Multihop Mobile and Vehicular Networks

Ľubomír Doboš
lubomir.dobos@tuke.sk
Technical University of Košice
Faculty of Electrical Engineering and Informatics
Dept. of Electronics and Multimedia Communications

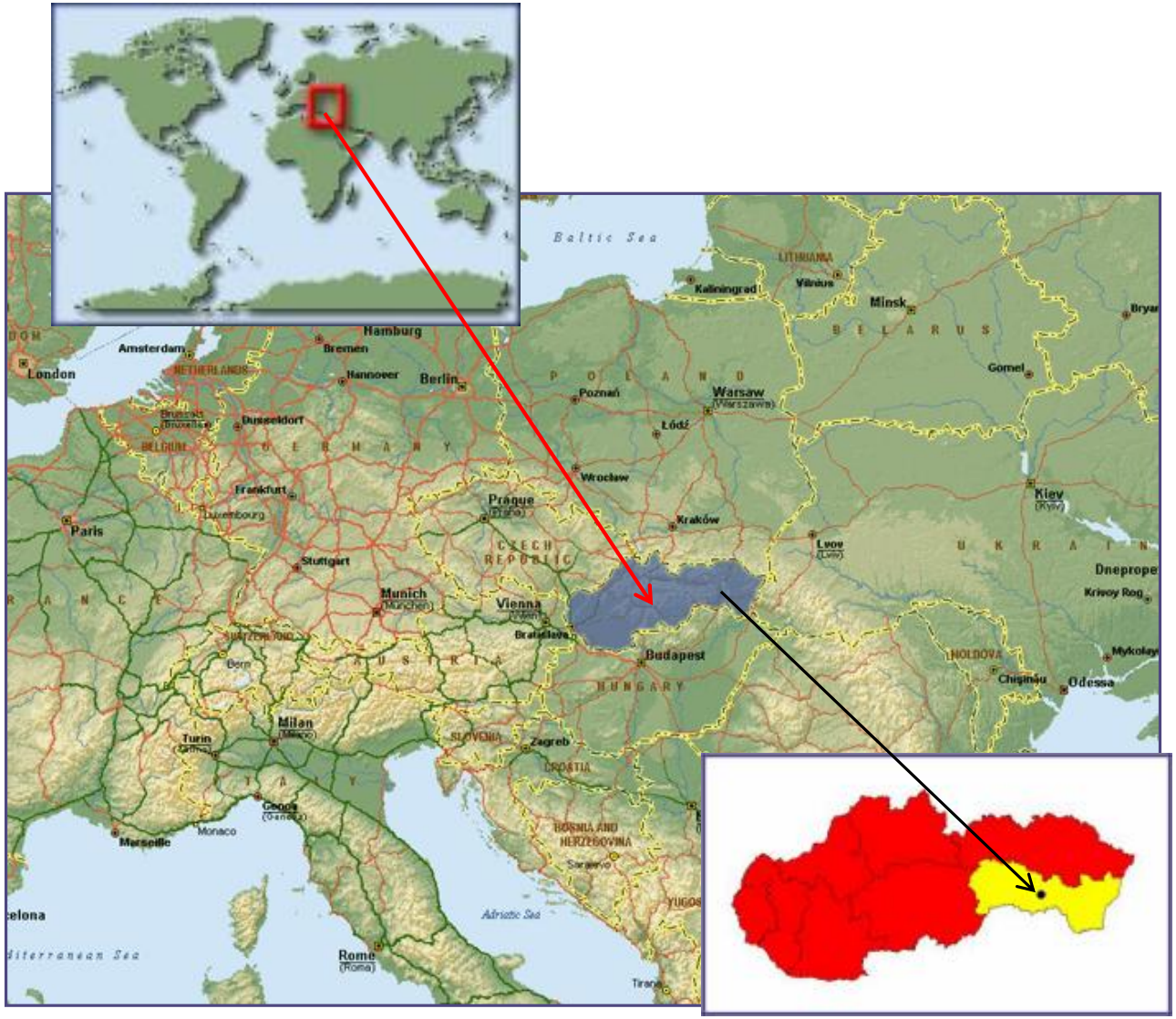
Where am I from?

Košice

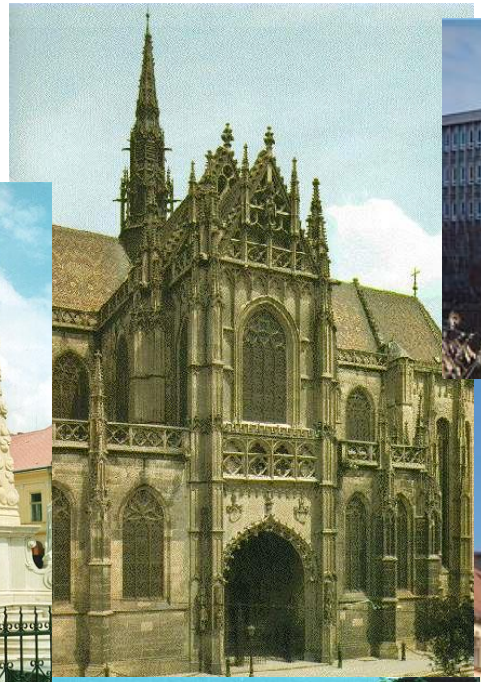
Slovak Republic

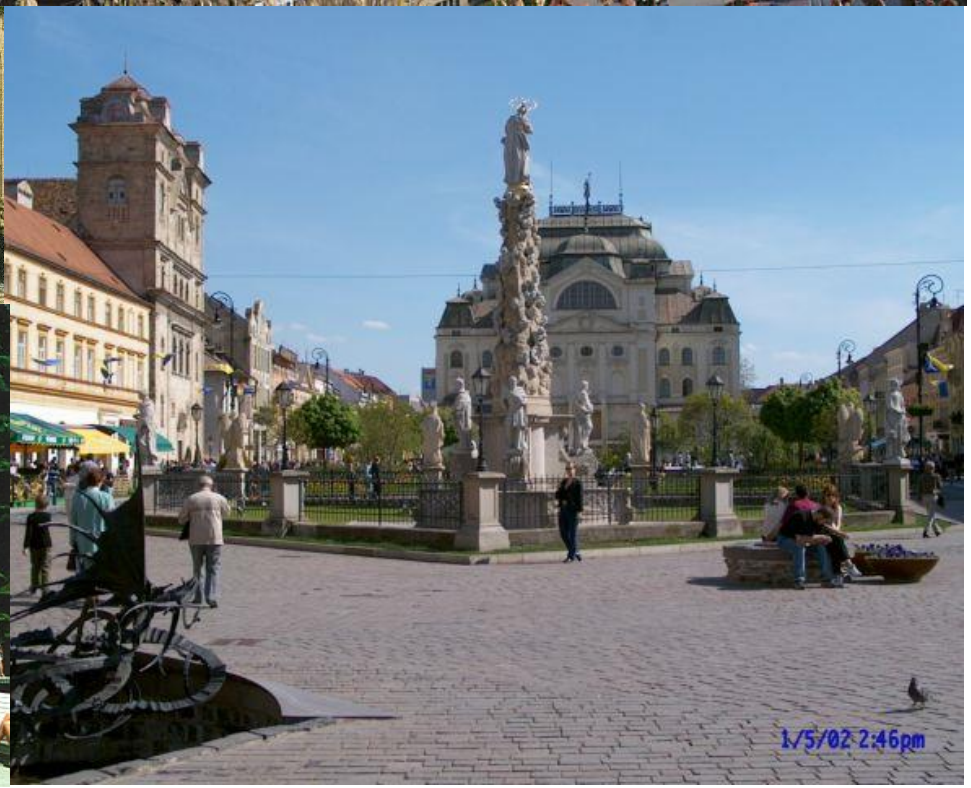
Location:

At the eastern part of Slovakia, not far from the borders with:
Hungary – 20 km
Ukraine – 80 km and
Poland - 90 km.



Košice





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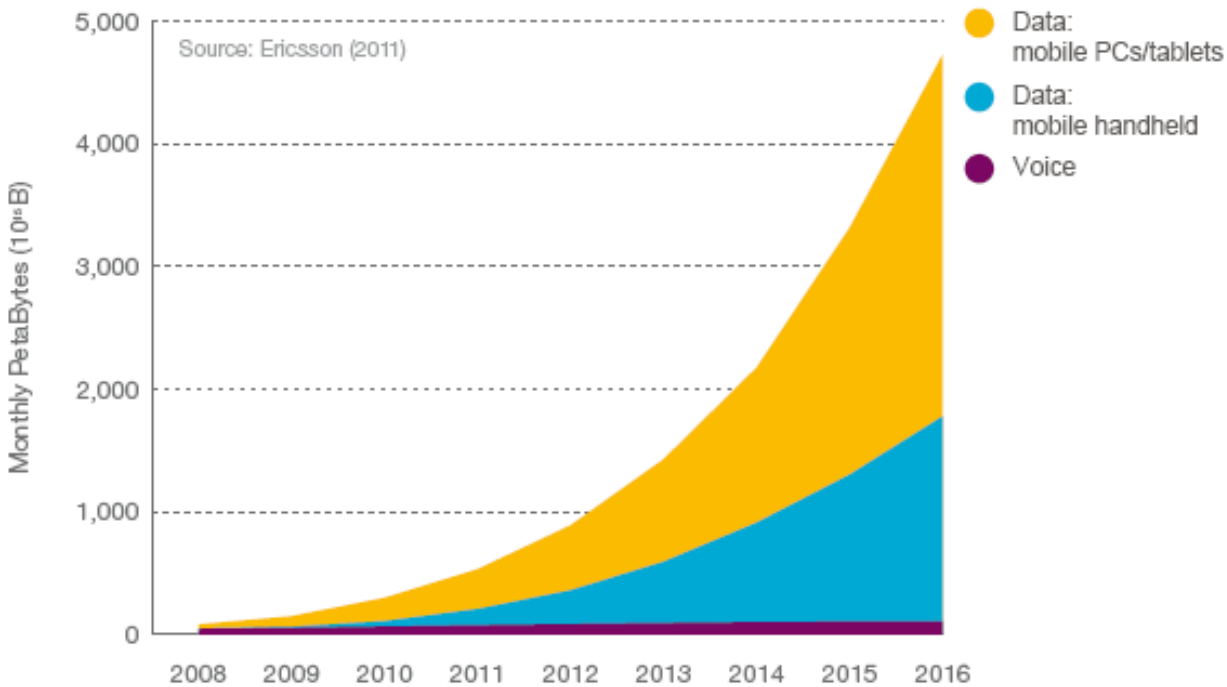
Global Mobile Data Traffic Forecast

Pentabyte=10^{15}

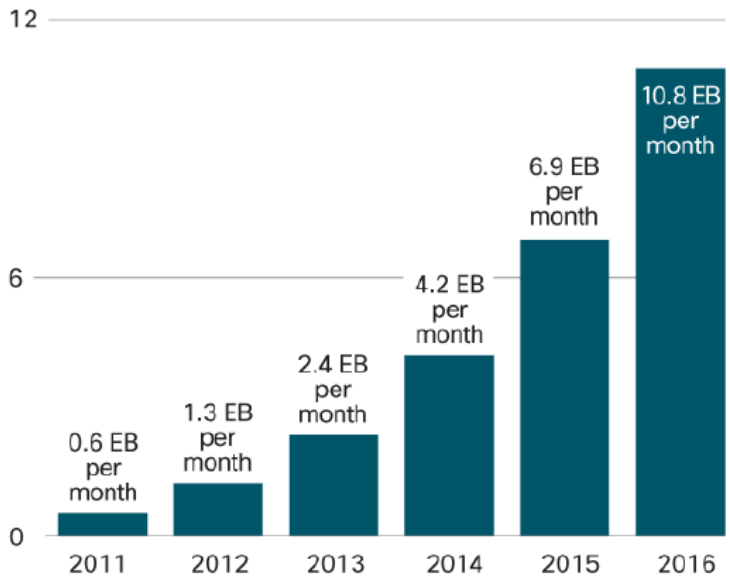


Mobile traffic: voice and data, 2008-2016

- „Traffic“ refers to aggregated traffic in mobile access networks.
- DVB-H and Mobile WiMax or WiFi traffic have not been included.
- M2M traffic not included.

