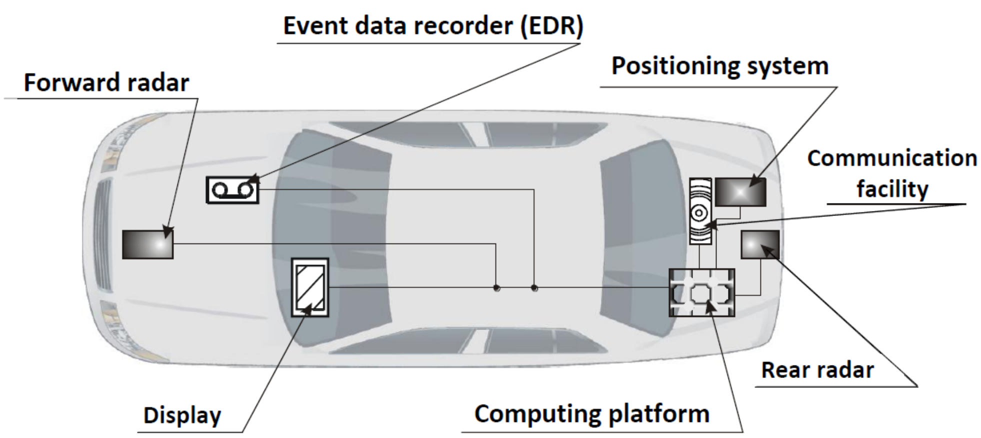
Vehicular Ad-Hoc Networks (VANET)

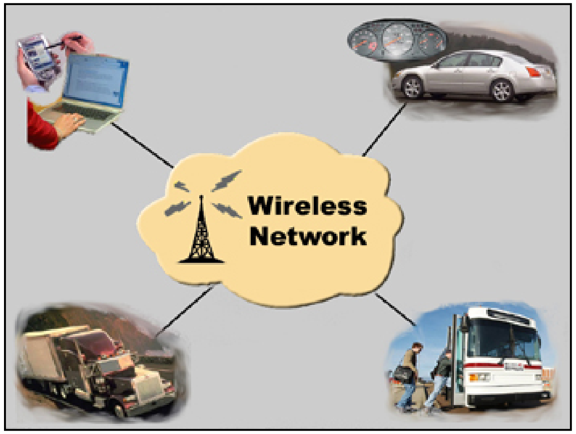
Outline

- Introduction to vehicular networks
  - What are vehicular networks?
  - Why vehicular networks?
- Characteristics of VANETs
- Routing in VANETs
- Conclusion

What are Vehicular Networks?

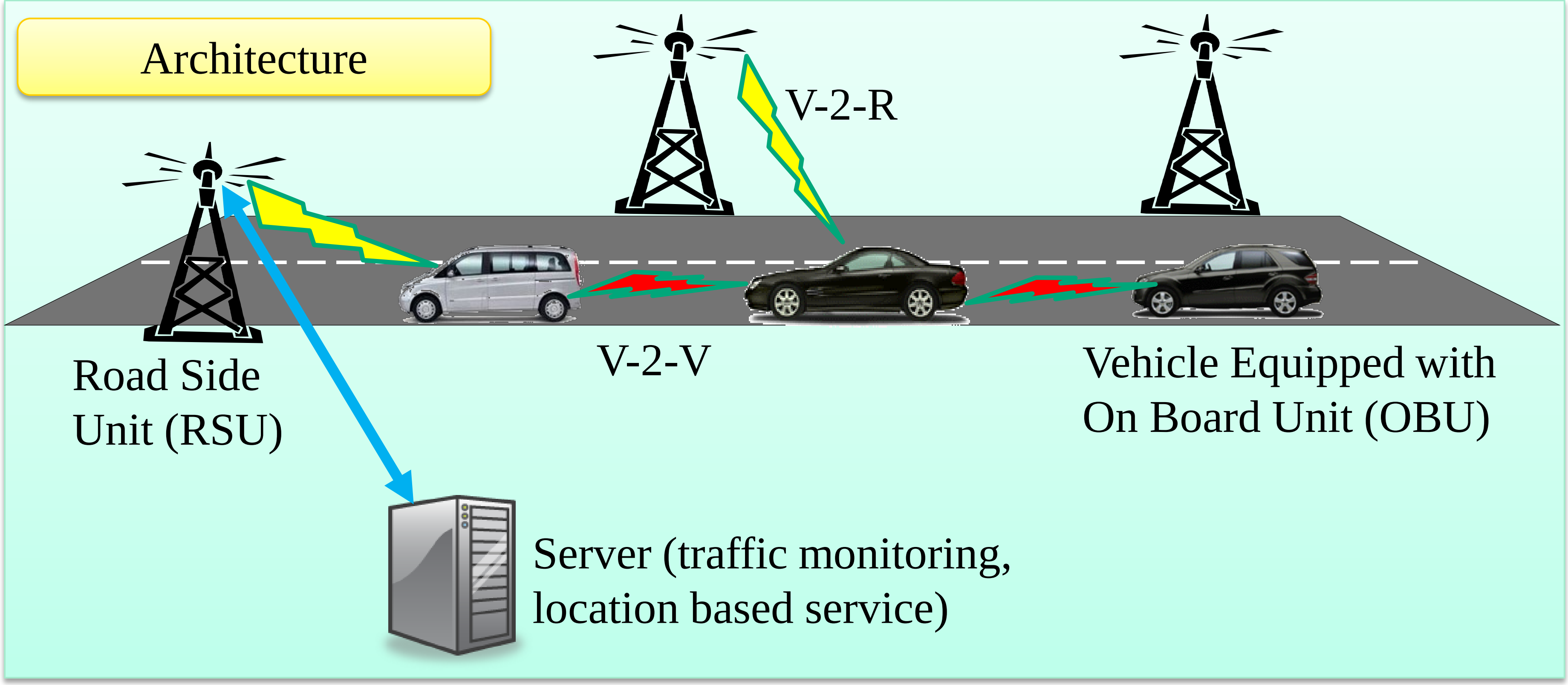
- A vehicle is an integrated system with on-board sensors, computers and communication devices
- Vehicular network is an emerging technology to enable vehicles to communicate wirelessly and form a network on road





