Leveraging Content Connectivity and Location Awareness for Adaptive Forwarding in NDN-based Mobile Ad Hoc Networks

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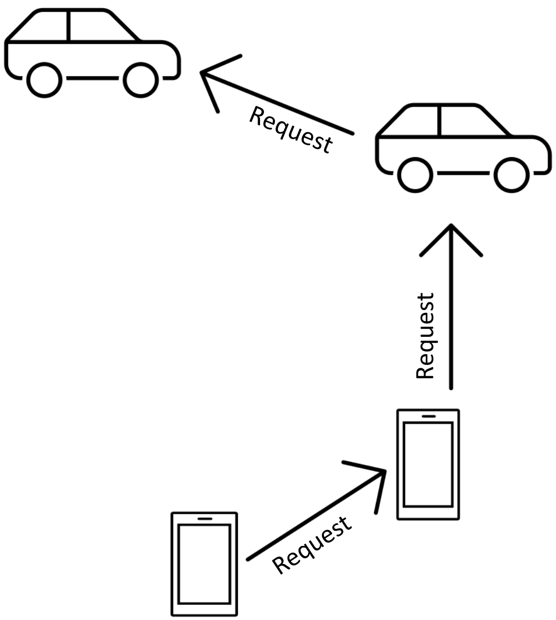
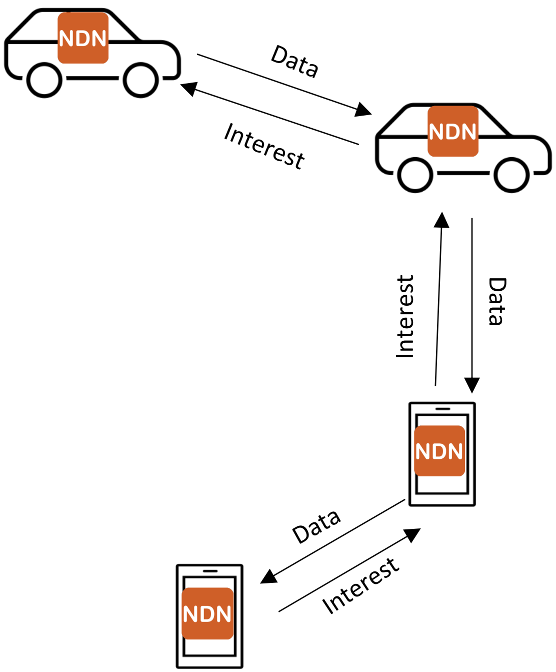
Motivation

- Wireless networks are ubiquitous.
- Mobile Ad-Hoc Networks are useful in many scenarios.
    - Vehicle-to-Vehicle Communication.
    - Military Missions.
    - Emergency Response.
- Data sharing enables vehicles to acquire information not in sensors' range.
    - Avoid collision
    - Know road information and change route accordingly.



NDN over MANET

- NDN has unique advantages over TCP/IP for wireless mobile communication.
  - Name-based Forwarding [1]
  - Pervasive caching
  - Network-Layer Security [2, 3]
- Develop a forwarding strategy for NDN-based MANET that can make smart forwarding decisions with minimal or no routing information.



[1] L. Wang, R. Wakikawa, R. Kuntz, R. Vuyyuru, L. Zhang, "Data Naming in Vehicle-to-Vehicle Communications", IEEE INFOCOM Workshop on Emerging Design Choices in Name-Oriented Networking, 2012
[2] M. Chowdhury, A. Gawande, L. Wang, "Secure Information Sharing among Autonomous Vehicles," ACM IoTDI, April 2017
[3] M. Chowdhury, A. Gawande, L. Wang, "Anonymous Authentication and Pseudonym-Renewal for VANET in NDN," ACM ICN, poster Sept. 2017