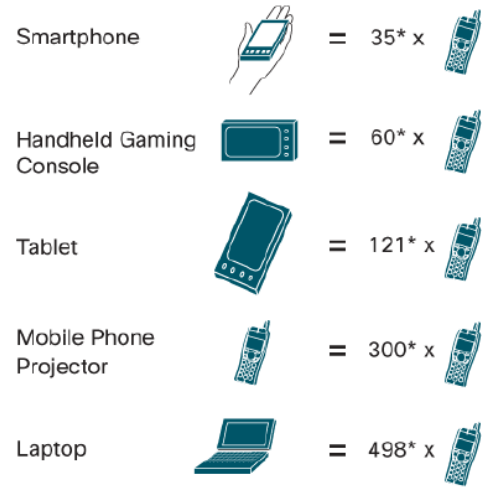
Introduction

Global Mobile Data Traffic Forecast



Source: Cisco VNI Mobile, 2012

Exabyte=10^{18}



* Monthly basic mobile phone data traffic

Source: Cisco VNI Mobile, 2012

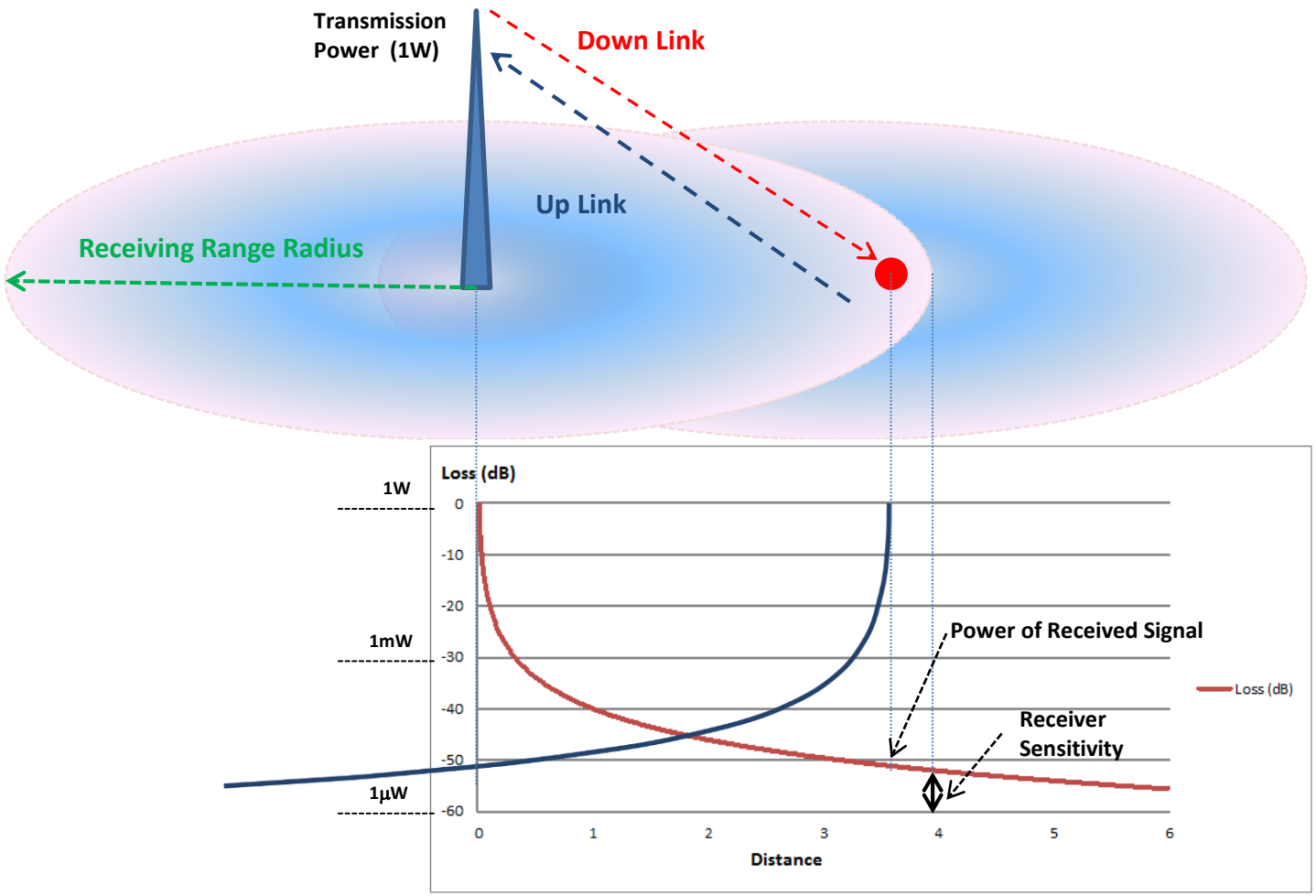
The proliferation of high-end handsets, tablets, and laptops on mobile networks is a major generator of traffic, because these devices offer the consumer content and applications not supported by previous generations of mobile devices.

A single smarthphones can generate as much traffic as 35 basic-feature phones; a tablet as much traffic as much as 121 basic-feature phones; and a single laptop can generate as much traffic as 498 basic-feature phones.

Mobile Networks in General

- Growing demand for low-cost mobile broadband connectivity is driving the development of heterogeneous cellular networks.
- A range of different radio access technologies (RATs) and WiFi will all co-exist, and macro cells will be complemented by a multitude of smaller cells, such as micro, pico and femto cells.
- Such heterogeneous systems will be significantly more complex to manage than today's networks and therefore require fully Self Organizing Networks (SON).

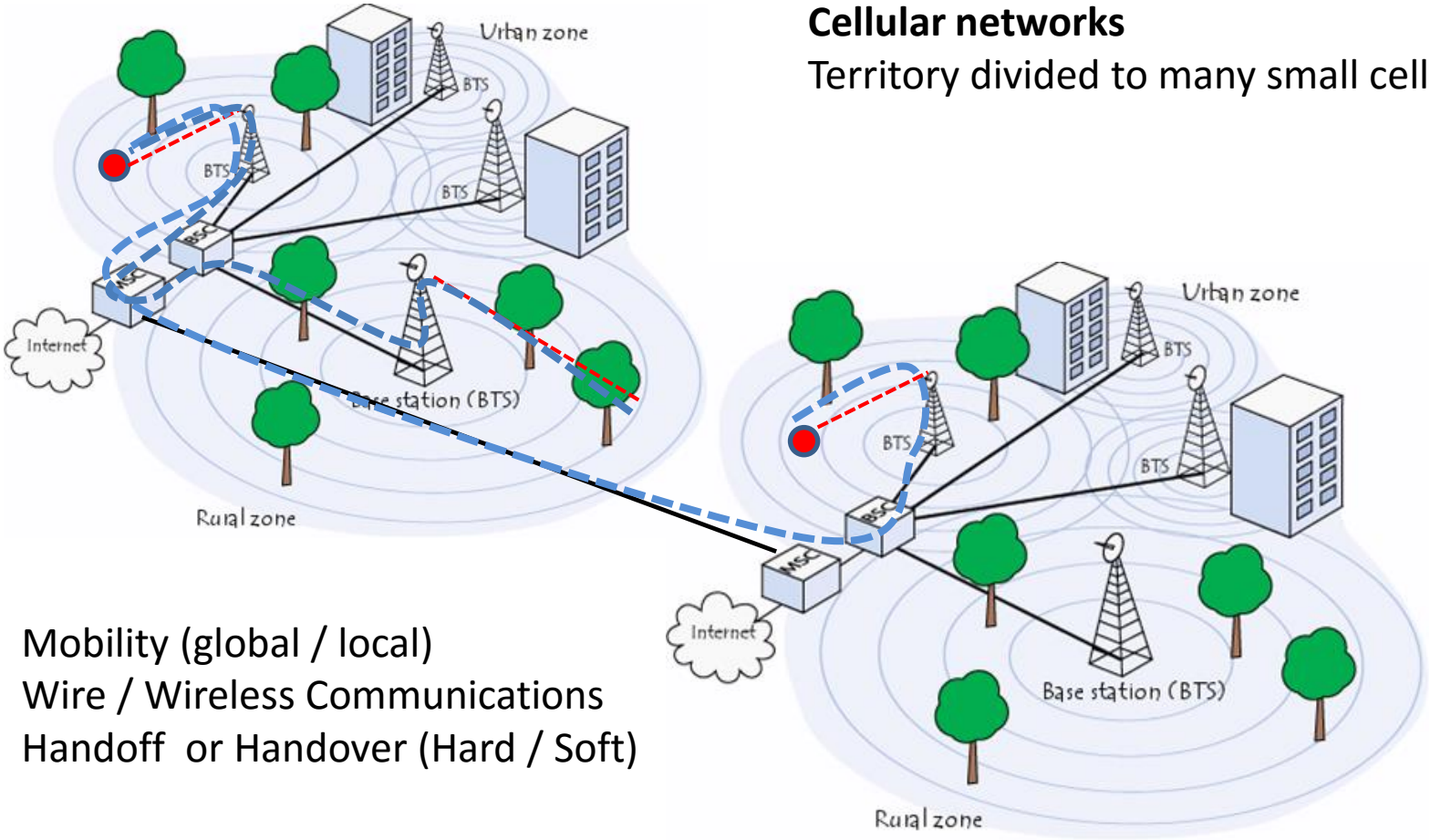
Basics of Wireless/Mobile Communications



Wireless / Infrastructured Mobile Networks

Cellular networks

Territory divided to many small cells



Mobility (global / local)

Wire / Wireless Communications

Handoff or Handover (Hard / Soft)

Wireless / Infrastructured Mobile Networks

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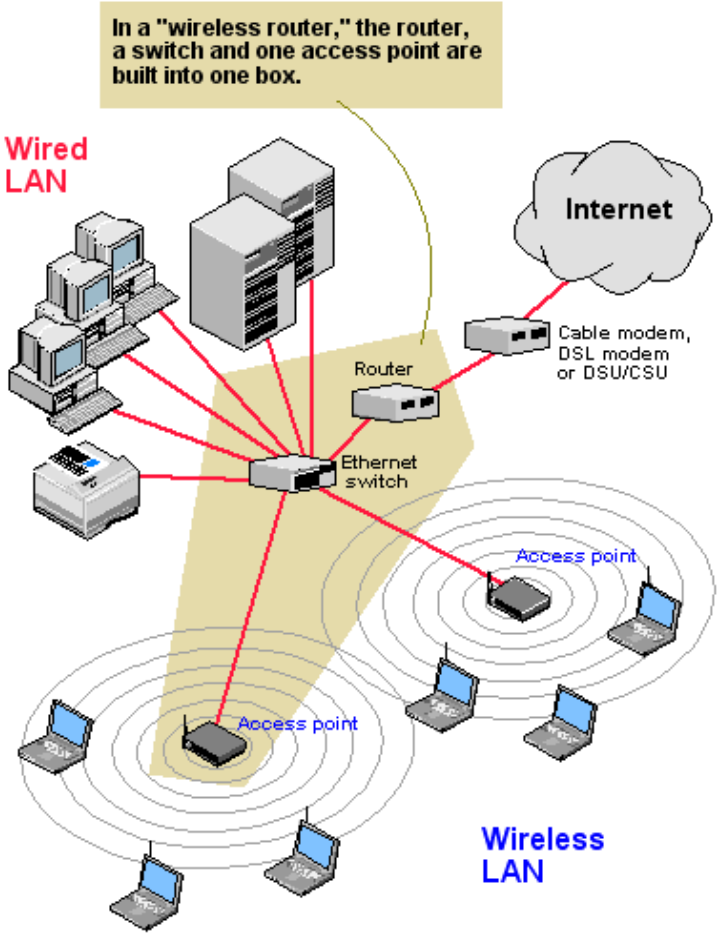


Wireless Local Area Networks
(WLAN or WiFi or IEEE802.11.x)
Local Mobility

Technology Evolution

Cellular Technology

			Frequency	Bandwidth	Data Rates
1.	Generation	NMT	400MHz	30kHz	0
2.	Generation	GSM	900MHz	200kHz	9,6kbit/s
3.	Generation	UMTS	2000MHz	5MHz	2Mbit/s
4.	Generation	LTE	800-2000MHz	2-20MHz	300/100Mbit/s
5.	Generation	?			Gbits/s

WiFi.....Now Gbits/s

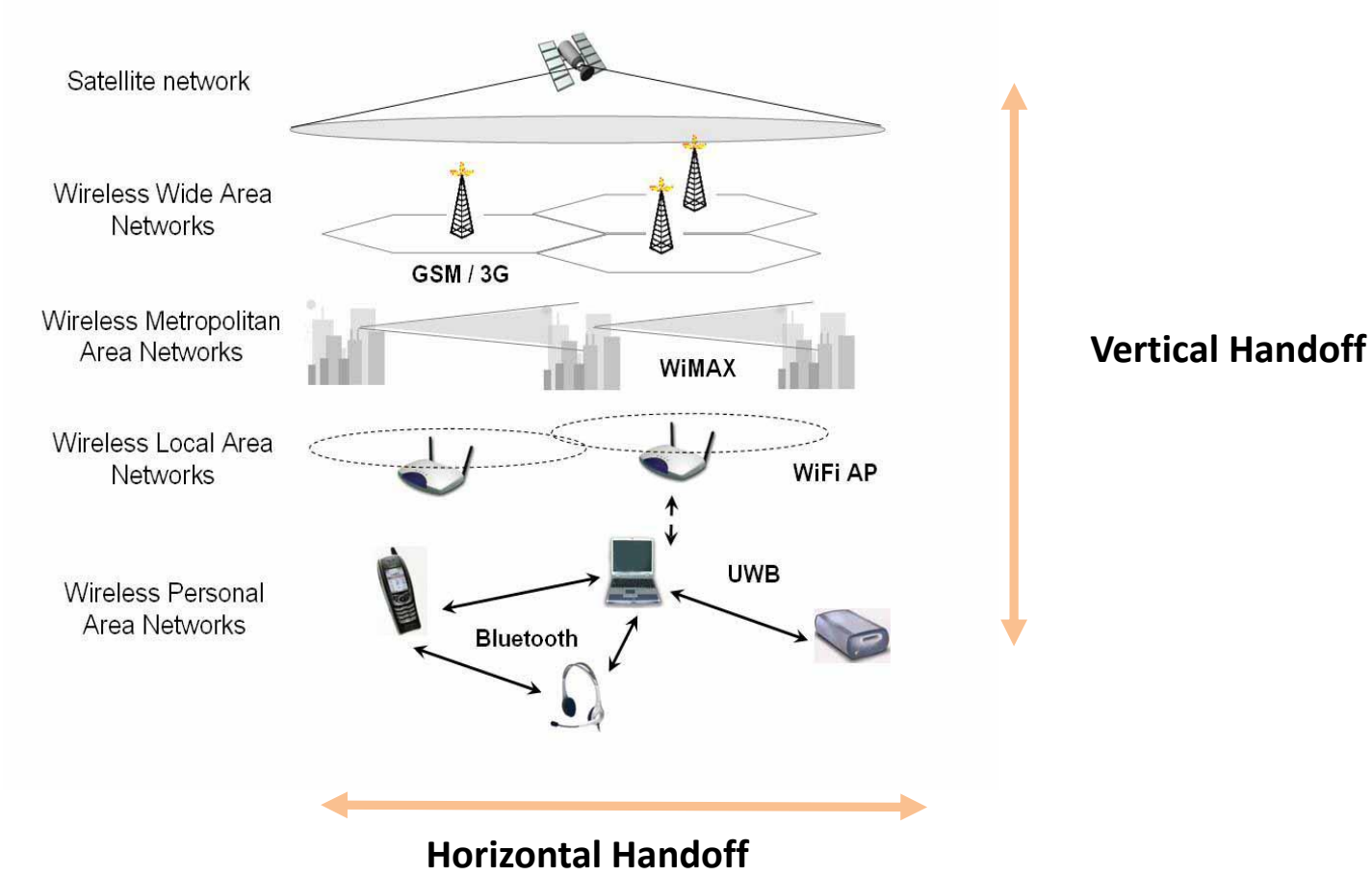
Heterogeneous Networks definition

Reference to a HetNet often indicates the use of **multiple types of access nodes** in a wireless network. A Wide Area Network can use macrocells, picocells, and/or femtocells in order to offer wireless coverage in an environment with a wide variety of wireless coverage zones, ranging from an open outdoor environment to office buildings, homes, and underground areas.

