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High Quality Multimedia Content Sharing Based on Network Coding Over Multiuser Cognitive Networks

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Abstract

According to the recently published report by the Federal Communications Commission, the spectrum regulatory authority in the United States, traffic distribution across the radio spectrum is extremely uneven. The phenomenon can be utilized to improve the multimedia content sharing. This paper proposes a novel model of multimedia sharing in wireless communication networks. The proposed multimedia sharing mechanism offer services to users who want to access the multimedia networks. At the same time, it does not affect the QoS of existing paying users. The numerical results show that the proposed sharing mechanism provides higher throughput and quality of service than the existing system.

***Keywords**: multimedia content sharing, QoS, continuous time Markov chain, failing probabilities*

1. Introduction

As a program of entertainment and passing the time, video/audio program is certainly a good choice. Some consumers wish to access the multimedia network freely, that is to say, they want to enjoy without paying (called unlicensed user or non-paying user). Non-paying users can bear program's discontinuity and advertisement's occurring frequently, because they do not pay for it. As the video playing needs waiting for a long time (20 seconds or more), these users would choose to give up these programs, which causes the advertising push and relay transport process to fail. The purpose of this paper is to design a multimedia sharing mechanism, which can make non-paying users enjoy better payment services, at the same time, without affecting the QoS of existing paying users.

Existing spectrum regulation has advantages, for example, it is easy to manage. But there are also disadvantages, for example, spectrum resources cannot meet the needs of users. As the demand for spectrum resource increases rapidly (*e.g.*, [1-3]), there are increasingly more challenges and complications yet ironed out. For example, the application of a large portion of the assigned wireless spectrum is uneven [4], leading to underutilization of a significant amount of spectrum. According to the published report by the Federal Communications Commission (FCC), unlicensed portions of the spectrum (*e.g*. 2.4GHz and 5GHz bands) are heavily occupied by most wireless networks operate (*e.g*. WLAN and WiFi), whereas the licensed portions of the spectrum (*e.g*. TV White Space band) are used sporadically. Hence, dynamic spectrum access (DSA) techniques were proposed to solve these spectrum inefficiency problems in which the non-paying users can exploit unused portions of the licensed spectrum while safeguarding the transmissions of the paying users. The sharing scheme provides the capability to share the wireless spectrum resource with non-paying users in an opportunistic operation. On the one hand, robust CR can effectively suppress interference to nearby licensed users in [5].

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On the other hand, [6] study the interaction between CR and Digital TV. The images are shown on video graphics array monitor in real time [21]. The energy effective MAC protocol is superior in improving throughput and multimedia transmission delay [22]. Video multicast and video conferencing systems in WLAN are studied in [23].

For the non-paying users, the spectrum availability varies as the licensed user's access. This characteristic complicates coordination among the non-paying users during data transmission. In order to cope with the characteristic, non-paying users achieve several important functions. Some aspects have been studied well (*e.g.*, spectrum sensing) [7-15]. However, there are a lot of problems to tackle in sharing.

It is due to the better sharing scheme can improve the User Experience (UE) and network performance greatly, so scholars actively study the correlative technology and many excellent mechanism are emerging in the past ten years. Compared with the optimal model and competitive model, the cooperative model [16] could reach the maximum total profit for unlicensed users with better fairness. A modified 802.11-based opportunistic spectrum access is proposed for single-channel wireless networks where licensed users operate on a slot-by-slot basis. Continuous-time Markov chain was used to developed analytical model and derive the expressions to compute the grade of service performance metrics. Buffering mechanism is proposed for the unlicensed subscriber. Prioritized unlicensed user traffic (*i.e.*, high transmission rate and low transmission rate) is considered [17-21].

Unlike the above works, in this paper, we consider prioritization among the video traffic and text traffic of non-paying users while accessing the licensed spectrum. For example, the unlicensed users with video traffic have higher priority than those with text traffic. Further, text traffic are going to be operated with network coding if there is no enough channel to access. We use continuous-time Markov chain to analyze the model. The performance of the model is evaluated in terms of the general parameters, such as blocking probability of video and text traffic, the termination probability of video and text traffic, and the system throughput including both video traffic and text traffic of non-paying users'.

