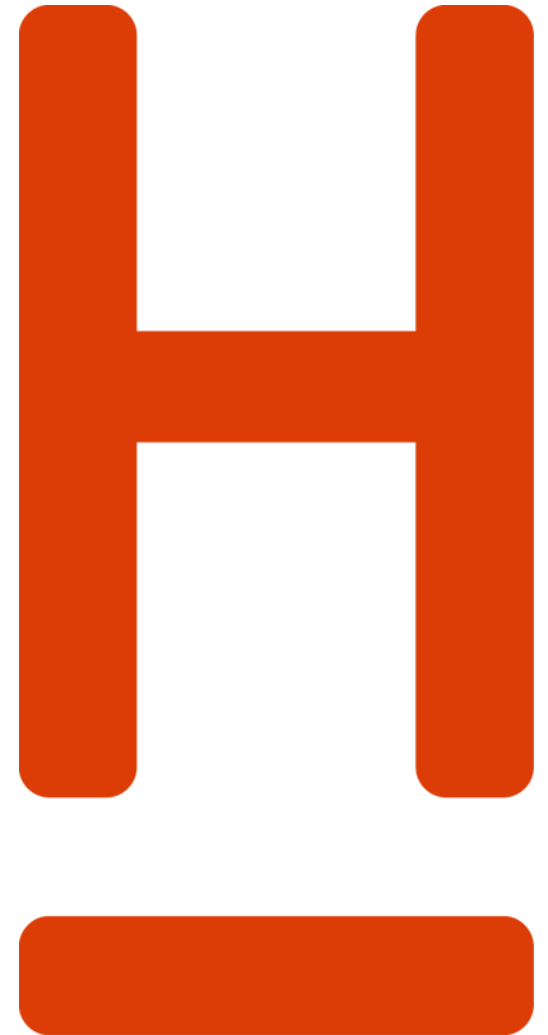


**HOCHSCHULE  
HANNOVER**  
UNIVERSITY OF  
APPLIED SCIENCES  
AND ARTS

–  
*Fakultät IV  
Wirtschaft und  
Informatik*

# **Fahrzeugvernetzung – V2X**

*Lecture 3: Geographic Routing and Forwarding*



# Lecture 3

## *Previous Lecture*

- ▶ Facilities Layer
- ▶ Cooperative Awareness (CA) Basic Service
- ▶ Decentralized Environmental Notification (DEN) Basic Service
- ▶ Message Type and Structure



# Lecture 3

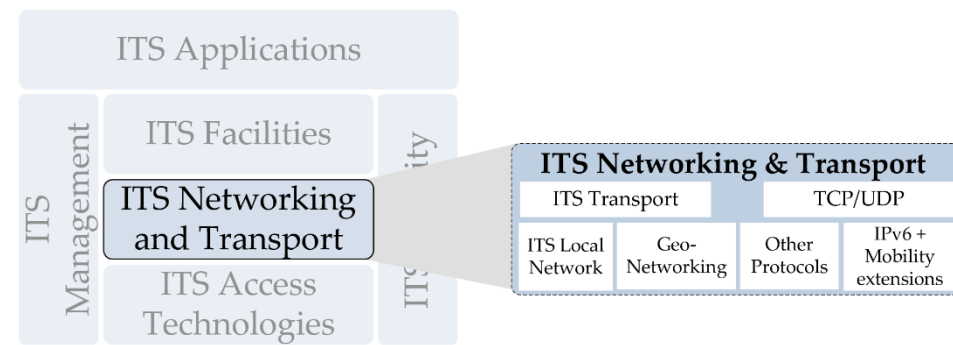
## *Outline*

- ▶ 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**



# Lecture 3

## *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



# Lecture 3

## *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

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



# Lecture 3

## *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**



# Lecture 3

## 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*

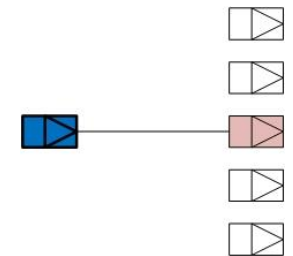
- *Packets* are sent to all members of a group

### ► Broadcast: one-to-all

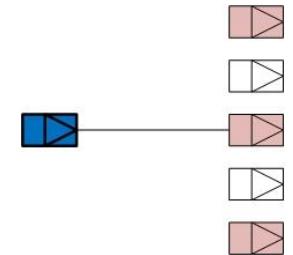
- Packets are delivered to all nodes in a certain network

### ► GeoNetworking

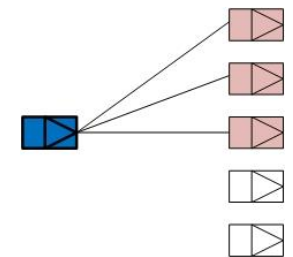
- Packets are delivered to a group of destination nodes by their geographical locations