Mobile Experts defines the HetNet as a network with complex interoperation between macrocell, small cell, and in some cases WiFi network elements used together to provide a mosaic of coverage, with handoff capability between network elements.

Heterogeneous Mobile Network

Heterogeneous networks combine a range of radio access technologies.



Hierarchical Overlay Network

- Many different communications systems coexist around us
  - Ethernet, Wireless LAN, GPRS, 3G, 4G,…
- Each owns different characteristics
  - Bandwidth, delay, cost……
- Hierarchical overlay network
  - The combination of these heterogeneous networks

Vertical Handoff (VHO)

Two categories of vertical handoffs:

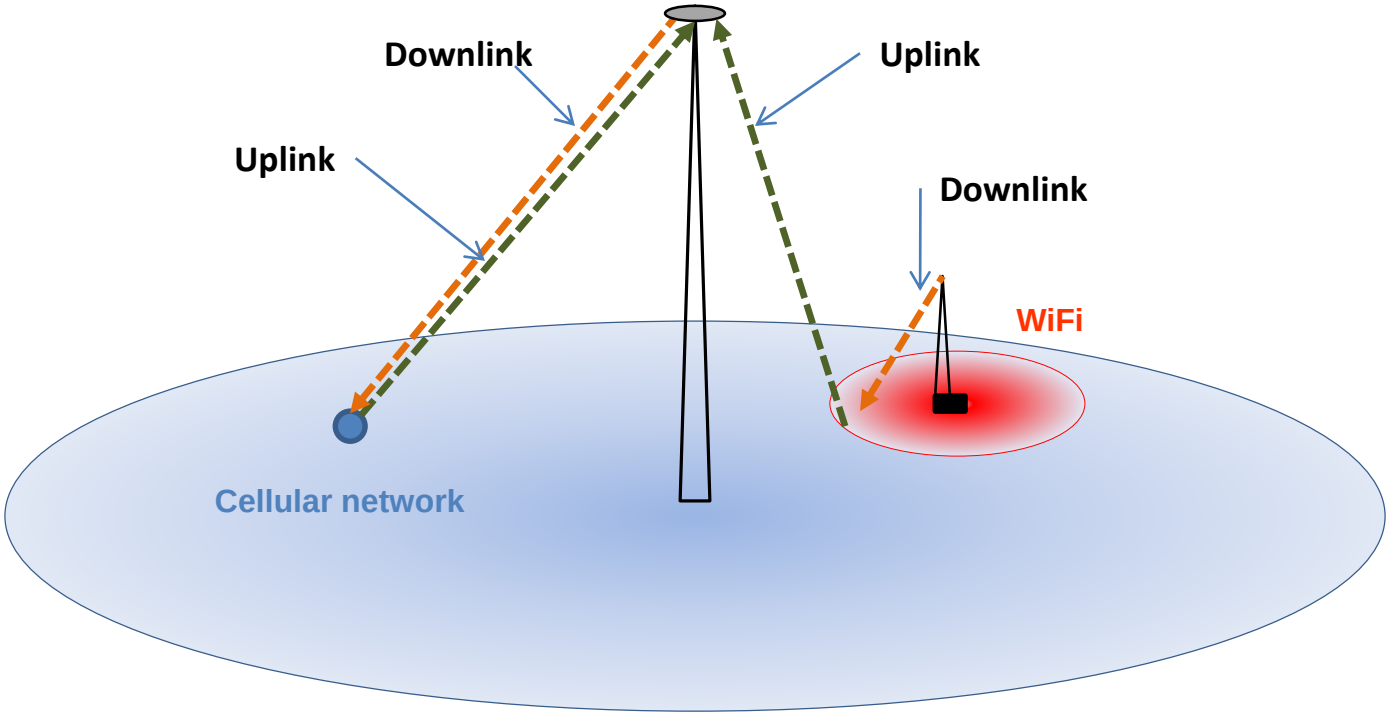
- **Upward vertical handoff** is a handoff to a network with a larger cell size, (larger size lower bandwidth connections)

- **Downward vertical handoff** is a handoff to a network with a smaller cell size

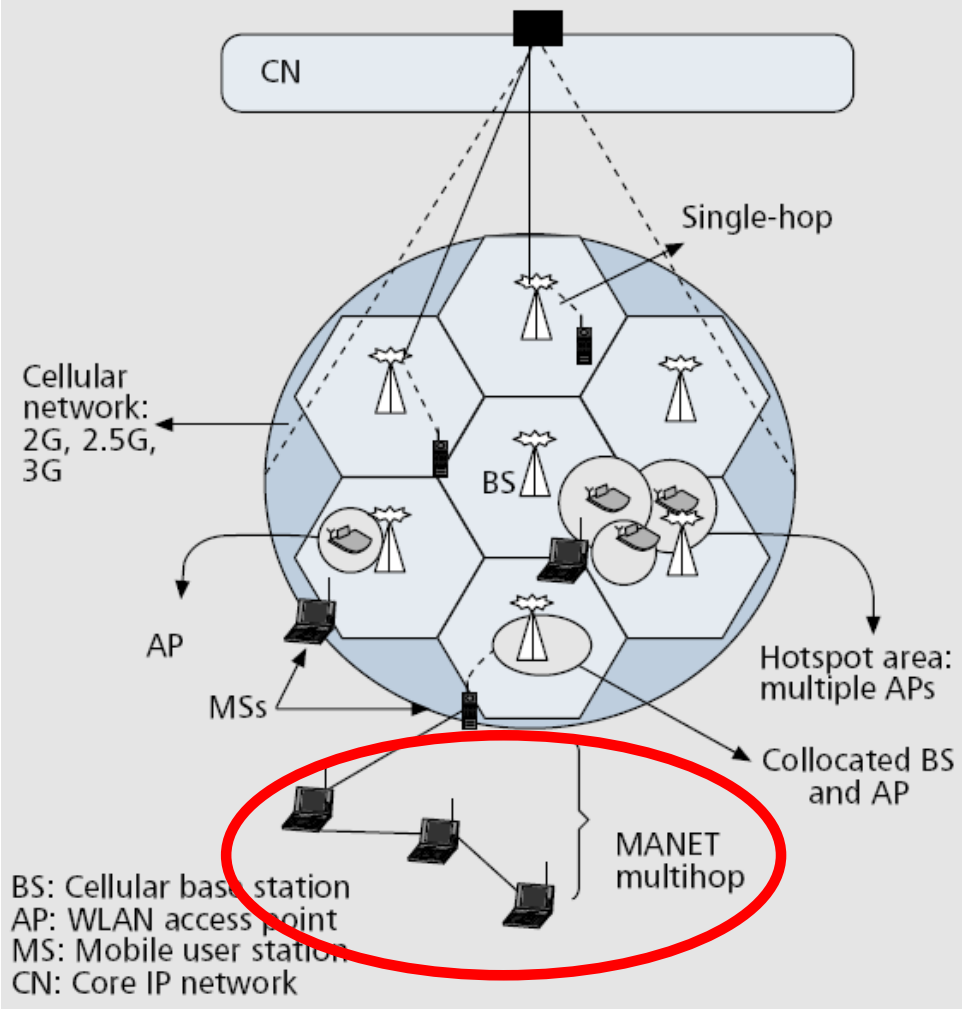
These two cases are not necessarily symmetric:

The handoff from a lower overlay (one with higher bandwidth per unit volume) to a higher overlay (one with lower bandwidth per unit volume) usually does not appear the same to a Mobile Host (MH), in terms of connectivity, as a handoff from a higher to lower overlay.

Vertical Handoff (VHO)



Heterogenous Network Architecture



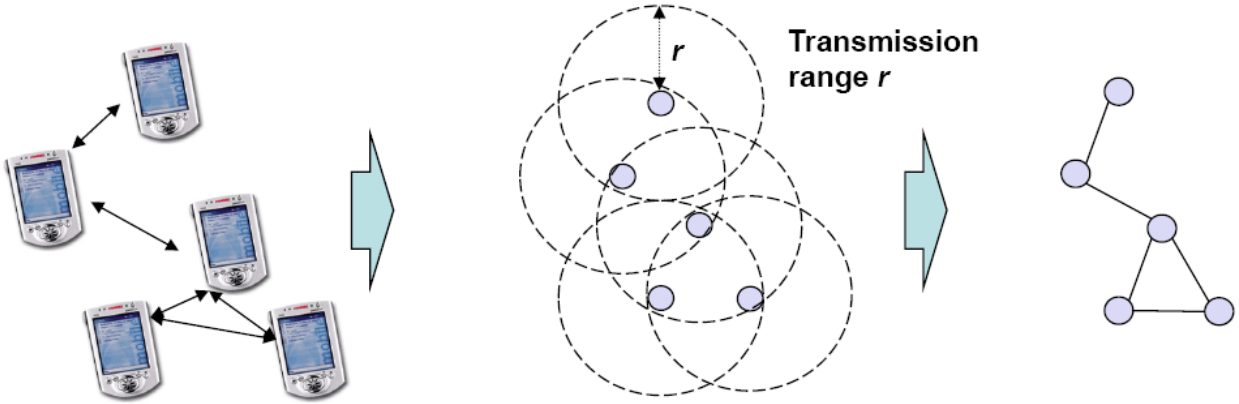
Mobile Ad-Hoc Networks (MANETs)

Definition: Infrastructureless Networks

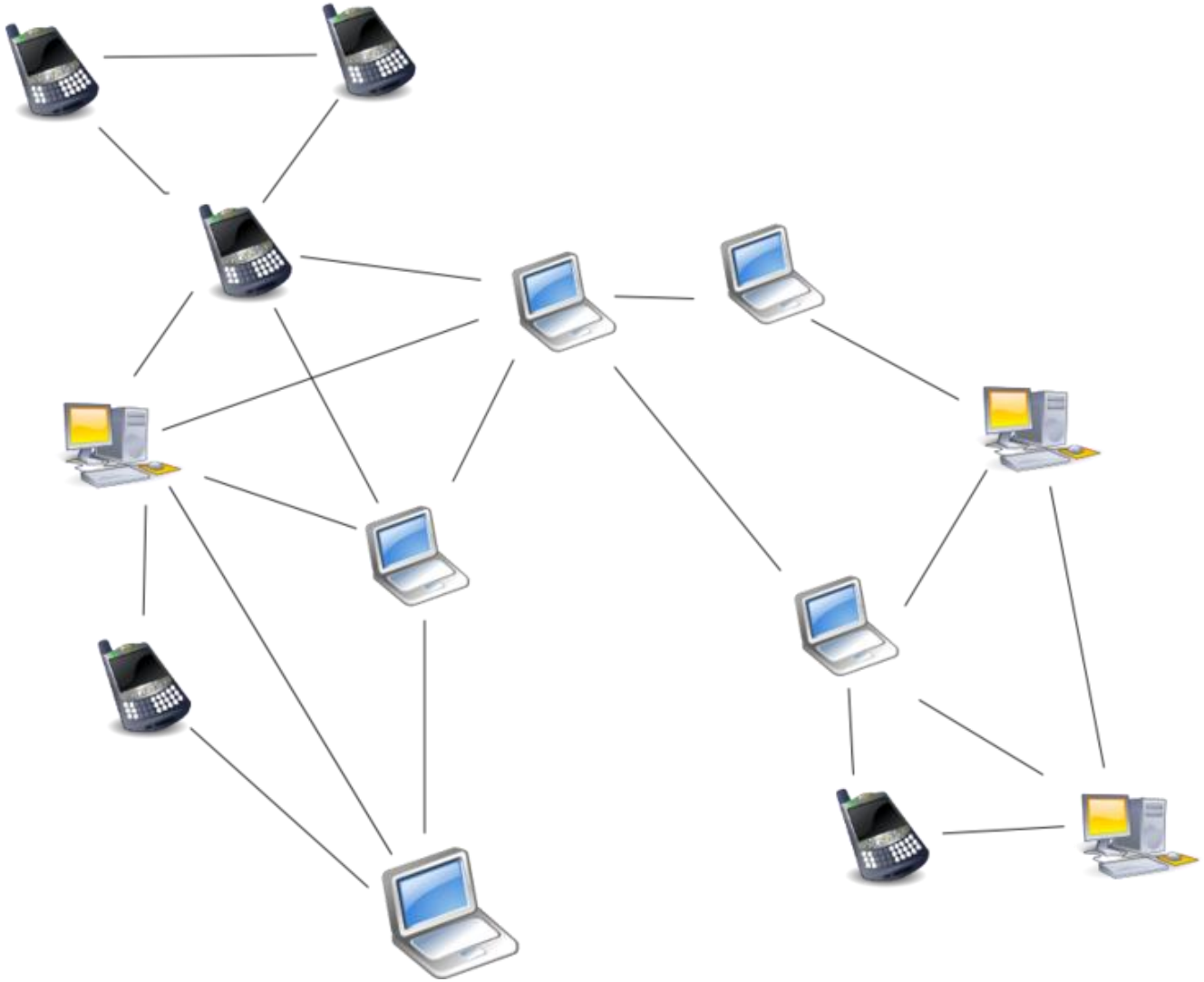
- A wireless network of mobile devices, which is structureless and self configuring.
- Within a MANET, each device will act as a router, which can cause difficulties given the unpredictable nature of the network.
- Each device is free to move independently, and frequently change its links to other devices.

