Study of Network Coding for Multi-antenna Switched Links-based Vehicle-to-Vehicle (V2V) Communications

Wai Chen[1], Ratul Guha[1], Jasmine Chennikara-Varghese[1], Rama Vuyyuru[2], Junichiro Fukuyama[2]

[1]Telcordia Technologies
[2]Toyota InfoTechnology Center

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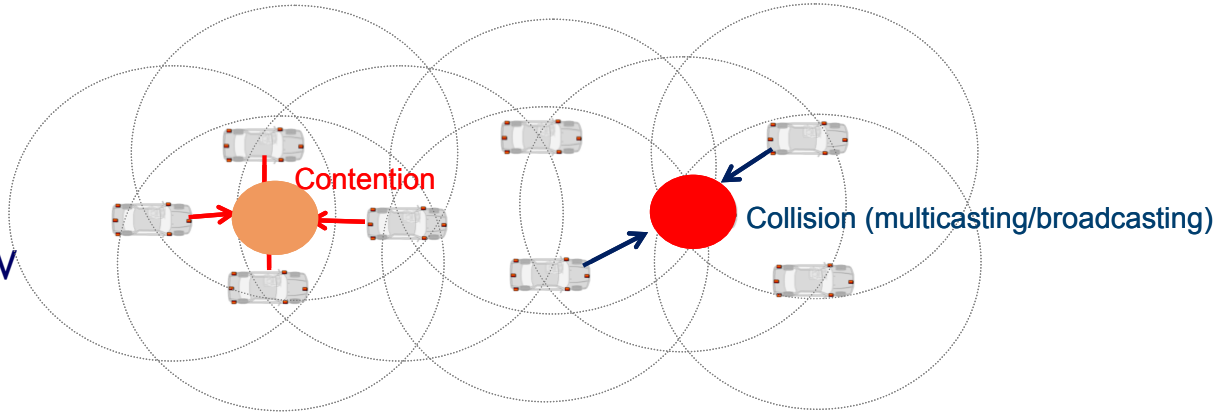
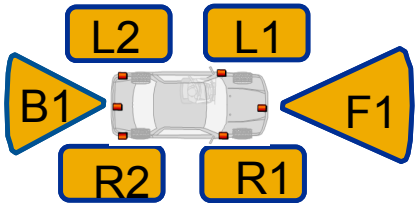
Motivation

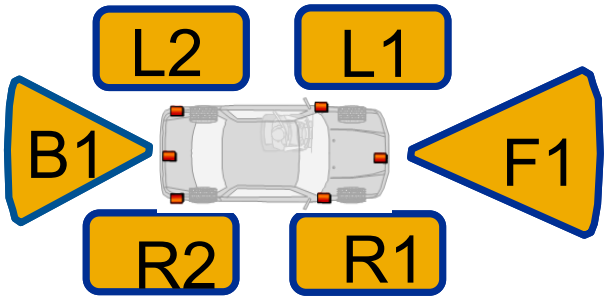
- DSRC / WAVE based networks:
  - Contention-based media access protocol
  - Omni-directional antenna
  - Complex to achieve reliable V2V communications



- Radio and antenna technologies continue to advance
  - 60 GHZ radio, millimeter wave
- Costs expected to drop
- => Switched-Links based Architecture



Radio Interface Characteristics



- **Designation of radio interface**
  - Naming based on positions:
  - Front: F1, F2,..
  - Left-side (driver): L1, L2,…
  - Right-side (passenger): R1, R2,…
  - Back: B1, B2,…

