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FAIRNESS ACCESS IN THE IEEE 802.11P-BASED DUAL-RADIO/SINGLE-RADIO VEHICULAR NETWORKS

Guilu Wu and Pingping Xu

National Mobile Communication Research Lab Southeast University, Nanjing, China

ABSTRACT

In this paper, we develop an analytical model to discuss the unfairness problem related with dual-radio/singleradiovehicle that exists in IEEE 802.11p-based vehicular networks. According to IEEE 1609.4 standard, dual-radiovehicle accesses continuously channel through control channel interval(CCHI) and service channel interval (SCHI),but single-radio vehicle only simultaneously accesses channel in SCHI. So there is the unfairness problem forchannel access between dual-radio vehicle and single-radio vehicle. Our aim is to find a solution to solve thisunfairness problem. The minimum contention window based on the access time to achieve the optimal fairness is adopted. The simulation results show our claims can be supported.

Index Terms

Dual/Single radio, Fairness index, Optimal contention window, Throughput.

I. INTRODUCTION

IEEE 802.11 has been more widely adopted in wireless networks. More importantly, the Distributed Coordination Function (DCF) is the core of contention access mechanism in the IEEE 802.11-based network. Alternatively, the IEEE 802.11p standard as a supplement is known for wireless access in vehicular environment [1]. And IEEE 1609.4 [2] works on top of the IEEE 802.11p and enables operation of upper layers across multiple channel access. The salient characteristic of IEEE 1609.4 is that the shared channel is divided into one Control Channel (CCH) and six Service Channels (SCHs) to implement multi-channel operations. A pair of CCHI and SCHI, with fixed length of 50 ms respectively, forms a Synchronization Interval (SyncInterval).

In SyncInterval, dual-radio vehicle could still transmit safety and non-safety messages synchronously on CCH and SCH while single-radio vehicle must switch channel every 50 ms to transmit safety or nonsafety messages. In other words, dual-radio vehicle has more 50 ms to access channel than single-radio vehicle. Apparently, it results in unfairness in throughput of bit based between dual-radio and single-radio vehicles. Since the work mode for single-radio and dual-radio vehicles is different: switching channel, designing coexistence fairness becomes an issue in the mid-term deployment of vehicular networks for the co-existence of single-radio and dual-radio devices. In this paper, we design minimum contention window based on channel access time to contribute the fairness. Using fairness index, we validate our claims for dual/single-radio vehicle in the network.

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II. RELATED WORK

There are some existing works to fairness access. [3]–[5] change the transmission opportunity according to vehicle speed to solve the unfairness problem. [6] develop a mechanism for fair channel allocation. [7]propose an algorithm in terms of minimizing variability of the number of OBUs connected to each RSU to increase fairness of access to services in V2I communications. In [8] a fair multichannel MAC protocol is proposed to address proportional fairness. Above works may look at the unfairness problem from a number of perspectives in vehicular networks, including sojourn time, service type, resource allocation, etc.. As far as I know, most works do not consider the unfairness problem at accessing channel time for single and dual-radio devices, particularly in one SyncInterval.

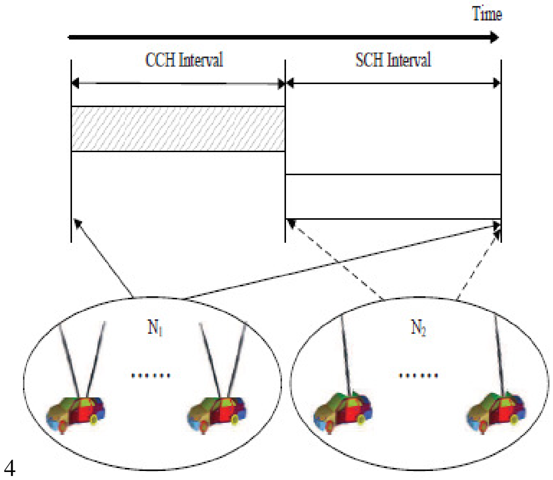

Fig. 1: Diagram of channel access mode related with dual-radio/single-radio vehicle.