Mobile Ad-Hoc Networks (MANETs)

- Spontaneous federation of wireless devices
  - No infrastructure (base station / access point), no backbone
  - Devices can be mobile
- Packet-based forwarding
  - Each device must serve as a router
  - Routes between devices can span multiple hops
- Ad hoc networks are self organizing
  - No central components



Mobile Ad-Hoc Networks (MANETs)



MANETs Advantages and Application Scenarios

- **Advantages**
  - Easy and cheap deployment
    - E.g. using 802.11 in license free ISM band (2.4 GHz)
  - Reduced transmission power
  - Robust to component failures
- **Application: where is no access to infrastructure**
  - Military applications
    - Groups of soldiers, tanks, planes...
  - Civil applications
    - Conferences, exhibitions, meetings, lectures, gaming, …
  - Car-to-car-communication, network for taxis, police, …
  - Extension of cellular networks
- **Disaster recovery**
  - After crash of infrastructure (e.g. telephone network after earthquake)
  - Rescue (e.g. after avalanche)

MANETs Properties

- **Highly dynamic topology**
  - Mobility of devices
  - Changing of quality of wireless channel (fading)
  - Partitioning and merging of ad hoc networks possible
- **Asymmetric / unidirectional links**
  - Different quality in both directions
- **Wireless medium is semi-broadcast medium**
  - Hidden and exposed terminals
- **Limited battery capacity of mobile devices**
  - Additional battery drain due to (e.g.) routing functionality
- **Limited bandwidth**
  - Additional bandwidth required for routing and MAC functionality
- **Time synchronization difficult**
  - Problem for low power modes (e.g. sleeping periodically)
- **Security mechanism hard to apply**
  - Every devices must be able to forward packets → no encryption of routing headers

MANET Routing Protocols

Routing Protocols - added into MAC Layer of OSI

Routing Protocols are responsible for:

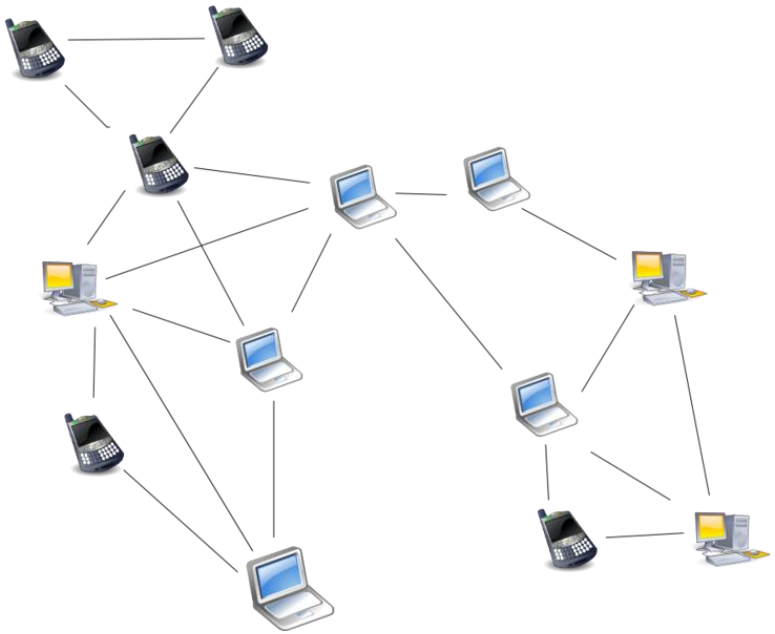
1. Path / paths finding from sorce node S to destination node D
2. Path / paths maintenace (mobility of nodes->topology (path) changing)
3. Data (packet) transfer from S to D

Unicast Routing Protocols

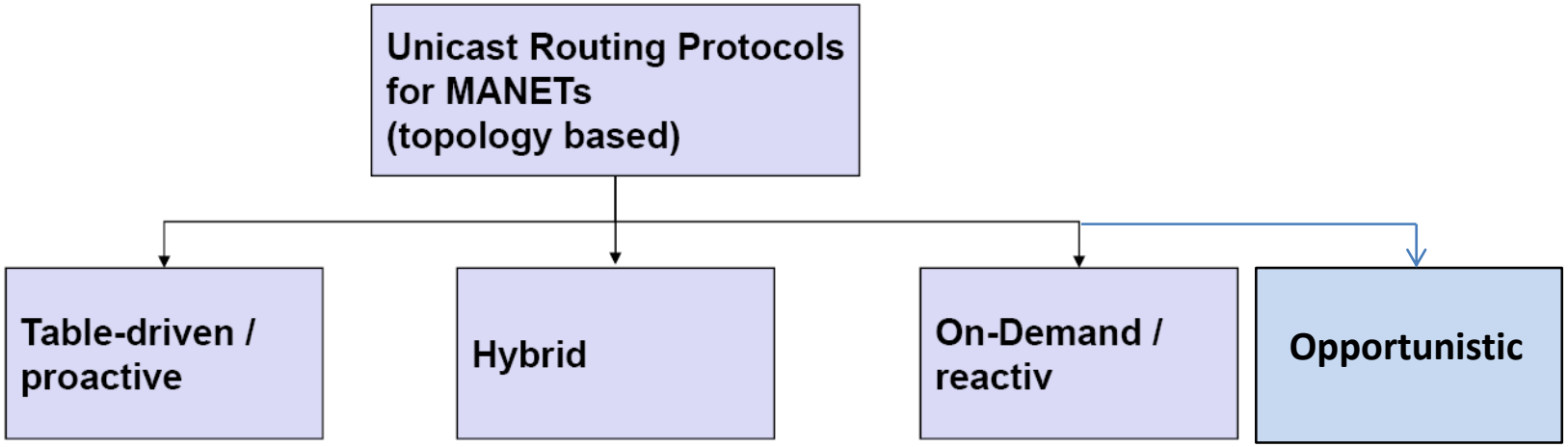
Only one path is using

Multicast Routing Protocols

Two or more paths are using



Classification of Routing Protocols



- **OLSR**
- *LANMAR*
- *TBRPF*
- *FSR*
- *STAR*
- *DSDV*
- ...

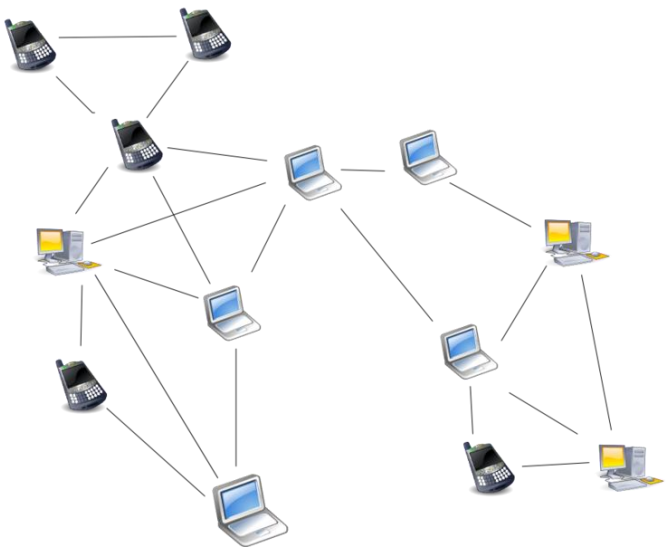
- **ZRP**
- ...

- **AODV**
- **DYMO**
- *DSR*
- *TORA*
- ...

Not covered:
Position-based routing protocols

Ad Hoc Routing Protocols: Overview

- **Flooding of data packet**
  - Easy "protocol": each node forwards every data packet exactly once
  - High overhead
- **Proactive routing (table-driven)**
  - Continuous maintenance of all possible routes
  - Routes are always available
  - High control overhead
- **Reactive routing (on-demand)**
  - Routes are constructed when required (route discovery)
  - Delay for first packet until construction has finished
  - Control overhead depends on number of connections
- **Hybrid routing**
  - Mix of proactive and reactive routing
- **Opportunistic routing (Delay Tolerant Networks)**
- **There is no "one-size-fits-all" routing protocol for MANET**
  - Best protocol depends on scenario



Proactive Routing Protocols

Nodes constantly construct and maintain routes to all other nodes

- Distance Vector Routing
  - Based on Bellman-Ford algorithm (computes single-source shortest paths in a weighted digraph)
  - Each nodes computes for each destination
    - Next hop on the route
    - Length of the route
  - These information are sent to all neighbors periodically
  - Examples
    - Wired networks: Routing Information Protocol (RIP)
    - Ad hoc networks: Destination-Sequenced Distance Vector Protocol (DSDV)
- Link State Routing
  - Each nodes sends periodically
    - Its own link state
    - The link state received by the neighbors
  - Thus, each node knows entire network topology
  - Computation of routes using Dijkstra's algorithm (solves the single-source shortest path problem for a graph with nonnegative edge path costs)
  - Examples
    - Wired networks: Open Shortest Path First (OSPF)
    - Ad hoc networks: Optimized Link State Routing (OLSR)

Reactive Routing Protocols

- **Basic principle**
  - Node knows only routes that it is currently using
  - No periodic route maintenance
- **Tasks of a reactive routing protocol**
  - **Route discovery**
    - Triggered if route to destination is unknown
  - **Route maintenance**
    - Only for routes that are currently in use
- **Comparison to proactive protocols**
  - **Advantages**
    - No unnecessary construction & maintenance of routes
    - No periodic messages → lower resource consumption
  - **Disadvantages**
    - Delay at the beginning of communication due to route discovery
    - Control overhead depends on number of connections and mobility

Ad Hoc On-Demand Distance Vector Routing (AODV)

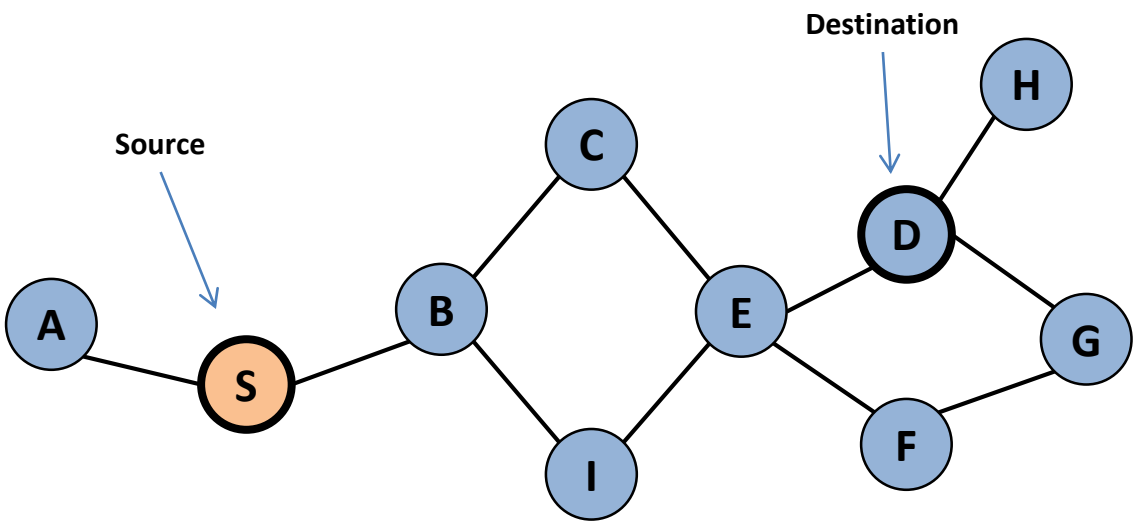
(Reactive)

Route discovery

- Sender S floods ***route request (RREQ)*** for destination D
  - RREQ contains source and destination address
- Node that forward RREQ save pairs of source address and nodes from which the RREQ was received
  - Construction of ***reverse path*** to sender S
  - Only works for bidirectional links!
- When RREQ reaches destination D a ***route reply (RREP)*** is generated
  - RREP contains destination and source address
- RREP is forwarded towards S on reverse path
  - Construction of ***forward path*** to destination D
- Forward and reverse path are used for forwarding data packets
  - If route from S to D is established, we have automatically a route from D to S

AODV: Flooding of RREQs I

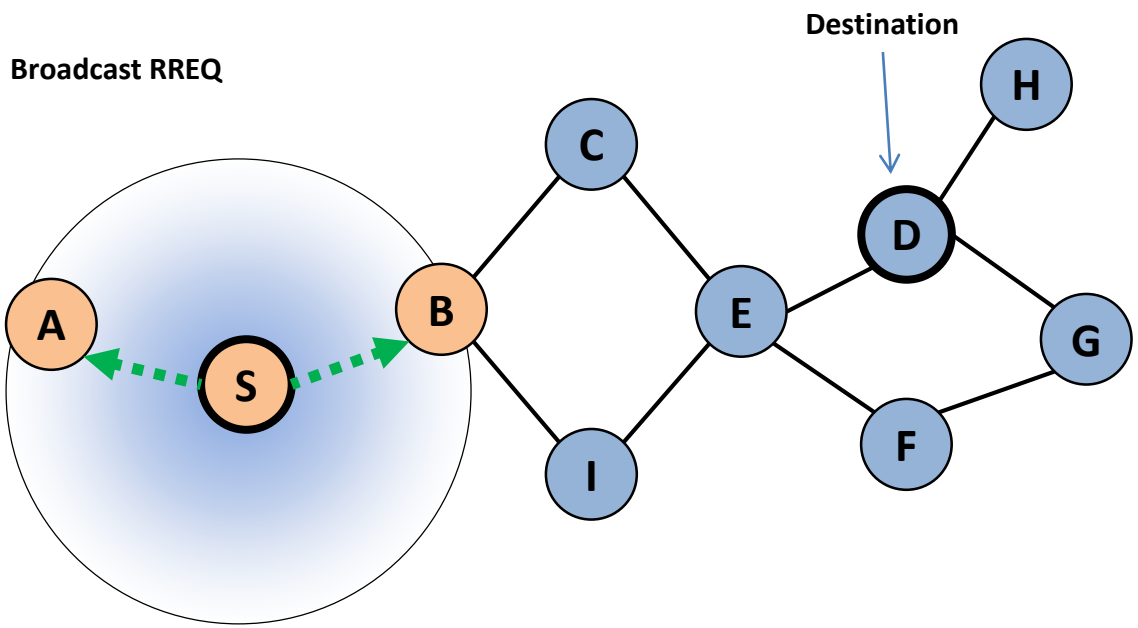
Route discovery from S to D:



