Safe driving in Crowded Spectrum: Cognitive radios for VANETs

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Mario Gerla

UCLA, Computer Science Dept

The Mobile Cloud

- **Internet Cloud (eg Amazon, Google etc)**
  - Data center model
  - Immense computer, storage resources
  - BroadBand Connectivity
  - Services, security
- **Mobile Cloud Computing (traditional)**
  - What most researchers mean:
  - Access to the Internet Cloud from mobiles
  - Tradeoffs between local and cloud computing (eg m-health)
- **Recently, new Mobile Cloud paradigm:**
  - Mobile nodes increasingly powerful (storage, process, sensors)
  - Emerging distributed applications not suited for Amazon
- **Enter: Mobile Computing Cloud (MCC)**

Vehicular Cloud

Observed trends:

1. **Vehicles perform increasingly more complex (sensor) data collection/processing services**

   - road alarms (pedestrian crossing, electr. brake lights, etc)
   - cooperative content downloading via P2P car- torrent
   - surveillance (video, mechanical, chemical sensors)
   - road mapping via “crowd sourcing”
   - accident, crime witnessing (for forensic investigations, etc)

2. **Spectrum is scarce => Internet upload expensive**

3. **Keep and process data on *vehicles***

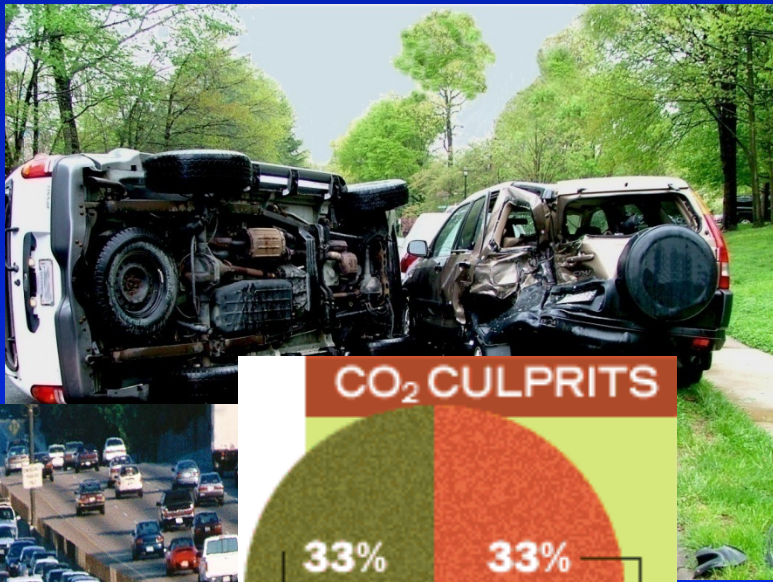
Enter Vehicular Cloud Computing

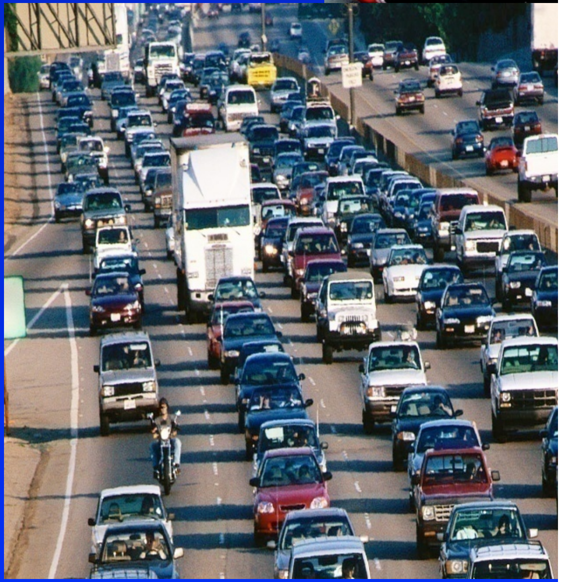
The Vehicle Transport Challenge

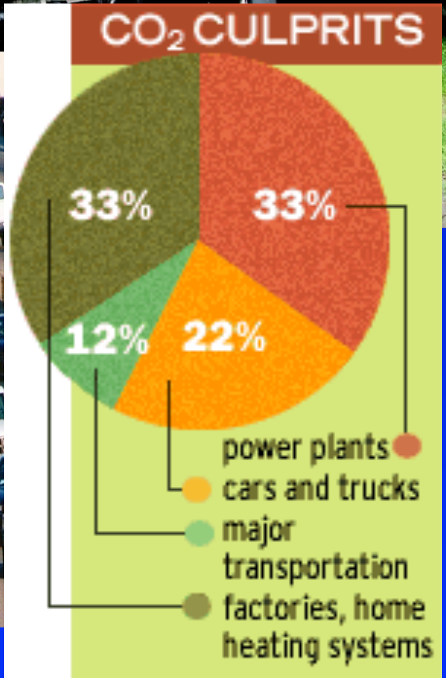
Safety
- 33,963 deaths/year (2003)
- 5,800,000 crashes/year
- **Leading cause of death for ages 4 to 34**

Mobility
- 4.2 billion hours of travel delay
- $78 billion cost of urban congestion

Environment
- 2.9 billion gallons of wasted fuel
- 22% CO_2 from vehicles







In 2003 DOT launches: Vehicle Infrastr. Integration (VII)

- **VII Consortium: USDOT, automakers, suppliers, ..**
- **Goal: V2V and V2I comms protocols to prevent accidents**
  - Technology validation;
  - Business Model Evaluation
  - Legal structure, policies
- **Testbeds: Michigan, Oakland (California)**
- **Positive result: DSRC standard was borne**
- **However: 10 year to deploy 300,000 RSUs and install DSRC on 100% cars**
- **Meanwhile: can do lots with 3G and smart phones**
  - Can we speed up "proof of concept"?

Enter Connected Vehicle (2009-2014)

The Connected Vehicle Program

- **Before (Vehicle Infrastr Integr)**
  - DSRC for all applications
  - Start with V2I and evolve into V2V (safety)
- **Connected Vehicle Program (2009-2014)**
  - *Safety → DSRC*
    - Aggressively pursue V2V
    - Leverage nomadic devices to accelerate benefits
    - Retrofit when DSRC becomes universally available
  - *Non-safety (mobility, environment)*
    - Leverage existing data sources & communications; include DSRC as it becomes available
- **End 2014 US DOT decision about DSRC**
  - *This stimulates research on more vehicular network options*

Emerging Vehicle Applications

- Safe Navigation
- Location Relevant Content Distr.
- Urban Sensing
- Efficient, Intelligent, Clean Transport

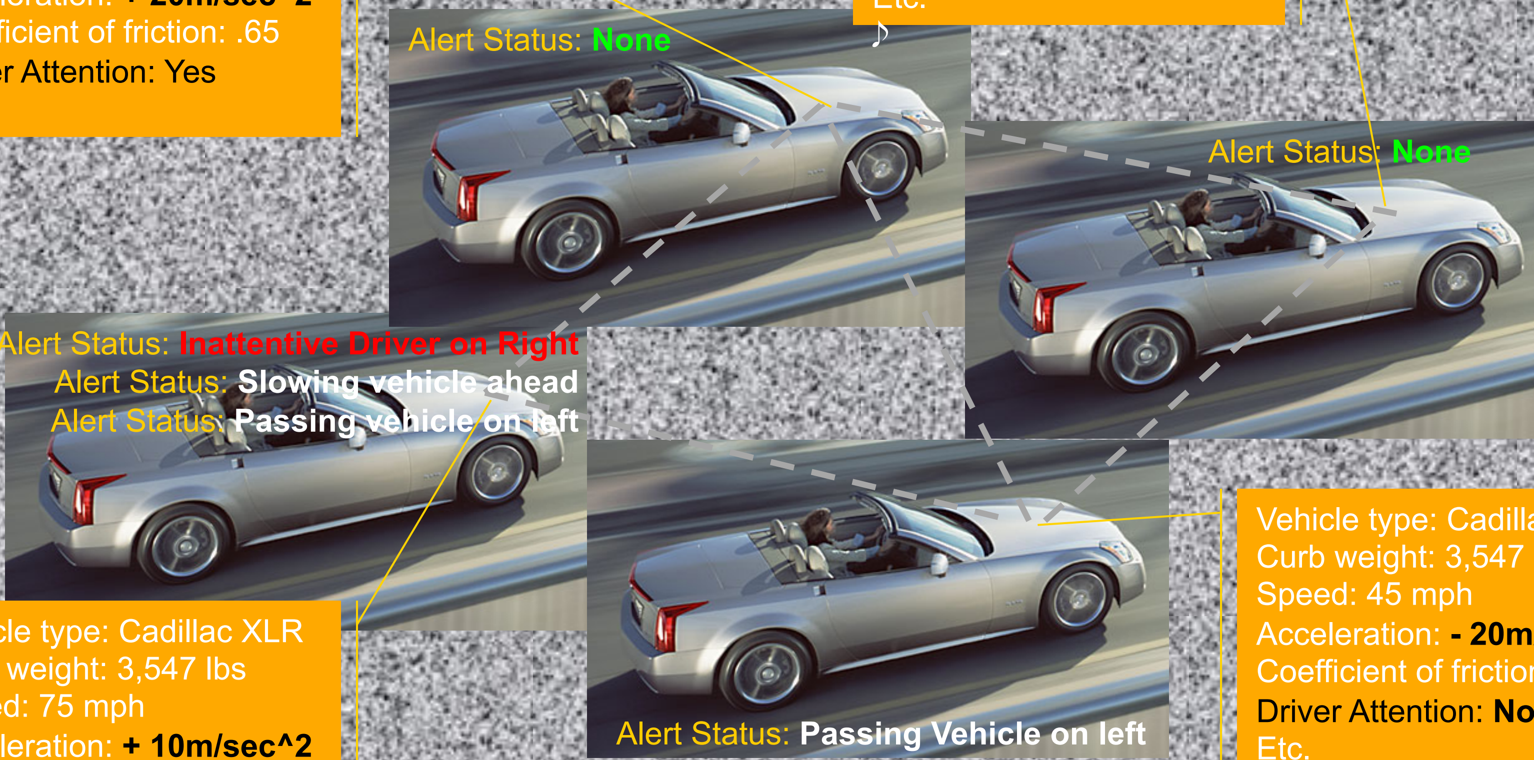
V2V for Safe navigation

- **Forward Collision Warning,**
- **Intersection Collision Warning…….**
- **Platooning (eg, trucks)**
- **Advisories to other vehicles about road perils**
  - “Ice on bridge”, “Congestion ahead”,….

V2V communications for Safe Driving

Vehicle type: Cadillac XLR
Curb weight: 3,547 lbs
Speed: 75 mph
Acceleration: **+ 20m/sec^2**
Coefficient of friction: .65
Driver Attention: Yes
Etc.

Vehicle type: Cadillac XLR
Curb weight: 3,547 lbs
Speed: 65 mph
Acceleration: **- 5m/sec^2**
Coefficient of friction: .65
Driver Attention: Yes
Etc.



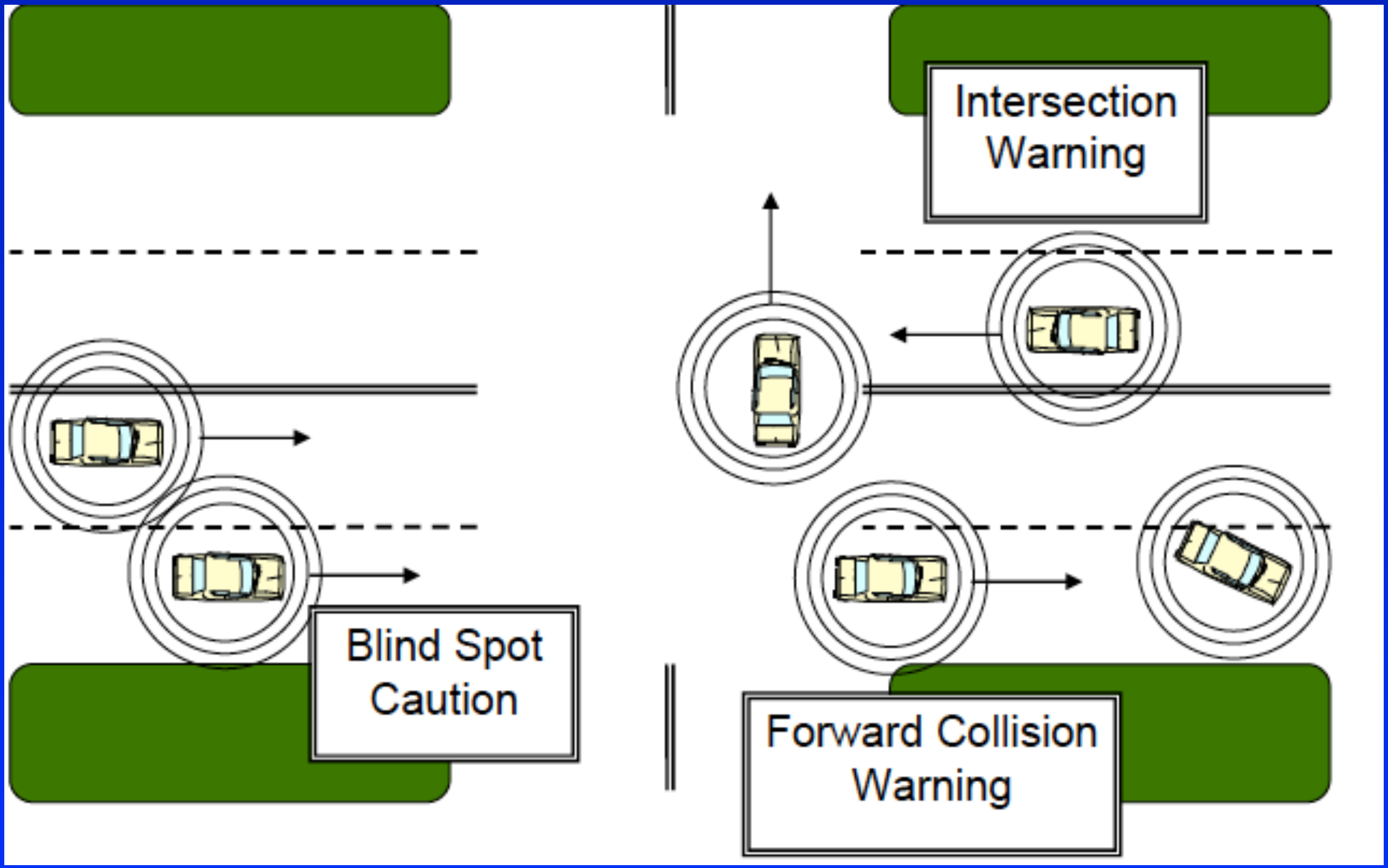
Vehicle type: Cadillac XLR
Curb weight: 3,547 lbs
Speed: 75 mph
Acceleration: **+ 10m/sec^2**
Coefficient of friction: .65
Driver Attention: **Yes**
Etc.

