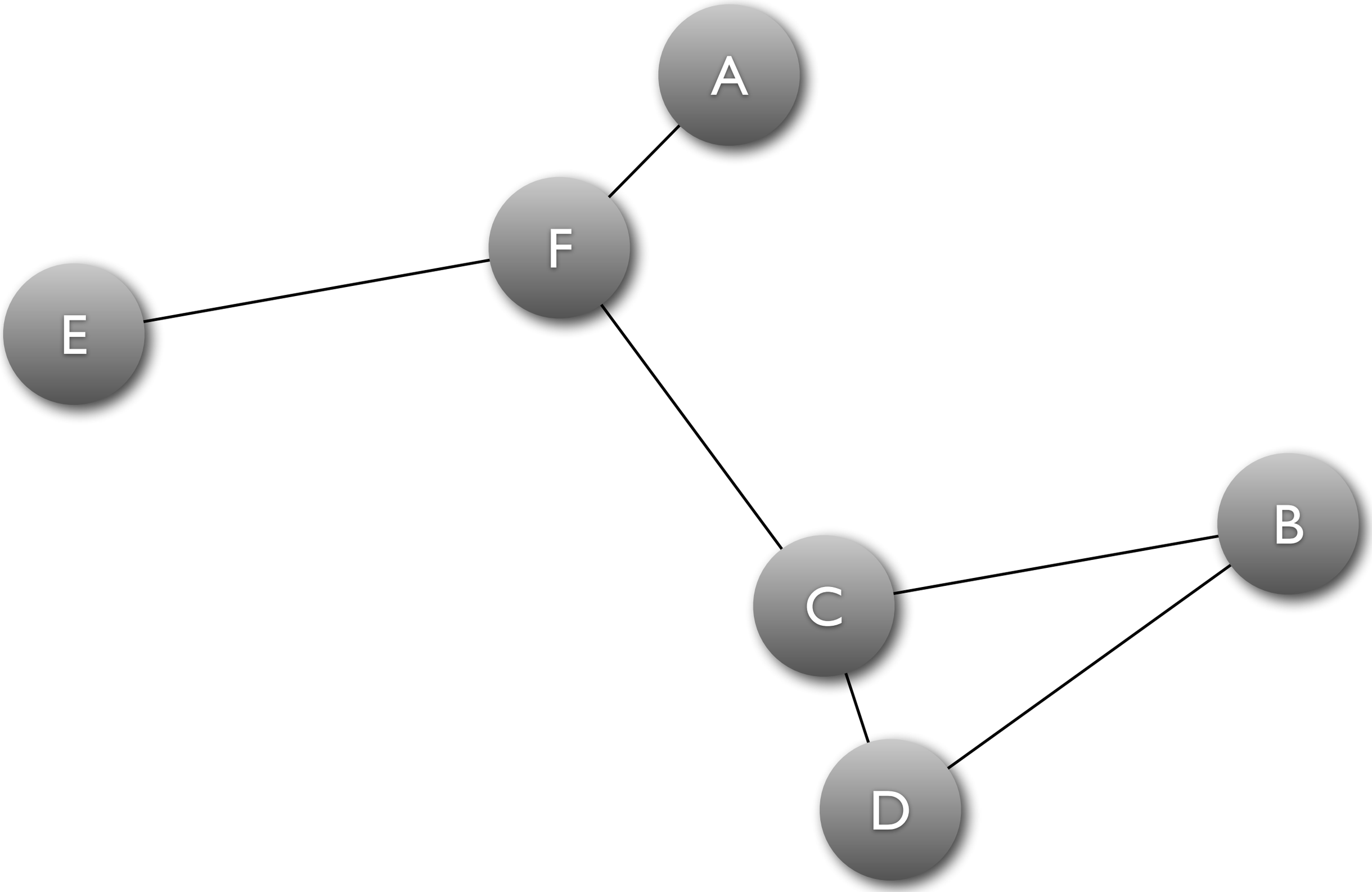




Beaconing



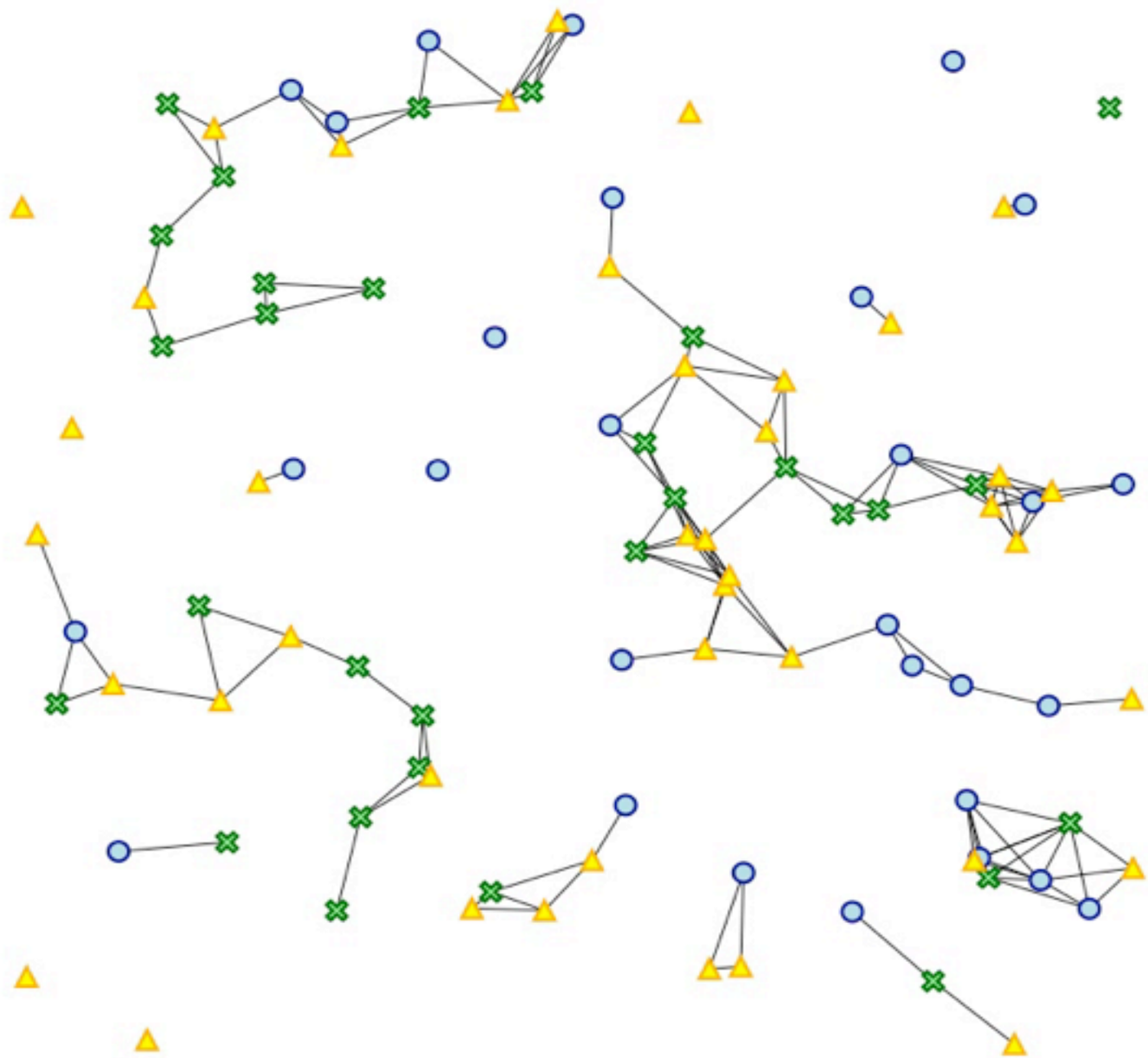
Coverage Areas



Routes Yet **to be Established ...**

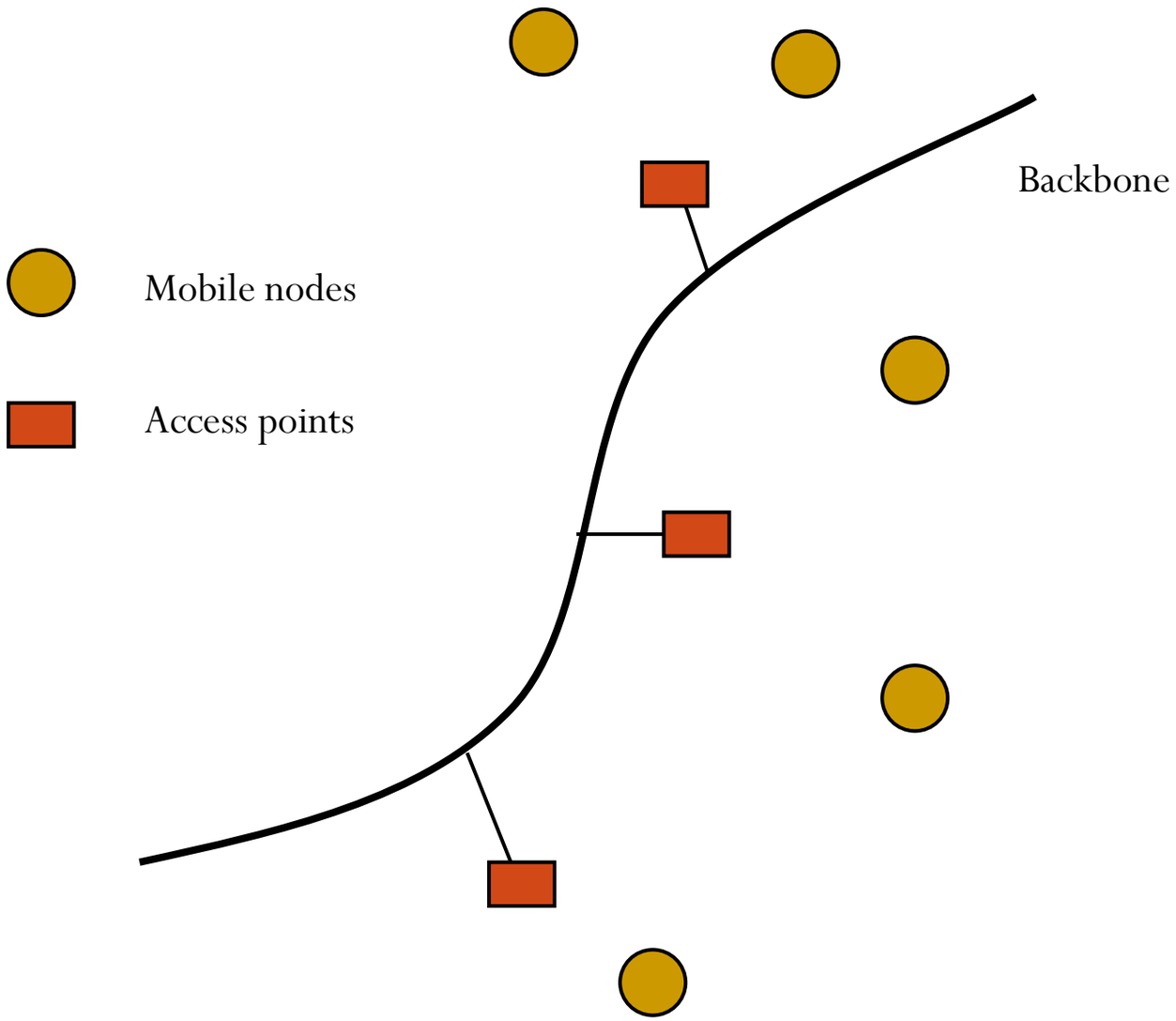
Mobile Ad hoc Networks, MANETs

"Decentralised, self-organising networks capable of forming a communication network without relying on any fixed infrastructure" [Hek06]

