HotICN 2022

2022 5th International Conference on
HOT INFORMATION-CENTRIC NETWORKING

November 24th-26th, 2022
Virtual

Efficient Content Delivery in Vehicular Named Data Networking

Jiangtao Luo (雒江涛)

Chongqing University of Posts and Telecommunications

Hosted by 广东工业大学 Guangdong University of Technology

Organized by 广东工业大学 计算机学院

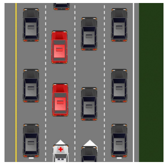
Co-organized by 紫金山实验室 Purple Mountain Laboratories, 北京邮电大学, 江苏省未来网络创新研究院 FNII JIANGSU FUTURE NETWORKS INNOVATION INSTITUTE

Contents

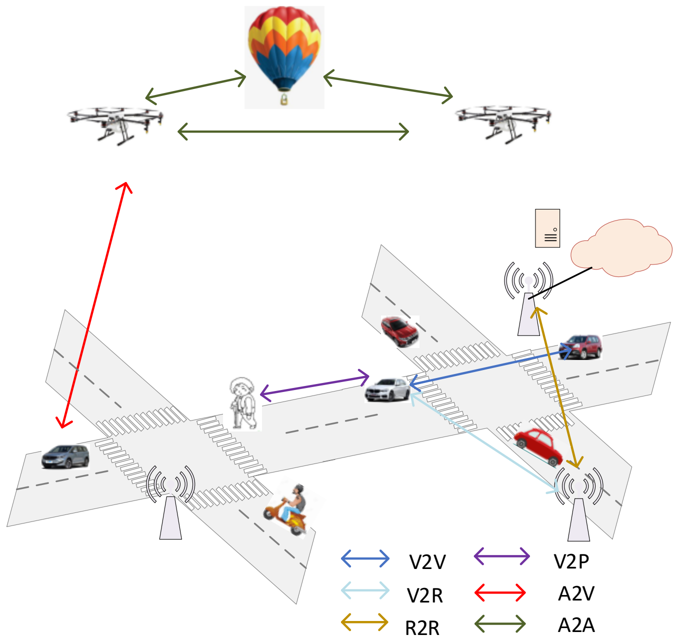
1. Background

❑ Content delivery in vehicular networks

➢ Application scenarios

• Safety	• Convenience	• Entertainment
 **Emergency message**	 **Intelligent transportation system (ITS)**	 **Video**
 **Collision avoidance**		 **VR**
 **Self-Driving**	 **Map**	**music**

➢ Communication models : V2X



Most or all applications → **Content Delivery**

High performance, Good QoE — Efficient

1. Background

❑ Challenges for Content Delivery in VN

VN scenario

- High speed nodes
- Dynamic trajectories
- Various contents and requirements
- Complex environment
- … …

→

Complexities of Networks

- Dynamic topology
- Sporadic link connectivity
- Different QoS requirements
- Collision & Intefreence

→

Challenges to IP

- Slow routing convergence
- Poor Mobile IP
- Unreliable QoS (Best Effort)
- Poor Multicast

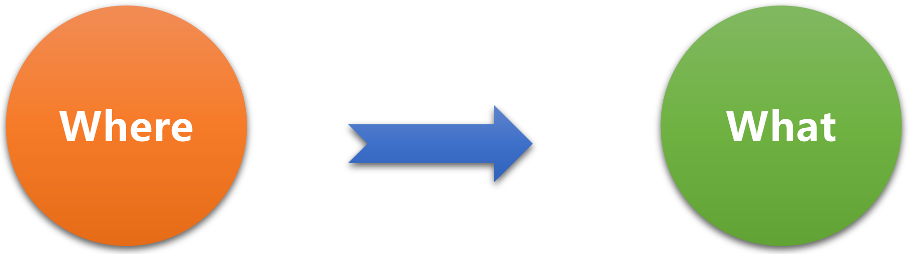
Host centric nature

IP-based VN is inefficient and complex for content delivery

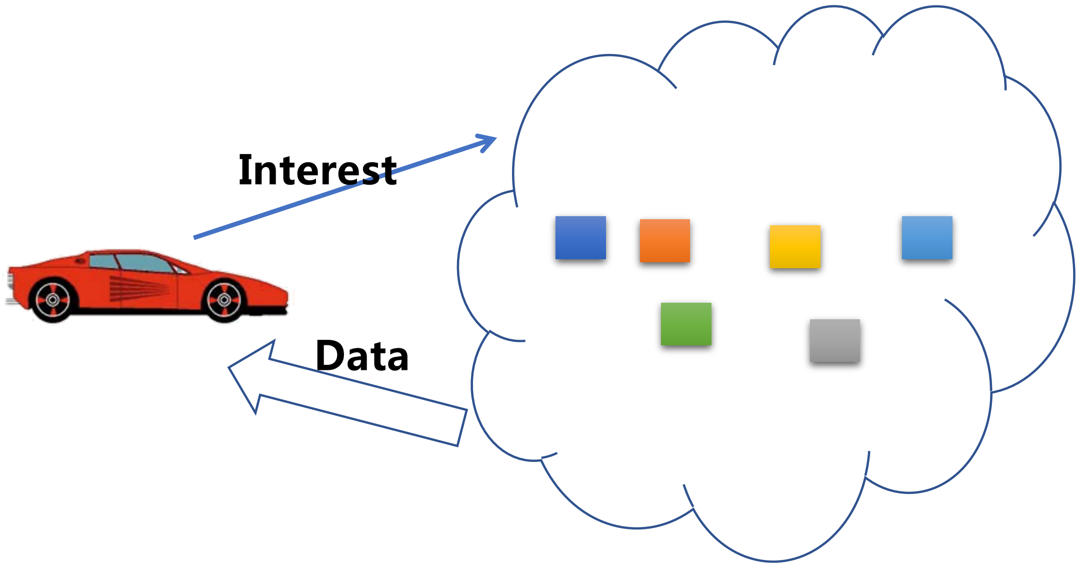
1. Background

❑ Why NDN?

- 2010s, Lixia Zhang's team in UCLA
- Example design of information-centric networking (ICN).
- Focus transition: "**Where**" (Host) to "**What**" (Content)



Hosts **Contents**



Topology changed, but contents still exist

Zhang, Lixia, et al. **Named Data Networking**, *SIGCOMM Comput. Commun. Rev.* , 2014.07

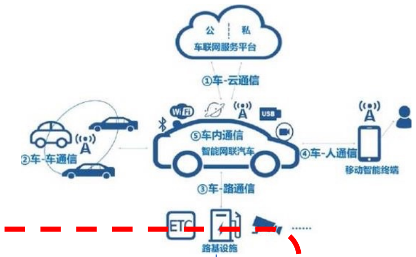
1. Background

❑ NDN-enabled application scenarios

NDN typical applications

Content dissemination

- Content based addressing
- Traffic aggregation
- In-network caching



Vehicular Networks

- connectionless data delivery
- In-network caching
- Data mule

Internet of Things

- connectionless = unlimited connections

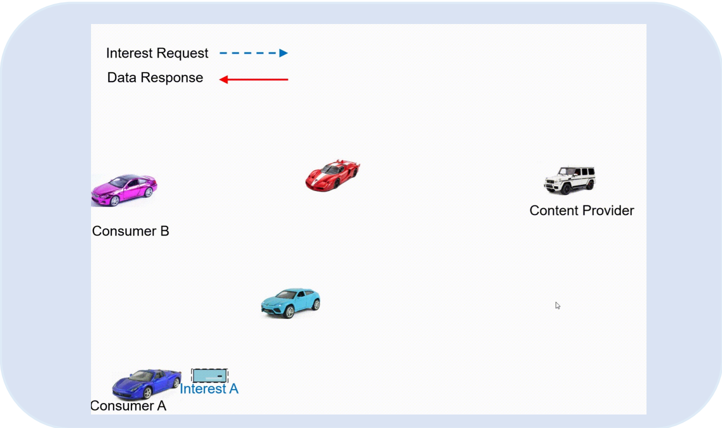
Delay/Disruption Tolerance Network

- Emergency supporting & disaster recovery
  - Infrastructure free communications
- Opportunistic routing