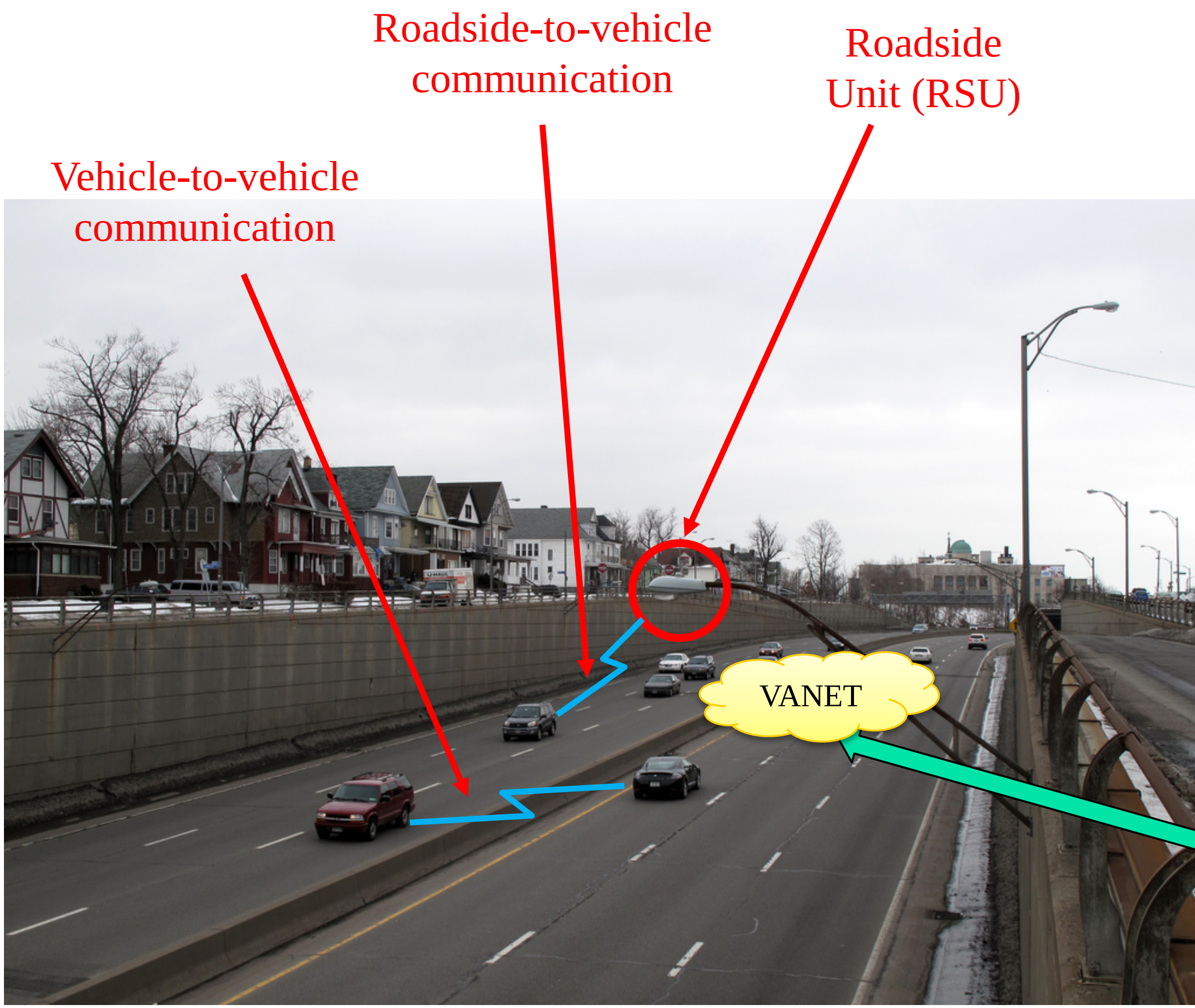
Smart Car Model: © J. P. Hubaux, S. Capkun, and J. Luo, “The Security and Privacy of Smart Vehicles“.

Architecture of Vehicular Networks



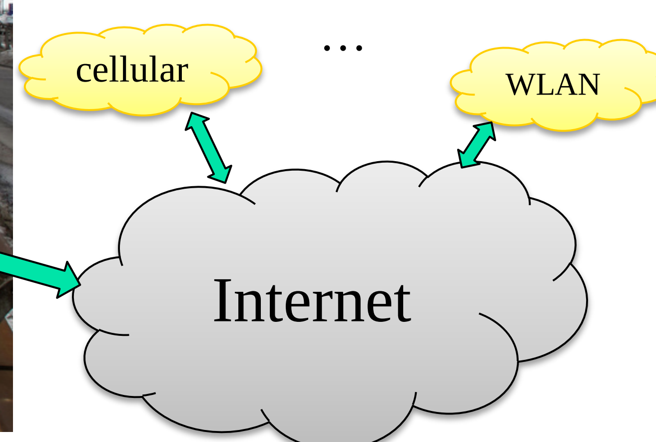
- In 1999, FCC has allocated a specific spectrum band (5.850 – 5.925GHz) on Dedicated Short Range Communication (DSRC) for the exclusive use of vehicular communications
- In 2010, IEEE 802.11p - Wireless Access in Vehicular Environments (WAVE)

Integrated Communication System



The Internet acts as the backbone of the network platform:

- various wireless networks provide the front-end accesses to the Internet
- supporting pervasive data access and mobile computing

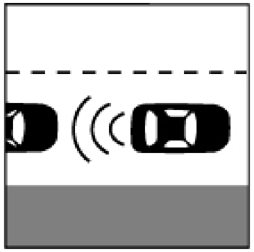


Growing Trend of VANETs

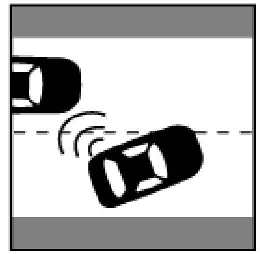
- VANET is a solution to connected cars
  - Internet Access: cars become gateways to Internet access for passengers
  - Road-safety Enhancement: the new technology enhances safety by facilitating vehicles to communicate with their external environment
- VANETs make the on-road life safer, more interesting and productive

[1]. http://www.kpmg.com/global/en

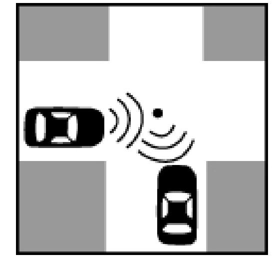
Safety Applications



Co-operative Collision Warning



Lane Change Warning

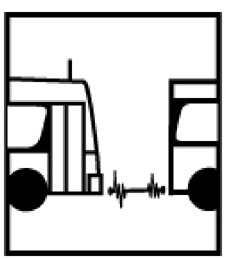


Intersection Collision Warning

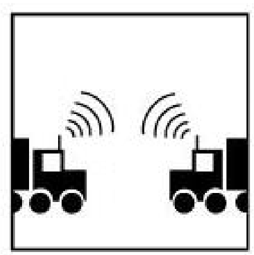
Approaching Emergency vehicle

Rollover Warning

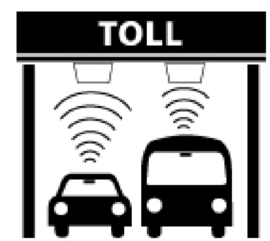
Work Zone Warning



Coupling/Decoupling



Inter-Vehicle Communications



Electronic Toll Collection

Why Vehicular Networks?

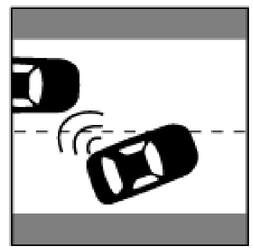
We already have cellular networks, and many WiFi hotspots around us:

Why vehicular networks?