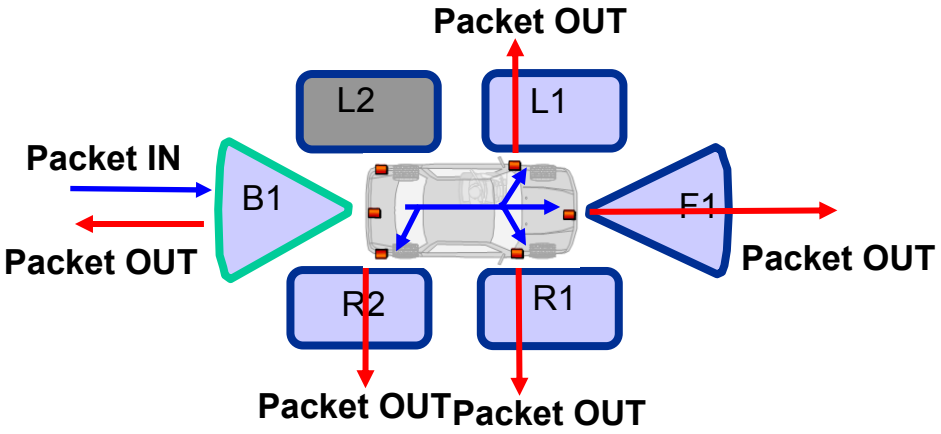
- Each vehicle has N antennas which can provide directional links.
- Each radio has the capability to detect and form a directional link with another radio in the range.
- Each directional link is one-way; a bi-directional (full duplex) link needs two directional (one-way) links.
- Radios communicate status through periodic beacons.

