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IMPROVING DELAY PERFORMANCE FOR TIME-CRITICAL COMMUNICATIONS IN VANET

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To ensure the functionality of intelligent transportation, time-critical information is of great importance in Vehicular Ad-hoc Network (VANET). Meanwhile, non-time-critical information still exists in the network, with which regular services can be provided. A key problem in VANET is to guarantee delay performance for time-critical traffic while still satisfying demand of non-time-critical traffic. To achieve this object, a multiple threshold policy derived from TEOS (Threshold Enabled Opportunistic Scheduling) is studied in this paper. With this policy, overall channel efficiency is optimized while a throughput requirement from the non-time-critical traffic is still considered. Thus, two objects can be achieved simultaneously: time-critical packets can have a better channel access probability as a result of a more free channel; and non-time-critical traffic can be transmitted as required. Numerical results and simulations show that this approach can provide smaller delay for time-critical transmissions in VANET.

Keywords: Time-Critical Communications, opportunistic scheduling, VANET, TEOS

1 Introduction

Vehicular Ad-hoc Network which is also known as VANET, is an emerging branch of wireless ad-hoc network research. Due to the large requirement of intelligent transportation systems, it has attracted tremendous attentions from both research community and industries. Former researches, e.g., [1, 2], have provided varied approaches to achieve better QoS in VANET. However, all these studies are focused on the higher layers of network structure in VANET. Little work has been done with Physical and MAC layer. As mentioned in [3], opportunistic scheduling can provide large improvement by exploiting physical channel. Thus in this paper, we give a method to explore opportunistic scheduling technique in a VANET scenario in order to provide better network performances.

Comparing to the other wireless networks, links in VANET suffer a more frequent and wider-range fluctuations due to the mobility of the nodes. It is a big difficulty in network design, but also means that the uncertainty is rich, which is important for achieving optimization in opportunistic scheduling. Another issue in VANET is that there exists different services and diversified requirements. For example. most of the communications are used to maintain the connections and to report the vehicle conditions. These types of services are considered to be with a regular manner, and is not time-critical. Emergency report is another type of service in VANET which is hard to predict and is time-critical.

As a result of these characteristics, the scenario in VANET is different from the other ad-hoc networks in which existing opportunistic scheduling schemes can not be directly used. Diversity among different services has to be taken into consideration. Therefore in our approach, a DiffServ model is applied. As throughput and delay are two most critical performance factors in VANET, we classify traffic with differential delay requirements and throughput requirements. In this way, we can provide optimized delay performance to time-critical traffic, while guaranteeing the throughput requirement of non-time-critical traffic at the same time.

Considering a distributed network, due to the lack of centralized control, transmission opportunity cannot be assigned voluntarily to the links with time-critical traffic. Thus the more time slots are taken by non-time-critical traffic, the longer period of time nodes have to wait before transmitting a time-critical packet. When there is too much traffic in the channel, time-critical packets may be totally blocked which leads to disastrous problems. The only solution is to improve the channel efficiency, which is the major thrust in the idea of opportunistic scheduling. We have to note that our scheme can not provide efficient functionality if non-time-critical traffic is already beyond the channel capacity. Congestion controlling technology has to be deployed for this kind of conditions which is beyond the scope of this study. In the following sections, in order to simplify the writing, we will use TC to say time-critical, and NTC to say non-time-critical.

This paper is organized as follows. Section 2 gives a description of opportunistic scheduling approach and discusses related research. Section 3 gives the problem formulation and describes the mechanism to spare channel for time-critical traffic in VANET. An opportunistic scheduling scheme for VANET wich is called VTEOS is given in section 4. Analysis and results are given in section 5 and we conclude our paper in section 6.

2 Background and Related research

Before proceeding to the problem formulation and to the description of our contribution, it is more appropriate to recall the approach used in this paper to improve the QoS in VANET. This section therefore provides a description of Opportunistic Scheduling and outlines its main use in the literature. This section discusses also our motivation for which we have used this approach.