Fast and Direct Communication

- Fast, direct and efficient communications in proximity
- Desirable for urgent safety communications

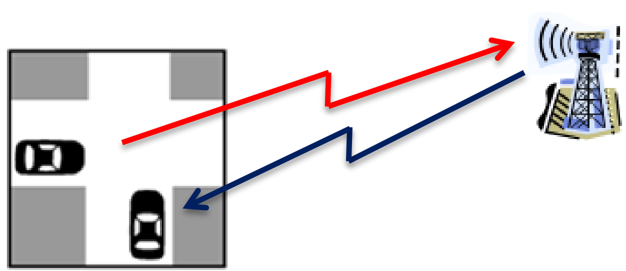
Intersection Collision Warning



Lane Change Warning

Approaching Emergency vehicle

- Traditional cellular networks are indirect, slow and costly to attain the same usage



Low Cost

- Cost-effective approach for infotainment applications
- Cellular Networks
  - Need to pay monthly subscription fee
  - Guaranteed data volume, but not guaranteed download speed and delay!
- Vehicular networks: cheap and efficient services by
  - Enabling vehicles to exchange contents stored in buffers
  - Cooperative communication to download Internet contents

[5] http://www.bell.ca, retrieved on 5th Sept from

Characteristics of VANETs

- Highly dynamic topology
  - Due to high speed of movement between vehicles
- Sufficient energy and storage
- Geographical position assisted routing
  - forward packets to specific geographical areas
  - Mobility modeling and predication
- Various communications environments
  - Highway traffic scenarios
  - City (Urban) scenarios
- Interaction with on-board sensors
  - GPS, speed sensors, steering sensors, ……

Routings in VANETs

- Ad hoc routing
  - Prediction-based AODV (Ad-hoc On-demand Distance Vector) routing
    - Prediction of nodes mobility, as nodes are moving along roads
    - Each node dynamically maintains a distance vector to other nodes via node mobility prediction
- Position-based routing (GPS-assisted routing)
  - Greedy Perimeter Stateless Routing (**GPSR**)
  - Greedy Perimeter Coordinator Routing (**GPCR**)
- Cluster-based routing
  - Forming stable cluster structure

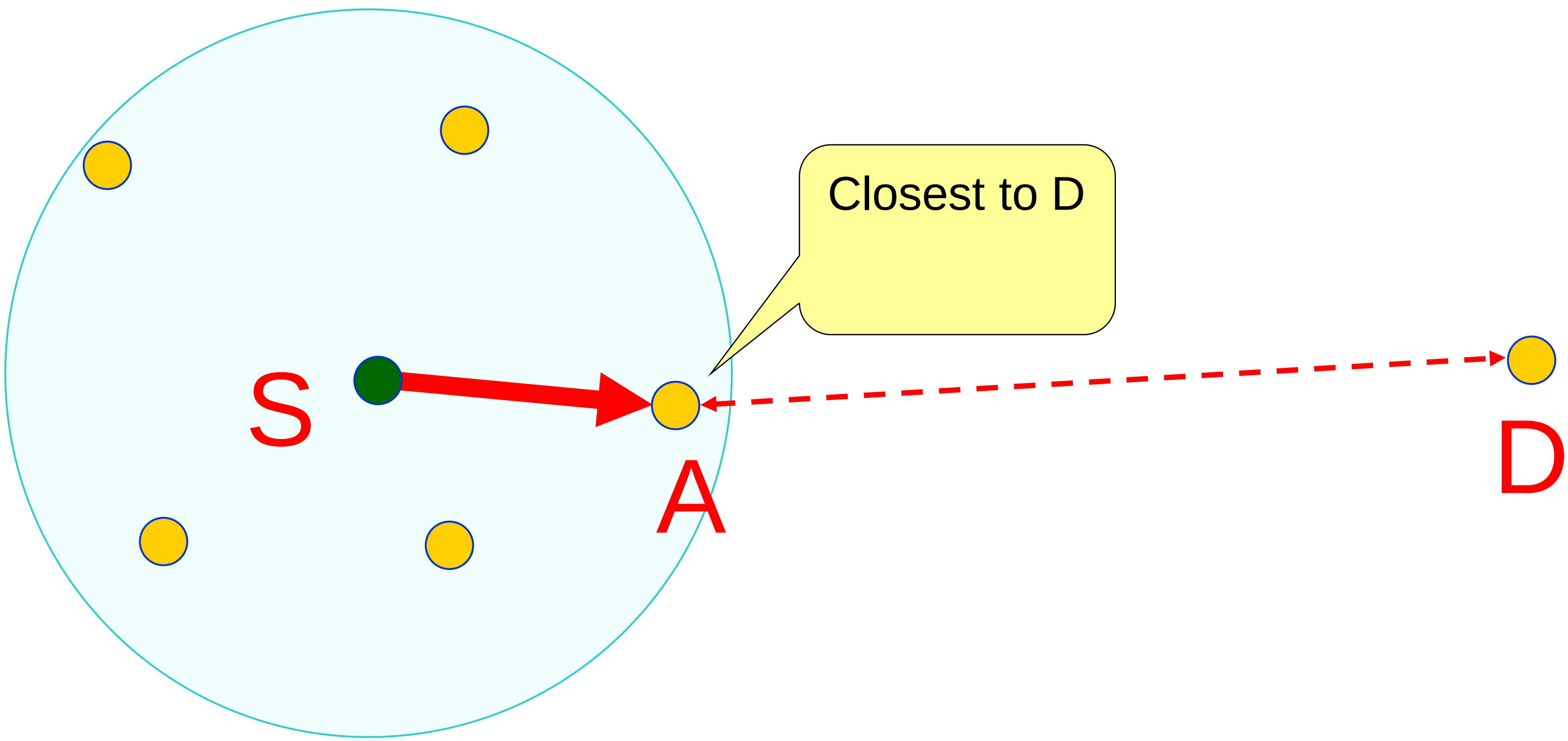
Greedy Perimeter Stateless Routing

Greedy Perimeter Stateless Routing (**GPSR**)

- Combine greedy routing with perimeter routing
- Greedy routing mode: forwards the packet to the node that is geographically closest to the destination
- Perimeter routing mode: to get out of the local minimum where greedy fails
- Suitable to city street VANETs