Nodes that have already received RREQ

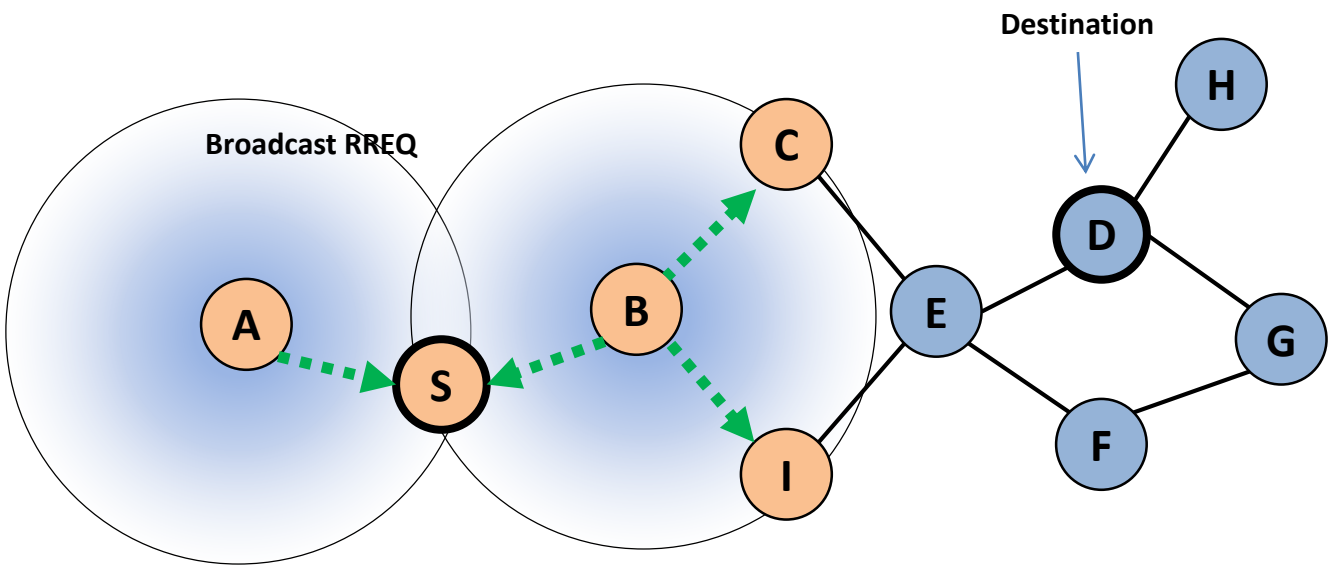
Nodes in mutual transmission range (bidirectional links)

AODV: Flooding of RREQs II



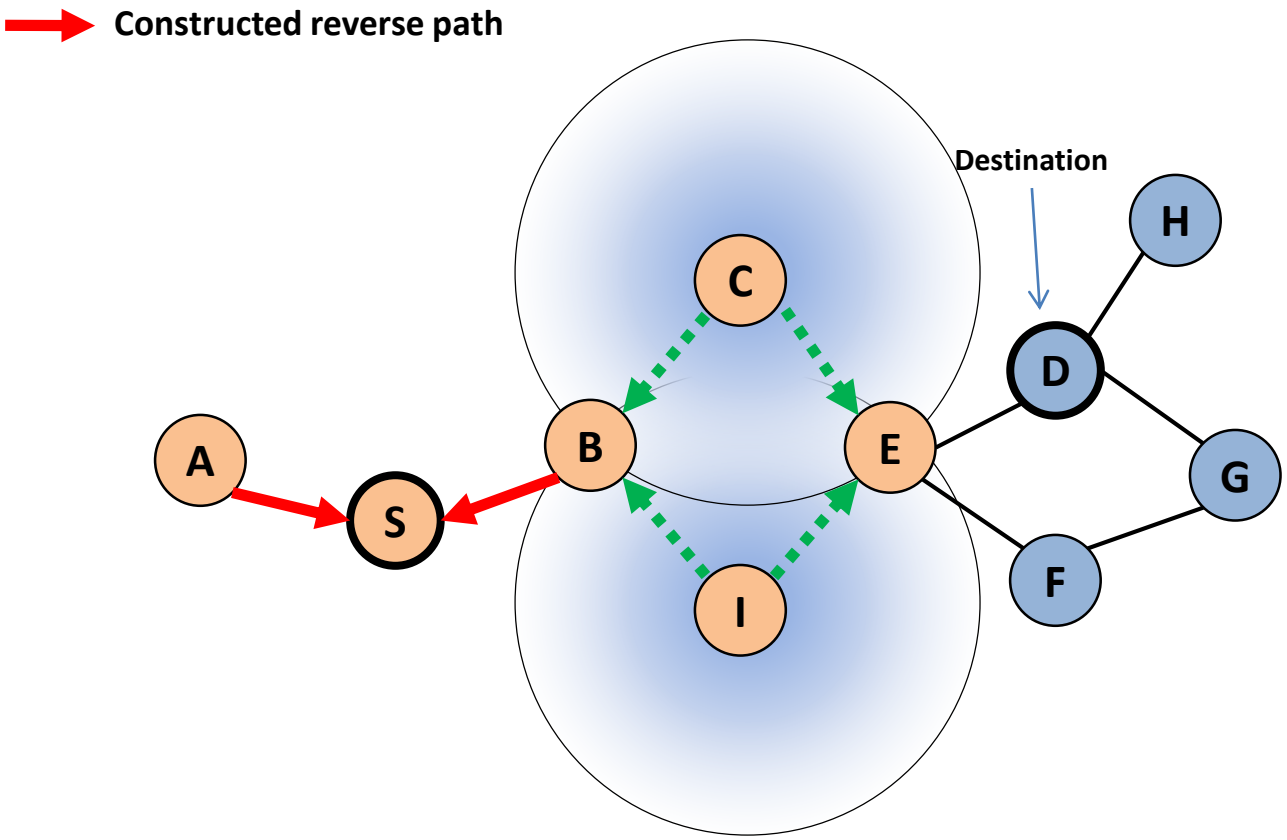
RREQ is transmitted by broadcast – Received by all nodes in transmission range

AODV: Flooding of RREQs III



Every node that receives RREQ forwards it by broadcast – Of course S does not forward its own RREQ

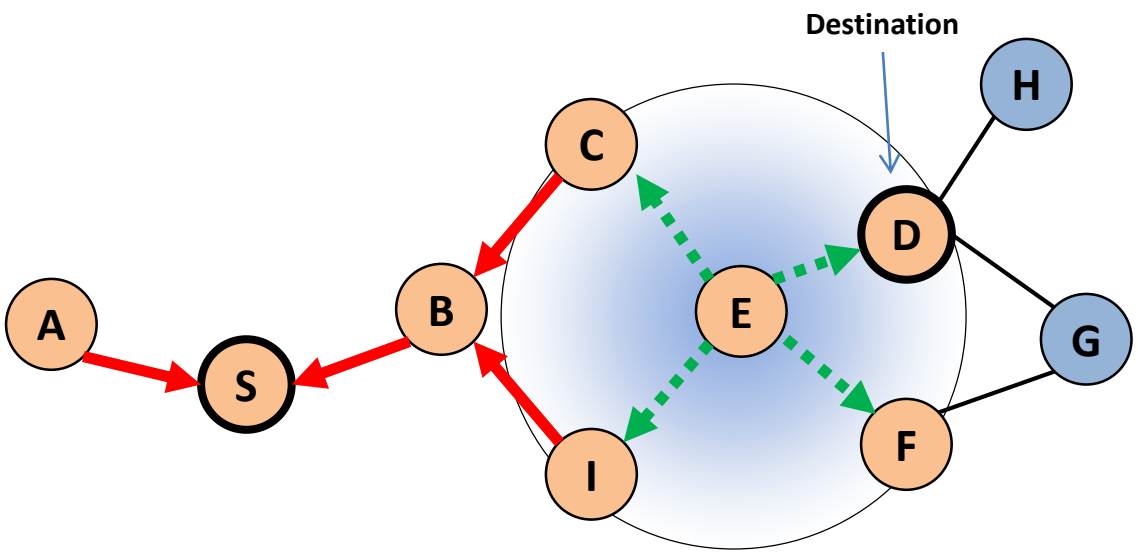
AODV: Flooding of RREQs IV



Nodes remember "from where" the RREQ was received
– If multiple RREQ are received the one with the lowest hop count isselected
– Reverse path is constructed

AODV: Flooding of RREQs V

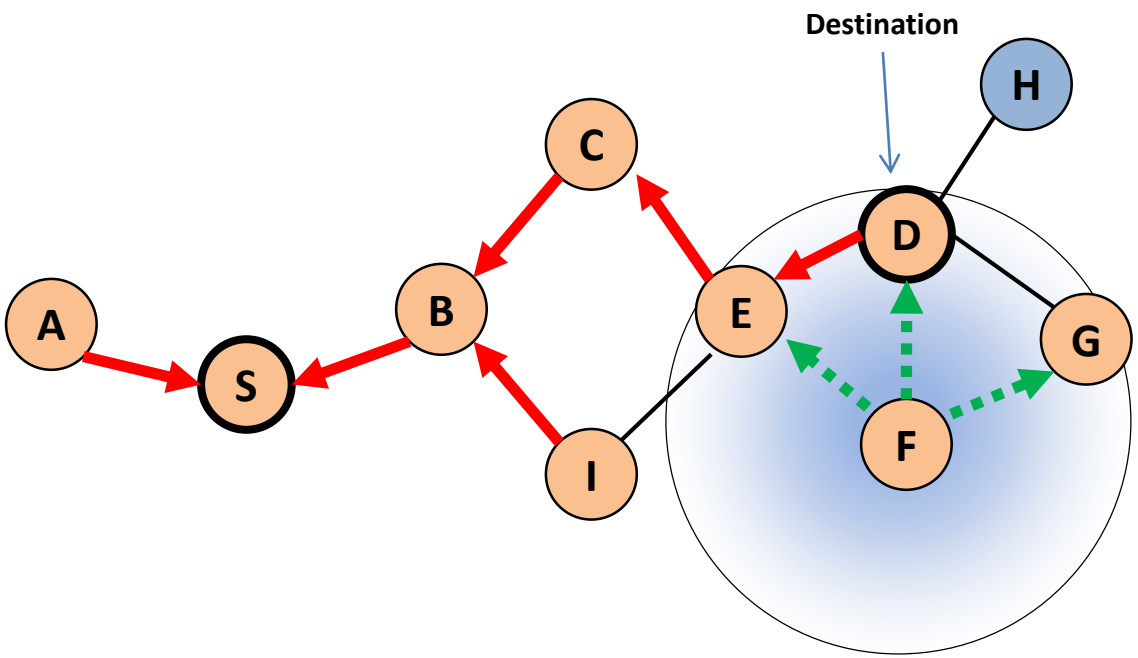
Constructed reverse path



Duplicate RREQ are detected by sequence numbers and discarded
– Requires state maintenance

AODV: Flooding of RREQs VI

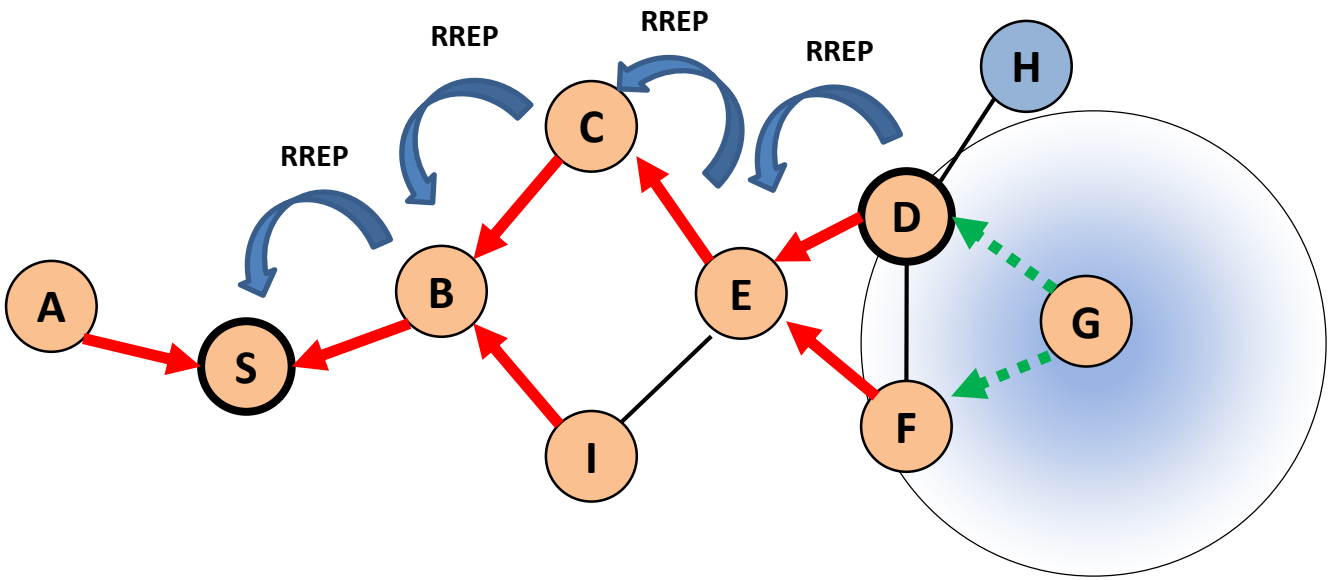
Constructed reverse path



Destination D has received the RREQ
– Complete reverse path from D to S has been constructed