2. Proposed System Model

The proposed system model shown in Figure 1 consists of a licensed user network and an unlicensed user network. A licensed user network, operating over a given service area, contains a licensed base station and licensed users. Then, an unlicensed user network contains an unlicensed base station and non-paying users. The wireless spectrum is shared by the paying users and non-paying users. The paying users have the highest priority in using the channels. The traffic of non-paying users are classified into two priority classes. The high priority non-paying user are denoted as video traffic user (VU) while the low priority non-paying user are denoted as text traffic user (TU). On one hand, the licensed service area D1 can be extended to D2 by TU1 (*i.e.*, relay link C2). On the other hand, licensed user LU2 obtain better signal quality and higher transmission rate through relay link C3, C4 and C5.

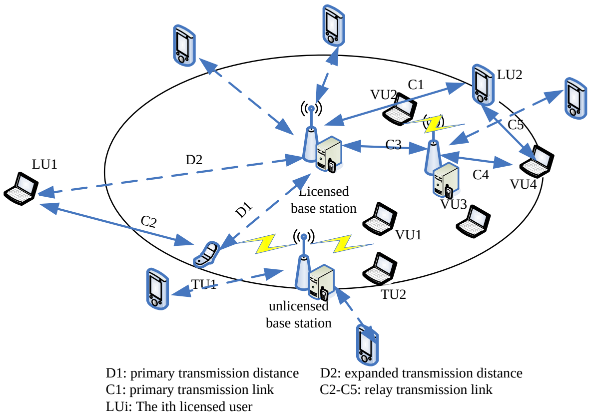

Figure 1. System Model

The system model of proposed sharing mechanism is presented in Figure2, where a higher priority is given to video traffic over text traffic. For non-paying users, text traffic is replaced with video traffic to access channel when only one channel is idle. Both video traffic and text traffic of SU are going to be dropped when all channels are occupied by licensed users. Otherwise, the text traffic of non-paying user can be transmitted by means of coding. A licensed user will be blocked (blocked licensed user traffic) if all wireless resource are occupied by other licensed user. If all channels are busy and a licensed user call arrive, non-paying user will be terminated (terminated non-paying user traffic).

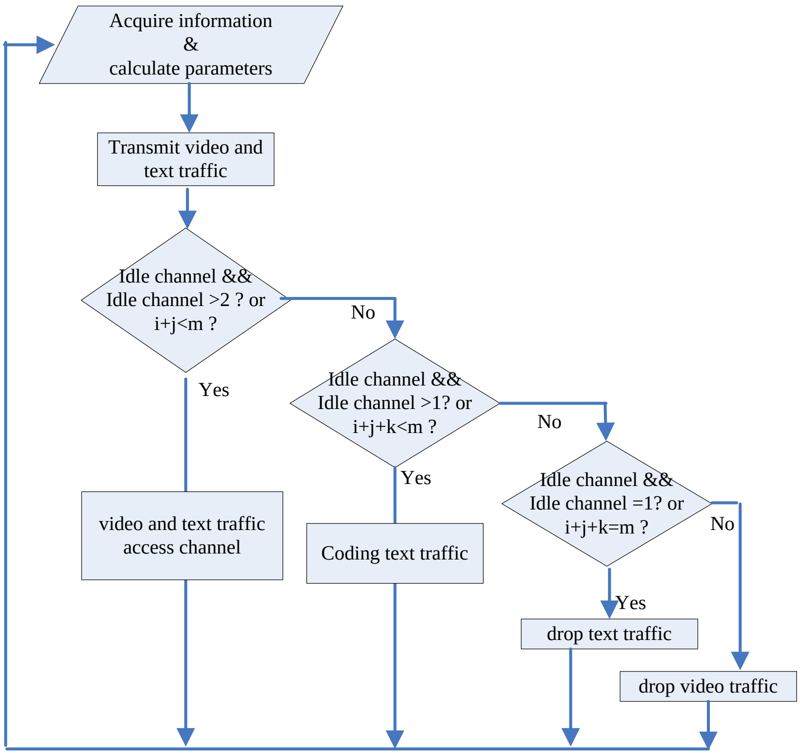

Figure 2. Proposed Users Sharing Mechanism

3. Steady State Performance Analysis

In this section, we develop the model using continuous time Markov chain (CTMC). The state of the CTMC is defined as (i, j, k), where $i \in (0,1,2,\cdots,m)$, $j \in (0,1,2,\cdots,m)$ and $k \in (0,1,2,\cdots,m)$ represent the number of ongoing licensed user, video traffic of non-paying user and text traffic of non-paying user in the scheme respectively. A valid state (i, j, k) should not exceed m.

