Wai Chen
Chief Scientist and Director
Applied Research, Telcordia Technologies, Inc.

ISO IEC ITU International Telecommunication Union

Architecture and Technology for Adaptive Multi-hop V2V Networking in Dynamic Environments

Wai Chen*, Taek-Jin Kwon*, Marcus Pang*, Ryokichi Onishi**, Rama Vuyyuru**

*Telcordia Technologies

**Toyota InfoTechnology Center

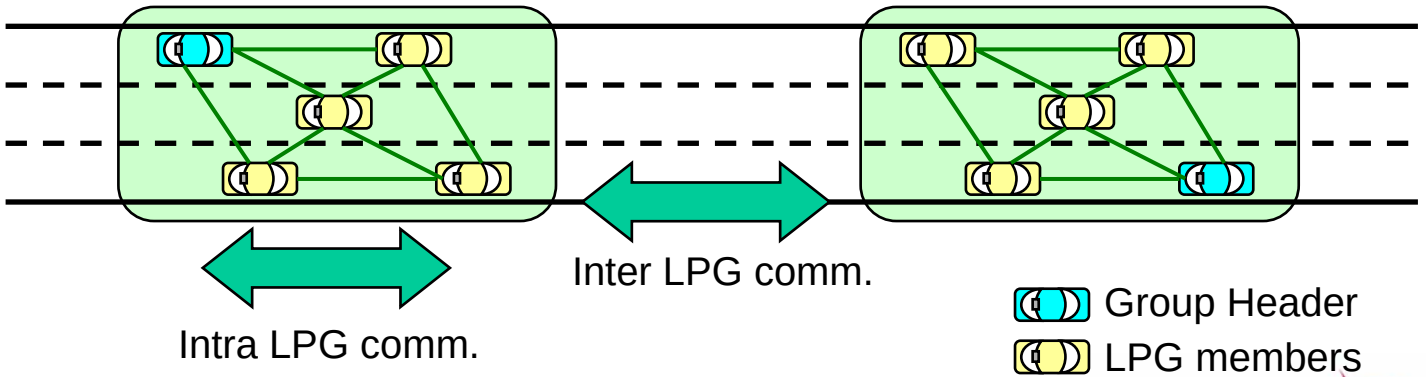
The Fully Networked Car
Geneva, 4-5 March 2009

Social Requirements on Automotive and Transportation Systems

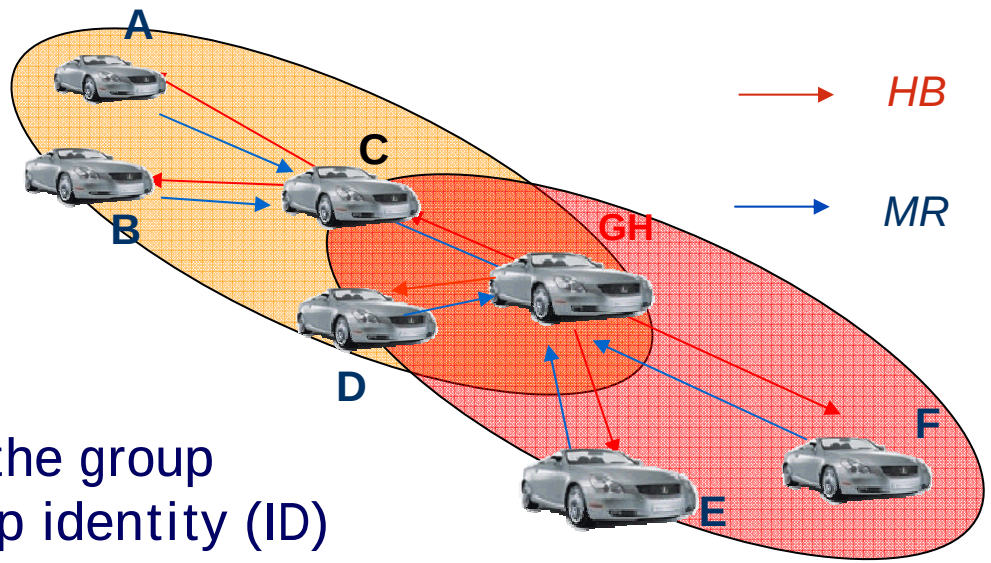
- Driving Safety
  - US: over 40,000 (casualty) & 3 million (injuries)
- Traffic efficiency
  - Less congestion
  - Less energy consumption
  - Clear air
    - US: ~ 3B gallons of fuel wasted on congestion per year
    - Highway congestion accounts for ~50% of CO_2 emissions
- Comfort and convenience