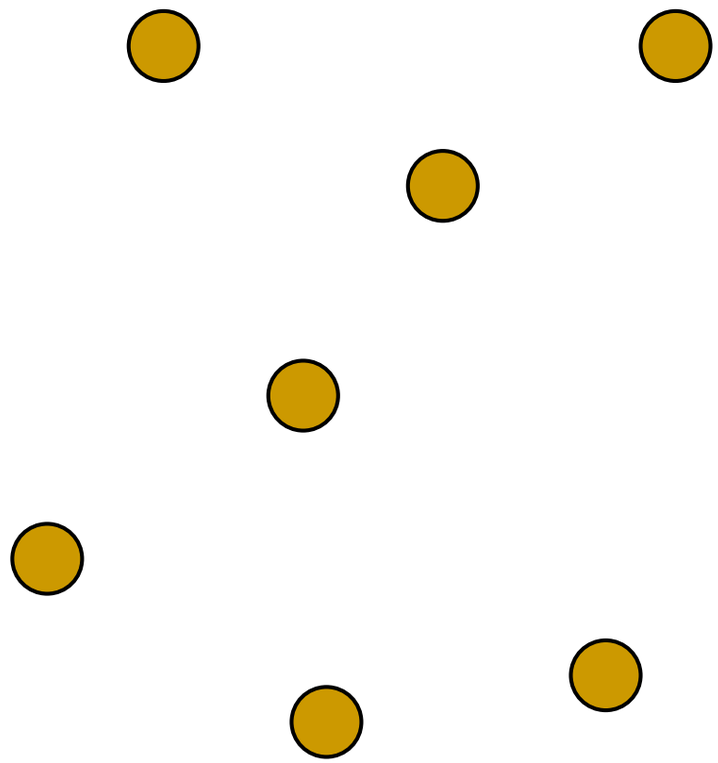


[Hek06] R. Hekmat. Ad-hoc Networks: Fundamental properties and network topologies. Springer. 2006.

Mobile ad hoc networks



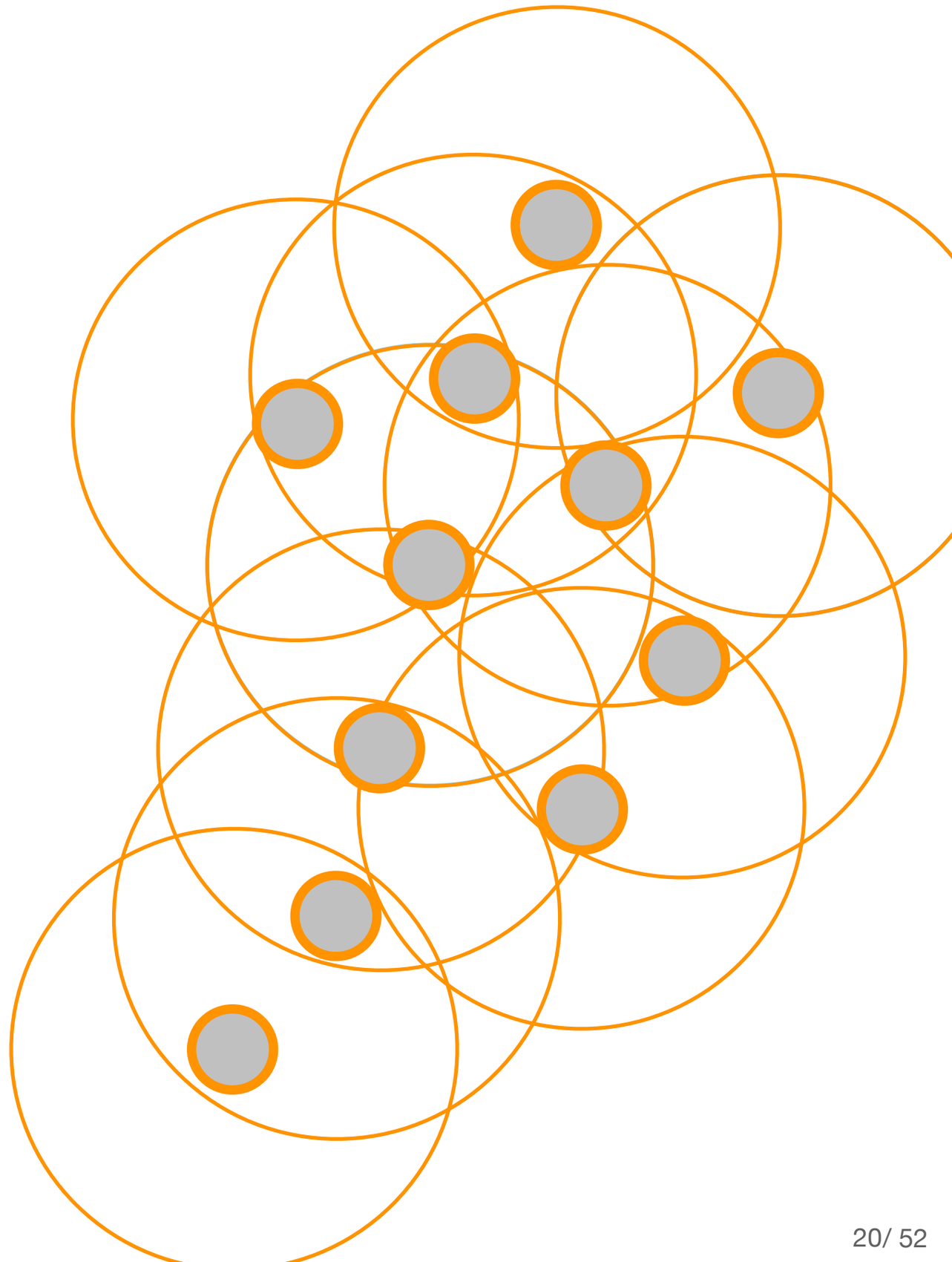
Wireless Mobile Network



Wireless Mobile
Ad hoc Network

Characteristics of mobile ad hoc networks

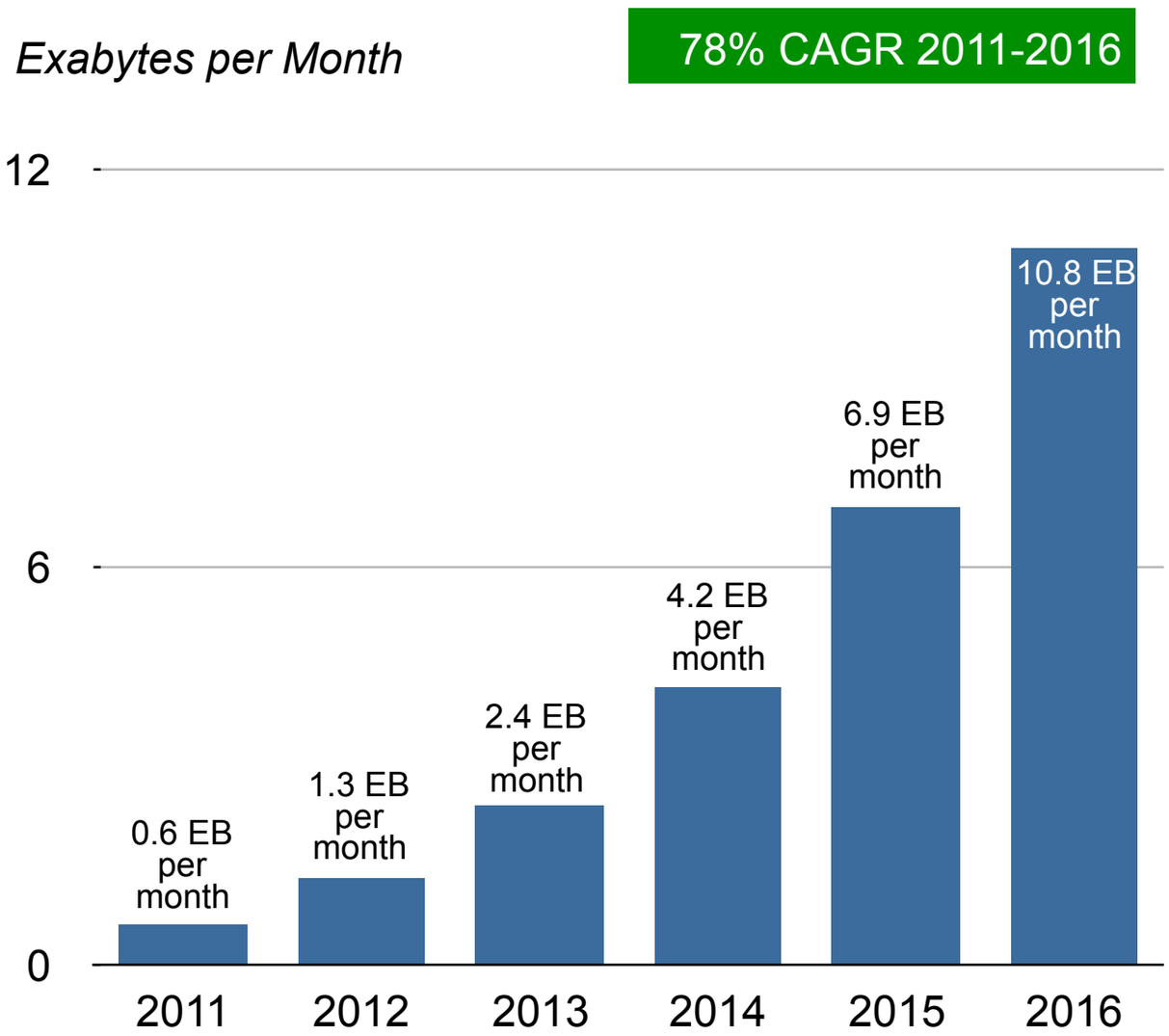
- Decentralization
- Self-organization
- Limited network resources
- Energy limitations
- Dynamism
- Heterogeneity
- Scalability
- Multi-hop
- Security



Potential applications

- Personal area networking
  - cell phone, laptop, ear phone, wrist watch
- Military environments
  - soldiers, tanks, planes
- Civilian environments
  - taxi cab network
  - meeting rooms
  - sports stadiums
  - boats, small aircraft
- Emergency operations
  - search-and-rescue
  - policing and fire fighting

- Alleviate Network Congestion!



