HOCHSCHULE HANNOVER
UNIVERSITY OF APPLIED SCIENCES AND ARTS
–
Fakultät IV Wirtschaft und Informatik

Fahrzeugvernetzung – V2X

Lecture 3: Geographic Routing and Forwarding

Hugues Tchouankem, 13.10.2021

Lecture 3
Previous Lecture

► Facilities Layer

► Cooperative Awareness (CA) Basic Service

► Decentralized Environmental Notification (DEN) Basic Service

► Message Type and Structure

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Outline

► Geographic Networking (GeoNetworking)

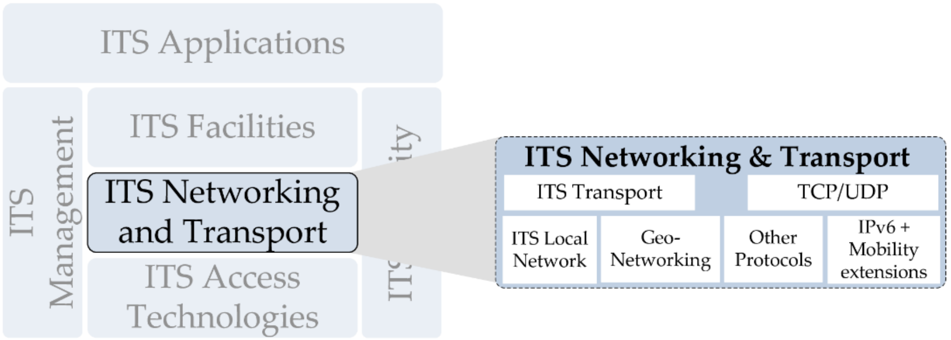
► Addressing Methods

► Forwarding Algorithms

► Location Service

► Duplicate Packet Detection Technique

Lecture 3
GeoNetworking (1/2)



- **Network-layer protocol** for mobile ad hoc communication based on wireless technology
- Enables a communication in mobile environments **without the need for a coordinating infrastructure** (e.g. road side unit)
- **Geographical positions** are used for dissemination of information and transport of data packets
  - No IP addressing
- Communication over **multiple wireless hops** could be achieved
  - Nodes in the network can **forward data packets** to extend the **communication range**

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GeoNetworking (2/2)

- Works **connectionless** and **fully distributed** based on ad hoc network concepts, with intermittent or even without infrastructure access

- Adequate for **highly mobile network** nodes and frequent changes in the network

- **Multi-hop dissemination** of packets in geographical regions for
  - emergency warnings
  - unicast packet transport for Internet applications

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Functions provided by GeoNetworking

- **Geographical addressing**
  - Unlike addressing in **conventional networks**, in which a node has a communication name linked to its identity (e.g**. a node's IP address**)
  - Data packets are sent **to a node** by its **position** or to multiple nodes in a **geographical region**

- **Geographical forwarding**
  - *P*rocess of transporting information **from a source** towards its **geographical destination**
  - Forwarding usually involves **intermediate nodes** that relay data packets on behalf of the source

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Geographical Addressing

- A station can select and specify a **well-delimited geographic area** to which messages should be delivered

- **Intermediate stations** serve as message relays (forwarder) and only the stations located **within the target area** process the message and further send it to corresponding applications
  - **Only stations** that are actually affected by **a dangerous situation** or a traffic notification are notified
  - Stations **unaffected** by the event are **not targeted**

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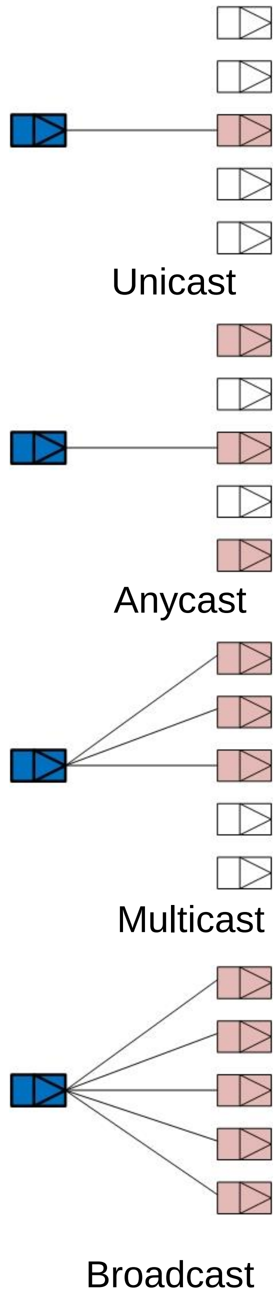
Addressing Methods

- **Unicast: one-to-one**
  - Packets are delivered to a single, specific node uniquely identified by a destination address
- **Anycast: one-to-one-of-many**
  - Packets are delivered to at least one member of a distinct group sharing common criteria
- **Multicast:** *one-to-many-of-many*
  - *Packets* are sent to all members of a group
- **Broadcast: one-to-all**
  - Packets are delivered to all nodes in a certain network
- **GeoNetworking**
  - Packets are delivered to a group of destination nodes by their geographical locations



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Geographical Forwarding

- **Prerequisites:**
  - Every node has a **partial view** of the network topology in its vicinity
  - Every packet carries a **geographical address**, such as the **geographical position** or **geographical area** as the destination

- When a node receives a data packet, it compares the **geo-address in the data packet** and the node's view on the network topology, and makes an **autonomous forwarding decision**
- Packets are forwarded **without need for setup** and maintenance of **routing tables** in the nodes

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GeoNetworking Beaconing (1/2)

- ► In **GeoNetworking** each mobile node has to periodically **inform neighbors** about its **presence** by **periodically broadcasting** a specific packet called GeoNetworking **Beacon** (Similar to CAM)

- ► **Beacons** are used to build a **Location Table** (LT) which can be consulted at any time to know the **neighboring nodes** and their **locations**

- ► **Location Table** is populated not only with information about **direct neighbors**, i.e. those that are located within one hop communication range **but also** with farther neighbors, i.e. those located **at two-hops distance and more**
  - ► In contrary to CAM content which **are not forwarded**