Forwarding in NDN-based MANET

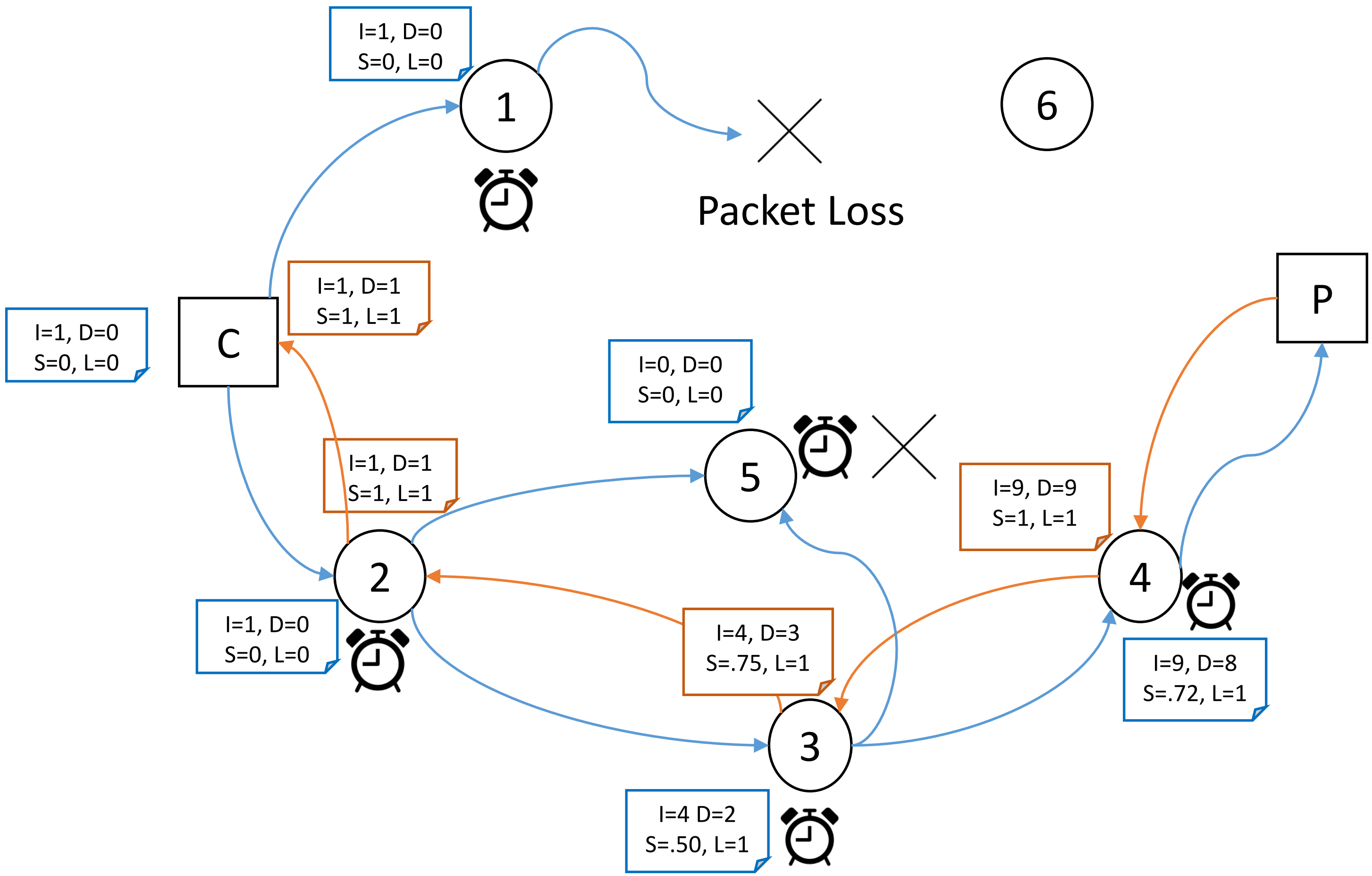
- VANET via Named Data Networking (VNDN) [1]
  - Nodes farther from consumer will wait less time before forwarding.
- Navigo [2]
  - Nodes closer to the Data location will be selected for forwarding.
- VNDN and NAVIGO are geo-location based routing.
  - Need to resort to broadcast when location information is not available.
- STRIVE [3]
  - Centrality Score → Interest satisfaction rate of a vehicle → A measure of the connectivity of a vehicle.
  - Topology based: Vehicular Network is always changing → Frequently update the table.
  - Generalized score.