Source: Cisco VNI Mobile, 2012

Advantages of MANETs

- Ease and speed of deployment
- No dependence on infrastructure
- High flexibility
- High mobility
- Price
- Considered a robust network
  - non-hierarchical distributed control
  - non-hierarchical distributed management mechanism

Challenges

- Limited processing power
- Devices heterogeneity
- Battery constraints

Nodes

- Mobility-induced route changes
- Mobility-induced packet losses

Dynamic Environment

- Nodes may join and leave the network at any time

- Limited wireless transmission range
- Potentially frequent network partitions
- Packet losses (transmission errors & interferences)

Wireless Network

- Ease of snooping on wireless transmissions
- No one in charge, and no standard services
- All nodes must collaborate

Security and Reliability

Challenges

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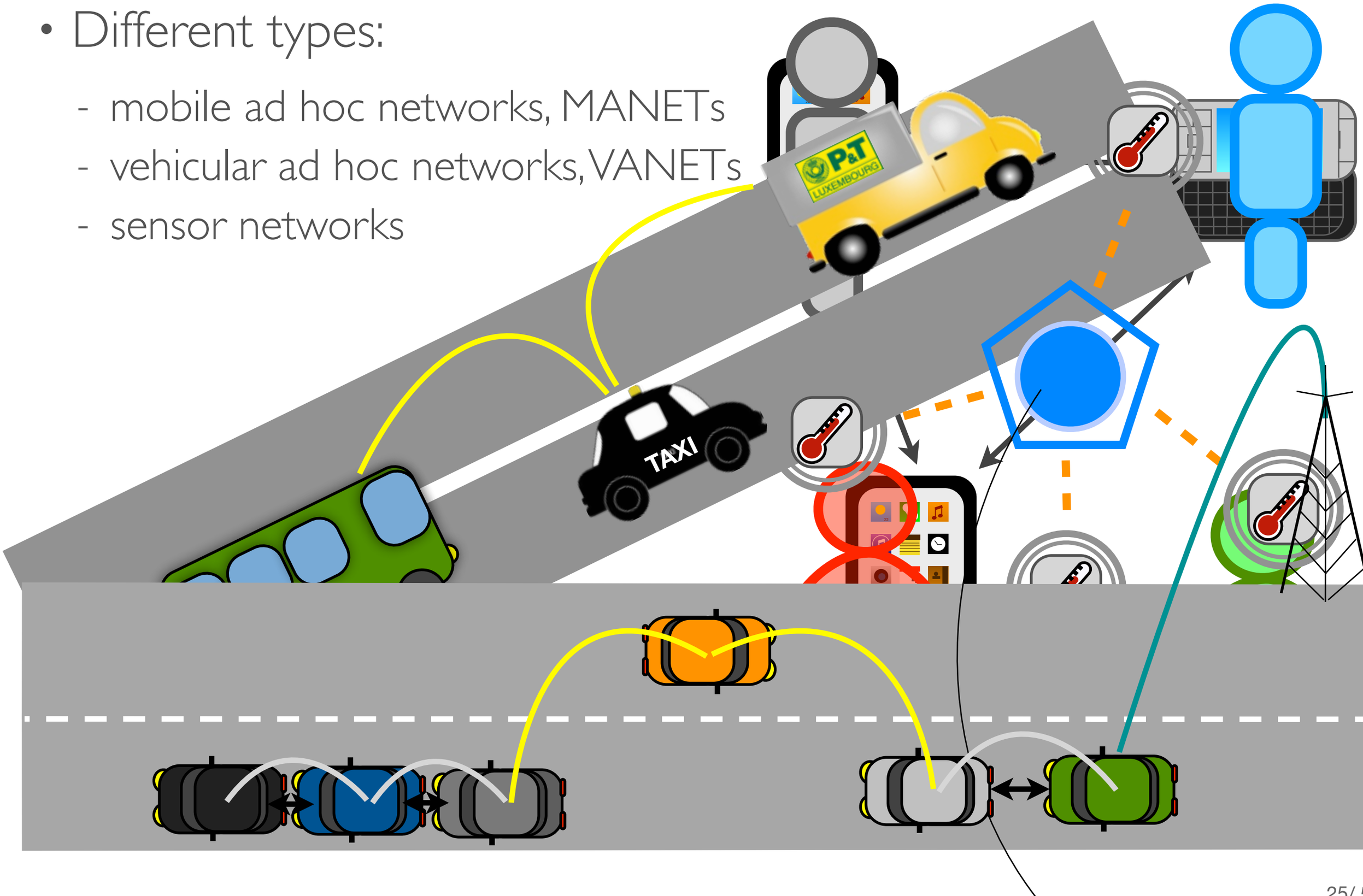
Need of specific communication protocols for MANETs

Wireless ad hoc networks

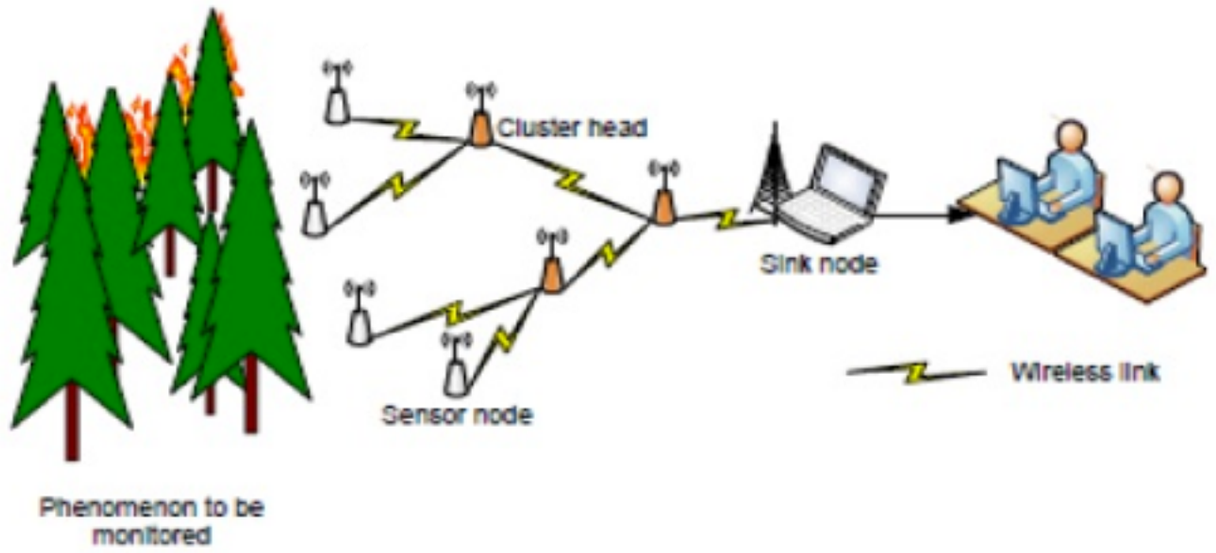
- Different types:
  - mobile ad hoc networks, MANETs
  - vehicular ad hoc networks, VANETs
  - sensor networks



Wireless Sensor Networks (WSN)

Wireless sensor networks

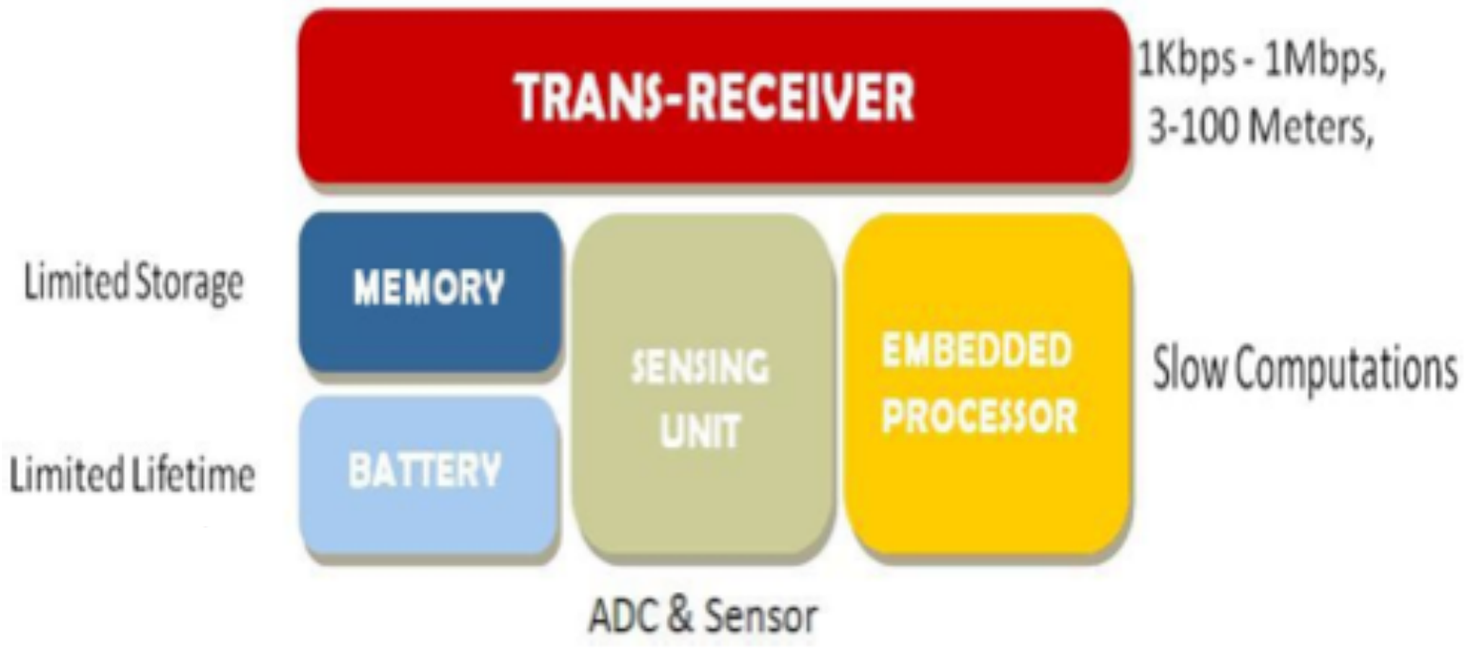
- Collection of a large number of motes deployed in a region
  - One form of an ad hoc wireless network
  - Motes cooperatively monitor physical or environmental conditions
- Motes
  - Small devices
  - Limited computation
  - Low cost and low power
  - Take information from their environment
  - Process and communicate the data to other motes
  - High energy consumption concern

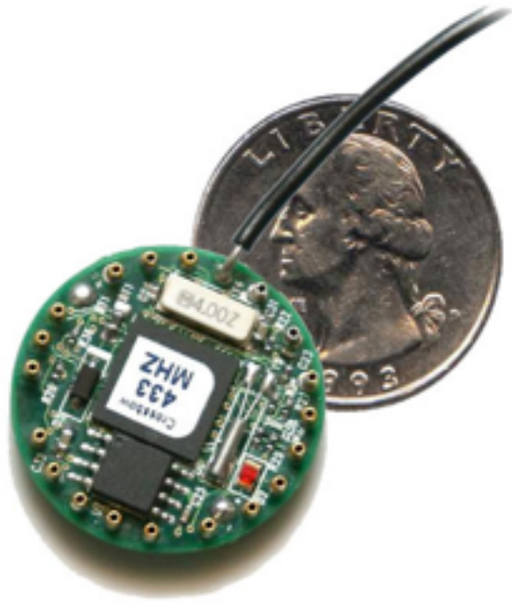


- There are a variety of sensors, including acoustic, seismic, image, heat, direction, smoke, and temperature sensors.