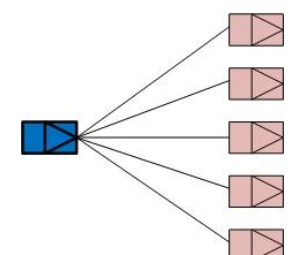
Unicast



Anycast



Multicast



Broadcast



# Lecture 3

## *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



# Lecture 3

## *GeoNetworking Beaconsing (1/2)*

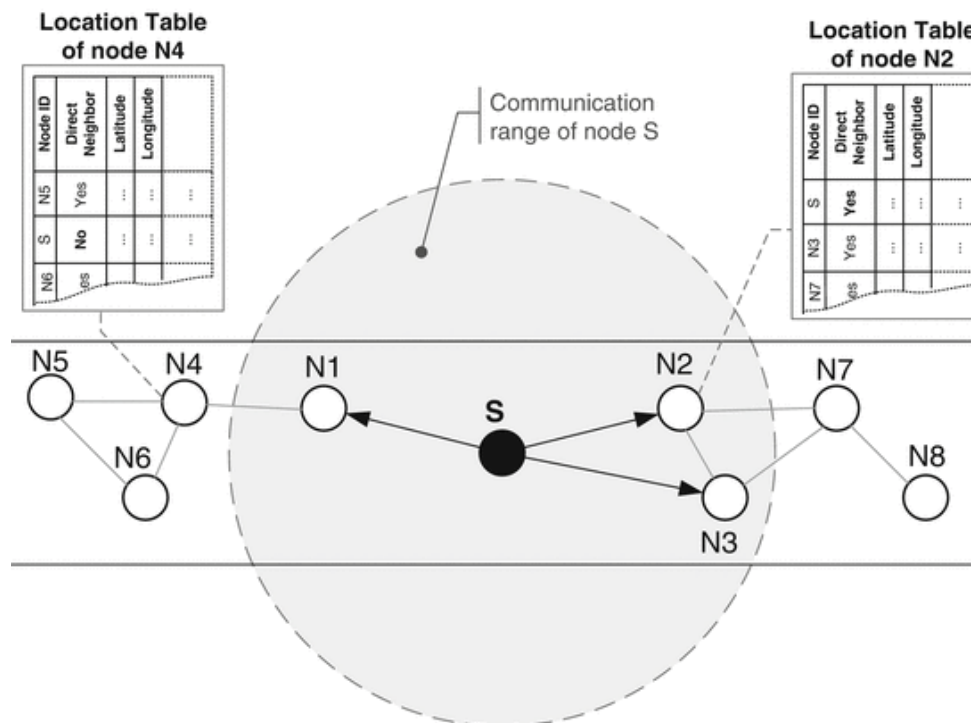
- ▶ In **GeoNetworking** each mobile node has to periodically **inform neighbors** about its **presence** by **periodically broadcasting** a specific packet called **GeoNetworking Beacon** (Similar to CAM)
- ▶ **Beacons** are used to build a **Location Table** (LT) which can be consulted at any time 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**



# Lecture 3

## GeoNetworking Beaconsing (2/2)

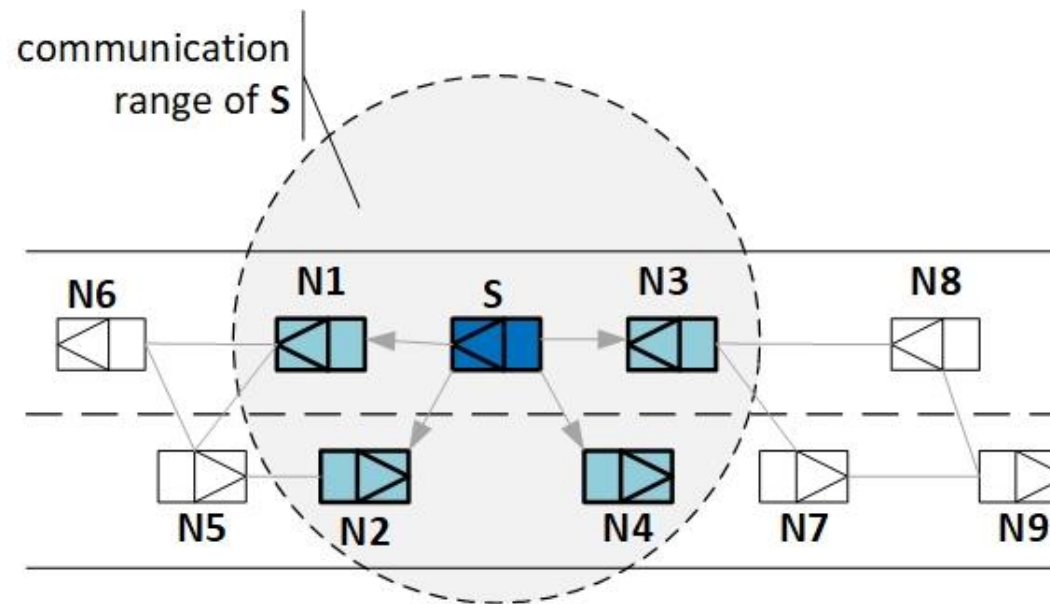
- ▶ S is surrounded by **direct neighbors (N1–N3)** as well as **non-direct neighbors (N4–N8)**
- ▶ Direct neighbors are inserted into the Location Table of S as soon as a beacon is received from them, while non-direct neighbors are added to the LT of S only if a packet that contains the location information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



# Lecture 3

## Single-Hop Broadcast (SHB)

- ▶ Sender S reaches only **neighbor nodes (N1-N4)** within its communication range
- ▶ It 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