AODV: Flooding of RREQs VII

Constructed reverse path

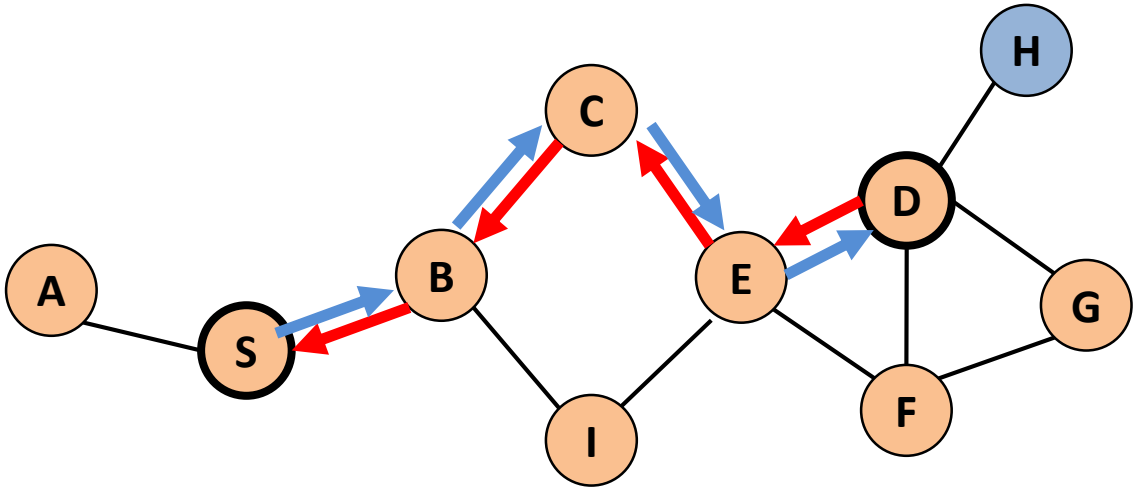


Node D replies with RREP to S using reverse path
– Each hop on reverse path can be directly addressed (no broadcast)

AODV: Flooding of RREQs VIII

Constructed reverse path

Constructed forward path

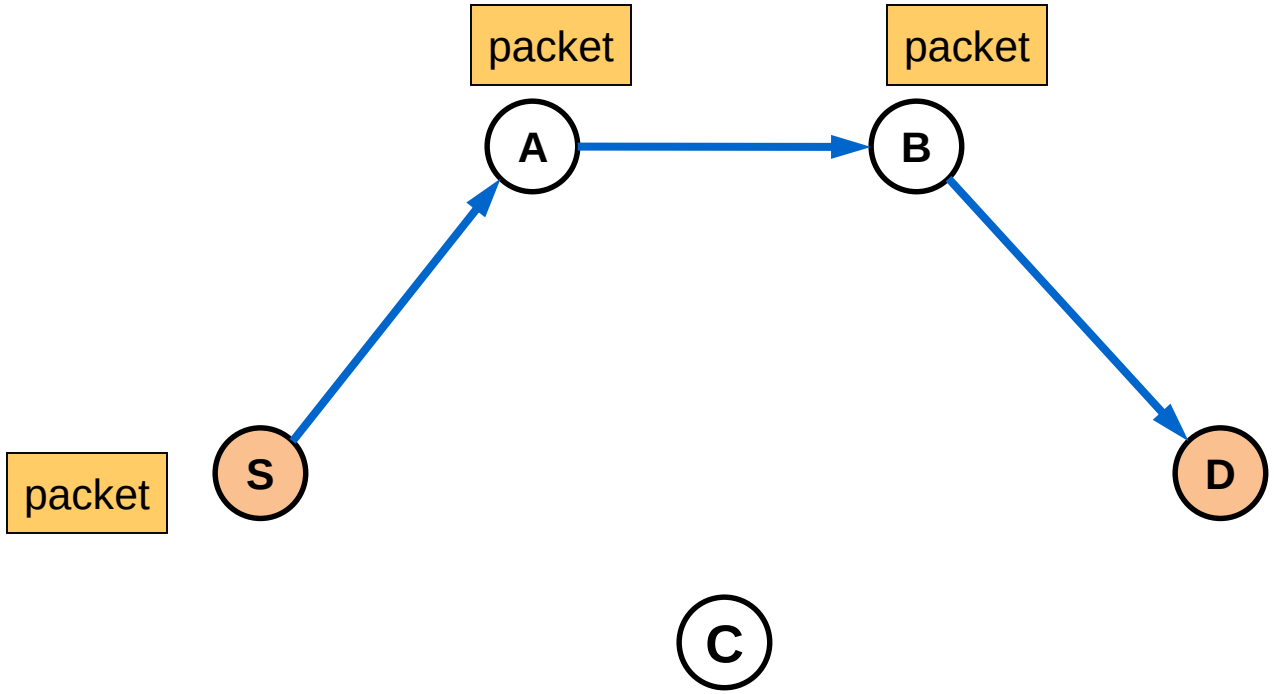


- Forward path from S to D is constructed
  - Can be used for data transport between S and D (bidirectional)
- Unused reverse path entries will be discarded after timeout

Opportunistic networks (Delay Tolerant Networks)

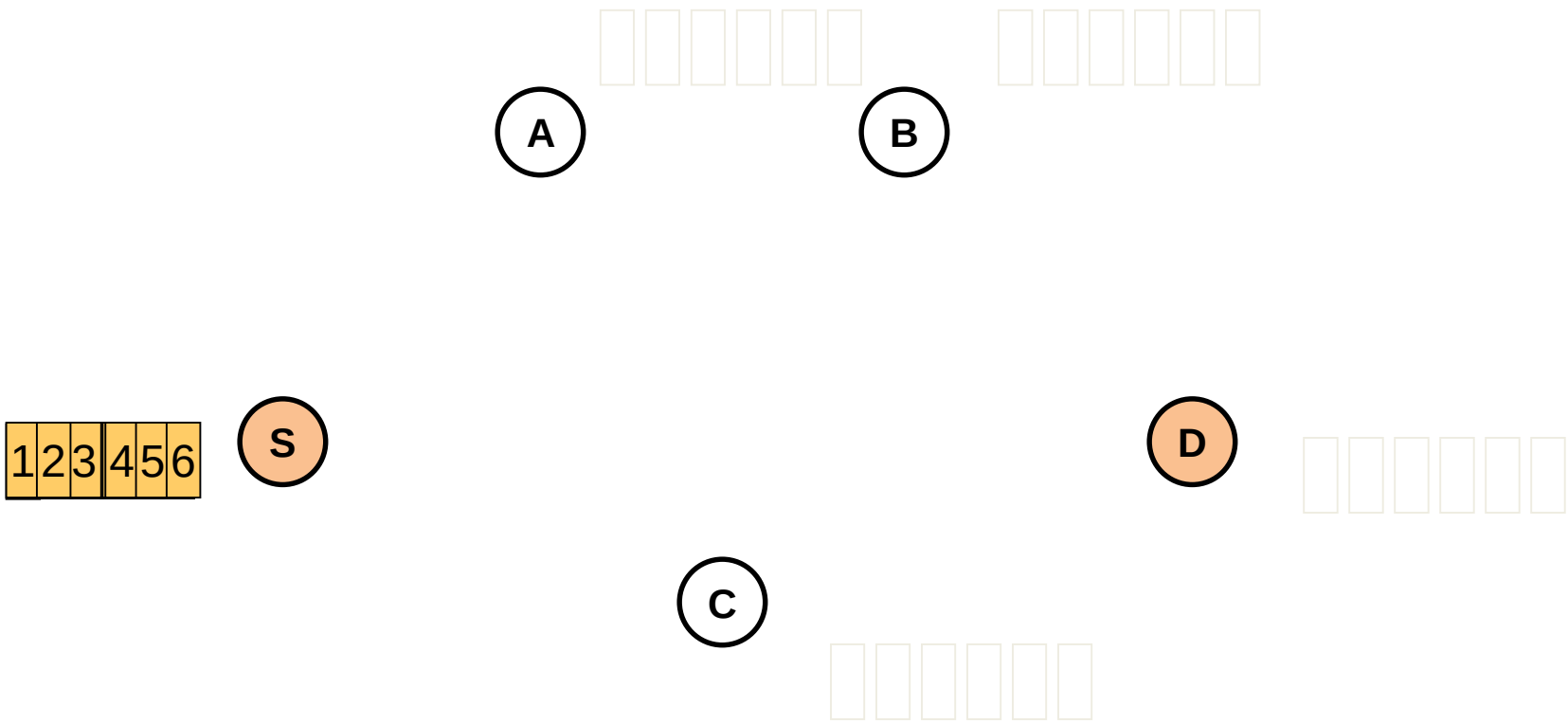
- Clearly, multihop communication can involve multiple relays, and in such a case the step above is repeated until the packet is received at the destination.
- For more than a decade, multihop forwarding has been considered a suitable strategy for networking in ad hoc networks, since it fits well in scenarios characterized by dynamic topology with no available infrastructure or central management.
- However, the main issue with multihop routing is that it tries to fortify the scenario so that it ***behaves like a wired network*** instead of exploiting the key features of wireless technology:
  - ***the broadcasting and***
  - ***the unreliability***.

Initial Approach: Traditional Routing



- Identify a route / path, then forward data/packets over links
- Abstract radio to look like a wired link

Radios aren't wires



- Every packet is broadcast
- Reception is probabilistic

Opportunistic Routing Challenges

The major challenge in opportunistic routing is to maximize the routing progress of each data transmission toward the destination without causing duplicate transmissions or incurring significant coordination overhead.

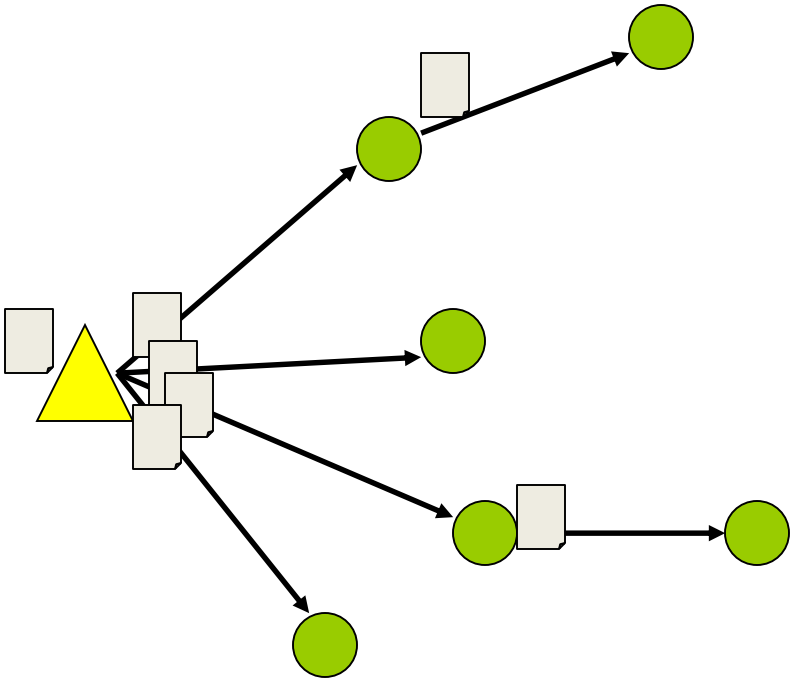
In order to achieve the potential benefits of opportunistic routing and avoid the above-mentioned problems, an effective protocol should implement the following tasks according to a distribute strategy:

1. Broadcast packet forwarding
2. Candidate selection
3. Forwarder election
4. Forwarding responsibility transfer
5. Duplicate transmission avoidance.

Opportunistic Routing Models

- Flooding based protocols
  - Epidemic, Erasure coding
- Knowledge based routing
  - Oracle, Message Ferrying, Practical routing
- Probabilistic routing
  - PROPHET, RPLM, MaxProp , MobySpace, ExOR

Flooding based routing



Flooding is a simple routing algorithm in which every incoming packet is sent through every outgoing link.

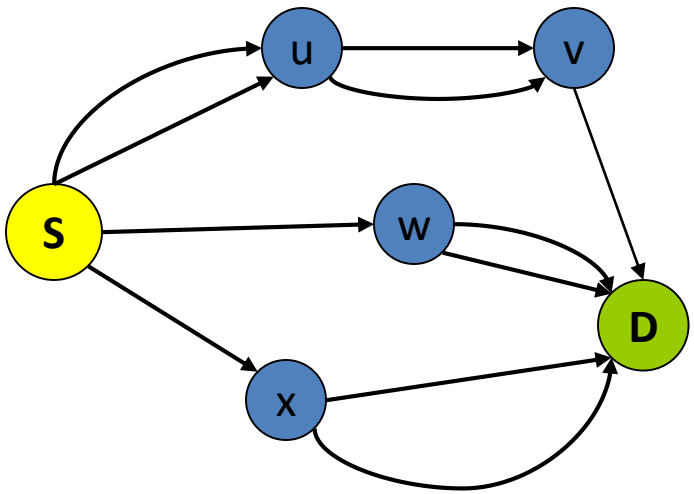
There are several variants of flooding algorithm. Most work roughly as follows:

- Each node acts as both a transmitter and a receiver.
- Each node tries to forward every message to every one of its neighbors except the source node.

This results in every message eventually being delivered to all reachable parts of the network.

Knowledge based routing

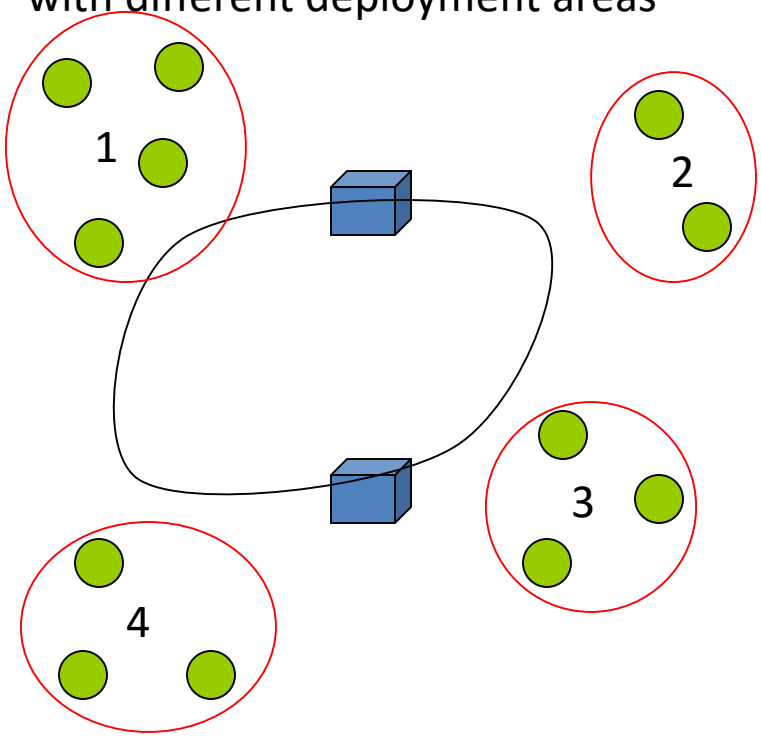
Each edge is a contact meaning an opportunity to transfer data.



