Performance Analysis of CSMA with Guard Channels in Heterogeneous Wireless Network

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Abstract. We propose a CSMA scheme with guard channels in heterogeneous wireless network. In this system, there are two different networks B and A. Original users of A network (called network A users) can use the wireless resources of network A and B. Original users of B network (called network B users) can only use the wireless resources of network B. There are $N_g$ guard channels in network B, in order to guarantee the service quality of B network users. We model the system by three dimensional continuous time Markov chain and solve the steady state probability. We also obtain the system performance measures such as the total throughput, the loss probability of network A and network B users. Numerical results show that number of guard channels and the arrival rate of different network users give an important impact on the system performance, and the performance of our proposed CSMA scheme with guard channels is better than that of without guard channels.

1. Introduction

With the rapid development of wireless communication service and communication technologies, isomerization, ubiquity and cognition have become the development direction of wireless network in the future. The future wireless network is a heterogeneous network composed of many different kinds of networks. Therefore, how to reasonably allocate spectrum resources in heterogeneous wireless networks is one of the important problems to be solved in the future wireless communication networks. Cognitive radio technology is an effective scheme to improve spectrum utilization and has been widely used in the research of spectrum access schemes.

There have been many studies on the spectrum access scheme for cognitive radio networks [1-6]. Cognitive radio networks can be classified as homogenous [1-3] and heterogeneous [4-6]. Jin et al. [2] analysed the performance of the novel centralized spectrum allocation scheme and Kim et al. [3] proposed decentralized cognitive MAC protocols in homogenous cognitive radio networks. Recently, Zhu et al. [4] proposed a $p$-select CSMA scheme in heterogeneous wireless networks environment. In this scheme, each secondary user (SU) senses the channels of network before its packet transmission. Since there are two different networks, the SU randomly selects one from A and B networks with probability $p$ and $1-p$. Zhao [5] proposed an unslotted CSMA scheme based on secondary user’s priority in heterogeneous cognitive wireless networks environment. In this scheme, the low and high priority users adopt different sensing mechanisms and handoff mechanisms respectively, in order to meet the different service requirements of low and high priority users. Xie et. al. [6] researched the spectrum resource allocation scheme of heterogeneous cognitive wireless networks, proposed an algorithm to
allocate spectrum resources based on capacity which aims to ensure the maximum network capacity. These studies focus on how to share the wireless resources of different networks from the perspective of unlicensed users in the heterogeneous network environment.

However, there are also such heterogeneous network environments in real life. The wireless resources of one network can be shared to licensed users of other networks. For example, when mobile network and public WiFi network coexist, the mobile network users will of course give priority to access to public network. But if too many other networks licensed users to access a shared wireless network, the network’s performance will decline, resulting in a decline in the quality of communication services for the inherent users in the network. Therefore, in this heterogeneous network environment, how to allocate wireless spectrum resources efficiently and reasonably is also an important problem to be solved. It is the purpose of our work. We will propose and analyse the CSMA scheme with guard channels in heterogeneous wireless network.

The rest of this paper is organized as follows. The CSMA with guard channels in heterogeneous wireless networks is introduced in the next section. In section 3, we analyse the performance of CSMA with guard channels through continuous time Markov processes. Section 4 considers some numerical examples. Finally, the conclusion is given in section 5.

2. System Model

We consider a heterogeneous wireless network environment consisting of two different networks, A and B. Original users of A network (called network A users) can use the wireless resources of network A and B. Original users of B network (called network B users) can only use the wireless resources of network B. Let the number of channels in network A and network B is C1 and C2, respectively. To guarantee network B user’s QoS, there are Ng guard channels in network B. The CSMA scheme with guard channels in the heterogeneous wireless network is operated as follows:

(1) When the network B user arrives at the system, if there is any idle channel in B network, then the user selects one of idle channel and transmits its message. The network B user will give up its data transmission when there is no idle channel in network B.

(2) When the network A user arrives at the system, it preferentially senses the network B. If there are idle channels in the network B and the number of idle channels is more than K, then the user can selects one of idle channel in the network B and transmits its message. If there are idle channels in the network B but the number of idle channels is less than or equal to Ng, then the user can’t access network B and try to access network A. If there are any idle channels in network A, then the user selects one of idle channel in network A and transmits its message, otherwise the user will give up its data transmission.

(3) When the network A users are transmitting data in the network A, the users will continue to sense the channels in network B try to access network B. If the number of idle channels in the network B is more than Ng, then the users in the network A will perform spectrum handoff to the network B. Network B will randomly select one of them and allocate one of idle channels to the handoff user. The handoff user continues to transmit his message in network B.