Vehicle type: Cadillac XLR
Curb weight: 3,547 lbs
Speed: 45 mph
Acceleration: **- 20m/sec^2**
Coefficient of friction: .65
Driver Attention: **No**
Etc.

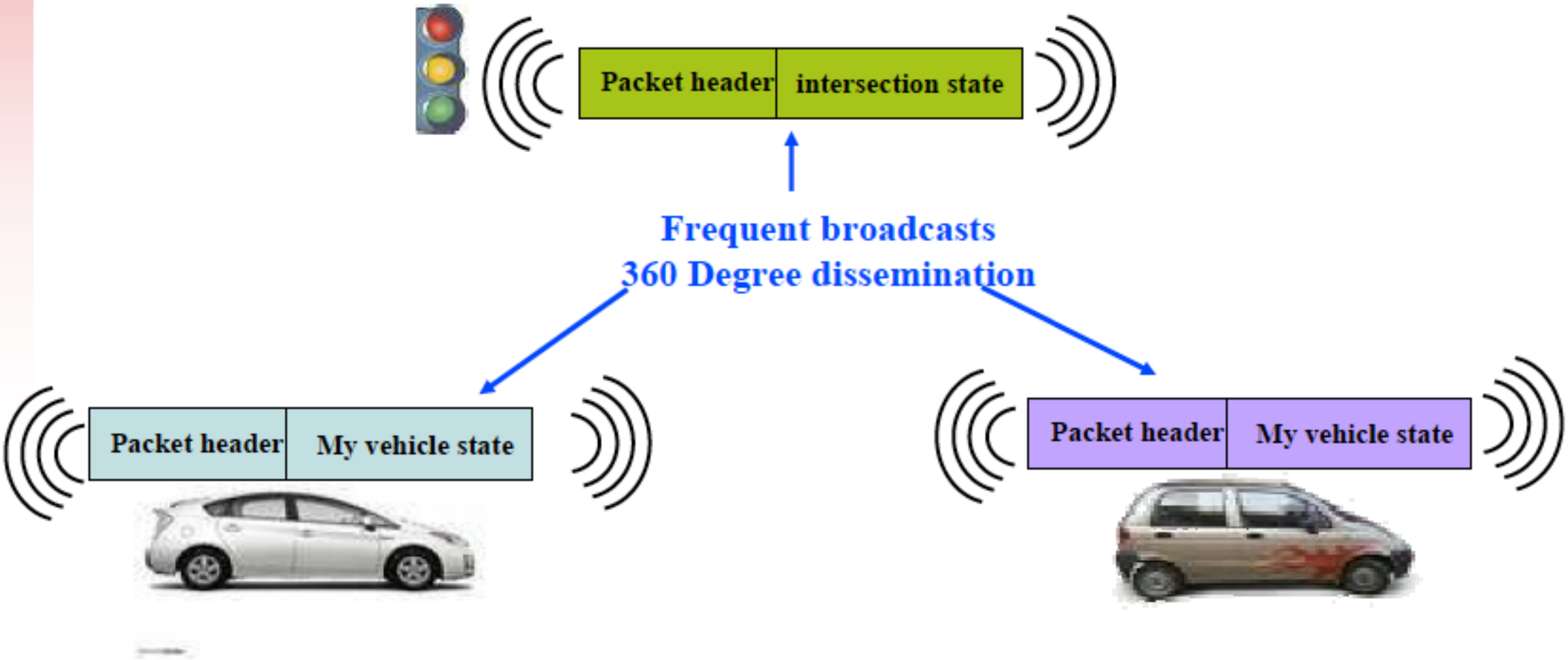
V2V for Platooning

Study will offer insight into autonomous vehicle grids

V2V for Collision Avoidance

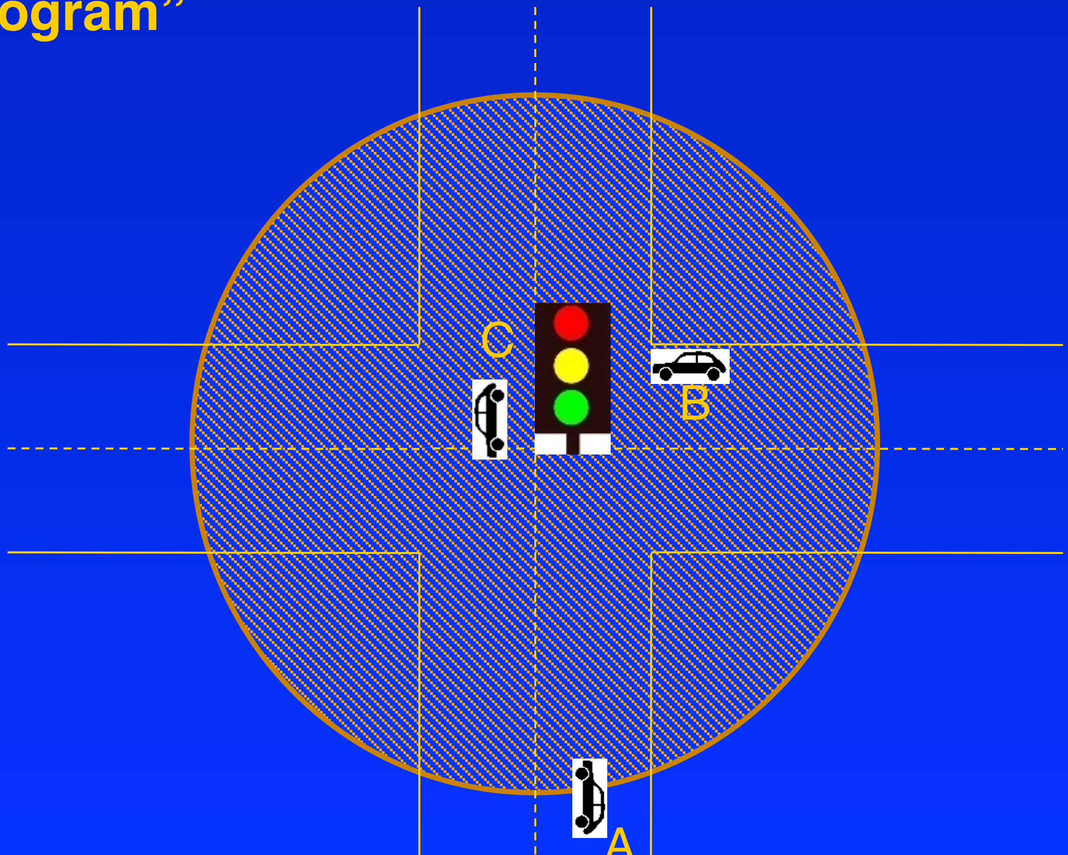


V2V for Intersection Collision Avoidance



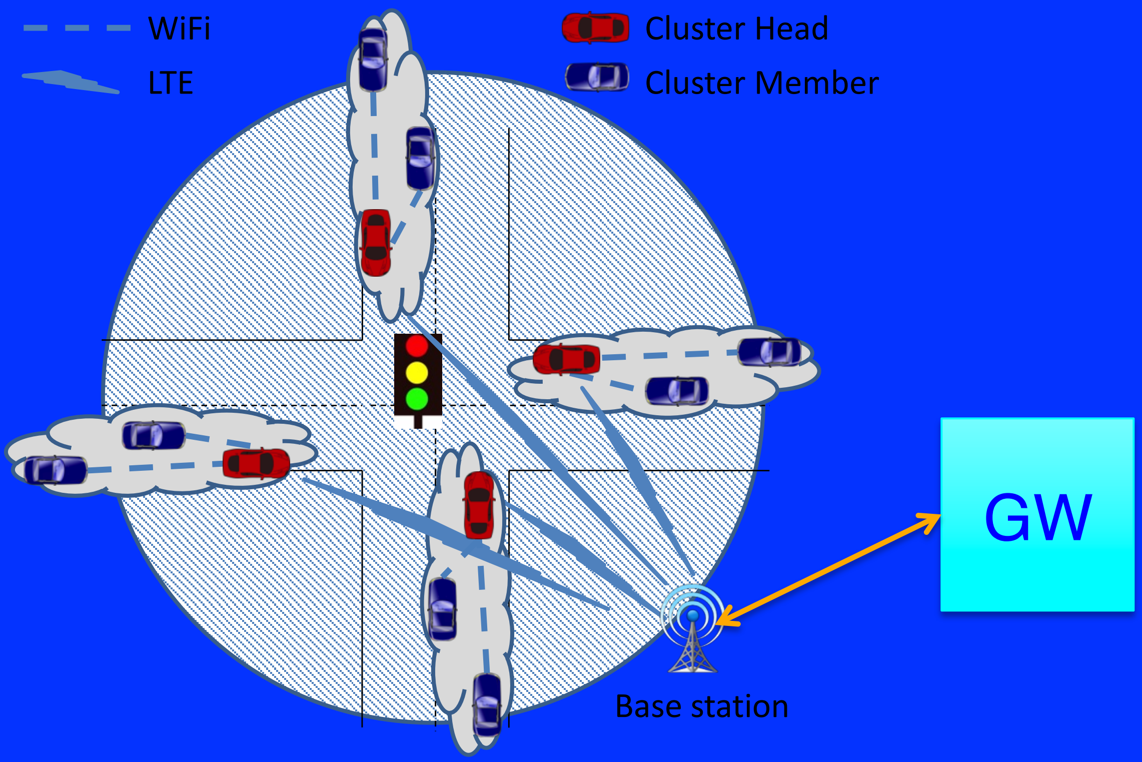
Intersection Collision Avoidance using DSRC

1. Vehicle A, B and C broadcast DSRC beacons
2. RSU in traffic light forwards beacons around the corner
3. Problem: RSU's will not be deployed in the "Connected Vehicle Program"



Clusters + LTE Around the Corner

- Cluster members communicate GPS position to CHs via Wi-Fi
- CHs connect to the LTE base station
- CHs exchange cluster position information via the GW
- Use V2V communications in the cluster

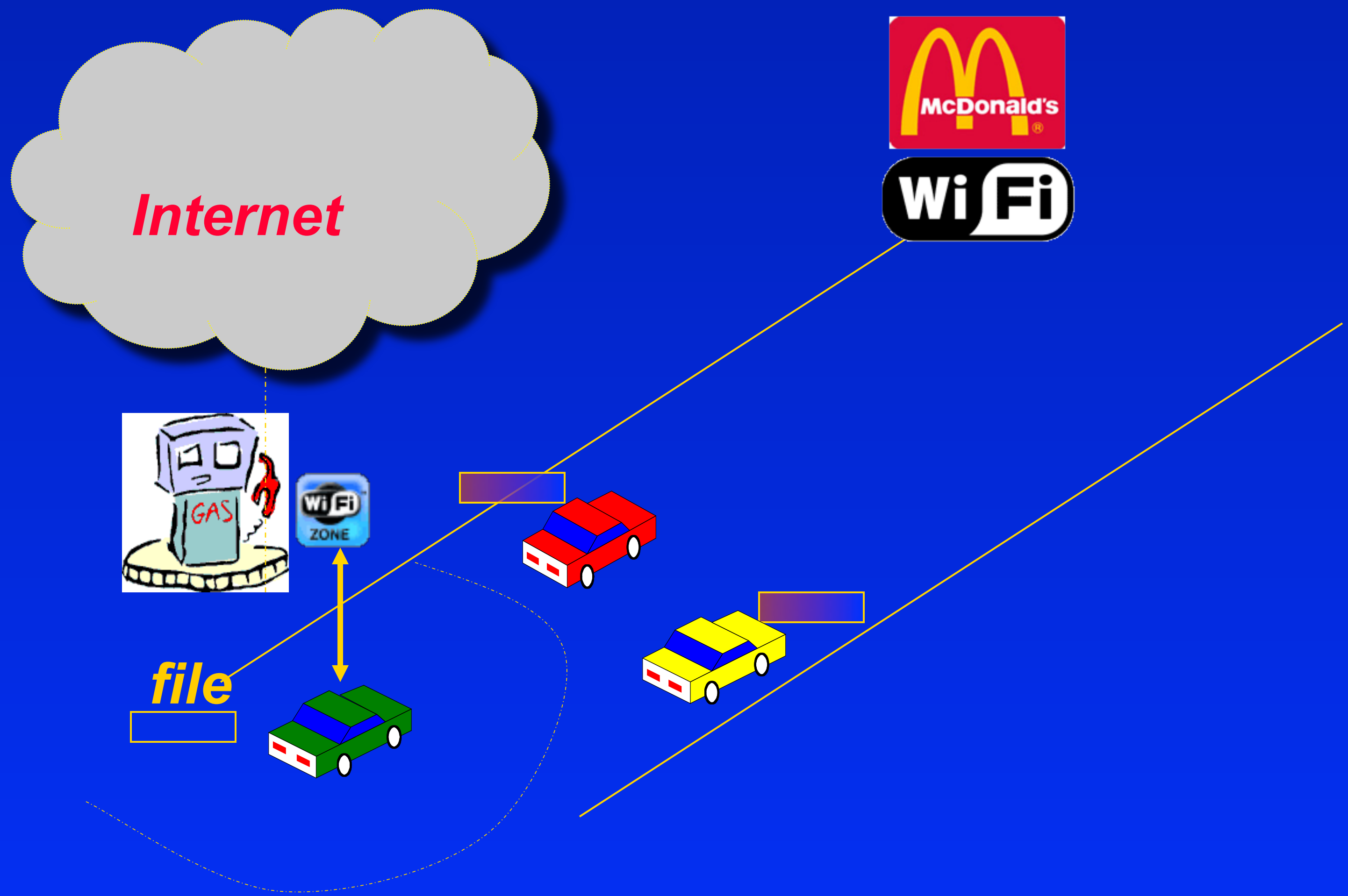


V2V for Location relevant content delivery

- Traffic information
- Local attractions, advertisements
- Tourist information, etc

You are driving to Vegas
You hear of this new show on the radio
Video preview on the web (10MB)

One option: Highway Infostation download



Incentive for opportunistic "ad hoc networking"