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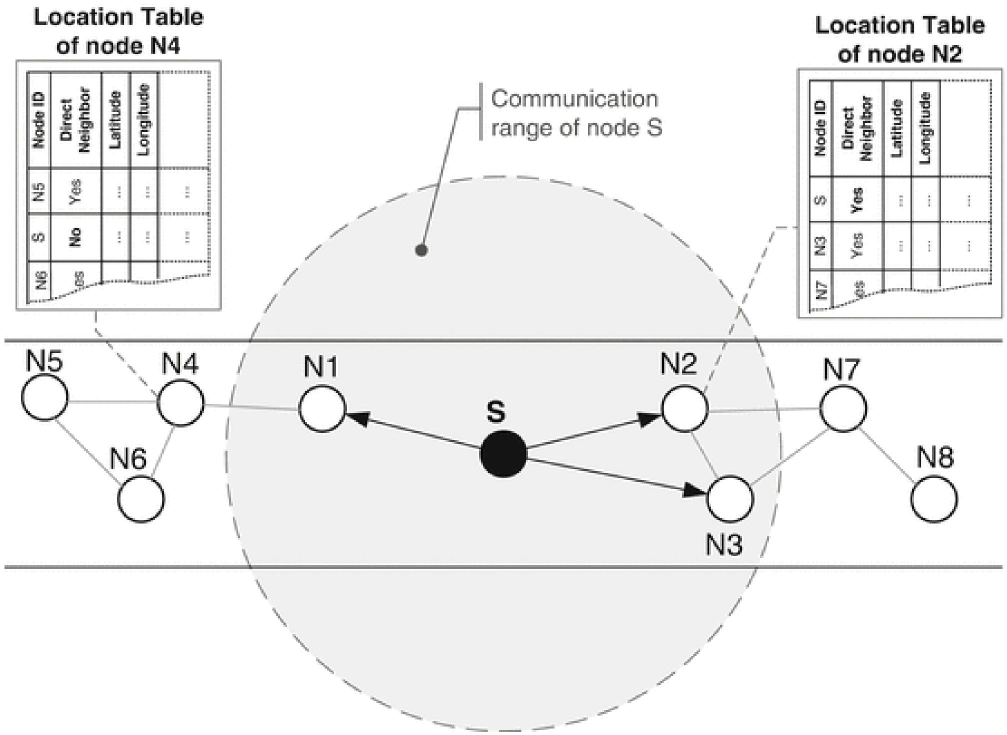
GeoNetworking Beaconing (2/2)

- **S** is surrounded by **direct neighbors (N1–N3)** as well as **non-direct neighbors (N4–N8)**
  - Direct neighbors are inserted into the Location Table of S as soon as a beacon is received from them, while non-direct neighbors are added to the LT of S only if a packet that contains the **location information** of that neighbor is received



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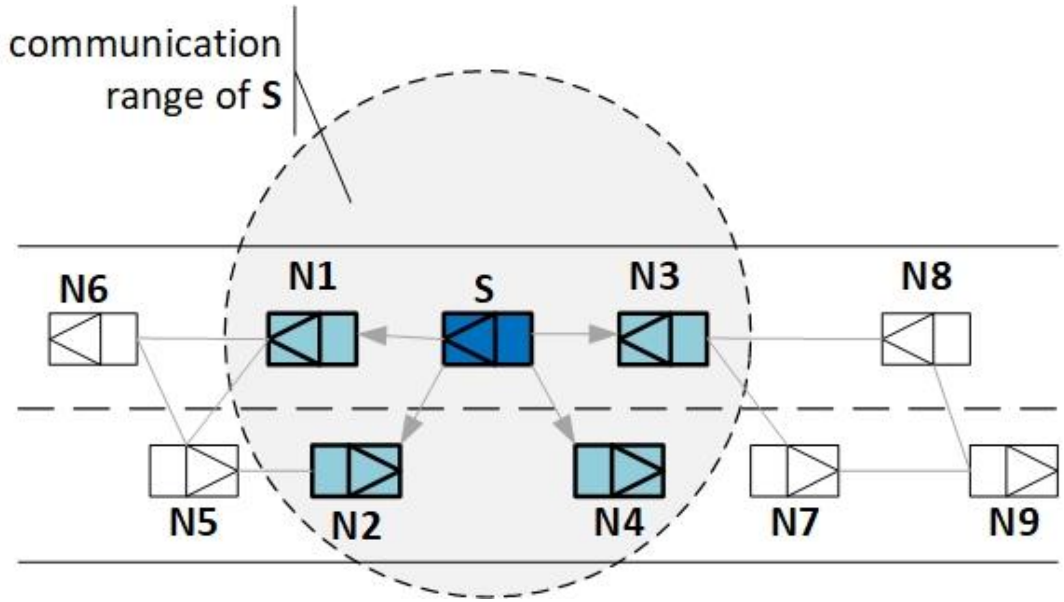
Single-Hop Broadcast (SHB)

- ► Sender S reaches only **neighbor nodes (N1-N4)** within its communication range
- ► It is used by safety applications that require fast information dissemination in the surrounding space
  - ► E.g. CAM-based applications
- ► Transmitted packet **is never forwarded** by the receivers



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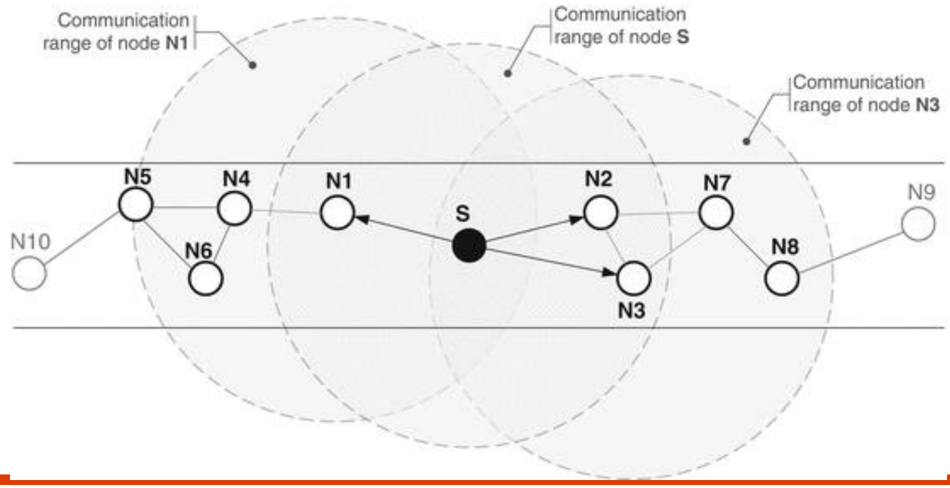
Topological Scoped Broadcast (TSB)

- TSB **rebroadcasts a packet** from a source to all nodes in the **n-hop neighborhood**
  - Single-hop broadcast (SHB) is a specific case of topologically-scoped broadcast, which is used to send packets only to one-hop neighborhood
- If as **same packet** reaches a destination or an intermediate node through **different neighbors** (i.e., different forwarders), only the **very first packet is processed**, and all the other **duplicates** are just dropped
  - **Sequence Number (SN)** is used to detect duplicate packets
  - Prevent/limit **broadcast storm** which may result to severe **network congestion**