3. Performance Analysis

To analyse the performance of our proposed scheme, we assume that the users of network A and B arrive the system according to independent Poisson processes with rate λ1 and λ2, the transmission times of messages for network A and B have exponential distribution with rate μ1 and μ2, respectively.

Let NA(t) = the number of network A users successfully access network B at time t; NB(t) = the number of network B users in service at time t; NA(t) = the number of network A users successfully access network A at time t.

Then \( \{NA(t), NB(t), NA(t) | t \geq 0\} \) forms three dimensional continuous time Markov process and the state space is given by:
Since the process \( \{(N_{A,t}, N_{B,t}, N_{A,t}) \mid t \geq 0\} \) is an irreducible Markov process and has finite state space, so it is always ergodic. Let \( p_{i,j,k} \) be the steady state probability that the Markov process is in state \((i,j,k)\), then we have the following balance equations:

If \( 0 \leq j < C_2 - N_g - i \)

\[
P_{i,j,k}[(i + j)\mu_1 + j\mu_2 + \lambda_2 + \lambda_3] = P_{i-1,j,k}(i+1)\mu_1 + P_{i-1,j,k}\lambda_2 + P_{i,j-1,k}(j+1)\mu_2 + P_{i,j-1,k}\lambda_2
\]

(1)

If \( j = C_2 - N_g - i, k = 0, N_g = 0 \)

\[
P_{i,C_2-N_g-i,k}[i\mu_1 + j\mu_2] = P_{i-1,C_2-N_g-i,k}\lambda_2 + P_{i,C_2-N_g-i,k}\lambda_2
\]

(2)

If \( j = C_2 - N_g - i, k = 0, N_g > 0 \)

\[
P_{i,C_2-N_g-i,k}[i\mu_1 + j\mu_2 + \lambda_2] = P_{i-1,C_2-N_g-i,k}\lambda_2 + P_{i,C_2-N_g-i,k}(i+1)\mu_2 + P_{i,C_2-N_g-i,k}(i+1)\mu_2
\]

(3)

If \( j = C_2 - N_g - i, k = 0, N_g > 0 \)

\[
P_{i,C_2-N_g-i,k}[(i + k)\mu_1 + \lambda_2 + (C_2 - N_g - i)\mu_2] = P_{i-1,C_2-N_g-i,k}\lambda_2 + P_{i,C_2-N_g-i,k}\lambda_2
\]

(4)

If \( j = C_2 - N_g - i, 0 < k < C_1, N_g = 0 \)

\[
P_{i,C_2-N_g-i,k}[(i + k)\mu_1 + \lambda_2 + (C_2 - N_g - i)\mu_2] = P_{i-1,C_2-N_g-i,k}\lambda_2 + P_{i,C_2-N_g-i,k}(i+1)\mu_2 + P_{i,C_2-N_g-i,k}(i+1)\mu_2
\]

(5)

If \( j = C_2 - N_g - i, k = C_1, N_g > 0 \)

\[
P_{i,C_2-N_g-i,C_1}[i\mu_1 + \lambda_2 + (C_2 - N_g - i)\mu_2] = P_{i-1,C_2-N_g-i,C_1}\lambda_2 + P_{i,C_2-N_g-i,C_1}\lambda_2
\]

(6)

If \( j = C_2 - N_g - i, k = C_1, N_g = 0 \)

\[
P_{i,C_2-N_g-i,C_1}[(i + C_1)\mu_1 + (C_2 - N_g - i)\mu_2] = P_{i-1,C_2-N_g-i,C_1}\lambda_2 + P_{i,C_2-N_g-i,C_1}\lambda_2
\]

(7)

If \( C_2 - N_g - i < j < C_2 - i, 0 \leq k < C_1 \)}
\[
p_{i,j,k}[(i+k)\mu_i + \lambda_2 + \lambda_1 + j\mu_2] = p_{i-1,j,k}\lambda_2 + p_{i-1,k}\lambda_1 + p_{i,j-1,k}(\mu_1 + \lambda_2) + p_{i,j+1,k}(j+1)\mu_2 \\
+ p_{i+1,j,k}(\mu_1 + \lambda_2 + j\mu_2)
\]  
\(\text{(8)}\)

If \(C_2 - N_g - i < j < C_2 - i, k = C_1\)

\[
p_{i,j,C}[(i+C_2)\mu_i + \lambda_2 + j\mu_2] = p_{i-1,j,C}\lambda_2 + p_{i,j-1,C}\lambda_2 + p_{i,j+1,C}(j+1)\mu_2
\]
\(\text{(9)}\)