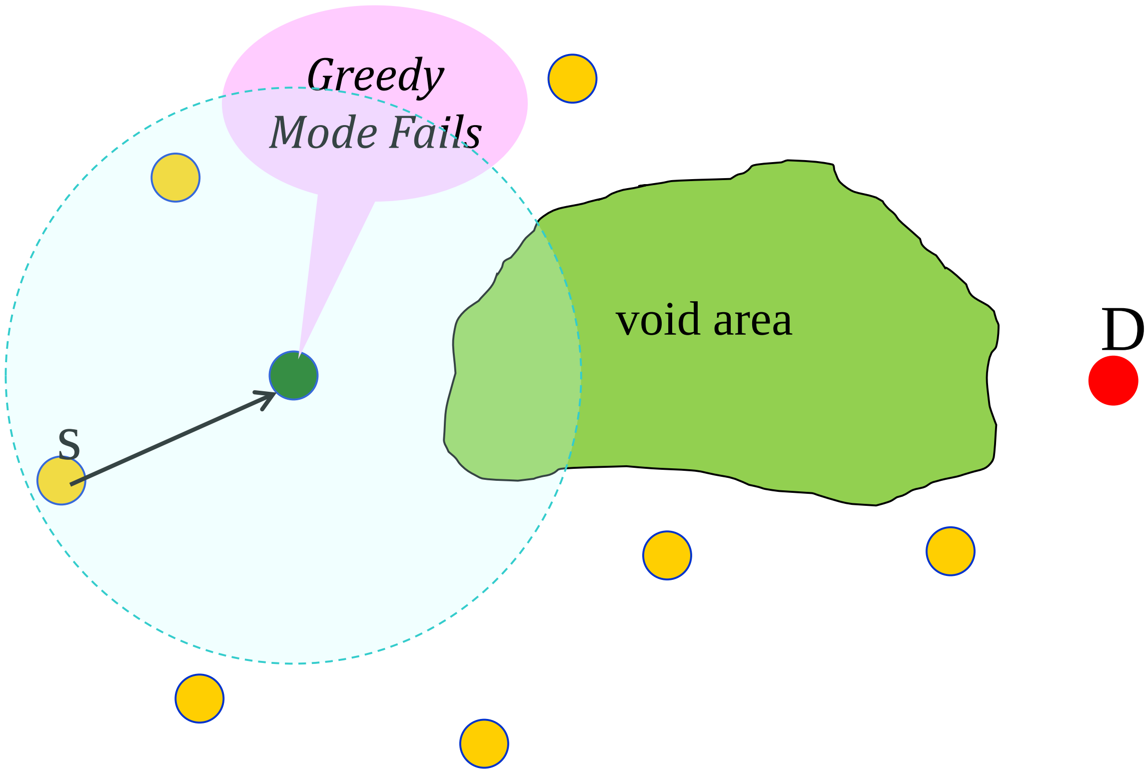
GPSR: Greedy Forwarding

- Select the neighbor that is geographically closest to the destination as the next hop



Greedy forwarding does not always work!

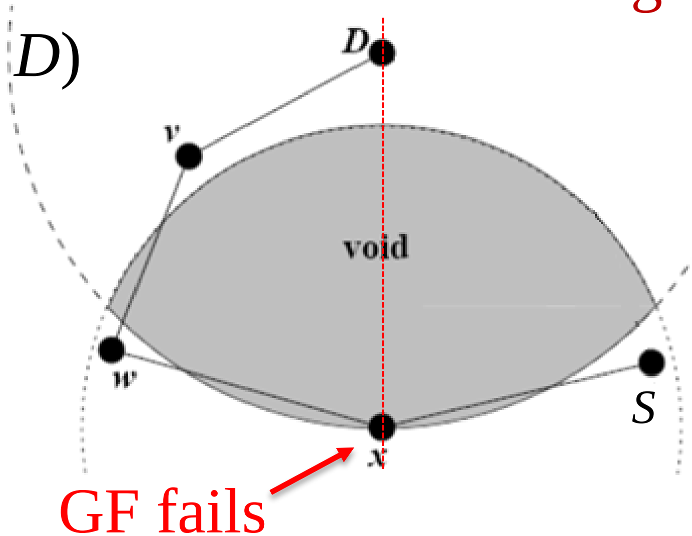
- Stuck in a local minimum where Greedy Forwarding (GF) fails



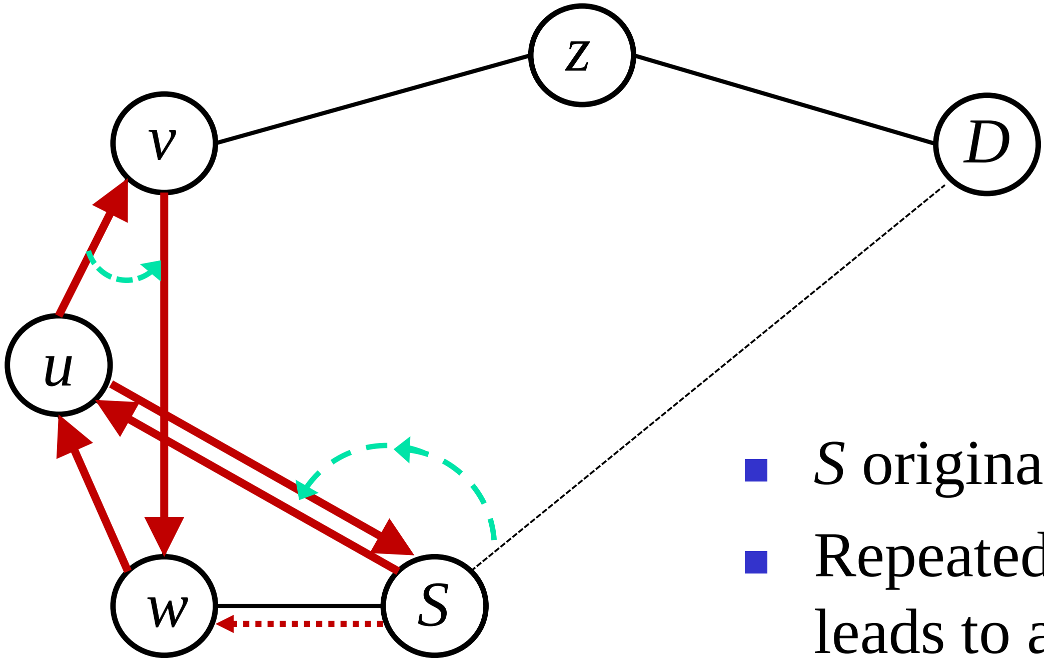
Perimeter routing: Left-hand Rule

The left hand rule (perimeter mode)

- When arriving at node *x* from source *S*, *x* finds GF fails. It switches to perimeter routing mode
- *x* forwards the packet to the 1st edge in anti-clockwise from the axis of *xD* (start of perimeter mode)
- Each node thereafter forwards the packet to the 1st outgoing edge in anti-clockwise from the incoming edge (notice: NOT from the axis to *D*)

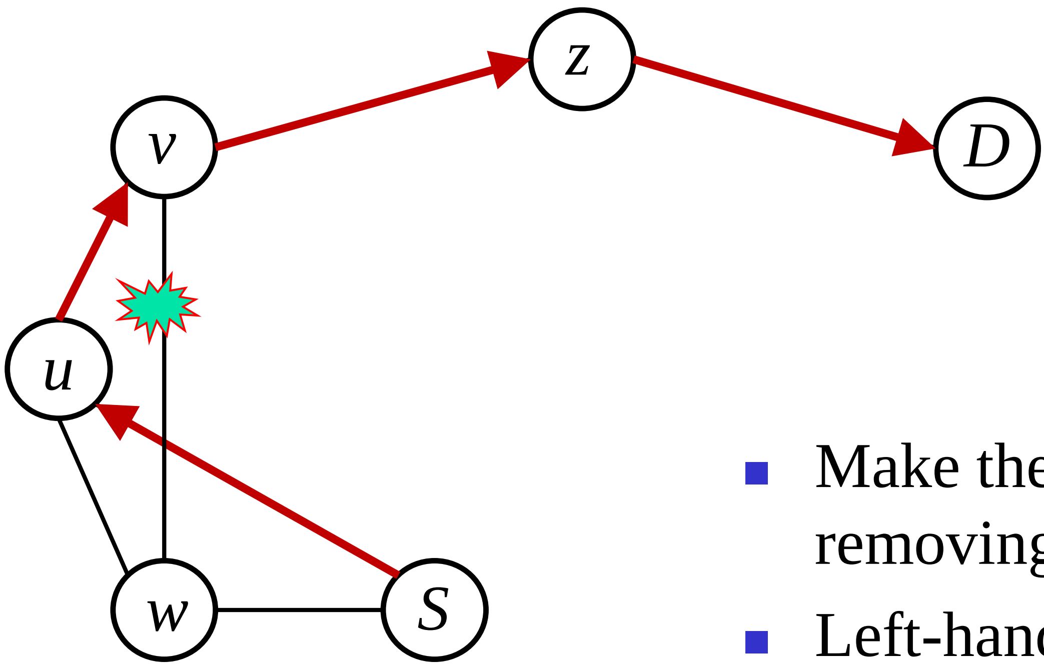


Left-Hand Rule Does Not Work with Crossing Edges



- *S* originates a packet to *D*
- Repeatedly applying left-hand rule leads to a circle *S*-*u*-*v*-*w*-*u*-*S*-……

