Predictive Time Division Transmission Algorithm for Segmented Caching in Vehicular Networks

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Abstract. With the increasing number of different types of applications for road safety and entertainment, it demands more flexible solutions for caching and transmitting large files in vehicular networks. In order to decrease the transmission delay and raise the hit ratio of cached files, there is already a lot of research on caching technology, including segmented caching technology. But the problem of long transmission delay and low successful transmission ratio caused by the high dynamic of vehicles still needs to be solved. In this paper, we proposed an algorithm named Predictive Time Division Transmission (PTDT) to reduce transmission delay and raise the ratio of successful transmission for segmented cached file in vehicular networks. Our algorithm predicts the link duration between requesting vehicle and neighboring vehicles according to the relative inter-vehicle distances and velocities. By predicting the transmit rate of each vehicle on different time point, we divide the link duration into slices for subsequent transmitter selections. And finally we compare those time points and select the vehicles that make the transmitting delay the lowest. In the mean time, we arrange the transmitting order of those vehicles to guarantee the success of full file transmission process. The simulation results show that after applying our algorithm, transmission delay has reduced and successful transmission rate has increased substantially.

Keywords: Vehicular networks · Segment caching · Transmission delay · Successful transmission ratio

1 Introduction

With the development of vehicular networks and the increasing demands for many applications that require data of big size, caching technologies and transmission schemes are attracting more and more attentions. There are two types

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of communication systems in vehicular networks, which are Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I). In V2I communication, the limited storage of road side units (RSUs) and the great expenses of building them impel the emerge of distributed caching technology. In order to achieve better performance, there have been a lot of research on V2V caching technology [3–5]. To raise the hit ratio of cached files, and make the best of the storage at the same time, a method named segmented caching appeared. By applying this technology, a file is divided into pieces, the pieces of a file are distributed over multiple vehicles to be cached and forwarded to the requesting vehicle [6]. However, for the transmission of segmented file, due to the highly dynamic of vehicles, long transmission delay caused by big relative velocity, and high probability of transmission failure caused by connection break are still two problems that need to be solved.

There are many researches on how to maximize throughput and minimize transmission delay in vehicular networks. Basing on [7], an architecture which improves the throughput and resolve the problem of increasing traffic by using clustering technology in D2D links, [8,9] proposed an algorithm named CSVD which divides files into pieces and file pieces are cached at multiple SMs, selected UEs in each cluster are used for caching to reduce inter-cluster interference. And to maximize total throughput, [10] proposed a cooperative downloading strategy which utilizes both V2I and V2V communication. To minimize the transmission delay, [11] proposed a scheme which automatically choose the most appropriate mobility information when deciding next data-relays. But some thorough research on the above mentioned problems is still required.

In this paper, we focus on reducing transmission delay and raising successful transmission ratio for segmented cached files in vehicular networks. Since a requested file is divided into pieces and cached in different vehicles, the vehicles which are to be chosen as transmitters and the order of them to start transmitting matter a lot. Due to the highly dynamic of vehicles, connection break between vehicles happens all the time, if a vehicle starts transmitting file without analysing the ability of success, there is a big chance that the connection would break during the process of transmitting. And even though the transmitting process succeed, without analysing the delay each vehicle needs, the delay would be too long. And a big part of the transmission delay comes from the process of collecting data from all the vehicles in the communication range of the control center repeatedly.

To solve the two problems mentioned above, we proposed an algorithm named Predictive Time Division Transmission (PTDT). Our algorithm predicts the link duration between requesting vehicle and other vehicles, by using the relative inter-vehicle distances and velocities. Then analyse the probability of successful transmission to avoid transmission failure. By predicting the transmit rate of each vehicle on different time point, we divide the link duration into slices for subsequent transmitter selections. And we select vehicles with lowest transmission delay, at the same time arrange the transmitting order of those vehicles to ensure successful transmission.

The rest of this paper is organized as follows, In Sect. 2, we provide the system model we use. In Sect. 3, we present the proposed algorithm. In Sect. 4, The Simulation scenarios and results are present. The conclusions are stated in Sect. 5.

2 System Model

The communication scenario is considered as in a two-way street which is within the communication range of a base-station in an urban setting, and we assume there is no congestion, the velocity of each vehicle is not affected by other vehicles.