Local Peer Group Communication

- Local Peer Group Communication (LPG)
  - Group formation and maintenance
    - Intra LPG communication
      - Tight coordination of vehicles in the immediate vicinity
    - Inter LPG communication
      - Loose coordination among inter-connected LPGs
  - Cross-layer design
    - Channel assignment & usage
    - Dissemination (topology- or position-based)



Dynamic Vehicle Group Organization

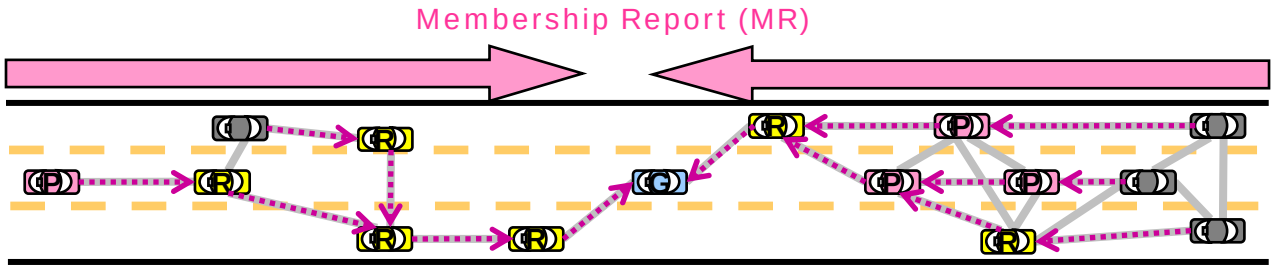


- Group Header (GH)
  - A node elected to manage the group
  - Creates and maintains group identity (ID)
  - Handles changes in group membership
  - Periodically broadcasts HeartBeat (HB) with group ID, GH info and member list
- Group Node (GN)
  - Node in group which is not a group header
  - Responds to the HB with a Membership Report (MR) to maintain membership in group
  - Can become a GH if current GH disappears (GH timeouts)

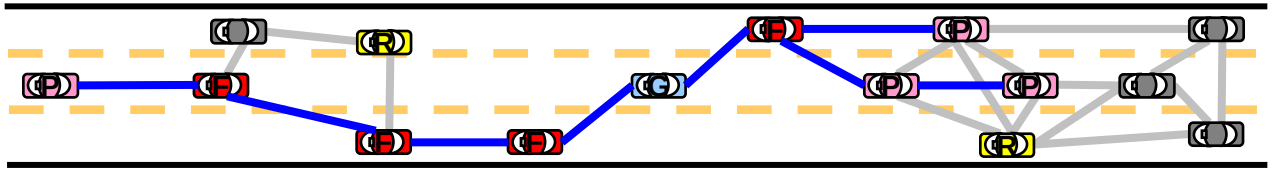
Dynamic Vehicle Group Multicast

- Multicast protocol (GHM)
  - HB/MR messages for tree formation and maintenance; use of light suppression to control multicast forwarding

Multicast participants join the multicast tree via their MR messages.

