

# Cross-layer Resource Allocation on Broadband Power Line Based on Novel QoS-priority Scheduling Function in MAC Layer

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## ABSTRACT

Traditional resource allocation algorithms use the hierarchical system, which does not apply to the bad channel environment in broadband power line communication system. Introducing the idea of cross-layer can improve the utilization of resources and ensure the QoS of services. This paper proposes a cross-layer resource allocation on broadband power line based on QoS priority scheduling function on MAC layer. Firstly, the algorithm considers both of real-time users' requirements for delay and non-real-time users' requirements for queue length. And then user priority function is proposed. Then each user's scheduled packets number is calculated according to its priority function. The scheduling sequences are based on the utility function. In physical layer, according to the scheduled packets, the algorithm allocates physical resources for packets. The simulation results show that the proposed algorithm give consideration to both latency and throughput of the system with improving users' QoS.

**Keywords:** Broadband Power Line Communication; OFDM; Cross-layer; Resource Allocation; Scheduling

## 1. Introduction

With the construction of strong and smart grid and the rapid development of communication technology, broadband power line communications gradually develop into the high-speed. Traditional wired network

The wired networks adopt traditional hierarchical system: Open Systems Interconnection (OSI) model, which, from top to bottom, is divided into the application layer, presentation layer, session layer, transport layer, network layer, data link layer, and physical layer. Each layer is independent designed, and the interface between the layers is static. In broadband power line systems, due to the large differences of sub-channels, great changes of noise, multipath fading, dispersion and other unfavorable factors, the traditional hierarchical system cannot be flexible to adapt to fast-changing channel environment. Apply the cross-layer design into the OFDM system, and let the upper layer's dynamic business be in close contact with the physical layer's channel conditions, which could realize the dynamic allocation of resources and further improve the utilization of resources. In reference [1], an algorithm based on the satisfaction of packet exchange and resource allocation is proposed. The algorithm optimally defines the various satisfactory degree evaluation functions. Then, based on such functions, the algorithm calculates scheduling utility function, achieving user's

scheduling. In this algorithm, the differentiation between emergency services and non-emergency services is not obvious, which may lead to packet loss of real-time business. In reference [2], a scheduling algorithm based on the satisfactory factor is proposed. The algorithm defines satisfactory factor of quality of service, and gets the new utility function through improving the traditional index scheduling algorithm (EXP). The algorithm does not consider the queue's conditions, which could make packet loss rate increase for non-real-time services.

This paper introduces a cross-layer resource allocation algorithm on broadband power line based on a novel scheduling function in MAC layer. For real-time business, the algorithm considers the packets delay; for non-real-time business, it considers the queue length. Combining with the user channel conditions and factors above, users are divided into different priorities. And MAC layer utility function is proposed. In physical layer, we use equal power resource allocation method. The algorithm closely contacts the MAC layer with the physical layer, and processes packet scheduling and resource allocation reasonably, which improves the throughput of the system.

## 2. Model of Cross-layer Resource Allocation

Through information exchanging between layers, and

according to the system's overall conditions, the cross-layer resource allocation algorithm meets users' needs better in each layer. Therefore, cross-layer allocation algorithm provides more information to adaptive resource allocation. However, because of the increase of information, computational complexity of the algorithm will increase [3].

The model of cross-layer resource allocation is shown below:

According to the information interaction between layers and relevant scheduling rules, the scheduler reasonably allocates system resources, as is shown in **Figure 1**. The information between layers mainly includes channel estimation, feedback, resources of physical layer, queue status and the QoS requirements, etc. In broadband power line system, MAC-PHY cross-layer scheduler works as follows: data from the upper layer, which is assigned to different buffer queues, combines with physical channel conditions as the basis of the MAC layer scheduler.

In the broadband power line system, the operations of the upper layer are varied, and the QoS requirements are also different. In addition, the arrival of some business flows is sudden and random, and the power line channel is time-varying. To make full use of link resources, and ensure the validity and reliability, the scheduler must take real-time channel status into consideration. Thus, the scheduler could select the MAC-PHY cross-layer scheduling mode above.

### 3. Cross-layer Scheduling and Resource Allocation Algorithm

#### 3.1. User Scheduling on MAC

The scheduling is implemented in the MAC layer. The utility function may be provided on the joint of the delay, queue length, packet loss rate and other information on the MAC layer and channel information on the physical layer. The utility function determines the scheduling order of business, and completes scheduling [4].

For the sake of simplicity, it is assumed that, at the same moment, a user has only one service, and corresponds to only one queue. Each data packet scheduling is for each queue scheduling. Corresponds to the real-time and non-real-time user, the queue is divided into real-time queue and non-real-time one.

