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A Video Transmission Scheme in Wireless Cellular Networks

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Abstract

For the problem of long video transmission delay and low network efficiency caused by high energy consumption, a Dynamic Programming & Markov Decision Processes (DP-MDP) video transmission scheme is proposed. This scheme takes advantage of that the user instant request is independent to the past states. We combine the DP algorithm with MDP to solve relative problem in the user request process, therefore, we can significantly reduce the server and backbone network transmission loss of hot video, and also improve the network efficiency. The theoretical analysis and derivation based on DP algorithm are conducted to the entire transmission process, then we establish the analytical expression based on DP algorithm. The simulation results show that compare to conventional video transmission, the video transmission program based on the DP-MDP can effectively save total energy and reduce the system transmission delay.

Keywords: *video transmission, wireless cellular networks, energy consumption, transmission delay*

1. Introduction

The Information and Communication Technology(ICT) industry is responsible for 2%-10% of total carbon emission [1]. However in wireless cellular networks, the number of users and the types of business are increasing dramatically, then lead to the increasing of the BSs number. The data show that the energy of BSs is responsible for 80% of total energy [2]. Therefore, it plays an important role that reducing the BSs energy consumption in green mobile communication.

With the emerging of the smart phone and video service, the traditional transmission mode (BS to the user equipment (User Equipment, UE)) energy consumption increasing greatly, and with the increasing of user demands, it is difficult to ensure that the videos can transmit smoothly, in addition, it also has large transmission delay. So we deploy a number of RSs located in BSs and UEs near the edge of network, which are used for receiving, buffering and sending the videos requested by the users.

Domestic and foreign scholars have effectively explored the videos transmission caching mechanism in various applications. In the background of the wireless communication network applications, Subhabrata Sen et al. [3-5] proposed a prefix cache technology. This technology uses the internet proxy to store the initial frame of hot videos without introducing long replay delay. When the agency receives the video requests, he would transmit data frames to the client directly and request remaining frames for the server at the same time. The internet transmission delay can be reduced through this transmission way, and the videos can be ensured to transmission smoothly. In addition, Xie Fei [6] studied the energy consumption of video requests in detail based on the topology of network coverage for the video-on-demand (VOD) services of wireless relay network. These studies mainly include various caching techniques that based on BS caching [7], client caching [8,9] and caching schemes in ad hoc networks [10-12]. Wang Xiaolei of Tsinghua university [13, 14] designed a relay caching mechanism for the cellular network, one or more fixed RSs which can receive and cache multimedia information were installed near the cell edge, when users request a video, the video can be cached into the butter of RSs in order to serve the nearby users with next requests of the same video, rather than the BS transmit the video to the UE directly. This transmission mode can reduce the user demand for BS and mitigate network congestion, also improve the response time of the cache video and the energy efficiency of the cellular network. However, the

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range of serviced users is small in this transmission mode, and the user may wait for a long time while the network congestion occurs.

In this paper, we proposed a controllable delay video transmission scheme based on DP-MDP strategy. For the problem of long video transmission delay and low network efficiency caused by high energy consumption in the wireless cellular network, this scheme take advantage of feature that the user instant request is independent to the past states, then combine the DP algorithm with MDP to resolve related problem of the user request process, therefore it can significantly reduce the server and backbone network transmission loss of hot video, then improve the network efficiency.

2. System Model and Transmission Model

We consider a single cellular system with one BS and four RSs as our research object, the system model is shown in Figure 1. The distances between the BS and RSs are roughly equal, and each RS cover with the same radius, set to r, the users are assumed to be uniformly distributed in the cell and independent to each other. We assume that two users request for the same video in a cell and the RSs have enough space to store the videos, the transmission model is shown in Figure 2.

