University of Florence

Department of Information Engineering

An Integrated Framework for Fog Communications and Computing in Internet of Vehicles

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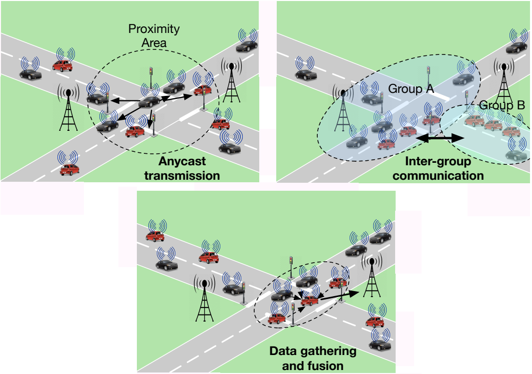
Outline

- **Cloud Computing** (CC): ubiquitous on-demand access to *remote* computing and storage platforms
- **Fog Computing** (FC): emerging paradigm that extends CC towards the network *edge*
  - where applications/services run directly *over* end-devices
- FC goals:
  - improve efficiency
  - reduce data processing and storage latency
- **Fog Communication and Computing** (FC^2): novel paradigm supporting configurability, adaptability, flexibility and energy/spectrum-efficiency

- **Internet of Vehicles** (IoV): wireless ecosystem that allows vehicles to *locally* gather, exchange and refine traffic-related information
  - FC^2 vision enhance reactiveness to sudden context variations and support real-time data analysis
- **Mobile Ad hoc NETworks** (MANETs): integrating vehicles and roadside units (RSUs)
  - **IEEE 1609/WAVE**: present reference standard
    - vehicle-to-vehicle (V2V) and RSU-to-vehicle (R2V) interfaces
  - future **5G** mobile communication systems:
    - abstract and flexible vehicle-to-everything (**V2X**) communication mode

- Traffic safety and management via information *broadcasting*
- *Cooperative* applications, where a group of vehicles *spontaneously* make *coordinated* and *mutually consistent* decisions
  - *agreement* on the exchanged data is essential

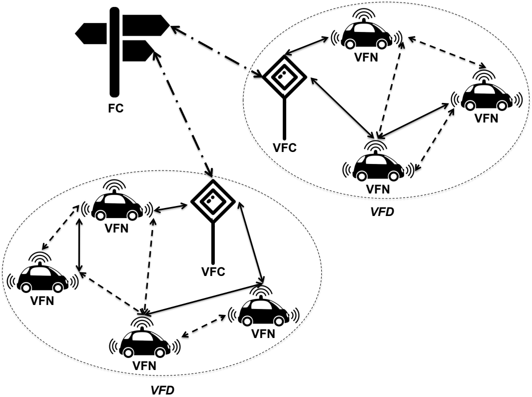


- Green Adaptive Fog Computing and Networking Architecture (**GAUChO**)
  - MIUR PRIN Bando 2015 (Grant 2015YPXH4W-004)
  - novel distributed and heterogeneous architecture able to integrate and jointly optimize FC and FN capabilities
  - supporting low-latency, energy-efficiency, security, self-adaptation, and spectrum efficiency
  - **Task T1.3**: advanced methodologies for network formation, allowing fixed or mobile devices to be *connected*, and to achieve a full *context-awareness* by means of exchanging and jointly refining context-related information

Proposed Integrated Framework

System Model

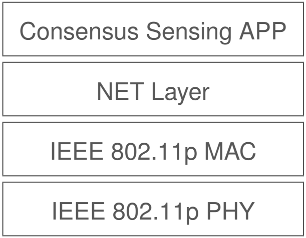
- Vehicular Fog Architecture



- VF Domains (**VFD**s): VF Nodes (**VFN**s) + VF Controllers (**VFC**s)
- logical (*overlaying* application) and physical (*underlying* network) communications interfaces
- Fog Controller (**FC**) for interoperability among VFDs

Proposed Integrated Framework
System Model

- VFN Reference Model



  - Consensus Sensing (CS) Application designed according to BC technology
  - no Transport Layer (i.e., UDP like) as usual in VANETs
  - Network Layer functionalities
  - Physical and Data Link Layers compliant with IEEE 802.11p
  - modeled with OMNeT++/Veins environment

Proposed Integrated Framework

Application Layer

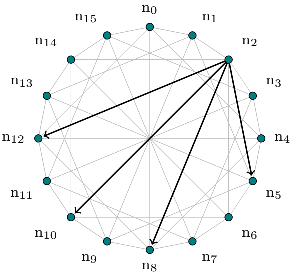
- Proposed CS protocol for information reconciliation
  - designed according to the **BlockChain** (BC) technology
    - participants **write** and **read** from a *distributed ledger*, i.e., a chain that records all the observations/decisions
    - *common view* of the *overall* information
    - integrity and consistency of the ledger and non ambiguous ordering

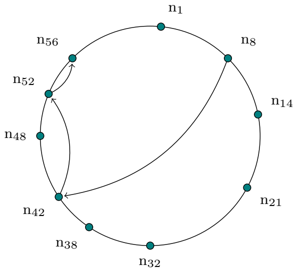
1. once the network is formed, a VFN sends collected information via `ObservationMessages` (OMs)
   - extends `WaveShortMessage`
2. each VFN updates its block as information is received
3. each VFN initiates the validation phase sending the validated block to other VFNs via a `ValidationMessage` (VM)
   - a `WaveShortMessage` that contains the Proof of Work (PoW)
   - probabilistic model of the validation latency
   - block size $B = N/2$, where N is the number of VFNs