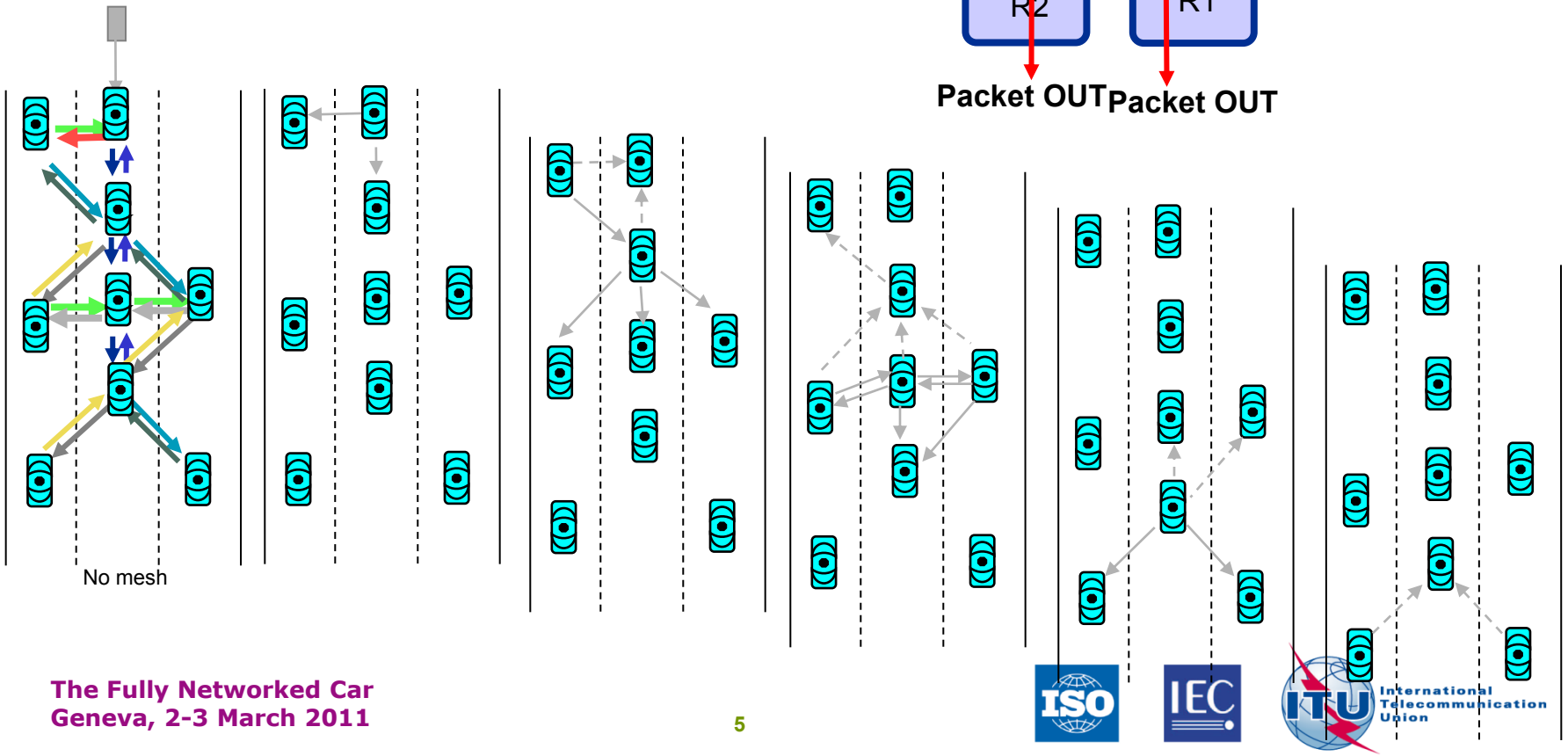
Neighborhood Broadcasting

- Information sent to all vehicles and vehicles pick-up as desired
- Support broadcasting, multicasting, and unicasting
  - **Broadcasting:** use directional links to forward messages – e.g., along a direction; all vehicles in the neighborhood can receive the messages;
    - Dissemination scope is enforced (e.g., stop at maximum hop count)
  - **Multicasting/unicasting:** use neighborhood broadcasting to forward messages (all neighbors hear the messages), but only multicast (or unicast) members actually pick up the messages.

Neighborhood Broadcasting – No Mesh

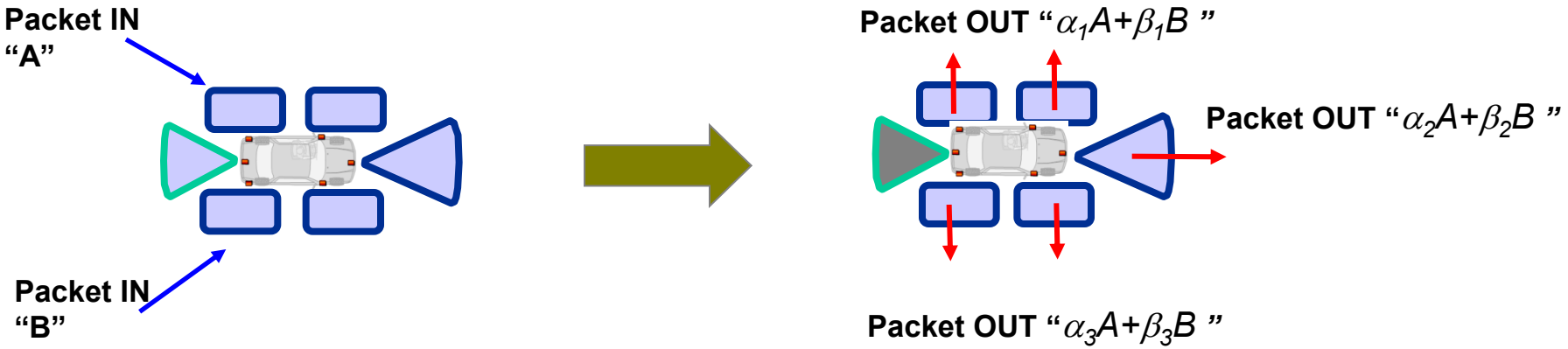
- Each vehicle passes each packet, *once*, to each of its immediately-linked neighbors
  - Each vehicle drops duplicate packets
  - Dissemination scope is enforced (e.g., stop at maximum hop count)





Network Coding
Input and Output

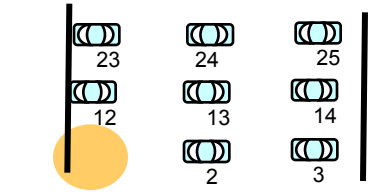
- In the exemplary diagram below, packets A and B are received at the vehicle. The output is obtained as a map from incoming packets A and B.
- For example, the mapping m_i can be a linear combination with random coefficients selected from a finite field.