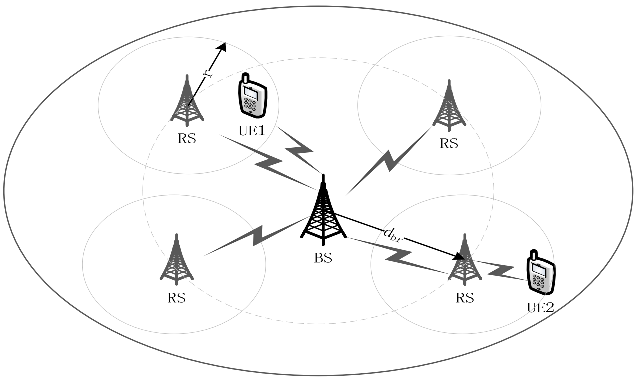

Figure 1. System Model

If the channel of transmission is slow fading channel, $W_{\max}$ denotes the maximum bandwidth that the system can provide, the mean value and variance of channel noise is 0 and 1, which is Gaussian noise. R_c denotes the transmission rate of channel. We assume that videos are of the same size, and a video has *N* frames.

We define *i-th* frame as a cut-off point, the frame before *i-th* frame is prefix, the size of prefix should be able to tolerate the condition that once round-trip delay at least, the frame after *i-th* frame is suffix. $Data_i$ denotes the data amount of *i-th* frame, and T_v denotes video playback time of each frame, transmission time of each frame video signal is:

$$\begin{aligned} & t_i = \frac{Data_i}{R_c} \\ s.t. \quad & R_c \le R_s \\ & R_s = W_{\max} \log_2 \left(1 + \frac{\eta P}{d^{\gamma}} \right) \end{aligned} \tag{1}$$

Where R_s denotes limit rate of system and meet the Shannon formula, $\eta = \frac{G}{N_o}$, N_o is noise, *G* is the antenna gain between BS or RS to UE; *P* is the transmission power; γ is the path loss exponent, d denotes the distance between BS to UE and RS, or RS to UE.

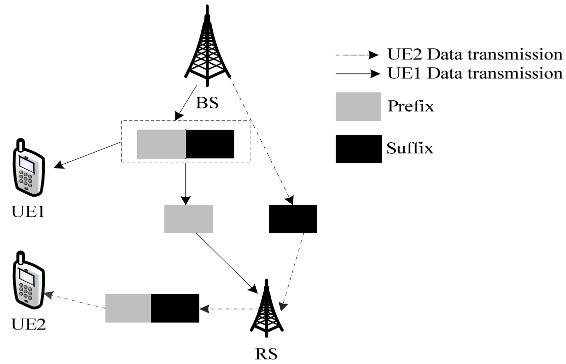

Figure 2. Transmission Model

The transmission delay of system is the difference of the transmission time of video signal and the time of play:

$$\tau = \sum_{i=1}^{N} t_i - NT_v = \sum_{i=1}^{N} \frac{Data_i}{R_c} - NT_v \tag{2}$$

From the above equation, R_c is the maximum, the transmission delay of system is minimum, at this time, the actual transmission rate of the channel is:

$$R = \arg\min\left(R_s - R_c\right) \tag{3}$$

The minimum transmission delay of system:

$$\tau_{\min} = \sum_{i=1}^{N} \frac{Data_i}{R} - NT_v \tag{4}$$

3. The Proposed DP-MDP Algorithm

Since the current user's requests are unrelated with past status and information of the user, and all the requests are independent of each other, the MDP can be combined with the DP algorithm to solve the related problems in the process of user requests.

The probability of each video being requested is known, and we do not consider the situation that the user must wait in line when BS and RSs in the state of full load. We assume that the distance is same between BS and RSs, each RS can buffer m prefixes of video at most. When the *k-th* request of UE arrives, the buffer status of RSs can be expressed as:

$$A_k = \left\{a^{(i)}\right\}_{i=1}^{k} \qquad \text{Prefix } a \in \text{Cache space} \tag{5}$$

The space of buffer states:

$$\mathbf{A} = A_1 \times A_2 \times \ldots \times A_k \times \ldots \times A_m \tag{6}$$

We set an appropriate directory of requests for each video prefix in buffer space, and update the directory after each request.