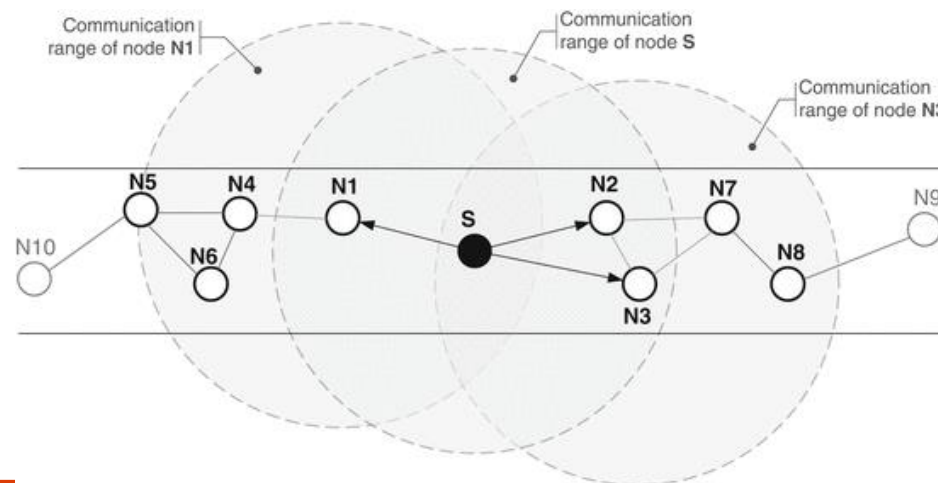


# Lecture 3

## *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 a **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**

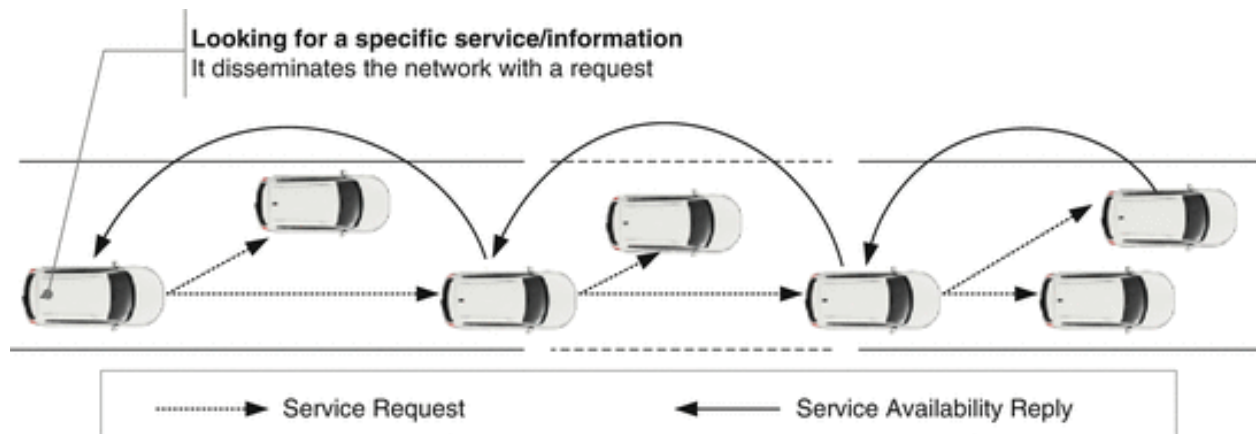
2-hop TSB scenario



# Lecture 3

## TSB Scenario

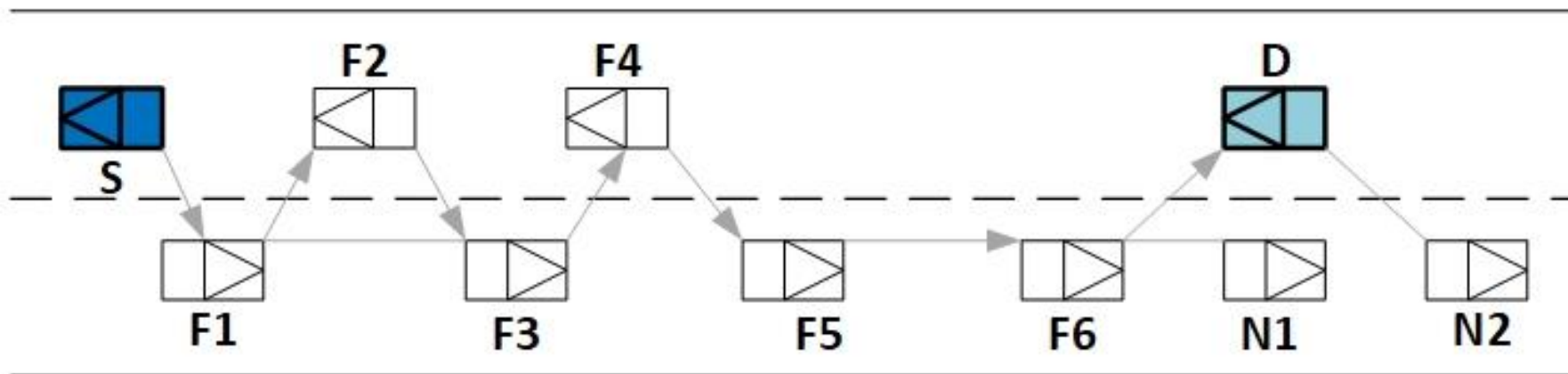
- ▶ A vehicle using topological broadcast communication to **search** for a wanted service or information within the **surrounding environment**
- ▶ A request for the specific service is disseminated to far-away neighbors through **multi-hop forwarding**
- ▶ **not only** to those stations **within the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