If \(j = C_2 - i, 0 \leq k < C_1\)

\[
p_{i,C_2-i,k}[(i+k)\mu_i + \lambda_2 + (C_2-i)\mu_2] = p_{i-1,C_2-i,k}\lambda_2 + p_{i,C_2-i,k}\lambda_2 + p_{i+1,C_2-i,k}(k+1)\mu_2
\]
\(\text{(10)}\)

If \(j = C_2 - i, k = C_1\)

\[
p_{i,C_2-i,C}[(i+C_2)\mu_i + (C_2-i)\mu_2] = p_{i-1,C_2-i,C}\lambda_2 + p_{i,C_2-i,C}\lambda_2 + p_{i+1,C_2-i,C}(C_2-i)\mu_2
\]
\(\text{(11)}\)

By above linear equations (1)-(11) and the initialization condition of probability, we can easily solve the probability \(p_{i,j,k}\).

The main system performance measures are the throughput and the loss probability of users in network A and B.

Let \(P_{l1}\) (or \(P_{l2}\)) be the loss probability of network A (or B) users. \(P_{l1}\) is defined as the probability that the arriving network A user can’t access network B and A, \(P_{l2}\) is defined as the probability that the arriving network B user can’t access network B. Then we can obtain

\[
P_{l1} = \sum_{i=0}^{C_2-N_g} \sum_{j=C_2-i}^{C_2-1} p_{i,j,C_1}, \quad P_{l2} = \sum_{i=0}^{C_2-N_g} \sum_{k=0}^{C_2-i} p_{i,C_2-i,k}.
\]
\(\text{(12)}\)

Let \(T_1\) and \(T_2\) be the throughput of network A and network B users. \(T_1\) is defined as the number of network A users who access network A or B and successfully send their messages per unit time. \(T_2\) is defined as the number of network B users who access network B and successfully send their messages per unit time. Then we have

\[
T_1 = \lambda_1(1 - P_{l1}), \quad T_2 = \lambda_2(1 - P_{l2}).
\]
\(\text{(13)}\)

The total throughput \(T\) of the system, is given by

\[
T = T_1 + T_2 = \lambda_1(1 - P_{l1}) + \lambda_2(1 - P_{l2}).
\]
\(\text{(14)}\)

4. Numerical Examples

To investigate the performance evaluation of CSMA with guard channels in in heterogeneous wireless network, we present some numerical examples. We set the parameters \(C_1=5\)channels and \(\mu_1^{-1}=0.5\)sec, \(\mu_2^{-1}=0.4\)sec.

Figure 1 displays the impact of arrival rate on the performance of users in network B. Figure 1a depicts the throughput of network B users as the arrival rate \(\lambda_1\) of network A users increases when \(\lambda_2=0.8, C_2=8, N_g =2,3,4,\).

Just as we expected, the throughput \(T_2\) of network B users decreases as the arrival rate \(\lambda_1\) increases, because high arrival rate of network A users leads to a little chance of network B user’s message transmission. Figure 1b shows the loss probability of network B users increases as the \(\lambda_1\) increases.
In Figure 1, we can also see that the throughput of network B users increases as the guard channel number $N_g$ increases. Figure 1 shows that the arrival rate of network A users and the number of guard channels give an important impact on the performance of network B users.

![Figure 1. System performance versus the arrival rate of network A users.](image)

Figure 2 displays the throughput and loss probability of network A users versus the arrival rate of network B users when $\lambda_1=0.8$, $C_2=8$, $N_g=2, 3, 4$. As expected, the throughput $T_1$ of network A users decreases and the loss probability of network A users increases as the arrival rate $\lambda_2$ increases, because high arrival rate $\lambda_2$ of network B users leads to a little chance of network A users’ access to network B. In figure 2, we can also see that the throughput of network A users decreases as the number $N_g$ of guard channels in network B increases.

Figure 3 compares the performance of our proposed scheme and the scheme without guard channels. Figure 3 displays the throughput of network B users versus the arrival rate $\lambda_1$ of network A users when $\lambda_2=0.8$, $C_2=8$, $N_g=4$. Figure 3 shows that the CSMA scheme with guard channels has better performance than that of without guard channels.

![Figure 2. System performance versus the arrival rate of network B users.](image)
5. Conclusions
We have proposed a CSMA scheme with guard channels in the heterogeneous wireless network and analysed the performance of this scheme by three dimensional continuous time Markov process. Through the numerical results we show that the performance of CSMA scheme with guard channels is better than that of without guard channels, and the number of guard channels has an impact on throughput of users in heterogeneous wireless network environment.

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