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BAYESIAN GAME-THEORETIC APPROACH BASED ON 802.11p MAC PROTOCOL TO ALLEVIATE BEACON COLLISION UNDER URBAN VANETs

Y. H. KWON[1)] and B. H. RHEE[2)*]

[1)]Department of Electronics Computer Engineering, Hanyang University, Seoul 04763, Korea
[2)]Department of Computer Engineering, Hanyang University, Seoul 04763, Korea

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ABSTRACT−Vehicular Ad-hoc Networks (VANETs) facilitate the broadcasting of status information among vehicles. In the IEEE 802.11p/WAVE vehicle network environment, the strict periodic beacon broadcasting of safety messages requires status advertisement to assist drivers in maintaining safety. The beacon broadcasting is required for real-time communication, and for avoiding the degradation of communication channels in high vehicular density situations. However, a periodic safety beacon in the IEEE 802.11p/WAVE standard can only transmit packets on a single channel using the MAC protocol. In high vehicular density situations, the channel becomes overloaded, thereby increasing the probability of beacon collision, and hence reducing the influx of successfully received beacons, which increases the delay. Many studies have indicated that appropriate congestion control algorithms are essential to provide efficient operation of a network. In this paper, to avoid beacon congestion, we have considered game theoretic models of wireless medium access control (MAC) where each transmitter makes individual decisions regarding their power level or transmission probability. We have evaluated the equilibrium transmission strategies of both the selfish and the cooperative user. In such a game-theoretic study, the central question is whether Bayesian Nash equilibrium (BNE) exists, and if so, whether the network operates efficiently at the equilibrium point. We proved that there exists only one BNE point in our game and validated our result using simulation. The performance of the proposed scheme is illustrated with the help of simulation results.

KEY WORDS : 802.11p, Game theory, Vehicular ad hoc network (VANET), Intelligent transport system (ITS)

1. INTRODUCTION

Vehicular Ad-hoc Networks (VANETs) use moving vehicles as nodes in a network to create a mobile network. It provides support for road safety, road traffic management, vehicle-to-vehicle (V2V) communication, and vehicle-to-infrastructure (V2I) communication, via wireless transmission. These characteristics have led mainly to make VANETs are an important part of any intelligent transportation system (ITS) (Wang *et al*., 2014).

The V2I communication provides internet or traffic information via roadside communication infrastructure, while V2V communication is used for vehicle safety when such central infrastructures are not available near the vehicle. The V2V communication exchanges safety-related information such as vehicle position, speed, and location between nearby vehicles, enabling them to take pre-emptive actions and mitigate crashes. The V2V communication based on VANETs is an essential component for improving vehicular safety on the road. As a result, public and private organizations have been set up for the emerging technology that supports direct vehicular communication.

Currently, the IEEE 802.11 working group initiated the development of an amendment to the IEEE 802.11 standard for vehicular environment called 802.11p and the IEEE 1609 working group has been formed to specify additional layers (kwon as IEEE 1609.1 to 1609.4) in the protocol stack. The combination of IEEE 802.11p (IEEE STD 802.11p, 2010) and the IEEE 1609 protocol stack (IEEE STD 1609.3, 2010; IEEE STD 1609.4, 2011) is called a wireless access in vehicular environments (WAVE) standard. The IEEE 802.11p, a media access control (MAC) protocol that is based on the dedicated short-range communication (DSRC), is the only standard with support for direct V2V communication. The V2V safety communication under IEEE 802.11p-based DSRC (Kenney, 2011; Taliwal *et al*., 2004) periodically exchanges messages by broadcasting the vehicle's status information, which includes the vehicles' speed, position, etc. The single-hop periodic messages, which contains the vehicles' status information, is called Basic Safety Messages (BSMs) or beacon in U.S (Kenney, 2011) and the cooperative awareness messages (CAM) in Europe (ETSI, 2012).

**Corresponding author.* e-mail: bhrhee@hanyang.ac.kr

The 802.11p MAC protocol uses the enhanced distributed channel access (EDCA), which is based on the carrier sense multiple accesses with collision avoidance (CSMA/CA) protocol, where nodes listen to the wireless channel before transmission (IEEE STD 802.11p, 2010). If a channel is busy, the node must perform a backoff on the contention window (CW). The backoff procedure in 802.11p protocol choose a random backoff time from the interval [0, CW], delaying the medium access for the duration of that backoff. When the channel is free and when the CW value becomes zero, transmitter are sending immediately. If no acknowledgment (ACK) is received, (e.g. ACK being lost or corrupted, collision occurs), it is update to double the size of the CW until it reaches a maximum CW size. Nevertheless, beaconing uses the IEEE 802.11p common broadcast channel (IEEE STD 1609.4, 2011), which does not support the acknowledgements of broadcasting the beacon and retransmission. Therefore, the initial CW size remains the same because the delivery failure in broadcast could not be detected. If considering a high vehicle density scenario, the channel can be heavily congested by periodic beacon broadcast. In this case, scientific congestion control methods are necessary to predict a current 802.11p/WAVE model for the common control channel (CCH) bandwidth allocation among vehicular nodes taking the mobility parameters and application Quality of Service (QoS) requirements into account.