Based on the reported results in these previous studies, we find that the design of a fairness access model with a reliable contention widow control scheme for single and dual-radio vehicle devices that can cope with the fairness problem of bits-based transmission is crucial. To accommodate single radio vehicle devices that must switch between CCH and SCH to support both safety and non-safety, we investigate the contention window size to assist channel access for single and dual-radio devices, which aims at delivering traffic messages with fairness channel access chance in heterogeneous vehicular networks. Our goal is to explore the bits-based throughput for messages delivery between the single-radio vehicles and the dual-radio vehicles and to model the fairness access mechanism.

III. SYSTEM MODEL ANALYSIS

Considering this case, as in Fig. 1, where two categories of vehicles are presented, and labeled as l1 = 1,…, N1 and l2 = 1,…,N2. For set l1, vehicle which has dual radio could continue access channel in Sync Interval. However, vehicle which is from set l2 only access channel in CCHI or SCHI. From the whole Sync Interval point of view, N1 vehicles access CCH in the first category and N1 + N2 vehicles access SCH in the second category.

Compared with a single-radio vehicle, a dual-radio vehicle has longer time to transfer data, owing to their different mode of channel operation. The problem of unfairness is caused in one SyncInterval. Accordingly, the bit-based data transfer of a single-radio vehicle is less than the bit-based data transfer of a dual-radio vehicle. According to Jain's fairness index [9], if n contention users share system resources, then the resource that the ith user could be allocated is xi. The fairness index is expressed as

$$F = f(x) = \frac{[\sum_{i=1}^{n} x_i]^2}{n \sum_{i=1}^{n} x_i^2}. \tag{1}$$

where fairness index indicates the equality attribute of user allocation x.

Note that the fairness index is indicated as f(x). The parameter x signifies that fairness would be different with the different of allocation metric. And the choice of the metric is decided by the application. The definition of the proposed fairness is suitable for any metric.

To make sure dual-radio and single-radio vehicles get fair chance to access channel. We define the throughput per vehicle for category $i, i \in \{1, 2\}$ as $s_{dual,single} = \frac{(S_{dual}, S_{single})}{N_i}$ where S_{dual} and S_{single} are total throughput corresponding to dual-radio and single-radio vehicles. And the total number of vehicles in the network is $\sum_{i=1}^{N1+N2} N_i = \Gamma.$ The following express is satisfied to ensure fairness

$$s_j = s, j = 1, 2, 3, \cdots, N_1 + N_2. \tag{2}$$

For different vehicle mode to satisfy the desired fairness in Fig. 1, we propose a model to analyze and further derive optimal minimum CW in the following section.

B. MODEL

To analyze the problem of unfairness of the 802.11-based vehicular networks, we design the model for two categories of vehicles, where all vehicles within each category have same system parameters including arrival rate and payload size. We assume vehicle always has a attempted transmission packet. Classical Markov model method is designed by Bianchi [10] to depict message transmitting procedure. Adopting a pair of integers (i; k) to represents the state of one station, where i represents the back-off stage and k traces network counter. i starts at 0 at the first attempting to transmit a packet, and increases by 1 after collision, up to a maximum m size. But i is reset after a successful transmission. k is initially chosen uniformly between $[0, W_i - 1]$, where $W_i = 2^i W_0$. The packet will be transmitted till k decrements to 0 when the channel medium is idle.

1) CCH: In CCHI, only category 1 vehicles access channel. According to [10], the probability τ_{DC} that a vehicle randomly chooses one slot time to transmit data is

$$\tau_{DC} = \frac{2}{W_{DC,min} + 1 + p_{DC} W_{DC,min} \sum_{i=0}^{m-1} (2p_{DC})^i}, \tag{3}$$