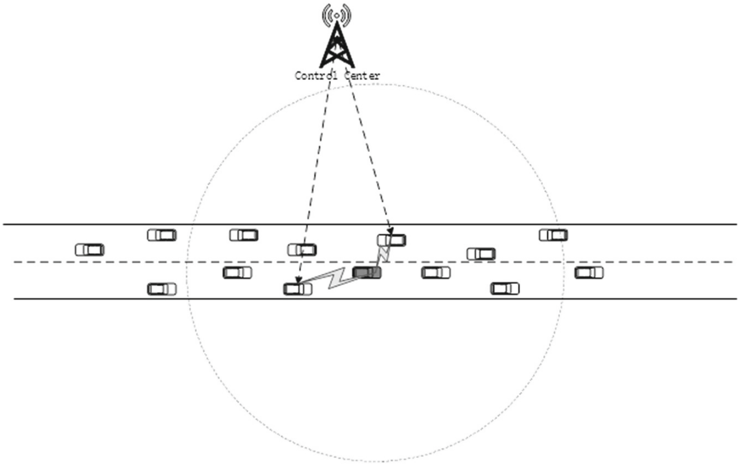

Fig. 1. Communication scenario

Consider the communication channel between vehicles as small-scale fading channel, The signal to noise ratio at the receiver node is denoted by $\frac{Z^2\beta\cdot P_t}{r^\alpha\cdot P_{noise}}$, where r is the distance between transmitter and receiver, Z is the fading coefficient, β is a constant associated with path loss model, P_t is the transmit power, α is the path loss exponent, and P_{noise} is the total additive noise power [1]. Here $\beta = \frac{G_T G_R \lambda^2}{2\pi {d_0}^2}$, where G_T and G_R are the gain of transmitter and receiver antennas, we assume all the antennas of vehicles are omni directional, so that $G_T = G_R = 1$. The total addictive noise power is P_{noise}, given by $P_{noise} = F k_B T_0 r_b$, where F is the receiver noise figure, $k_B = 1.38 \cdot 10^{23} J/K$ is the Boltzmann constant, T_0 is the room temperature, $T_0 = 300K$ and r_b is the data transmission rate [2]. Assuming that $E[Z^2] = 1$, the average SNR can be written as

$$\Upsilon = \frac{\beta \cdot P_t}{r^\alpha \cdot P_{noise}} \tag{1}$$

As for communication range, we assume a transmitting process would success only if the signal to noise ratio (SNR) at the receiver node is above a specific threshold Υ during the process. Thus the communication range can be given by

$$r = \sqrt[\alpha]{\frac{\Upsilon \cdot P_{noise}}{\beta \cdot P_t}} \tag{2}$$

And for transmit rate, according to Shannon's equation, the maximum transmit rate can be denoted as the channel capacity, which is $R_{max} = B \cdot \log_2(1 + \Upsilon)$, where B is the bandwidth of the communication channel. Using Eq. 1 the transmit rate can be given by

$$R = B \cdot \log_2(1 + \frac{\beta \cdot P_t}{r^\alpha \cdot P_{noise}}) \tag{3}$$

We assume the files are segmented into many pieces, and each vehicle can cache any pieces of any files if it has enough space. And a vehicle can communicate with any vehicles in its communication range.

3 Proposed Algorithm

Our algorithm first group vehicles by the file pieces, and predict the link duration between requesting vehicle and other vehicles using the relative velocity and SNR threshold. Then we divided the link durations into different slices according to the inter-vehicle distance (to get the transmission rate at that distance) and the size of file pieces, each slice represent the delay of transmitting the file piece for one time. The link duration which has been divided into slices called time scale. Then according to the time scale, we select one vehicle in each group as the transmitter of each file piece. The main goals of our algorithm are reducing transmission delay of segmented file by selecting the most suitable vehicles as transmitter and increasing the successful transmission ratio by arranging the order of each transmitter we selected.

3.1 Grouping

When a requesting vehicle sends request to the control center, the control center first collects parameters of all the vehicles in its communication range R, including position, velocity, transmit power, the index of file piece it has. First our algorithm will eliminate those vehicles which don't have any piece of the requested file cached, then analyse the ability of vehicles for successfully transmitting file piece at least once. The ability is determined by comparing the maximum time needed for transmitting the piece and the maximum link duration, the maximum time needed for transmitting is calculated by suing the minimum transmitting rate which we assume to be $6 * 10^6 b/s$, the maximum link duration is calculated by using SNR threshold Υ and Eq. 2. Vehicles that cached the same file piece and are able to successfully transmit file piece will be grouped together. Every group has five parameters, which are index of vehicles that have the same file piece, the relative velocity of its members to the requesting vehicle, the distance of its members to the requesting vehicle at the starting point, the maximum transmitting round and max waiting time.

