Wireless Information-Centric Networking with Edge Computing for Vehicular Applications

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Outline

- V2X Networks
- ICN/NDN/CCN
- MEC/Fog/Cloudlet Computing
- ICN + Edge Computing
- Issues on ICN for Multi-Hop V2X
- Conclusion
Vehicular Networks


Current & Future

Generating & Gathering
- Massive Data

Transmitting & Receiving

Requirements

- Delay Tolerant or Real Time Comms.
- Distributed & Connectionless Comms.
- Information Analysis
- Large Computing Capability

Reality

- IP & Connection-Oriented
- Centralized & CC-dependent Architecture
- High Traffic Loads
- Long Latency

Solutions

- Information Centric Networking
+ Edge Computing

VANET, Connected Vehicles, V2X, C-ITS, VAN

Vehicle-to-vehicle communications (V2V)
Vehicle-to-roadside communications (V2R)
Vehicle-to-infrastructure communications (V2I)
Vehicle-to-pedestrian, vehicle-to-bicycle, ...

Vehicle’s resources

Internet

eNodeB

RSU

BcNLab at Hongik University
Key idea of ICN (1)

- In a word ➔ Connectionless & Asynchronous Communications
- Different from TCP/IP-based networking in terms of
  - Naming
  - Caching
  - Content Security
  - Content Forwarding & Routing
Key idea of ICN (2)

- To search for content Using “Name”, no IP address!
  - Focuses on content rather than IP addresses (“Where” is replaced by “What”)
  - Data is directly requested at the network level (not its holder, no more DNS: less delay)
  - Packets are routed and forwarded based on names.
  - Solution for the lack of IP addresses and IoT/M2M
  - How to construct and design “Name”?

Example of hierarchical naming:
ccnx:/parc.org/video/widget1/version2/chunk2
Key idea of ICN (3)

- To cache contents in any node!
  - Rely on close data storage (*on-path caching*)
  - Anybody with the content can be a content server!
  - Reduce content retrieval time
  - Cooperate with Delay-Tolerant-Network (DTN)
Key idea of ICN (4)

- To secure ‘Content’ itself, not endpoints
  - Regardless of where packets travel across the network, content is protected from damage, alteration, or snooping from unauthorized parties.
  - Name-content mapping verification via per-data packet signature
    - Data packet is authenticated with digital signature

Data packet

<table>
<thead>
<tr>
<th>Content Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signature</td>
</tr>
<tr>
<td>(digest algorithm, witness, ...)</td>
</tr>
<tr>
<td>Signed Info</td>
</tr>
<tr>
<td>(publisher ID, key locator, stale time, ...)</td>
</tr>
<tr>
<td>Data</td>
</tr>
</tbody>
</table>

```
/parc.com/george/videos/WidgetA.mpg/v3/s0/0x3fd99a4...
```

Signed checksum

0x1b048347

Key

```
parc.com/george/desktop public key
```

Signed by

```
parc.com/george
```

Signed by

```
parc.com
```

CCN trust establishment by associating content namespaces w/ public keys
Key idea of ICN (5)
Key idea of ICN (6)

- Message Types
  - Interest
  - Data

- Data Structures
  - Content Store (CS)
  - Pending Interest Table (PIT)
  - Forwarding Information Base (FIB)
Key idea of ICN (7)

- Forwarding / Routing

Source needs to announce its contents cross over the network in advance.
Key idea of ICN ()
ICN for Connected Vehicle

Why ICN for Vehicular Networks?

- More than 15 years of research, but there is no VANET implementation.
  "No Perfect Routing protocol for VANETs"

- Mobility support: enable two communicating parties to interact asynchronously and seamlessly without establishing and maintaining an end-to-end connection.

- Intrinsic Security: Not over the transport channel, but Data itself.

- Location-independent naming: Eliminate the need of reassigning the host identifier (such as IP address) to the moving node.

- In-network caching: to exploit broadcast nature of wireless channel to listen and subsequently cache content → lower redundant requests and content retrieval latency.

- Broadcast nature: Might be better reliability.
ICN with Connected Vehicle

- Demonstration of ICN with connected car by Cisco
  - Community ICN (CICN): CISCO’s open-source project
  - Features
    - Seamless Mobility,
    - Asynchronous Multicast,
    - Native Multihoming
    - Anchorless Producer Mobility

http://news.itu.int/key-to-5g-networks-leveraging-information-centric-networking-icn/
ICN with Connected Vehicle

Where to analysis Information?
Where to store huge data?

Edge Computing

- Key Idea of Edge Computing
  ✓ Let’s place mini-Cloud-like functions close to users
  ✓ Let’s place Cloud-like service around users
  ✓ Let’s make heterogeneous mini-Cloud servers cooperative
  ✓ Only if necessary, let’s forward the service to Cloud Data Center

“Edge (Cloud) Computing”

MEC, Fog, Cloudlet, Mist, m-DC

Source: "Fog Computing with Vortex" PrismTech
Cloud Computing vs. Edge Computing

<table>
<thead>
<tr>
<th>Cloud Computing</th>
<th>Edge Computing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Storage, High Computing performance</td>
<td>Less Storage, Less Computing Performances</td>
</tr>
<tr>
<td>Centralized</td>
<td>Distributed</td>
</tr>
<tr>
<td>Far from the user</td>
<td>Close to the user</td>
</tr>
<tr>
<td>Long Delay</td>
<td>Less Delay</td>
</tr>
</tbody>
</table>

Source: http://www.collaboraact.com/cloud-different-edge-iot-environment/
Candidates for Edge Computing - MEC

**Mobile Edge Computing (MEC)**

- **Multiple-access Edge Computing**
- Lead by ETSI from 2014.
- MEC pushes the CC capabilities close to the Radio Access Networks (RAN) in Cellular-based networks
- ETSI is developing a system architecture and std. for a number of APIs
- The most active organizations among candidates for edge computing