1. G. Grassi, D. Pesavento, G. Pau, R. Vuyyuru, R. Wakikawa, and L. Zhang."VANET via named data networking." IEEE INFOCOM WKSHPS, 2014.
2. G. Grassi, D. Pesavento, G. Pau, and L. Zhang, "Navigo: Interest forwarding by geolocations in vehicular named data networking." IEEE WoWMoM, 2015
3. J. Khan and Y. Ghamri-Doudane. "Strive: Socially-aware three-tier routing in information-centric vehicular environment." IEEE GLOBECOM, 2016.

Content Connectivity and Location-Aware Forwarding (CCLF) Design

- Tableless timer-based forwarding.
  - Each node takes forwarding decision independently.
- Leverage Geo-Location in forwarding whenever available.
  - Not mandatory in Forwarding.
- Uses Centrality Score in Forwarding.
  - Interest satisfaction ratio.
  - Prefix-wise Centrality Score.
- Node-Density Aware Interest/ Data suppression mechanism to encounter Broadcast storm.

How CCLF Works - Overview



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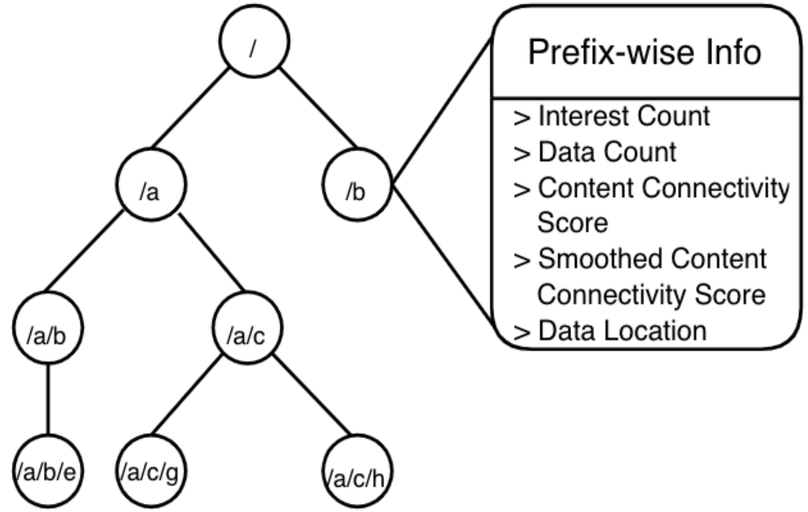
Prefix-based Content Connectivity Score

- Each node in the C-L tree has a name-prefix and it's corresponding score and location.
- The score represents how successful a node has been in getting data under a name prefix.



C-L Tree

- Score of a prefix j: $CCS_j = \frac{D_j + \sum_{i \in Desc(j)} D_i}{I_j + \sum_{i \in Desc(j)} I_i}$
- Periodically update Smoothed Score $\widehat{CCS_{i,N}} = \alpha \, CCS_{i,N} + (1-\alpha)\, \widehat{CCS_{i,N-1}}$

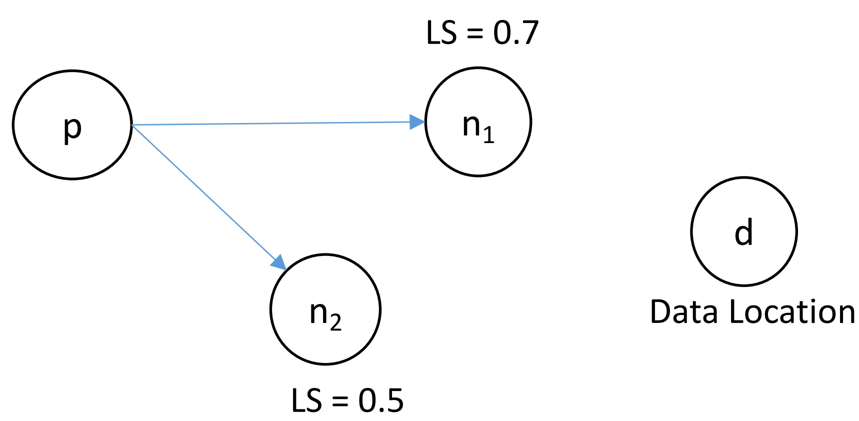
Wait-time Calculation: Location Score

- A node waits for **FW-Delay timer** before forwarding an Interest. The timer is calculated using **Location Score** and Centrality Score.