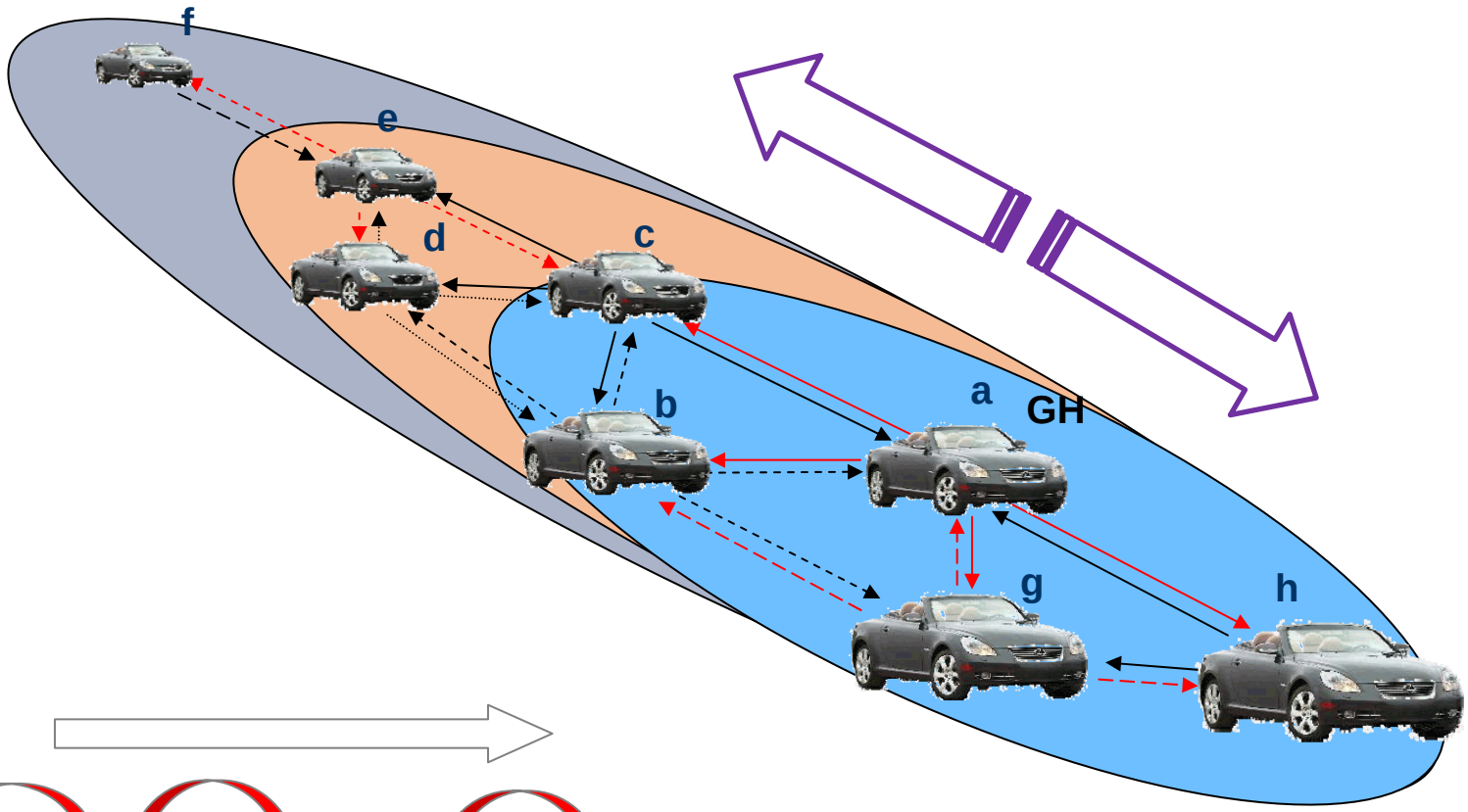


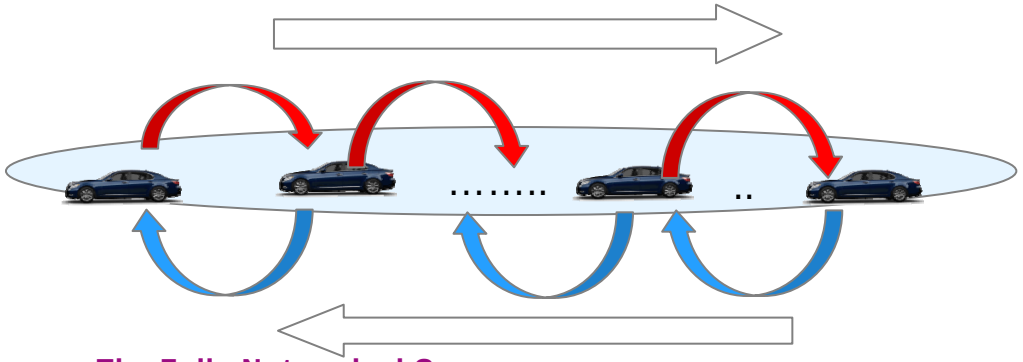
MR takes the reverse paths of HB toward the GH; a multicast tree is formed accordingly.



Group Header node
Member node
Membership Report
Multicast participant node