2-hop TSB scenario



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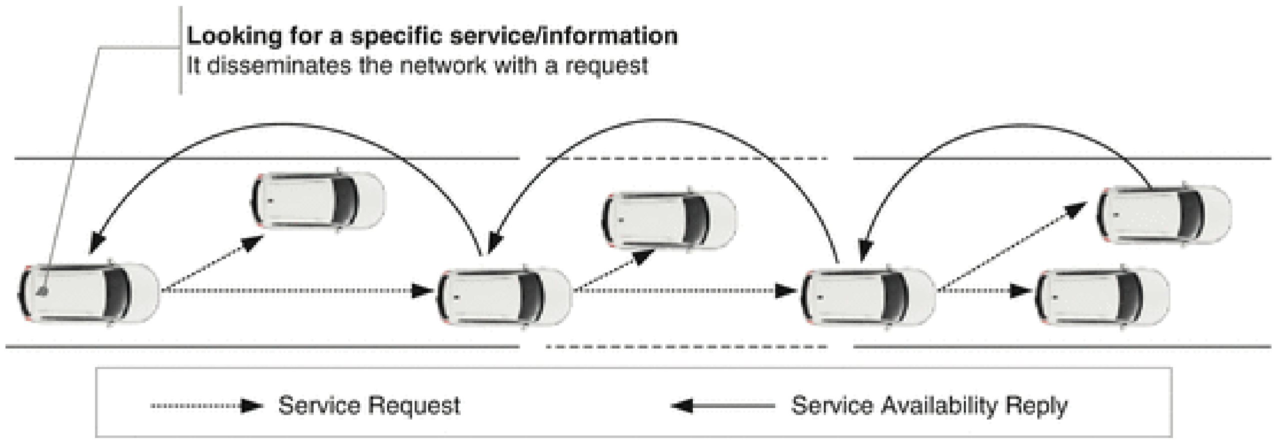
TSB Scenario

- A vehicle using topological broadcast communication to **search** for a wanted service or information within the **surrounding environment**
- A request for the specific service is disseminated to far-away neighbors through **multi-hop forwarding**
  - **not only** to those stations **within the communication range**



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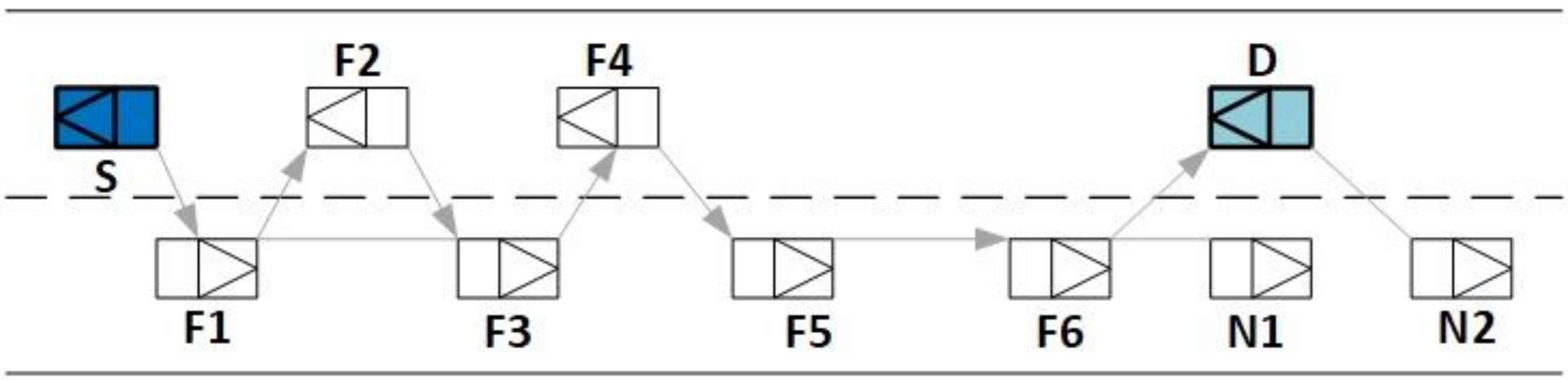
GeoUnicast

- GeoUnicast addresses **a single and specific station**
  - When a station wishes to send a unicast packet, it first determines the **destination's position** and then
  - forwards the data packet to a station **towards the destination**,
  - which in turn **re-forwards** the packet along the **path**
  - until the packet reaches the **destination**



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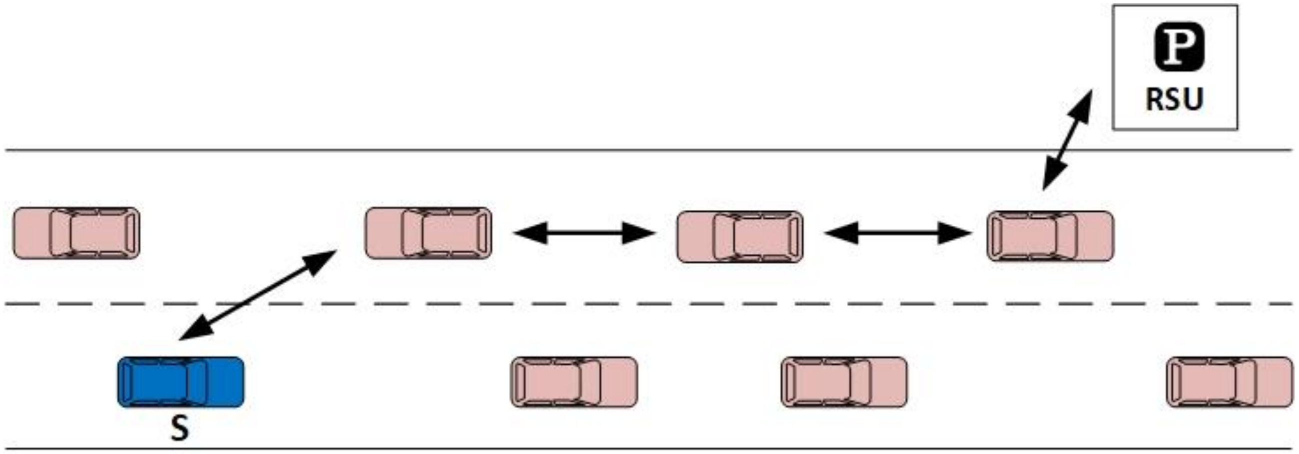
GeoUnicast Scenario

- A **multi-hop** communication based on GeoUnicast exchange of packets between a **vehicle** and a **parking lot**
  - A vehicle communication with a parking lot to check parking availability
  - Vehicle S sends a **request** for parking reservation
  - Parking RSU **replies** to confirm the parking availability along with a reservation number



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GeoUnicast Forwarding Algorithms