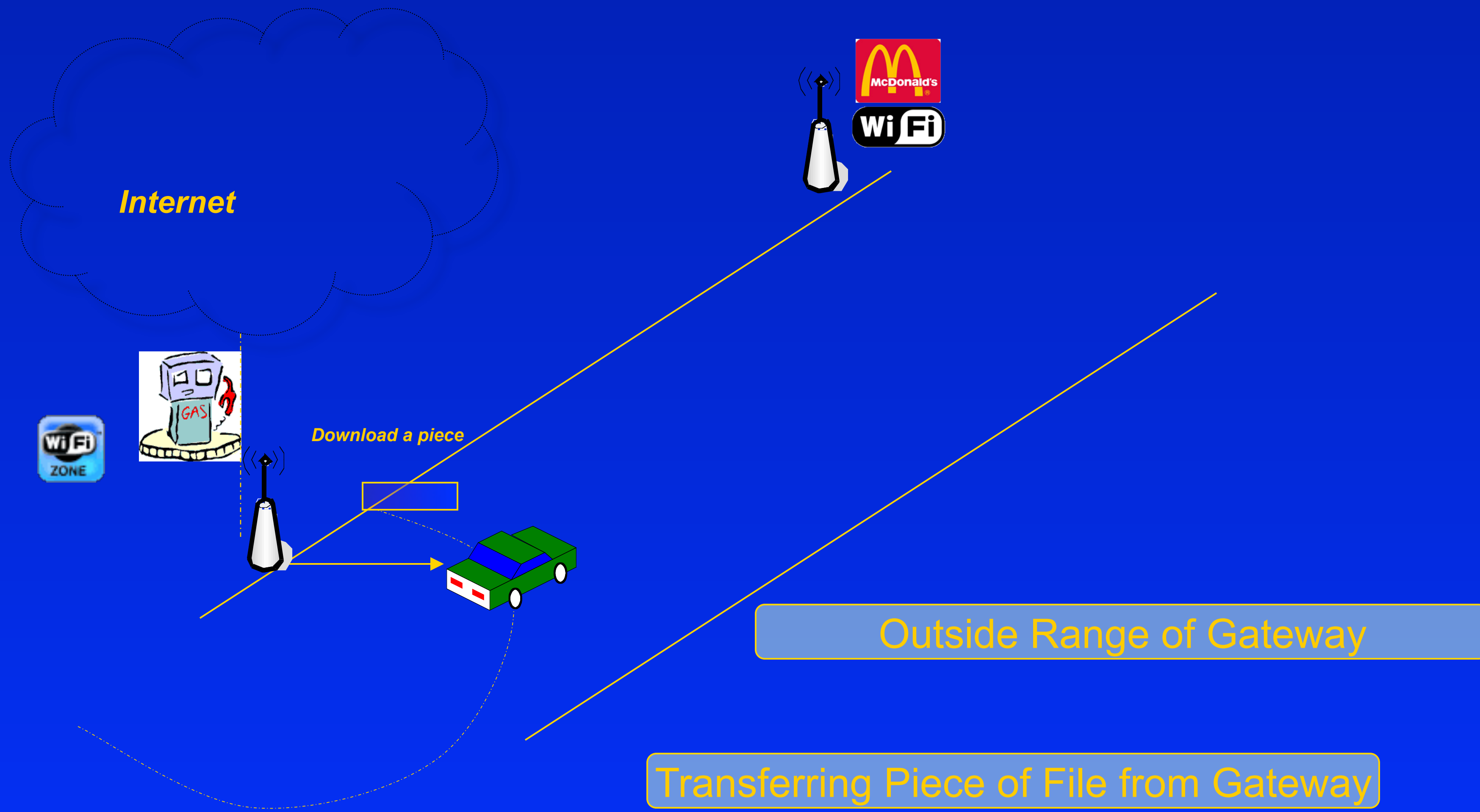
Problems:

- *Stopping at gas station for full download is a nuisance*
- *Downloading from GPRS/3G too slow and quite expensive*
- *3G broadcast services (MBMS, MediaFLO) only for TV*

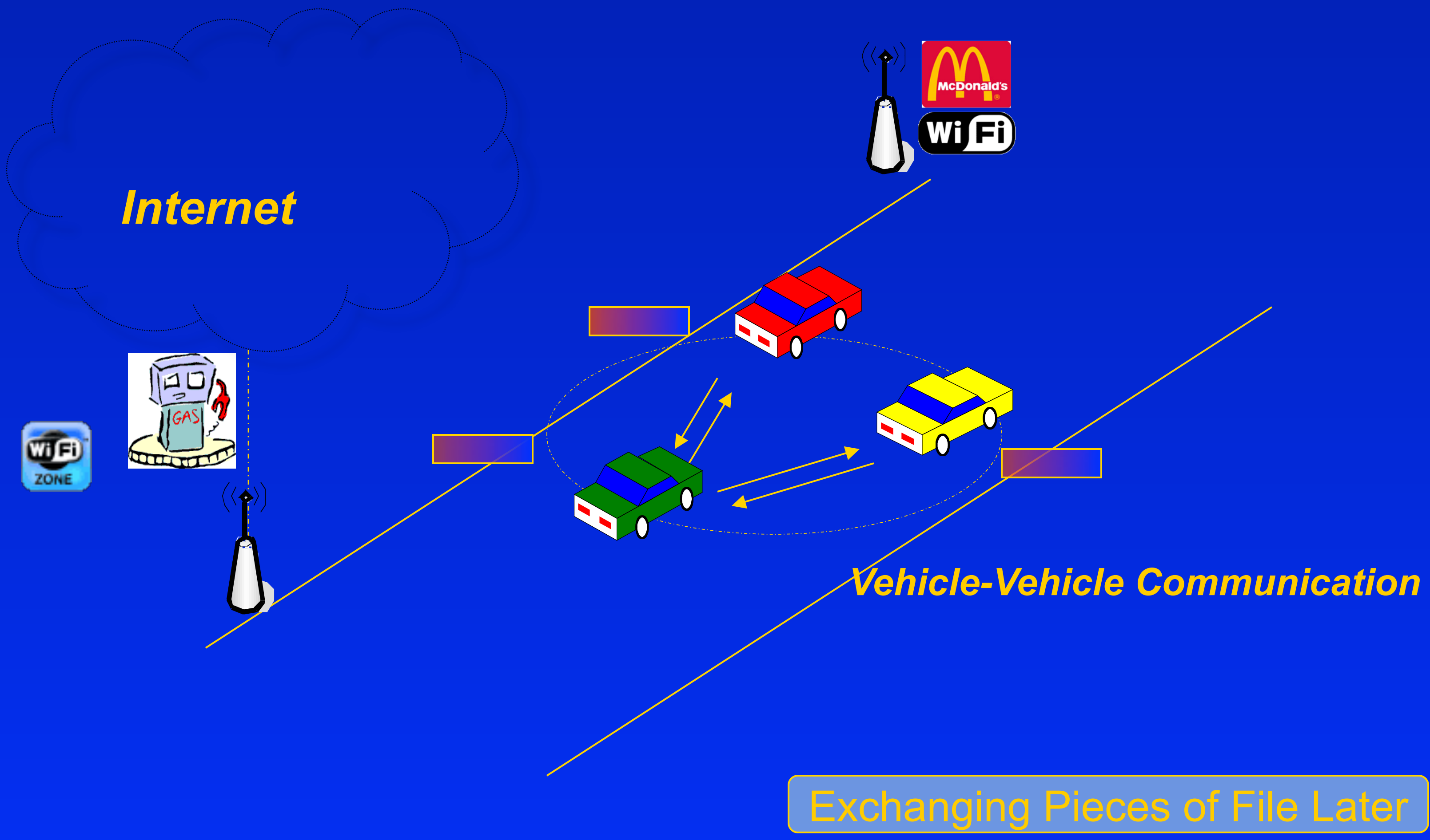
Observation: many other drivers are interested in download sharing

Solution: Co-operative P2P Downloading via Car-Torrent (like Bit Torrent in the Internet)

Co-operative Download: V2V CarTorrent

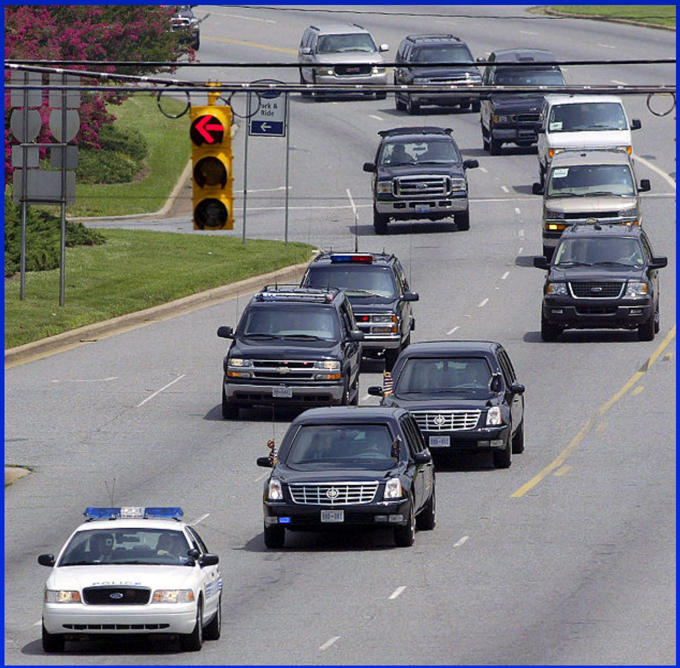


Car Torrent



Can also download from LTE
Better safety – no stopping at gas stations
Inexpensive V2V spectrum used

V2V for Surveillance



- President Motorcade with 100’s of vehicles
- **Surveillance video streams** are generated by escort cameras and are multicast to patrollers
- Strictly V2V for security/privacy

URBAN V2V => Cognitive Radios

- **V2V critical for Vehicular Cloud applications:**
  - V2V for collision avoidance, Intersection clusters, multimedia
- **V2V Problems:**
  - DSRC spectrum reserved for navigation safety applications – besides, it may go away!
  - WiFI urban spectrum is becoming increasingly crowded because of residential users and mobile phone offloading (from cellular)
- **Solution:**

vehicles must coexist with residential WiFi users – using Cog Radios

Question: what about V2I?

difficult but no Cog Radios required

Example: Presidential Motorcade

- **Platoon with 100's of vehicles**
  - **Surveillance video streams** are generated by sensor-enabled escorts and are multicast to patrollers
- ***Primary network – WiFi residential***
  - Dense WiFi access point deployment
- ***Secondaries -vehicles:***
  - must minimize interference to residential WiFi
  - In turn, **avoid interference** created by residential traffic

Westwood experiment (4 blocks) IEEE 802.11b/g

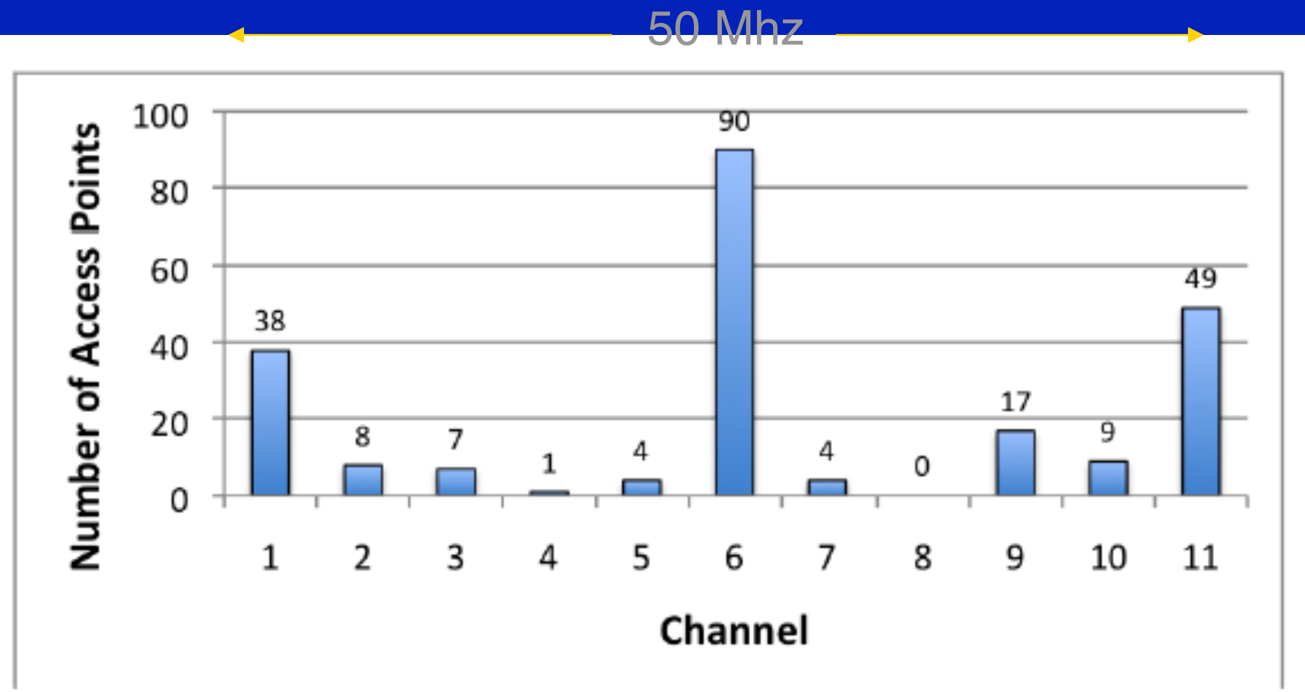
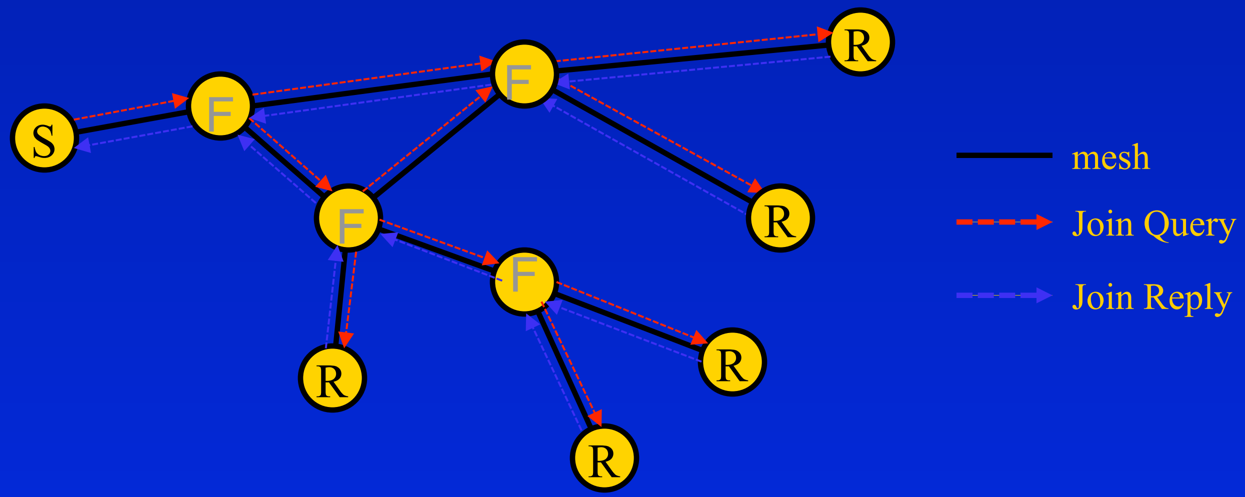


Fig. 3. Environmental Interference: Channel occupancy of APs in the area

227APs discovered using wireless card in automatic detection mode. Orthogonal channels 1,6,11 are predominant

On-Demand Multicast Routing Protocol (ODMRP)