To optimize the beacon broadcasting decentralized, the resource-allocation schemes often allocate most of the CCH radio resource to the vehicular nodes with good channel condition. However, this allocation can be very biased, because the vehicular nodes in the same class may same priority for beacon service. An important trade-off exists between performance and fairness among vehicular nodes. For example, allowing any vehicular node with good condition to transmit may result in high throughput, but meanwhile this action should be lead the result to the detriment of transmissions of other vehicular nodes. The study (Bilstrup *et al*., 2009) was shown that the MAC method used in 802.11p does not fulfill this criterion and is therefore unsuitable for CAMs. Therefore, a cooperative system is used where each vehicle cooperates by relaying the information packet to other vehicles. Considering the scenarios in which users are “selfish” and act noncooperatively to use the network and its services. Such vehicles consume bandwidth for transmitting data. Therefore, they may always set for themselves the best channel access conditions to maximize their payoff. If all the vehicles act selfishly, the performance of such networks will be zero dramatically because of the inefficient competition for the radio resource among selfish users. Thus, ensuring cooperation among selfish users becomes an important issue for designing channel allocation scheme. A game theory is an effective tool to achieve a desirable solution between efficiency and fairness.

To address this issue, this paper proposes a novel distributed solution to the channel access problem at the MAC layer. In this solution, vehicular nodes know each other’s types according to a Bayesian mechanism and play the best-response strategies against their type beliefs that evolve dynamically over time. Our proposed solution does not assign any random backoff slot like as IEEE 802.11p EDCA. When a random backoff time, a beacon attempted to access channel given a time slot. Periodic beacon messages need to be sent within its time period, but the random backoff depending on CW size may cause a delay longer than the time period. As a result, broadcasting of the beacon by the neighboring nodes cannot be predicted accurately. Therefore, we assume that the channel occupancy around the nodes reflect the probability of the nodes to start communications. In particular, we consider a grid-like urban street pattern to model the downtown area of a city. Vehicles are moving in the grid. Each vehicle chooses the channel to transmit beacons according to the payoff; thus, nodes achieve the Bayesian Nash Equilibrium (BNE) when the nodes transmit a beacon packet. Finally, simulation results show our analysis and demonstrate that, with the proposed scheme, vehicles can achieve higher utility and fairness compared with the random access. This paper is an extended version of a previous publication (Kwon and Rhee, 2014). The extensions include additional analysis, and details about simulator implementation.

The remainder of this paper is organized as follows: Section 2 introduces related work. In Section 3, we describe the system model and assumptions. In Section 4, we provide a Bayesian game model to solve the problem with a repeated auction game. Simulation results and analysis are given in Section 5. Section 6 concludes this paper.

2. RELATED WORK

In the recent literature, many solutions to the problem of the congestion of the periodic broadcasting of beacon messages were proposed (Boukerche *et al*., 2009; Torrent-Moreno *et al*., 2009; Fallah *et al*., 2010, 2011; Huang *et al*., 2010). The authors presented a prediction approach for position control that requires all vehicles to exchange a beacon message containing GPS estimate position table so that a neighboring vehicle does not exceed a predefined threshold (Boukerche *et al*., 2009). A fair transmit power control algorithm was proposed to control the load of periodic messages on the channel and avoid saturated channel conditions (Torrent-Moreno *et al*., 2009). A transmission control protocol was presented (Huang *et al*., 2010), which allows each vehicle to track all its neighboring cars with an acceptable accuracy while avoiding congestion in the shared channel. The authors proposed a beacon period based on position estimate errors of the neighboring vehicles. The efficiency of beacon message under the constraint was studied that the number of nodes receiving a beacon message is maximized (Fallah *et al*., 2011).

To improve broadcasting of beacon messages using the MAC protocol were studied (Zhu and Roy, 2003; Yang *et al*., 2004). The modified IEEE 802.11 MAC protocol was investigated to be improved by dynamically adjusting the contention windows to meet the maximum saturation throughput and the weighted fairness (Zhu and Roy, 2003). A periodic beacon message to evaluate the MAC performance in terms of the reception probability was studied and the channel busy time of every node for the duration of the broadcasting of a beacon (Yang *et al*., 2004).

