MAC Layer Performance of ITS G5
Optimized DCC and Advanced Transmitter Coordination

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Marc Werner, Radu Lupoaie,
Sundar Subramanian, Jubin Jose

mwerner@qualcomm.com
Outline

- Performance of 802.11p (WAVE) at high node densities
- DCC approach to congestion control
  - Methodology
  - Performance analysis
- Optimized power control scheme
  - Performance metrics
  - Modification of DCC state machine
  - Performance – comparison with DCC
- An alternate standard-compliant approach: Sync-MAC
  - Methodology
  - Performance – comparison with optimized TPC
Congestion Issues in 802.11p MAC

- V2V safety applications rely on periodic broadcasting
  - No RTS/CTS – hidden terminal issue
  - No ACK/NACK – no collision window adaptation; fixed value of CW (15)

- Behavior of CSMA for periodic broadcasting at high density
  - When density is high, many nodes with back-off counter 0 transmit simultaneously
  - Packet collision leads to poor packet delivery ratio even for vehicles close by
  - No geographical separation exists for nodes transmitting simultaneously

- Well known issue in literature

CSMA degrades to ALOHA at high density

- 4 lane road scenario
  - 2km*16m, uniform distribution
DCC Congestion Control Approach

- **Core idea**
  - Observe the channel load
  - Move to a lower power / larger packet interval if channel is congested

- **State machine based approach**
  - Each state specifies: Power, Modulation, CS threshold, Periodicity
  - Transition rules

- **Aspects of congestion control**
  - Transmit Power Control (TPC)
  - Transmit Rate Control (TRC)
  - Transmit Data rate Control (TDC)
  - DCC Sensitivity Control (DSC)
  - Transmit Access Control (TAC)

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ETSİ TS 102 687 V1.1.1 “Decentralized Congestion Control Mechanisms for Intelligent Transport Systems operating in the 5 GHz range; Access layer part”
DCC State Machine for G5CC

- DCC control loop based on state machine with three states - RELAXED, ACTIVE, and RESTRICTIVE
  - Objective: Keep the channel load $CL$ between predefined boundaries: $0.2 < CL < 0.5$ (DCC standard parameters)
  - State change is triggered if measured channel load exceeds threshold for a period of time

\[
\text{min}(CL) > CL_{up} \text{ for } T_{up} = 1s
\]

\[
CL_{up} = 0.2 \quad \text{RELAXED} \quad P = 33\text{dBm}, PI = 0.04\text{ s} \\
\text{CST} = -95\text{dBm}, \text{MCS} = 0
\]

\[
CL_{up} = 0.5 \quad \text{ACTIVE} \quad P = 15\text{dBm}, PI = 0.5\text{ s} \\
\text{CST} = -85\text{dBm}, \text{MCS} = 2
\]

\[
CL_{down} = 0.15 \quad \text{RESTRICTIVE} \quad P = -10\text{dBm}, PI = 1\text{ s} \\
\text{CST} = -65\text{dBm}, \text{MCS} = 4
\]

\[
\text{max}(CL) < CL_{down} \text{ for } T_{down} = 5s
\]

$CL_{up} = 0.2 \quad CL_{down} = 0.15 \quad CL_{up} = 0.5 \quad CL_{down} = 0.4$

$PI = \text{Packet Interval}$

$MCS = \text{Modulation & Coding Scheme}$
- $MCS = 0$ (BPSK $\frac{1}{2}$, 3 Mbps)
- $MCS = 2$ (QPSK $\frac{1}{2}$, 6 Mbps)
- $MCS = 4$ (16QAM $\frac{3}{4}$, 12 Mbps)
Nodes do not converge to any state – oscillations imply instability

RELAXED state results in high CL & ACTIVE state results in very low CL – this leads to oscillations
Performance of ETSI DCC

- Packet success rate vs. distance
- Absolute number of Rx packets

- DCC appears to improve performance significantly
- Improvement at the cost of reducing periodicity – nodes transmit very infrequently!
Plain WAVE vs ETSI DCC

- Absolute number of Rx packets per second vs. distance
- Average measured channel load vs. density

High packet success rate for DCC at the cost of reduction in number of transmitted packets

Channel capacity is under-utilized at most node densities

Plain WAVE: P = 20dBm, PL = 50 ms
Common Idea of TPC, TRC, TDC: Reduce channel load to prevent simultaneous transmissions within sensing range

What is a good channel load?
- We consider power control alone (fixed packet interval): What is ‘optimum’ Tx power?