- The **GeoUnicast forwarding algorithm** is executed by a forwarding station to relay a packet to the next hop

- Two basic approaches to select the next hop
  - **Sender-based:** Explicit selection of a next hop by the **current forwarder**
  - **Receiver-based:** Implicit selection of a forwarder among all candidates through a **decentralized coordination function**

  - **Greedy Forwarding (GF) algorithm**
    - It follows a sender-based forwarding scheme
  - **Contention-based forwarding algorithm (CBF)**
    - It follows a received-based forwarding scheme

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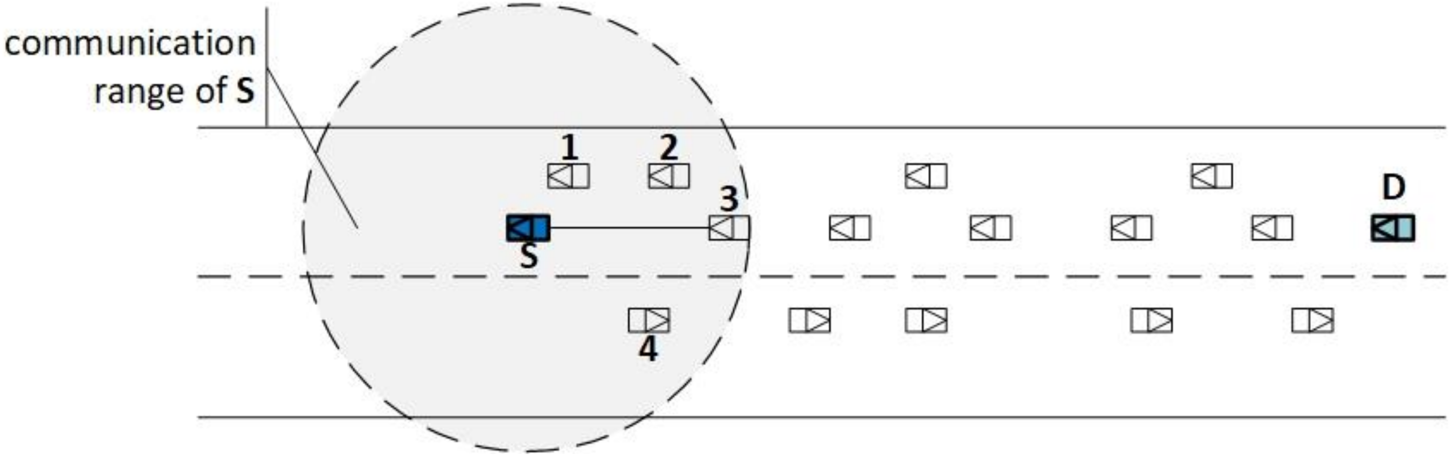
Greedy Forwarding Algorithm (GF)

- Each station that needs to forward a packet **explicitly selects the next hop** among all its known **neighbors**
- **Forwarding station** uses the location information of the destination carried in the packet header and selects **one of the neighbors** as the next hop
- **Most Forward within fixed Radius (MFR)** policy is used:
  - It selects the neighbor with the **smallest geographical distance to the destination**, thus providing **the greatest progress** when the packet is forwarded (e.g. station 3)
  - If no neighbor with greater progress than the local forwarding station exists, the packet has reached a **local optimum**



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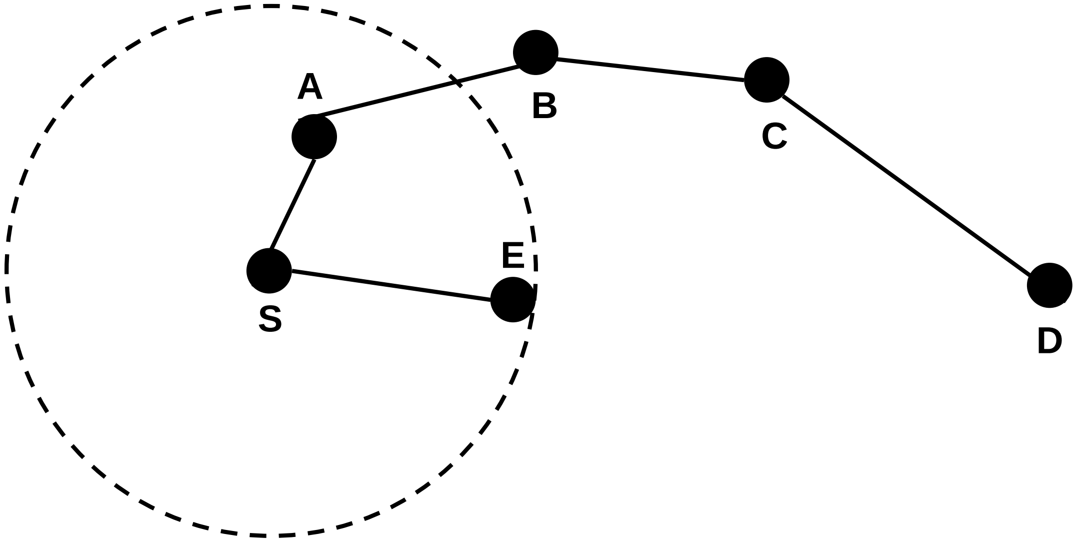
GF Limitation – Local Minimum

- ► Node E is closer to D than A
- ► S will not choose to forward to A using GF
- ► Although the path S→A→ B→C→D exists
- ► E is a **local minimum** in its proximity to D
- ► **Right hand rule** is used to solve this issue



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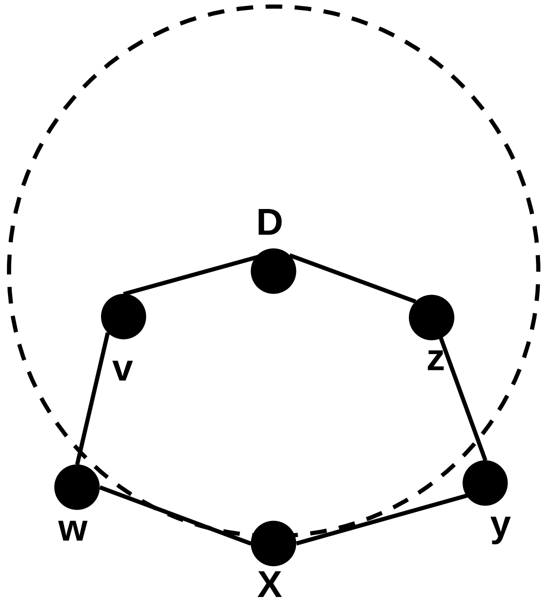
GF Limitation – Local Maximum