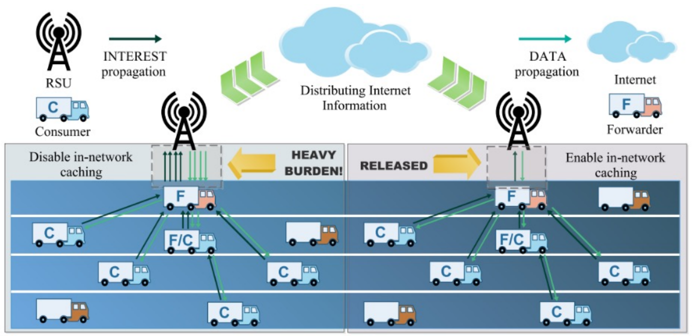
Information-Centric Networking: Baseline Scenarios, IRTF RFC 7476, March 2015

1. Background

❑ Content delivery in V-NDN



Pull-based model



In-network caching: load release/Resource saving

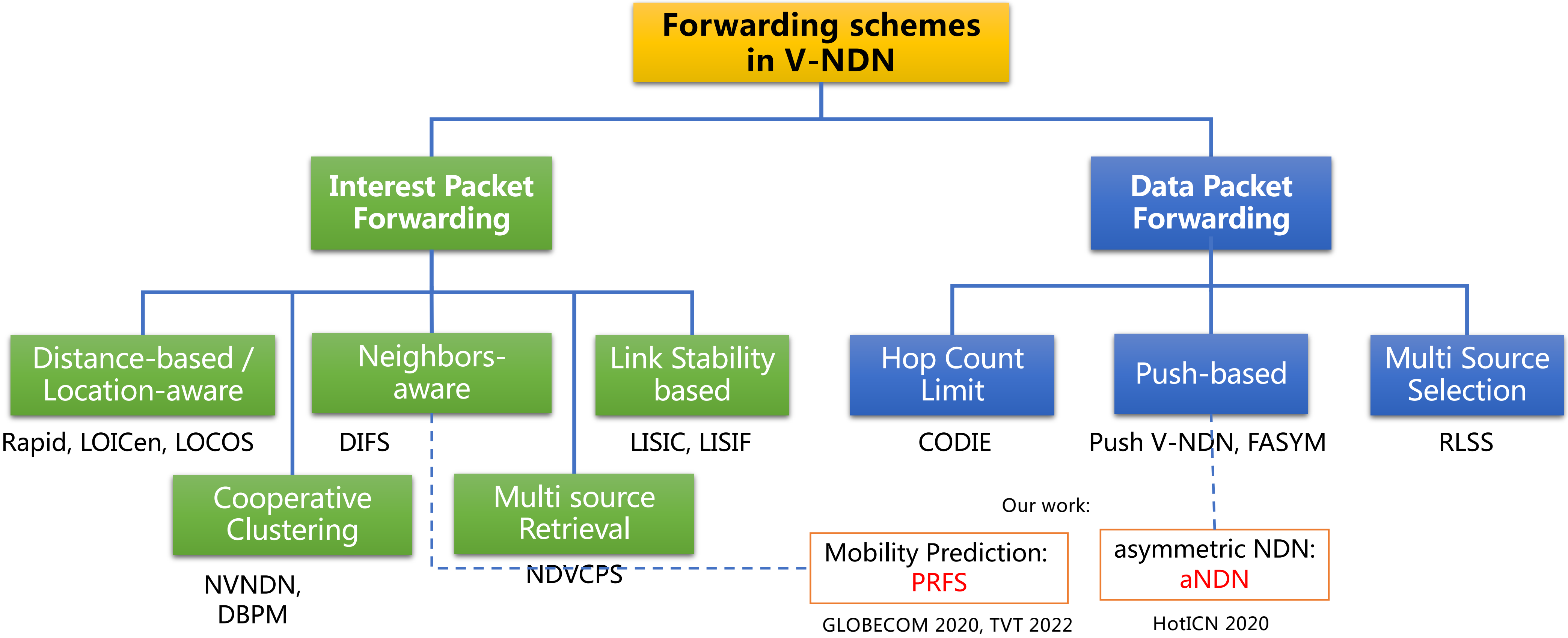
➢ **Two basic procedures**
- **Discover/Reach the Content**
  - Interest packets forwarding
- **Data packets are sent back**
  - Data packets forwarding

➢ **About this talk**
- Ground V-NDN
- UAV-assisted

Contents

2. Content Delivery in Ground V-NDN

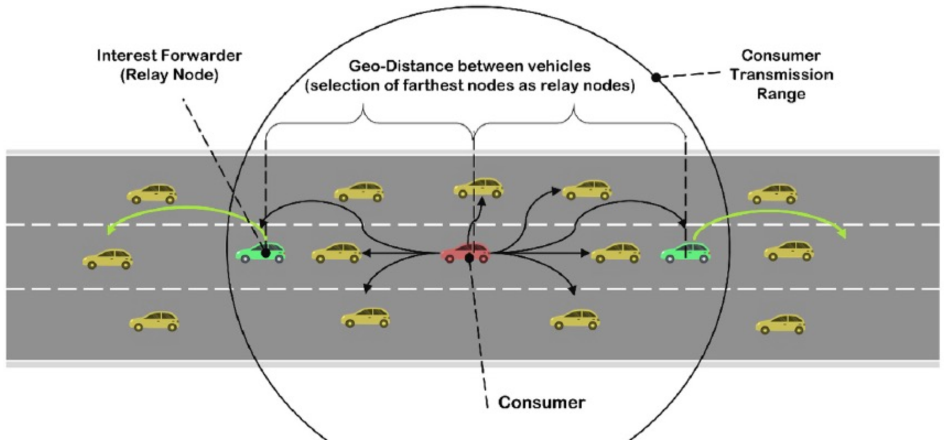
- ❑ Taxonomy of forwarding in ground V-NDN



2. Content Delivery in Ground V-NDN

❑ 2.1 Distance-based forwarding

- Feature:
  - The farthest vehicle from the current forwarder is selected as the forwarder.
- Advantage:
  - make Interest packets reach the content producer fast.
  - alleviate broadcast storm.
- Disadvantage: a farther next-hop regularly leads to a shorter link duration and a more vulnerable return path.