- **Delay Tolerant Network** (DTN): support data dissemination over links that may lack *continuous* connectivity:
  - Geographic protocols, which are based on nodes location
  - **Epidemic** protocols: inherent *anycast* addressing scheme suited for CS applications
    1. **Blind Flooding** (BF): each node forwards the received message to *all* its neighbors
    2. **TTL-based Flooding** (TF): a Time To Live (TTL) counter limits the retransmission of a message
    3. **Probability-based Flooding** (PF): each node retransmits the message to its neighbors with a probability P
- **Generalized Multiflow Network Coding** (NC):
  - enhanced DTN approach where each VFN iteratively stores, carries and forwards a *random linear combination* of the previously received packets (blocks)

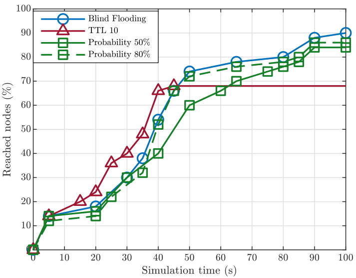
Proposed Integrated Framework
Network Layer

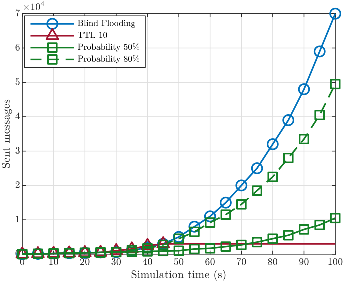
- **Chord** protocol:
  - decentralized peer-to-peer (P2P) *overlay* network based on distributed hash tables (DHT)
  - mapping of *keys* into nodes (L2 and L3 addresses resolution)
  - $O(\log N)$ known nodes for each VFN
  - $O((\log N)^2)$ messages to manage *join* and *leave* topology changes in a *dynamic* and *distributed* way





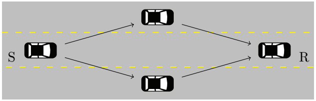
- Epidemic DTN
  - *grid map* imported from Open Street Map
  - accident management ($N = 50$)
  - Veins' `Car` and `RSU` modules
  - communication provided by `Nic80211p` via `WaveShortMessages`

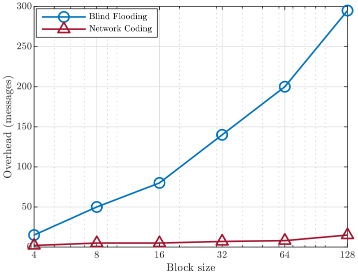




- reached VFNs:
  - TF worst (70%)
  - BF and PF comparable
- protocol overhead:
  - PF outperforms BF ($P = 0.5$ it is about $1/7$)

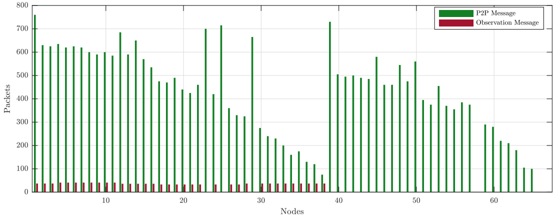
- *Multiflow* Network Coding
  - *diamond topology*: two Relay + Sender (S) + Receiver (R)
  - Relay only performs store, combine and forward
  - external library (`Eigen`) to manage the messages cod & decoding
  - module entirely developed, messages are `WaveShortMessages`





- NC overhead:
  - gap w.r.t. BF increases at the increasing of packet block size
  - diversity gain provided by the two independent Relays

- Chord
  - more realistic map and traffic patterns (default Erlangen map on SUMO mobility simulator)
  - $N = 35$, *Small-World Network* paradigm
  - `Car` and `RSU` Veins modules
  - communication provided by `Nic80211p`
  - new `P2PMessage` (P2PM) extending `WaveShortMessage`

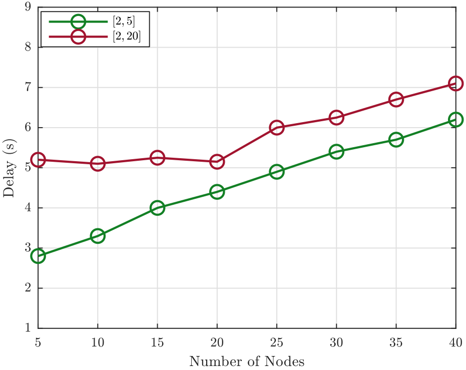


- Chord overhead (P2PMs + OMs):
  - two different networks formed
  - overhead gradually decreases with time
  - P2PMs higher than OMs: Chord network formation more critical

Routing Protocols Comparison

- number of messages per vehicle needed to disseminate an information block:
  - BF $\approx 2 \cdot 10^3$
  - DTN $\approx 10^3$
  - NC $\approx 10^2$
  - Chord $\approx 2 \cdot 10^2$
- but Chord always supports reliable data distribution
  - thus representing the *better* candidate

- CS Application Layer related metric:
  - overall latency need to validate a block
  - integrated BlockChain over Chord networks
  - two different PoW time duration intervals



- good scalability w.r.t. the number of FVNs (*N*)

Conclusions

Concluding Remarks

- FC^2 paradigm application to context awareness VANET services
- Integrated system architecture
  - APP and NET Layers
    - DTN Flooding based, NC multiflows and **Chord** protocols
    - **BC** technology for distributed consensus making
- Modelling and Development with OMNeT++/Veins Framework
  - modularity, high fidelity and flexibility
- Comprehensive simulation campaign
  - Chord reactiveness in topology controlling allows a fast and reliable consensus achievement and flexibility

- *Future Developments*:
  - Redesign over 4G/5G systems with SimuLTE+Veins
  - Extension to FANETs using OLSR and Paxos protocols

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