- ► Node X is closer to D than its neighbors w and y
- ► D has a radius equal to the distance between x and D
- ► Although two paths (X→y→z→D) and (X→w→v→D) exist
- ► X will not choose to forward to w or y using GF
- ► X is a **local maximum** in its proximity to D
- ► **Right hand rule** will also solve this issue



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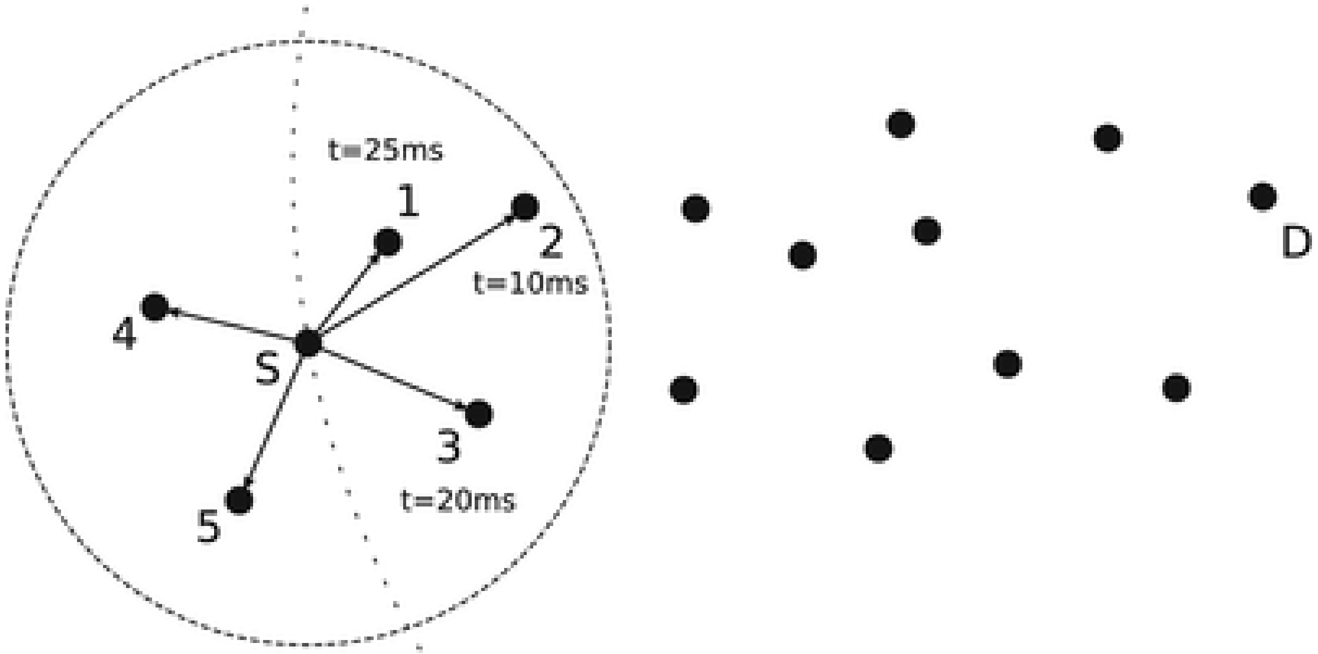
Contention-based Forwarding (CBF) (1/3)

- ► **Receiver decides** to be a **forwarder** of a packet
- ► In contrast to the GF which is a **sender-based forwarding** where the sender determines the next hop
- ► The CBF uses **a timer-based re-broadcasting** with overhearing of duplicates
  - ► Enabling an **implicit forwarding** of a packet by the **optimal station**



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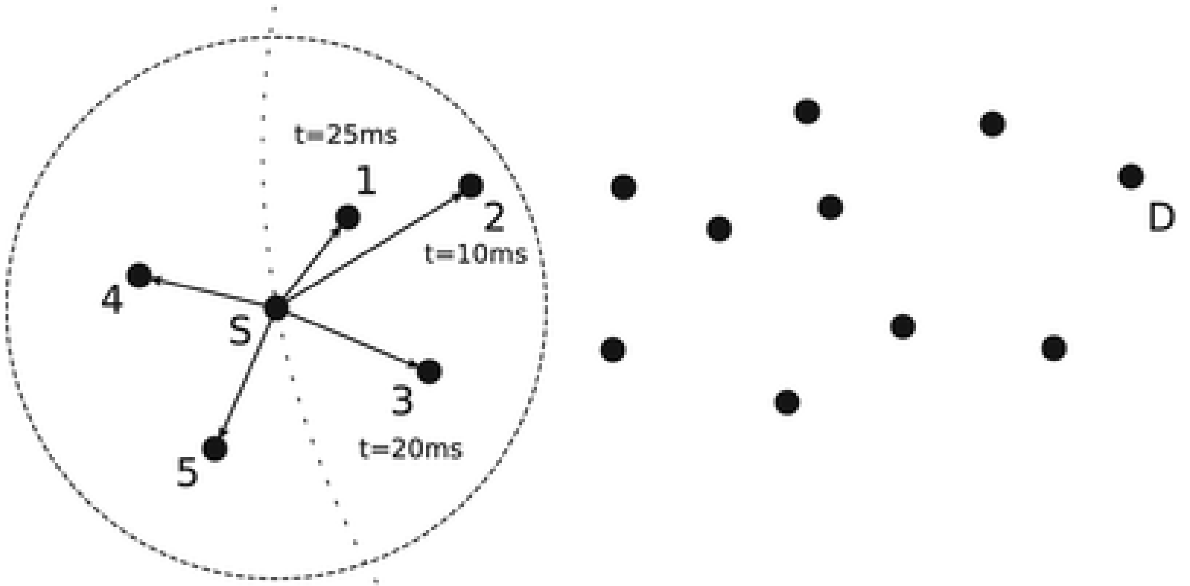
Contention-based Forwarding (CBF) (2/3)

► Steps:

1. **Forwarding** node transmits the packet as **a single-hop broadcast** to all neighbors
2. **All neighbors**, which receive the packet, process it
3. The packet is buffered in **CBF packet buffer** and a timer is started
4. Upon **expiration of the timeout**, the forwarding station **re-broadcasts** the packet



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Contention-based Forwarding (CBF) (3/3)

- The timeout is **inversely proportional** to the **distance** between the **forwarding** position and the **destination's** positions d

$$T = \begin{cases} T_{\min} + \dfrac{T_{\max} - T_{\min}}{D_{max}} \times d & \text{for } d \leq D_{max} \\ T_{\min} & \text{for } d > D_{max} \end{cases}$$

  - $T_{\min}$ is the minimum duration the packet shall be buffered $T_{\min} = 1 \text{ ms}$
  - $T_{\max}$ is the maximum duration the packet shall be buffered $T_{\max} = 100 \text{ ms}$
  - $D_{\max}$ is the theoretical maximum communication range $D_{\max} = 1000 \text{ meter}$