2.1 Opportunistic Scheduling

QoS is one of the most important domains in wireless research. Mechanisms and algorithms have been proposed from varied aspects within recent decades. Then why do we propose opportunistic scheduling as a new solution? The answer is related to physical layer of wireless ad-hoc networks. Most traditional QoS mechanisms focus on the problem of allocating resources (e.g., bandwidth and time) to different users. On the other hand, they can only provide scheduling function with the resource provided to them, no matter how much it is.

However, channel is unstable in wireless ad-hoc networks. With different approaches, a different amount of resource may be achieved. For example, in an ad-hoc network, throughput per second is not a fixed number. It is determined by the nodes that have transmitted packets in a certain instant, and is also affected by the node's transmission rate of this instant.

Opportunistic scheduling is different from the traditional QoS mechanisms. It is designed to explore the channel condition, and can maximize the quantity of resource. For example, in the case of a wireless ad-hoc network, the overall throughput may be good if the transmitters are with a good channel condition, or it may be bad if the transmitters suffer a channel problem. While opportunistic scheduling is applied, it detects the channel condition of each link. Then the transmission opportunity can be given to the link with good channel condition. Thus, the overall performance can be largely enhanced.

2.2 The Origin: From Multiuser Diversity to Opportunistic Scheduling

The frequent channel variation is an important characteristic of wireless ad-hoc networks. It is caused by diversified reasons and at multiple time scales. For example, multipath fading can result in small time-scale fluctuations, and long-distance fading is a reason for large time-scale channel alterations. To adapt these variations of channel condition and harvest stable digital channel for transmission, techniques ranging from coding mechanisms to power controlling algorithms have been developed.

Among all these mechanisms for solving the time-variation problem, diversity is considered as an important breakthrough. The channel efficiency can be multiplied while diversified sub-channels are provided to one or more users simultaneously. There already exist different approaches for exploiting these types of diversity, e.g., FDMA (Frequency-division multiple access) for utilizing multi-frequency diversity, TDMA (Time-division multiple access) for obtaining multi-time-interval diversity, and multi-antenna technology for exploiting multi-space diversity.

Another special form of diversity is called multiuser diversity, which is derived from multiuser wireless environment. The key idea in multiuser diversity can be explained as follows: "Diversity gain arises from the fact that, in a system with many users whose channels vary independently, and there is likely to be a user with a very good channel at any one time. Overall system throughput is maximized by allocating at any time the common channel resource to the user that can best exploit it" [4]. Actually, this idea is firstly discussed in [5], in which authors model a communication system with a base station and multiple users. Almost at the same time, in [6] authors provide a similar result for a network with multiple download links. Authors in [4] ended up giving the name multiuser diversity.

From then on, researchers have proposed varieties of approaches to explore multiuser diversity [7][8][9][10]. Since transmission opportunity coordination is the major task for MAC layer, more delicate scheduling schemes are designed in these research. These schemes share a common concept: exploring the best transmission opportunity opportunistically. Thus, they are categorized as "opportunistic scheduling". Results show that huge performance augmentation can be achieved in wireless environment. Therefore, opportunistic scheduling becomes one of the attractive research domains in recent years.

2.3 Related Research

Multiuser diversity exists in all wireless networks that consists of multiple users. After the pathbreaking paper [4] from D. Tse in 2002, research on the exploitation of multiuser diversity has been carried on in different wireless networks. An example can be found in [11], from which a large scale Wi-Fi network is built, and multiuser diversity is used for finding the best route for multi-hop packet transmission.

The term of "opportunistic scheduling" comes from [7]. The usage of multiuser diversity in MAC layer scheduling have been concluded in this literature, and a framework is proposed. The authors show that previous work in this area can fit into or at least relate to their framework. Based on this framework, authors also provide detailed scheduling policy to several scenarios, i.e., temporal fairness scheduling scheme, utilitarian fairness scheduling scheme and minimum-performance guarantee scheduling scheme.