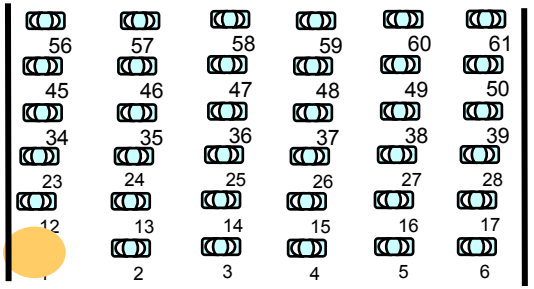
- Diversified packet out: $m(A,B)= \alpha A+\beta B$ where coefficients α and β are randomly chosen from a finite field. Each outgoing link transmits a different packet.

Network Coding Scenario

- High-bandwidth applications need to run in the presence of other traffic in the network.
  - As such the available capacity may be lower than the requirements of the high-bandwidth application
- In the scenario, a single source sends high-bandwidth traffic.
- Node 1 in the leading edge of the road segment broadcasts packets at 4.3 Mbps for 20 seconds
  - The capacity of each link is 2 Mbps
- We measure the performance at the other vehicles on the roadway with and without network coding (no-mesh approach).
  - Two layouts are shown on the right



Vehicles in road segment =9
3-Lanes



Vehicles in road segment =36
6-lanes

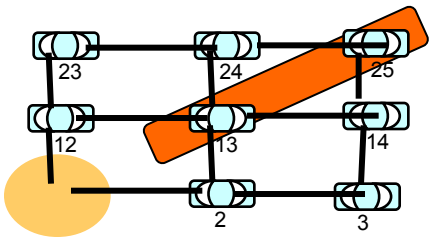
Network Coding Scenario
Simulation Parameters

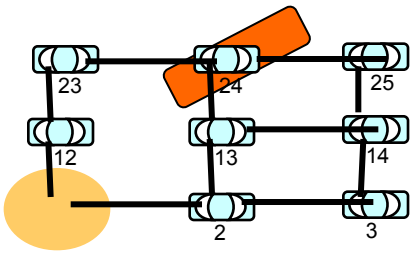
Application Parameter	Value
Number of sources	1
Application Rate	4.3 Mbps
Packet Size	2000 Bytes
Packet generation start time	5 seconds
Packet generation end time	25 seconds

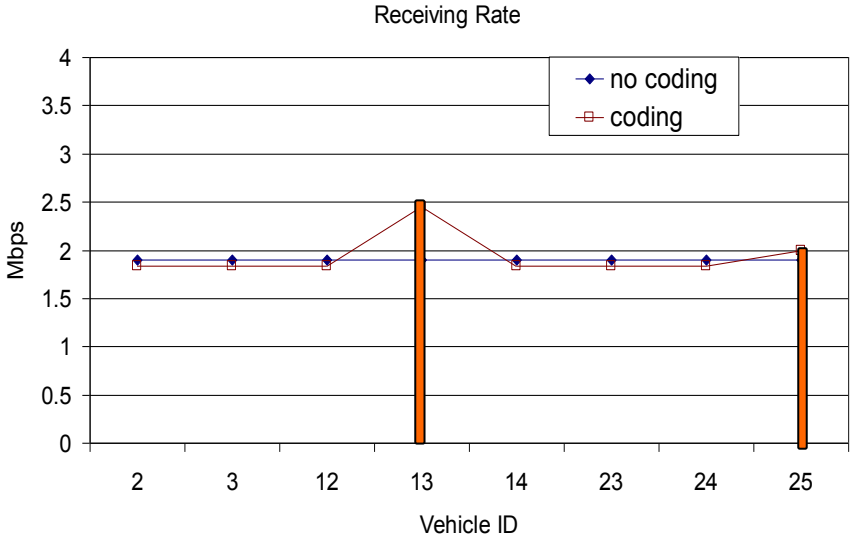
Simulation Parameter	Value
Simulation Time	60 seconds
Link Bandwidth	2 Mbps
Radio Range Switched-link	Wired
Number of vehicles	9,36
Road length	300 meters
Number of vehicles per lane	3, 6
Lane width	3 meters
Number of lanes	3,6