# Lecture 3

## GeoUnicast

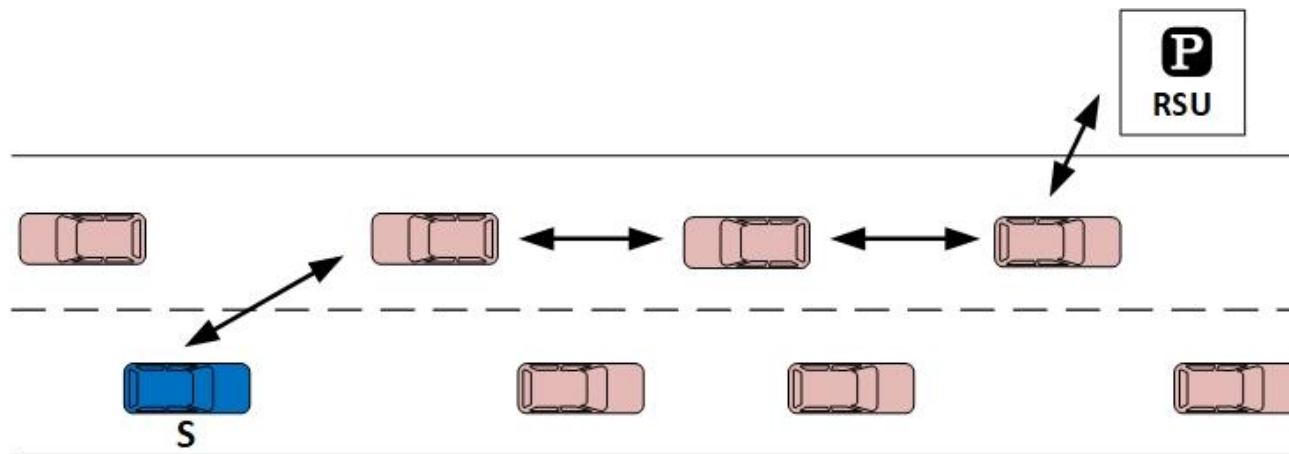
- ▶ GeoUnicast addresses a **single and specific station**
  - ▶ When a station wishes to send a unicast packet, it first determines the **destination's position** and then
  - ▶ forwards the data packet to a station **towards the destination**,
  - ▶ which in turn **re-forwards** the packet along the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



# Lecture 3

## *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





# Lecture 3

## *GeoUnicast Forwarding Algorithms*

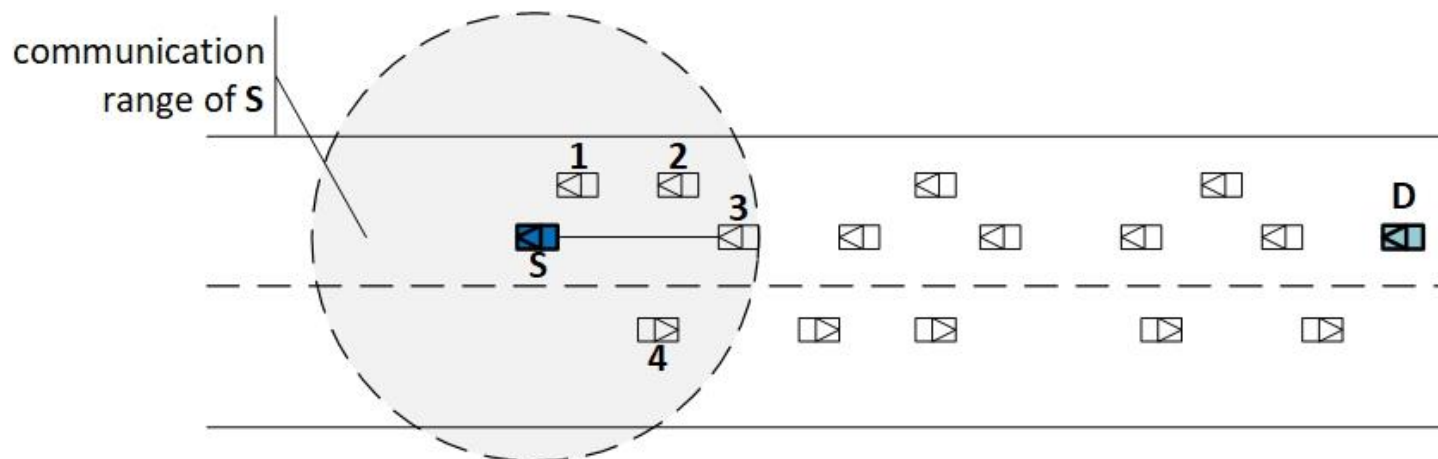
- ▶ The GeoUnicast forwarding algorithm is executed by a forwarding station to relay a packet to the next hop
- ▶ Two basic approaches to select the next hop
  - ▶ **Sender-based:** Explicit selection of a next hop by the **current forwarder**
  - ▶ **Receiver-based:** Implicit selection of a forwarder 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 receiver-based forwarding scheme