A congestion control methods by adapting the traffic transmission rates in the application layer was proposed (Fallah *et al*., 2010). This algorithm is based on the feedback scheme for monitoring and controlling congestion in VANET and considers some parameters such as message broadcasting rate, message-broadcasting range, size of the contention window, and the occupancy status of channels for handling congestion in the network. In addition, a number of recent works have focused on the application of game theory to improve fairness resource allocation to broadcast beacon messages (Yu and Ko, 2009; Chen *et al*., 2011; Sommer *et al*., 2011; Kwon and Rhee, 2013). A cooperation game approach in forwarding the messages was applied (Chen *et al*., 2011). The proposed idea is to reward a node by a virtual credit center (VCC) based on the number of copies of a message received and forwarded by the node. Each time a node forwards a message, a small coalition of neighboring nodes are formed whose strategy is to drop unimportant messages from their buffers to avoid congestion. This process is repeated at the source and at each intermediary node until the message reaches the destination node. The other approach was proposed, the velocity-based strategy was applied to select the beacon messages (Yu and Ko, 2009). In this strategy, the vehicle with the highest-velocity vector is selected in a load block and the message is transferred to the related vehicles. This proposed algorithm always broadcasts the message to compare the velocity whenever new vehicles enter the block.

To solve the problem of spectrum scarcity in VANETs, The authors (Cheng *et al*., 2014) conducted an investigation on the fairness problem by proving the existence of a Nash equilibrium of the cognitive radio VANETs engaged in distributed opportunistic spectrum access. In a previous study (Kwon and Rhee, 2013), we investigated the saturation performance of the broadcast scheme in VANETs, taking into account the IEEE 802.11p backoff counter to deal with selfish and noncooperating nodes in the beacon forwarding process of the Bayesian Nash equilibrium. The method using the message utility and channel quality was proposed to adapt the rate of beacons in nonsafety applications in VANETs (Sommer *et al*., 2011).

3. SYSTEM MODEL

3.1. Channel Model

Assume that a set of nodes $N = \{x_1, x_2, \ldots, x_n\}$ move along a road. Each node periodically sends a beacon within the carrier sensing range to some or the entire set of nodes by multi-hop routing. We assume that the nodes cannot transmit and receive at the same time. Moreover, they cannot multicast information. Therefore, only a single node is involved during the transmission of a message. When node i send a beacon packet to another node j, the signal received at the destination signal Y is given by;

$$Y = \sqrt{h_i} X_{i,t} + \sum \sqrt{h_j} X_{j,t} + Z_t \tag{1}$$

where $X_{i,t}$ and $X_{j,t}$ are, respectively, the transmitted and the received signal at the nodes i and j at time t, $\sqrt{h_i}$ denotes the channel gain from node i to node j, and Z_t is the additive white Gaussian noise (AWGN). To simplify the notation, we will omit the time index t in the rest of the paper. Since this paper assumes that the nodes are close to each other, the distance variations among the nodes are negligible. In addition, each node's signal-to-interference noise ratio (SINR) is independent and identically distributed (*i.i.d.*), and The channel over the L such coherence periods can be modeled as a parallel channel with L sub channels that fade independently. However, the transmitter does not know what the channel gains are; a reasonable strategy is to allocate same power to each of the sub-channels. According to the Shannon-Hartley theorem (Shannon, 1949), the capacity (in bits/symbol) of reliable communication using the OFDM channel is;

$$\mathrm{C} = \sum_{l=1}^{L-1} \log_2 \left(1 + \frac{P_l |h_l|^2}{\sigma^2}\right) \tag{2}$$

where P_l is the allocated power to sub channel l and σ^2 is the AWGN noise power. The receiver of each node is subject to interference from various noise sources such as thermal noise, background interference, and interference by the link gain. We model the thermal noise and background interference as a single source of additive white Gaussian noise (AWGN) with variance σ^2.

The Shannon-Hartley law implies that the probability of error at the receiver can be made arbitrarily small. This means that, theoretically, it is possible to transmit information almost without error up to the limit of bits transmitted over the link, as long as Equation (2) holds.

When a player increases his power level, this will increase his own SNR, but will decrease the SINRs of all the other players. According to the model, each user competes for channel access according to their own power strategy. Therefore, the random access game can be described as finding a transmission scheme based on these power strategies.

3.2. Function of Utility and Cost

We apply game-theoretic concepts of equilibrium to identify the best tradeoff points between throughput and power consumption. We consider that each node uses some power in transmitting the packets and both the utility function and the cost function are linear functions of energy consumption. Node *i* consumes its own power to access the channel for a successful packet transmission. Then, with fixed packet duration, node *i* chooses a power allocation p_i to maximize the utility $u_i(P_i, P_{-i})$, subject to the maximum power constraint, where P_{-i} is the power strategy of all the others except node *i*.