Wireless sensor networks

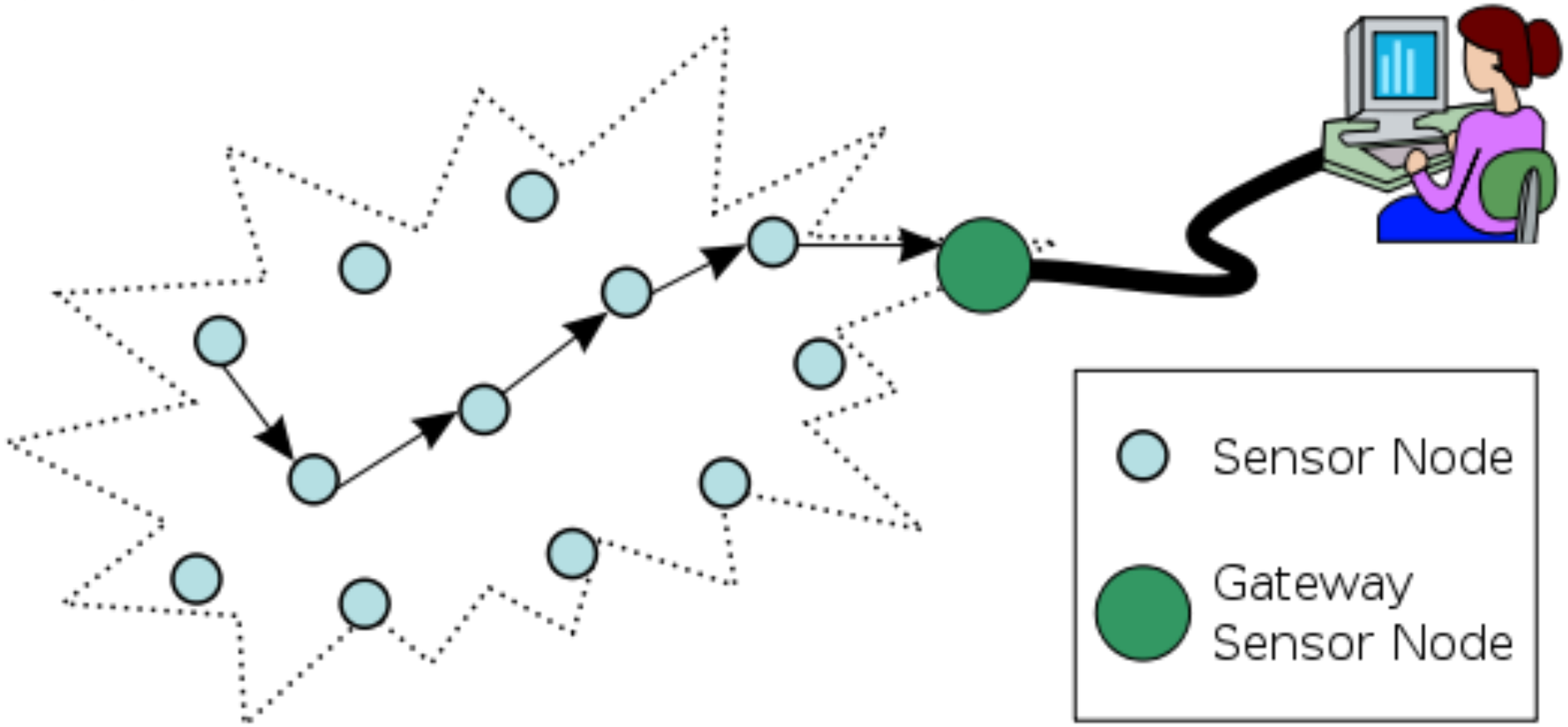
- Mote
  - Made up of four basic components
    - Sensing unit, Processing unit, Transceiver unit, and Power unit
  - Additional application-dependent components
    - Location finding system, power generator, and mobilizer
  - Scattered in a sensor field
  - Collect data and route data back to the sink





Wireless sensor networks

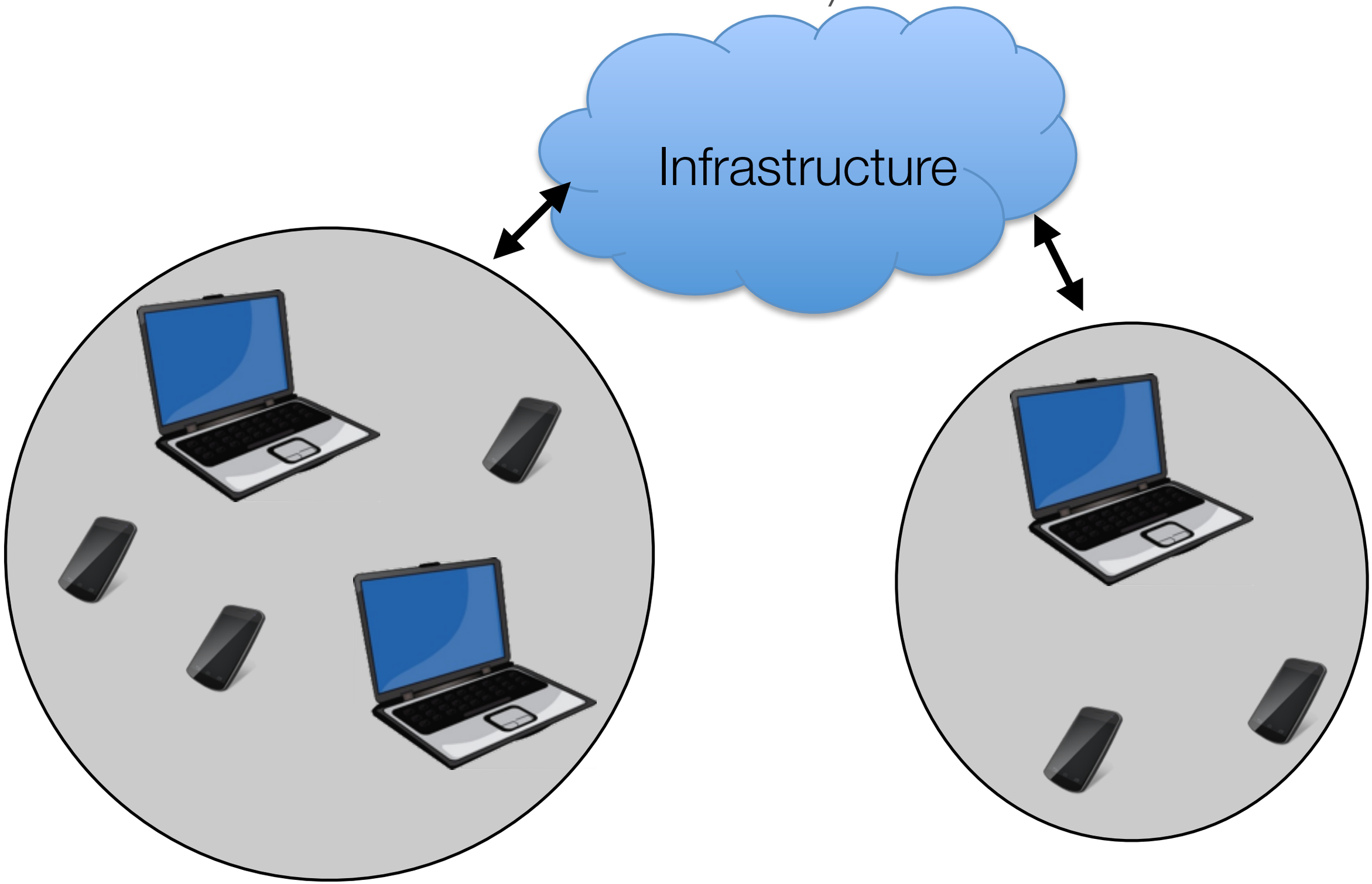
- Sink node
  - Collects information from sensors
  - Perform some computations/statistics on the collected data
  - Provides information to allow critical decisions to be made
  - Communicates with the task manager node (user) via Internet or satellite



Hybrid Networks

Hybrid networks

- Infrastructure + Ad hoc connectivity



Hybrid networks

- Some hosts connected to a backbone, most are not

- Exploit heterogeneity to choose access points
  - Nodes with more processing capacity
  - Nodes with better communication capabilities
  - Nodes with more energy
  - More reliable nodes
  - …

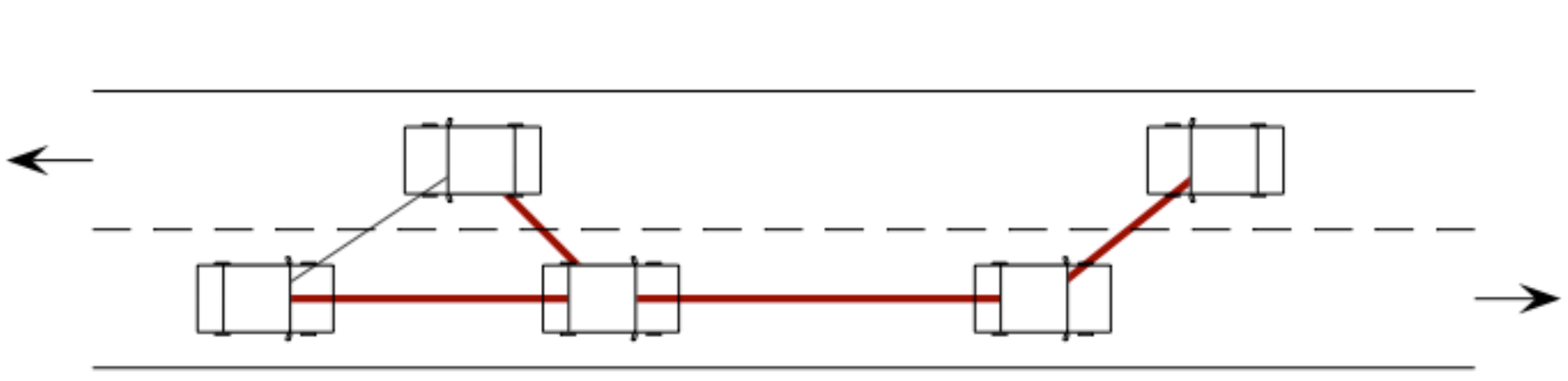
Benefit over pure ad hoc networks

- Infrastructure provides a frame of reference
  - Can assign **approximate locations** to the mobiles
    - Provide location-aware services
    - Reduce route discovery overhead
- Infrastructure can **reduce diameter** of the network
  - Lower delay
  - Potentially greater per-flow throughput
- Infrastructure can help **overcoming network partitioning** and other problems
  - Address assignment
  - Security (central authority is possible)
  - Easier to detect and penalize misbehaving nodes