3.2 Transmitting Round Calculation

Every vehicle in the group has a link duration T according to the starting distance to the requesting vehicle and the SNR threshold, and a required transmitting time T_t at any distance to the requesting vehicle. By using T_t we can divide T into many slices, the process is as follows:

At any time point t_0 in the time scale of any vehicle we have the distance d_0 between this vehicle and the requesting vehicle, so that using Eq. 1 we get the required transmitting time Tt_0, Tt_0 means if this vehicle starts transmitting file at time point t_0, how long it will take for this vehicle to finish transmitting the file piece. Then move to the next time point which is $t_1 = t_0 + Tt_0$, using relative velocity of this vehicle to the requesting vehicle we get the inter-vehicle distance at t_1, then start the above process again till the time point moves to the end of link duration. Thus we'll have many points which represent the time point where vehicle could finish transmitting the file piece if it start transmitting at the time point ahead of this time point. We assume a vehicle would only start transmitting file at any of the points we calculated, this link duration with time points is called time scale, every vehicle has a time scale for the process of our algorithm. The point of dividing T into slices is that we want to choose the vehicle which has the lowest delay in every group to transmit file piece without calculating every time. Because in each round, it's not clear which vehicle will be chosen to transmit file piece, it is not clear what time it will finish transmitting, but the transmit rate of each vehicle is related to the distance to the requesting vehicle, which means if we don't divide T into slices and specify the transmit time point, every time a vehicle is chosen, we'll have to calculate the transmit delay of other vehicles according to the time that the chosen vehicle finishes transmitting.

3.3 Maximum Waiting Time

After grouping and calculating the time points of all vehicles, we now have the maximum waiting time. The maximum waiting time is determined by the vehicle which has the longest link duration in a group, and the maximum waiting time of this group is the last time point of that vehicle. The meaning of this is when the process is about to reach the maximum waiting time, if none of the vehicles in this group has ever been chosen to transmit file piece, we have to pick one vehicle in this group to transmit file piece otherwise we'll miss the chance of transmitting this file piece.

3.4 Algorithm Flow

Suppose the requested file is divided into M pieces, so there are M groups of vehicles, vehicles in the same group has the same file piece cached. The total transmitting delay is denoted as t and the transmitting round is denoted as R, at the beginning $t = 0$, $R = 1$, all the vehicles are in the left vehicle queue, assuming vehicle p is the one that has the lowest transmit delay in round 1, then vehicle p is chosen to be the first vehicle to transmit file piece. Then we move the transmit delay t to the finishing time point of vehicle p. Then those vehicles in the same group would be eliminated from the left vehicle queue. After first round, time delay t moves to t_{p1}, and the next choosing round starts. Now our algorithm needs to pick the vehicle which has the lowest transmitting delay in the second round, which should be the vehicle whose second time point behind t_{p1} is the earliest if t_{p1} is not about to reach any of the maximum waiting time of any group. The number of picking round is supposed to be the same as the number of file pieces, which means every piece of the file should only be transmit by one vehicle. Once there is no vehicle left in the left vehicle queue, we need to check if the number of the vehicles we picked is the same as the number of groups, and the vehicles we picked are in deferent groups. If not, we consider this process a failure, and set the time delay of using our algorithm as infinite, but as the experiment result shows this situation is rare to arise. The algorithm flow is shown in Algorithm 1.

Algorithm 1 Predictive Time Divided Transmission

```
Input: $M$: the number of file pieces; $t$: total transmission delay; $timeScale$: timescale
    of all the vehicles; $R = 1$: current picking round; $maxWait$: the maximum waiting
    time of all groups;
Output: $t$
while $(R \leq M) and (t \neq Inf)$ do
    if the row number of $timeScale$ is zero then
        $t = Inf$ return
    end if
    if $R = 1$ then
        find the minimum time point $t_1$ behind 0 in all $timescale[i]$.
        $t \leftarrow t_1$.
    else
        if $maxWait[i]$ close to $t$ then
            find the minimum second time point $t_R$ behind $t$ in $timescale$ that belong
    to those vehicles in group $i$.
        else
            find the minimum second time point $t_R$ behind $t$ in all $timescale[i]$.
        end if
        $t \leftarrow t_R$.
    end if
    $R = R + 1$.
    eliminate rows which belong to vehicles in the same group with the one just
    picked from $timescale$.
end while
```

4 Simulation Results and Discussions

In this section, we conducted simulations to see the performance of our algorithm, we compared the delays to transmit files of different sizes and the successful transmit ratios after applying our algorithm.