And the collision probability p_{DC} that a transmitted packet encounters collision is

$$1 - p_{DC} = (1 - \tau_{DC})^{N_1 - 1}, \tag{4}$$

When N1 vehicles contend on the CCH, we know that each vehicle transmits a packet with probability τ_{DC}. If more than one vehicle transmit packets in one slot, the transmission probability, $P_{tr_{DC}}$, is given by

$$P_{tr_{DC}} = 1 - (1 - \tau_{DC})^{N_1}, \tag{5}$$

Under the premise of at least one transmission, the successful transmission probability $P_{s_{DC}}$ that there is only one transmission on CCH, is written as

$$P_{s_{DC}} = N_1 \tau_{DC} (1 - \tau_{DC})^{N_1 - 1} / P_{tr_{DC}}, \tag{6}$$

Let Ts be the time for a successful transmission and Tc be the time for a collision. Then the average slot time in CCH is written by

$$E_{sDC} = P_{tr_{DC}} P_{s_{DC}} T_s + P_{tr_{DC}} (1 - P_{s_{DC}}) T_c + (1 - P_{tr_{DC}}) \sigma, \tag{7}$$

So, the normalized throughput for vehicles in category 1 is

$$S_{DC} = \frac{P_{tr_{DC}} P_{s_{DC}} L_{DC}}{E_{sDC}} E[T_{CCH}]. \tag{8}$$

where, L_{DC} and $E[T_{CCH}]$ are separately corresponding to the average payload size and average residence time for category 1 in CCHI.

2) SCH: Similarly, when all vehicles from category 1 and category 2 access channel in SCHI time, we have

$$\tau_{DS} = \frac{2}{W_{DS,min} + 1 + p_{DS} W_{DS,min} \sum_{i=0}^{m-1} (2p_{DS})^i}, \tag{9}$$

$$\tau_{SS} = \frac{2}{W_{SS,min} + 1 + p_{SS} W_{SS,min} \sum_{i=0}^{m-1} (2p_{SS})^i}, \tag{10}$$

$$1 - p_{DS} = (1 - \tau_{DS})^{N_1 - 1} (1 - \tau_{SS})^{N_2}, \tag{11}$$

$$1 - p_{SS} = (1 - \tau_{SS})^{N_2 - 1} (1 - \tau_{DS})^{N_1}, \tag{12}$$

When N1 +N2 vehicles contend on SCH, each transmission probability from category l1 and category l2 is τ_{DS} and τ_{SS}, respectively. While there is at least one transmission in the given slot, the probability, $P_{tr_{DSS}}$, can be written as

$$P_{tr_{DSS}} = 1 - (1 - \tau_{DS})^{N_1}(1 - \tau_{SS})^{N_2}, \tag{13}$$

Under the premise of at least one vehicle transmission, the successful transmission probability $P_{s_{DS}}$ and $P_{s_{SS}}$ that there is only one vehicle transmission on SCH, is given by

$$P_{s_{DS}} = \frac{N_1\tau_{DS}(1-\tau_{DS})^{N_1-1}(1-\tau_{SS})^{N_2}}{P_{tr_{DSS}}}, \tag{14}$$

$$P_{s_{SS}} = \frac{N_2\tau_{SS}(1-\tau_{SS})^{N_2-1}(1-\tau_{DS})^{N_1}}{P_{tr_{DSS}}}, \tag{15}$$

Let Ts be the time for a successful transmission and Tc be the time for a collision. Then the average slot time in SCH is written by

$$\begin{aligned} E_{sDSS} = P_{tr_{DSS}}(P_{s_{DS}} + P_{s_{SS}})T_s + P_{tr_{DSS}}(1 - P_{s_{DS}} - P_{s_{SS}})T_c + \\ (1 - P_{tr_{DSS}})\sigma, \end{aligned} \tag{16}$$

So, the normalized throughput for each category vehicles is

$$\begin{cases} S_{DS} = \dfrac{P_{tr_{DSS}}P_{s_{DS}}L_{DS}}{E_{sDSS}}E[T_{SCH}], \\ S_{SS} = \dfrac{P_{tr_{DSS}}P_{s_{SS}}L_{SS}}{E_{sDSS}}E[T_{SCH}]. \end{cases} \tag{17}$$

Where L_{DS} and L_{SS} is the average payload duration for a vehicle in category i and $E[T_{SCH}]$ is mean residence time for category i in SCHI. Exactly, we know $E[T_{CCH}] = E[T_{SCH}] = 50\,ms$ and $L_{DC} = L_{DS} = L_{SS}$.