Al-Omaisi, et al.,
A survey of data dissemination schemes in vehicular named data networking
Vehicular Comm., 2021

- Core idea of rapid V-NDN :
  - The farthest to be the selected one.
  - Deferring timer inversely proportional to the distance for re-broadcasting

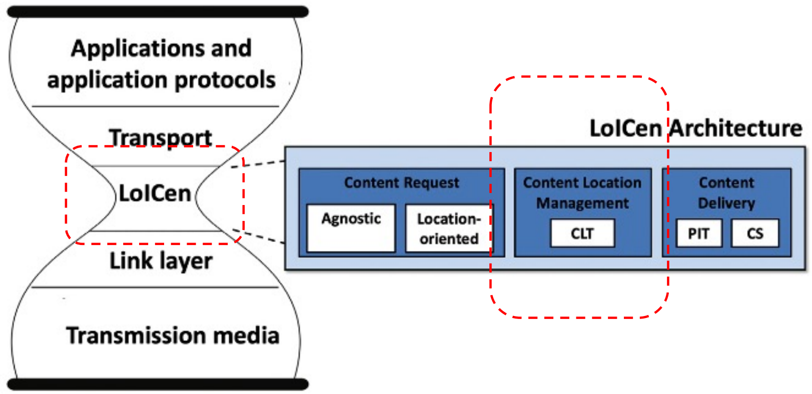
Lucas Wang, et al. Rapid traffic information dissemination using named data[C]. ACM NoM Workshop, 2012.

2. Content Delivery in Ground V-NDN

❑ 2.2 Location-aware forwarding

➢ Feature:

- Collect and maintain the locations of potential content providers.
- Direct Interest packets to the area where the content may be located



➢ Core idea of LoICen:

- Maintain a content location table (CLT), managing the locations of vehicles that might have desired content in their cache.
- Location and caches information carried by Interest and Data packets with additional headers, informing intermediate vehicles.
- Location-oriented content request

Table 1: Example of the CLT in the LoICen architecture.

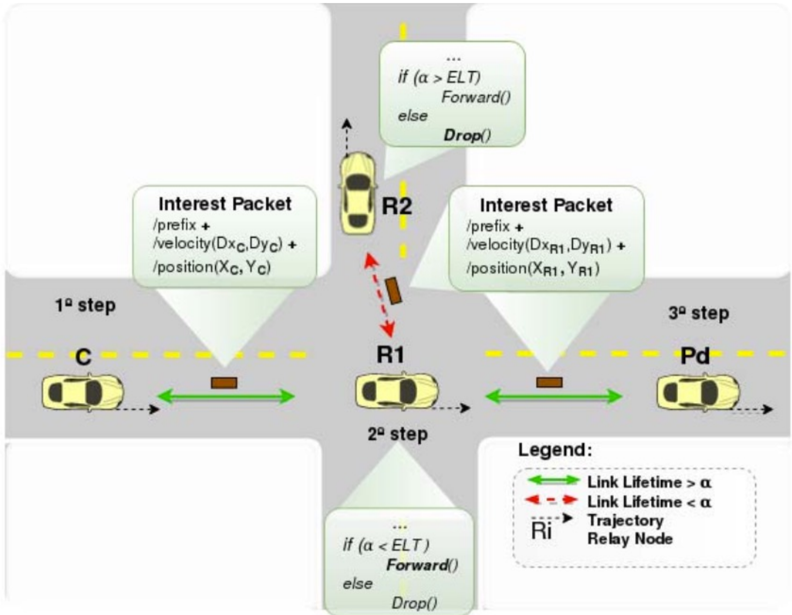
Content Name Prefix	Location	Timestamp
/CBC/Ottawa/*	(lat_D, lon_D)	Feb 16 13:36:23 EST 2019
/Spotify/Pop/*	(lat_P, lon_P)	Feb 16 13:36:45 EST 2019
/Google/Photo/*	(lat_Q, lon_Q)	Feb 16 13:37:09 EST 2019

A. Boukerche, "LoICen: A novel location based and information-centric architecture for content distribution in vehicular networks," *Ad Hoc Netw.* 2019.

2. Content Delivery in Ground V-NDN

❑ 2.3 Link stability-based forwarding

- Features : Choose the next-hop forwarders with long link durations.
- Advantage:
  - prevent the return path from becoming invalid before completing the data packet transmission.
  - alleviate broadcast storm.
- Disadvantage:
  - maybe inefficient due to more hop counts



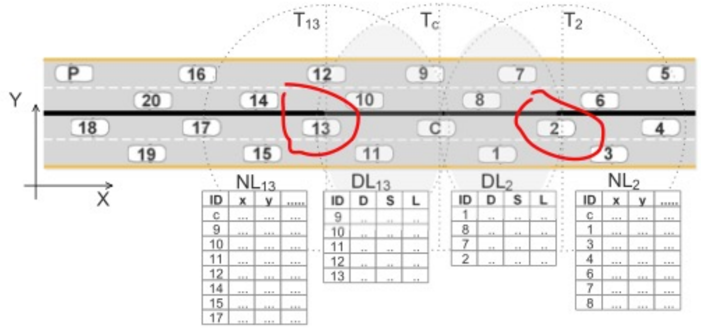
- Core idea of LISIC
  - a deferral is inversely proportional to the estimated link stability with the last interest sender.

- Core idea of LSIF
  - the ELT (Estimated Link Lifetime) greater than the local threshold (historical data packet delay)
  - ELT calculated from transmission range, velocity and position vectors.

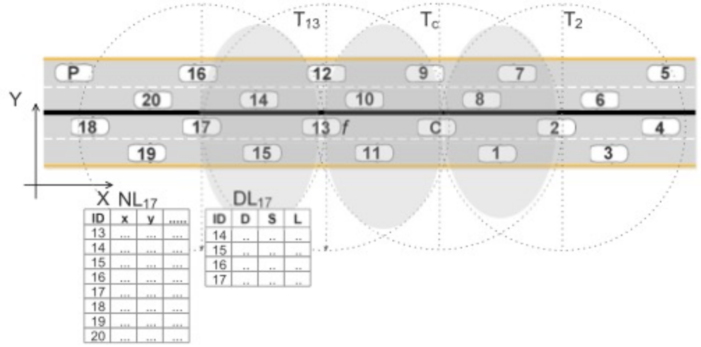
A. Boukerche, LISIC: a link stability-based protocol for vehicular information-centric networks, IEEE Int. Conf. Mob. Ad Hoc Sens. Syst., 2017.
A.M. de Sousa, A link-stability-based interest-forwarding strategy for vehicular named data networks, IEEE Internet Comput. 2018.

2. Content Delivery in Ground V-NDN

❑ 2.4 Neighbors-aware forwarding



(a)



(b)

- Feature :
  - Considering multi-attributes, such as link duration and distance.
- Advantage/Disadvantage:
  - Tradeoff between efficiency and reliability
  - Large overhead caused by beacon messages
- Core ideas of DIFS
  - Consider multi attributes of neighbors, e.g., 1-hop distance, relative velocity, link duration
  - Each intermediate vehicle calculates the overall weight using TOPSIS method to rank neighbors include itself (distributed)
  - The one with the maximum weight is the selected one.

S.H. Ahmed et al., *DIFS: distributed interest forwarder selection in vehicular named data networks*, IEEE TITS. 2018.