In practice, it is hard for wireless nodes to know the exact channel access probabilities of others' type. Each node assumes the contention of the wireless network by observing the cost, which is a function of the power consumption of the node's channel access probabilities.

We consider γ_i as player *i*'s achievable rate, as defined in Equation (2) and we define the utility function as;

$$u_i(P_i, P_{-i}) = f(\gamma_i) - \beta \tag{3}$$

where β is the cost value of power consumption for transmission at the node *i*. We assume $\beta_i > 0$, since nodes do not know whether the channel is occupied by other nodes, they always need to access the channel irrespective of the other nodes transmitting a beacon packet on the channel. Therefore, the cost value β has a range (0, 1]

3.3. Game Model and Assumption

In 802.11p CSMA/CA system, contention window is a certain period divided into slots. Each node that is ready to transmit chooses a random number of slots as its waiting time. The number of slots in the window changes according to the binary exponential backoff strategy. This means that it is set to one slot the first time and then doubles each time the station cannot detect an idle channel after the Inter-Frame Space (IFS) time. In the contention window, a node needs to sense the channel after each time slot. If the channel is not occupied, node *i* sends a packet. Otherwise, node *i* does not transmit. It stops the timer and restarts the backoff counter when the channel is sensed as idle. If the node *i* transmits a packet during the same time slot that the other nodes are transmitting, it will encounter a collision.

Node *i* can always successfully transmit a packet if the slot number chosen by node *i* is less than those of the other nodes. Under 802.11p MAC based protocol, *t* is the first time slot selected by node *i* in the backoff period and choosing not to transmit or other nodes are regarded as choosing time slot *t*+1. The stage game depends only on the number of slots that are competing for the channel.

We assume that each node can get feedbacks on his moves. When a node gets a feedback from another node, both the nodes to update their beliefs about the current state of the game simultaneously can use this feedback, using Bayesian rule. In this paper, based on Bayer's theorem and Bayesian probability rules, we assume that there is no exponential backoff strategy when beacon collision happens and that each game is played in a distinct period but give a 'posterior' belief, which may be used as the basis for inferential decisions. Before we describe the game model, we provide the requirements as follows (Osborne, 2004);

Requirement 1: At each information set, the player who gets to move must have a belief about the nodes in the information set that have been reached by the play of the game.

Requirement 2: Given their beliefs, the players' strategies must be sequentially rational. That is, at each information set, the actions by the players must form Nash equilibrium in the continuation of the game.

Requirement 3: Beliefs must be weakly consistent with the strategies. That is, strategies and observed actions must generate the beliefs via Bayesian rule.

From the above requirements, it is clear that each node transmits a packet with their strategies and updates the beliefs about the game state from their history. If we assume that each node knows the number of nodes to send packets to, we can model a power-controlled MAC game as follows;

Definition 1: Power-controlled MAC game

Players: There are *N* players, the *i*th player is denoted by node $i = \{1, \dots, N\}$

Actions: Action set: $P = P_1 \times \dots \times P_k$ where $P_k = [0, P_{max}]$, a player's action is defined as its transmit power. In this paper, we set P_{max} to 1.

Player's strategy: We only consider pure strategies throughout this paper. Let $\{P_i(\cdot), P_{-i}(\cdot)\}$ denote the strategy profile where all the players play Bayesian game. P_i and P_{-i} denote the composite vectors of strategies of the *i*th player and those of all players other than the *i*th player respectively.

Player's belief: In Bayesian game, players have initial beliefs about the type of each player and can update their beliefs according to Bayesian rule as play takes place in the game, Let ϕ denote a player's belief, with probabilistic distribution $\phi \in [0,1]$.

4. SYMMETRIC BAYESIAN NASH EQUILIBRIUM

We start this section with the following definition.

Definition 2: In pure strategy condition, the strategy profile $p^*(\cdot) = \{p_i^*(\cdot)\}$ is a Nash equilibrium, if for all *i*

$$u_i(P_i^*, P_{-i}^*) \geq u_i(P_i, P_{-i}^*)$$

From this definition (Osborne, 2004), it is clear that no node can individually improve its performance by changing its power strategy while the other nodes keep their strategy unchanged at the Nash equilibrium. According to the rules of the Bayesian game, a node chooses the best power level in response to the power chosen by other players given its information set. At this point, we need the following assumption;

Assumption 1: The nodes of the same type have the same beliefs distribution and update their beliefs according to the same rule, and the nodes have the same average power constraint, $P_i=P_j=P_{max}$

Theorem 1: If the type of transmitters is unknown and the nodes of the same type have the same beliefs and update their beliefs according to the same rule, the optimal power strategy p^* at any time depend on the channel gain h;

$$p^*(h)=\left(\frac{1}{\lambda}-\frac{\sigma^2}{|h|^2}\right)^+ \tag{4}$$

where λ is Lagrange multiplier.