# Lecture 3

## *Greedy Forwarding Algorithm (GF)*

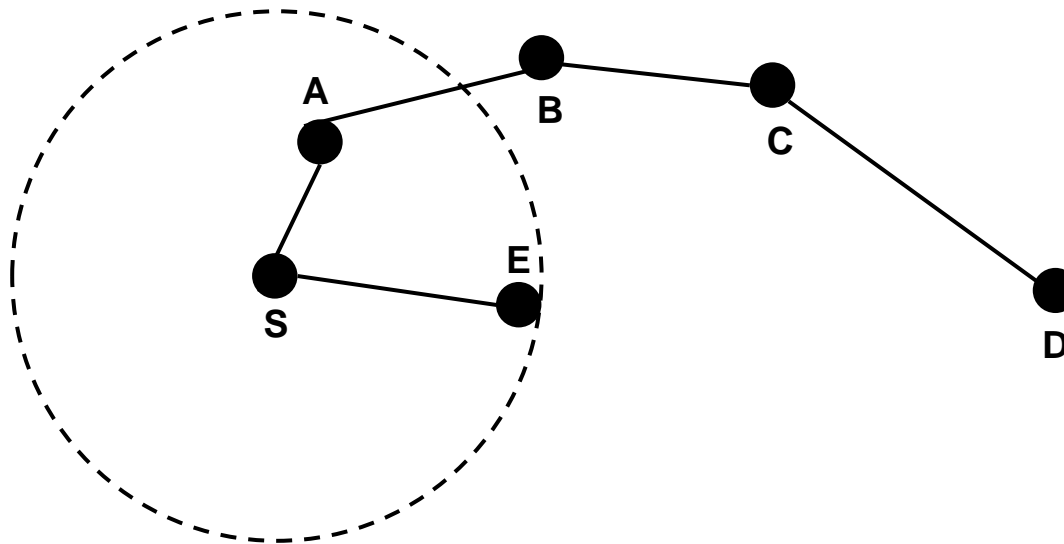
- ▶ Each station that needs to forward a packet **explicitly selects the next hop** among all its known **neighbors**
- ▶ **Forwarding station** uses the location information of the destination carried in the packet header and selects **one of the neighbors** as the next hop
- ▶ **Most Forward within 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**



# Lecture 3

## *GF Limitation – Local Minimum*

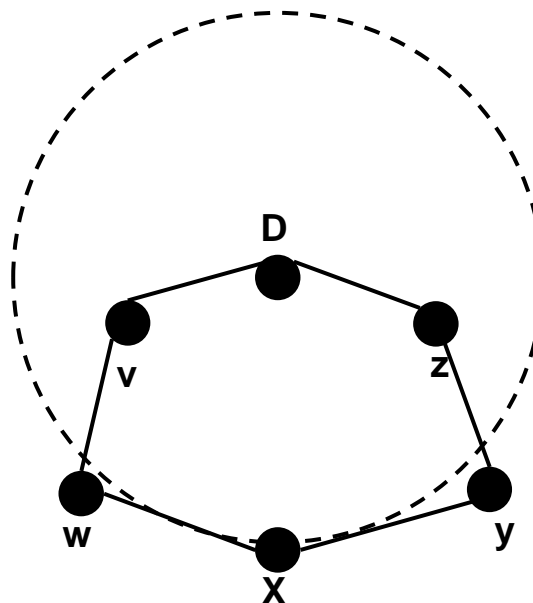
- ▶ Node E is closer to D than A
- ▶ S will not choose to forward to A using GF
- ▶ Although the path  $S \rightarrow A \rightarrow B \rightarrow C \rightarrow D$  exists
- ▶ E is a **local minimum** in its proximity to D
- ▶ **Right hand rule** is used to solve this issue



# Lecture 3

## *GF Limitation – Local Maximum*

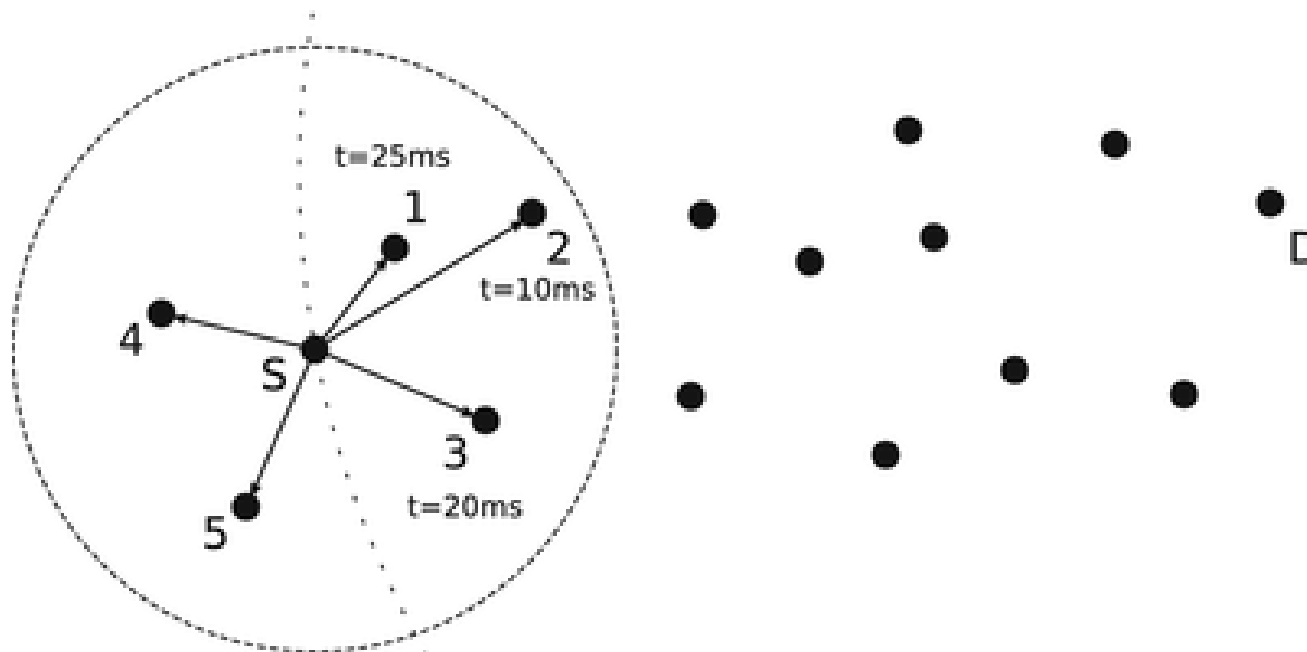
- ▶ Node X is closer to D than its neighbors w and y
- ▶ D has a radius equal to the distance between x and D
- ▶ Although two paths  $(X \rightarrow y \rightarrow z \rightarrow D)$  and  $(X \rightarrow w \rightarrow v \rightarrow D)$  exist
- ▶ X will not choose to forward to w or y using GF
- ▶ X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