2. Content Delivery in Ground V-NDN

❑ 2.5 Cooperative clustering-based forwarding

- Use a proxy, called cluster Header, to control the interest forwarding representing a cluster.
- Advantage:
  - Reduce some information redundancy, i.e., request aggregation in cluster head.
- Disadvantage:
  - Instability of the cluster
  - Single-point failure in the cluster head

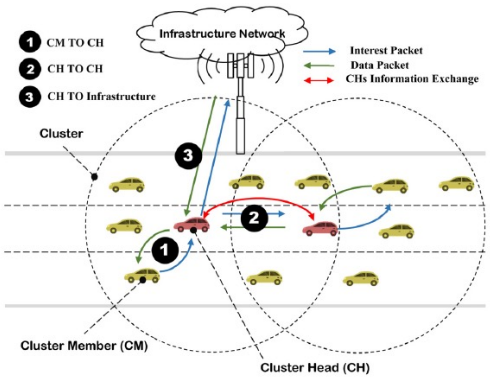
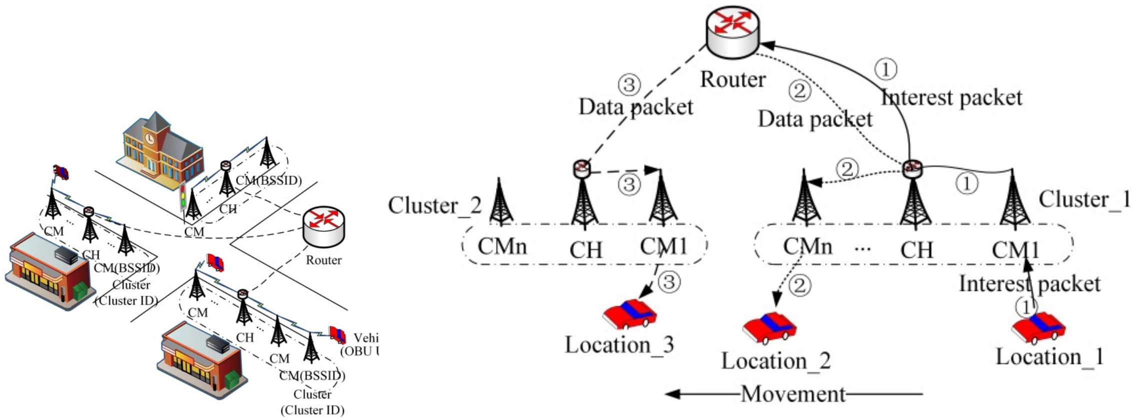


Fig. 11. V-NDN cooperative clustering-based interest forwarding scheme.

(a) Clustering of vehicles



(b) Clustering of RSUs

Al-Omaisi, et al., *A survey of data dissemination schemes in vehicular named data networking*, Vehicular Comm. 2021

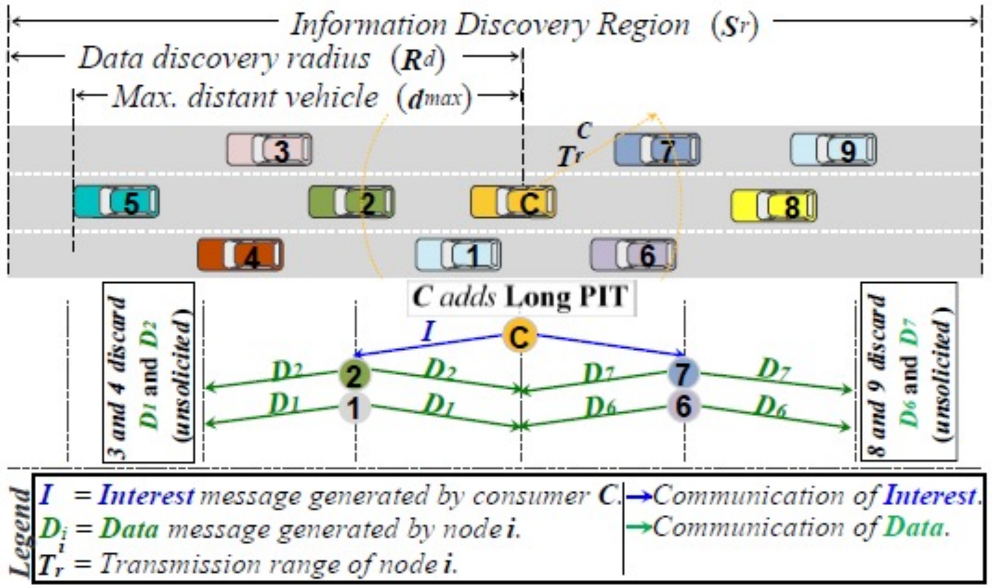
X. Wang, *Vehicular Named Data Networking Framework*, IEEE TITS, 2020.

Rui Hou, et al., *Cluster Routing-Based Data Packet Backhaul Prediction Method in Vehicular Named Data Networking*. TNSE 2021

2. Content Delivery in Ground V-NDN

❑ 2.6 Multi-source data retrieval

- Objective:
  - Enable a single Interest to discover and retrieve multiple Data packets from different content sources
- VCPS Multimodal-Data Applications
- Core idea:
  - Long PIT: expires instead of receiving the first Data packet.
  - Nonce in Data packets to detect duplicate forwarding
  - Interest broadcast suppression (IBS) mechanism: defer by hop-counts, distance, and other network parameters.



One Interest packet, Seven Data packets

- S.H. Bouk, Multimodal named data discovery with interest broadcast suppression for vehicular CPS, IEEE Trans. Mob. Com-put. 2020.
- S.H. Bouk, Efficient Data Broadcast Mitigation in Multisource Named-Content Discovery for Vehicular CPS, IEEE Communications Letters. 2019.
- M. Amadeo, Information Centric Networking in IoT scenarios: The case of a smart home, ICC 2015.

2. Content Delivery in Ground V-NDN

❑ 2.7 Data Hop Count Limit / Braking

- Objective
  - Ensure that the packet not go further than the actual consumer
- Advantages & Disadvantages
  - Decrease unnecessary transmission of Data packets
  - Possible changes of hop counts
- Core idea of CODIE
  - Traversed **Hop counter** recorded in Interest packets and PIT
  - **DDL in Data packets**: data dissemination limit
  - DDL decreases 1 every hop； check DDL > 0

Algorithm 4 Received DATA in the Proposed CODIE

Received [Name, MetaInfo, DDL, Content,]
if Name in PIT **then**
  if Face is Application
    Node Received DATA.
  else
    if h in PIT $\leq DDL$ **then**
      $DDL = DDL - 1$ {Decrement DDL}
      Replace DDL in DATA.
      Forward DATA to Face.
      Remove [Name, NONCE, h, Face] from PIT.
    end if
  end if
else
  Drop DATA.
end if

S.H. Ahmed, *CODIE: controlled data and interest evaluation in vehicular named data networks*, IEEE TVT. 2016.

2. Content Delivery in Ground V-NDN

❑ 2.8 Critical Data Pushing

➢ Objective

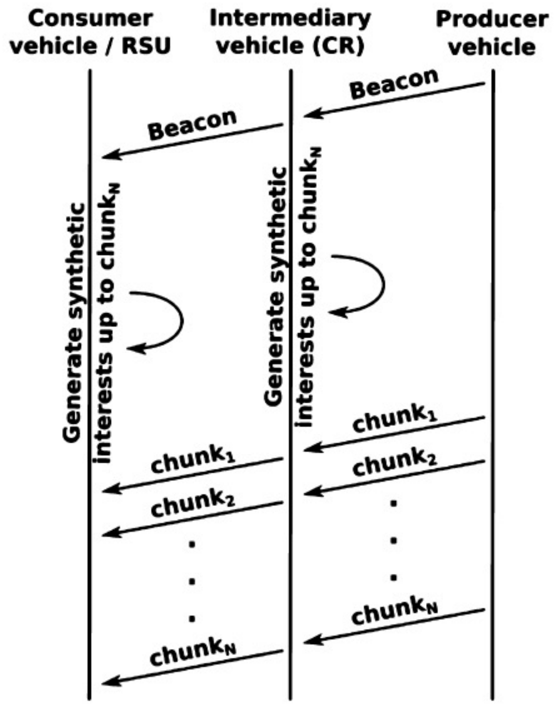
- Broadcast emergency messages without previous interest packets and reduce latency.