First, according to the urgency degree of every queue, packets are divided into two categories: high priority packets and ordinary packets.

The priority of queue of real-time business is determined by delay. Let maximum delay which can be tolerated by real-time business of user  $k$  is  $D_k^{\max}$  and assume waiting time of packets of real-time business queue of user  $k$  is  $D_k^{\text{current}}$ , the priority of packets of real-time business queue of user  $k$  is divided according to equation

(1).

$$\eta_k^{RT} = \frac{D_k^{\text{current}}}{D_k^{\max}} \quad (1)$$

Packet loss of non-real-time business queue is mainly caused by the overflow of packets, so its priority is determined by the length of queue [5]. Set the maximum number of buffered packets of buffered queue is  $Q^{\max}$ . In the slot  $t$ , the prioritization function of non-real-time business queue of user  $k$  is:

$$\eta_k^{NRT} = \frac{Q_k}{Q^{\max}} \times \beta \quad (2)$$

where  $\beta$  is the coordination factor, which is a positive number less than 1.

The emergency degree of data packets in each queue is determined as follows:

$$\eta_k = \begin{cases} \eta_c \leq \eta_k \leq \text{high priority} \\ \eta_k \leq \eta_c \quad \text{ordinary} \end{cases} \quad (3)$$

where  $\eta_k$  shows the emergency function of real-time or non-real-time services,  $\eta_c$  is the threshold of emergency function.

When the priority of the head packet of each queue is judged, scheduling sequences of different priority is judged by the scheduling function of high priority and ordinary packets. Scheduling function is expressed as follows:

$$U_k[i] = \begin{cases} \frac{PD_k[i]}{R_k^c[i]} \times \eta_k[i] \text{ high priority} \\ \frac{R_k^a[i]}{R_k^c[i]} \times \eta_k[i] \quad \text{ordinary} \end{cases} \quad (4)$$

where  $PD_k[i]$  represents the packet loss rate of the queue  $k$  before the  $i$ -th frame, and  $PD_K$  represents the maximum packet loss rate. And  $R_k^c[i]$  represents the maximum supported rate of the queue  $k$ 's  $i$ -th frame, that is, when all of time-frequency blocks of the  $i$ -th frame distribute to the queue, the transmission rate can reach the maximum [6]. And  $R_k^a[i]$  represents the weighted average rate of the queue  $k$  before the  $i$ -th frame. The iterative formula describes as follows:

$$R_k^a[i] = \left(1 - \frac{1}{t_c}\right) R_k^a[i-1] + \frac{1}{t_c} R_k[i-1] \quad (5)$$

where  $R_k[i-1]$  shows the actual rate of the  $i-1$  frame of queue  $k$ , and  $t_c$  is the length of the sliding time window.

Based on the scheduling function above, packets of each queue are scheduled. The scheduling principle is that, dispatch high priority packets firstly, and then, schedule ordinary packets. The packets of same priority are scheduled according to the descending order of scheduling function.

Average sending rate of each user is indicated as a

vector:  $Packet\ Rate = [R_1, R_2, \dots, R_K]$ . According to the priority function, the number of current scheduling packets of each user is determined as follows.

$$N_k^{queue} = \left\lceil R_k \times (1 + \overline{\eta}_k) \right\rceil \quad (6)$$

where  $\overline{\eta}_k$  is the normalized priority.

$$\overline{\eta}_k = \frac{\eta_k}{\sum_{k=1}^K \eta_k} \quad (7)$$

### 3.2. Physical Resource Allocation

The method of equal power allocation is applied on physical layer. Suppose the total power of the system is P, the number of subcarriers is N, the number of bits which can be transmitted for user k on the subcarrier n is:

$$Rb_{k,n} = \left\lfloor \log_2 \left( 1 + \frac{(P/N)g_{k,n}}{\Gamma_k} \right) \right\rfloor \quad (8)$$

In accordance with the number of scheduling packets identified on the MAC layer, the sub-carrier which is the optimal matching is assigned to each user. When the resource allocation on physical layer is complete, the current round of resource allocation is end. If the rate of users reaches the scheduling requirement and the system also has the remaining resources, the remaining resources are needed to be allocated.

### 3.3. Remaining Resource Allocation

If all users have reached the fixed rate and the unused available sub-carriers are still present in the system, the algorithm allocates the remaining resources. Remaining resource allocate principle is as follows.

- Export the highest priority packet according to the MAC layer scheduling algorithm.
- The optimal sub-carrier is assigned to corresponding packet until bits allocation of the packet is completed.