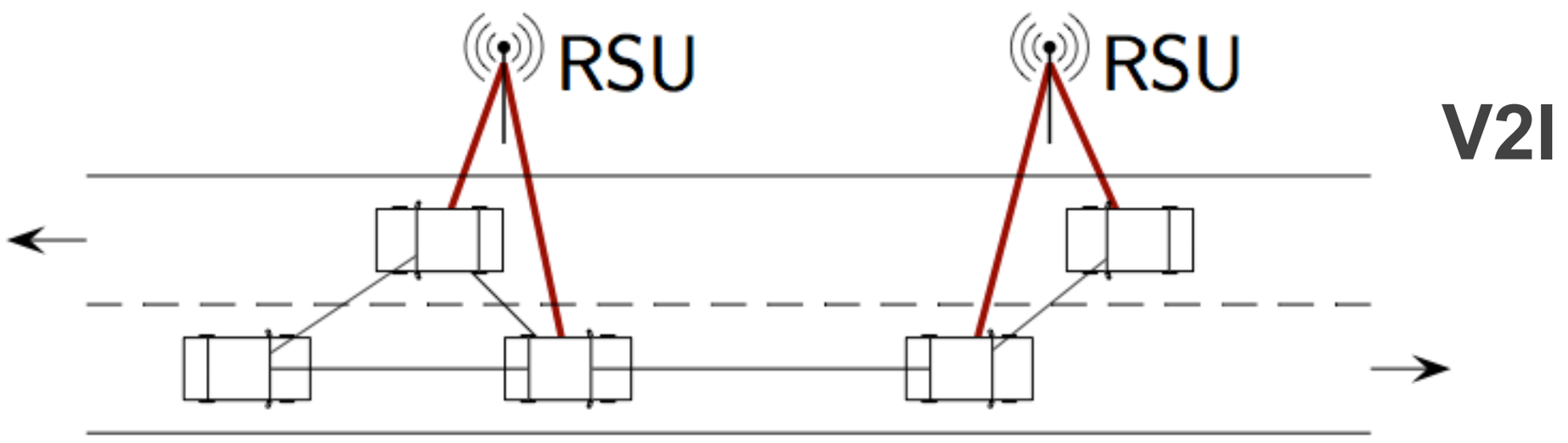
Vehicular Ad Hoc Networks (VANETs)

Vehicular ad hoc networks

- Used for communication among vehicles…

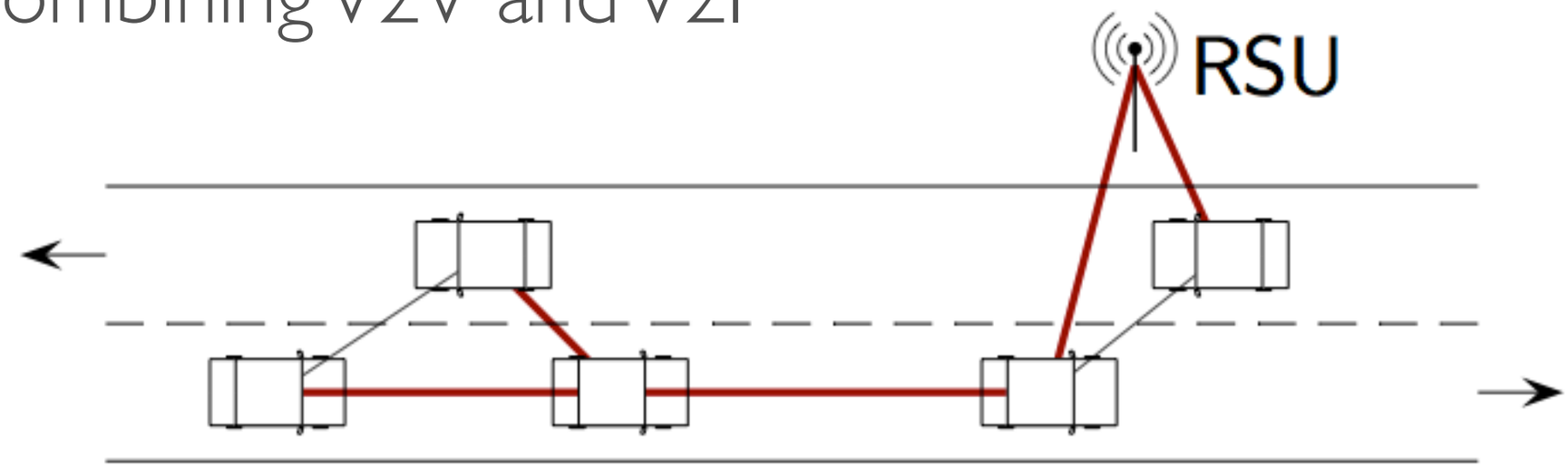


- … and between vehicles and roadside equipment…



Vehicular ad hoc networks

- … or combining V2V and V2I

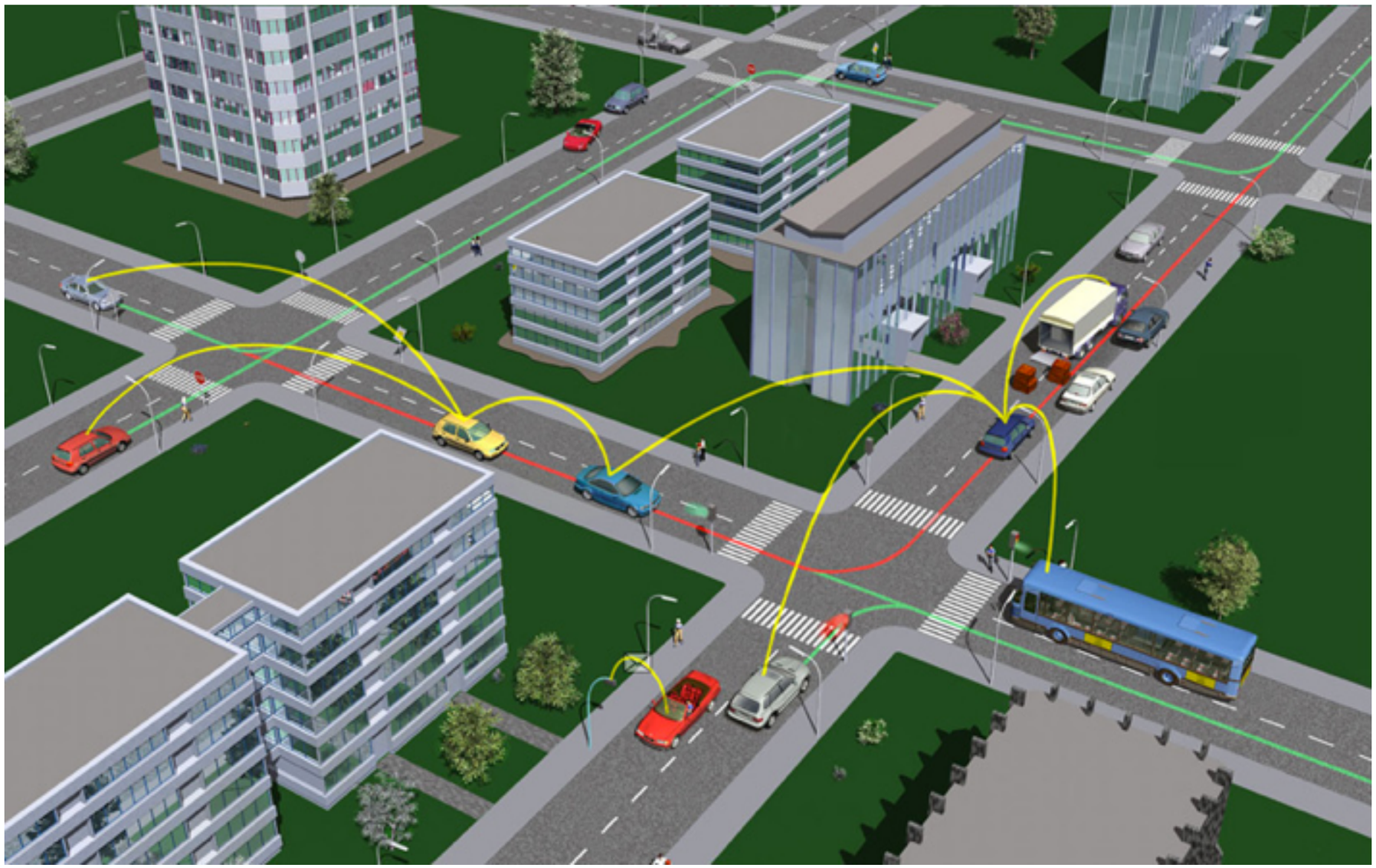


- In a near future, they are expected to
  - Improve safety, route selection, geographic notifications…
  - Allow Internet in vehicles, real-time traffic information, entertainment…

[car-2-car.org]

Vehicular ad hoc networks

- Nodes
  - Less energy restrictions
  - Bigger coverage
- Mobility
  - Vehicles move in an organized fashion
  - Fast speed



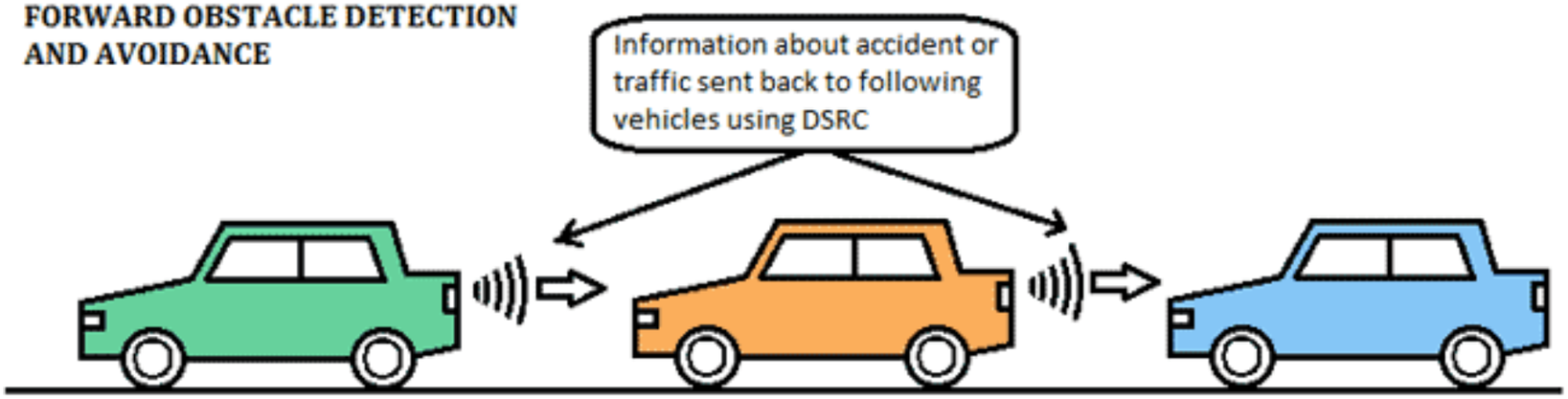
[car-2-car.org]