➢ Advantages & Disadvantage

- Accelerate broadcast of critical messages, without breaking NDN basic rules
- Beacon messages overheads
- Risk of beacon dropping

➢ Core idea of push-based V-NDN

- Synthetic interests to create PIT entries.



V-NDN critical data push-based scheme

M.F. Majeed, *Enabling push-based critical data forwarding in vehicular named data networks*, IEEE Commun. Lett. 2017.
JHicham Khalifé, *Optimized NDN Forwarding in Tactical Networks with Asymmetric Radio Links*. MILCOM 2021.

2. Content Delivery in Ground V-NDN

❑ 2.9 Multi data source selection

➢ Objective

- Select or optimize the selection of multi data source for large data blocks, e.g., HD map.

➢ Core ideas

- Construct a multi-parameter system, optimized by DQN
- State information: smoothed RTT, interval time, vehicle speed, and vehicle driving direction.
- Agent: vehicle (consumer) that makes a selector for data source and handover decisions.
- Reward: the link throughput, link duration time, and RTT.

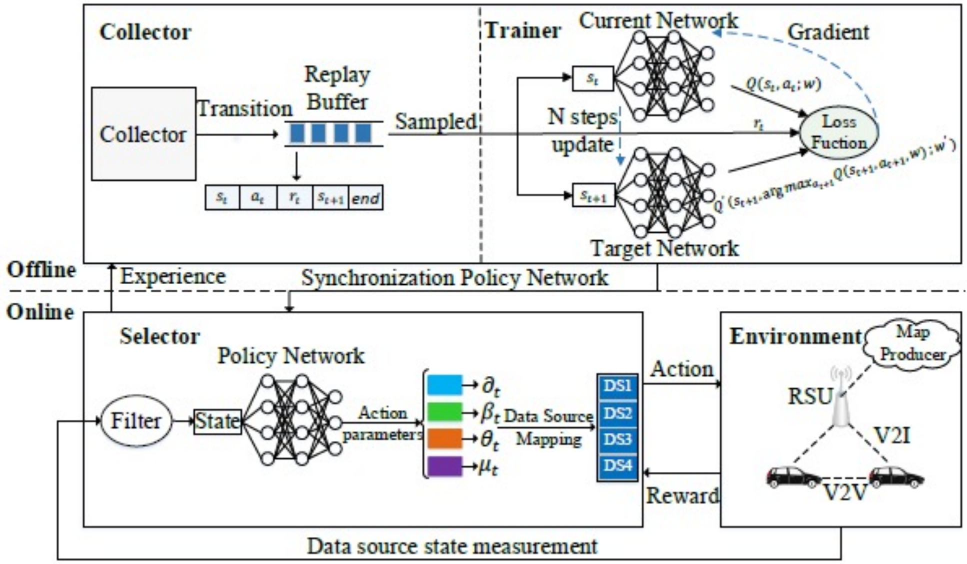


Fig. 5: The RLSS framework

Fan Wu, Wang Yang, et al., *RLSS: A Reinforcement Learning Scheme for HD Map Data Source Selection in Vehicular NDN*, IoT Journal , 2021

2. Content Delivery in Ground V-NDN

CHONGQING UNIVERSITY OF POSTS AND TELECOMMUNICATIONS

❑ Our related work： （1） Asymmetric NDN -- aNDN

➢ Problem statement:

- Symmetric Path is OK for stable wired Internet, but not proper for mobile wireless networks.

➢ Core idea

- Asymmetric paths
  - ✓ Decoupling paths of Interest and Data
- Both Pull and Push

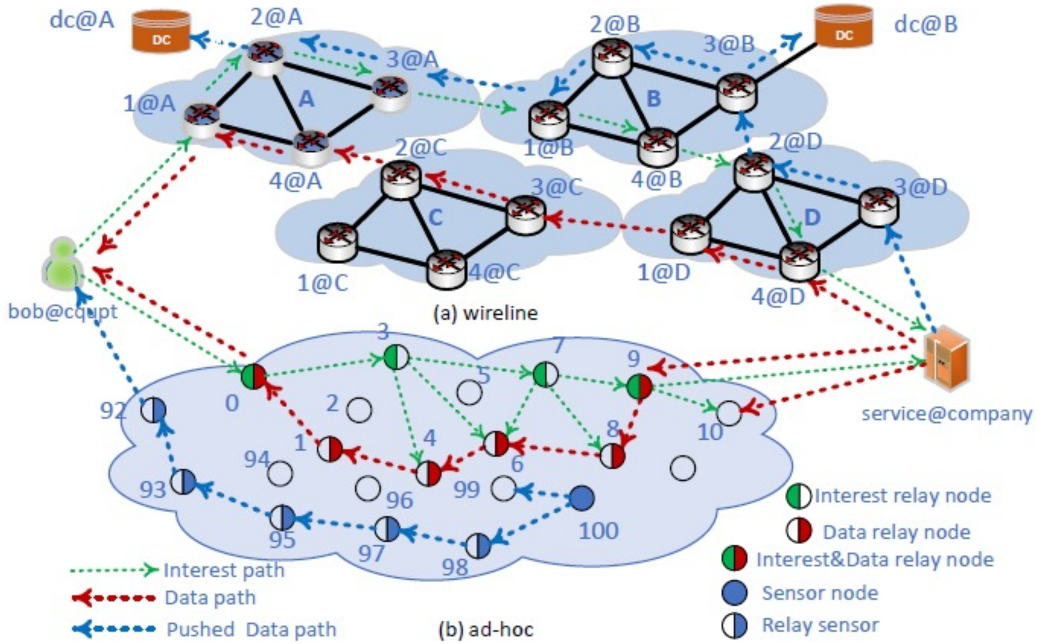


Fig. 2. The system model of asymmetric NDN.

NDN needs to evolve!

J. Luo, Asymmetric Framework Evolution of Named Data Networking and Use Cases in VANET, 2020 HotICN.

2. Content Delivery in Ground V-NDN

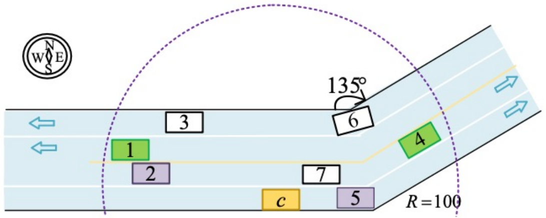
❑ Our related work：（2）Predictive Forwarding -- PRFS

➢ Problem statement:

- Wrong next-hop forwarder may be selected due to the Outdated NBT.

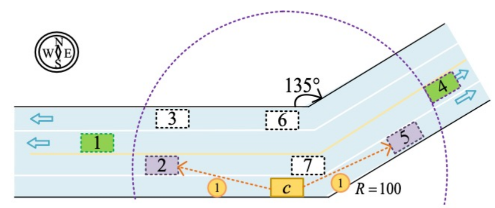
➢ Core idea of PRFS

- **Actual positions of neighbors are estimated** when selecting the next-hop forwarder, using predicting method, e.g., LSTM.
- Hybrid forwarding strategy:
  - LET (Link Expired Time)
  - DR (Distance along Road) based on the predicted NBT.
- Dual forwarding directions: road direction and Reverse road direction.