Absolute number of received packets per second vs. distance:

- Reduce Tx power to avoid packet collisions between nearby nodes
- Performance metric: Packet success rate within a given Tx-Rx distance
  - e.g., 200m
• Optimum Tx powers
  • according to 0…200m packet success rate

• Average channel load vs. density, for optimum Tx powers

• Observation: channel load corresponding to optimum Tx powers is around 0.6…0.8
- Transmit power control – a 6 state DCC machine
- Transitions depend on measured channel load (similar to DCC)
  - Main difference: Regulate channel load between 0.6 and 0.8
  - All states use same CL thresholds

\[
\begin{align*}
\text{RELAXED} & : P = 20 \text{ dBm} \\
\text{ACTIVE1} & : P = 17.5 \text{ dBm} \\
\text{ACTIVE2} & : P = 15 \text{ dBm} \\
\text{RESTRICTIVE} & : P = 7.5 \text{ dBm} \\
\text{ACTIVE4} & : P = 10 \text{ dBm} \\
\text{ACTIVE3} & : P = 12.5 \text{ dBm}
\end{align*}
\]

\[
\begin{align*}
\text{CL} > \text{CL}_{\text{max}} & \text{ for } T_{\text{up}} = 1 \text{ s} \\
\end{align*}
\]

\[
\begin{align*}
\text{CL} < \text{CL}_{\text{min}} & \text{ for } T_{\text{down}} = 5 \text{ s} \\
\end{align*}
\]

Same conditions for the transitions between any two successive states:
\[
\begin{align*}
\text{CL}_{\text{min}} & = 0.6 \\
\text{CL}_{\text{max}} & = 0.8
\end{align*}
\]

Range chosen to provide stable operation

\[
\begin{align*}
\text{CST} & = -82 \text{ dBm} \\
\text{MCS} & = 1, \text{ QPSK } 1/2 \\
48 \text{ data bits/OFDM sym.} \\
\text{PI} & = 50 \text{ ms}
\end{align*}
\]
- TPC improves the packet success probability of close-by nodes
A synchronous MAC can be introduced without a standards change.

- Slotted synchronized TDM structure overlay on MAC timeline
- Devices wait for chosen slot & inject packets immediately at slot beginning
- Choice of slot based on past occupancy and conflict

Packet enters MAC exactly at the beginning of slot

Packet duration = $T$ (EIFS + guard)

Sufficient silence periods for backoff counters to reset to zero before new interval

All devices in same slot transmit concurrently and immediately

Geographic separation among concurrent transmitters to improve discovery

EIFS = Extended Interframe Space
• Each device transmitting tracks other resources (slots)
  • Keeps track of energy in other resources

• Transmits a shorter “collision detection” packet in original slot periodically
  • Shorter packet transmissions at random, e.g. once every 5 transmissions
  • Observes transmissions in its current resource

• Compare the quality of current resource with other resources
  • Choose a new resource if current resource is not among “top” resources – (with some hysteresis & randomization)
Comparison: Sync-MAC & TPC

- Sync MAC: Simultaneous transmissions as far away as possible for a given number of resources → “a good packing”
  - Very good performance in close-by distances – important for safety applications
  - Low probability, long distance transmissions are eliminated (similar to ideal CSMA)
Conclusions

• Current ETSI parameters for DCC appear to be very conservative
  • Stability of the DCC algorithm is also unclear

• Review of Transmit Power Control
  • Design of optimized TPC using a modified DCC state machine
  • Improved stability and performance by reaching for a good channel occupancy

• Synchronous MAC – a parallel approach to congestion control
  • Can further improve on gains from TPC
  • Can be introduced without change of 802.11p standards
  • Requires node synchronization
Questions?
Backup
Optimized TPC vs DCC

Absolute Number of Received Packets – 4 Lane Road

- 200 nodes TPC
- 400 nodes TPC
- 600 nodes TPC
- 200 nodes ETSI DCC
- 400 nodes ETSI DCC
- 600 nodes ETSI DCC

Number of Received Packets per Node per Second

Tx-Rx Distance (m)

0 100 200 300 400 500

0 5 10 15 20
• Results indicate that an “ideal” channel load based approach is effective & robust
Congestion Control: An Intuition

- Many simultaneous transmitters within CS → synchronous countdown and collisions

- Parallel approaches to congestion
  - Reduce periodicity or reduce power

- Common Idea: Reduce channel load to prevent simultaneous transmissions within sensing range → What is a good channel load?