Other detailed issues in scheduling are also studied by the research community. In [9], researchers focus on the uncertainty of measurement in the wireless channel. They consider the gap between measuring and reality, and a special scheduling scheme is developed. Simulation results show that this new scheme can achieve a 35 percent of theoretical delay reduction comparing to other schemes without this consideration. The multiple link category issue is studied in [10]. Authors sort packets from different links into different categories to provide delicate scheduling service. Intuitive analysis is carried on in the literature, and a scheduling scheme similar to the framework in [7] is provided.

It has to be noted that most publications in this area are based on the assumption that there exists an omniscient node which can control every single node in the network. This kind of mechanisms are easy to be implemented in the environment with centric-control. However, in wireless ad-hoc network, distributed scheduling is more valuable.

A recent study [12] has provided an interesting solution to this challenging task. Authors show that it is possible to let each node to make distributed decision for achieving opportunistic scheduling. A mathematical method called optimal stopping theory is used to formulate the optimization problem, based on which a threshold policy is derived. Nodes in the network are designed to compare their real-time transmission rate with this threshold. Only a positive result can lead to a packet transmission. Numerical results show that this distribute scheduling scheme is efficient in achieving performance optimization. Further studies (e.g., [13]) extend the results of [12]. In [13], a delay constraint is considered, and a similar threshold policy is proved to be applicable for achieving distributed opportunistic scheduling. However, there are still many detailed research topics remaining uninvestigated in this attractive area.

To apply opportunistic scheduling in MAC layer protocols, we face both opportunities and challenges. The opportunities lie in the fact that popular protocols (e.g., DCF) are also distributed, a similar structure can be learnt from them. Thus, the design work can be much easier.

However, the scheduling policy is simple in DCF. It can be summarized as: to transmit while the channel is free. In opportunistic scheduling, the optimization efficiency is determined by the scheduling policy. Therefore, much more delicate scheduling policies have to be designed. On the other hand, although performance optimization is valued in opportunistic scheduling, other issues like fairness are also of great importance. This also increases the difficulty of the research.

3 Mechanism of Sparing Channel for Time-critical Traffic in VANET

Though existing opportunistic scheduling schemes are not suitable for VANET, the threshold policy still offers a solution for providing high channel efficiency. Considering a VANET scenario with a regular requirement of NTC transmissions, a majority of channel resource is used for transmitting these packets. While emergent TC packets arrive, they may be delayed due to the busy channel which is occupied by the NTC transmissions. Thus, if the transmission time for NTC transmissions can be reduced as much as possible, the delay performance of TC traffic can be boosted. In this section, the concept of TEOS (Threshold Enabled Opportunistic Scheduling) [3] is studied for this purpose, and a corresponding scheduling policy is presented.

3.1 Problem Formulating

In a VANET, there are multiple mobile nodes in the network. We assume that, by implementing the power control technology, nodes can restrict their efficient signal propagation range within their neighbors. Thus, with multiple one-hop links between each pair of neighbor nodes, a link-level network can be constructed. An AODV protocol (Ad hoc On-demand Distance Vector) [14] can be deployed to form the multi-hop routing table. In this way, a VANET communication system can be built. A demonstration of this kind of network can be seen in Fig.1, which is a typical vehicular communication system on highway.

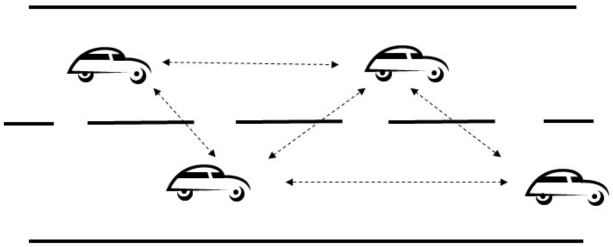

Fig. 1. A demonstration of Vehicular Ad-hoc Network

Probing packets are used to detect current channel state, and also for claiming medium access to avoid interferences. If the probing packet is correctly received, decoded and acknowledged, the pair of users (also known as link) can take the transmission opportunity.