# Lecture 3

## 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**

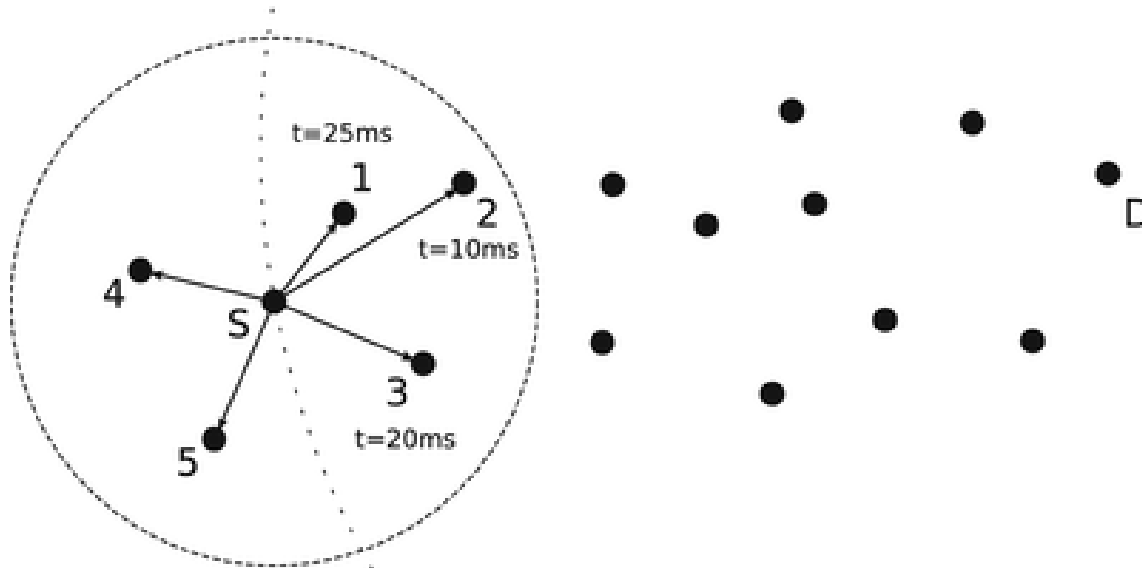


# Lecture 3

## 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



# Lecture 3

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

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

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

- ▶  $T_{\min}$  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



# Lecture 3

## *Greedy vs. Contention-based Forwarding*

### ► Greedy 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





# Lecture 3

## *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



# Lecture 3

## *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



# Lecture 3

## *Reactive Location Service (RLS)*

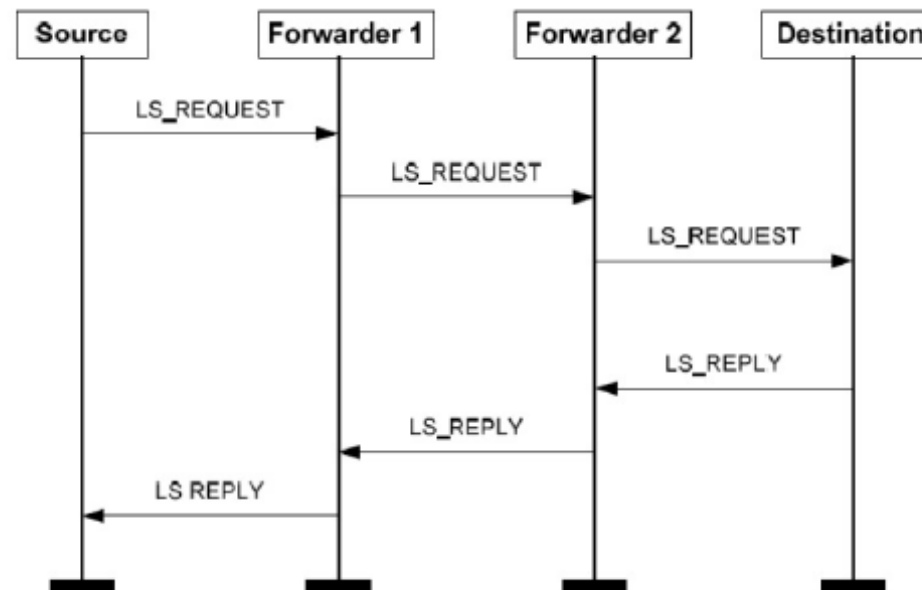
- ▶ Each node in the network maintains locally a location table in which an entry is updated on **on-demand fashion**
- ▶ When receiving a packet from a direct or a faraway neighbor node and this packet carries **the updated location information** of that node, the receiver updates the related entry 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