Distance of this node from Data location

$$LS = 1 - \frac{Dist\ (n,d)}{\max(Dist(n,d), Dist(p,d))}$$

Distance of Previous node from Data location



Wait-time Calculation: Weight of a Node

- The weight of a node for a prefix:

$$w = \beta \cdot \widehat{CCS} + (1 - \beta) \cdot LS$$

Smoothed Centrality Score for the prefix

Location Score for the prefix (0 if Location not available)

- FW-Delay timer of the node for the prefix :

$$t = \begin{cases} min(\frac{1}{w}, T), & \text{if } w > 0 \\ T, & \text{if } w = 0 \end{cases}$$

At the beginning, when a node doesn't have Location Information or Centrality Score

T is an upper bound on t . The forwarding timer is set to a random value uniformly distributed between $0.5t$ μs and $1.5t$ μs

Density Aware Packet Suppression

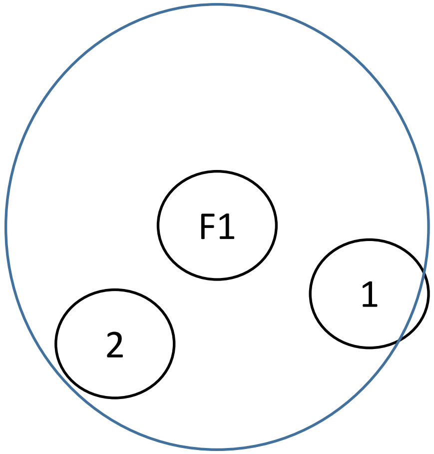
- Receives same Interest before timer expires

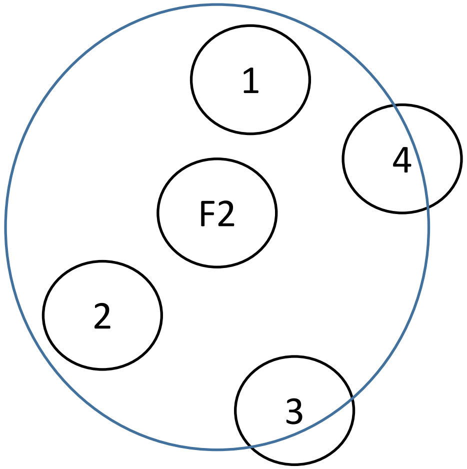
  → Calculates suppression probability

$$p = \min(K * n, 1)$$

$K = Suppression\ Constant, n = Number\ of\ Neighbors$

- Higher the number of neighbors, higher probability of suppression.
- We have run experiments to find a suitable value for *K* in suburban and urban environment.