Proof: The capacity maximization problem of Equation (2) is;

$$\begin{aligned}&\max_{p_1,\ldots,p_L}\sum_{l=1}^{L-1}\log_2\left(1+\frac{P_l|h_l|^2}{\sigma^2}\right)\\ &s.t\ \sum_{l=1}^{L-1}P_l\le P_{max}\\ &\quad P_l\ge 0\end{aligned} \tag{5}$$

where P_{max} is the average power constraint. The Lagrange-multiplier based constraint optimization problem is then;

$$L_l=\max_{p_1,\ldots,p_L}\sum_{l=1}^{L-1}\left[\log_2\left(1+\frac{P_l|h_l|^2}{\sigma^2}\right)-\lambda P_l\right] \tag{6}$$

with λ is the Lagrange multiplier chosen such that the total power constraint is satisfied. The Karush-Kuhn-Tucker (KKT) condition for the optimality of a power allocation is;

$$\frac{\partial L_l}{\partial P_l}\begin{cases}=0 \text{ if } P_l>0\\ \le 0 \text{ if } P_l=0\end{cases} \tag{7}$$

The parameter is a constant, depending only on the channel statistics but not on the specific realization of the fading process. Hence, the optimal power solution at any time depends on the channel gain h at time is given by;

$$P^*(h)=\left(\frac{1}{\lambda}-\frac{\sigma^2}{|h|^2}\right)^+ \tag{8}$$

where we use the notation $x^+\equiv\max(x,0)$. This is the classic water-filling solution.

Also, we use the Karush-Kuhn-Tucker (KKT) conditions to Equation (5), which yield the necessary and sufficient conditions for BNE in this case, the uniqueness of BNE can be proved (Osborne, 2004).

4.1. Symmetric BNE for Multistage Game

In this subsection, we analyze the dynamic situation where each node decides its action on other node types based on the outcome of the power controlled MAC game at each time slot. In order to the proposed Bayesian action game as formatted as a repeated game, the time-period is equal intervals of length. Within time-period, all player interact sequentially to access channel on p-persistent CSMA/CA. Define p_i and p_j as the transmission power for nodes. Each node updates ϕ_i and ϕ_j, individually, based on the opponent's strategy via the SINR feedback from the receiver back to the transmitters. ϕ_i and ϕ_j, are uniform distributions over [0, 1]. We assume that all nodes are rational, so nodes of the same type have the same belief distributions and update their beliefs according to the same rule.

Let P_0^K define opponent's power and ϕ_i^k as the belief of ϕ_i at the kth slot. Each node updates their beliefs on the opponent's type according to the Bayesian rule;

$$\phi_i^{K+1}=\frac{\phi_i^K\alpha_i^K P_o^k}{\phi_i^K\alpha_i^K P_o^k+(1-\phi_i^K)\varepsilon_i^K P_o^k}, \tag{9}$$

$$\alpha_i^k P_o^k=\Pr\left(P_o^k|\text{the opponent of node } i \text{ is selfish}\right)$$

$$\phi_j^{K+1}=\frac{\phi_j^K\alpha_j^K P_o^k}{\phi_j^K\alpha_j^K P_o^k+(1-\phi_j^K)\varepsilon_j^K P_o^k}, \tag{10}$$

$$\varepsilon_i^k P_o^k=\Pr\left(P_o^k|\text{ the opponet of node } i \text{ is nonselfish}\right)$$

where $i\in\{\text{selfish, nonselfish}\}$. $\alpha_i^k P_o^k$ and $\varepsilon_i^k P_o^k$ can be computed as;

$$\alpha_s^K P_o^k=\begin{cases}0, & P_o^k<(1\text{-}\phi_s^k)^2,\\ 1, & P_o^k\ge(1\text{-}\phi_s^k)^2,\end{cases} \tag{11}$$

$$\varepsilon_a^K P_o^k=\varepsilon_s^K P_o^k=\begin{cases}0, & P_o^k>1,\\ 1, & P_o^k\le 1.\end{cases} \tag{12}$$

A selfish node eventually detects the type of the selfish opponent's node with power P_o^k, whenever P_o^k > 1 or detects the type of the altruistic opponent, whenever $P_0^k<(1-\phi_s^k)^2$. From Equations (9) and (10), we obtained $\phi_s^{k+1}=\phi_s^0$, until the opponent's type is detected. The kth slot that detects the type of the opponent is a random variable with success probability $(1-\phi_s^0)^2$.