Hence, the throughput of dual-radio and single-radio vehicles is given out, respectively:

$$S_{dual} = S_{DC} + S_{DS}. \tag{18}$$

$$S_{single} = S_{SS}. \tag{19}$$

To ensure the fairness index $\digamma$ becomes equal to unity, the throughput per vehicle for category 1 and category 2 vehicles satisfy that equation $s_{dual} = s_{single}$. To observe (11) and (12), we derive $(1-p_{DS})(1-\tau_{DS}) = (1-p_{SS})(1-\tau_{SS}) = (1-\tau_{DS})^{N_1}(1-\tau_{SS})^{N_2}$. Obviously, $W_{dual,min} = W_{DC,min} = W_{DS,min}$, $W_{single,min} = W_{SS,min}$ and let's us assume $W_{dual,min}, W_{single,min} \gg 1$ and $\tau_{DC}, \tau_{DS}, \tau_{SS} \ll 1$. Suppose the restrictions are available again and again to solve (3), (9) and (10), then we can achieve the following approximation: $\frac{\tau_{DC}}{\tau_{SS}} = \frac{W_{SS,min}}{W_{DC,min}} = \frac{W_{single,min}}{W_{dual,min}}$ and $\frac{\tau_{DS}}{\tau_{SS}} = \frac{W_{SS,min}}{W_{DS,min}} = \frac{W_{single,min}}{W_{dual,min}}$.

The ratio of throughput for category 1 and category 2 vehicles is calculated by equation (8) and (17). The result is given out

$$\begin{aligned}
\frac{S_{dual}}{S_{single}} &= \frac{S_{DC}+S_{DS}}{S_{SS}} \\
&= \frac{P_{tr_{DC}}P_{s_{DC}}\frac{L_{DC}}{E_{sDC}}E[T_{CCH}] + P_{tr_{DSS}}P_{s_{DS}}\frac{L_{DS}}{E_{sDSS}}E[T_{SCH}]}{P_{tr_{DSS}}P_{s_{SS}}\frac{L_{SS}}{E_{sDSS}}E[T_{SCH}]} \\
&= \frac{N_1\tau_{DC}(1-\tau_{DC})^{N_1-1}\frac{L_{DC}}{E_{sDC}}E[T_{CCH}] + N_1\tau_{DS}(1-\tau_{DS})^{N_1-1}(1-\tau_{SS})^{N_2}\frac{L_{DS}}{E_{sDSS}}E[T_{SCH}]}{N_2\tau_{SS}(1-\tau_{SS})^{N_2-1}(1-\tau_{DS})^{N_1}\frac{L_{SS}}{E_{sDSS}}E[T_{SCH}]} \\
&\approx \frac{\frac{N_1\tau_{DC}}{1-\tau_{DC}} \cdot \frac{(N_1\frac{\tau_{DS}}{1-\tau_{DS}}+N_2\frac{\tau_{SS}}{1-\tau_{SS}})+\frac{\sigma}{T_S-T_C}}{N_1\frac{\tau_{DC}}{1-\tau_{DC}}+\frac{\sigma}{T_S-T_C}} + N_1\frac{\tau_{DS}}{1-\tau_{DS}}}{N_2\frac{\tau_{SS}}{1-\tau_{SS}}} \\
&= \frac{(N_1\frac{\tau_{DS}}{1-\tau_{DS}} + N_2\frac{\tau_{SS}}{1-\tau_{SS}}) + N_1\frac{\tau_{DS}}{1-\tau_{DS}}}{N_2\frac{\tau_{SS}}{1-\tau_{SS}}} \\
&\approx \frac{N_1}{N_2}\cdot\frac{2\tau_{DS}}{\tau_{SS}} + 1
\end{aligned} \tag{20}$$