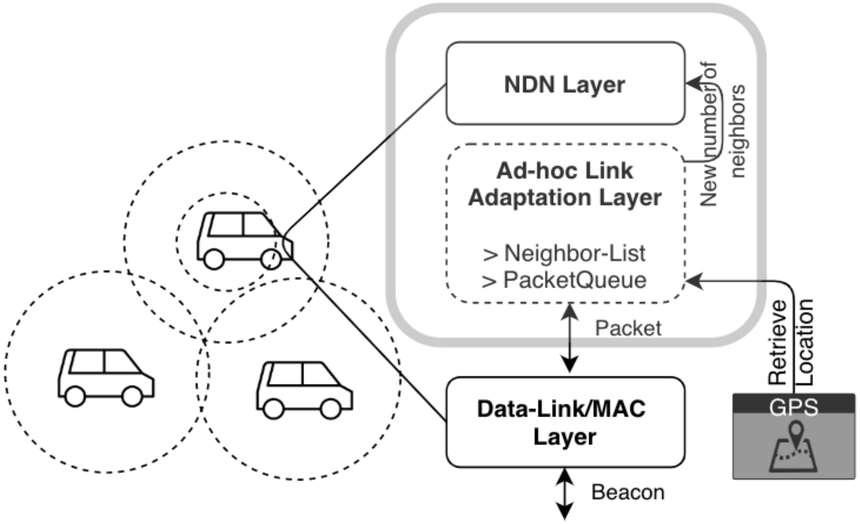




F2 will have a higher probability to cancel forwarding and suppress a received packet.

Ad-Hoc Link Adaptation Layer (ALAL)

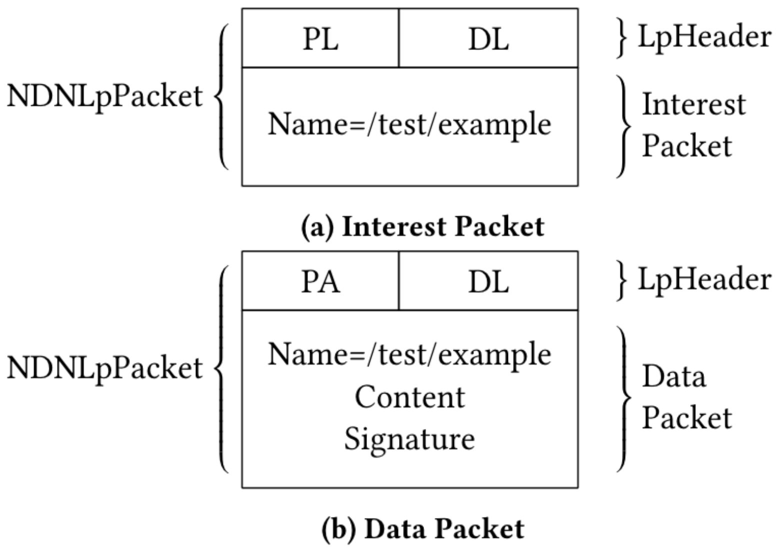
- Enhance reliability of packet forwarding in Mobile Ad-hoc Network.



- Roles of ALAL
  1. Keep track of number of the neighbors in Tx range.
  2. Queue outgoing packet when no neighbors around.
  3. Get location information from GPS and add Location header.

Obtaining Geo-location and Prefix Information

- Add Location Header in NDNLP[1] packet.
    - Previous node's location
    - Data location
- Interest can carry the Location header.
- Data can carry Data-Location field and Prefix Announcement header.



- C-L tree will be populated by the Prefix Announcement and Location in the Data packet

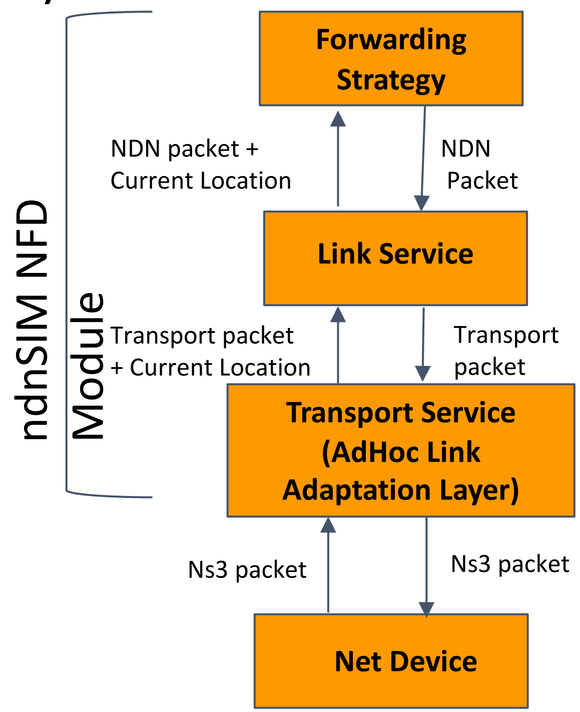
[1] Shi, Junxiao, and Beichuan Zhang. "NDNLP: A link protocol for NDN." *NDN, NDN Technical Report NDN-0006* (2012).

