LETTER

Resolving Distributed Power Control Anomaly in IEEE 802.11p WAVE

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SUMMARY In the IEEE 802.11p WAVE system, applications can directly control the transmission power of the messages sent in WAVE Short Message Protocol (WSMP). This feature enables the vehicles to control the transmission range based on the application requirements and/or the vehicle density. Seemingly straightforward, however, the distributed power control between vehicles can easily go awry. Unless carefully coordinated, the power assignments can irrevocably deviate from the vehicle density pattern. In this letter, we first show that such anomaly happens for a straightforward power control where the power level reacts to the number of messages heard from ambient vehicles. Then in order to resolve the anomaly, we propose an application layer scheme that adapts the WSMP transmission power so that the power assignments precisely reflect the vehicle density pattern.

key words: *IEEE 802.11p, vehicle-to-vehicle (V2V) communication, power control, anomaly*

1. Introduction

In the IEEE 802.11p Wireless Access in Vehicular Environment (WAVE) systems, vehicle safety information and service management messages are transmitted in WAVE Short Message Protocol (WSMP) [1], [6]. WSMP allows the application layer to directly control the physical layer properties such as transmission power, channel, and transmission rate. Among these, the transmission power can be used to control the transmission coverage in order to reflect the vehicle density or wireless channel environments. For instance, the power can be increased when the vehicle density is low as in rural areas, and decreased when it is high as in city streets. However, the power control based on the ambient vehicle density measurement [4] easily leads to an anomaly where the power assignment becomes totally irrelevant of the vehicle density. In this letter, we develop a power control scheme that prevents the anomaly.

In the IEEE WAVE, the measurement of the ambient vehicle density can be enabled by the detection of so called the “safety beacons” (which are not to be confused with the IEEE 802.11 beacon messages) periodically transmitted by vehicles, which is the most basic applications of the WAVE environment. The safety beacons facilitate many traffic safety applications such as cooperative collision warning [2] and and safety message routing [3]. The safety beacons are broadcast typically with low frequencies such as 10Hz or less [2]–[5]. The safety beacons are transmitted in the control channel interval (CCHI) in the 802.11 broadcast, and are encapsulated in the WSMP protocol [6].

Algorithm 1 Straightforward power control.

```
$P = P_{init}$
for each period $T$ do
    if $BeaconsHeard < \theta$ then
        $P = \min(P + \alpha,\ P_{max})$
    else if $BeaconsHeard > \theta$ then
        $P = \max(P \times \beta,\ P_{min})$
    end if
    Transmit with power $P$
end for
```

A straightforward power control algorithm would be to let each vehicle measure the intensity of the ambient safety beacon traffic and control its own safety beacon transmission rate around a threshold. For instance, if the measured beacon load does not exceed the threshold, the power can be increased [4]. Conversely, if it is over a desirable level, then it can be decreased. Note that this assumes cooperative control, where the vehicles in the neighborhood will sense a similar vehicle density and react similarly in terms of power assignment. A generic additive-increase multiplicative-decrease (AIMD) algorithm is given in Algorithm 1. In the algorithm, θ is the desirable number of beacons from different vehicles, and $BeaconsHeard$ is the actual number of beacons detected in a given period. Comparing it with θ, the transmission power is either increased by α or decreased by a factor of β.

In order to show that the straightforward power assignment based on the sensed beacon traffic can fall into a pathology, we place 500 vehicles equi-distant on a circle of 1Km in diameter, and let them transmit the safety beacons at $f = 10$(Hz). Due to the homogenous vehicle density, we would expect the power settings converge to comparable levels across all vehicles. However, the result points otherwise. Fig. 1 shows the time evolution of the power level assignment made by vehicles in

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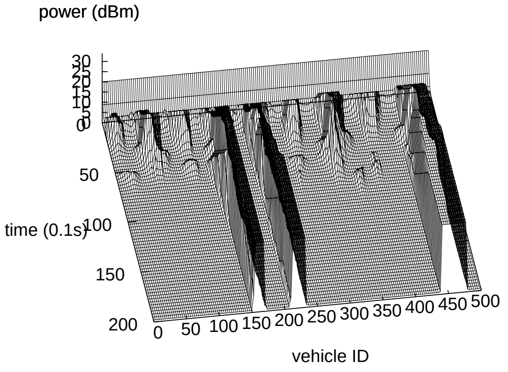