4.1 Simulation Setup

We implemented the algorithm in MATLAB. The parameters are shown in Table 1. For the control center, the communication range is set as 2 km, which means it collects data in this area every time it choose a vehicles as transmitter for a piece of file. And the size of file piece is set as 5 Mb, we assume every piece of file has the same size for convenient application. And to make sure that the numbers of vehicles which have the same piece of file would not influence the simulation results, in different situation(applied our algorithm and without algorithm), the numbers of vehicles with the same file pieces in the communication range of requesting vehicle are the same. The range of velocity is set as $[-20\,\mathrm{m/s}, 20\,\mathrm{m/s}]$.

4.2 Simulation Results

Average Reduction in Transmission Delay The average transmission delays and average reduction in transmission delays of transmitting a file which is segmented into four pieces are shown in Figs. 2, 3, 4. As shown in the figures, after applying our algorithm the average transmission delay has dropped in all situations. The main reason is that when using our algorithm the control center only needs to collect data from all the vehicles in its communication range once, but without our algorithm, if a vehicle requests a specific file, every time before transmitting a piece of the file, the control center needs to collect data from other vehicles and choose one to be the transmitter. If the density of vehicles in its communication range is high, the time of collecting data would make a big difference. Our algorithm avoids this repeating collections by predicting the relative distance between vehicles that have the file pieces cached and the requesting vehicle at the beginning.

Performance Under Different Path Loss Exponent Figure 5 shows the average transmission delays under different path loss exponent. As shown in the figure, with the increasing of path loss exponent, the average transmission delays under our algorithm is getting lower. When the path loss exponent increases, the communication range of vehicles under the same SNR threshold gets smaller, which means the link durations between vehicles will get shorter. And in order to ensure that the number of vehicles which cached the file pieces we need is the same in two different situation, when communication range gets smaller, the density of vehicles gets higher, which makes the collecting time of control center longer (transmitting delays bigger).

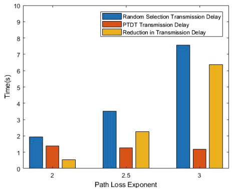

Fig. 2. Reduction in transmission delays under different path loss exponent

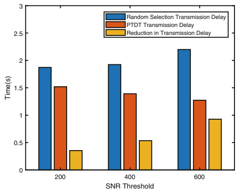

Fig. 3. Reduction in transmission delays under different SNR threshold

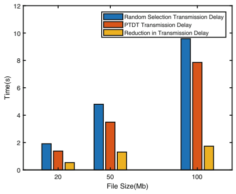

Fig. 4. Reduction in transmission delays under different file size

Figure 6 shows the average successful transmission ratios under different path loss exponent. As shown in the figure, after applying our algorithm, the average successful transmission ratio has increased to around 99%. That is because before we select the vehicles with different file pieces as transmitters, we first analyse the ability of those vehicles to finish transmitting file pieces to ensure successful transmission. With the increasing of path loss exponent, the communication range of vehicles under the same SNR threshold gets smaller, so that the probability of the connection break gets higher.

Table 1. Simulation parameters

Parameter	Value
Control center coverage range (m)	2000
Vehicle transmission power P_t (mw)	100
Vehicle speed v (m/s)	[–20, 20]
Channel bandwidth B_w (MHz)	10
File piece length Q (mB)	5

Performance Under Different File Size Figure 7 shows the average transmission delays of transmitting files with different sizes. As shown in the picture, with the increase of file size, the average transmission delays increase no matter with or without our algorithm. Reason is obvious, with the file size gets bigger, the time for transmitting it increases. But still the average transmission delays after applying our algorithm is lower than not using algorithm.