The set of *k* requests number:

$$\begin{aligned} &I = \left\{i_j \,\middle|\, j = 1, 2, \ldots, k\right\} \\ &s.t.\;\; i_s < i_j \quad s = 1, 2, \ldots, k \\ &\quad\;\; i_s \in I \end{aligned} \tag{7}$$

If there is a new video request New_k which does not exist in the buffer space after the k-th request, the RSs would buffer the New_k prefix in the status A_{k+1}. If there have already been m videos in buffer space of RSs before inserting the new prefix, the lowest request times of prefix in A_k would be discarded. The equation of state transition is:

$$A_k \rightarrow A_{k+1} = g\left\{A_k, New_k\right\} \tag{8}$$

Without considering the video transmission when network congestion exists, there is a new video request New_k , the system in the A_k state should meet the blocking conditions:

$$P_{bl}\left(A_k\right) = P_r\left(\mathrm{I}_{W_{New_k}<\infty}(W_{New_k} + \sum_{i=1}^{k} W_{A_i} > W_{\max})\right) \quad s.t.\ \ P_{bl}\left(A_k\right) \le P_{th} \tag{9}$$

Where W_{New_k} denotes the required bandwidth of the new video requests, $W_{A_i}\left(i = 1,...,k\right)$ is the bandwidth in the A_i state, P_{th} is the blocking threshold which is known. If the blocking probability in the A_k status beyond the blocking threshold, network congestion would occurs.

There are two communication patterns in this paper: the unicast-based communication from BS or RSs to the UE; the multicast communication from BS to the UE or RSs. The large-scale path-loss model of the two different communication modes as follows:

(1) Unicast:

$$L_1\left(d\right) = K_1 \gamma \log_{10} d + C_d \tag{10}$$

Where d denotes the distance between BS or RSs to UE location d_{bu} or d_{ru} , K_1 is a constant coefficient which depend on the antenna characteristics and the average channel loss, γ is the path loss exponent, C_d is the constant coefficient which independent of the distance in the unicast communication.

(2) Multicast:

$$L_2\left(d_{bu}, d_{br}\right) = K_2 \gamma \max\left\{\log_{10} d_{bu}, \log_{10} d_{br}\right\} + K_3 \gamma \log_{10} d_{bu} + K_4 \gamma \log_{10} d_{br} + C_d^{'} \tag{11}$$

Where d_{br} denotes the distance between BS and RSs, K_2, K_3, K_4 denote the constant coefficients with this channel condition, $C_d^{'}$ is the constant coefficients which are independent to the distance in the multicast communication.

The coverage radius of RS is *r*, if the UE within the coverage of the RSs, $d_{ru} \le r$, and then we assume that the V_k denotes the *k-th* requested video, there are two possible transmission paths: □ multicast route from BS to RS and UE is T_{bru} ; □ unicast route from BS to RS and RS to the UE is $T_{br,ru}$.

Two transmission paths can be expressed as:

$$F_1 = \left\{T_{bru}, T_{br,ru}\right\} \tag{12}$$

If the UE is not within the coverage area of RSs, then $d_{ru} > r$:

$$F_2 = \left\{T_{bru}\right\} \tag{13}$$

The space of objective decision:

$$\mathbf{F} = F_1 \times F_2 \tag{14}$$

The transmission energy consumption of the video V_k at the time of *t*:

$$L_k(t) = \begin{cases} L_2(d_{bu}, d_{br}, t), & \text{若} V_k = T_{bru} \\ L_2(d_{br}, t) + L_1(d_{ru}, t), & \text{若} V_k = T_{br,ru} \end{cases} \tag{15}$$