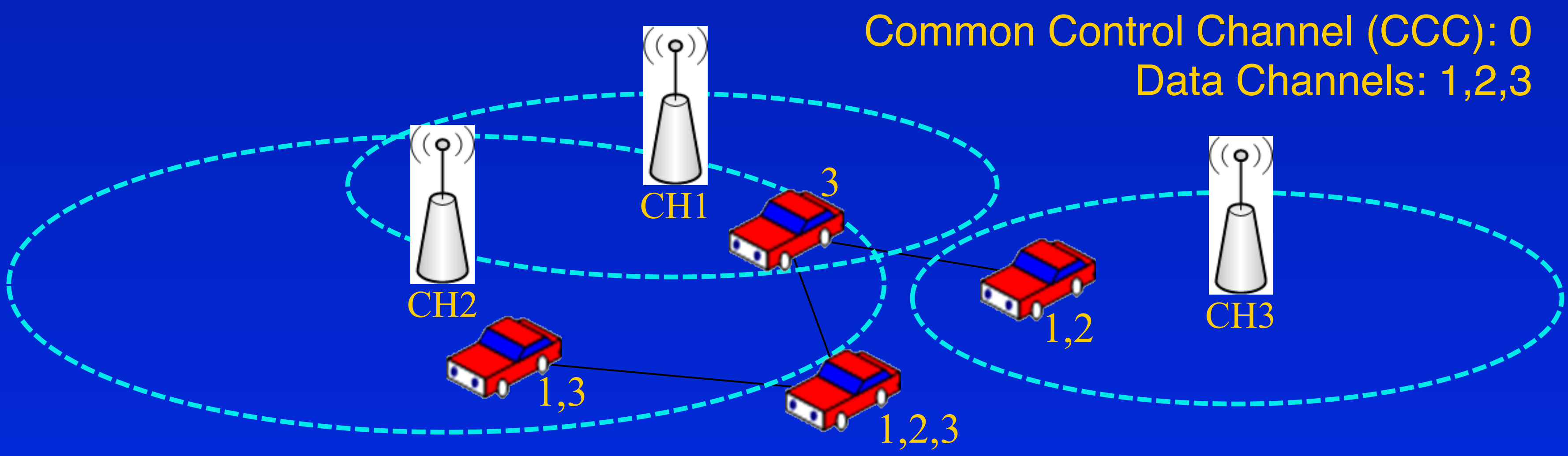


- **On-demand mesh creation**
  - A source initiates **Join Query** flooding when it has data to send.
  - Intermediate nodes relay **Join Query** after recording the previous hop as backward pointer.
  - Multicast subscribers send **Join Reply** messages, following backward pointers to the source.
  - Upon receiving a **Join Reply**, a node declares itself as part of the **forwarding group**.

CoCast (Cognitive MultiCast) Protocol

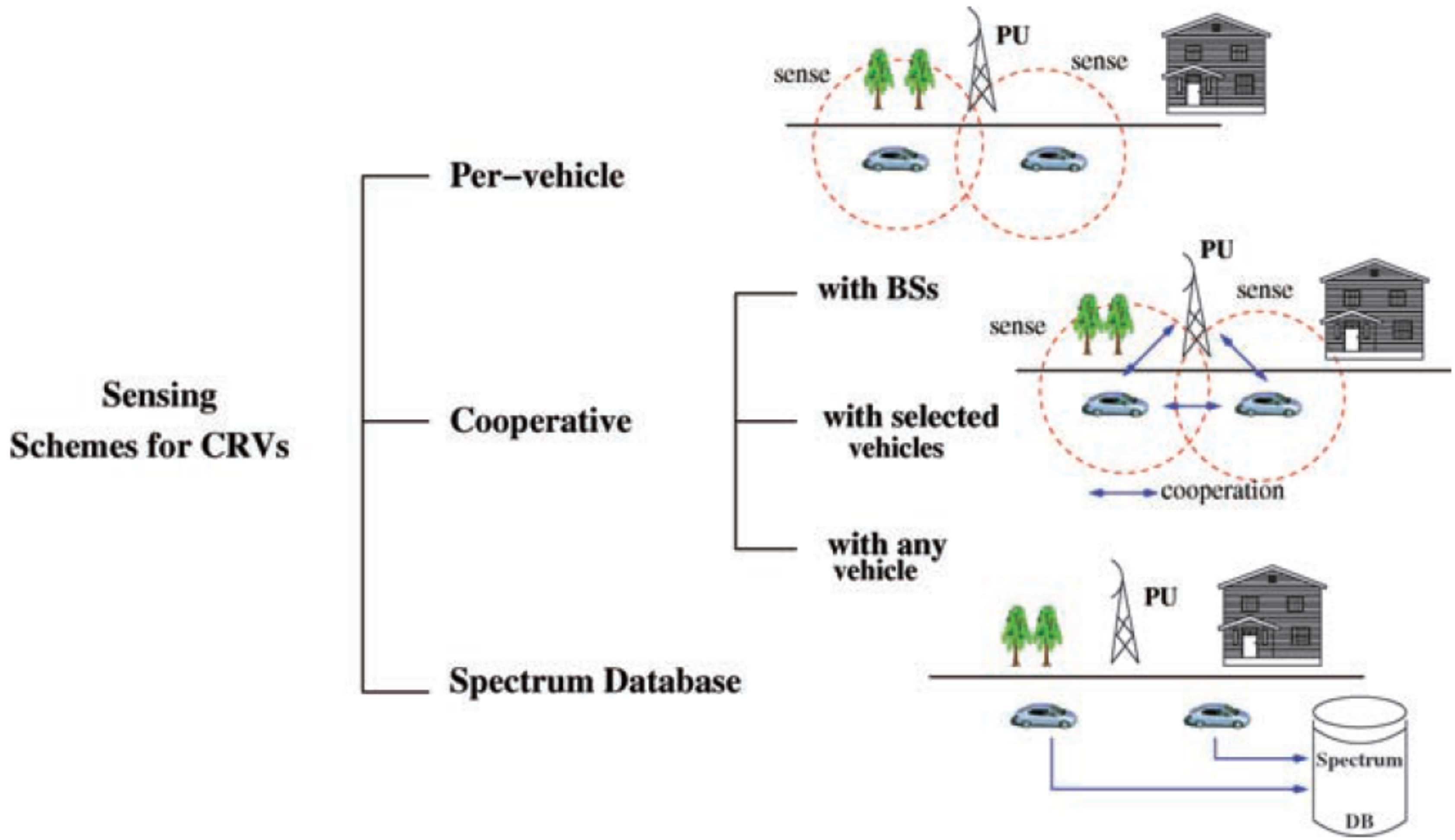
- Extension of ODMRP
- Assumes that every node has one **single radio** interface.
- There is a common control channel (CCC) known to all nodes
  - Arbitrary 802.11 channel, “rotated” to minimize impact on residents
- **Channel Sensing**
  - Vehicles scan the spectrum periodically, all at the same time, to identify idle residential channels.
- **Multicast tree construction**
  - As in ODMRP, Join Query and Join Reply message exchange in CCC
  - Each Source builds own Multicast Tree
  - Channel availability piggybacked on control messages.
- **Periodic Route (mesh) maintenance** and refresh

CoCast: Channel Sensing



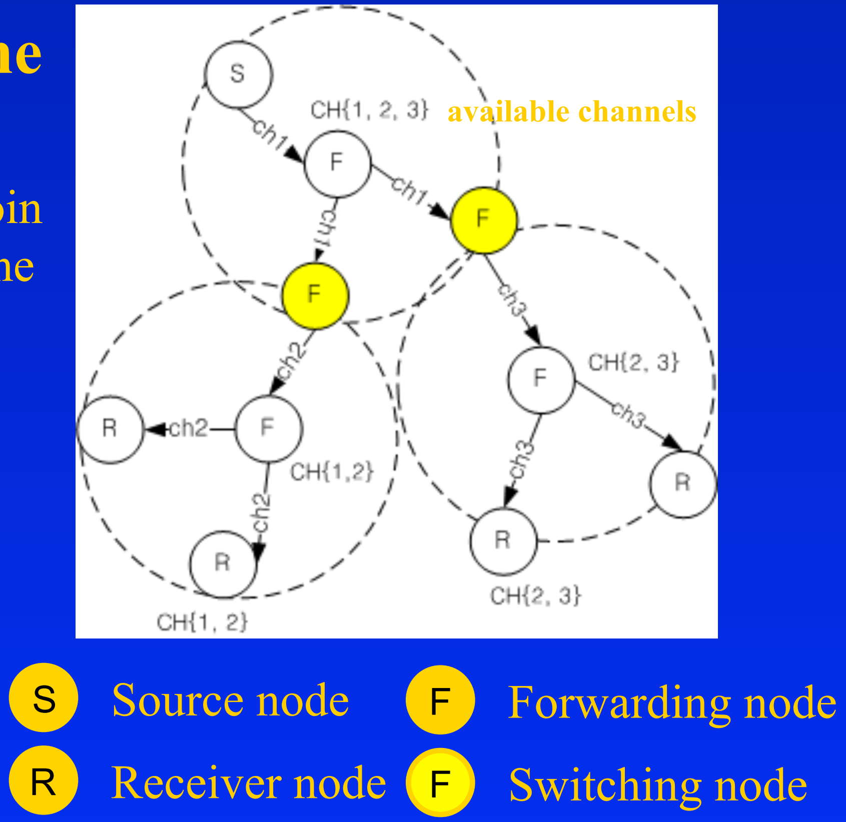
- **Nodes periodically sense spectrum and keep the list of available (idle) channels.**
- **Nodes exchange available channel information (e.g. frequency, load, etc.) with peers through the CCC.**

Vehicle Spectrum Sensing



CoCast: Multicast Tree Construction

- **Each source builds a multicast tree and allocates channels on the fly.**
  - Source floods Join Query and receives Join Reply from multicast receivers through the CCC.
  - Join Query includes channel availability information.
  - Join Reply includes channel selection.
  - **Goals:**
  - **minimize hidden terminal conflicts**

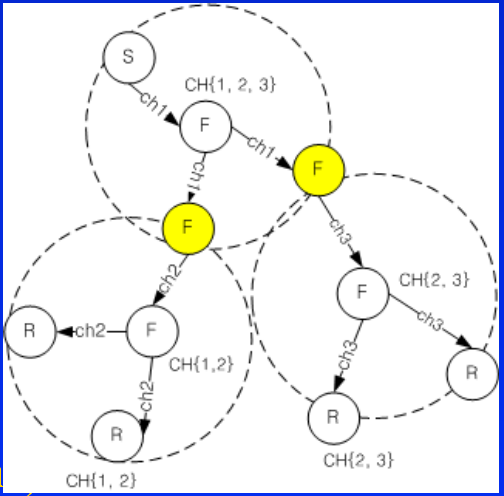


CoCast Penalty: Frequency Switching Delay

- **Channel frequency switching with a single radio**
  - **Switching nodes**: nodes that must switch from one channel to another.
  - Contributions to Channel switching delay (D_{switch}):

$$D_{switch} = D_{hw} + D_{protocol}$$

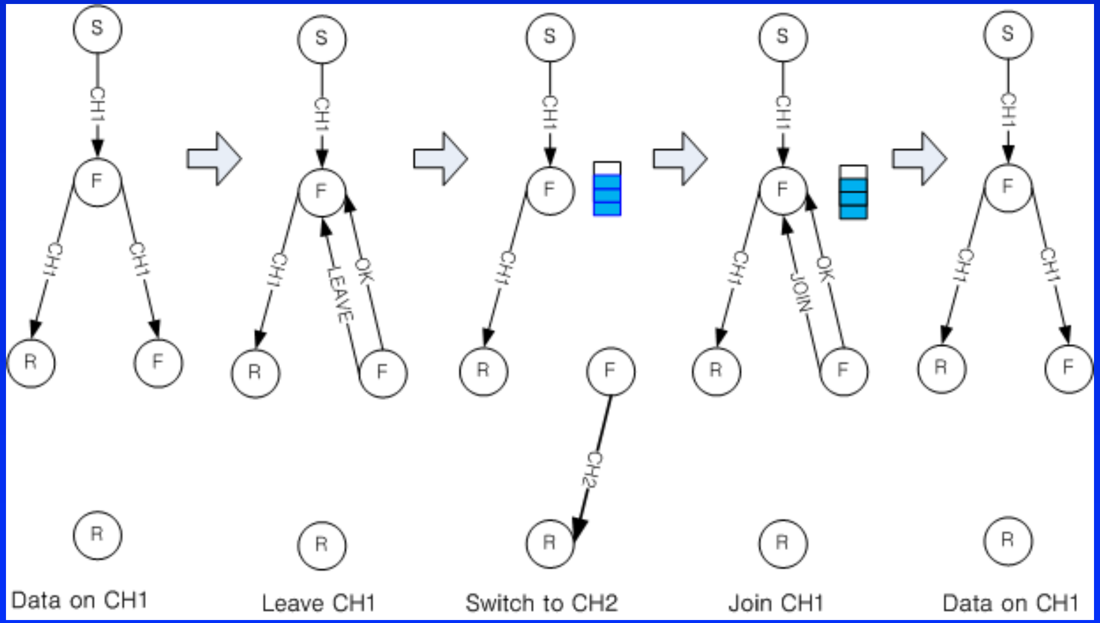
$$D_{hw} = D_{RF\_Rec} + D_{BB\_Rec}$$



- D_{hw}: hardware delay
  - D_{RF_Rec}: RF switching delay (80μs ~ several m
  - D_{BB_Rec}: baseband reconfiguration delay (0 to hundreds of ms)
- $D_{protocol}$: protocol delay (overhead in the underlying MAC/ PHY protocol)

CoCast: Frequency Switching(2)

- **Deafness problem**
  - Switching nodes create deafness problem (cannot receive packets from upstream ch when tuned on different downstream ch).
  - A switching node issues a LEAVE message before switching to another channel, and the preceding forwarding node buffers packets until it receives a JOIN message.