How does CCLF address existing schemes' limitations?

- Topology-based proactive schemes:
  - High overhead ← **CCLF** has no routing messages
- Topology-based reactive schemes:
  - High delay ← **CCLF** uses name-prefix based connectivity score to avoid initial learning delay.
- Pure geo-location based schemes:
  - Local optimum and broadcast ← **CCLF** uses connectivity score to get around local optimum and avoid broadcast storm.

Implementation and Evaluation

- Forwarding Strategy is implemented in ndn-cxx library and NFD.
  - Added NDNLP headers in ndn-cxx.
  - Forwarding Strategy in NFD.
  - AdHoc Link Adaptation Layer in Transport Service
- Simulation using ndnSIM.
  - Traffic Trace and Map: SUMO[1]
- Metric
  - Interest Satisfaction Ratio
  - Data Fetching Delay
  - Message Overhead



[1] Krajzewicz, Daniel, et al. "SUMO (Simulation of Urban MObility)-an open-source traffic simulation." *Proceedings of the 4th middle East Symposium on Simulation and Modelling (MESM20002)*. 2002.

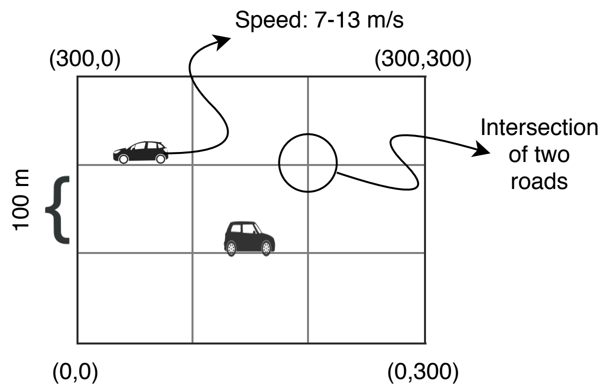
Simulation Parameters (Vehicular Topology)

Communication Parameter Setting

Parameters	Value
Propagation Loss Model	Range Propagation
WiFi Transmission Range	100 m
Wifi Standard	802.11p
Physical Mode	OfdmRate6MbpsBW10 MHz
Propagation Delay Model	Constant Speed
Data Packet Payload Size	1200 B