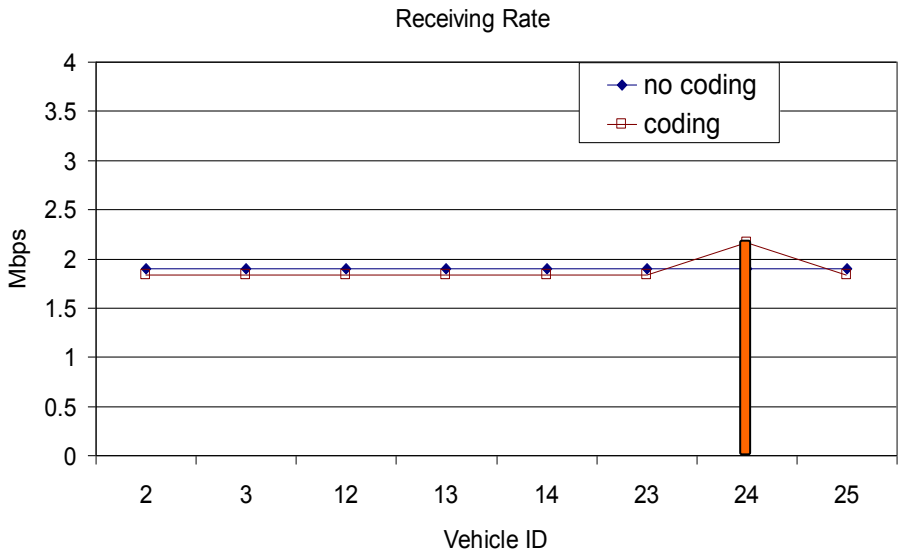
- In the subsequent charts “no coding” denotes the performance of switched link system with no-mesh
- “Coding” refers to the performance of the switched link system with no-mesh in the presence of network coding

Network Coding
3-lane case with 9 vehicles







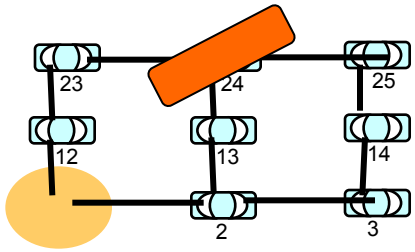


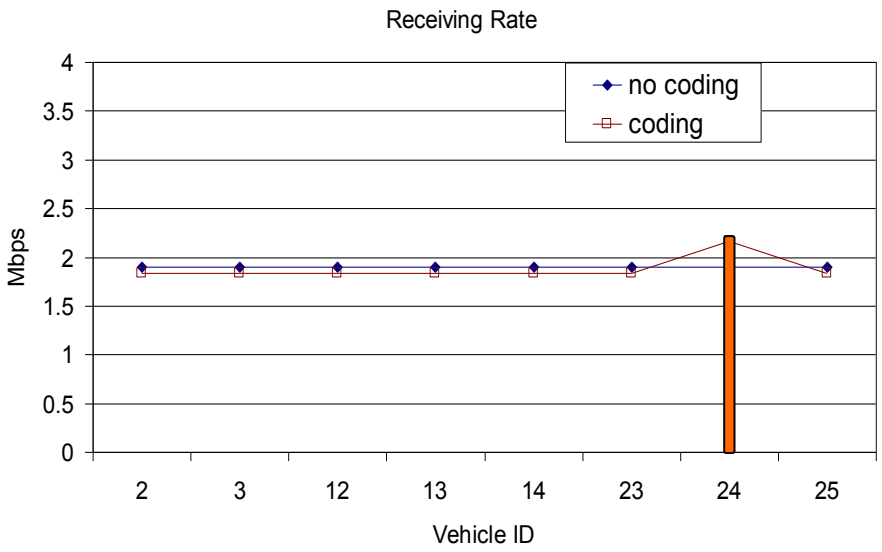
- Vehicles in shaded area (on a diagonal path from source) are able to leverage the benefits from coding
- PDR for coding and no coding is 100%