Multicast forwarding node
Multicast message tree

Dynamic Vehicle Group Size Control





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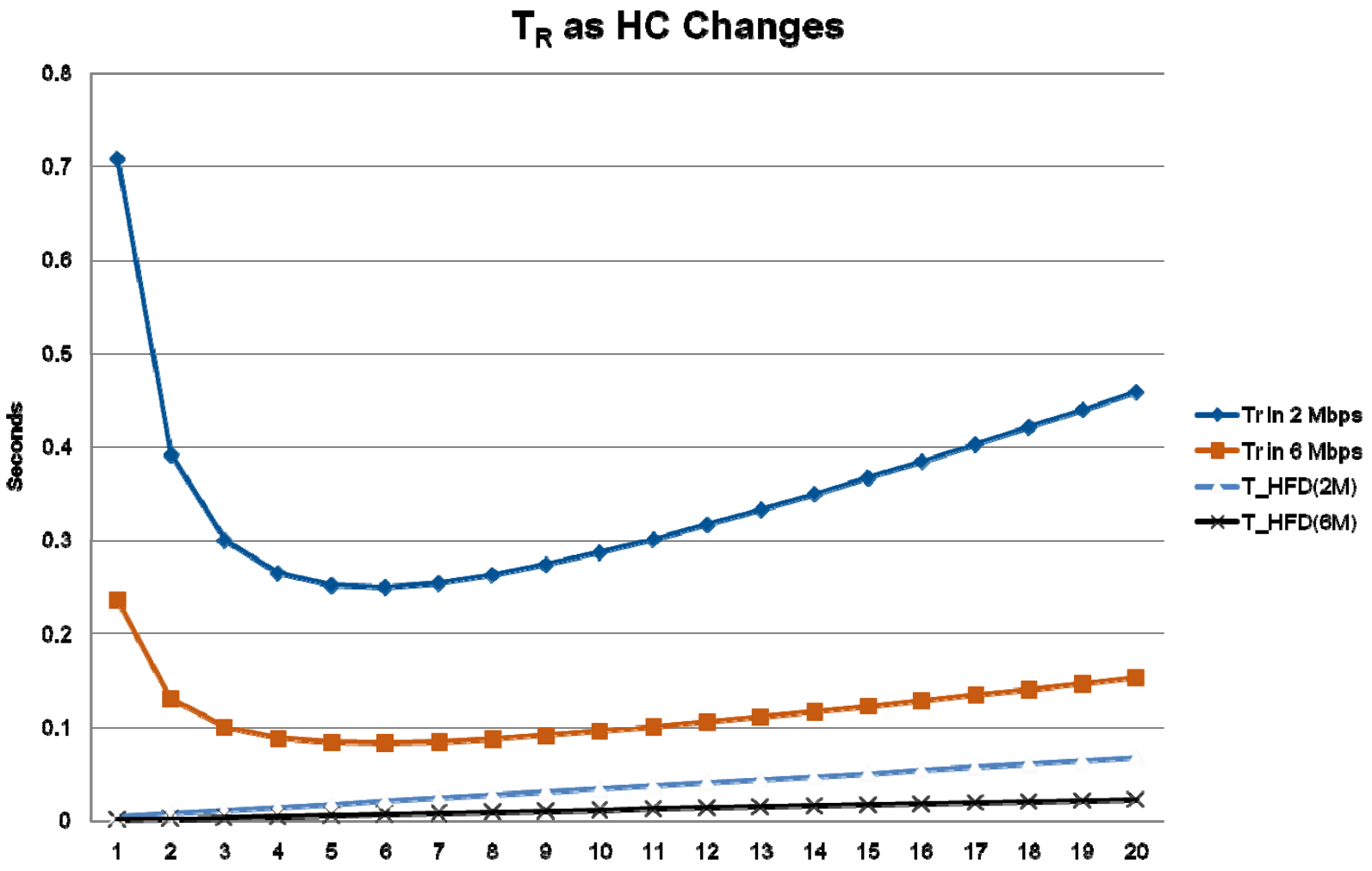
T_R as HC Changes (N=100, p = 10^{-4})