V_k is the function of variables $A_k, New_k, d_{bu}, d_{ru}, d_{br}$ in the *k-th* request, it can be expressed as:

$$V_k = D_k(A_k, New_k, d_{bu}, d_{ru}, d_{br}, t) \tag{16}$$

$\boldsymbol{\mu}$ denotes the space of all decision-making factor:

$$\boldsymbol{\mu} = D_1 \times D_2 \times D_3 \times, ..., \times D_k \times, ..., \times D_n \tag{17}$$

Within a period of time *T*, the total energy consumption of n requests can be expressed as:

$$P = \int_0^T \sum_{k=1}^{n} L_k(t) dt \tag{18}$$

$L_k(t)$ denotes the transmission energy consumption of video V_k at the time of *t*.

In the A_k state, the higher the requested times i_j $(j = 1, 2, ..., k)$ of the video in the buffer space of RSs, the higher the popularity of the video. The larger the high popularity of videos in RSs buffer space, the greater the energy savings. If the number of requests is the maximum $\max\{i_j\}(j = 1, 2, ..., k)$, we call this buffer state is the best state, denote as A_k^*.

The cost function for the state A_k:

$$\begin{aligned} & J^*(A_k) = \min\{E[L_k(V_k, d_{bu}, d_{ru}, d_{br})]\} + J^*(A_{k+1}) \\ & s.t. \; J^*(A_k) \geq J^*(A_k^*) \end{aligned} \tag{19}$$

Where $J^*(A_k^*)$ denotes the cost function of best state A_k^*.

DP-MDP algorithm can be described as:

$$\begin{aligned} & \min \int_0^T \sum_{k=1}^{n} L_k(t) dt \\ & s.t. \;\; V_k = D_k(A_k, New_k, d_{bu}, d_{ru}, d_{br}, t) \\ & \qquad V_k \in \mathbf{F} \\ & \qquad \boldsymbol{\mu} = D_1 \times D_2 \times D_3 \times, ..., \times D_k \times, ..., \times D_n \\ & \qquad A_{k+1} = \begin{cases} g(A_k, New_k) & V_k = T_{bru} \\ A_k & otherwise \end{cases} \\ & \qquad P_r\left(\operatorname*{I}_{W_{New_k} < \infty} (W_{New_k} + \sum_{i=1}^{k} W_{A_i} > W_{\max}) \right) \leq P_{th} \end{aligned} \tag{20}$$

4. Results and Analysis

As shown in Figure 1, the study object in this paper is a single cellular system with one BS and four RSs. The system transmission channel is an independent and i.i.d. slow fading channel, the mean value and variance of channel noise are 0 and 1, which is Gaussian noise. Assume that the radius of the cell is 10, the radius of each RS is 3, users in the BS coverage area are evenly distributed. If there are 15 videos with different request times, assume that each RS can cache 10 prefix of video at most, $m = 10$. The path loss exponent $\gamma = 2$, the number of users request $n = 100$, the length of fram $N = 30ms$, the bandwidth of system $B = 300kHz$.

With increasing of the video requests, the buffer space of RSs reaches saturation gradually, when $m = 10$, the upper limit of buffer space, if a new request arrives, the video prefix of minimum requests would be discarded at the previous state before the RSs to cache new video prefix, when $m > 10$, the curve of cache remain stable near the upper limit. It is shown in Figure 3.