Remove Crossing Edge



- Make the graph planar by removing (*w*,*v*) from the graph
- Left-hand rule leads to the path *S*-*u*-*v*-*z*-*D*

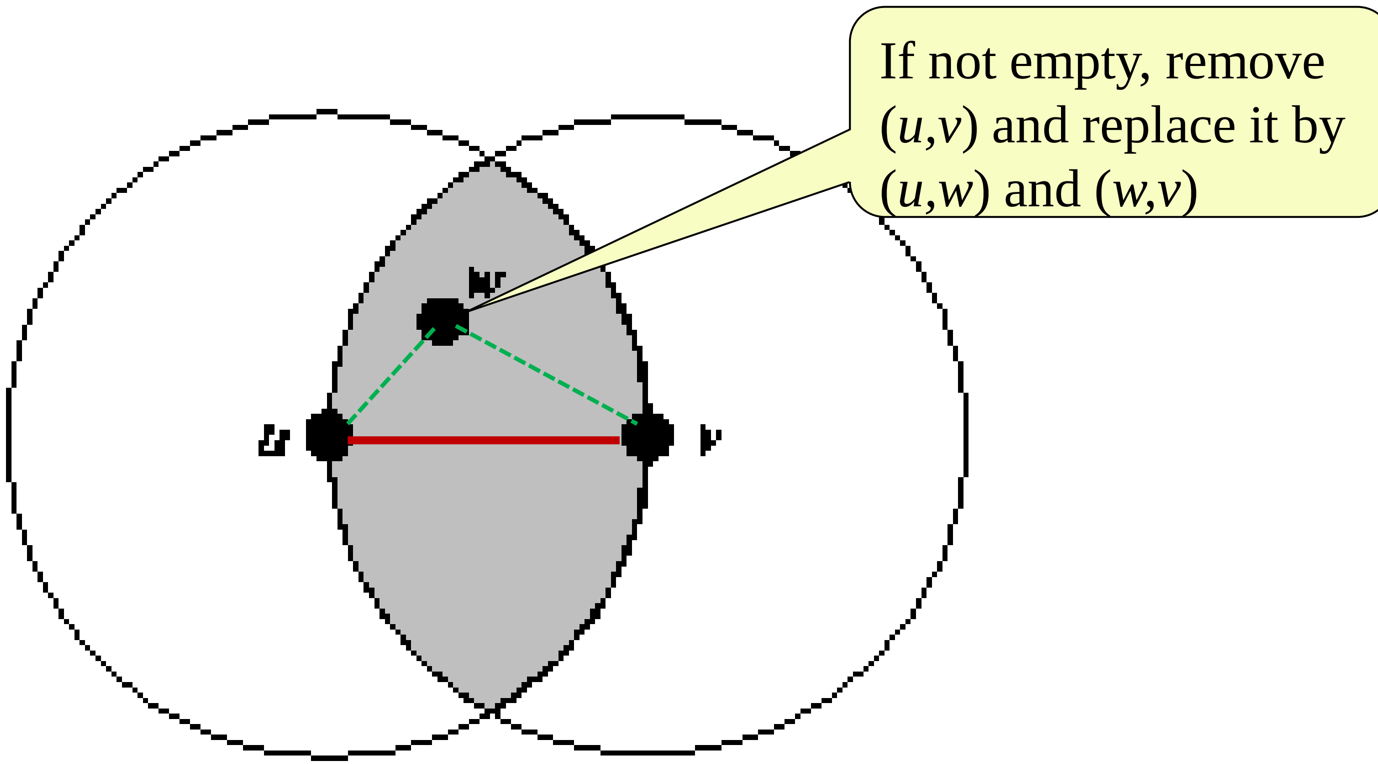
Make a Graph Planar

- Convert a connected graph to planar non-crossing graph by removing “bad” edges
  - Ensure the original graph will not become disconnected
  - Two types of planar graphs:
    - Relative Neighborhood Graph (RNG)
    - Gabriel Graph (GG)

Relative Neighborhood Graph (RNG)

- Edge (u,v) exists iff no other vertex w is present within the overlapped area of two circles centered at u and v:

  No node w, $w \neq u$ or v: $\max\{d(u,w), d(v,w)\} < d(u,v)$

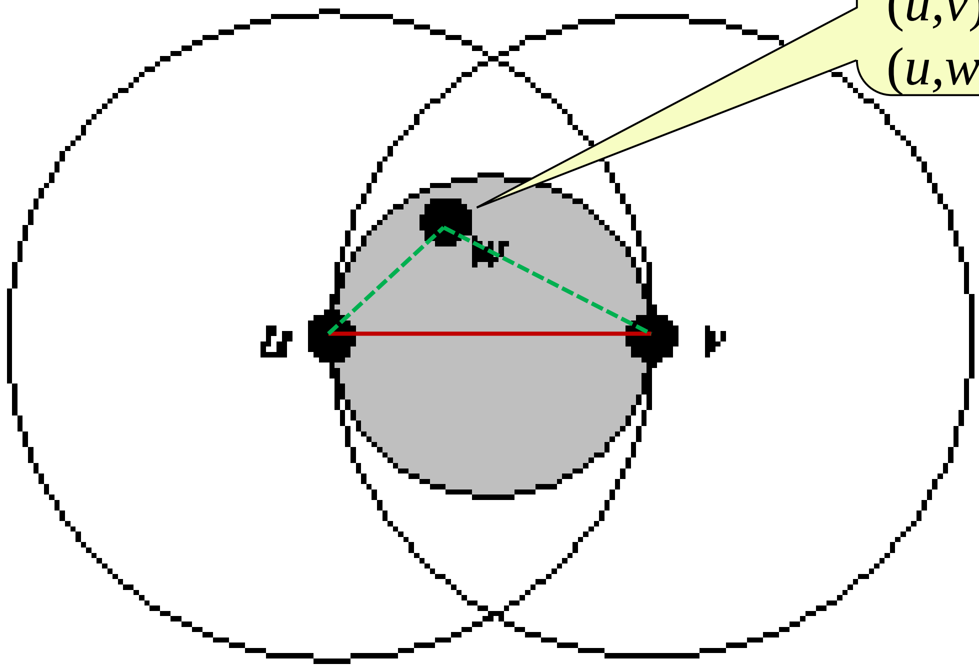


Gabriel Graph (GG)

- Edge (u,v) exists iff no other vertex w is present within the circle of diameter uv:

$$\text{No node } w,\ w \neq u \text{ or } v:\ d^2(u,w) + d^2(w,v) < d^2(u,v)$$

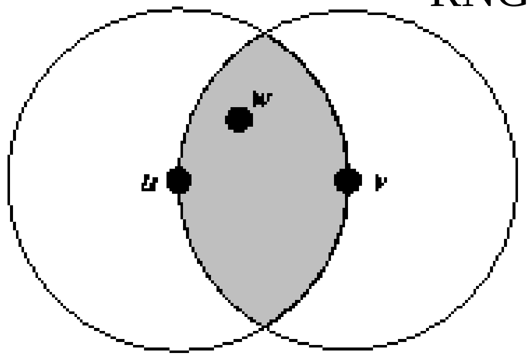
If not empty, remove (u,v) and replace it by (u,w) and (w,v)