- Before the timer expires, the forwarding **may receive a duplicate** of the packet from an another forwarding station with a **shorter timeout**, i.e. with a smaller distance to the destination.
  - In this case, the forwarding station inspects its packet buffer, stops the timer and **removes the packet** from the packet buffer

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Greedy vs. Contention-based Forwarding

- **Greddy Forwarding (GF)**
  - Simple and efficient use of the communication channel
  - Selection of a specific node can have negative consequences for reliability
  - Packets get lost when next hop moved out of transmission range or disappeared
  - Sensitive to packet losses
- **Contention-based Forwarding (CBF)**
  - Reliability mechanism ensures that a packets is re-forwarded by an alternative forwarder
  - Implicit reliability mechanism at the cost of larger forwarding delay and increased channel usage
  - Reliability ensures also in the case an optimal forwarder does not receive the packet, e.g. due to packet losses

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Location Service (LS)

- The **location service** is used if a forwarder needs to determine the position of another forwarder. This is the case when a GeoUnicast packet is sent from the source to the destination, and the source does not have **the position information** for the **destination** in its location table

- LS provides **updated and accurate localization** information of the destination node which is at least required by the GeoUnicast addressing
  - Topology of the vehicular network changes frequently and quickly

- Whenever the **location information** of the destination node is either **unknown** or **outdated**
  - **Location Service** (LS) is used to determine the most updated location of the **destination node**
  - LS resides on **top of the forwarding functions** and can therefore use any forwarding type

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Location Service Mechanisms

- Two main mechanisms:
  - **Reactive**
    - Location service request is triggered whenever needed (on-demand)
  - **Proactive**
    - Location information of relevant nodes (or destinations) is kept updated locally through periodic exchange of control packets

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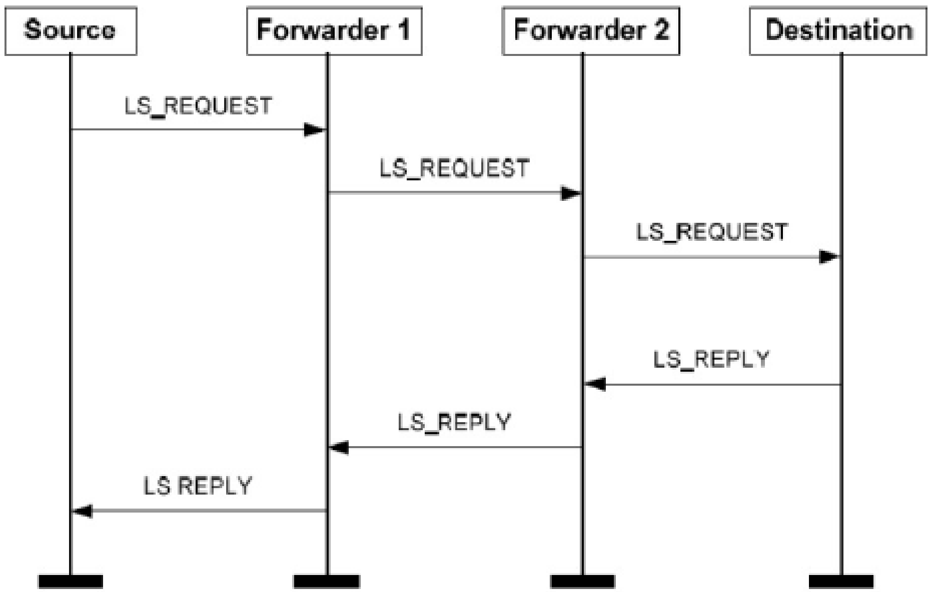
Reactive Location Service (RLS)

- Each node in the network maintains locally a location table in which an entry is updated on **on-demand fashion**
  - When receiving a packet from a direct or a faraway neighbor node and this packet carries **the updated location information** of that node, the receiver updates the related entry in its location table
  - When a GeoUnicast communication needs to be initiated, the **source node** looks-up the location of its destination from **the location table**

Lecture 3
Reactive Location Service (RLS)

► If the **location table** does not contain an **updated entry** for the desired destination node, then a **LS request is flooded** in the network to trigger a **location reply** from the wanted **destination node** itself or any other node in the network that knows the location of the wanted node



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Simple Location Service (SLS)

- Every node in the network keeps **transmitting periodically** at a certain rate its location information as well as that of **its neighbors to all nodes in the neighborhood** and at a lower rate to faraway neighbors

- The most updated location information is available at any time when needed

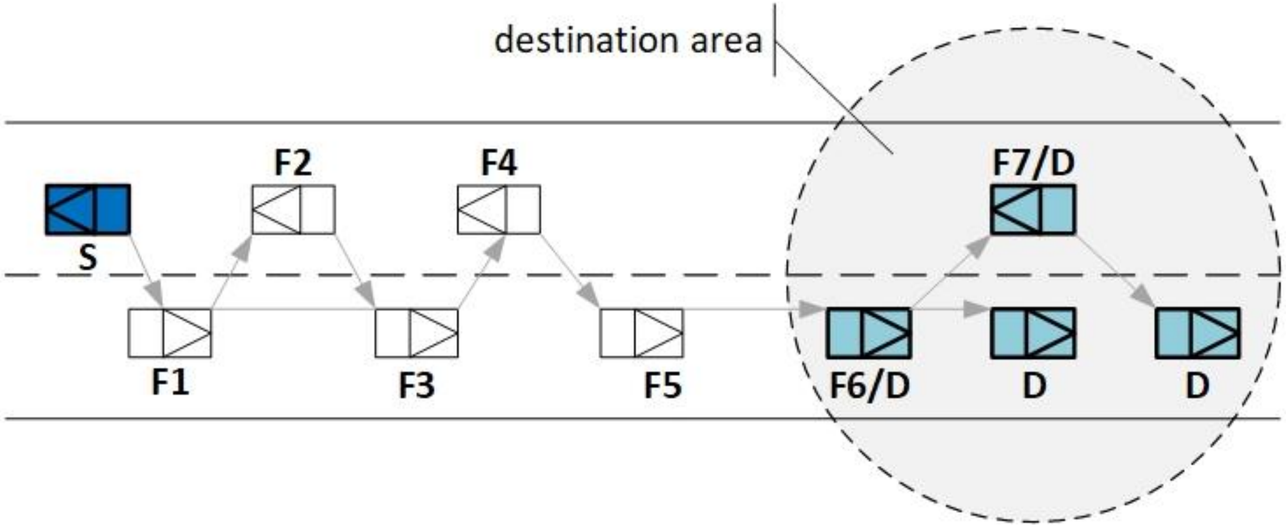
- BUT, a **high number of control packets** need to be flooded in the network to maintain the location information updated at each node → **Overload of the network**