To simplify network model and make our analysis tractable, we make the following simplifications and assumptions. First of all, the system works in a discrete time fashion, i.e., users try to access the channel and make decision at $\tau = 1, 2, ...$ We assume at each system time τ, users will try to access channel with a probing packet. $\Omega = \{1, 2, \ldots, N\}$ is used to present the links. Due to the dynamics of wireless environment, we model the time-varied transmission rate into a random variable X with p.d.f $f_X(x)$, distribution function $F_X(x)$ and a finite range $[\underline{X}, \overline{X}]$. For the convenience of derivation, we denote t as the time duration of a slot and t_p as the data transmission duration which is no greater than the channel coherence time.

As mentioned in the above part, NTC always comes for an ordinary purpose, and is possible to be predicted. To apply opportunistic scheduling to these regularly-generated packets, we use the following application model to simplify the scenario. We assume that the throughput requirement of NTC traffic for all the links are $\mu = \{\mu_1, \mu_2, \ldots, \mu_N\}$, where μ_i is the individual NTC throughput requirement for link i. Also, we use a statistical probability p_i to present the possibility of probing for link i's regular packets. As emergent situations can never be foretold, the arrival rate of TC traffic is stochastic. However, we assume that the TC packet uses a probability of $p_{t,i}$ to try to access the channel after the packet arrives at the nodes. $p_{t,i}$ is smaller than 1 so that while there are multiple TC packets, they may not block the channel. Also, when an ongoing emergency probing packet is detected by other links, they stop probing for their own regular transmissions to spare the channel.

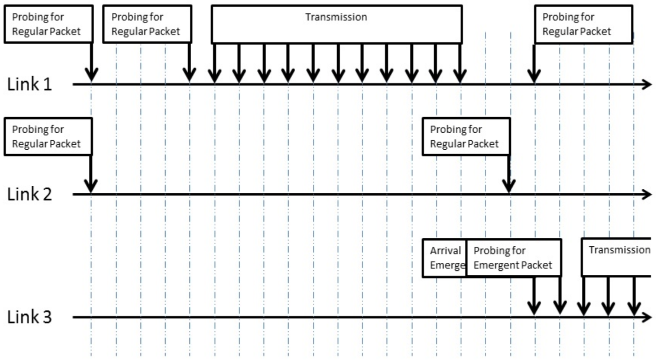

Fig. 2. System Model for Packet Probing and Transmission

Then the scheduling problem for NTC packets can be treated as a scheduling problem with individual throughput requirement, and TEOS can be used directly. In the following part, we first introduce TEOS to show how to use it to improve channel efficiency for NTC traffic in a VANET network.

3.2 TEOS: Threshold Enabled Opportunistic Scheduling

TEOS (Threshold Enabled Opportunistic Scheduling) is a scheduling method which is proposed in [3]. It is used to handle the problem introduced by individual throughput requirement. To be more specific, every link's need of transmission is taken into consideration in designing the scheduling policy. Accordingly, individual threshold is derived for each link. Links in the network are designed to compare their real-time transmission rate with this threshold. Only a positive result can lead to one round of packet transmission. Otherwise, the transmission opportunity is skipped, and the packet is delayed. The idea within TEOS is opportunistic scheduling. The threshold policy in TEOS is used to judge whether the user's channel condition is good enough.

The major mechanism of TEOS is an iterative algorithm. Two scales of iteration are used in the algorithm. In the large scale, TEOS tries to approach a possible threshold set step by step, hereby, defined as step k. In the small scale, TEOS derives the threshold for link i with other links' thresholds that have already been calculated in current step k, i.e., $T_1^{(k)} \dots T_{i-1}^{(k)}$, and thresholds that have not yet been renewed in current step, i.e., $T_{i+1}^{(k-1)} \dots T_N^{(k-1)}$. It is proved in [3] that when there exist solutions for the scheduling policy, the iterative algorithm comes to a fixed point $\mathbf{T}^* = \{T_1^*, T_2^*, \dots, T_N^*\}$, and this fixed point is the individual threshold set for solving the scheduling problem. As TEOS is only used as a tool in this paper, [3] can be referred to for further details of this algorithm.