4.2. Symmetric BNE for Random Access MAC Game

We consider random access game where the nodes choose between either transmitting or waiting in a time slot. Assume a synchronous slotted system with collision

Table 1. Strategic form of the game.

Player j

		T	W
Player i	T	$(-\beta, -\beta)$	$(f(\gamma_i)-\beta, 0)$
	W	$(0, f(\gamma_i)-\beta)$	$(0, 0)$

channels such that more than one simultaneous transmission fails. Assume player i chooses to transmit with probability p $(0 \le p \le 1)$ and player j with probability q $(0 \le q \le 1)$. We define T and W as the actions of transmitting and waiting, respectively, with the corresponding expected utilities for user i. To find the Bayesian Nash equilibrium (BNE), we consider only the pure strategies for the sake of clarity and simplicity.

The strategies available to player i are {transmit if $\phi = W$, wait if $\phi = T$}, while that to player j are $\{T, W\}$. Table 1 shows the strategic form of the two game players in a slot time.

Lemma 1: In the stage game as defined in Definition 1, there exists a belief threshold ϕ^*, such that the pure strategy BNE exits if, at equilibrium, all players i with $\phi > \phi^*$ play transmit, while the rest play wait.

Proof: From Table 1, both the nodes can improve their payoffs by conflicting each node from the strategy pair. Let p_i = {transmit if $\phi = W$ wait if $\phi = T$}. For node j, if $p_j = T$, the expected payoff is;

$$E_{\mathrm{i}}(u_{\mathrm{i}}) = pq(-\beta) + (1-p)q(f(\gamma_{\mathrm{i}}) - \beta) \tag{13}$$

If p_{j} = wait, the expected payoff is;

$$E_{\mathrm{j}}(u_{\mathrm{j}}) = 0 \tag{14}$$

Since the expected payoff in Equation (13) is greater than that of Equation (14), the dominant strategy for node j would be to transmit; however, the best response for player i is to wait. At equilibrium, all players i has ϕ_{i} as belief. Hence $(P_{\mathrm{i}}, P_{\mathrm{j}})$ = {(transmit if $\phi = 0$, wait if $\phi = 1$), wait} is a BNE under the condition that $\phi > \phi^*$.

Let $(P_{\mathrm{i}}, P_{\mathrm{j}})$ = {transmit for all ϕ, wait}. If player j choose not to wait, the best response for player i is to transmit if $\phi = 1$. Therefore, there is a BNE if $(P_{\mathrm{i}}, P_{\mathrm{j}})$ = {transmit for all ϕ, wait} and the equilibrium strategy profile is given by $(P_{\mathrm{i}}, P_{\mathrm{j}})$ = {(transmit if $\phi = W$ wait if $\phi = T$), wait}.

Based on the BNE, we propose a medium access method based on 802.11p protocol. In our access method, each node estimates its conditional probability and adjusts its channel access probability. Consider M as the maximum number of wireless nodes in a network with contention-based medium access. Let N_{s} and N_{n} denote the number of selfish nodes and nonselfish nodes, respectively, where $N_{\mathrm{s}}, N_{\mathrm{n}} \le M$, Let $Pr(N, N_{\mathrm{s}})$ and $Pr(N, N_{\mathrm{n}})$ denote the joint probability mass function of N_{s} and N_{n}, as believed by a selfish and a non-selfish node, respectively. Under the symmetricity assumption, it is a symmetric game model with the transmission probability p and q for any selfish and non-selfish node, respectively. Each non-selfish node wishes to minimize the sum of the total throughput by selfish nodes and increases a cost by unity for each successfully transmitting selfish node. Each selfish node, on the other hand, wishes to maximize the payoff and decrease the transmission cost.

In this paper, we assume channel access game model based on SINR. To maximize channel access, it seems reasonable to use low transmission power. Therefore, we adopt the symmetric Bayesian Nash equilibrium strategies, p_{s} and p_{n}, for selfish and non-selfish transmitters, that are;

$$p_{\mathrm{s}} = \min([p_{\mathrm{n}}^*]^+, 1), \qquad p_{\mathrm{n}} = \min([p_{\mathrm{n}}^*]^+, 1), \tag{15}$$