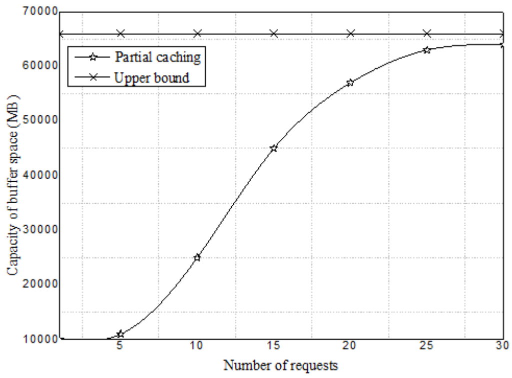

Figure 3. Change of Buffer Space

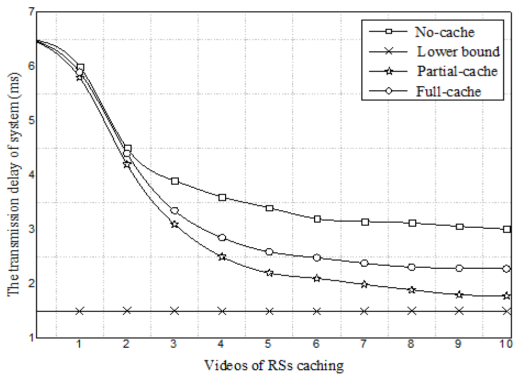

Figure 4. Transmission Delay of System

In the conventional transmission mode the BS transmit the requested video to UE directly when the UE requests a video; Wang Xiaolei of Tsinghua university [13] deployed that one or more RSs which can receive and buffer multimedia message are fixed near the cell edge, the BS transmits the requested video to the UE while transmit to the RSs, the RSs receive and cache the entire video; In this paper, we proposed the RSs only cache the prefix of the video based on the literature [13], it transmits the cached prefix to the UE while requests BS for the rest of the video. For simplicity, this transmission is called as RSs partial-cache mode, the transmission of traditional and the literature [13] are called no-cache and full-cache mode respectively. The transmission delay and energy consumption of system are compared under three different transmission modes, as shown in Figure 4 and Figure 5.

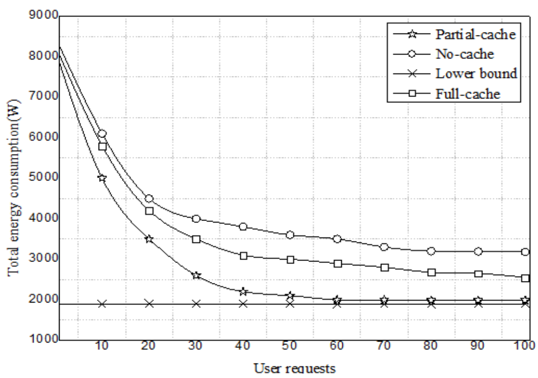

Figure 6. Transmission Energy Consumption

As shown in Figure 4, when the number of RSs cached video is small, the transmission delay of three transmission types are similar, however, with the number of RSs cached video increasing, the transmission delay of RSs partial-cache is significantly less than the no-cache and full-cache, and gradually approaching the lower bound of delay (that is the delay when the channel's actual transfer rate corresponding to the theoretical maximum). When the UE has the same requests, the video prefix in the RSs cache space can be directly transmitted to the UE. Therefore, when the number of videos in the RSs cache space increase, the species of cached video increase, the range of users that can be served also increases. In full-cache pattern the entire video is cached, so the types of video can be buffered are fewer under the same condition of the RSs' capacity. In addition, the network edge users are far from the BS, so the transmission energy consumption of BS transmission to the edge of the users is larger in no-cache pattern. In partial-cache the RSs are usually arranged near the edge of the network to cover most of the edge users, at the same time the RSs undertake most of the transmission tasks to reduce the burden of BS transmission effectively, therefore, as shown in Figure 5, the energy consumption of the partial-cache is smallest, and with the increasing of user requests, it would be more close to the lower bound of energy (that is the energy expectation in ideal buffer state).

5. Conclusion

In this paper, the theoretical derivation and analysis of the whole transmission are carried based on DP-MDP algorithm. According to the three factors, the short-term traffic flow of actual network, the properties of nodes and the high probability of data, we conduct a detail analysis to the data transmission process and the DP-MDP algorithm analytical expression, we also discuss the problems of network congestion. Simulation results show that the transmission scheme based on DP-MDP is different from the conventional and full-cache modes. It can effectively reduce the transmission delay of videos and energy consumption of network while meeting the customer service quality, and then improve the efficiency of entire network.

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