- Based on link selection, specific nodes benefit from coding
- All nodes have 100% PDR
- Node 24 benefits from coding

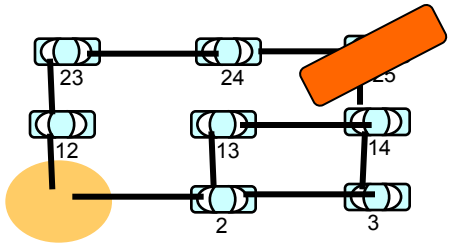
Network Coding With Link Selection

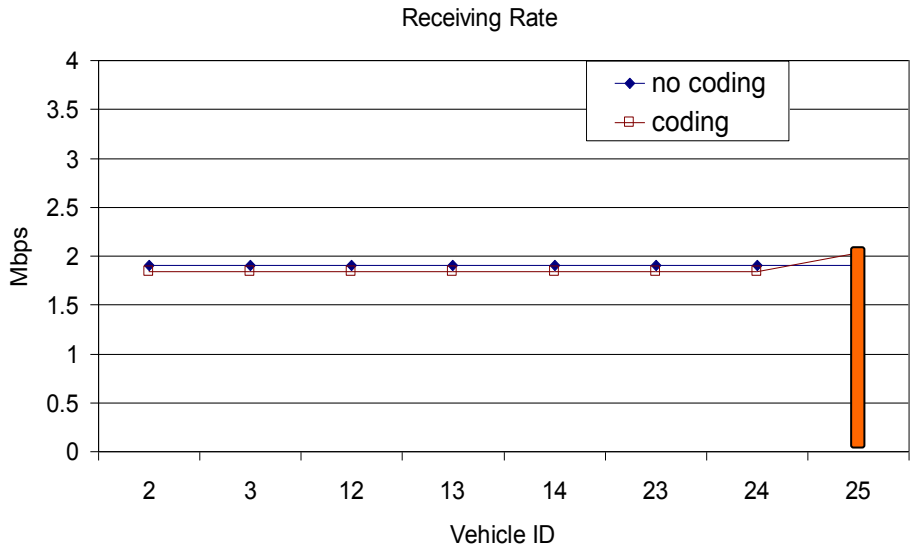
3-lane case with 9 vehicles





- We can select node to benefit from coding
- All nodes have 100% PDR
- Node 24 benefits from coding