Where $\frac{\sigma}{T_S-T_C} \approx 0$ according to system parameters. Further, the ratio of the throughput each vehicle is derived by

$$\begin{aligned}
\frac{s_{dual}}{s_{single}} &= \frac{S_{dual}/N_1}{S_{single}/N_2} \\
&= (\frac{N_1}{N_2}\frac{2\tau_{DS}}{\tau_{SS}} + 1)\cdot\frac{N_2}{N_1} \\
&= 2\frac{\tau_{DS}}{\tau_{SS}} + \frac{N_2}{N_1} \\
&\approx 2\frac{W_{single,min}}{W_{dual,min}} + \frac{N_2}{N_1}.
\end{aligned} \tag{21}$$

When $s_{dual} = s_{single}$, $\digamma = 1$, we can derive the optimal minimum CW of the Dual-radio and Singleradio vehicle, respectively,

$$W^*_{dual,min} \approxeq \lceil 2\frac{N_1}{N_1-N_2}W_{single,min}\rceil. \tag{22}$$

$$W^{*}_{single,min} \approxeq \lceil \frac{1}{2}(1 - \frac{N_2}{N_1})W_{dual,min} \rceil . \tag{23}$$

where, N1 > N2 and $\lceil \cdot \rceil$ is Top Integral Function.

IV. VALIDATION

In this section, the packets transmission for dual-radio and single-radio vehicle and fairness index are analyzed. We built the simulation platform used by MATLAB programming to validate the proposed

TABLE I: System parameters

Parameter	Value
Packet payload	1024 Byte
PLCP Header length	24 Byte
Preamble length	32 Byte
ACK	22 Byte
Data rate	1 Mbit/s
δ	1 μs
σ	20 μs
DIFS	64 μs
SIFS	32 μs

TABLE II: Throughput (per-vehicle): default $W_{dual,min}$ and $W_{single,min}$ and optimal minimum $W_{dual,min}$ and $W_{single,min}$

Number of vehicles		CW_{min} settings	Dual-radio vehicle$(*10^4 bit)$		Single-radio vehicle$(*10^4 bit)$	
			Analytical	Simulation	Analytical	Simulation
N_1=12	Default	$W_{dual,min} = 16$ $W_{single,min} = 16$	2.8568	2.9815	2.3203	2.3617
		$W_{dual,min} = 32$ $W_{single,min} = 32$	3.1919	3.3916	2.5444	2.6450
	Bit-based	$W^*_{dual,min} \approx 55$ $W_{single,min} = 16$	1.3905	1.3612	1.3791	1.3987
N_2=5		$W^*_{dual,min} \approx 110$ $W_{single,min} = 32$	1.0351	1.0868	0.9747	1.0655
N_1=12	Default	$W_{dual,min} = 16$ $W_{single,min} = 16$	2.8234	2.8041	2.1862	2.1790
		$W_{dual,min} = 32$ $W_{single,min} = 32$	3.1505	3.0981	2.4588	2.4426
	Bit-based	$W^*_{dual,min} \approx 64$ $W_{single,min} = 16$	1.1337	1.0989	1.1447	1.1560
N_2=10		$W^*_{dual,min} \approx 128$ $W_{single,min} = 32$	1.3998	1.4032	1.3665	1.3808

analytic model. The system parameters in simulation are configured in the Table I.

Considering with two cases, where there are two categories of vehicles, N1 = 12, N2 = 5 and N1 = 12, N2 = 10, we find the throughput for dual-radio and single-radio vehicles by analysis results using (20) is close to simulation results. And Table II gives out the results. The results show that the throughput for dual-radio vehicles with optimal minimum CW_{min} setting is large compared to single-radio vehicles. This is caused by unfairness channel access for dual-radio and single-radio vehicle according to IEEE 1609.4 standard. At case of default CW_{min} setting in TABLE II, we find from express (21) that our simulation results validate the analytical results.