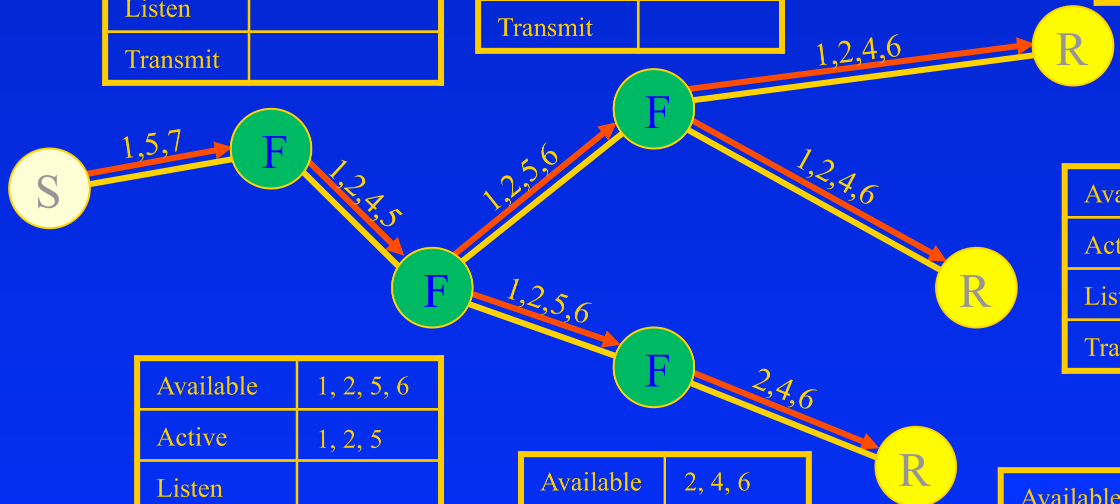
S Source node

R Receiver node

F Forwarding node

CoCast: Channel Allocation

- **Join Query flooding in the CCC**
  - Cognitive nodes compute **Active channels** (*two-way available*) after receiving Join Queries that contain **Available channels.**



Available	1, 5, 7
Active	
Listen	
Transmit	

Available	1, 2, 4, 5
Active	1, 5
Listen	
Transmit	

Available	1, 2, 4, 6
Active	1, 2, 6
Listen	
Transmit	

Available	3, 6, 7
Active	6
Listen	
Transmit	

Available	1, 2, 6, 7
Active	1, 2, 6
Listen	
Transmit	

Available	1, 2, 5, 6
Active	1, 2, 5
Listen	
Transmit	

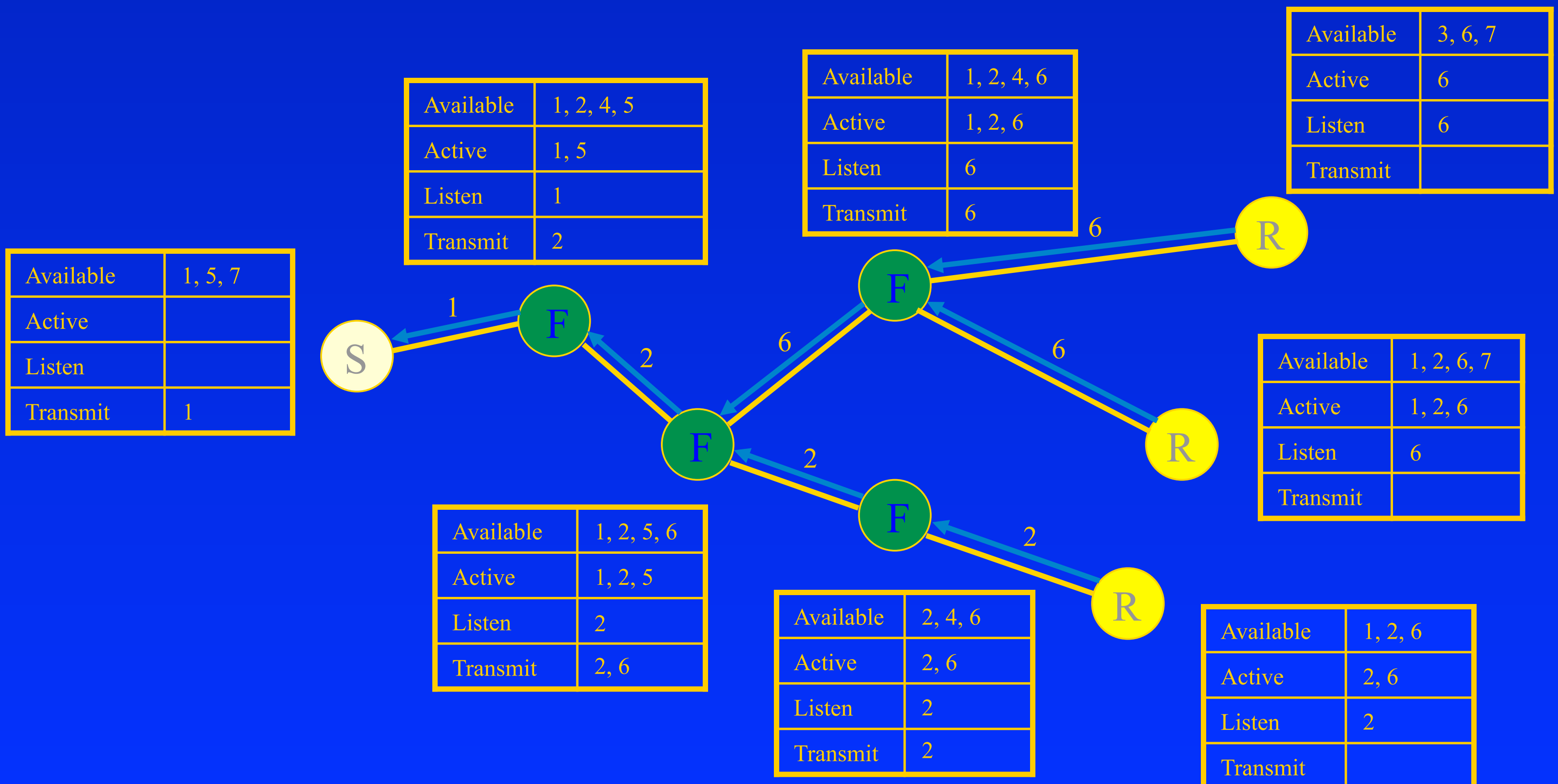
Available	2, 4, 6
Active	2, 6
Listen	
Transmit	

Available	1, 2, 6
Active	2, 6
Listen	
Transmit	

7 data channels (1~7),
1 common control channel (0)

CoCast: Channel Allocation

- **Sending back Join Reply**
  - Receiver selects **Listen channel** from Active channel list, reports in **JR**
  - Forwrd nodes set own **TX Channel** to **Listen channels**
  - **Goal:** minimize # of **channel frequency switches** along path

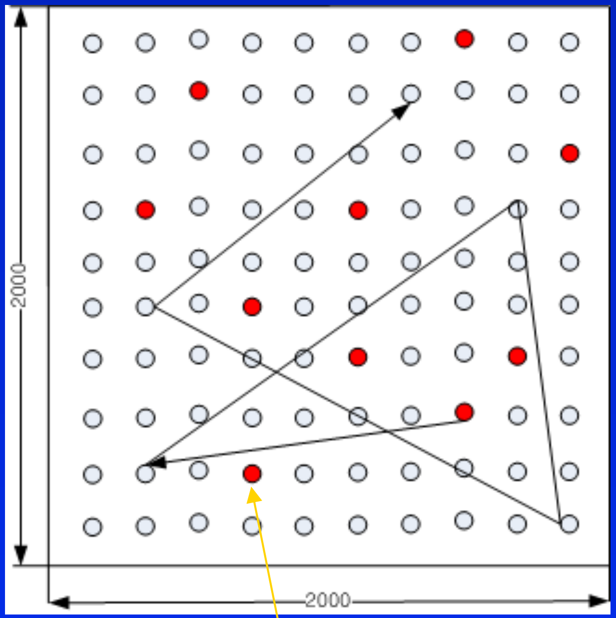


Simulation Setup

- **Simulation configuration in QualNet 3.9**

Parameter	Value
Number of Nodes	100
Mobility	random waypoint, 20m/s
Switching delay (D_{switch})	0~50 ms
Number of channels	7 Data channels
Channel data rate/ range	2 Mbps/ 230m
Packet size/rate	512 Bytes, 4pps

Starting topology



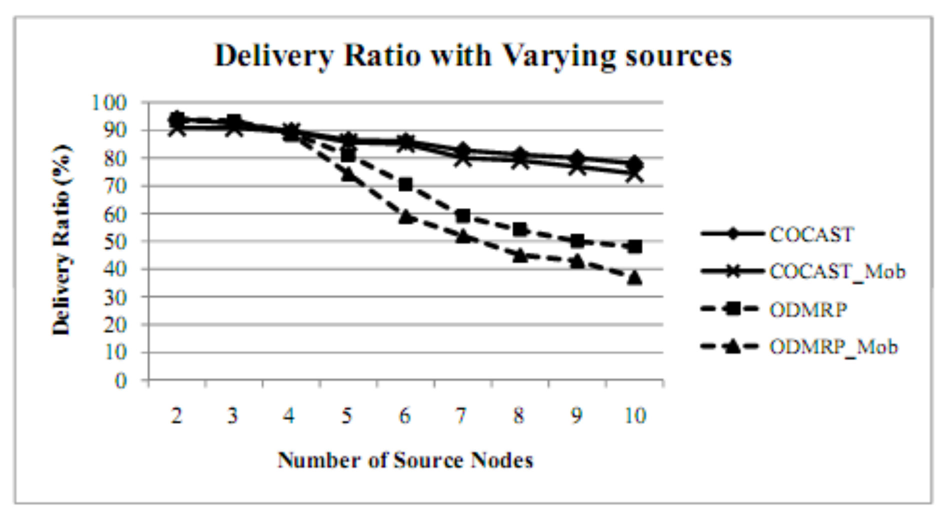
source

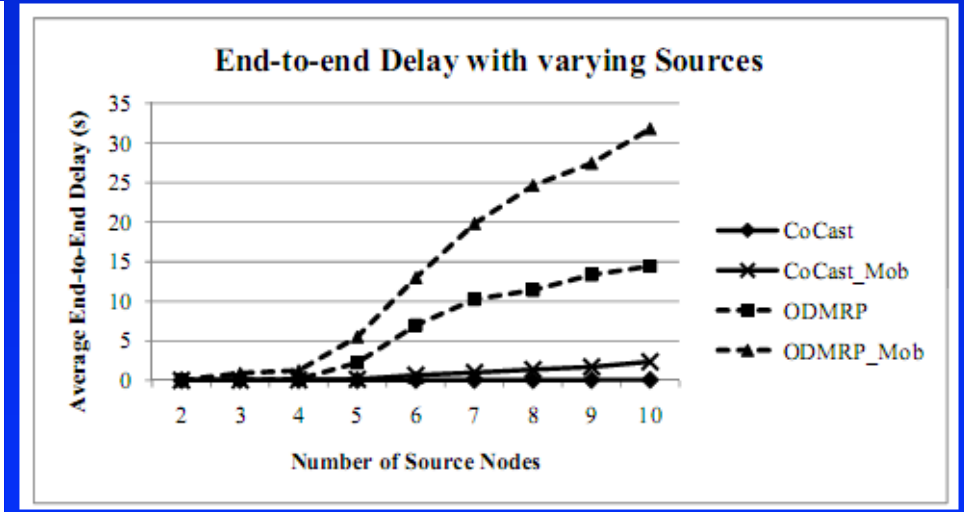
- **Random way point motion**
- **Each area of the field has different WiFi channel occupancies**
  - Channel idle/busy state changes randomly in space and time (.5 busy probability)

Simulation Results

- **Variable number of sources**
  - 2 ~ 10 source nodes within the multicast group
  - Comparison between ODMRP and CoCast

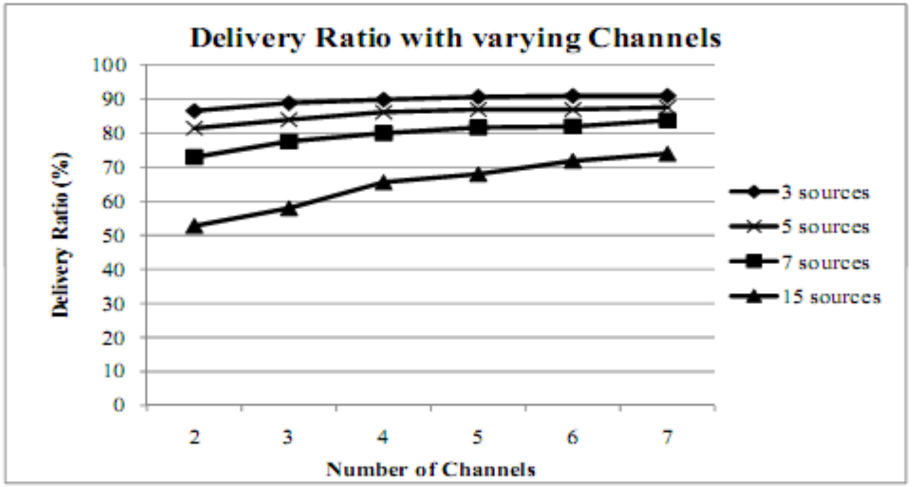
    ODMRP uses fixed channel, invading primary users
  - Static case vs. mobile case
  - CoCast scales better with increasing number of source nodes.

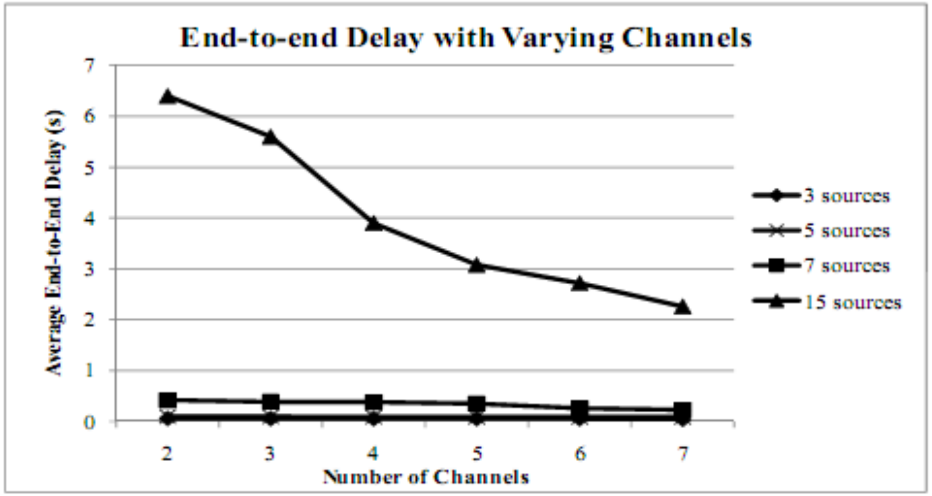




Simulation Results

- **Varying the number of Channels and Sources**
  - 2 to 7 channels
  - 10 receivers
  - The benefit of having multiple channels increases as the number of sources increases (ie, as traffic increases).





Conclusions

- CoCast extends ODMRP to multihop, multichannel "cognitive" primary/secondary network scenarios.
- Opportunistic use of multiple channels in WiFi urban scenario (while deferring to pre-existing WiFi users) improves robustness of multicast in vehicular platoons.