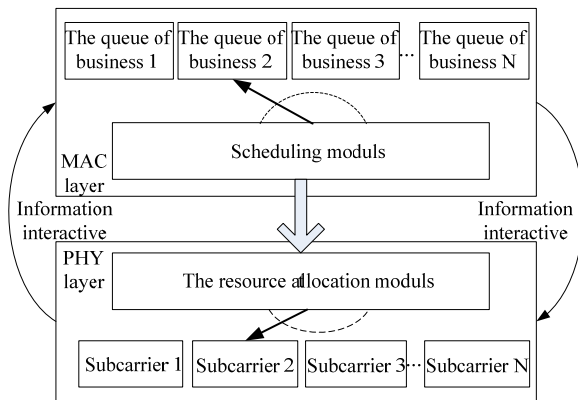


Figure 1. Cross-layer resource allocation system diagram.

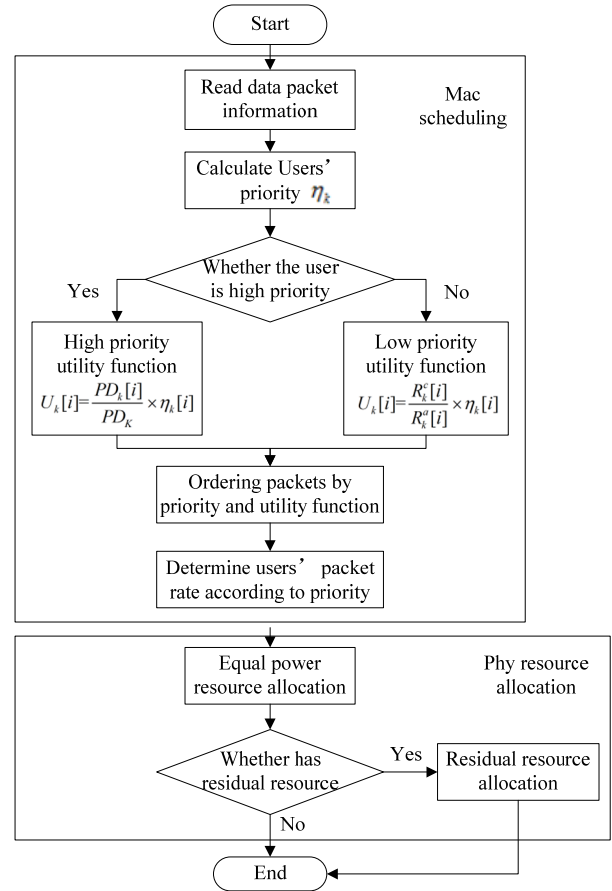


Figure 2. The flowchart of cross-layer resource allocation.

- If the system does not have enough sub-carriers to transmit bits of the packets, they are not sent in this OFDM symbol, and the allocation algorithm of the present OFDM symbol finishes. If the allocation can be finished and the system still has sub-carriers to be used, return to the first step.

The flowchart of cross-layer resource allocation on broadband power line communication is shown in Figure 2.

## 4. Simulation and Analysis

### 4.1. Traffic Source Model

With the development of broadband power line communication, services hosted on it become diverse increasingly. In order to facilitate the analysis, service which has high time delay requirements belongs to real-time service, and others are non-real-time service. Two types of services are modeled.

Packets of real-time service queue arrive obey the two-state Markov distribution, as is shown in Figure 3. ON indicates the activation period. OFF indicates the quiet period.  $\mu$  and  $\nu$  indicate the corresponding transition probability.

$$\mu = 1 - (-T / T_{OFF}) \tag{9}$$

$$\nu = 1 - \exp(-T / T_{ON}) \tag{10}$$

In which T is the length of one OFDM symbol,  $T_{OFF}$  is the average of quiet period,  $T_{ON}$  is the average of activation period.

Packets of non-real-time service queue arrive obey the Poisson distribution.

$$P(N = n) = \frac{e^{-\lambda t} (\lambda t)^n}{n!} \tag{11}$$

In which  $\lambda$  is the average packets arrival rate of non-real-time service.

In order to ensure the stability of the system, the average capacity of services should not exceed the system's total transmit capacity. Service source models created using above distributions are shown in **Figure 4** and **Figure 5**.

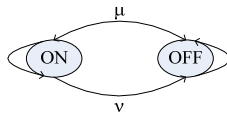


Figure 3. The real-time service Markov model.