Fig. 1 Power levels polarize over time and become irrelevant with respect to homogeneous vehicle density.

the straightforward algorithm. We let $P_{init} = 20$dBm, $P_{max} = 33$dBm, $P_{min} = 0$dBm, $\alpha = 0.5$dBm, $\beta = 0.8$, $T = 1$s, and $\theta = 500$. We can see that the vehicles start from the same power level, but the power assignments quickly deviate from the equi-distant vehicle pattern.

2. Mean power control

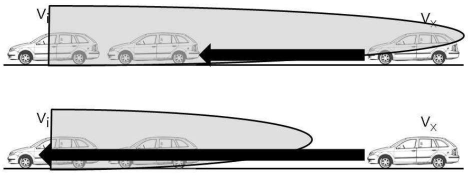
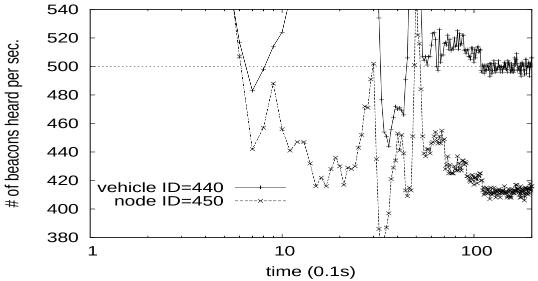
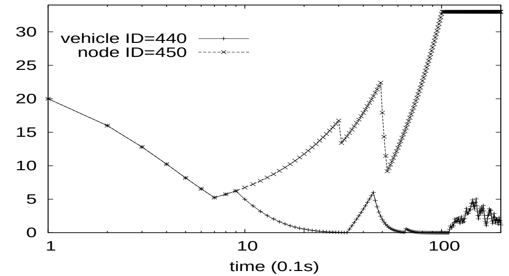


Fig. 2 Power reduction at v_i may not reduce the number of safety beacons heard.

The most basic expectation on the cooperative power control is that neighboring vehicles would sense and react to the same ambient traffic situation. However, as Fig. 1 shows, using the straightforward power control algorithm can render even adjacent vehicles have wildly different and distorted knowledge of the surrounding traffic density. This “anomaly” can adversely affect traffic safety applications such as CCW and disturb the construction of efficient multi-hop network connectivity. At the core of this power control anomaly is the fact that the changed power has impact not on its immediate neighborhood but on the fringe of the transmission coverage. For instance in Fig. 2, let v_x denote a node located in the fringe of the transmission range of v_i (above). When v_i reduces the power, v_x stops hearing the beacons from v_i. Under the straightforward algorithm, it gives a false impression to v_x that the number of vehicles in its vicinity decreased. As a consequence, v_x gets to increase its power (below). Thus v_i does not see the situation improve, and it gets to continue to decrease the power. Such undesirable feedback loop polarizes the power settings among the vehicles.



(a) Beacons heard



(b) Consequent power assignments

Fig. 3 Number of beacons heard vs. corresponding power adaptation.

Under the probabilistic 802.11 MAC transmission, vehicles get to see disparate number of safety beacons even if homogenous vehicle density is given. This is because messages are exposed to probabilistic losses from the collision or the hidden node problem. Fig. 3 takes two vehicles, 440 and 450, from Fig. 1 to show how delicate and irrevocable the consequence can be. At $t = 9$, these two vehicles first see different situations with respect to the given threshold $\theta = 500$. The following actions at $t = 10$ are opposite, and they can never agree on the ambient traffic density again.