Future work:

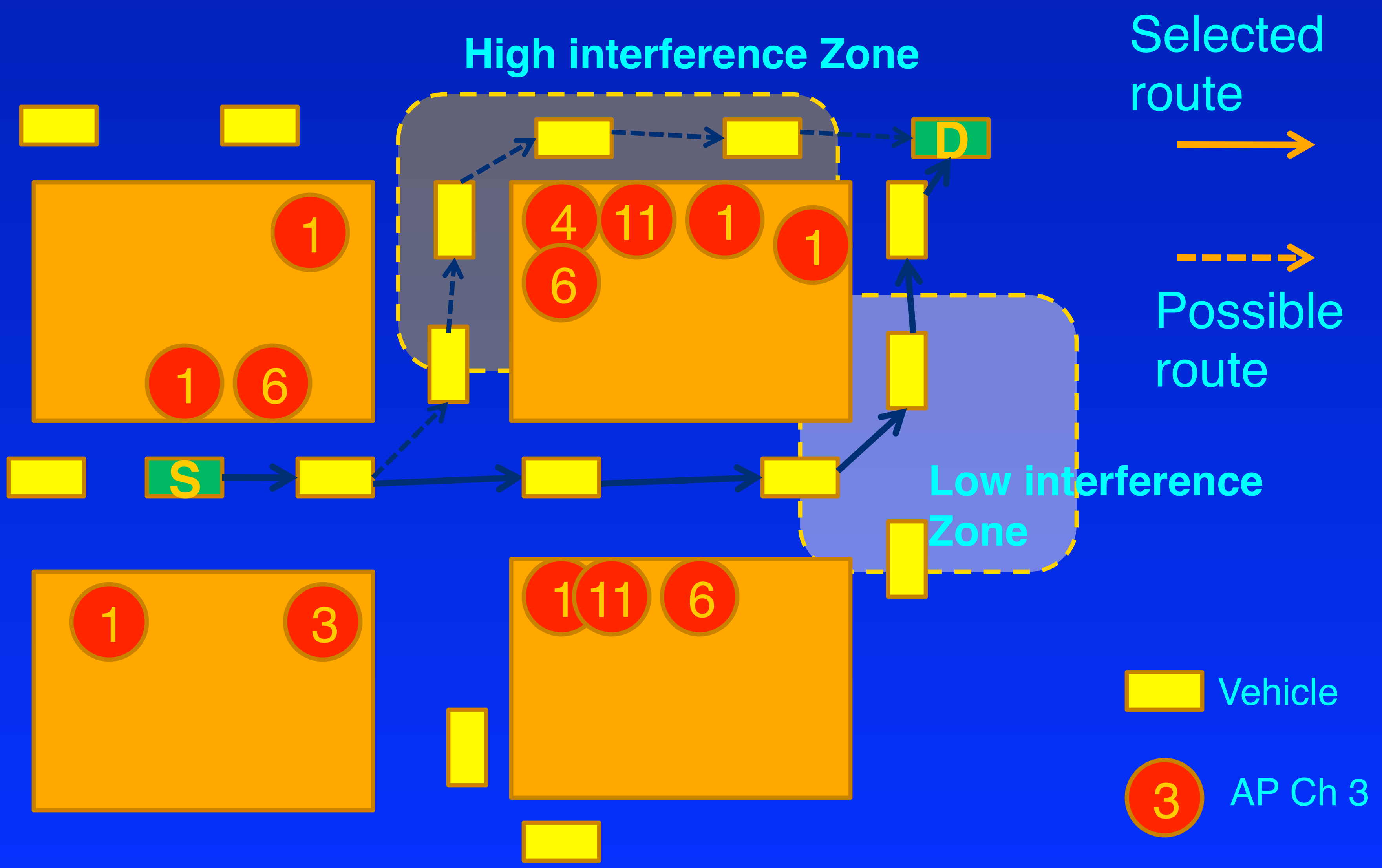
- develop performance bounds using Branch and Bound techniques
- Explore use of multiple radios on vehicles

CoRoute: A New Cognitive Anypath Vehicular Routing Protocol

IWCMC 2011, Istanbul, Turkey July 4-8, 2011

W. Kim, M. Gerla – UCLA
S. Oh – Utopia Compression
K. Lee - CISCO

CoRoute: which route is best?



CoRoute: Cognitive anypath Routing

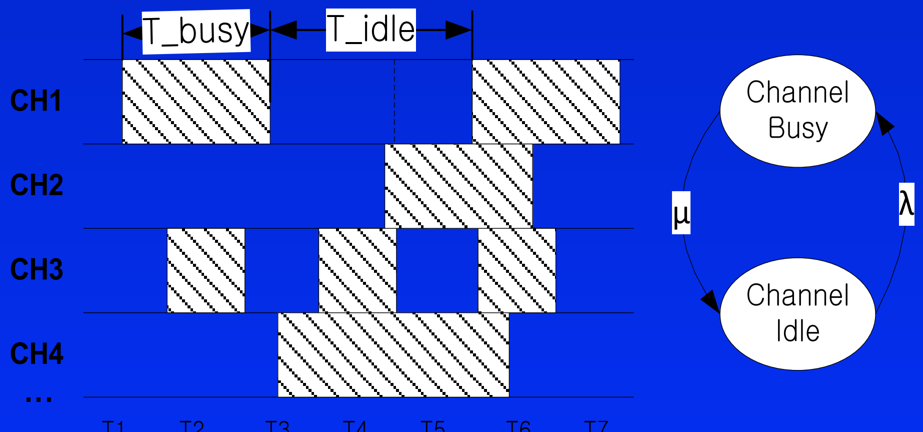
- **CoRoute design approach: VANET routing + Cognitive ISM channel selection**
  - VANET challenges
    - High mobility -> dynamic topology
    - Variable node density -> sparse connectivity
  - CogRadio challenges
    - Varying residential AP traffic -> Varying PN interference
    - Non uniform PN channel occupancy -> spatial reuse

CoRoute

- **Basic assumptions:**
  - **Anypath geo-routing** to handle dynamic topology
  - periodic **PN sensing**,
  - select least interfered route based on min cost path (i.e. **ETT: expected transmission time**)
  - **Multiple radio interfaces**: R1 (Rx), R2 (Tx) and CCC (Common Control Channel)
    - Rx set on least loaded local channel – changes slowly
    - Tx dynamically reset for each pkt transmission

Spectrum Sensing and Primary Traffic Estimation

- **Main goal:**
  - <u>Estimate channel workload (ω) of primary users</u>
  - Channel workload varies with node, time, channel and location
  - Assume two-state (busy, idle) Markov model (Gilbert) for each channel:



< PN traffic pattern >

Channel workload (ω) = average channel occupancy

Channel Assignment

- **Calculate maximum residual capacity**
  1. Calculate residual capacity for secondary node, Ci
     → $C_i = R_0 * (1 - \omega)$,

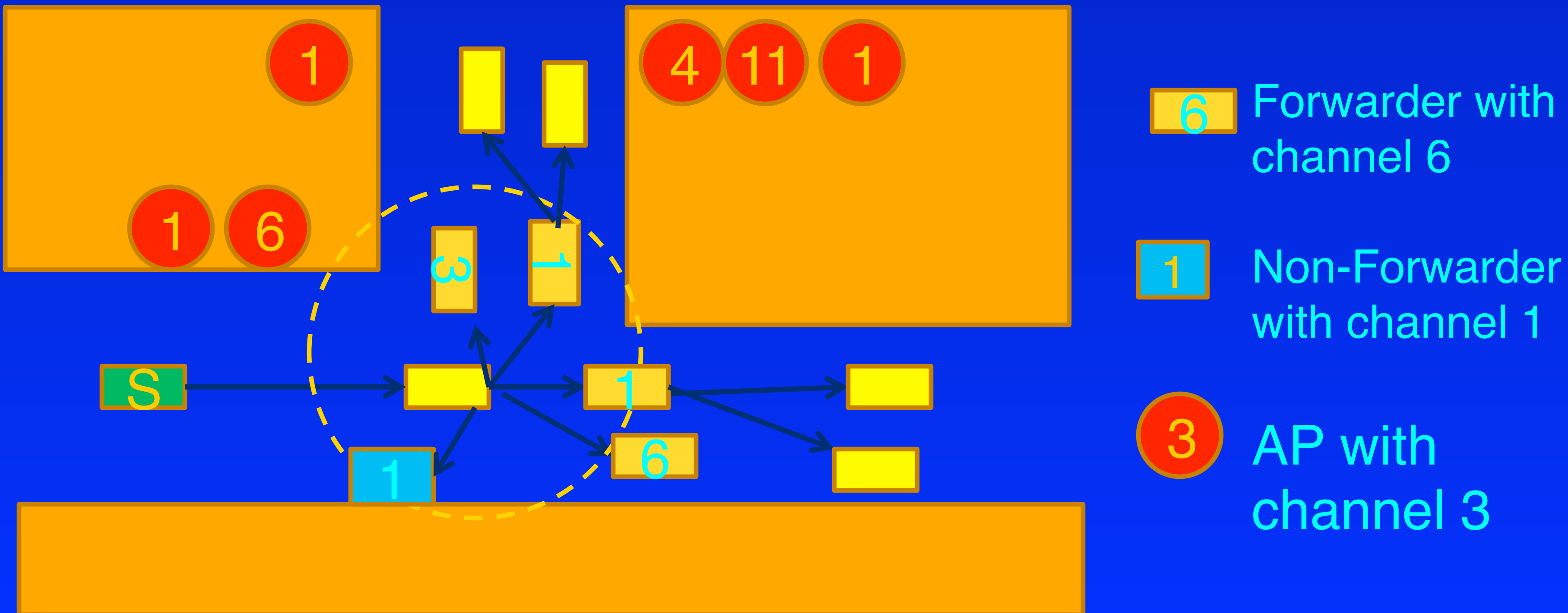
  where: ω = primary channel workload, R_0 = channel data rate (eg, 11Mbps in 802.11b)

  2. Adjust capacity according to number of secondary neighbor nodes , *N(i)* with receivers tuned to channel ***i,***

$$C_i' = \frac{C_i}{N(i)}$$

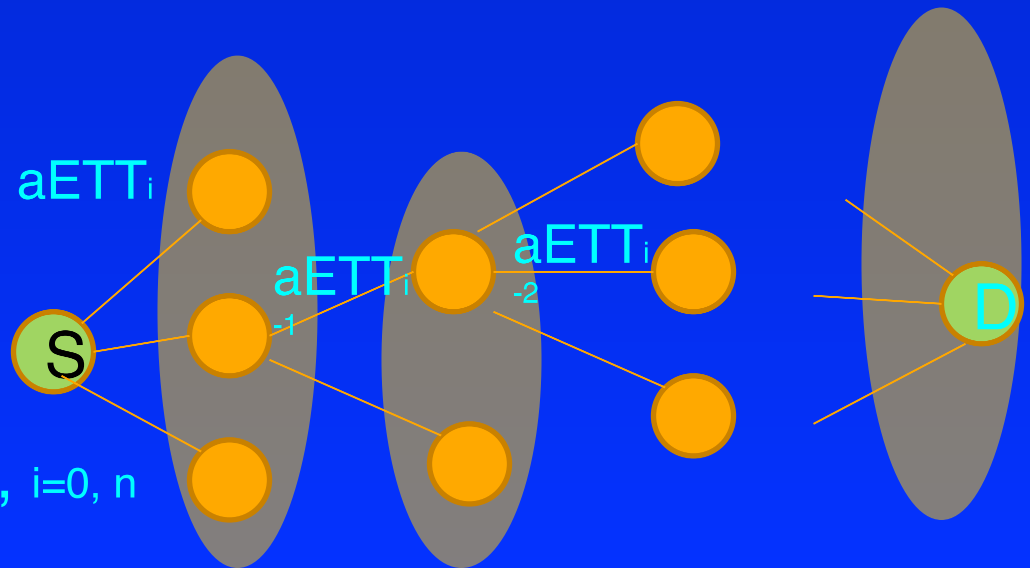
Forwarder set selection

- A set of vehicles closer to destination (i.e. GeoRouting)
- A set of vehicles that have minimum path cost to dest
- Minimum number of transmissions; a transmitter must switch over multiple channels to reach forwarders with different channels.



Path cost: ETT (Expected Transmission Time) calculation

- **CoRoute path cost**
  - Calculate link ETT = 1/(1- Pe) * S/Ci, where Pe: packet error rate, S: packet size, Ci: residual capacity for secondary nodes (vehicles)
  - Calculate path ETT = sum of average ETT from next hop to destination



$$Pc(SID) = \sum aETT_i, \quad i=0, n$$

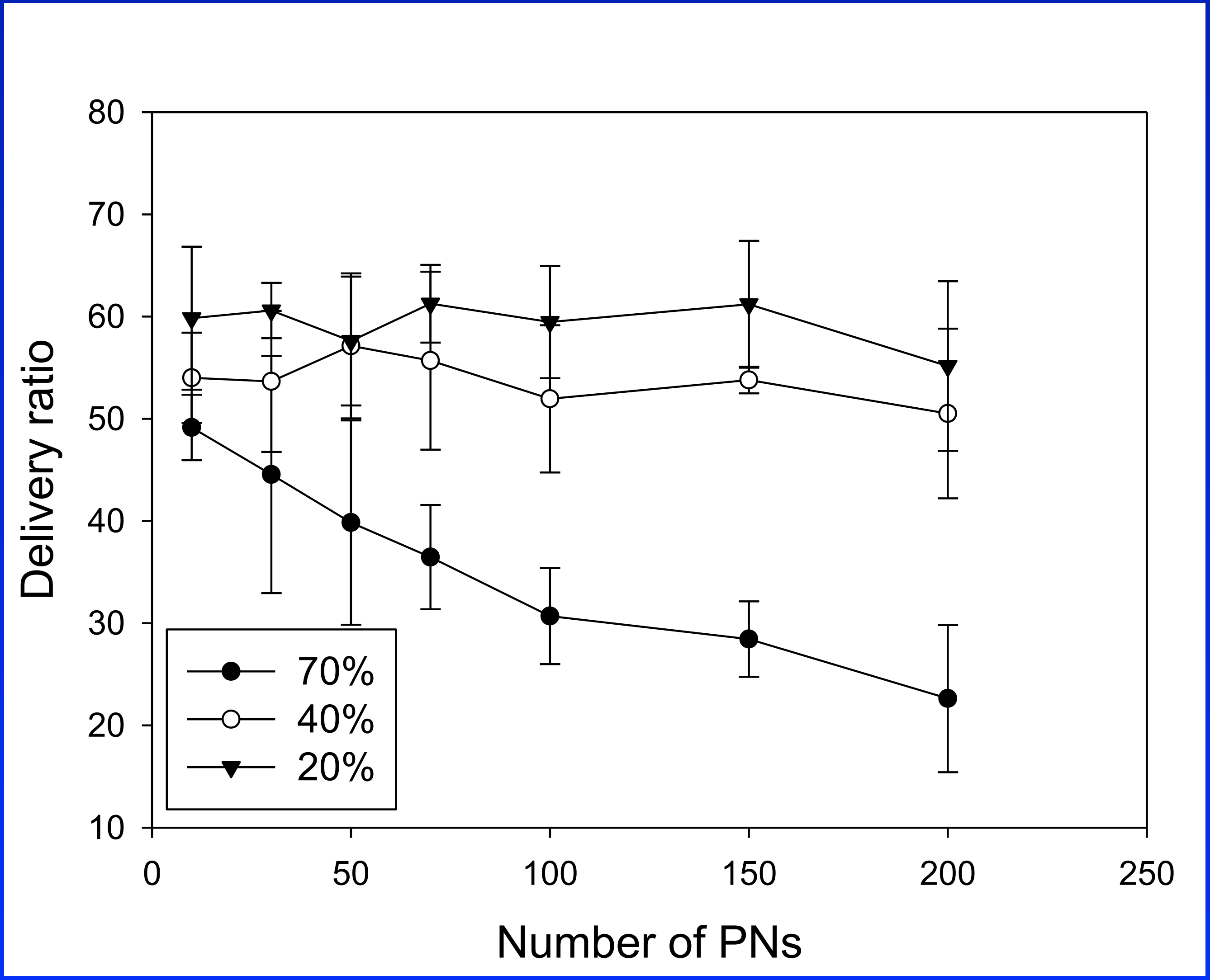
Implementation

- **Extend GeoRouting protocol with Cognitive radio**
  - Exchange GPS information using HELLO
  - Piggyback channel information on HELLO
  - Maintain channel table: channel workloads by PN, channels selected by neighbor nodes
  - Maintain flow table as a forwarder: a source & destination address of a flow, addresses of forwarders, channels of forwarders (linked to channel table)
  - Priority based packet forwarding: a forwarder with lower path ETT has higher priority. Others overhear forwarding notification on Comm Contr Chnl (CCC)