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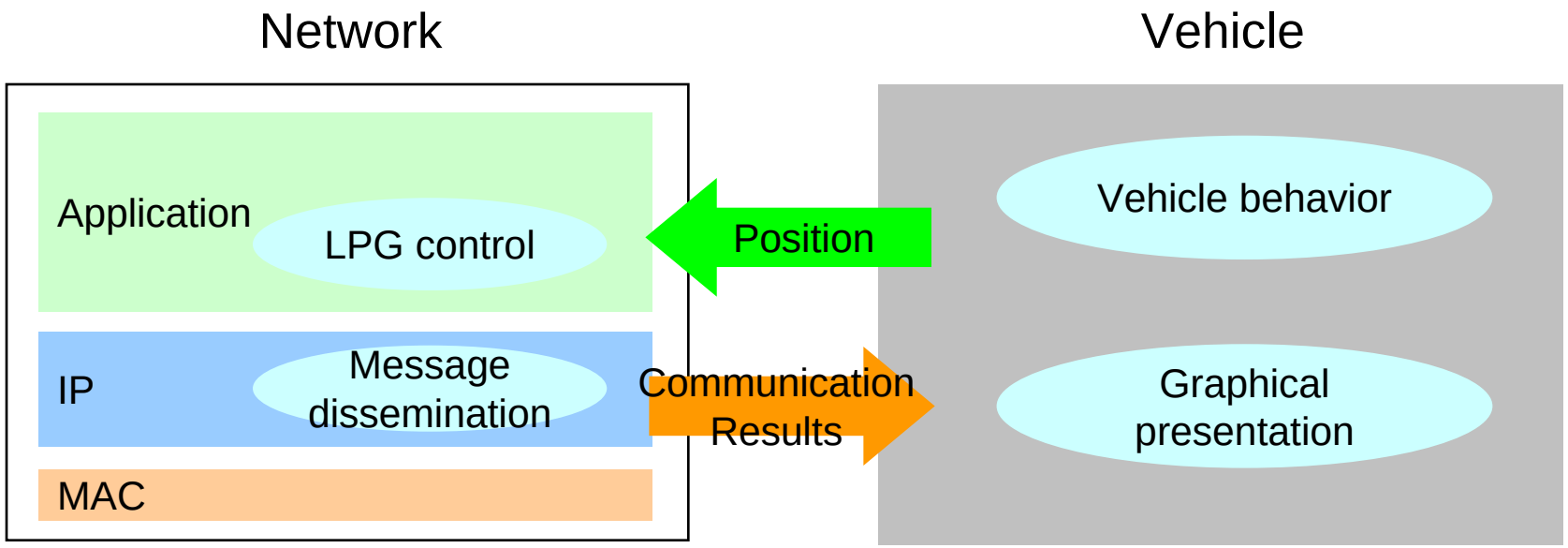
Simulation Implementation

- Integrated simulator
  - Network simulator
    - LPG control and message dissemination
  - Vehicle simulator
    - Vehicle behavior calculation and graphical presentation