Traffic Parameter Setting

Parameters	Value
Road Topology	3x3 Grid
Area	300x300 m^2
Speed	7-13 m/s

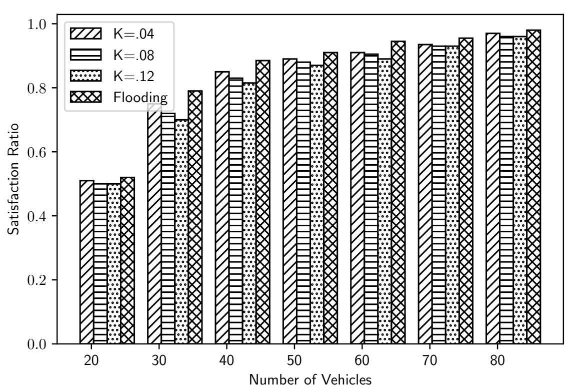


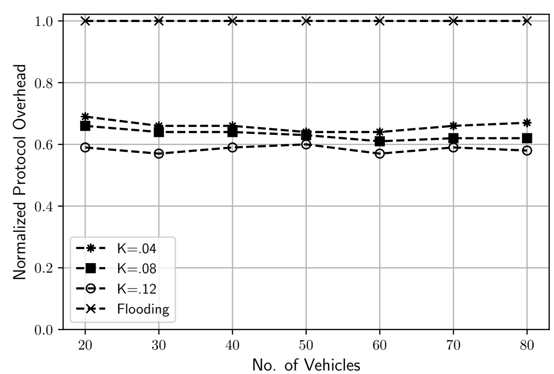
Determining the value of K

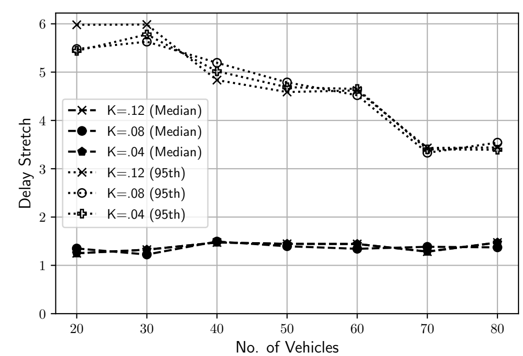
- Suppression Constant, K = 0.04.

Traffic Condition	No. of Vehicles/Mile / Lane	Median No. of Neighbors (2 Lane)	Median No. of Neighbors (Grid)	Duplicate Suppression Probability (2 Lane)	Duplicate Suppression Probability (Grid)
Sparse	1-12	1-4	1-11	4%-16%	4%-44%
Medium	13-30	5-10	12-26	20%-40%	48%-100%
Dense	31-40	10-15	26-34	40%-60%	100%

- Performance of CCLF for various value of K in Grid topology.

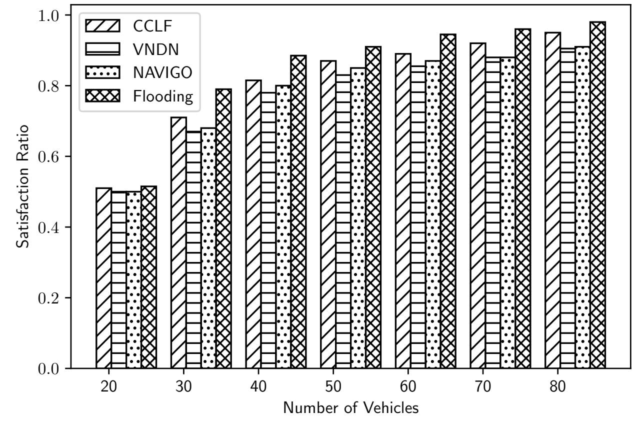


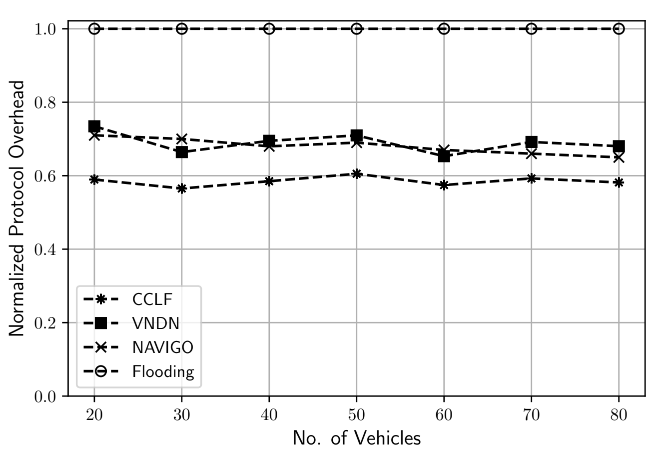


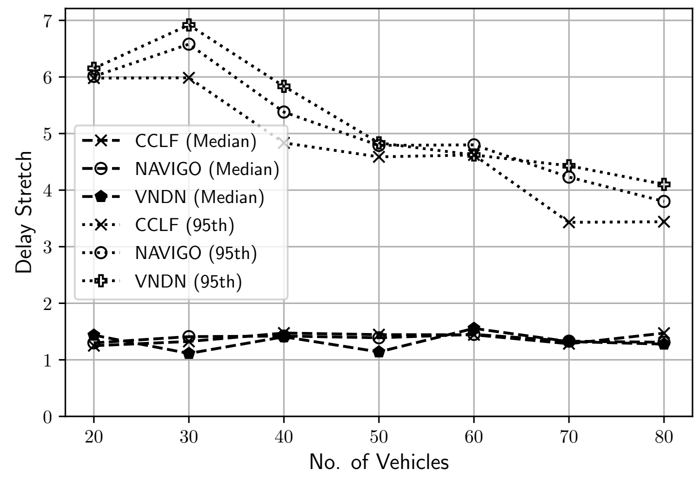


Results: CCLF (With Geo Location)

- One consumer and One producer.
- Consumer sending one interest/second.
- Comparing CCLF with other geo-location-based strategies: VNDN and NAVIGO.