Need of standards

- Vehicles of all categories and all brands must be able to communicate with each other
- Standardization bodies: ASTM, IEEE, SAE, ISO
- Car manufacturers, consortiums, projects...:

Standards: Physical and MAC layers

- DSRC standard — IEEE
  - Dedicated Short-Range Communication
    - One-way or two-way short-range to medium-range wireless communication channels specifically designed for automotive use
    - Corresponding set of protocols and standards



- IEEE 802.11p (MAC & PHY)
- Communication Access for Land Mobiles (CALM) — ISO
- C2Cnet — Car-2-car Communication Consortium

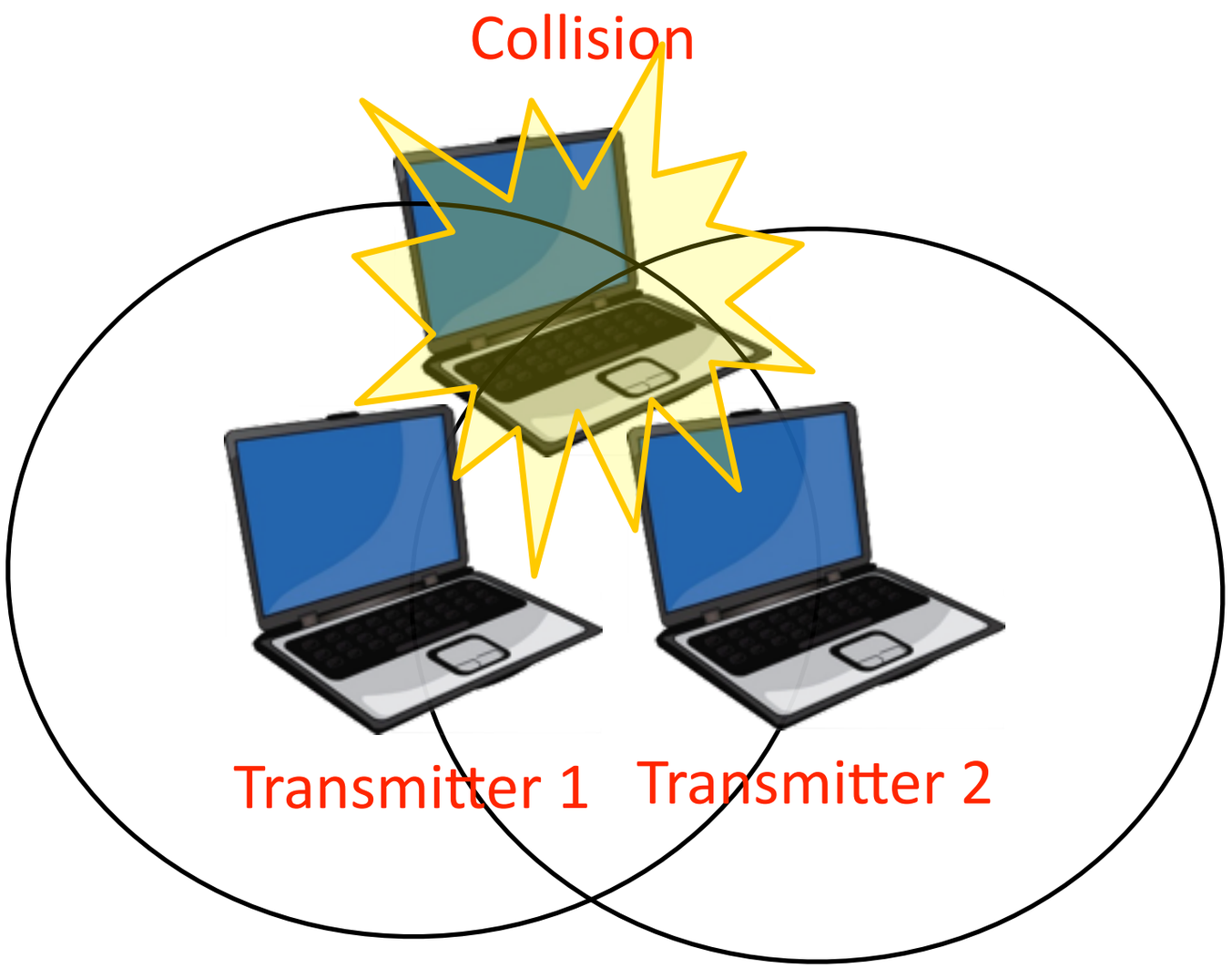
Some Problems in Mobile Ad hoc Networks

Problems and issues in MANETs

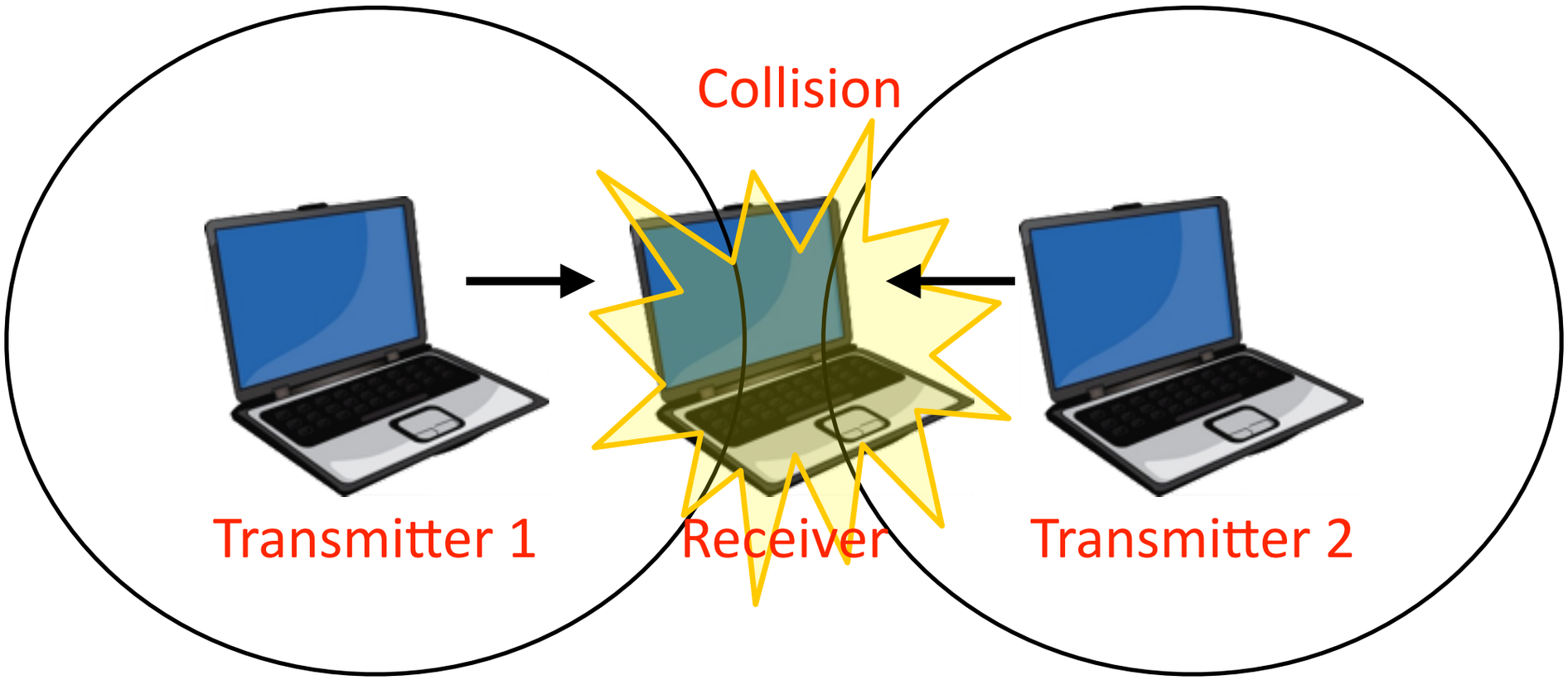
- Network contention
- Hidden terminal problem
- Exposed terminal problem
- Address assignment
- Duplicated addresses problem
- Transport protocol performance
- Distributed knowledge
- Heterogeneity of devices
- Network partitioning
- Dynamism

Problems: network contention

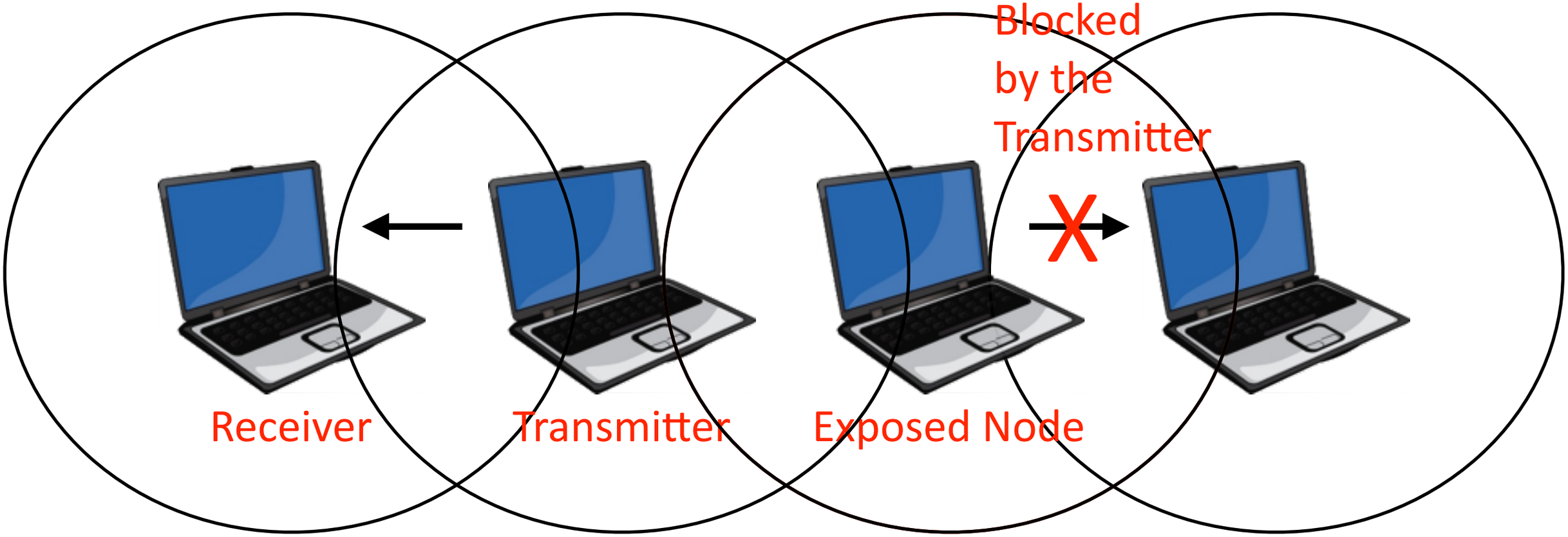
- Shared medium: only one node can transmit at a time
- Else, listener would hear noise