Experiment Configuration

- Topology 1500x 1500m (Manhattan grid 6x6)
- 802.11b - 11 channels with 2 Mbps data rate
- **VANET traces with IDM (intelligent driver model); maximum speed = 60 Km/h**
- **Experiment results – compare delivery ratios of: CoRoute vs Route (i.e. GeoRouting) and CoAODV**
  - CoAODV (Cognitive AODV) checks not only path length but also channel load along a route (see Ref4 DySpan 07)
- **UDP stream traffic with 64Kbps data rate**

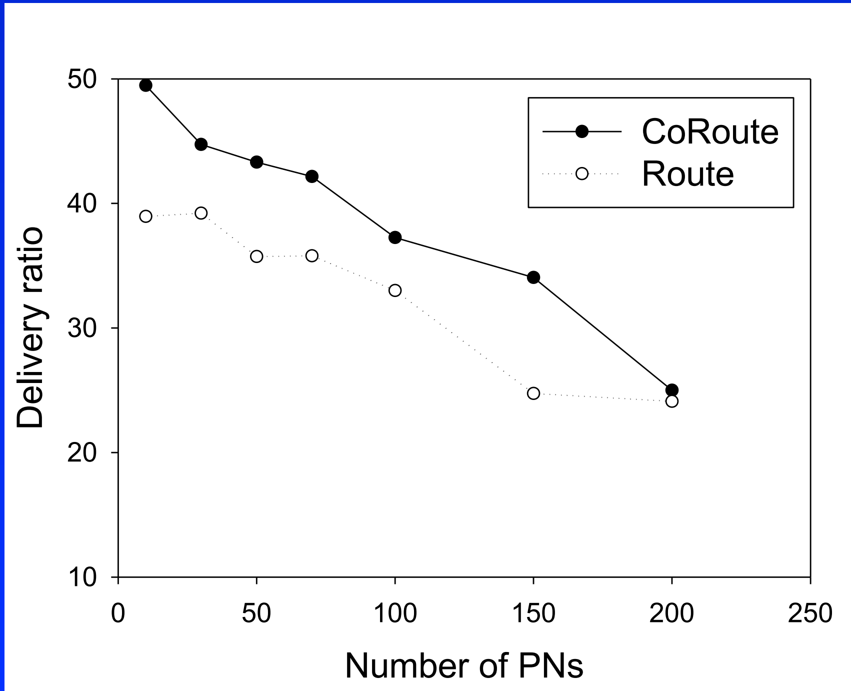
CoRoute Delivery Ratio vs number of PNs

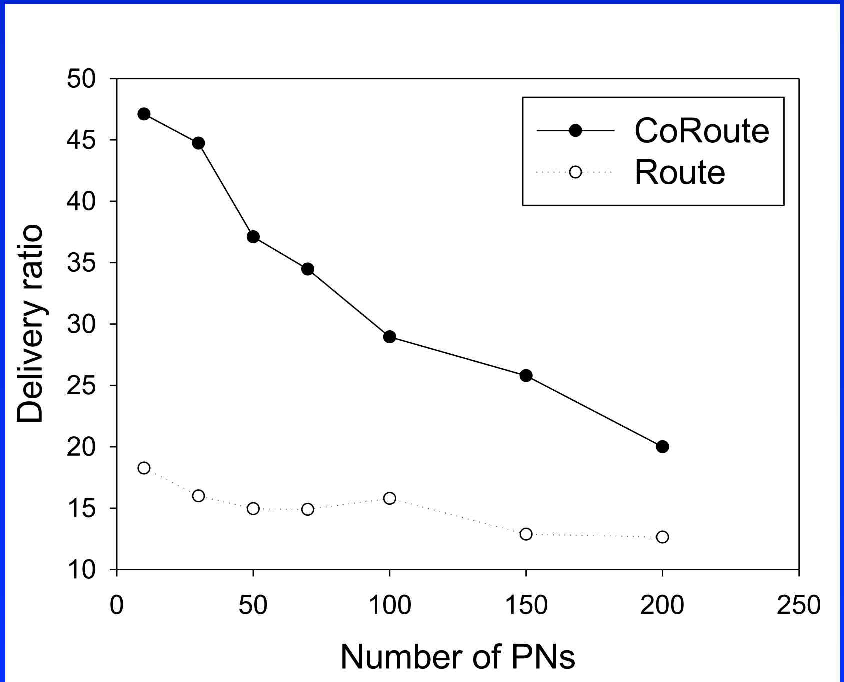


3 PN workloads: 20, 40 and 70%

CoRoute vs Route

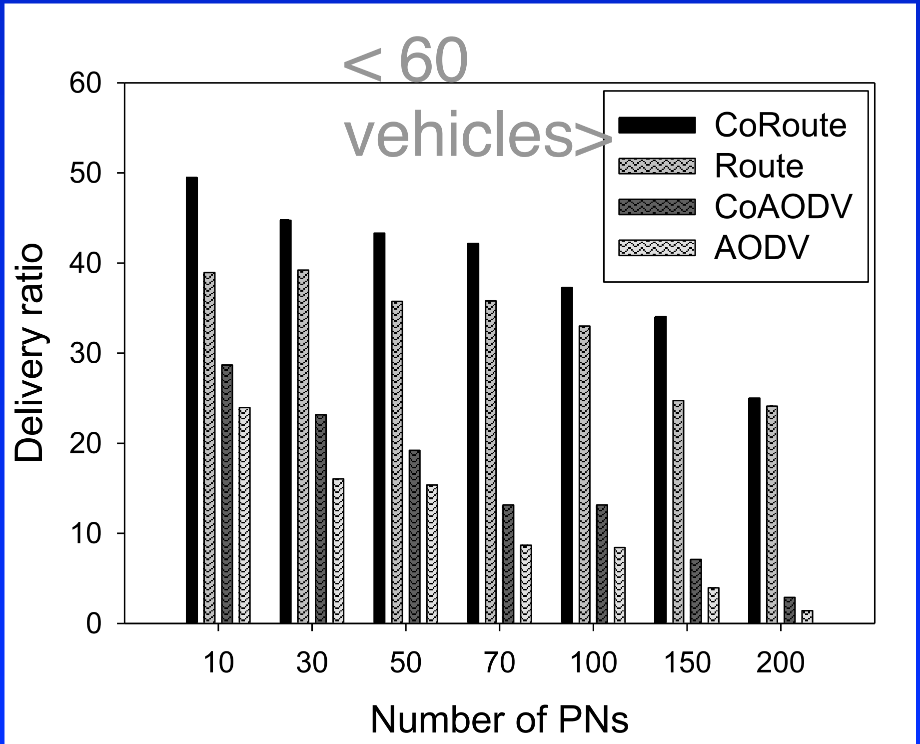
- **Delivery ratio comparison between single channel ‘Route’ and multiple channel ‘CoRoute’**
  - 60 vs. 120 vehicles
  - PNs with 40% workloads
  - ROUTE delivery ratio degrades rapidly with vehicle density due to high number of collisions on a single channel

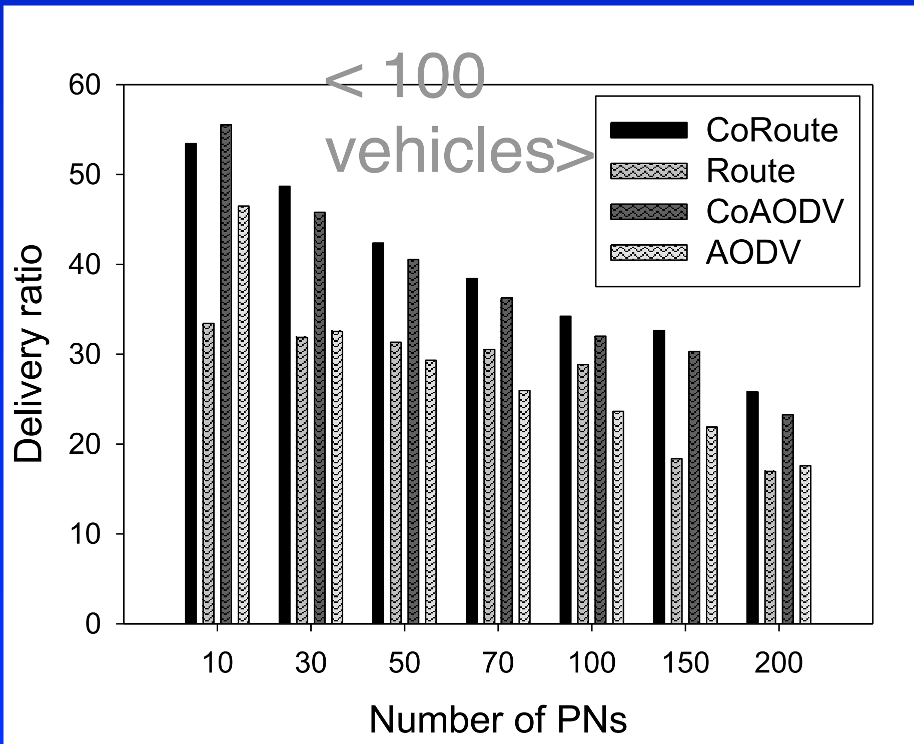




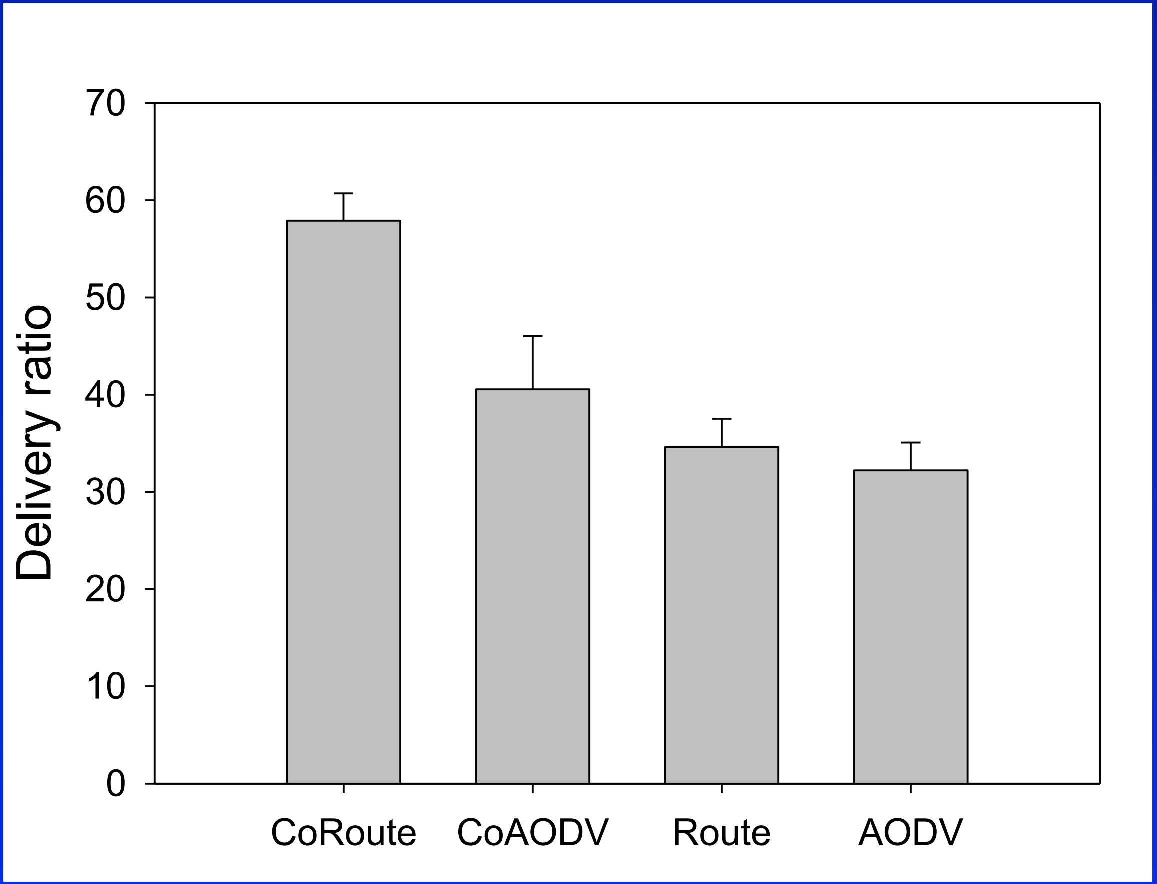
CoRoute and CoAODV

- Delivery ratio comparison; two cases: 60 and 100 vehicles
  - Random number of PNs with 40% workloads
  - With 60 vehicles, connectivity is weak; AODV routes often break; GeoRouting (CoRoute) outperforms on-demand routing (CoAODV)
  - With 100 vehicles, CoAODV is comparable to CoRoute





Delivery ratios comparison



– Varying number of vehicles from 60 to 120
– Random number of PNs with 40% workloads