Table 1. System Parameters

m	The number of all licensed channels
i	The number of ongoing PU, $i \in (0,1,2,\cdots,m)$
j	The number of ongoing video traffic of SU, $j \in (0,1,2,\cdots,m)$
k	The number of ongoing text traffic of SU, $k \in (0,1,2,\cdots,m)$
g_{ij}	transition probability from state i to state j
Ψ	The state space
λ	Arrival rate
$1/\mu$	The mean of service times
$\pi_{i,k,j}$	The steady state probability for a state (i, j, k)

The state of the Markov chain model is defined as $\Psi = (i, j, k)$. We assume that the licensed user, video traffic of non-paying user and text traffic of non-paying user arrival processes follow Poisson process with the arrival rate λ_1, λ_2 and λ_3, respectively. The service times for them follow an exponential distribution with mean $1/\mu_1$, $1/\mu_2$ and $1/\mu_3$, respectively. Let (i, j, k) represent a system state, where i, j, k denote the number of channels used by the licensed user, video traffic of non-paying user and text traffic of non-paying user, respectively. The system state transitions in Ψ can be depicted in Figure3.

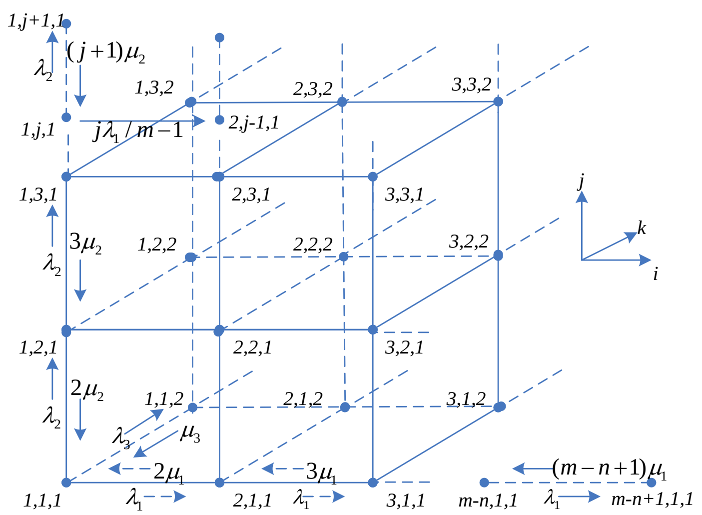

Figure 3. System State Transitions Diagram in 3-Dimension

The evolution of the state (*i*, *j*, *k*) of the Markov process is presented under three cases:

$$i+j < m, k = 0 \tag{1}$$

$$i + j + k < m, k \neq 0 \tag{2}$$

$$i + j + k = m \tag{3}$$

According to dynamic multimedia sharing scheme of system presented above, the system state transitions diagram can be obtained as in Figure3. On the basis of the transition rate diagram, we can get the set of global balance equations as following.

Objective:

$$\{\prod | \pi_{1,}\pi_{2,}\pi_{3,}\cdots,\pi\} \tag{4}$$

s.t.