# Lecture 3

## *Proactive Simple Location Service (SLS)*

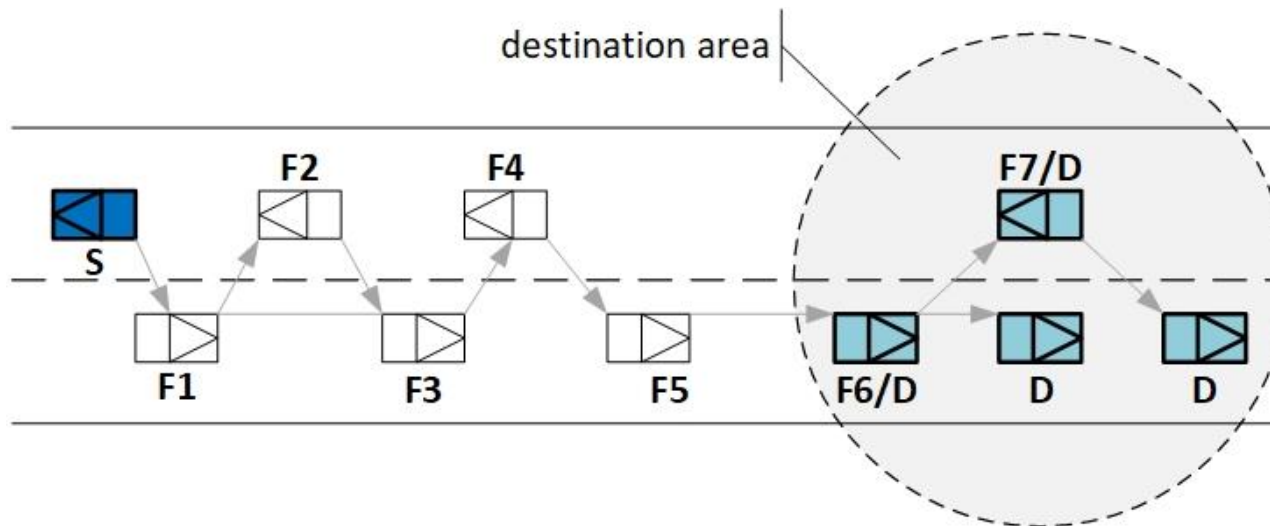
- ▶ Every node in the network keeps **transmitting periodically** at a certain rate its location information as well as that of **its neighbors to all nodes in the neighborhood** and at a lower rate to faraway neighbors
- ▶ The most updated location information is available at any time when needed
- ▶ 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

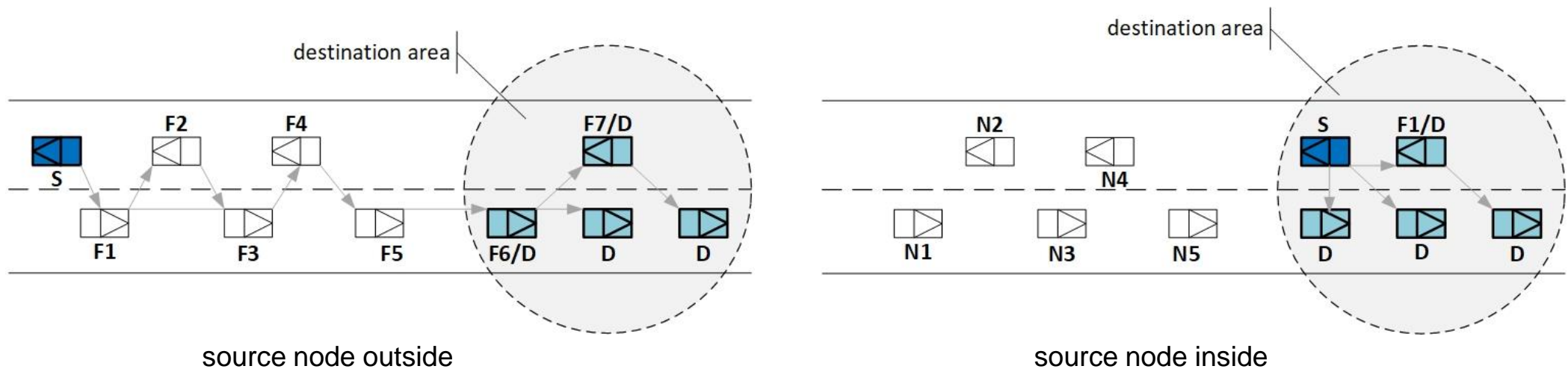
- ▶ **GeoBroadcast** addresses **all (broadcast) stations** within a specific destination area
- ▶ A **location service** to calculate the location of the destination nodes is **not required**, as the information of the destination area is known at source node
- ▶ **Roadwork warning** application which triggers a GeoBroadcast communication to disseminate the area surrounding the segment of road which is relevant to the road work