Assuming that all the nodes follow symmetric BNE strategies, the expected utility of a selfish node is;

$$E(u_{\mathrm{s}}(P_{\mathrm{i}}, P_{-\mathrm{i}})) = \sum_{N=1}^{M} \sum_{N_{\mathrm{s}}=1}^{N} \Pr(N, N_{\mathrm{s}})(p[-\beta_{\mathrm{i}} + (1-p)^{N_{\mathrm{s}}-1}(1-q)^{M\text{-}N_{\mathrm{s}}}]) \tag{16}$$

and that of a nonselfish node is;

$$E(u_{\mathrm{n}}(P_{\mathrm{i}}, P_{-\mathrm{i}})) = \sum_{N=1}^{M} \sum_{N_{\mathrm{s}}=1}^{N} \Pr(N, N_{\mathrm{n}})(-q\beta_{\mathrm{i}} + (1-q)[-N_{\mathrm{s}}p(1-p)^{N_{\mathrm{s}}-1}(1-q)^{M\text{-}N_{\mathrm{s}}-1}]) \tag{17}$$

5. SIMULATION RESULTS AND ANALYSIS

To simulate and validate the mathematical model described in the previous section, this paper has developed a MATLAB code to follow the 802.11p MAC protocol specification (IEEE STD 802.11p, 2010), so that all nodes share a single channel to transmit a beacon packet. For the purpose of simulation, this paper is assumed that the channel follows an exponential distribution with mean λ, and with a Rayleigh fading channel where λ is set to one. We use Monte Carlo technique to analyze the transmission probability of various channel gain h. For the rest of the section, unless otherwise noted, we set the following values for the parameters: λ=1, $\sigma^2 = 1$ and SNR threshold=10 dB.

To evaluate our MAC protocol, this paper is considered an urban scenario as shown in Figure 1, where placed 25 vehicular nodes pre one lane randomly move along the roads on square region of area 100 km × 100 km. In this paper, it is assumed that a large number of vehicles sends beacons at a high frequency at intersections and set the transmission range to 100 m and the interference range to

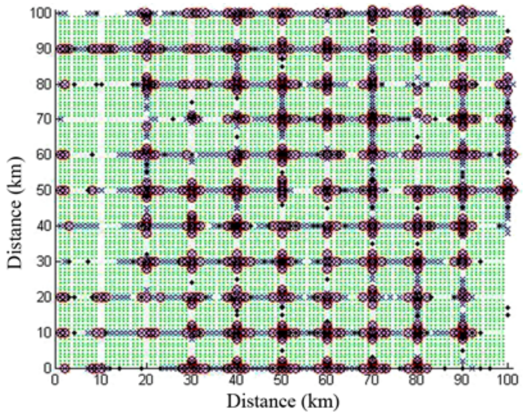

Figure 1. Screenshot of the utilized scenario, which consists in urban environment with two lanes.

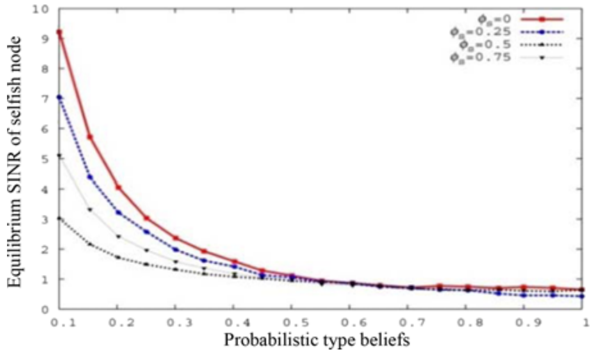

Figure 2. Equilibrium SINR node as a function of type belief probabilities for different values of distribution ϕ_s.

200 m. As shown in Figure 1, A red marks is assumed that a large number of vehicles send beacons at a high frequency at each intersection with the transmission range to 100 m and the interference range to 200 m. A beacon packet is transmitted if the received SNR is larger than a threshold; otherwise, it remains in the waiting state.

First, we show the existence of equilibrium SINR for nodes in Bayesian game. We vary the probability of the player's type belief for the selfish nodes, while all other nodes remain cooperative. In Figure 2, we observe that the equilibrium offers low value of the channel attempt probability as the selfish node increases. Note that it is possible for a user to benefit from deviating from the optimal threshold. For example, if a node deviates by decreasing its threshold, its expected payoff increases due to more opportunity for transmission compared to other nodes. If any node starts acting selfishly, he may continue to decrease his threshold down to zero resulting in the maximum payoff. However, if all the nodes start acting selfishly, they would decrease their thresholds too low. As a result, all the transmission trials would be unsuccessful, and thus every node would just consume transmission power without gaining throughput. This observation implies that all the nodes will choose the symmetric BNE strategy to achieve balance among the nodes.