- An oracle which provides topology info.
  - Contacts, buffer constraints, traffic demands…
- Partial topology info.
  - Message ferrying
- Using history to predict future topology.
  - Practical routing

Routing with partial knowledge

Message ferrying: Sparse MANETs with different deployment areas

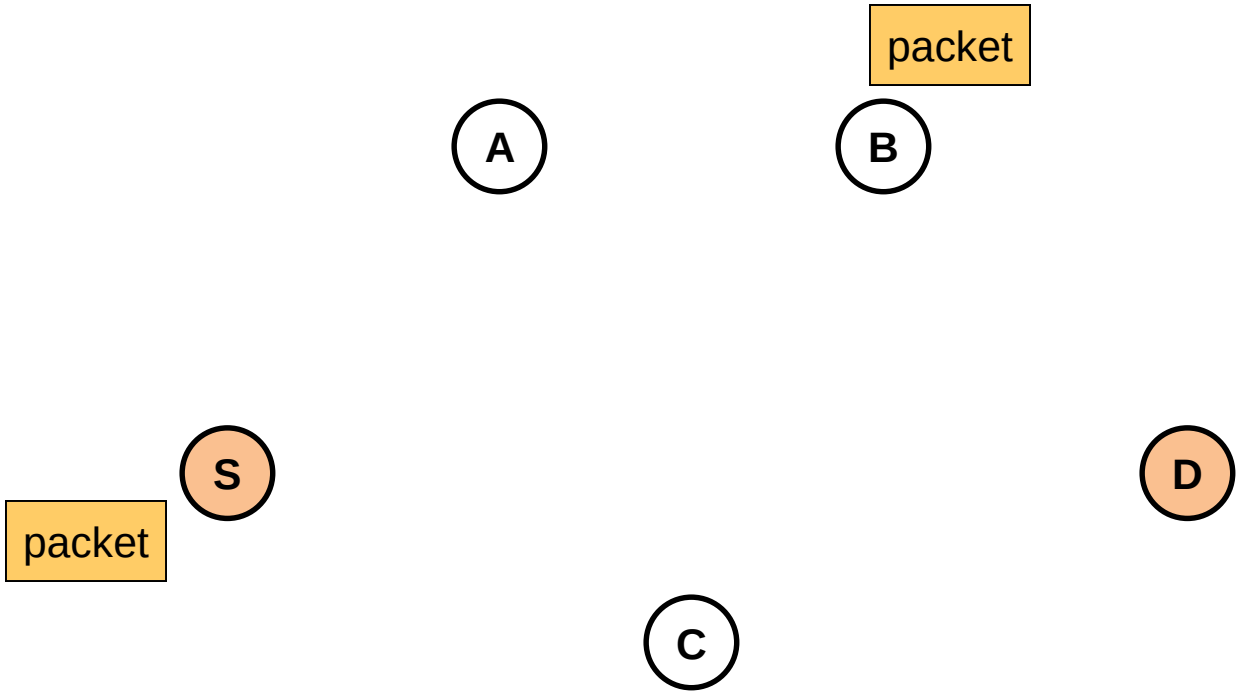


Scalability: How increasing number of mobile nodes affects number of ferries?

- Message ferrying
  - Ferries broadcast their situation.
  - Ferry route design to minimize drops.
- Practical routing
  - Instead of contact schedules uses contact history.
  - Per-contact routing vs. per-hop routing.

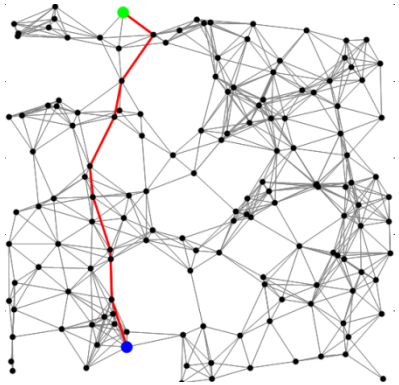
Probabilistic routing

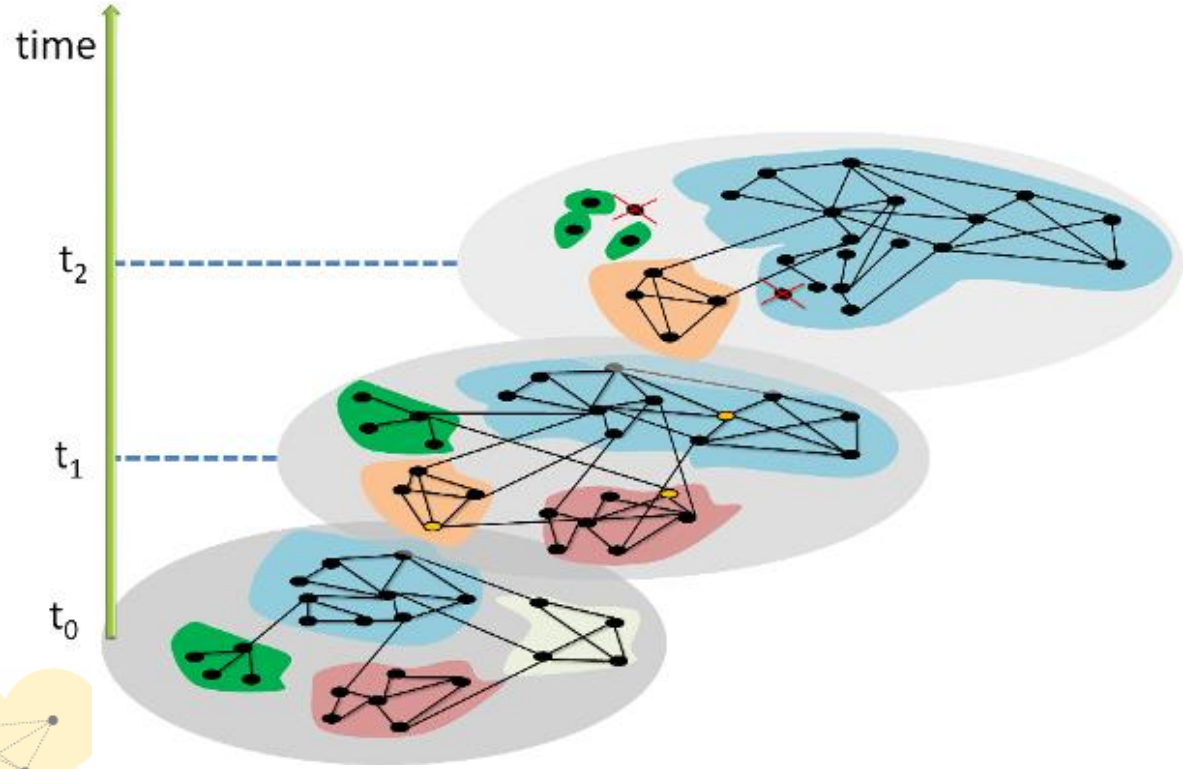
ExOR: exploiting probabilistic broadcast

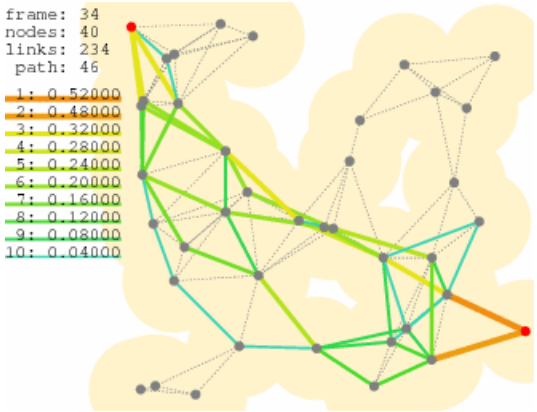


- Decide who forwards <u>after</u> reception
- Goal: only closest receiver should forward
- Challenge: agree efficiently and avoid duplicate transmissions