Continuing with this case, we enlarge the minimum $W_{dual, min}$ of the dual-radio vehicle in log scale with Fixed $W_{single,min} = 16.$ Fig. 2 shows that the relationship between the fairness index and the $W_{dual,min}$ of the dual-radio vehicle. We can find an optimal $W^*_{dual,min}$ by evaluating the fairness index for each $W_{dual,min}.$ When the fairness index of channel access for dual-radio and single-radio vehicle is F = 1, the optimal minimum CW related to dual-radio vehicle is $W^*_{dual,min} \approx 55.$

The ratio of throughput from our analytical model (21) for dual-radio and single-radio vehicles are shown

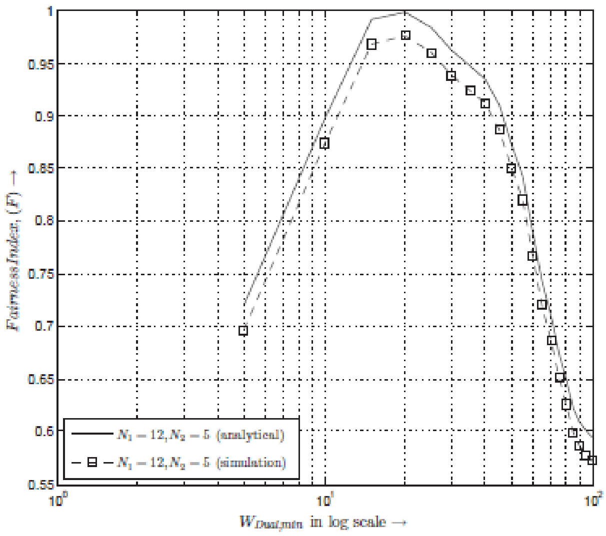

Fig. 2: Fairness Index VS $W_{\text{Dual, min}}$ for $W_{\text{single,min}}$ =16.

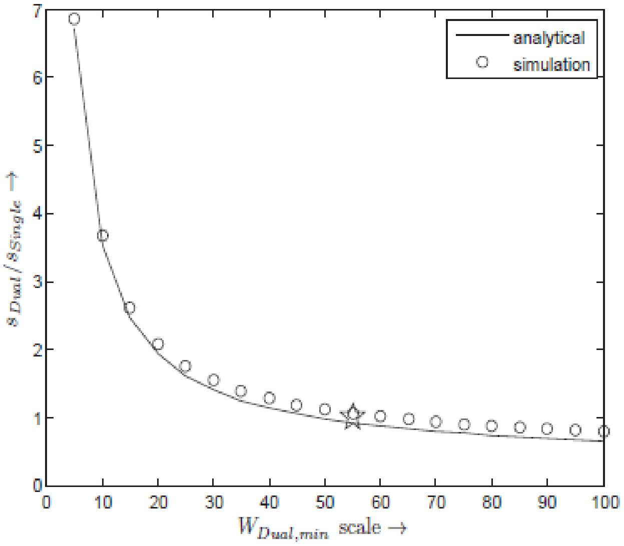

Fig. 3: The ratio of S_{dual} and S_{single} VS $W_{\text{dual, min}}$ for $W_{\text{single,min}}$ = 16, N1 = 12, N2 = 5.

in Fig. 3 with simulation results. It can be seen that our model accurately predicts bits-based throughput obtained from the simulation results. Note that the ratio related to throughput between dual-radio device and single-radio device is close to 1 (Star sign) at $W_{Dual,min} = 55$ for $W_{\text{single,min}}$= 16 N1 = 12, N2 = 5. Corresponding to Fig. 2, this result again indicates that our bits-based throughput analysis is able to model fairness index access with dual and single-radio devices in heterogeneous vehicular networks.

In this paper, we investigated the problem of unfairness in one SyncInterval based on dual-radio and single-radio hybrid vehicular networks. We presented a simple analytical model to compute the packets transferred for contending dual/single radio vehicles in hybrid network, considering their access time in whole SyncInterval. For dual/single radio vehicles, An unfairness problem that occur in one SyncInterval because of access channel time is analyzed. The ratio of packet transferred for vehicles with two-radio and single-radio is given out. Then,we got an optimal CW_{min} value required to achieve fairness. we can find out that these optimal CW_{min} value relate to number of dual/single radio vehicles in the network. Finally, simulation results were presented for packet transferred for dual/single vehicles.

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