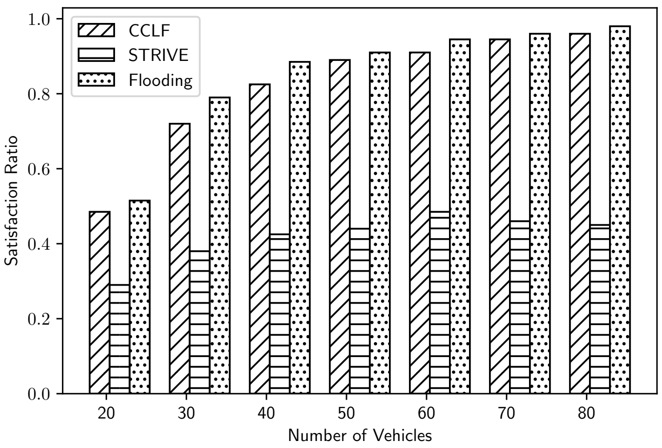


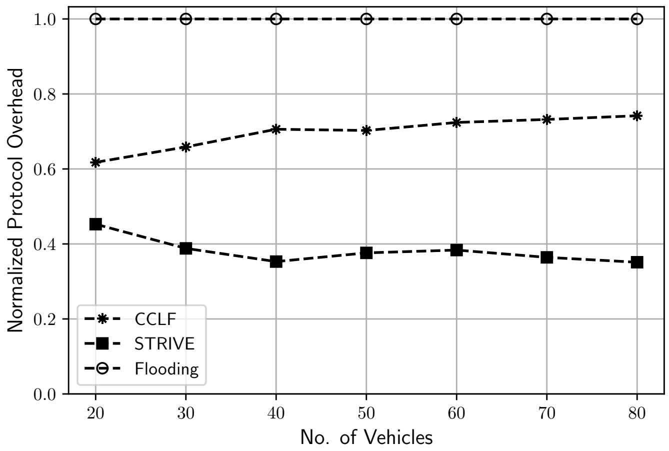


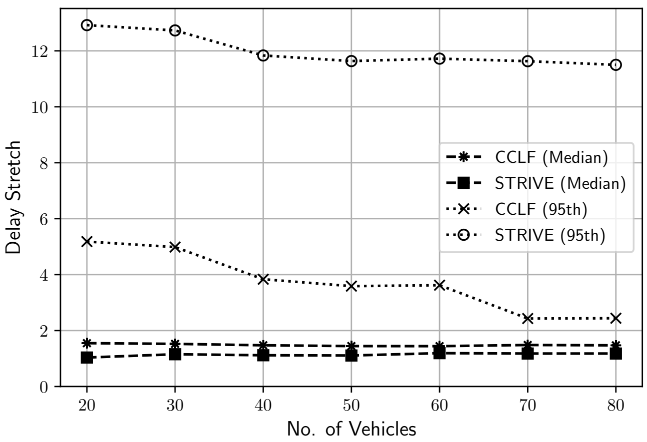


Results: CCLF (W/O Geo Location)

- One consumer and One producer.
- Consumer sending one interest/second.
- Comparing CCLF with a centrality score-based strategy : STRIVE.







Conclusion

- CCLF incurs lower protocol overhead ← Less Flooding + Density-aware packet suppression + Packet queuing at ALAL.
- CCLF incurs lower delay because Name-prefix based connectivity helps:
  - To avoid initial learning delay.
  - To find better connected path to data producer.
- Future Works
  - Study different ways to calculate forwarding timer and suppression probability.
  - Offer guidelines on setting CCLF parameters.