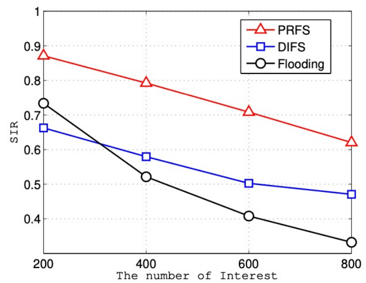
(a) The positions of vehicles in the NBT of consumer (vehicle c), where vehicle 1 and 4 are regarded as the best relay nodes.

(a) Vehicle **1**, **4** were candidates based on the outdated NBT

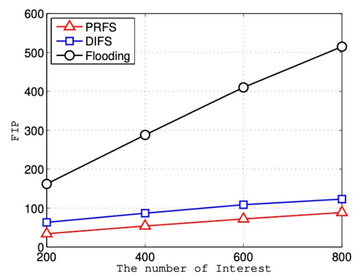


(b) The actual positions of vehicles in the NBT of consumer (vehicle c), where vehicle 2 and 5 are the best relay nodes.

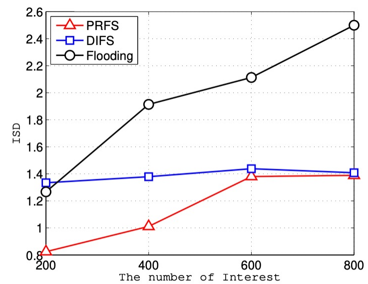
(a) Vehicle **2**, **5** are selected based on the predicted NBT



(a) SIR



(b) FIP



(c) ISD

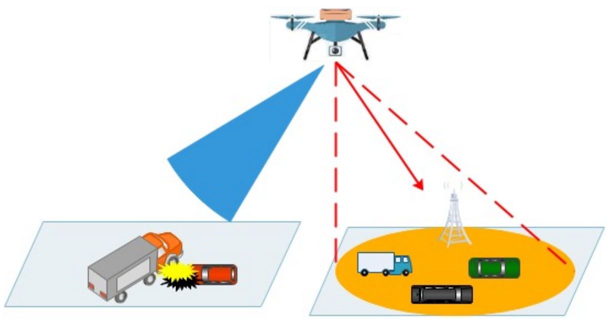
J. Wang, J. Luo, A Mobility-Predict-based Forwarding Strategy in Vehicular Named Data Networks. GLOBECOM 2020.
J. Wang, J. Luo, Towards Predictive Forwarding Strategy in Vehicular Named Data Networking, TVT 2022.（accepted）

Contents

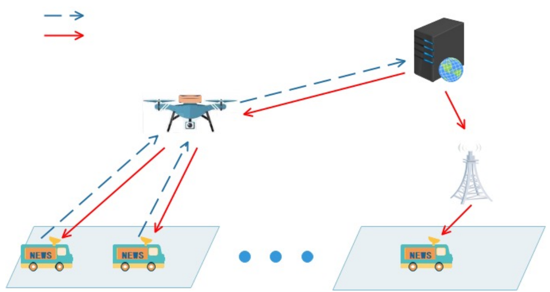
3. UAV-assisted Content Delivery

❑ Application Scenarios

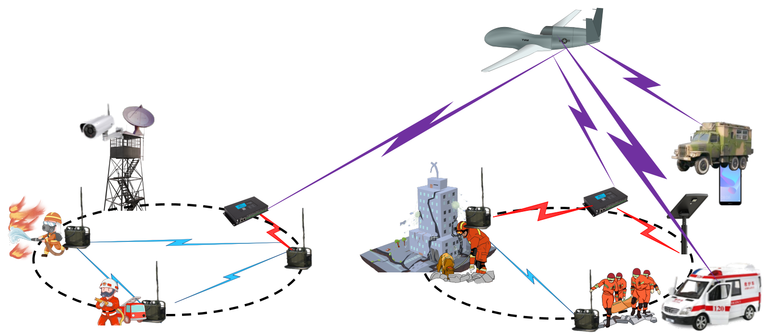
- ➢ Advantages
  - ✓ Agility: Fast deployment
  - ✓ Flexibility: Easily control
  - ✓ Networking & coordination
- ➢ Challenges
  - ✓ Limited energy & capacity
  - ✓ 3D Mobility
  - ✓ Complicated Model



(a) Information Discovery (new sensing method in tactical networks)



(b) Air Relay/ Offload



(c) Emergency Communications

3. UAV-assisted Content Delivery

CHONGQING UNIVERSITY OF POSTS AND TELECOMMUNICATIONS

❑ 3.1 Trajectory Planning and Cache Management

➢ Problem

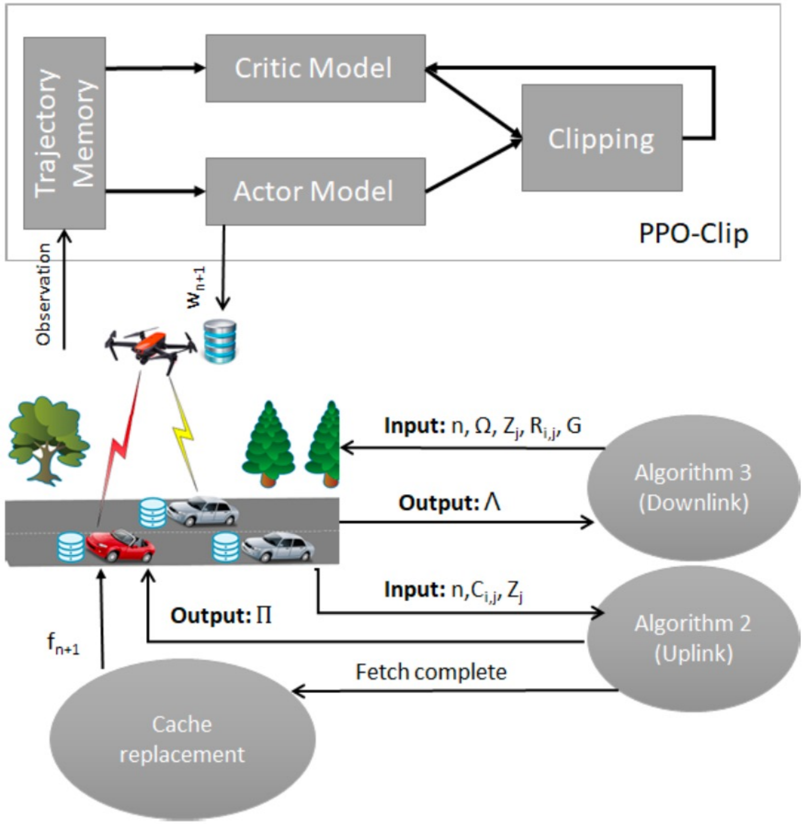
- Using one UAV to assist content delivery in vehicular networks on a highway