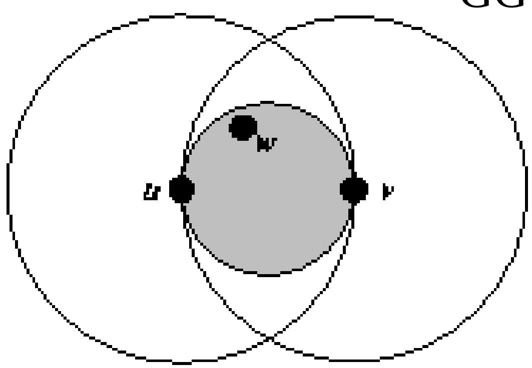
Properties of GG and RNG

- RNG is a sub-graph of GG
  - Because RNG removes more edges than GG
- Both RNG and GG are planar graphs
- If the original graph is connected, RNG and GG is also connected
- Routing on RNG/GG is also the most energy efficient
  - Energy costly long edges are replaced by energy efficient shorter edges

RNG

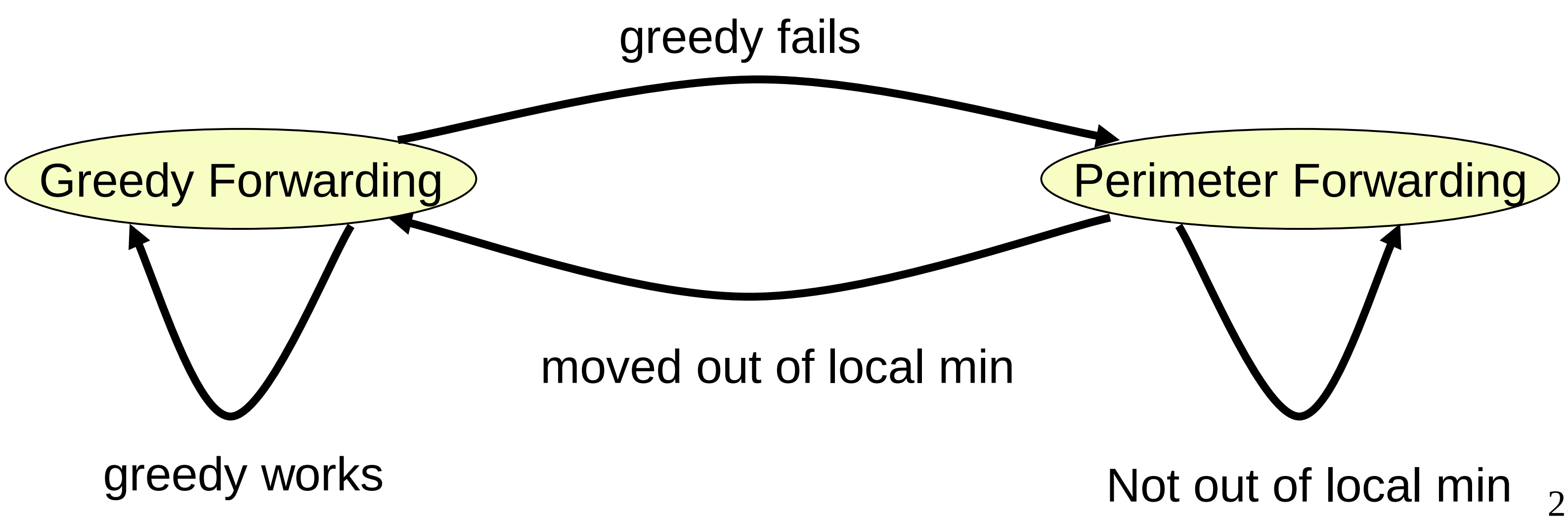


GG

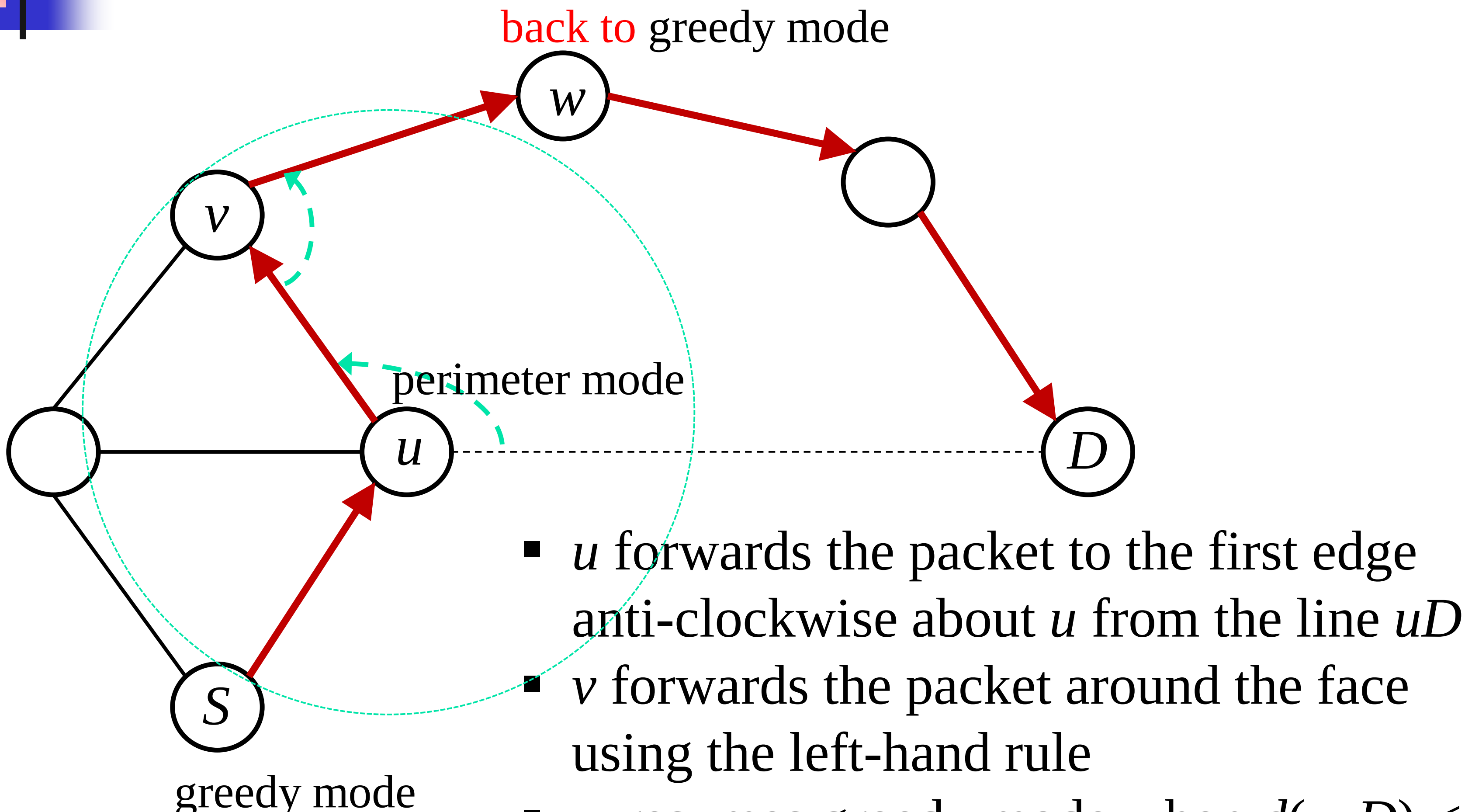


GPSR: switching between GF & Perimeter modes

- Combine greedy forwarding + perimeter routing
  - Use greedy forwarding whenever possible
  - Switch to perimeter mode when greedy mode fails and remember this location L_p
    - L_p is the switching point from greedy to perimeter mode
  - Resume greedy mode when the current node is closer to the destination than L_p (it is out of local minimum now)