Problems: hidden terminal



Problems: exposed terminal

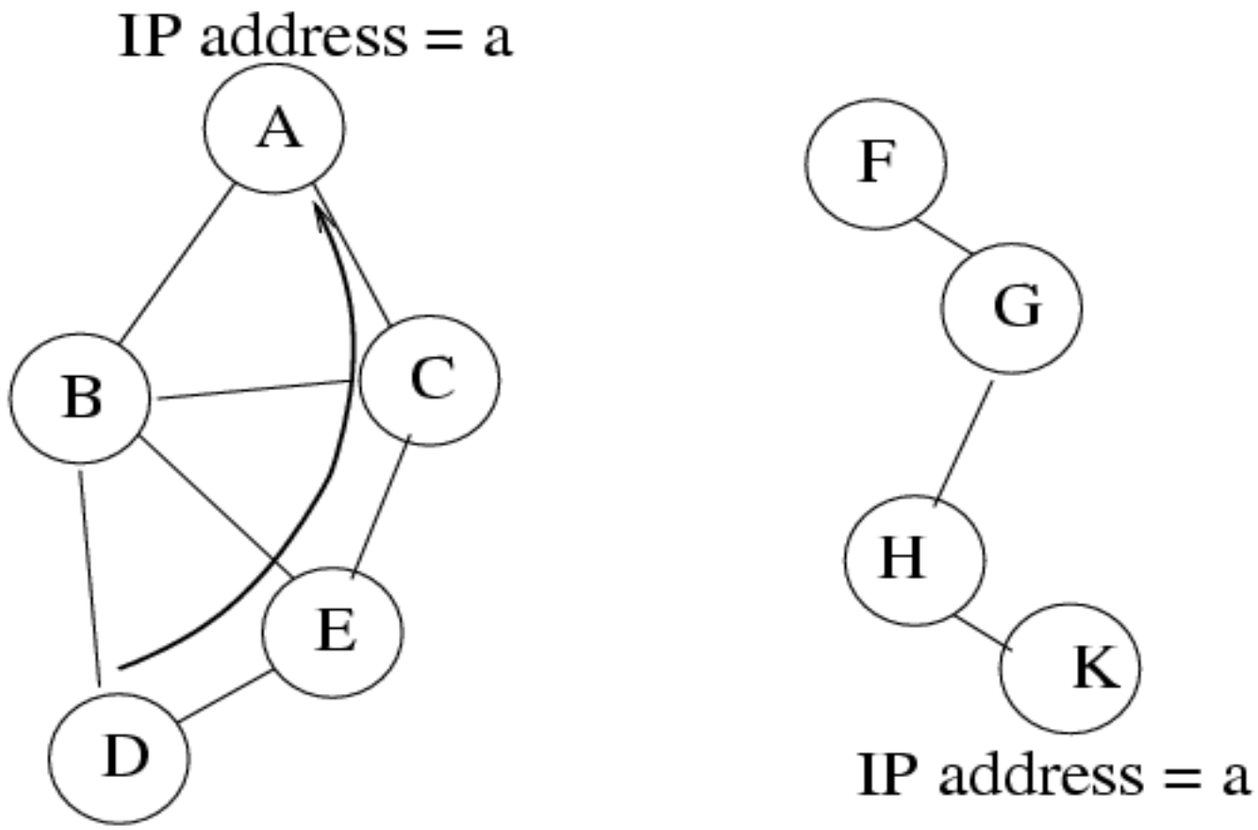


Problems: address assignment

- How to assign addresses to nodes in an ad hoc network ?
- Static assignment
  - Easier to guarantee unique address
- Dynamic assignment
  - Worst case network delays may be unknown, or highly variable, or unbounded
  - How to guarantee unique addresses when partitions merge?
- Do we need to guarantee unique addresses ?

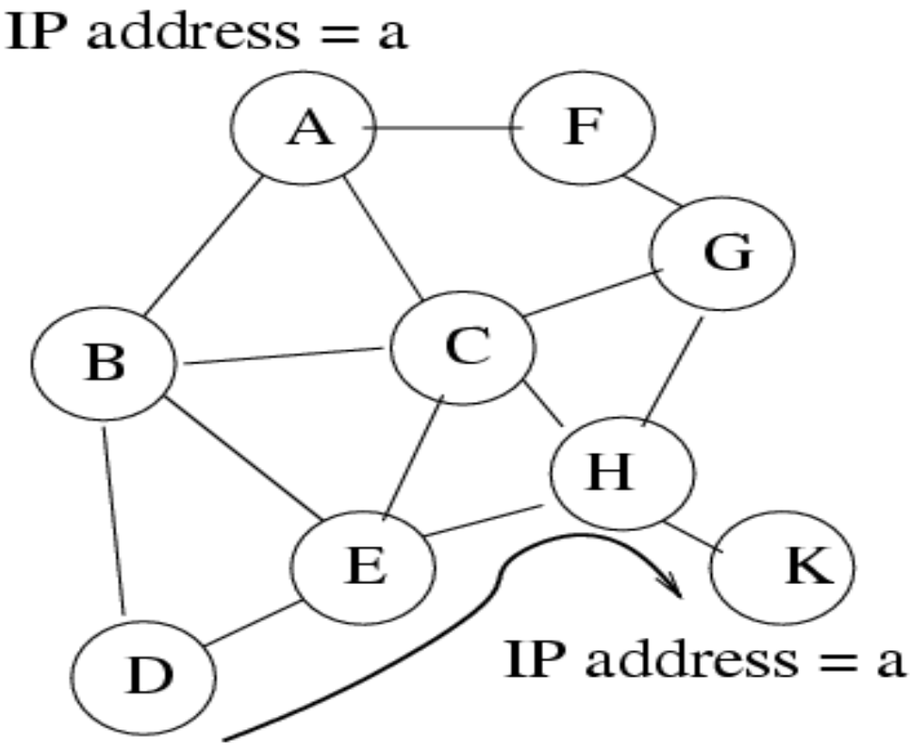
Problems: duplicated addresses

- D's packets for address 'a' routed to A



Problems: duplicated addresses

- Merged network:
  - Duplicate address detection (DAD) important to avoid misrouting



Strong DAD

- Detect duplicate addresses within t seconds
- Not possible to guarantee strong DAD in presence of unbounded delays
  - May occur due to partitions
  - Even when delays are bounded, bound may be difficult to calculate
    - Unknown network size
- Strong DAD impossible with unbounded delay
- How to achieve DAD ?