➢ Objective

- Find a suitable trajectory of the UAV to maximize its energy efficiency

➢ Core Ideas

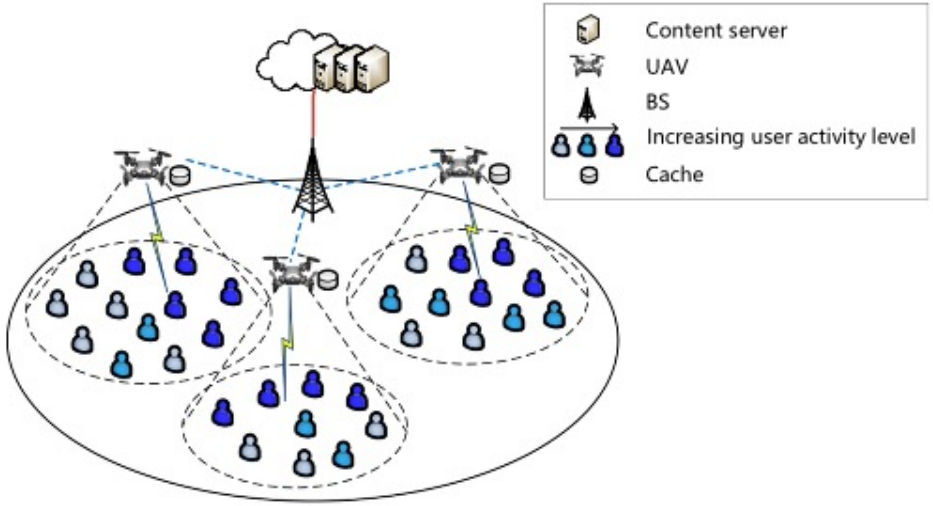
- Formulate the optimization problem of UAV trajectory, radio resources, and caching replacements
- Use Proximal Policy Optimization (PPO) in DRL to solve it.
- Heuristic algorithms to wireless resource allocation, cache replacement policy



A. Al-Hilo, et al, *UAV-Assisted Content Delivery in Intelligent Transportation Management*, ITS, Aug. 2021

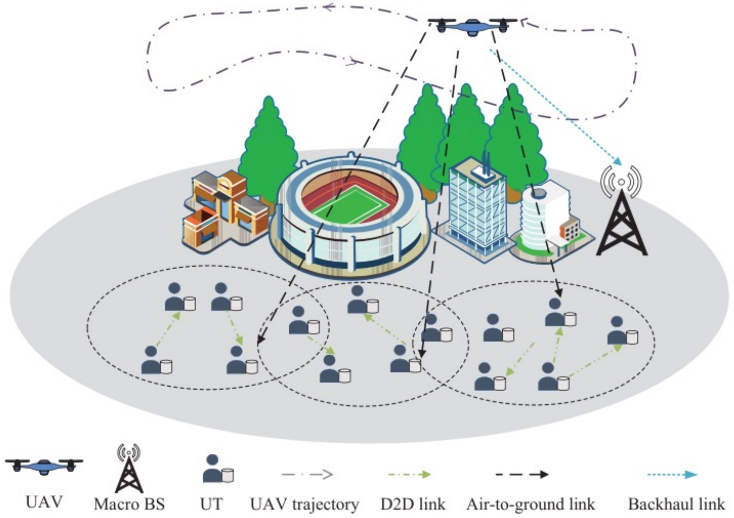
❑ 3.2 User-Centric UAV Deployment and Content Placement

- Problem
  - Prior work rarely considered user activity distribution
  - Based on static content library and known popularity
- Objective
  - To improve user QoE by optimizing UAV deployment and content placement under dynamic content library and unknown popularity.
- Core Ideas
  - Consider both user locations and activity level for UAV deployment, using a weighted location: $\boldsymbol{\mu_m} = \sum_{u \in U_m} \boldsymbol{v_u w_u} / \sum_{u \in U_m} \boldsymbol{v_u}$,
  - Learn the cache policy via Q-learning method, minimizing the average request delay.



Jingjing Luo, et al, *User-Centric UAV Deployment and Content Placement in Cache-Enabled Multi-UAV Networks*, TVT, May 2022

❑ 3.3 UAV Trajectory and SVC Cache Placement in UAV-D2D



Zhang, Tiankui, et al., *Joint Optimization of Caching Placement and Trajectory for UAV-D2D Networks*, TCOM, Aug 2022

➢ Problem

- For obtaining personalized SVC video, how to decide the UAV trajectory and cache placement on UAVs and UTs

➢ Objective

- Maximize the utility of caches on UAVs and UTs;
- Alleviate the backhaul pressure of macro BS.

➢ Core Ideas

- A collaborative caching architecture in cache-enabling UAV-D2D cellular networks
  - ✓ UTs share local SVC layer files with nearby UTs by D2D
  - ✓ The UAV caches SVC layer files for sharing with UTs on ground
- Formulate a joint optimization problem of UT caching placement, UAV trajectory and UAV caching placement.
  - ✓ Solve it by decomposing it into 3 sub-problems.
- The Utility is defined as the content sharing profit minus caching cost.

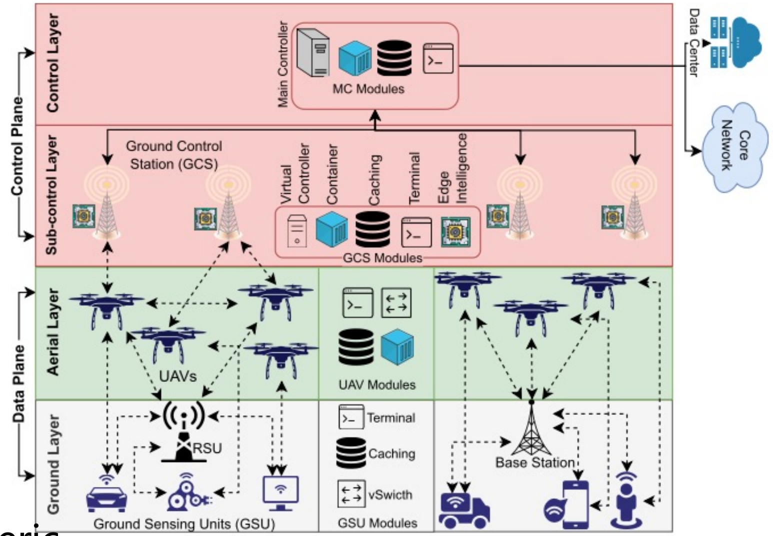
❑ 3.4 Multi-Layer Information-Centric SD FANET

➢ Problem

- Content orchestration among FANET, ground sensing, Edge, Cloud for efficiency and reliability

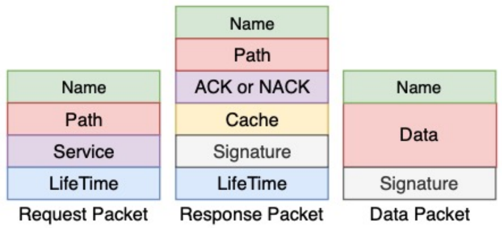
➢ Objective

- Give a UAV-assisted multi-layer IC-SDN solution, integrating SDN/NFV, ICN, Edge, Cloud, …



➢ Core Ideas

- Two planes, four layers framework
  - ✓ Control/Data plane
  - ✓ Ground, Aerial, sub-control, control
- Three kinds of packet:
  - ✓ Request, Response, Data
- Two phases:
  - ✓ Discovery: a global graph
  - ✓ Distribution: Pull/Push, caching
- Two traffic types
  - ✓ Request-driven generic
  - ✓ Response-driven computational
- Two flow assignment algor.
  - ✓ EGFA
  - ✓ ECFA