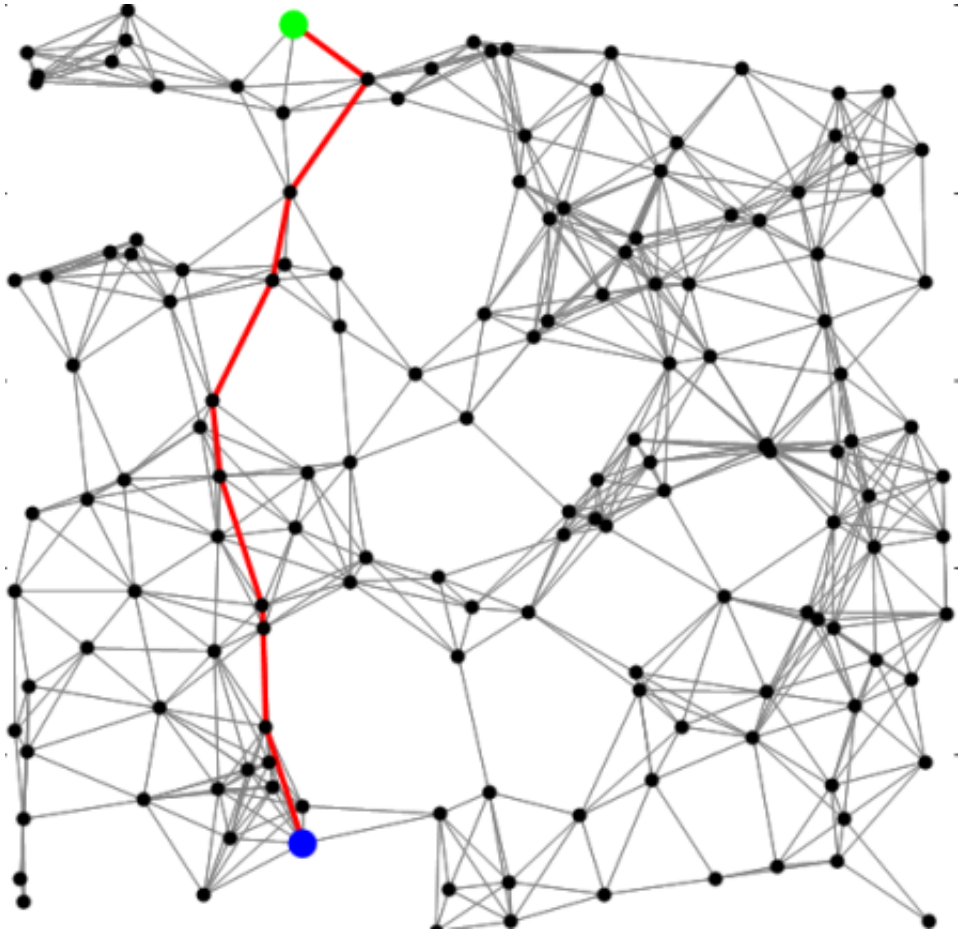
Hybrid MANET – DTN Networks



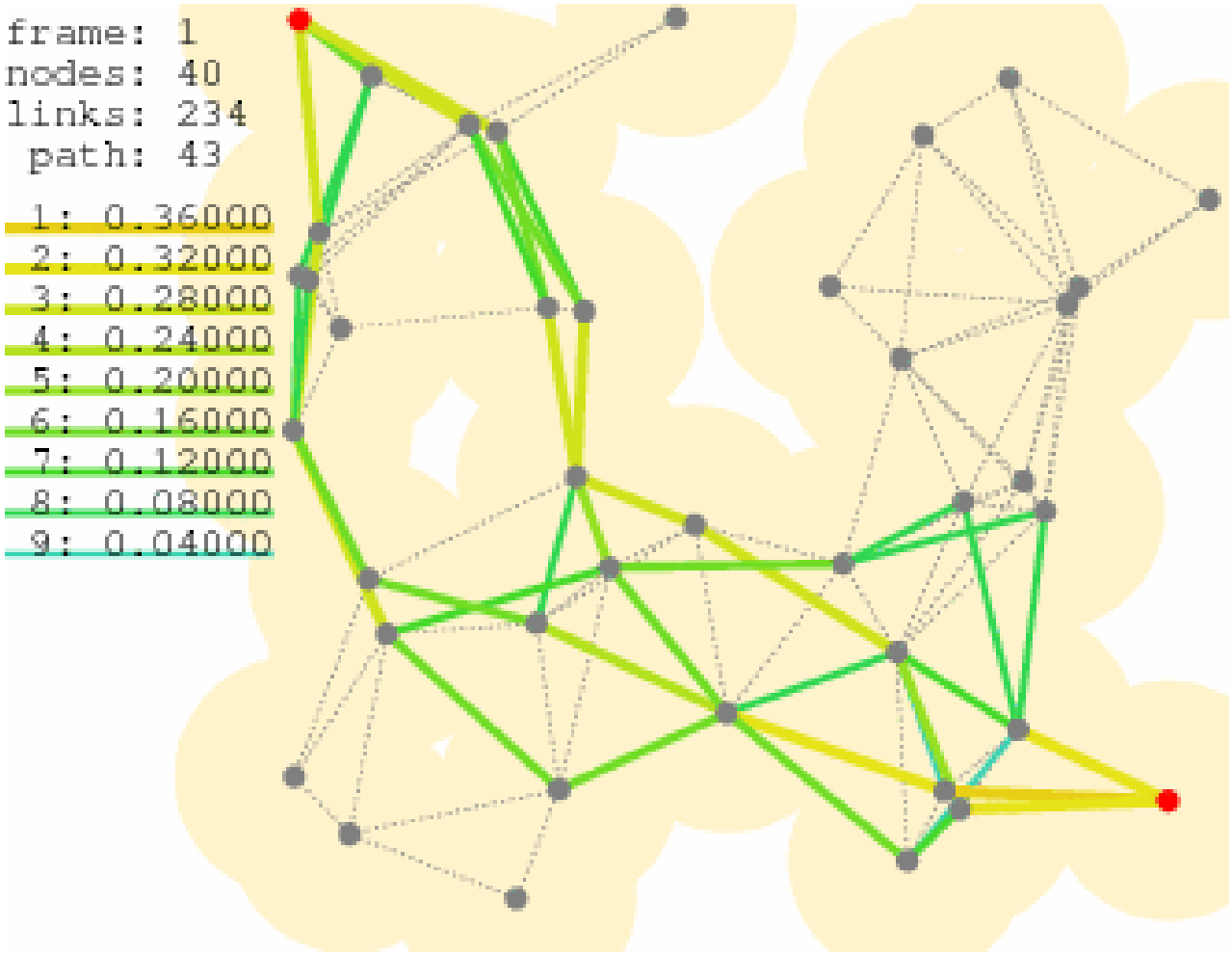




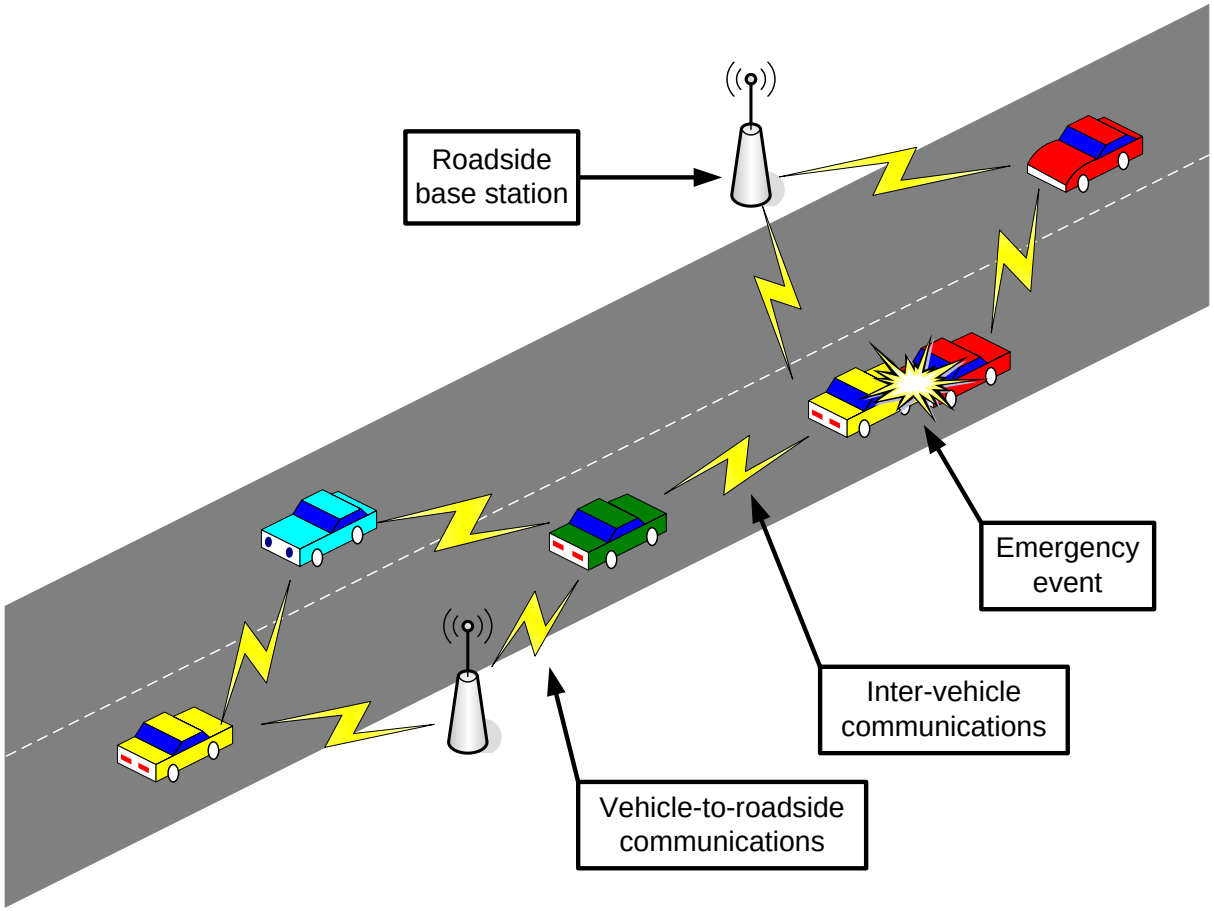
MANET Visualisation (1)



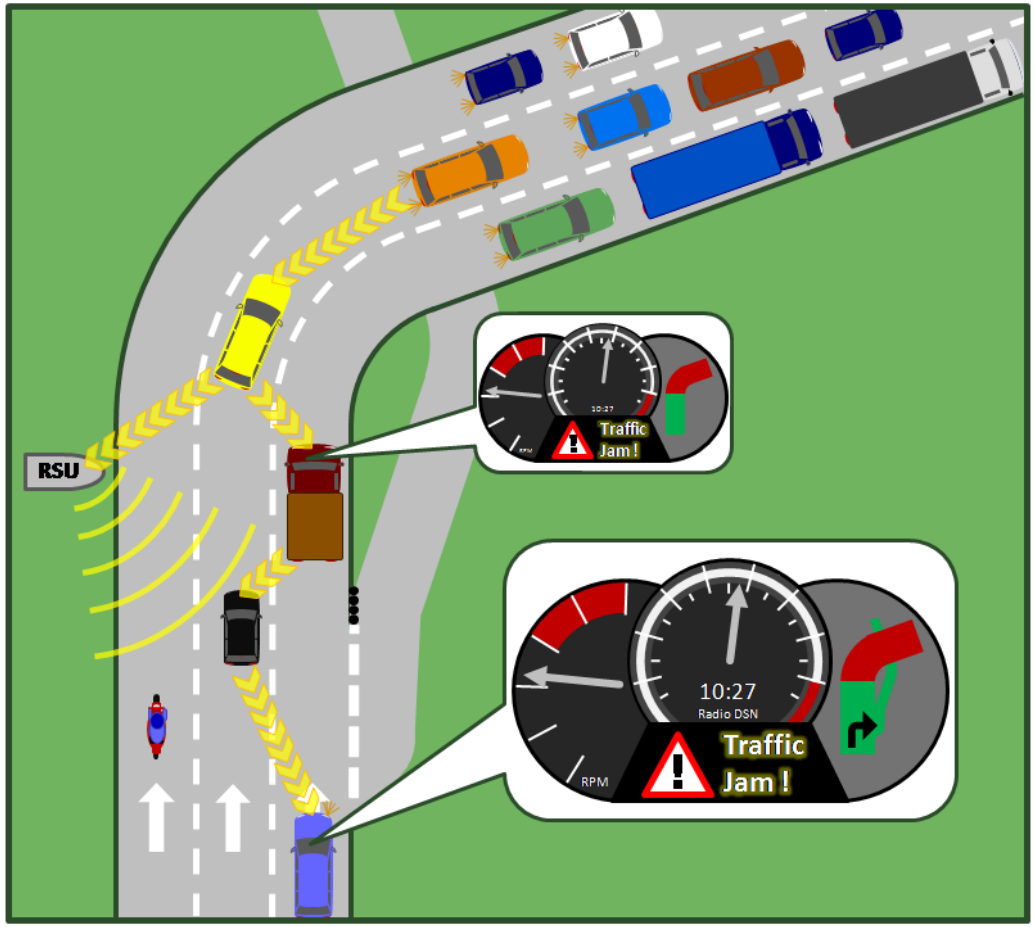
MANET Visualisation (2)



What is a VANET (Vehicular Ad hoc NETwork)?

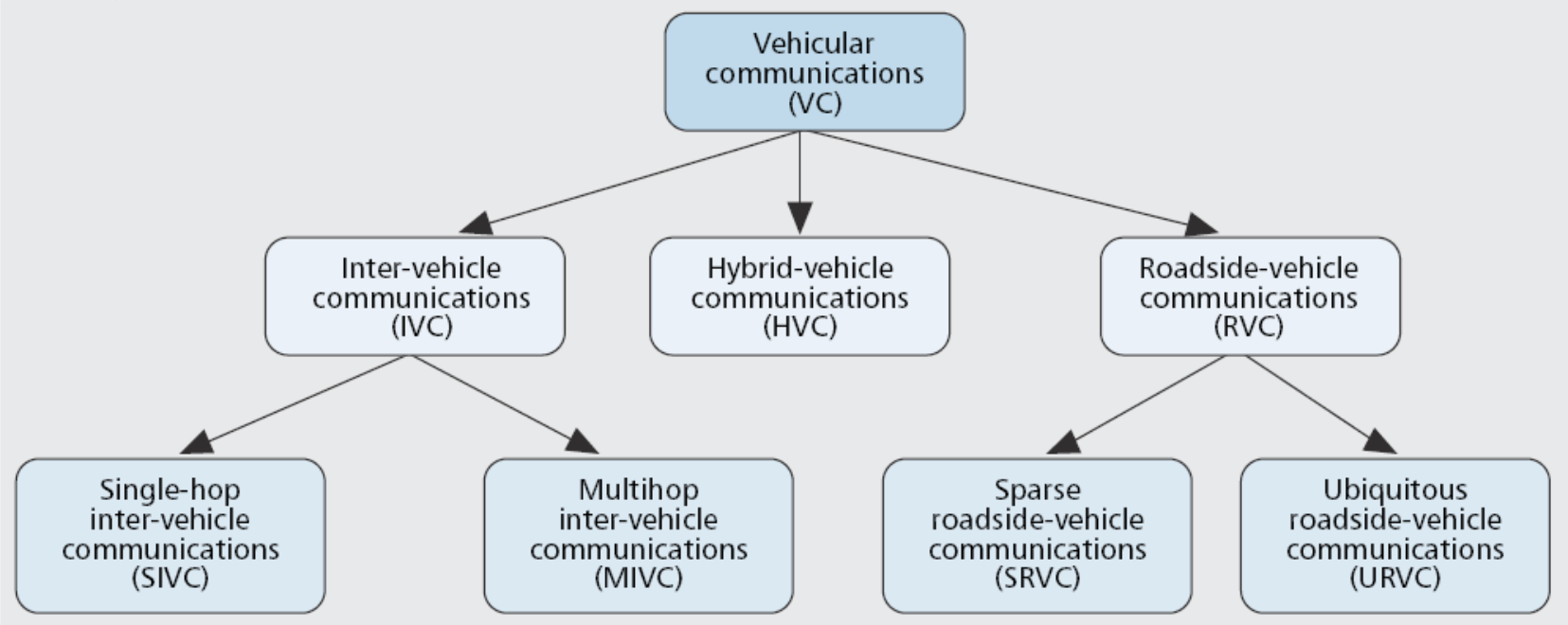


Scenario Traffic

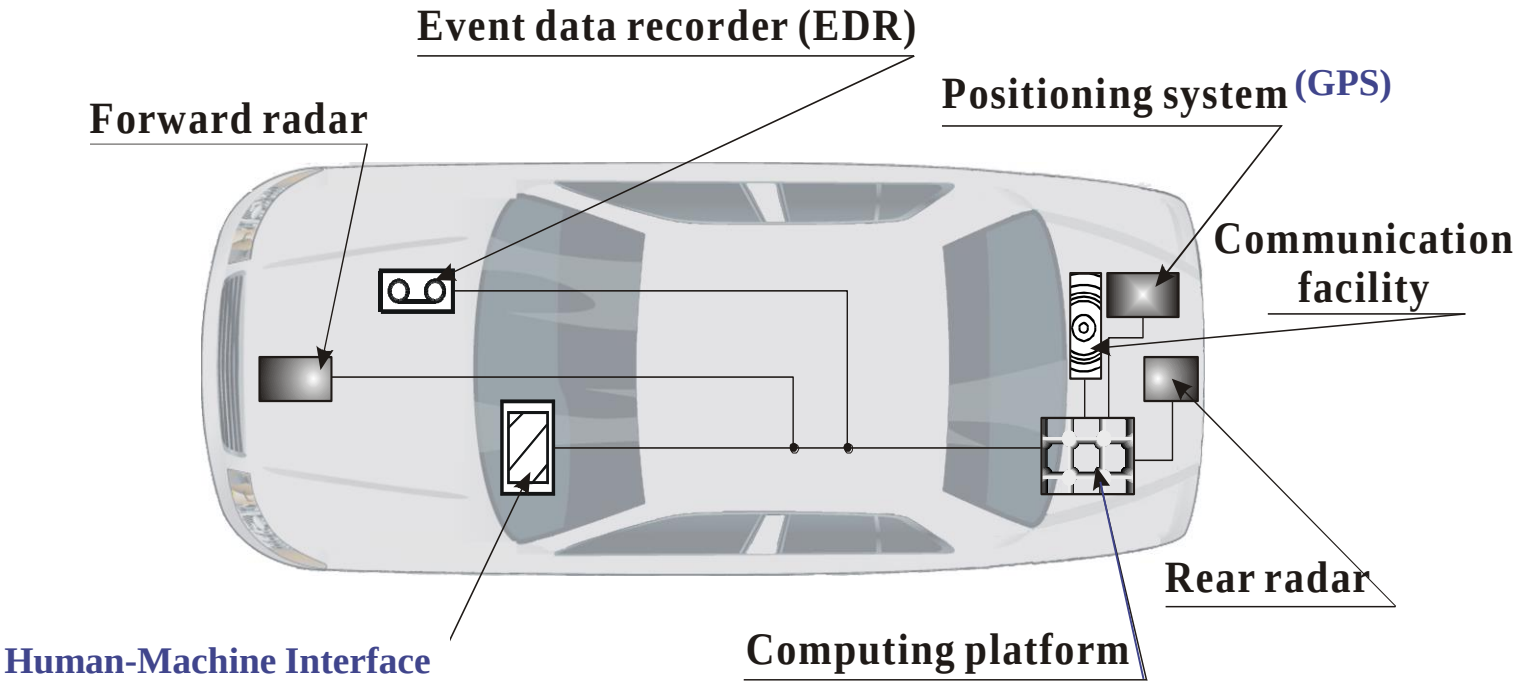


By vehicle-to-vehicle and vehicle-to-roadside communication, accidents can be avoided, e.g., by not colliding with a traffic jam, and traffic efficiency can be increased, e.g., by taking alternative routes.

A taxonomy of vehicular communication systems



A Modern Vehicle



Conclusion

Wireless and/or Mobile Network Evolution

- Cooperative Networks
- Cognitive Networks

Thank You!