The major task of TEOS is to judge whether and how to achieve a set of individual throughput requirement. In VANET, if the requirement set μ is within the channel capacity, individual threshold can be derived. However, these threshold is only one possible solution for achieving the throughput requirement of NTC packets of all links. There is still a gap between TEOS and our goal of improving TC delay performance in VANET.

Fortunately, TEOS has some interesting characteristics. According to proposition 4.3 in [3], the threshold set derived from TEOS iterative algorithm is the largest threshold set. To be more specific, the fixed point $\{T_1^*, T_2^*, \dots, T_N^*\}$ derived from above algorithm holds the largest value for all the link, e.g., $T_i^* > T_i^\dagger$, where for all i, $T_i^\dagger$ is a threshold from a solution set $T^\dagger$. The proof is also provided in [3]. With this largest threshold set, the least transmission opportunities, as well as the least time slots are used for transmitting NTC packets. Thus, we can have the best channel efficiency for required throughput.

3.3 Optimized Delay Performance for Time-critical Traffic

In this section, we will present how TEOS works for improving delay performance of TC traffic in VANET. Obviously, the physical channel condition and the scheduling scheme are the only factors that matter the delay performance. According to the statistics of the channel, the potential delay of an emergent TC packet can be estimated. When a TC packet arrives, the medium is for sure under either of two conditions: 1) packet transmission; 2) channel contention.

As we denote the probability for each link i to probe for a NTC packet as p_i, we have the probability for link i to successfully contend the channel as:

$$P_i = p_i \prod_{j \neq i} (1 - p_j). \tag{1}$$

Then we can have the overall probability for a successful channel contention as:

$$P_{succ} = \sum_{i}^{N} p_i \prod_{j \neq i} (1 - p_j). \tag{2}$$

Obviously, the number of slots for achieving a successful channel contention is a geometric random variable with the expectation of $1/P_{succ}$. It then follows that the expectation of the waiting duration for one successful channel contention can be denoted as $t_w = t/P_{succ}$. As a transmission duration of t_p follows directly after a successful channel contention, we have the expectation of one round channel contention and transmission as $t_w + t_p$. Therefore, a TC packet may arrive in MAC layer with probability $P_t = t_p/(t_w + t_p)$ when the channel is occupied by transmission. Also, with probability $P_w = t_w/(t_w + t_p)$, it may arrive when the channel is free for access.

Thus, we can have the following successful channel contention probability $P_{c,i}$ for time-critical packets in link i when the channel is free :

$$P_{c,i} = p_{t,i} \prod_{j \neq i}^{N} (1 - p_{t,j}), \tag{3}$$

$p_{t,j} = 0$ if there is no time-critical packets with link j.

Assuming that there is TC packet with only one link, similar to the condition with NTC traffic, we can have the expected waiting time for TC packet as $t_{w,c} = t/P_{c,i}$, while the channel is free of transmission. Then the overall expectation for TC packet's delay $t_{e,c}$ can be presented as:

$$t_{e,c} = t_{w,c} + P_t(t_{w,c} + E[t_p]) + t_p \tag{4}$$

The first part of $t_{e,c}$ is the expected delay time if the channel is free to access, and the second part represents the condition while another transmission takes place. The third part is the length of the packet. Therefore, the objective of our research turns to find out a mean for reducing $t_{e,c}$.