$$\sum_j \pi_i g_{ij} = \sum_i \pi_j g_{ji} \tag{5}$$

$$\begin{aligned} & i\mu_1\pi_{(i,j,0)} - \lambda_1\pi_{(i-1,j,0)} + j\mu_2\pi_{(i,j,0)} - \lambda_2\pi_{(i,j-1,0)} \\ & +\lambda_1\pi_{(i,j,0)} - (i+1)\mu_1\pi_{(i+1,j,0)} + \lambda_3\pi_{(i,j,0)} \\ & -\mu_3\pi_{(i,j,1)} + \lambda_2\pi_{(i,j,0)} - (j+1)\mu_2\pi_{(i,j+1,0)} = 0 \end{aligned} \tag{6}$$

$$\begin{aligned} & i\mu_1\pi_{(i,j,k)} - \lambda_1\pi_{(i-1,j,k)} + j\mu_2\pi_{(i,j,k)} \\ & -\lambda_2\pi_{(i,j-1,k)} + k\mu_3\pi_{(i,j,k)} - \lambda_3\pi_{(i,j,k-1)} \\ & +k\lambda_1/(m-i)\pi_{(i,j,k)} - \mu_1\lambda_3\pi_{(i+1,j,k-1)} \\ & +j\lambda_1/(m-i)\pi_{(i,j,k)} - \mu_1\lambda_2\pi_{(i+1,j-1,k)} = 0 \end{aligned} \tag{7}$$

$$\pi_{(i,j,k)} = 0, \{(i,j,k) | (i,j,k) \notin \psi\} \tag{8}$$

$$\sum_i \sum_j \sum_k \pi_{(i,j,k)} = 1 \tag{9}$$

While, the total number of occupied channels in the state (*i*, *j*, *k*) should satisfy the following condition:

$$\Psi = \{(i,j,k) | i + j + k \leq m\} \tag{10}$$

where g_{ij} denotes transition probability from state i to state j. $\pi_{(i,j,k)}$ denotes the steady state probability for a state (*i*, *j*, *k*). Then, Combining equations above and solving the linear program (5)～(10), we can get ($\pi_{1,}\pi_{2,}\pi_{3,}\cdots,\pi_l$). The array can be calculated with the flow shown as,

```
Initialize parameters, calling rate and service time of multimedia users;
if (i < 0)
 else if (i < m)
      real-time call=1
    else if (i = m)
          non-real-time call=1
    end if
  end if
end if
for (0: number of real-time user)
  for (0: number of non-real-time user)
    for (0: number of buffering user)
```

calculate steady states;

$$\Pi = \begin{pmatrix} \pi_0^1 & \pi_0^2 & \pi_0^3 \\ \vdots & \vdots & \vdots \\ \pi_i^1 & \pi_j^1 & \pi_k^1 \end{pmatrix}$$

seek matrix, len = state space;

for (0: len)

calculate Ψ;

4. Performance Evaluation

Based on the steady state probability analysis, QoS performance metric can be calculated, including system throughput, termination probability and blocking probability. The metric is expressed by function Q～[Thr, $P_{termination}$, P_{block}], where Thr, $P_{termination}$ and P_{block} are denoted as throughput, termination probability and blocking probability, respectively.

For the video traffic of non-paying user, it may be interrupted by the arrival of a licensed user call when no channel is idle. Let $P_{termination\_video}$ denote interruption probability of video traffic. So $P_{termination\_video}$ can be obtained as

$$P_{termination\_video} = \frac{\sum_{(i,j,k)\in\Psi|k=0} \pi_{i,j,k}}{\sum_{(i,j,k)\in\Psi|j>0} \pi_{i,j,k}} \tag{11}$$

Then, the probability that a channel occupied by the coded text traffic is reclaimed by a PU is k/(m-i). For the text traffic, Let $P_{termination\_text}$ denote interruption probability of text traffic. So $P_{termination\_text}$ can be obtained as

$$P_{termination\_text} = \frac{\sum_{(i,j,k)\in\Psi|k=0} \frac{k}{m-i}\pi_{i,j,k}}{\sum_{(i,j,k)\in\Psi|} \pi_{i,j,k}} \tag{12}$$

Video traffic and coded text traffic will be blocked when no channel is idle. Let P_{block_video} and P_{block_text} are denoted as blocking probability of video traffic and text traffic, respectively. So blocking probability for video traffic and text traffic can be calculated, respectively, as

$$P_{block\_video} = \sum_{(i,j,k)\in\Psi|i+j+k=m,k=0} \pi_{i,j,k} \tag{13}$$

$$P_{block\_text} = \sum_{(i,j,k)\in\Psi|i+j+k=m} \pi_{i,j,k} \tag{14}$$

Let Thr denote the total traffic load of SU. Thus, the throughput can be calculated as

$$Thr = \sum_{(i,j,k)\in\Psi|m} \pi_{i,j,k} \left(\sum_{(i,j,k)\in\Psi|j=1}^{m} \pi_{i,j,k}\mu_1 + \sum_{(i,j,k)\in\Psi|k=1}^{m} \pi_{i,j,k}\mu_2 \right) \tag{15}$$

Further, the QoS mentioned above can be given.