![Diagram showing Mobile Edge Computing (MEC) related concepts](image)

- **Above & Below 6GHz Enhanced Mobile Broadband (eMBB)**
  - ~20Gbps cell rate & 1Gbps per user
  - 100Mbps at the edge of a cell
  - < 10ms end-to-end latency
  - 500 km/h mobile speed

- **Massive Machine Type Communications (mMTC)**
  - < 100Kbps
  - 106 devices/km²

- **Ultra-reliable and Low Latency Communications (uRLLC)**
  - 1ms over-the-air-latency
Candidates for Edge Computing – FC

**Fog Computing (FC)**

- Proposed by Cisco (2011) and managed Open Fog Consortium (OpenFog)
- Extends the CC to the edge of networks, in particular wireless networks for the Internet of Things
- A highly virtualized platform that provides compute, storage, and networking services between end devices and traditional Cloud Computing Data Centers.
- Fog node can be any device with computing, storage, and network connectivity
- Focusing on time-sensitive and data-intensive IoT application & service
- The Fog is about pooling data and resources.

https://www.rtinsights.com/what-is-fog-computing-open-consortium/
Candidates for Edge Computing - Cloudlet

- **Cloudlet**
  - Concept was proposed (2009) and a prototype implementation is developed by Carnegie Mellon Univ. (2013)
  - Expand to Open Edge Computing (OEC)
  - Cloudlets are decentralized and widely-dispersed Internet infrastructure
  - Elijah-Cloudlet project: OpenStack++ (a set of cloudlet-specific API as OpenStack extensions)
Candidates for Edge Computing

- The others
  - Mist
  - m-DC
  - Dew Computing

![mDC with small cells]

- Server level
  - Delivery of application services to users
  - Coordination of applications
  - High-level application health / service quality monitoring
  - Deployment of new applications

- Gateway level
  - Management of local applications
  - Loading prioritized application rules
  - Tuning application parameters
  - Monitoring health of local nodes/network
  - Regular status reports
  - Critical parameters
  - Execution of computationally intensive services

- End device level
  - Application execution
  - Providing sensing services
  - Executing actuation tasks
  - Monitoring node properties
  - Monitoring link quality parameters
Candidates for Edge Computing

- MEC vs Fog vs Cloudlet

<table>
<thead>
<tr>
<th></th>
<th>MEC</th>
<th>Fog</th>
<th>Cloudlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication between edges</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>(Wireless Multi-hop)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connection with Cloud</td>
<td>No</td>
<td>Yes</td>
<td>Yes, a little</td>
</tr>
</tbody>
</table>

- OpenFog and ETSI have recently signed MOU

  "OpenFog Reference Architecture will extend the mobile edge with a physical and logical multi-layered network hierarchy of cooperating fog nodes that interface between cloud and edge, allowing for interoperability across operators."

ICN over Edge Computing (1)

ICN
- Naming
- Forwarding & Routing
- Caching
- Content Security

Edge
- XaaS
- Radio Network Information Services
- Traffic Offloading
- Low Latency
Content Delivery with only Edge
ICN over Edge Computing (3)

- Content Delivery with ICN + Edge: Caching

- Cache-Management over ICN + Edge
  - How to merge Edge and ICN?
  - Where is the content stored? Edge-Storage or ICN-Cache
  - Does it need to be stored in both?
  - How to manage contents in Edge & ICN-Cache? Can a content be shared with others?
  - Does Edge can be a provider of ICN?
ICN over Edge Computing (4)

- ICN + Edge: Inter-Communication between Edges
CCN + Edge Computing Project

- Content-Based Mobile Edge Networking (CBMEN)
  - Sponsored by DARPA
  - To design the network services and transport architectures to enable efficient, transparent distribution of content in mobile ad hoc network environments.

- Key Features
  - Routing and forwarding on disrupted mobile networks based on connectivity modeling and network coding;
  - A highly expressive content advertisement and querying-enabling discovery and collaboration on a distributed, tactical edge Semantic Web;
  - A robust, fine grained security and access control via functional encryption mechanisms.
  - Distributed content location and sharing over a mobile ad-hoc network on Android devices.

http://www.darpa.mil/program/content-based-mobile-edge-networking
CCN over Wireless vs. Wired Networks

- Lossy channel & Broadcast nature ➔ Reliability Issue
  - Retransmission?
  - Flooding?
  - Collisions & overhead?
  - Complete content might not be stored

- Mobility, Battery Constraints ➔ Varying Topology and frequent leave/join of node
  - Hierarchical Naming? Naming-based Forwarding?
  - Routing required?
  - Provider Handoff
Wireless CCN – CHANET (1)

- Content centric fashion mANET (CHANET)
- Based on IEEE802.11
- No FIB
- Content Naming = Unique ID
- Components
  - CoS(=CS), PIT, CPT
  - Interest-Data-Int-Ack Handshaking
    - Interest for the first request
    - Int-Ack for subsequent request and ACK for the previous Data.
- Defer time: to prevent from collision
  - seqNum & TTL
    - to prevent from loop
    - Distance-aware forwarding

Enhanced CHANET

Components:
- CS, PIT, FIB (for different wireless techs), CPT

Interest-Data Handshaking

Transport
- Interest Retransmission using RTO
- Control Interest transmission rate

Mobility Handler
- Consumer-driven handover
- Provider-driven handover

Distance-aware forwarding

Conclusion

- ICN + Edge computing might be a way to go for vehicular networks!
- Roles of ICN and Edge Computing are not overlapped, but there are synergies to be exploited.
- Need to deep dive for ICN + Edge
Thank You!