It follows that (4) can be further presented as:

$$t_{e,c} = \frac{t}{p_{t,i} \prod_1^N (1 - p_i)} + \frac{t_p}{t_w + t_p} \cdot \sum_{i=1}^{t_p} \frac{i}{t_p} + t_p. \tag{5}$$

Clearly, $t_{e,c}$ is influenced by two major issues as shown in (5). The first issue is the probability of successful channel contention for TC packet. If the channel is busy, it takes more time to contend the channel. The second issue is t_w. If the channel is occupied by one transmission, it is impossible to stop this transmission immediately. The TC packet has to wait until the channel becomes free. The more probably the channel is free, the less delay can be achieved by the TC traffic. Thus, to guarantee a better delay performance for TC traffic, two solutions can be used: 1) giving the TC traffic priority to contend the channel; 2) making the channel less busy. In the following section, we will try to find out how to use opportunistic scheduling to provide more spare time for TC traffic, which focus on the second approach.

From (5), we see that if we can augment t_w, a smaller $t_{e,c}$ can be achieved. Also, with individual threshold derived from TEOS, denoted as T_i for link i, we have a new overall probability $P_{v,succ}$ for successful channel contention of regular transmissions.

$$P_{v,succ} = \sum_{i}^{N} (1 - F_X(T_i)) p_i \prod_{j \neq i} (1 - p_j). \tag{6}$$

Then we have a smaller t_w, for $t_w = t/P_{v,succ}$. Thus, problem is solved. Two objectives are achieved: 1) to provide the largest $t_{e,c}$; 2) to guarantee the required NTC throughput μ.

4 VTEOS: An Opportunistic Scheduling Scheme in VANET

Based on above discussions, it can be concluded that delay performance can be improved for time-critical traffic in VANET. Thus, a following task is to design a corresponding mechanism to realize this concept. In this section, we will first introduce a mechanism that can help to achieve our system model in real applications, then a scheduling scheme is designed.

4.1 A Mechanism to Further Improve Delay Performance of TC Traffic

In a real application scenario, we can use some other design for TC packets so that it can access the channel with a better chance. To be more specific, TC packets are designed to have a better priority to probe the channel. To achieve this objective, we use a structure similar to SIFS (Short InterFrame Space) and DIFS (Distributed InterFrame Space) in IEEE 802.11 MAC.

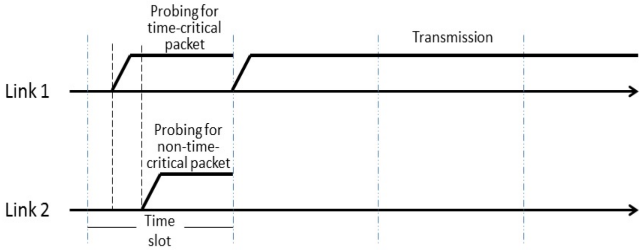

Fig. 3. Priority Probing for Time-critical Packets

As shown in Fig.3, by using priority probing mechanism for time-critical packets, the competition between time-critical and non-time-critical packets has been canceled.

4.2 Design of VTEOS

A new set of scheduling rules is also applied in VTEOS. The major difference between VTEOS and traditional random access scheduling is that after a successful channel contention, a certain policy should be implemented to make a judgement. The packet transmission only starts if the judgement result is positive. For the convenience of presentation, the period of time for an intact channel probing and packet transmission procedure is still called a contention round. Thus, the scheduling rules of VTEOS can be presented as follows:

1. Channel Probing. Channel probing is combined with channel contention, and is carried out before each transmission. If multiple nodes probe channel at the same time, an interference occurs, and all of them fail to claim the channel resource. If only one node probes, it successfully contends the channel and probes the channel state information of that link. Then this information will be used in scheduling policy to make further scheduling decision. A special rule is designed for TC packets that it can probe the channel earlier than all other packets which gives it a better chance to access the channel.

2. Link Establishment. Probing packet is also used to establish links. While probing packet from one new node is broadcasted in the network, all the existing nodes memorize

the information of this node and a potential link can be established according to the broadcasted information.