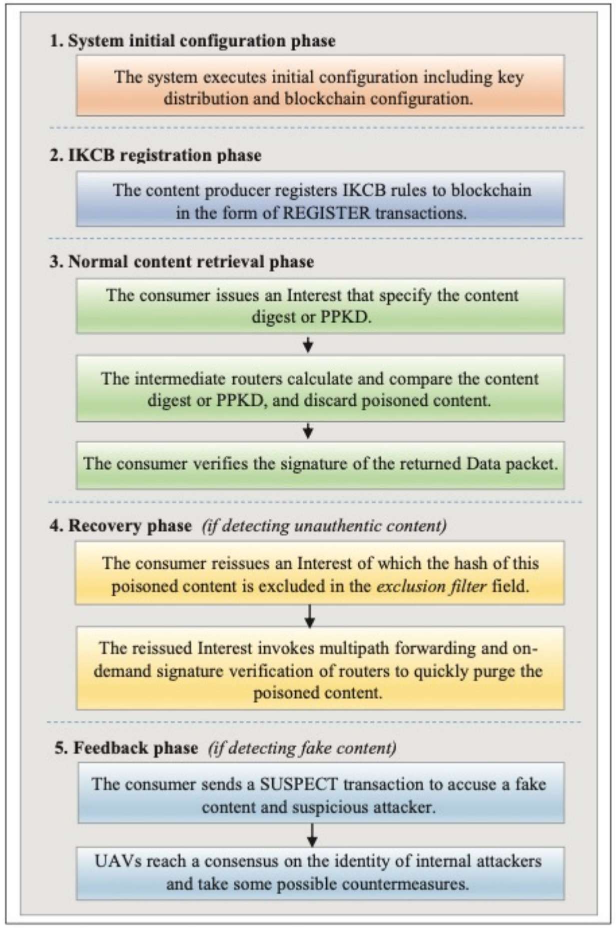


Liehuang. Zhu, et al, *Traffic Flow Optimization for UAVs in Multi-Layer Information-Centric Software-Defined FANET*, TVT, 2022 （Early access）

3. UAV-assisted Content Delivery

❑ 3.5 UAV Ad Hoc Networks with Blockchain

- Problem
  - Content Poisoning in ICN-based UAV Ad Hoc Networks
- Objective
  - Mitigate attacks of content poisoning
  - Enhance network-layer trust of NDN-based UAANETs
- Core Ideas
  - A framework integrates interest-key-content binding (IKCB), forwarding strategy, on demand verification.
  - Five-phase systematic procedure (on the right)
  - IKCB rules to bind content name/prefix, PPKD of publisher, and content digest together
  - A lightweight permissioned blockchain system
  - A lightweight, scalable, and efficient consensus algorithm



Kai Lei, et al, Securing ICN-Based UAV Ad Hoc Networks with Blockchain, IEEE Comm. Mag., June 2019

3. UAV-assisted Content Delivery

❑ 3.6 Our related work

➢ Problem

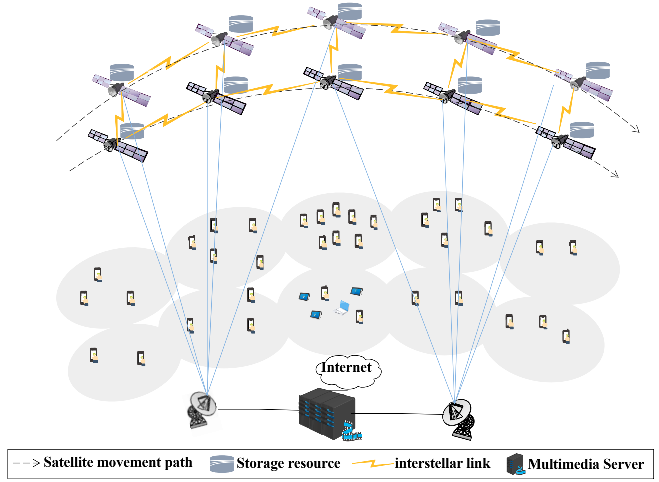
- Cooperative caching placement in LEO system

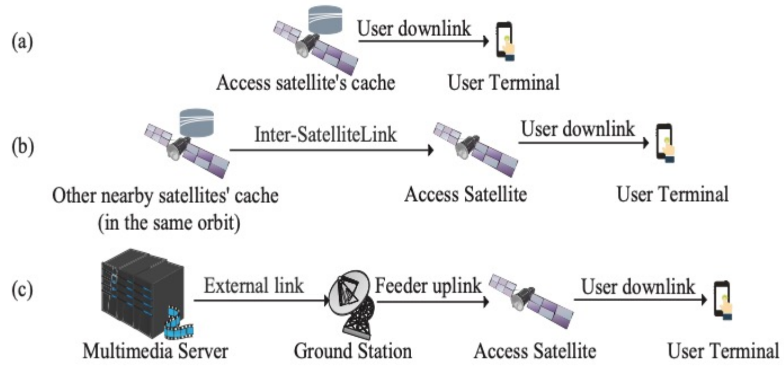
➢ Objective

- Minimizing the service delay by cooperative caching between the access satellite, adjacent satellites, and ground stations.

➢ Core Ideas

- Formulate a partially observable Markov decision process (POMDP) model.
- Solve by multi-agent deep deterministic policy gradient (MADDPG)
- Form a coverage-aware cooperative video caching algorithm (CACVC) scheme
- Results: reduce 1%~4% of the video average delivery delay and improve the 4%~18% hit ratio



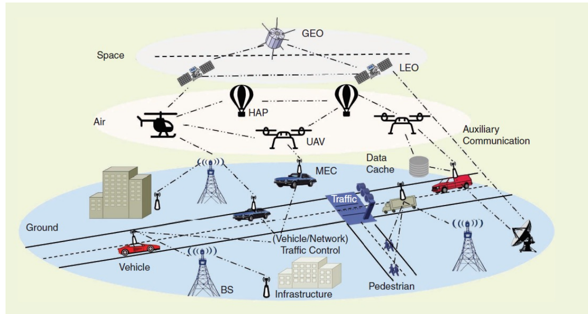


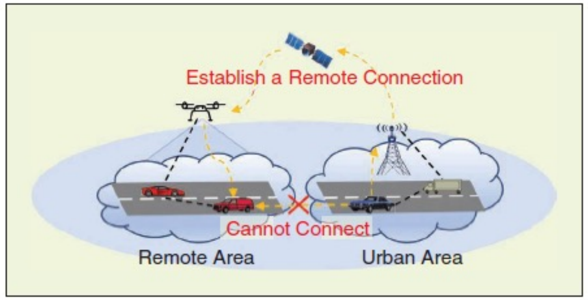
Ruili Zhao, Jiangtao Luo, et al., *Towards Coverage-Aware Cooperative Video Caching in LEO Satellite Network*, GLOBECOM 2022 （To be published）.

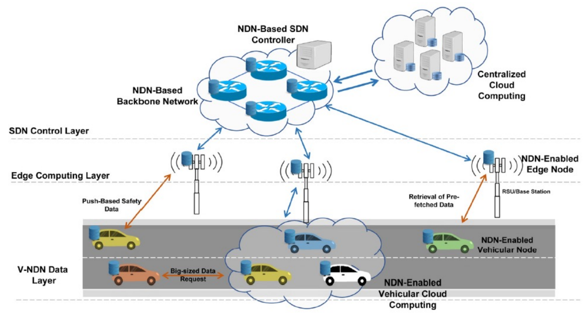
Contents

Takeaways

- ❑ **More Work are expected on UAV assisted System**
  - More constraints, e.g., energy
- ❑ **Space–Air–Ground-Integrated V-NDN**
  - Generic scenarios: more convenient, safer
  - Special scenario: disaster, tactical
- ❑ **Constructing and Leveraging of VCPS**
  - Global content discovery
  - Globally optimized delivery
- ❑ **QoS Delivery**
  - Distinct requirements
  - Few research
- ❑ **Integrated scenarios with AI approaches**







Thanks for Your Attention

Email: Luojt@cqupt.edu.cn