Simulation Implementation

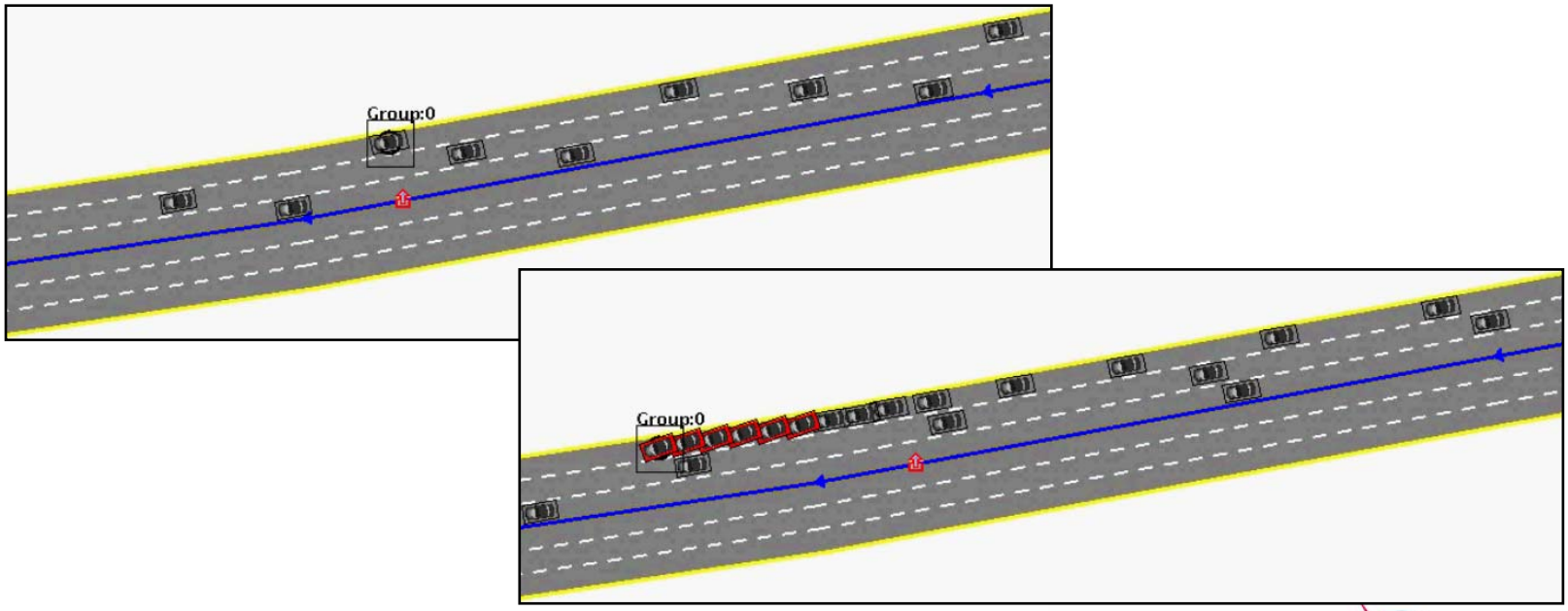
- Vehicle dynamics
  - Vehicle size: 5m length x 2m width
  - Human driver reaction
    - Tracking behavior
    - Driver reaction time of 1 second
    - Maximum deceleration on 4.5m/s^2
  - Electronic brake
    - Tracking behavior
    - Activation upon warning message reception
    - Maximum deceleration of 7.0m/s^2
- Tracking behavior
  - Acceleration/deceleration computed from minimal distance

Simulation Environment

- Demonstration
  - Comparison of electronic braking with LPG support
    - In contrast to human controlled braking
  - 3 lane mobility scenario
    - 20 nodes in each lane (60 total)
    - Initial vehicle spacing is 20m
    - Initial vehicle speed is 35m/s, i.e. 78mph
    - 802.11a radio with 100m range and 6Mbps effective
  - LPG
    - Size of 10 hops; One second HB sending cycle
  - Warning message
    - Sent once by designated vehicle at emergency point
    - 128 bytes size
  - Background traffic
    - 8 streams distributed in the network