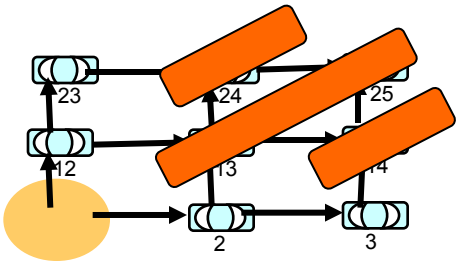




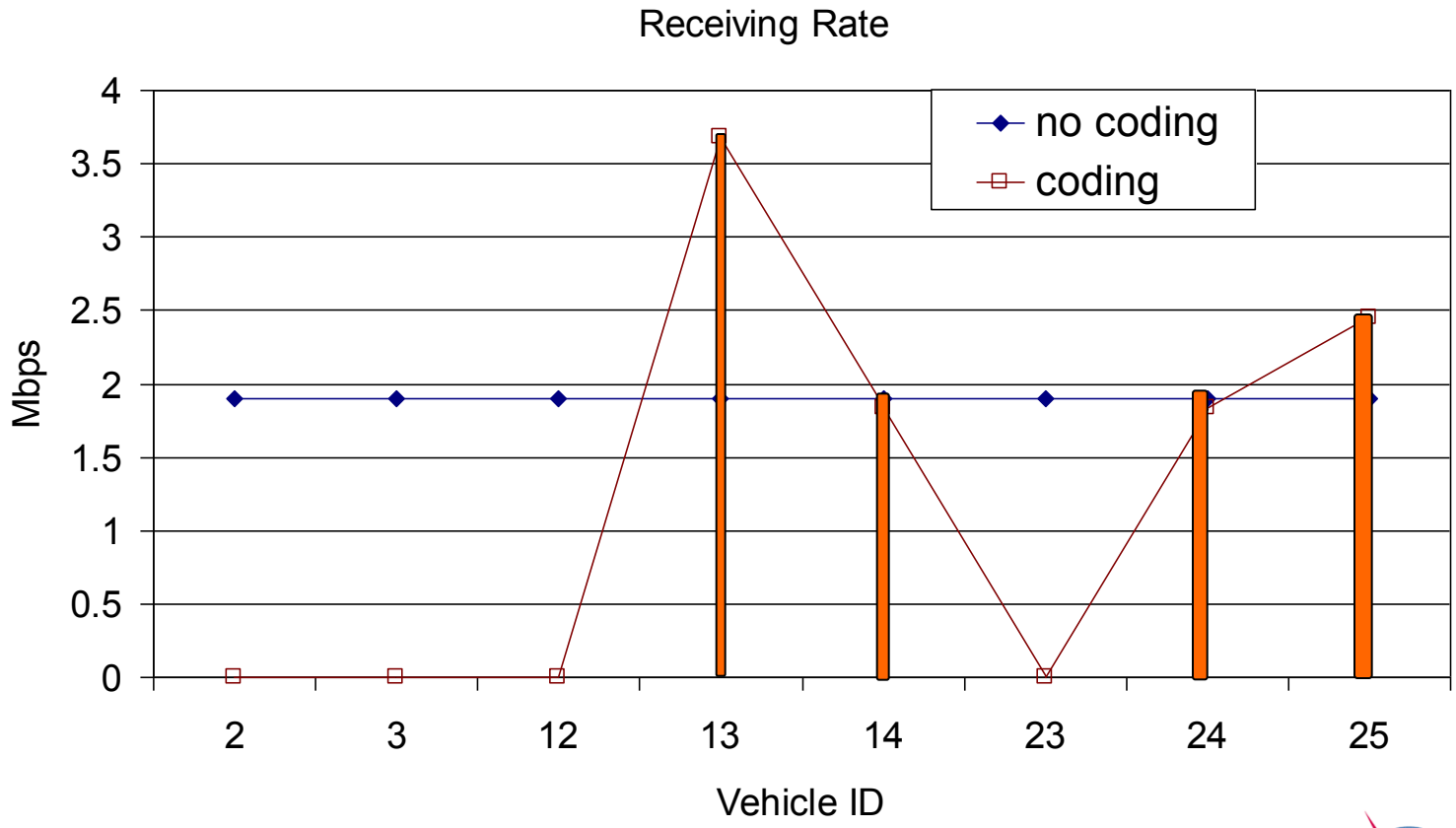
- All nodes have 100% PDR
- Node 25 benefits from coding

Network Coding with Link Selection

3-lane case with 9 vehicles



- Using unidirectional links increases benefits at unicast destinations
- Only target nodes have 100% PDR with coding