Next, we show how the symmetric BNE strategy should be adaptively depending on the total number of active selfish nodes over the networks. Figure 3 shows the effect of increase of the transmission cost. As β increases, each node should increase the threshold appropriately, because all nodes are rational and they would like to reduce the risk of packet loss. As the transmission cost increases, each node waits to transmit a beacon message until its channel is good enough to deliver a packet.

Third, we show the equilibrium throughput for nodes with symmetric BNE strategy on power controlled MAC game. The simulated result shows the existence of Nash equilibrium for this case. In this figure, E_n is the utility function of a probability distribution from Equation (17).

In Figure 4, we observe that the throughput decreases and vanishes when the players become more aggressive (reflecting an increase in selfish nodes). The equilibrium value is zero, or close to zero, when the number of selfish nodes exceeds 19 at intersection. This situation is similar to prisoner's dilemma, and we can explain it by noticing that when the users become very aggressive, the collisions increase, the activity probability increases towards one, and the system moves toward saturation.

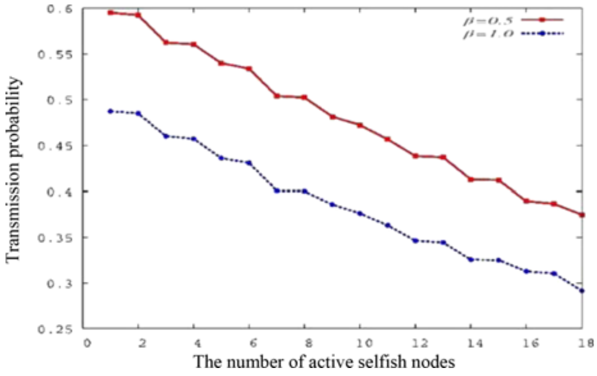

Figure 3. Effect of transmission probability on the cost value.

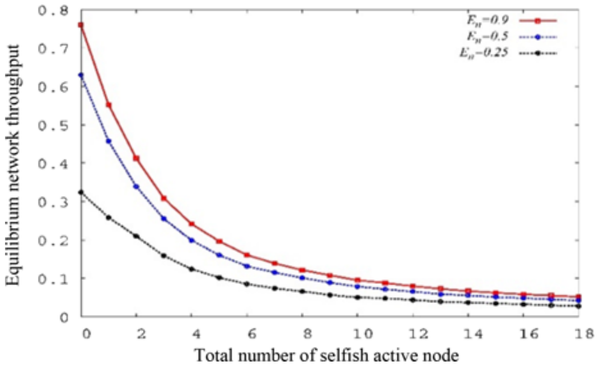

Figure 4. Throughput in Nash equilibrium as function of n, the number of selfish nodes.

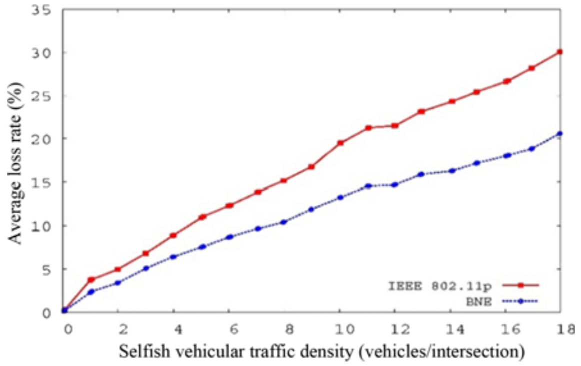

Figure 5. Selfish vehicular traffic density versus loss rate (at intersections).

Finally, we computed the average packet-loss-rate observed for all existing vehicles in the observed road intersection in Figure 5. We can easily see that our developed model provides an interesting improvement and minimizes the loss rate of emergency messages in the network. As showed in Figure 5, the average loss rate varies from 32 % to 40 % when no congestion control mechanism is deployed in the network. It is reduced to be achieved by dint of our congestion control scheme.

6. CONCLUSION

In this paper, we have presented a game theoretic model at the power control MAC layer of IEEE 802.11p. For selfish and non-selfish nodes of unknown type, a Bayesian non-cooperative game has been formulated to model the decision making process of nodes to broadcast a beacon packet for the radio bandwidth in an incomplete information environment. We considered our proposed strategy as Bayesian Nash equilibrium, where the nodes transmit a beacon packet according to a channel gain based threshold based on power control. We measured the performance in terms of throughput rewards and transmission energy costs. Simulations have shown that the game model based on IEEE 802.11p provide a stable outcome where the network is congested in a VANET.

A possible direction for future work is to focus on developing methods for setting optimum or sub-optimum values of the design parameters with lager number of vehicles and it will be better to devise realistic heterogeneous scenarios then show the improvements achieved with the proposed models.

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