Example of GPSR

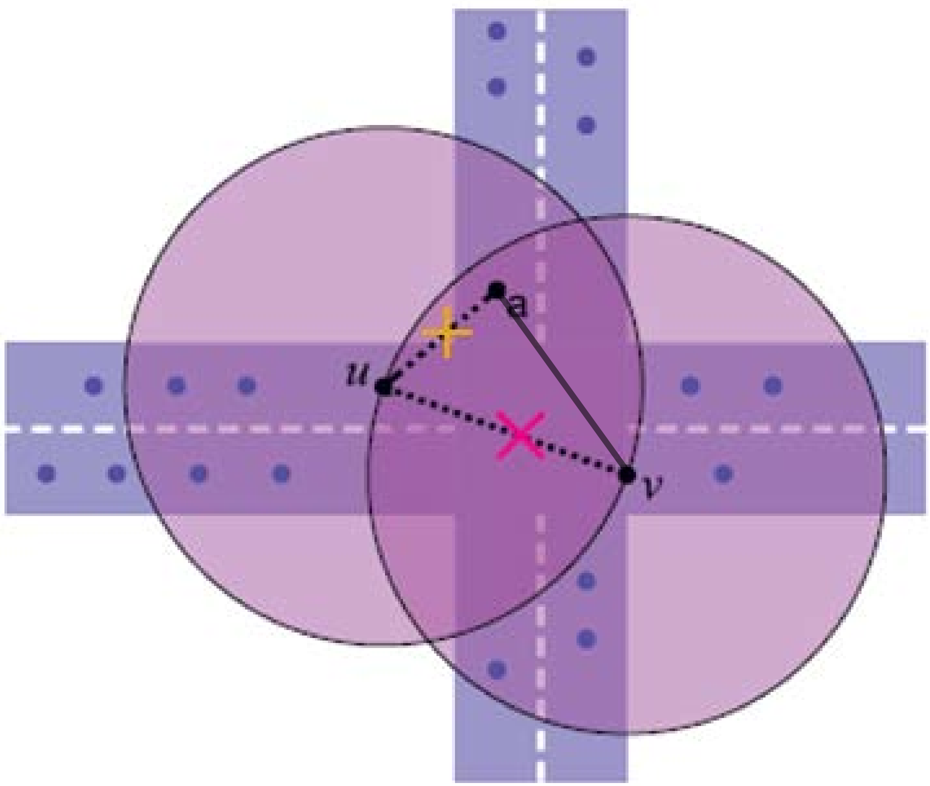


- *u* forwards the packet to the first edge anti-clockwise about *u* from the line *uD*
- *v* forwards the packet around the face using the left-hand rule
- *w* resumes greedy mode when $d(w,D) < d(u,D)$ (*u* is the switching point to the perimeter mode)

Problems with GPSR

Nodes may be disconnected (e.g., *u* and *v*)

- Some links are removed in planarization (link *uv*)
- Some links are blocked by obstacles, such as buildings and trees, (link *ua*)

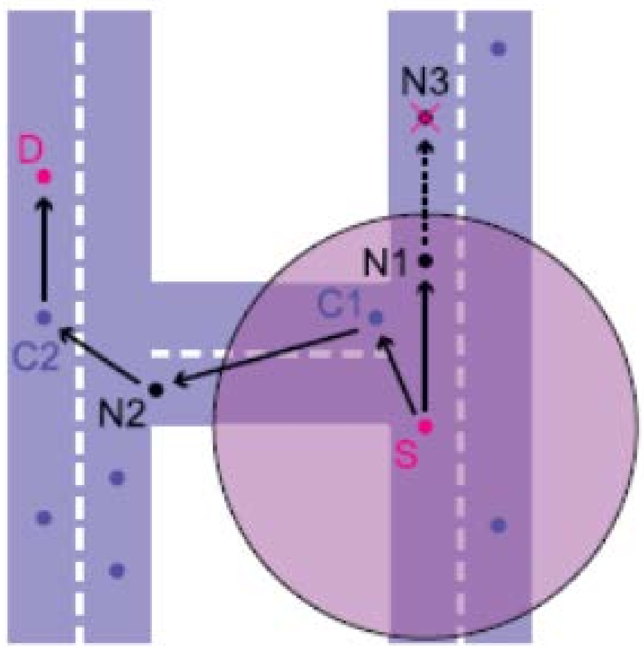


Greedy Perimeter Coordinator Routing

- GPCR consists of two parts:
  - A restricted greedy forward: always forward to junction nodes (coordinators) during greedy forwarding
  - A repair strategy: left-hand rule towards destination
- No need of planarization of a VANET topology
  - Easy to be applied to practical systems
  - Connectivity of the original VANET won't be affected

GPCR: Restricted Greedy Routing

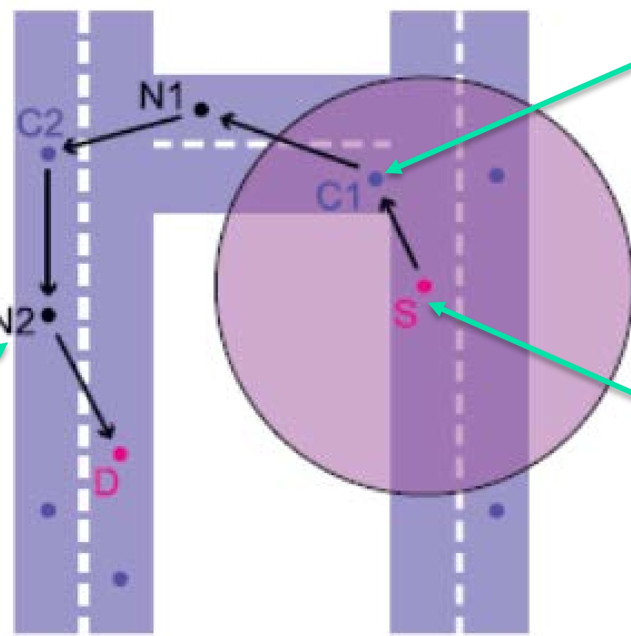
- Restricted Greedy: packets always be forwarded to a node on a junction (called *Coordinator*) rather than being forwarded across the junction.



- Source S wants to forward the packet to the destination D.
- If a regular greedy forwarding is used, the packet will be forwarded beyond the junction (Coordinator C1) to N1, which leads to a local minimum at N3.
- But by forwarding the packet to coordinator C1, an alternative path to the destination can be found without getting stuck in a local minimum.