Cognitive Radio approach improves delivery ratio by up to 50%

Conclusion

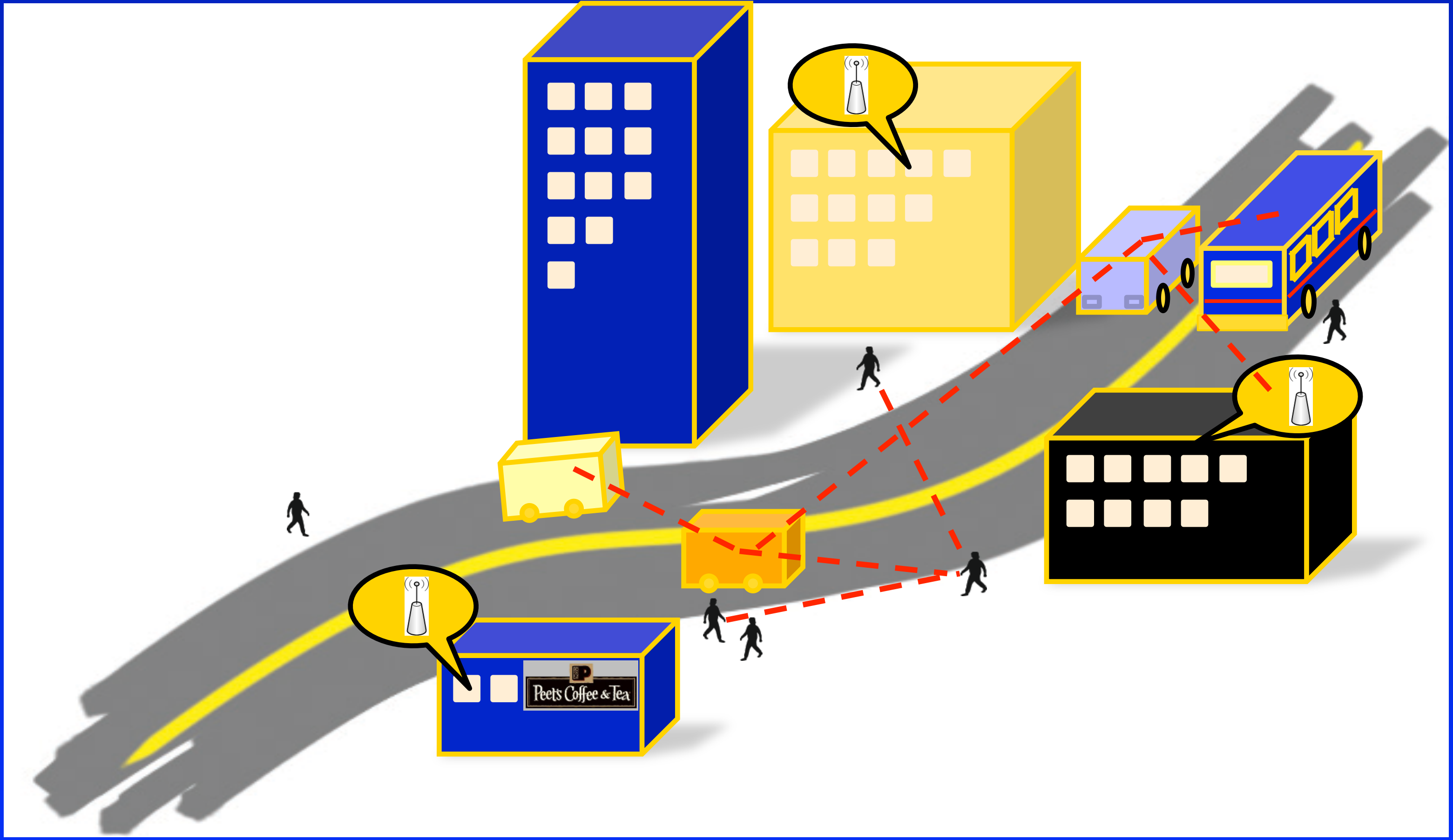
- **CoRoute is a new Cog Radio based routing protocol for VANETs:**
  - It utilizes ISM bands for non safety vehicular applications; it minimizes residential user disruption
- **CoRoute outperforms existing on-demand cognitive routing protocols (CoAODV) as well as single channel GeoRouting protocols.**

Cog-Fi: A Cognitive Wi-Fi Channel Hopping Architecture for Urban MANETs

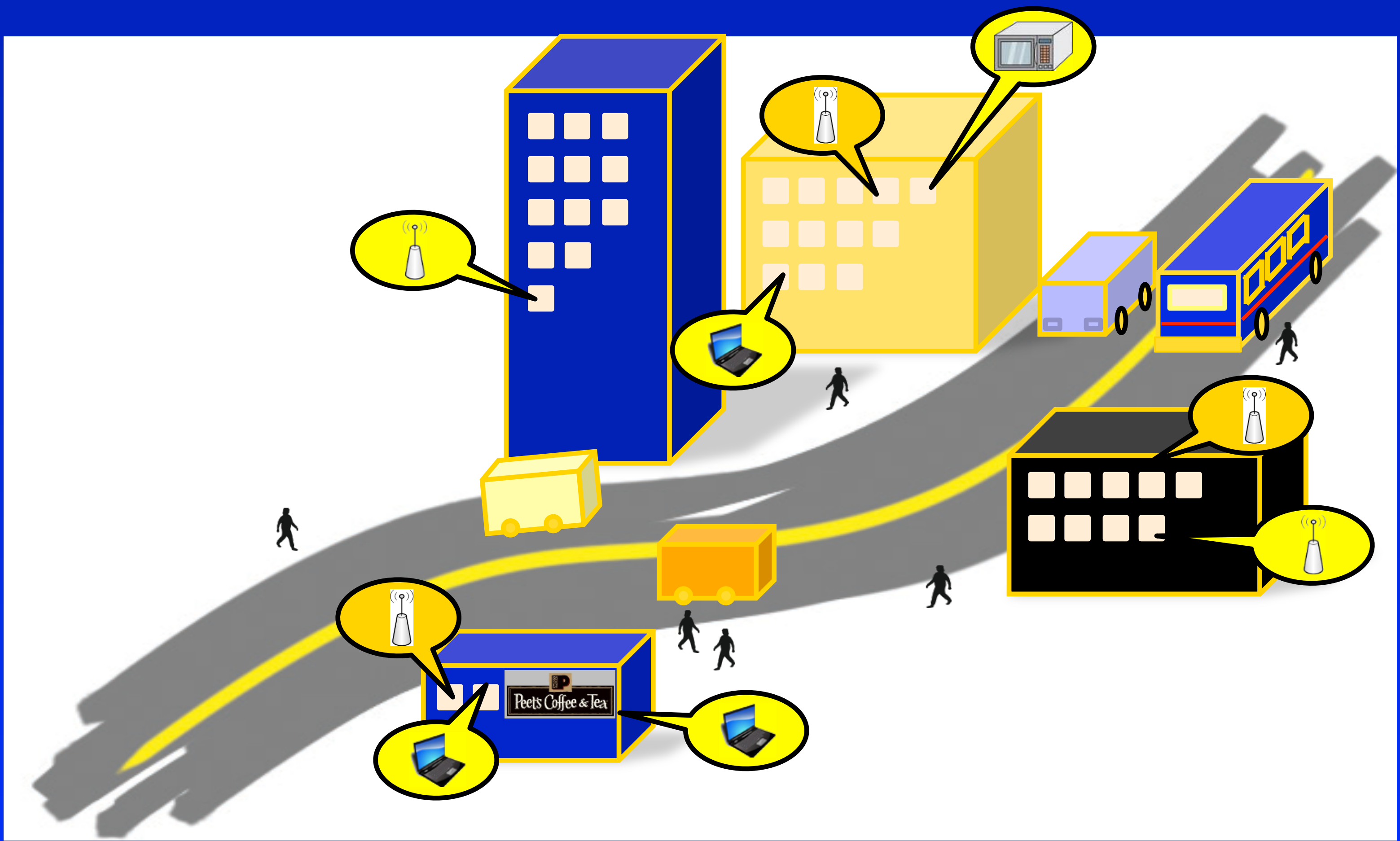
Sung Chul Choi and Mario Gerla

WONS 2012 Presentation

Motivation

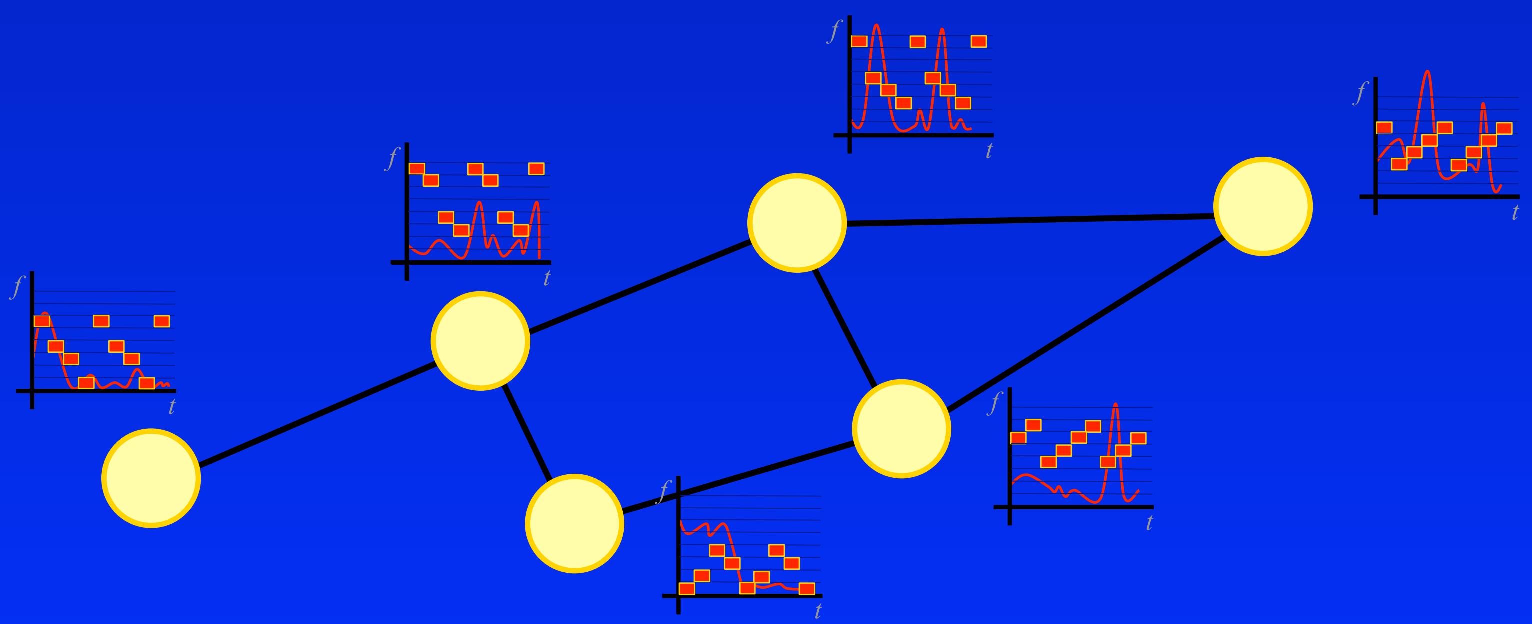


Motivation



Cognitive Channel Hopping

- **Cognitive Channel Hopping (CCH)**
  - Single-radio, channel-hopping solution in which each node picks its channels based on the load sensed on them



CCH: Protocol Operation

- **A node x periodically triggers *Channel Quality Assessment* (CQA).**
  - A **channel availability** vector $\boldsymbol{a} = \{a_1, \ldots, a_{|C|}\}$ is produced.
    - In this work, a_i = 1 - [*channel load in* i].
  - Based on channel availabilities, x picks a <u>channel set</u> $Q = \{q_1, \ldots, q_k\}$ from a predefined Quorum list (any two Q-sets have at least one common element)

$C = \{0, 1, 2, ..11, 12\}$

Q_1	$\{0, 1, 3, 9, 12\}$
Q_2	$\{1, 2, 4, 10, 0\}$
Q_3	$\{2, 3, 5, 11, 1\}$
	...
Q_{12}	$\{11, 12, 1, 7, 10\}$
Q_{13}	$\{12, 0, 2, 8, 11\}$

Example list of channel sets, each with size $k = 5$.

- It picks the channel set with the highest *combined channel quality*, defined as:

$$\hat{a}(Q) = \sum_{q_j \in Q} a_{q_j}$$

Cog-Fi: Evaluation Setup

- **QualNet 4.5**
  - CCH: implemented as a full-fledged MAC protocol.
  - CH-LQSR: implemented as a full-fledged routing protocol.
- **Channel environment**
  - 13 orthogonal channels in the 5-GHz band.
  - Interfering source: (x, y, tx_power, $channel$, $active\_\%$).
- **CCH parameters**
  - Use RBAR for rate adaptation [8], using 802.11a rates.
  - Channel set size k = 5.
  - Channel switching delay: 80μs.
  - Slot size: 10ms.
  - CQA Period: 3 seconds.

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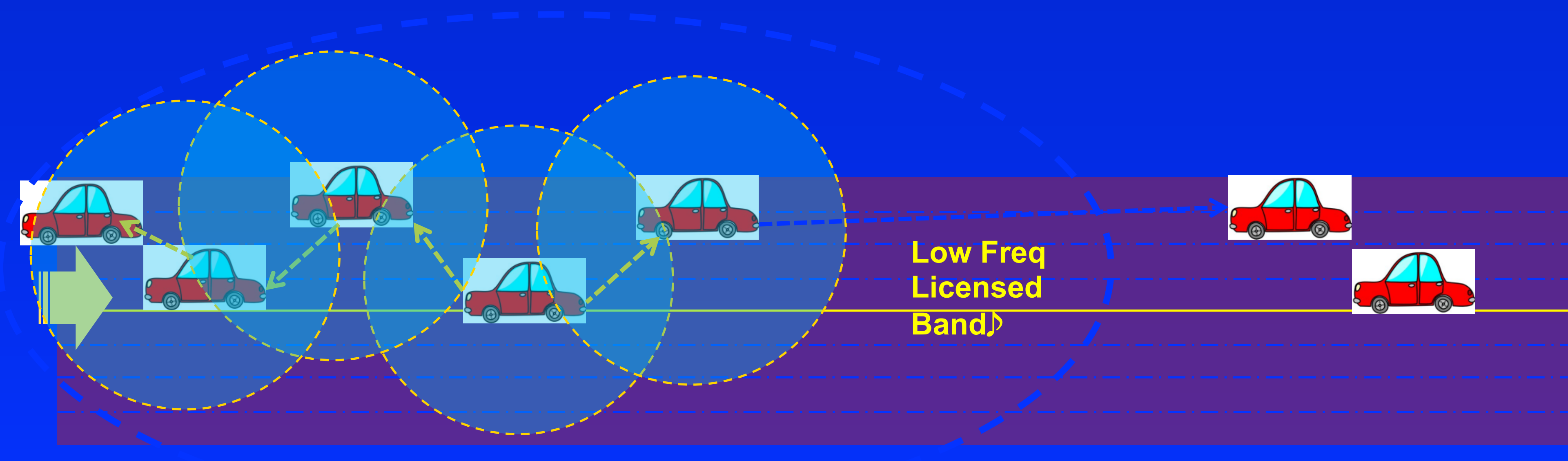
Another option: TV White Spaces

- **Why DSRC + TV WS?**
  - Alleviate congestion
    - Network Load distribution
    - Large transmission range
      - Reduced hops for covering large service area
  - Increase connectivity



Next Steps

- **Consider other options beyond DSCR, WiFI and LTE:**
  - TV White Spaces
  - LTE Direct
  - LTE Broadcast Service (MBMS)
  - 60Ghz spectrum
- **Reconsider the vehicle safety QoS reqs:**
  - Lasers and liders can prevent immediate crashes
  - Can relax the 100ms constraint (for non immediate risks)
- **Explore Roles of the Vehicular Cloud:**
  - Channel Info dissemination
  - Selection of best radio channel for given application
  - Reroute guidelines for non emergency huge files (eg 60Hz)

Conclusions

- As the vehicles become more autonomous and more powerful, the need for V2V communications will increase
- The wireless radio technology landscape will change dynamically given spectrum scarcity and value
- The future autonomous vehicle must be radio “cognitive” in order to deliver the safety, efficiency and comfort promised by automakers

Thank You

Questions?