5. Numerical Results

After description of the sharing scheme implementation of the non paying users, we present numerical results by comparing the proposed scheme with general scheme. For example, let HandOff-1 denote the method with fair scheme, HandOff-2 denote the method with priority scheme (*e.g.*, video traffic and text traffic for non-paying user), and

HandOff-3 denote the scheme proposed. In the experiments, we set m=5, $\lambda_3 \in [0.01, 0.1]$, $\mu_1 = 10\mu_2 = 10\mu_3$.

As shown in Figure 4 and Figure 5, the proposed scheme can provide lower termination probability and blocking probability than others for non-paying users. In Figure 6, the analysis result of system traffic load is given. With the rapidly increasing of data arrival rate, the proposed handoff scheme can support the largest system load. In Figure 7, we can find that the proposed handoff scheme can achieve the best performance.

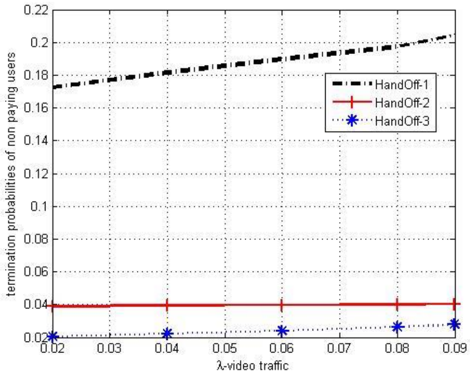

Figure 4. Comparison of Termination Probabilities with Different Handoff Schemes

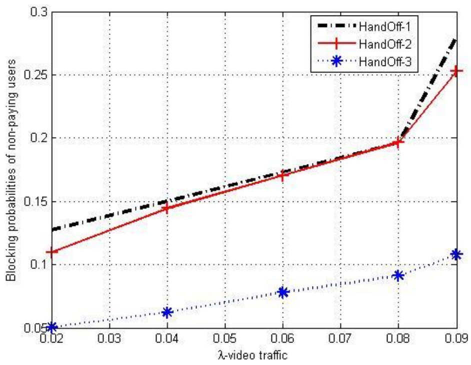

Figure 5. Comparison of Blocking Probabilities with Different Handoff Schemes

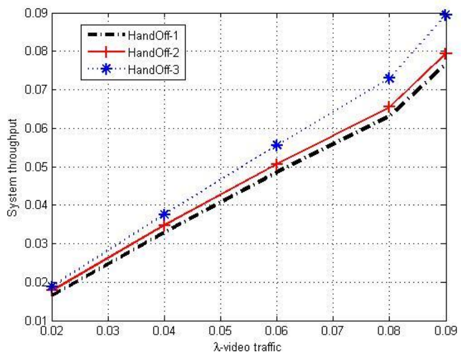

Figure 6. Comparison of System Throughput

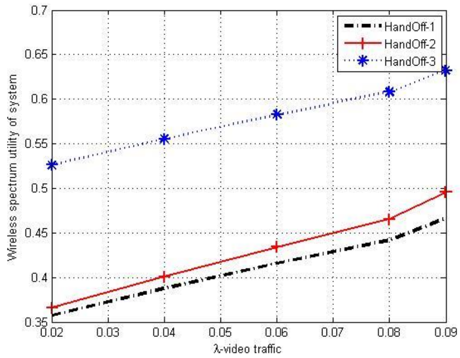

Figure 7. Comparison of System Spectrum Resource Utility

6. Conclusion

In this paper, we proposed a novel model of multimedia sharing in wireless network and analyze how to improve the non-paying users' QoS through mathematical method. Numerical results also showed that the proposed handoff scheme can effectively match the theoretical analysis.

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