GPCR: Repair Strategy

- Repair Strategy: At each junction, decide which street the packet should follow next by the left-hand rule
- Restricted Greedy: In between junctions, apply restricted greedy routing until reaching the next junction



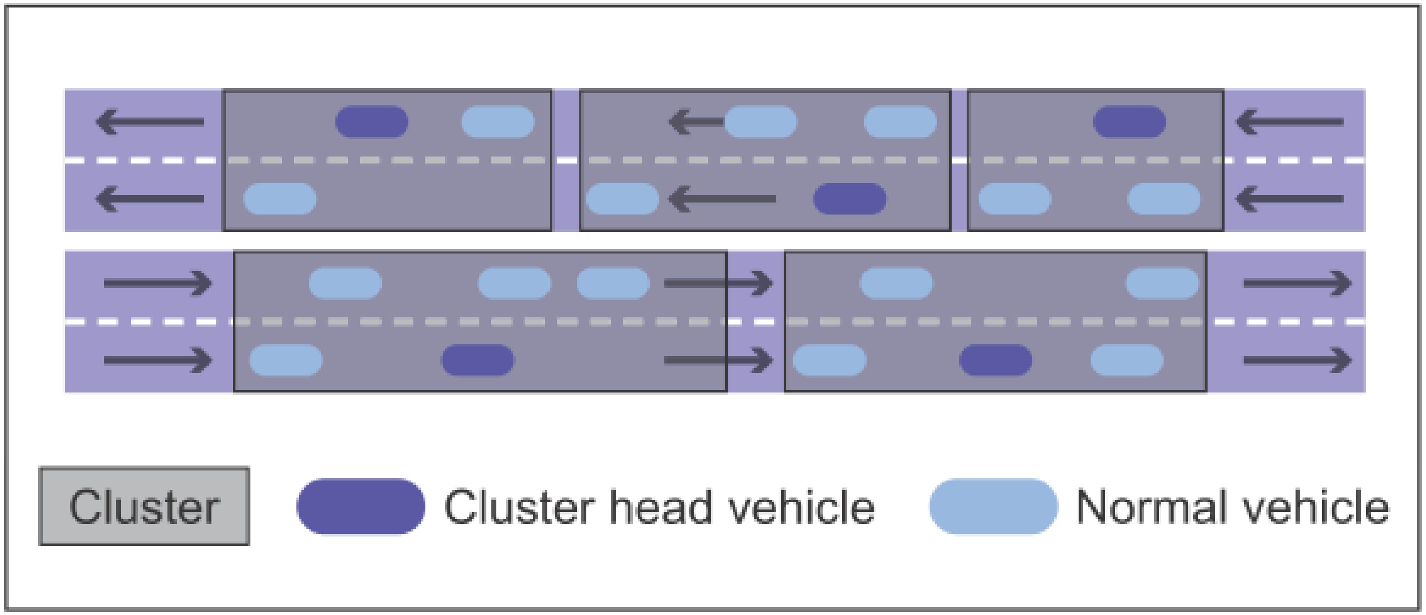
left-hand rule chooses the next street in anti-clockwise from the direction the incoming packet

If d(N2,D) < d(S,D), switch to restricted greedy routing

initial local minimum

Cluster-Based Routing

- Intra-cluster communication is via direct links
- Inter-cluster communication is via the cluster heads



Cluster-Based Routing

- MANETs clustering techniques are unstable in VANETs, since the clusters created are too short-lived to provide scalability with low communications overhead
- VANETs need o build relatively stable clustering structure
  - Vehicles that are close in distance and have similar speeds are clustered together
  - The most stable vehicles are elected as cluster heads

Stable Neighbors

- Classify vehicle neighbors into stable neighbors and non-stable neighbors
- Two neighboring vehicles are stable neighbors if their relative speed is less than $\pm\Delta v_{th}$
- When a vehicle initiates a cluster formation request, ***only its stable neighbors*** participate in the cluster formation process

Cluster-Head Election Metric

- Suitability value (*u*) represents the priority of a node to become a cluster head
- The value of *u* is based on the mobility of its neighbors
  - Calculated by considering only stable neighbors
  - Nodes having higher number of stable neighbors (*m*), closer avg distance to stable neighbors, and closer speed to the avg speed of stable neighbors have a higher suitability value:

    $u = m \cdot e^{-\alpha(|d_{norm}|+|v_{norm}|)}$, where $0 < \alpha \leq 1$,

    d_{norm} (or v_{norm}): the difference between d (or v) and d_{avg} (or v_{avg}) of stable neighbors

Cluster-Head Self Election

- A node whose speed is the slowest among all non-clustered nodes in 2-hop neighbors initiates a cluster formation process by broadcasting a *InitCluster* msg
- Upon receiving this *InitCluster* msg, each non-clustered node calculates its suitability u, and a time T_{wait} (waiting time before announcing the CH election)
  - higher u leads to shorter T_{wait}: $T_{\text{wait}} = \left\lfloor \frac{N_{\max} - u}{N_{\max}} * (CW_{\max} - CW_{\min}) + CW_{\min} \right\rfloor$
- If T_{wait} expires before receiving any *FormCluster* msg, the node wins the CH election and sends a *FormCluster(ID)* msg; otherwise it quits the election
- When a non-clustered node receives *FormCluster(ID)* msg, it sets CH as this *ID* (it becomes a member of this cluster)

Cluster Formation: join a cluster

- Only stable neighbors of the new CH join the new cluster
- If vehicle *n* has multiple CHs available to join, it calculates the *RT* (remaining time) within the transmission range (*r*) of these CHs, and joins the CH that it has the longest *RT* with:
  - $RT = \frac{r - dis(n,CH)}{\Delta v}$, if the vehicle is behind the CH and is slower than CH; or if the vehicle is ahead of the CH and is faster than CH (the case of drifting away)
  - $RT = \frac{r + dis(n,CH)}{\Delta v}$, if the vehicle behind the CH but is faster than CH; or if the vehicle is ahead of the CH but is slower than CH (the case of drawing closer, then drafting away)

Summary of Cluster-based Routing

- CH election is based on the stability value
  - making cluster structure more stable
- T_{wait} allows nodes with higher stability value to wait less before replying election msg
  - avoiding coordination and message collision
  - making the election complete early
- Members choose a CH to join according to their remaining time of the link with the CH
  - making the connection with the CH more stable

Summary

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    - Prediction-based AODV
  - Position-based routing
    - GPSR
    - GPCR
  - Cluster-based routing
    - Forming stable cluster structure

Exercise

In the cluster-based method for VANET:

1) Each node calculates a stability value *u* by:

$$u = m \cdot e^{-\alpha(|d_{norm}|+|v_{norm}|)}$$

A node with a higher value *u* has a higher priority to become the CH. Explain what are the factors that are considered in the above formula.

2) Each node needs also to calculate a time T_{wait}, which is the time that a node has to wait before it announces a CH election message (*FormCluster*). T_{wait} is important to reduce the conflict of CH election. What are the factors that should be considered for calculating T_{wait}?

$$T_{wait} = \left\lfloor \frac{N_{max} - u}{N_{max}} * (CW_{max} - CW_{min}) + CW_{min} \right\rfloor,$$

where N_{max} is the No. of 2-hop neighbors whose speeds are higher than this node, CW_{max} and CW_{min} are *max* and *min* Contention Window size for CSMA/CA.