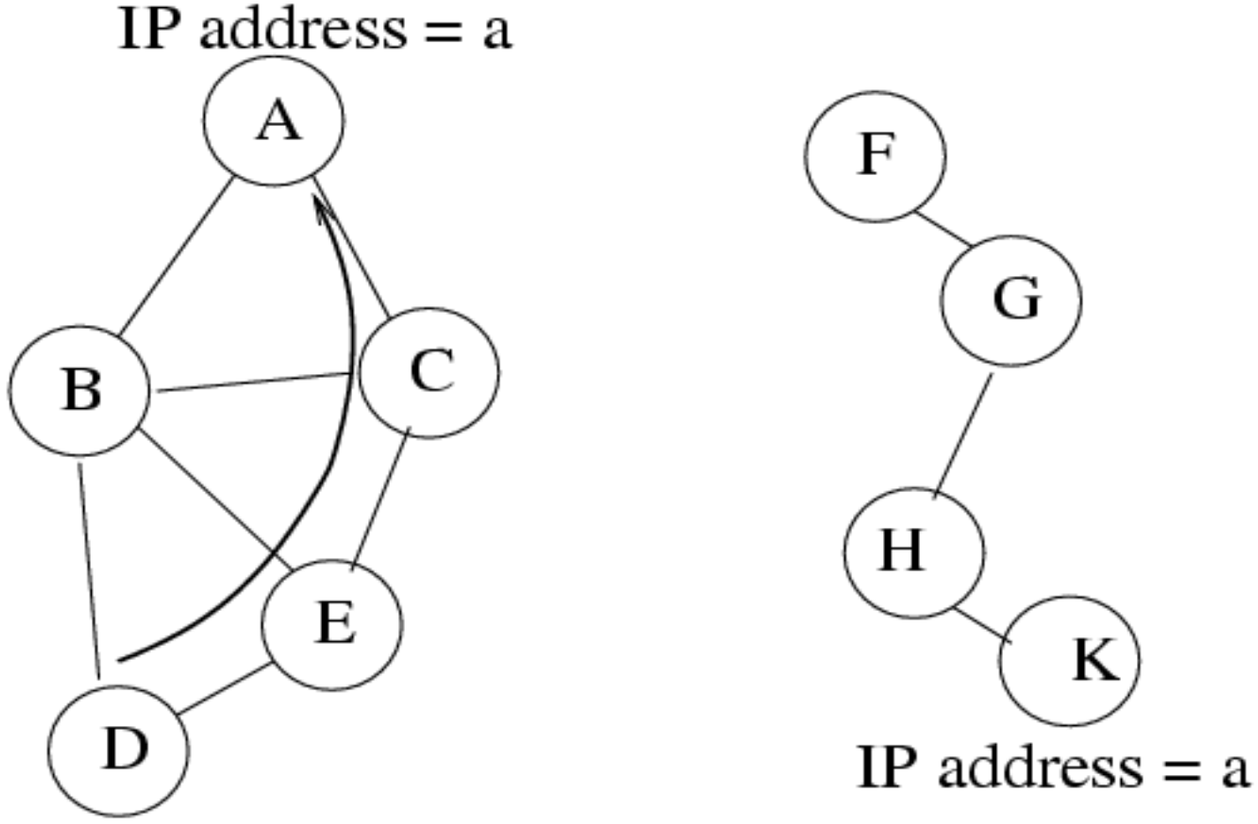
If you cannot solve a problem

Change the problem

Problems: duplicated addresses

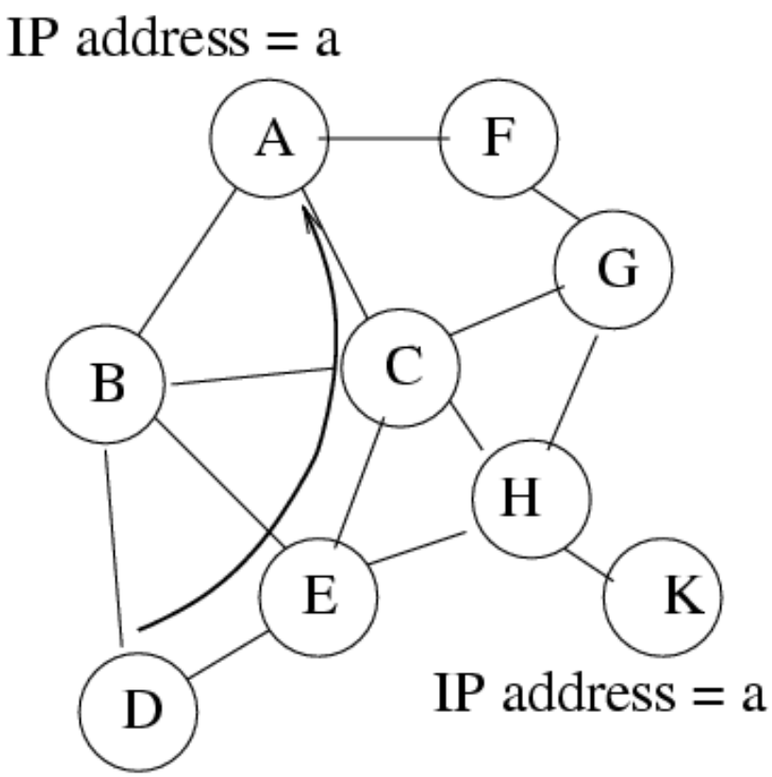
- Weak DAD
  - Packets from a given host to a given address should be routed to the same destination, despite duplication of the address

- D's packets for address 'a' routed to A



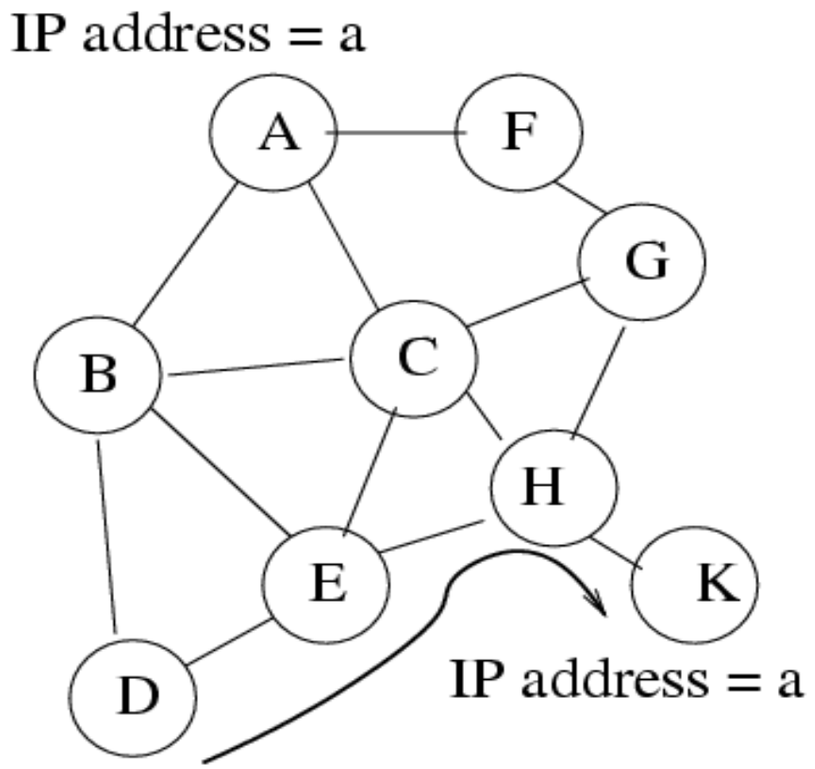
Problems: duplicated addresses

- Weak DAD
- Acceptable behavior



Packets from D to address 'a' still routed to host A

- Unacceptable behavior



Packets from D to address 'a' routed to host K instead of A

Problems: TCP

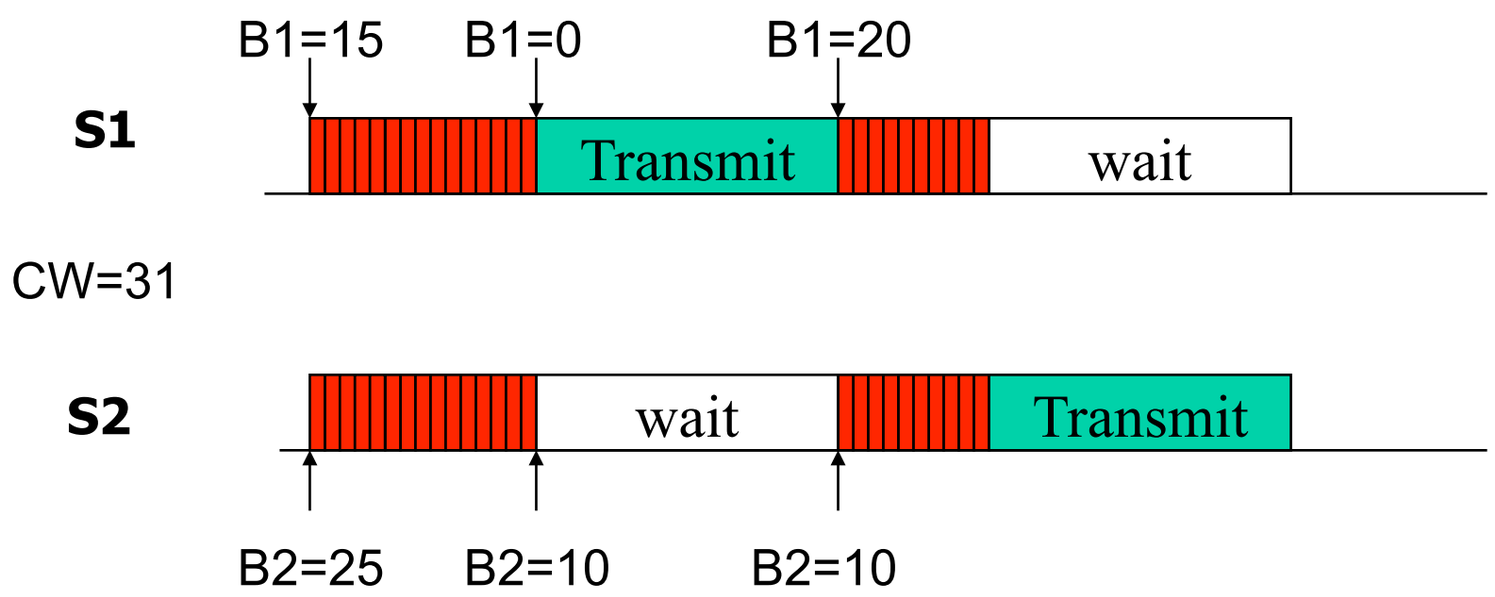
- TCP performance degrades in presence of route failures
- TCP cannot distinguish between packet losses due to route change and due to congestion
- Reduces congestion window in response
  - Unnecessary degradation in throughput
- Some techniques to inform sender about route failure
  - Does not decrease congestion window
  - New route might differ significantly from old route
    - How to choose appropriate timeout and congestion window?

Selfishness

- Why should I forward packets for some other nodes ?
- Need some incentive mechanism
- Policies to determine reward for performing each operation

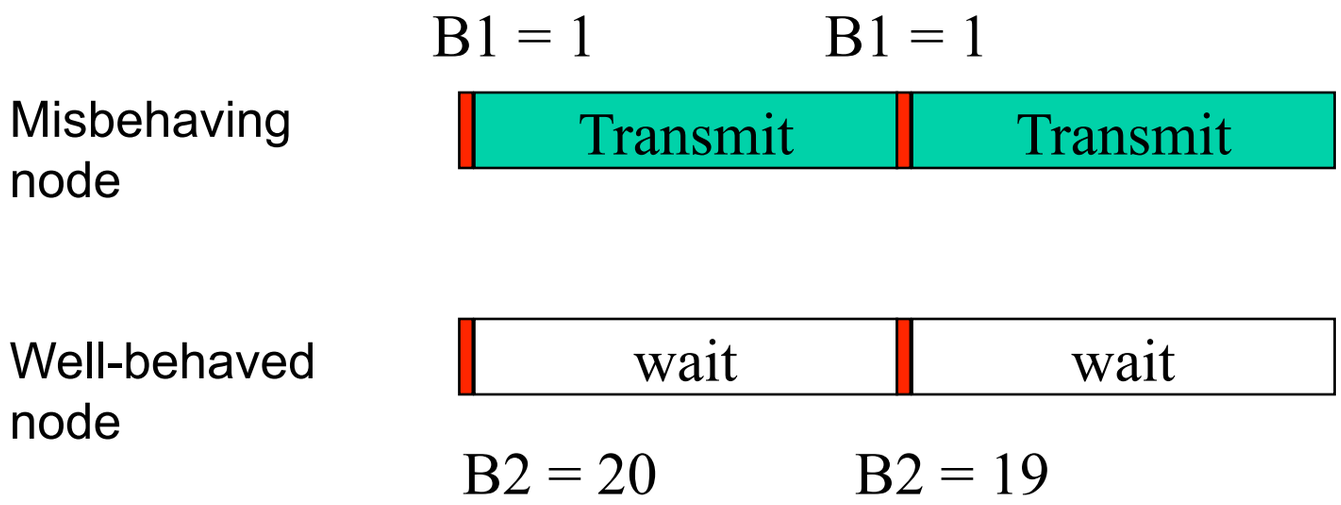
Misbehavior

- Choose backoff value B in range [0,CW]
  - CW is the Contention Window
- Count down backoff by 1 every idle slot



Misbehavior

- Backoff from biased distribution
  - Example: Always select a small backoff value



Effect of mobility on the protocol stack

- Application
  - new applications and adaptations
- Transport
  - congestion and flow control
- Network
  - addressing and routing
- Link
  - broken links
- Physical
  - transmission errors and interference

The State of the Art

- Lot of research activity on:
  - Routing
  - Medium access control
  - Quality of service
- More recently …
  - Capacity of wireless networks
    - Pure wireless networks
    - Hybrid networks
    - Delay-throughput trade-off
  - Graph-theoretic problems
    - Topology control
    - Dominating sets
    - Connectivity problems
    - Coverage problems in sensor networks

Plenty of opportunities for optimization!!