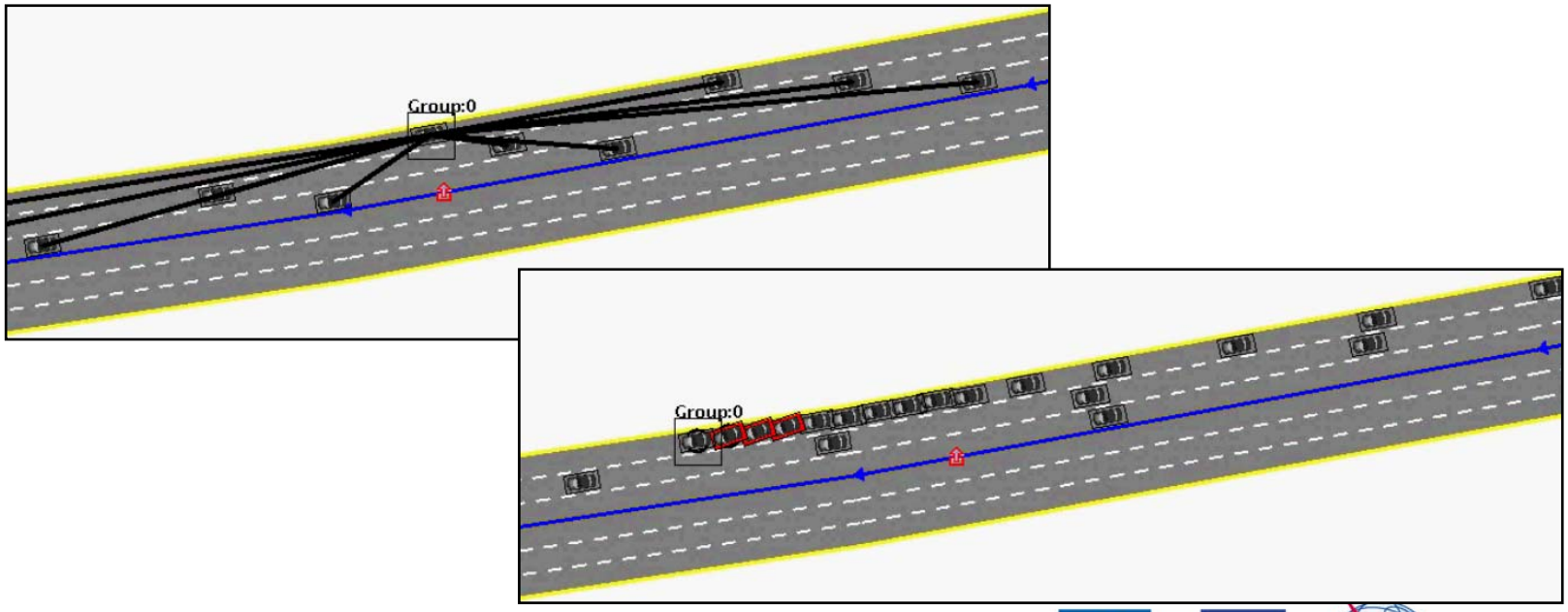
Simulation Demonstration

- Demonstration
  - Human controlled braking (no communication)
    - No warning about the emergency event is sent.
    - Multiple collisions occur since human reaction does not allow for braking early enough.



Simulation Demonstration

- Demonstration
  - Electronic braking with simple flooding support
    - The lead vehicle sends warning to the following vehicles.
    - The warning message does not go beyond the first hop due to interference.
    - Vehicle in the first hop stopped but there are still collisions.



Simulation Demonstration

- Demonstration
  - Cars using LPG to distribute the warning message
    - All vehicles can use electronic brake to stop in time.
    - The demo showed the capability of LPG approach to provide fast reliable multicast communications for safety applications.