# Lecture 3

## GeoBroadcast

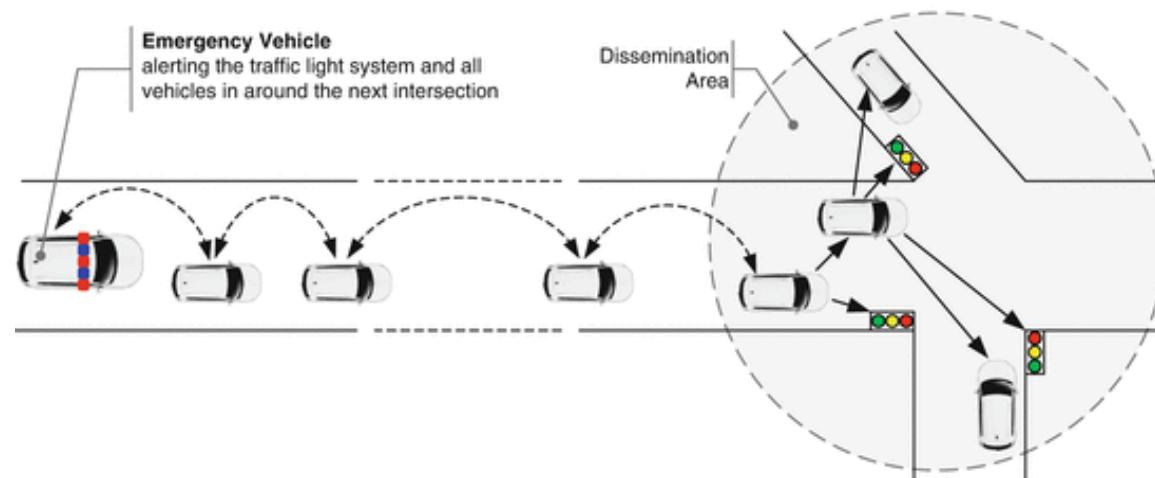
- ▶ The source node can be located either **inside** or **outside** the destination area
- ▶ Stations may rebroadcast the packet if they are located inside the **destination area**



# Lecture 3

## 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**



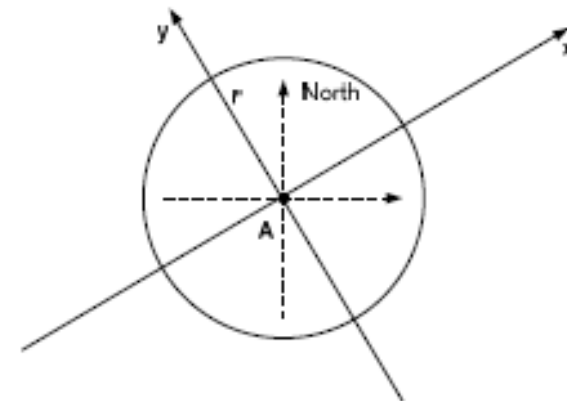
# Lecture 3

## Simple GeoBroadcast Forwarding Algorithm

- ▶ A function  $F(x, y)$  is used to determine whether a forwarder with position  $P(x, y)$  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



# Lecture 3

## *Advanced GeoBroadcast Forwarding Algorithm*

► It relies on **three** main mechanisms

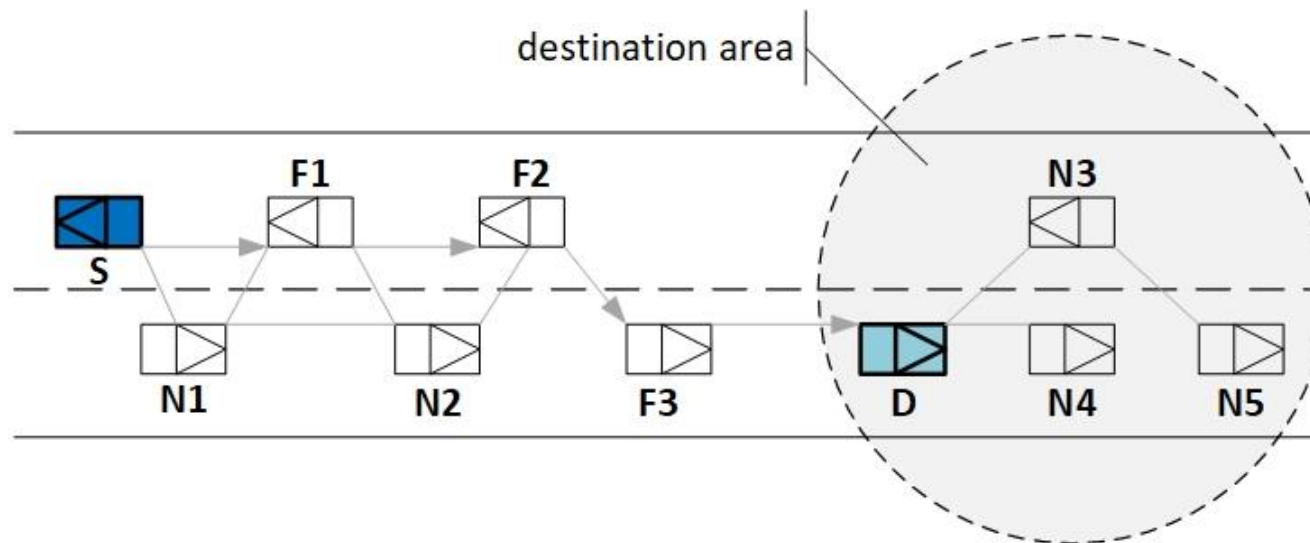
1. **CBF** is used to deal with uncertainties by potential reception failures caused by node mobility, fading phenomena and packet collisions on the wireless medium
2. To minimize the forwarding delay, CBF is **complemented with the selection of one specific forwarder at the sender**, referred to as 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

## *Duplicated 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

## *Duplicated 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

## *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”