Lecture 3
GeoBroadcast

► GeoBroadcast addresses **all (broadcast) stations** within a specific destination area

► A **location service** to calculate the location of the destination nodes is **not required**, as the information of the destination area is known at source node

► **Roadwork warning** application which triggers a GeoBroadcast communication to disseminate the area surrounding the segment of road which is relevant to the road work

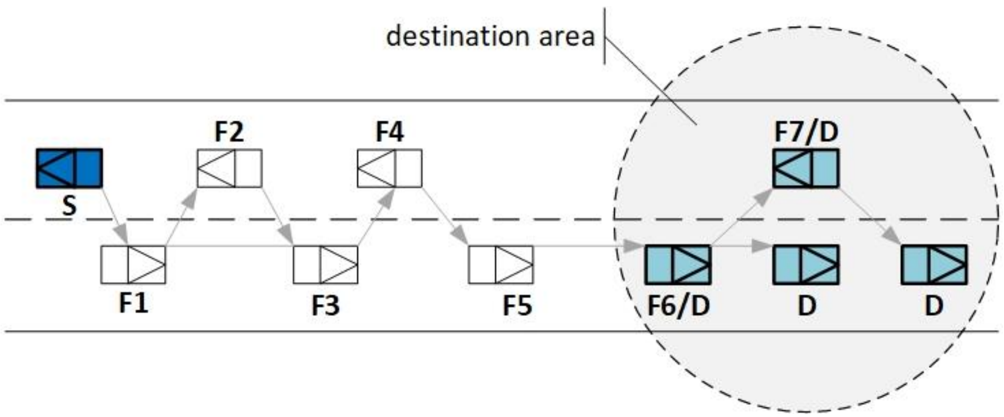


Lecture 3
GeoBroadcast

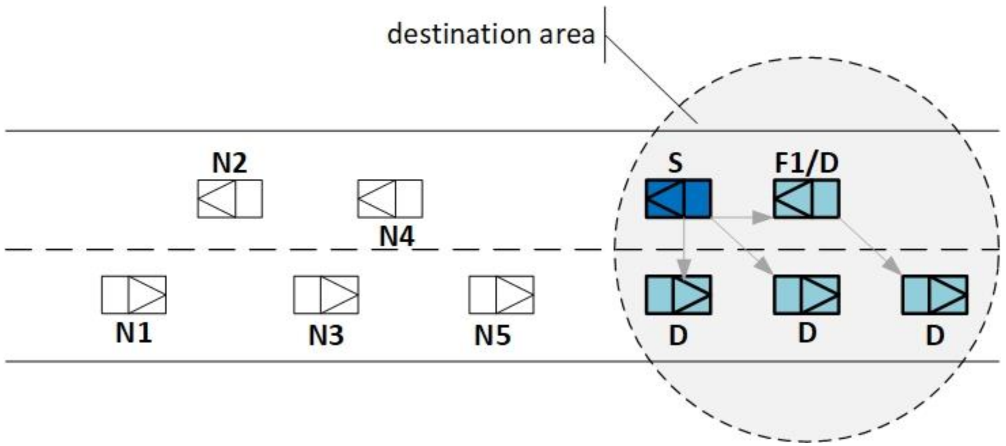
► The source node can be located either **inside** or **outside** the destination area

► Stations may rebroadcast the packet if they are located inside the destination area

► If the received packet is a GeoBroadcast packet, and the received node has been selected for forwarding the packet, then the packet is re-broadcasted to all nodes around to continue the dissemination of the packet within the **destination area**



source node outside



source node inside

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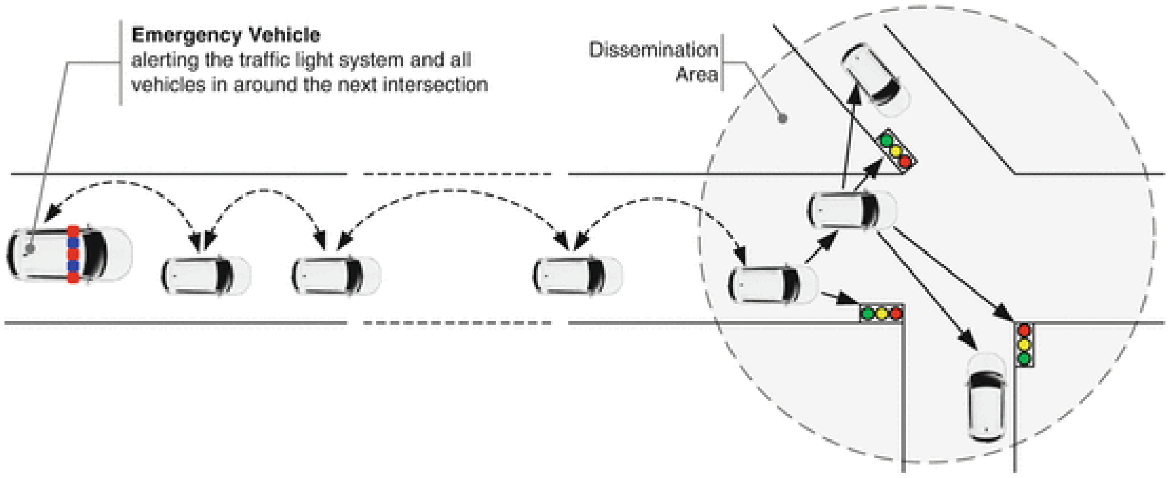
GeoBroadcast Scenario

- An **emergency vehicle** would inform all relevant vehicles located **around the next road intersection** about its arrival to allow a smooth and safe intersection crossing
- The information about the approaching emergency vehicle is disseminated to **all nodes within the destination area**, including both vehicles and traffic lights
- The packet is forwarded through **intermediate forwarders** till it reaches a vehicle or a roadside unit inside the targeted area, then **broadcast within that area**



Lecture 3
GeoBroadcast Forwarding Algorithms

- The GeoBroadcast forwarding algorithm is executed by a forwarding station to relay a packet to the next hop

- Two basic approaches to select the next hop
  - **Simple GeoBroadcast forwarding algorithm**
  - **Advanced GeoBroadcast forwarding algorithm**

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Simple GeoBroadcast Forwarding Algorithm

- A function $F(x, y)$ is used to determine whether a forwarder with position (x, y) is located inside, at the border or outside the geographical target area
  - If the forwarder is inside or at the border of the area, the **packet shall be re-broadcasted**
  - If it is outside the area, the packet **shall be forwarded** by the GF algorithm

$$F(x,y) \begin{cases} =1 & \text{for } x = 0 \text{ and } y = 0 \text{ (at the centre point)} \\ >0 & \text{inside the geographical area} \\ =0 & \text{at the border of the geographical area} \\ <0 & \text{outside the geographical area} \end{cases} .$$