3. Scheduling Policy. According to the current scheduling policy, transmission decisions are made. In VTEOS, a threshold policy for each link is used for NTC packets, and no rule for TC packet.

4. Transmission. Transmission is carried out with physical layer with regular transmission rate. A successful transmission is ended by an ACK packet.

5. Backoff Policy. If ACK is not received in transmission phase, the attempt is considered failure. It then follows a random backoff policy. A random period of time has to be waited before next attempt as in DCF. The attempt counter for this specific link increases by 1.

6. Packet Dropping. A pre-defined parameter is used to control packet dropping according to the wireless environment. If the attempt counter passes the parameter, the packet is dropped, and further packet transmission to this node is banned until a new establishment of the link with a channel probing packet.

5 Numerical Results and Analysis

5.1 Analysis Scenario

VANET systems are multiform, and the simulation is therefore complicated. As this paper is only a first-step attempt, we are not ambitious to cover too many aspects. A numerical analysis is initiated in a special case as depicted in the system model. Simulator is developed with MATLAB, AWGN channel with normalized SNR $\rho = 40$ is used for NTC traffic in 3 links. The traffic load is measured by the channel probing probability p_i. With different p_i, the delay performance of TC traffic is different. The requirement of NTC traffic is also pre-fixed in different analysis. The transmission rate of one link can be given by the Shannon capacity equation as $R = \log(1 + \rho|H|^2)$ nats/s/Hz where H denotes the random channel gain with a complex Gaussian distribution. Then we can get the distribution function of transmission rate for one link as:

$$F(r) = 1 - exp(-\frac{exp(r) - 1}{\rho}). \tag{7}$$

Time-critical traffic is assumed to arrive stochastically. A packet transmission duration is fixed as $t_p = 50$ time slots and channel contention mechanism for avoiding collisions is integrated with channel probing. If in one time slot there is only one link who performs the channel probing, it not only probes the channel information, but also successfully contends the channel. A transmission may be carried on in the following time slot by this link.

5.2 Results and Analysis

First, we examine the TEOS algorithm. It is of great importance that this algorithm can achieve the convergence point for an applicable solution set. A test is carried in our simulator with randomly generated requirements, and the results can be found in Fig.4.

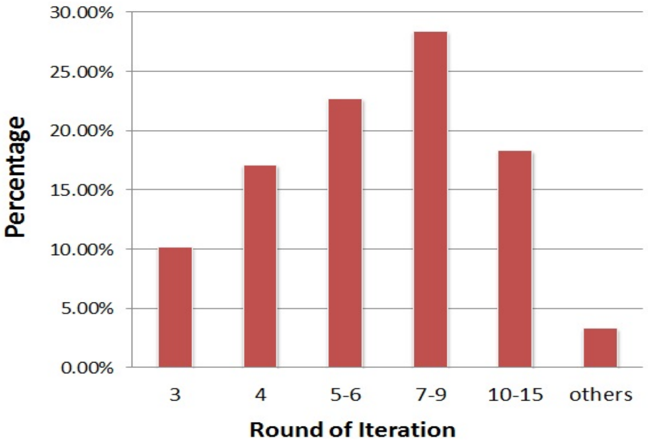

Fig. 4. Rounds of Iteration under Randomly Generated Conditions

Obviously, on most of time, the solution set can be harvested within 15 rounds of iteration, which guarantees that even in application scenarios we can apply this algorithm.

Then we examine the influence of channel probing probability. If the requirement is fixed as $0.5Nats/s/Hz$, the threshold in TEOS can be different if we change the channel probing probability of NTC traffic. In Fig.5, we show the threshold value for different traffic load. It is easy to find out that the thresholds become smaller and smaller due to the fact that channel is less occupied. A further simulation result of channel occupancy ratio under different channel probing probability is shown in Fig.6. Obviously, it is possible to achieve better delay performance for TC traffic under less busy channel condition.