Figure 8 shows the average successful transmission ratios under different file sizes. As shown in the figure, after using our algorithm, the average hit ratio stays flat and nearly reach 100%. The reason is when the file size increases, the number of pieces increases too, which means the probability of select a vehicle

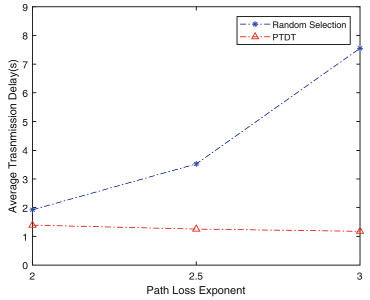

Fig. 5. Transmission delays under different path loss exponent

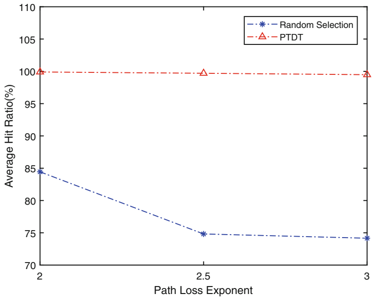

Fig. 6. Successful transmission ratios under different path loss exponent

whose link duration is not long enough to finish transmitting the piece of file gets higher, but this situation is considered fully in our algorithm.

Performance Under Different SNR Threshold Figure 9 shows the average transmission delays under different SNR threshold. As shown in the picture, with the increase of SNR threshold, the average transmission delays is getting lower after applying our algorithm, but is getting higher without the algorithm. The reason is when SNR threshold gets higher, the communication range of vehicles gets smaller, to ensure the numbers of vehicles with different file pieces stay the same, the density of vehicles gets higher, so the collection time of the control center gets higher.

Figure 10 shows the average successful transmission ratios under different SNR threshold. As shown in the figure, after applying our algorithm, the average successful transmission ratio stays close to 100%. Even though the SNR threshold influences the communication range of vehicles, as mentioned before, our algorithm has considered the link duration of any vehicles it chooses, so the average successful transmission ratio would not be influenced.

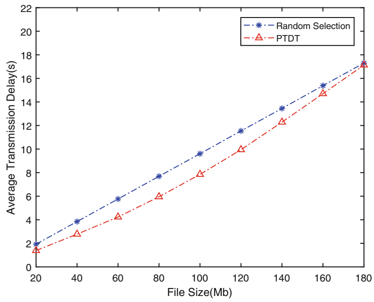

Fig. 7. Transmission delays under different SNR threshold

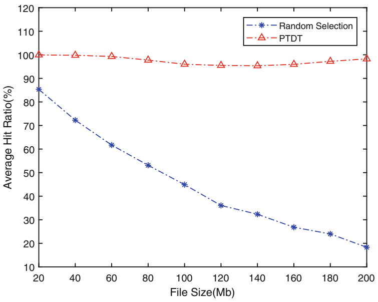

Fig. 8. Successful transmission ratios under different SNR threshold

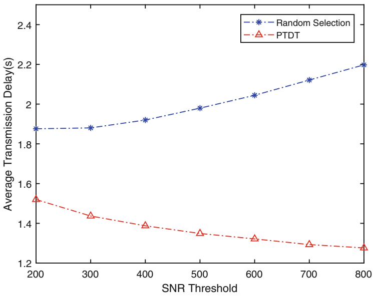

Fig. 9. Transmission delays under different file size

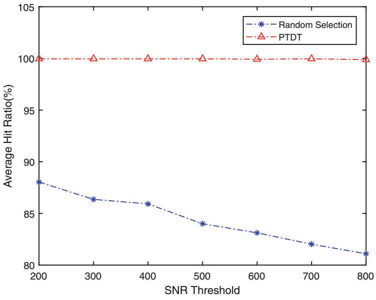

Fig. 10. Successful transmission ratios under different file size

5 Conclusion

In this paper, we proposed an algorithm named Predictive Time Divided Transmission (PTDT) for reducing the transmission delay and increasing the successful transmission ratio of segmented cached file in distributed vehicular networks. We predict the link duration of vehicles and divide it into time slices, the size of time slices are determined by the predicted inter-vehicle distance at the starting point of the time slice. Using those time slices of each vehicle, we analyse the ability of those vehicles for transmitting file pieces successfully, then select vehicles and arrange the transmit order of them, to ensure successful transmission and make the total delay the lowest. Simulation results show that our algorithm strongly improves the performance of transmission for segmented cached file in vehicular networks.

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