- $F(x, y) = 1 - \left(\frac{x}{r}\right)^2 - \left(\frac{y}{r}\right)^2$ for a circular destination area

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Advanced GeoBroadcast Forwarding Algorithm

► It relies on **three** main mechanisms

1. **CBF** is used to deal with uncertainties by potential reception failures caused by node mobility, fading phenomena and packet collisions on the wireless medium

2. To minimize the forwarding delay, CBF is **complemented with the selection of one specific forwarder at the sender**, referred to as next hop

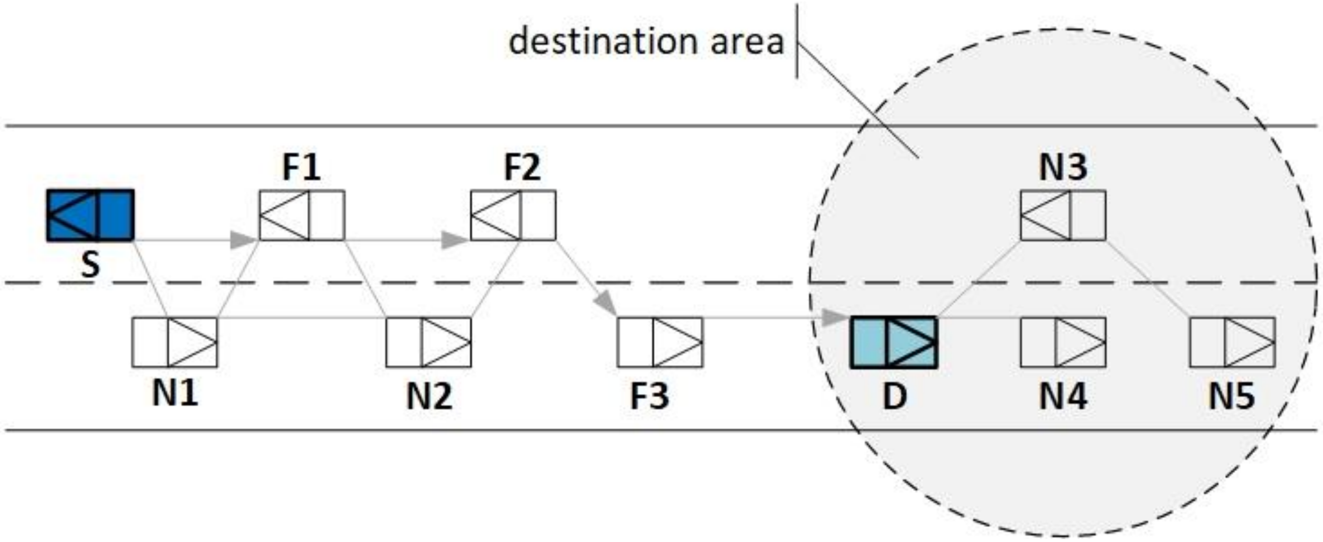
   ► Upon reception of the packet, the next hop - in case of correct reception - forwards the message immediately

   ► No need **to wait until the timer** expires

3. The reliability of the dissemination process is increased by a **controlled packet retransmission scheme** within the geographical target area

Lecture 3
GeoAnycast

- While GeoBroadcast targets **all nodes** within the destination area, the GeoAnycast target **only one node** within the destination area
- The packet is **forwarded till it reaches a first node inside** the destination area (so far similar to GeoBroadcast), and then stops at that first node as it is considered as the **destination node**
- A location service to calculate the location of the destination node **is not required**, as the information of the destination area is known at source node



Lecture 3
Duplicate Packet Detection (1/2)

- ► A station can receive **multiple copies** of the same packet
  - ► The same packet from multiple stations can be forwarded
- ► Packets are labeled with a **sequence number (SN) and timestamp (TS)** after generation
- ► GeoNetworking protocol uses following mechanisms to control/prevent the forwarding of duplicate packets
  - ► **Sequence number and timestamp-based**
    - ► Forwarding station maintains the SN and TS of the last packet from the originating
      - ► ***A duplicated packet is detected and not forwarded if***
        - ► SN of the last packet matched with the SN of the current packet, and
        - ► TS of the last packet matched with the TS of the current packet
    - ► Applies for multi-hop packets: **Topological-scoped Broadcast, Geobroadcast, GeoAnycast,** and **GeoUnicast**

Lecture 3
Duplicate Packet Detection (2/2)

- **Timestamp-based**
  - A duplicated packet is detected and not forwarded if
    - TS of the last packet matched with the TS of the current packet
  - Applies for packets that do not carry a **SN field**, i.e. single-hop packets (beacon)

- Remarks:
  - GeoNetworking does not provide packet re-ordering
    - **Out-of-sequence packets are discarded**

Lecture 3

Packet Data Rate Control

- Uses to provide differentiated and reliable support to V2X applications
- Enables the capability to **limit the forwarding of packets** by evaluating the **quantity of generated packets** by each neighbor
- An exponential moving average of the **Packet Data Rate (PDR)** for each entry in the location table is maintained by each station

$$PDR = (1 - \beta) \times PDR_t + \beta \times PDR_{t-1}$$

  - β is the weighting factor ($0 < \beta < 1$)
  - PDR_t is the instantaneous value of the packet data rate
  - PDR_{t-1} is the previous value at time $t - 1$ maintained in the location table

- In the case $PDR \geq PDR_{\text{threshold}}$ → Packets of the particular node are not forwarded

Lecture 3
Challenges of Geographic Routing in V2X Networks

- High **dynamic** topology of V2X-networks

- Communication links often exist only for a short moment and can suffer from significant fluctuations during their **lifetime**

- Traditional routing protocols based on **link state information** to determine end-to-end paths require a **massive overhead** to distribute link state updates

- A globally available metric defining how to get closer to the destination is required

Lecture 3
Literature

- ► ETSI EN 302 636-1: “GeoNetworking; Part 1: Requirements”
- ► Claudio Campolo, Antonella Molinaro, Riccardo Scopigno: “Vehicular ad hoc Networks - Standards, Solutions, and Research”, Springer, 2015
- ► ETSI EN 302 636-2: “GeoNetworking; Part 2: Scenarios”
- ► ETSI TS 102 636-3: “GeoNetworking; Part 3: Network Architecture”
- ► ETSI TS 102 636-4-2: “GeoNetworking; Part 4-2: Addressing - Media-dependent (ITS-G5)”
- ► ETSI EN 302 931: “Geographical Area Definition”