Obviously, the shown interactions between these two vehicles is an oversimplification of the collective power dynamics of the entire neighborhood. However, it provides an important clue to resolving the anomaly. Namely, the power assignments should be made not individually but in close coordination with the power levels of neighboring vehicles. Fortunately, the transmit power level of the safety beacon may be passed to the recipient via the WSMP header that carries the beacon [6]. Once it is done, each vehicle can set the power to the *average* of the power levels of neighboring nodes. By forcing the power assignments to move in lockstep with neighboring vehicles, we can prevent the bi-polarization of the powers and its undesirable consequences. Algorithm 2 is a generic mean power control, where the power assignments in the neighborhood $\mathcal{N}$ is additionally considered before the power assignment

Algorithm 2 Mean power control.

```
$P = P_{init}$
for each period $T$ do
    if $BeaconsHeard < \theta$ then
        if $P < \bar{P}(\mathcal{N})$ then
            $P = \min(P + \alpha,\ P_{max})$
        end if
    else if $BeaconsHeard > \theta$ then
        if $P > \bar{P}(\mathcal{N})$ then
            $P = \max(P \times \beta,\ P_{min})$
        end if
    end if
    Transmit with power $P$
end for
```

is made. Using the same parameters as in Fig. 1, we run the two algorithms on the traffic density as given in Fig. 4. The figure shows the number of vehicles within ± 50m of the given position. In a 8-lane highway, the highest density models the bumper-to-bumper situation, where the inter-vehicle distance is only 3 meters if we assume the average vehicle length is 5 meters.

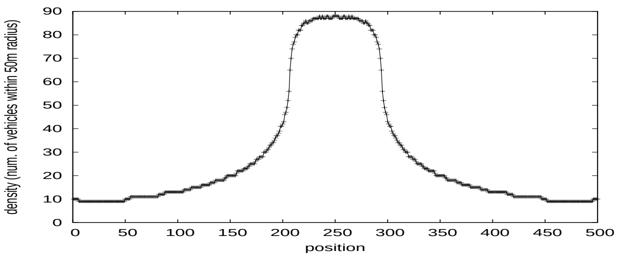
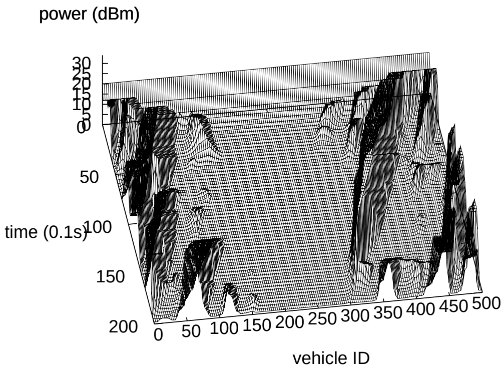


Fig. 4 Test vehicle density at each position.

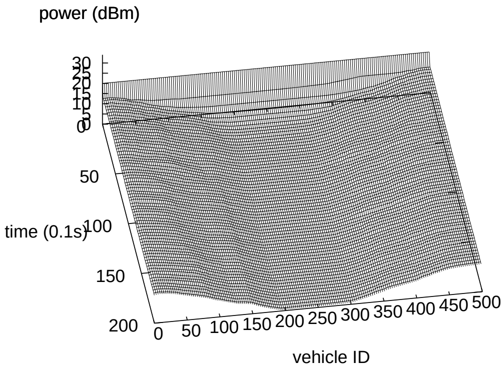
Fig. 5 shows the power assignments made by the algorithms. Again, the straightforward AIMD algorithm exhibits a severely erratic behavior with an exception for the high vehicle density region. In contrast, the mean power control successfully prevents the anomaly and correctly reflect the given traffic density to the power settings at vehicles.

3. Conclusion

In the IEEE 802.11p WAVE systems, correct traffic situation awareness based on periodic safety beacon exchange is a key to traffic safety as well as V2V communication reliability and efficiency. But the randomness and unreliability in the WAVE communication can easily trigger power assignments for the beacons that are irrelevant to the given traffic density. In this letter, we propose that the 802.11p WAVE employ the power control method for safety beacons that takes account of power assignments at neighboring vehicles. It uses the WSMP feature that the transmit power level may be passed to the recipient via the WSMP header. We show through simulation that the proposed power control method enables power assignments that correctly reflects the vehicular traffic situation.



(a) Straightforward power assignment



(b) Mean power assignment

Fig. 5 Comparison of power assignment results.

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