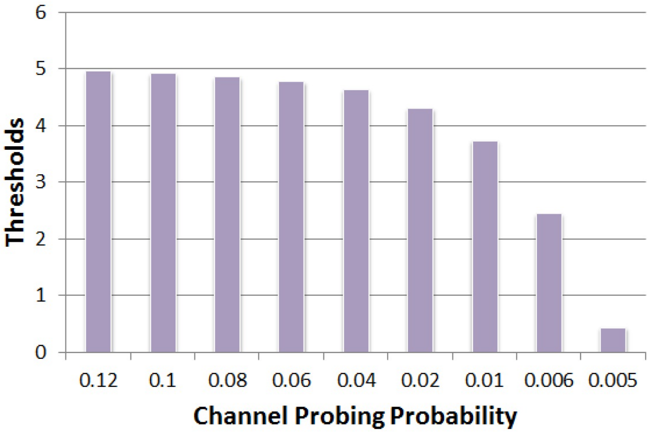

Fig. 5. Threshold under Different Channel Probing Probability

In Table 1, an improvement of delay performance with TEOS is presented. A two-link network is used in this simulation. Similar to the derivation above, the channel probing probability of NTC packets increases from 0.05 to 0.5, which represents the busyness of the network. When TEOS is used in the system, the delay performance of TC traffic can be

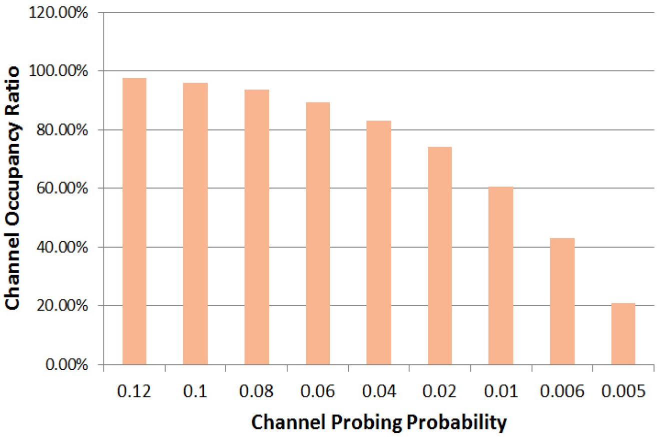

Fig. 6. Channel Occupancy Ratio under Different Channel Probing Probability

guaranteed, for the channel is spared for them. The column of "time slots spared" shows the percentage of time slots saved by TEOS (larger threshold leads to less time slots used for transmission). Thus, delay performance can be improved.

Table 1. Delay Performance Condition under Different Channel Contention Probability

p_i	0.05	0.1	0.15	0.2	0.25
Time Slots Spared(%)	33.28	35.85	36.88	37.41	37.7
Delay Performance Improved(%)	9.44	10.6	11.06	11.29	11.41
p_i	0.3	0.35	0.4	0.45	0.5
Time Slots Spared(%)	37.83	37.85	37.77	37.6	37.34
Delay Performance Improved(%)	11.47	11.48	11.44	11.37	11.26

6 Conclusion and Perspectives

Opportunistic scheduling is considered as one of the best approaches in exploiting channel uncertainties. It is a good choice in solving wireless ad-hoc network performance problem. In this paper, we thrusted into the functionality of opportunistic scheduling and we designed a protocol for Vehicular Ad hoc Networks to improve QoS performance. To be more specific, we studied a multiple threshold policy derived from TEOS and applied to VANET in order to guarantee delay performance for time-critical traffic without degrading non-time-critical traffic. Numerical analysis has proved our solution efficient.

The work included in this paper is a solution to an important QoS problem in VANET. However, it is only a single point in VANET QoS. There are two more steps of research waiting to be carried out in our future research. First, other QoS problems in VANET, e.g., packet loss probability and capacity, also have to be tackled. Secondly, a total solution which covers all the QoS issues has to be designed based on the results of all first-step researches, including this paper. Our research group has already started several researches on these subjects.

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