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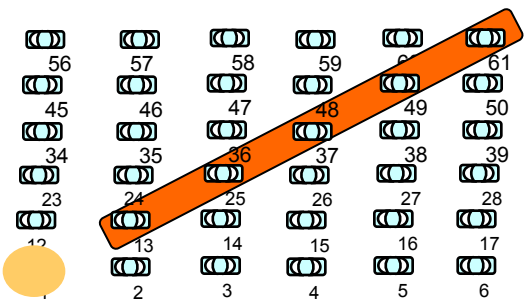
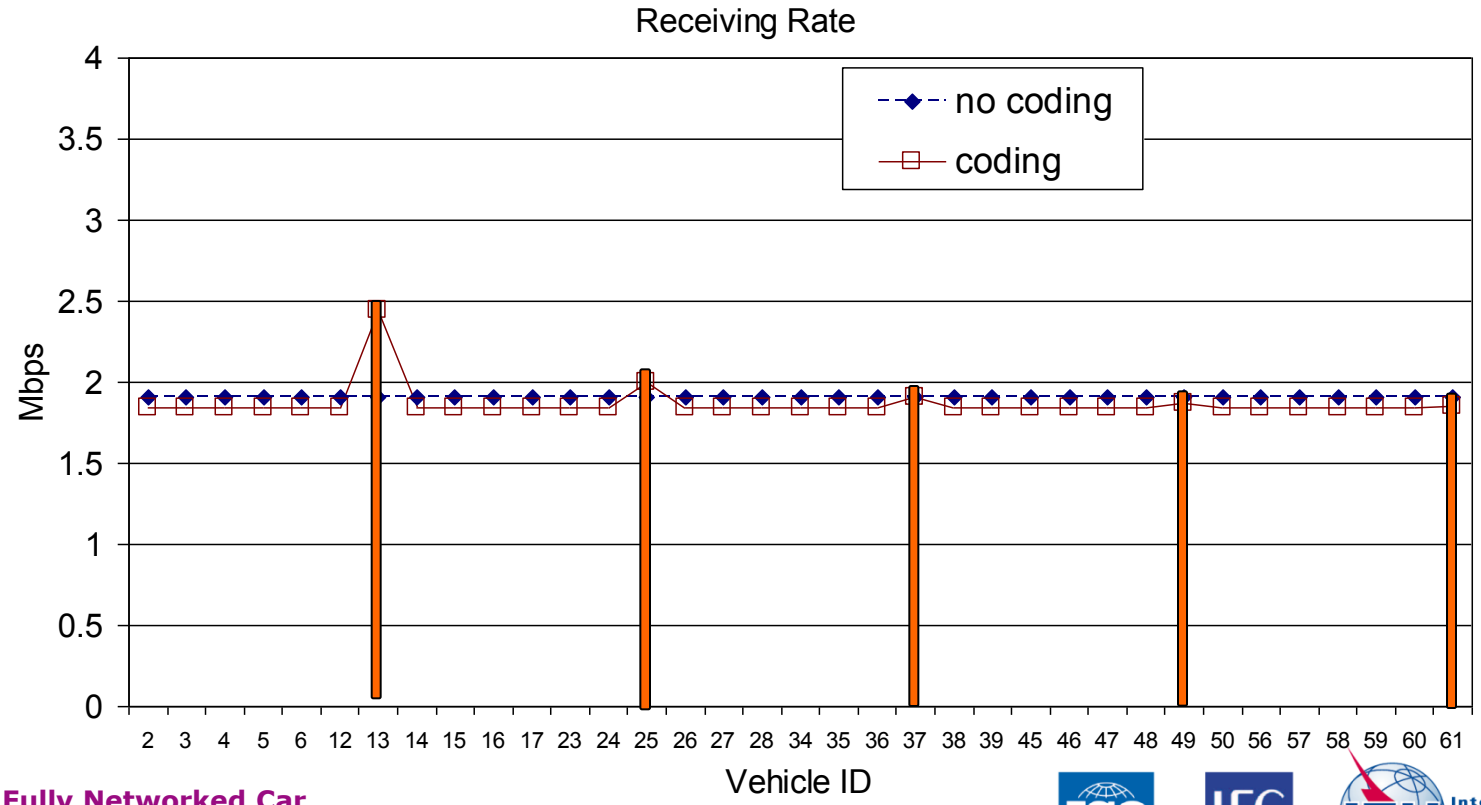
Network Coding
6-lane case with 36 vehicles



- Vehicles on specific paths from the source are able to leverage the benefits from coding
- The benefit decreases for vehicles farther away on the diagonal path
- PDR for coding and no coding is 100%



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Summary

- A novel architecture has been proposed to support multiple directional radios
  - The architecture provides a setup to enable high-throughput and low-overhead communications.
- The architecture supports efficient dissemination of messages among roadway vehicles
  - 100% PDR
  - Low Delay
- Network coding over well-defined switched links enhances network performance
  - Link selection can be used to benefit certain nodes.