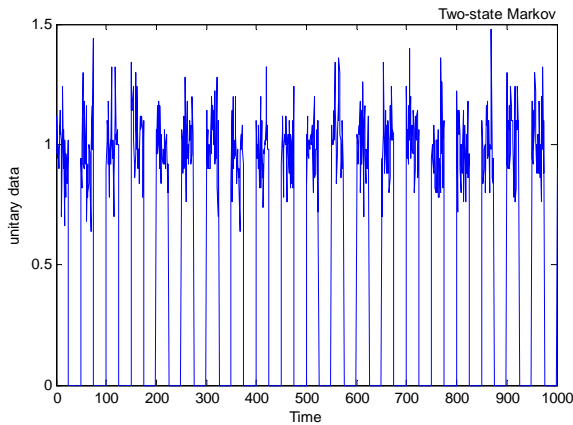


Figure 4. The real-time service model.

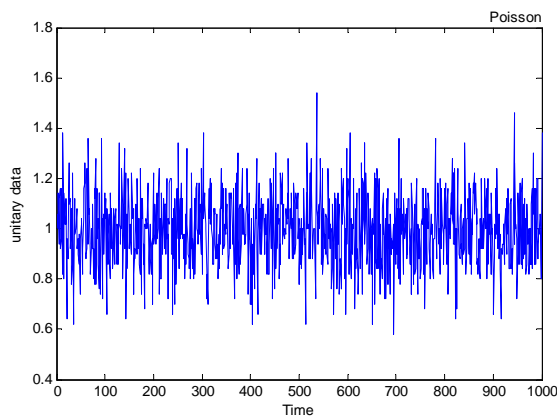


Figure 5. The non-real-time service model.

### 4.2. Simulation and Analysis of System Performance

The algorithm simulates in typical power line environment. The following parameters are set as follows: The frequency range is 0-20 MHz, power spectrum upper is -50-0.8 f (dBm/Hz) and f is in MHz. The number of sub-carriers is 128. Real-time business is corresponding to user 1 and 2 and the maximum delay is 10ms. Its maximum packet loss rate is  $10^{-3}$ . Non-real-time business is corresponding to user 3 and 4 and its maximum queue length is 600. Its maximum packet loss rate is  $10^{-3}$ .  $\beta = 0.7$ . Four users' average packets arrival rates are: 60 kbps, 60 kbps, 40 kbps and 30 kbps.

This article selects maximum throughput algorithm [7] (MAX/MIN) as the comparison. And the proposed algorithm compares and analyses the following factors, such as system throughput, delay and packet loss rate.

- Throughput performance comparison

**Figure 6** depicts that the MAX / MIN has an uneven distribution. User one has high throughput, but other users throughput is low. This paper algorithm's throughput matches users' average packets arrival rates and has high throughput.

- Delay performance comparison

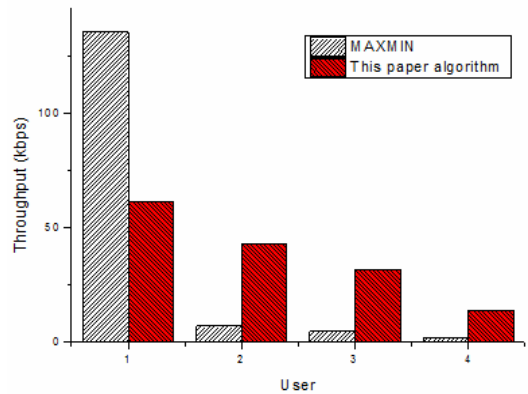


Figure 6. Throughput performance.

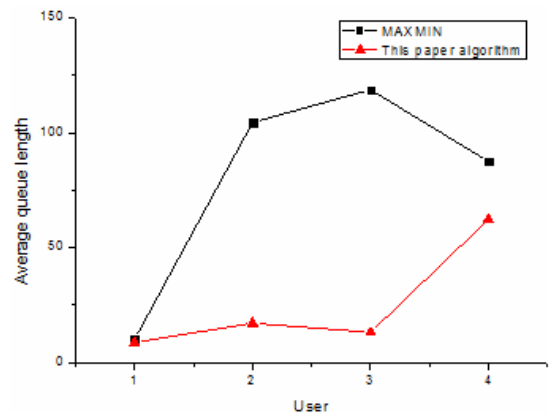


Figure 7. Average queue length.

**Figure 7** shows the average queue length of each user. The MAX\MIN has long queue length. It shows that users have higher delay. This paper algorithm has short queue length, which means the delay of packets is short.

- Performance comparison of packet loss rate.

Statistics show that the packet loss rate of MAX / I is 0.0015. The packet loss rate of this paper algorithm is zero. The algorithm proposed takes the users' average packets arrival rate into account, improving the packets' transmission rate. And, the algorithm possessed gets lower packet loss rate and ensures the user's QoS.

## 5. Conclusions

This paper discusses cross-layer resource allocation on broadband power line communication system and puts forward a MAC layer scheduling algorithm based on users' priority. The algorithm creates different scheduling function between the real-time and non-real-time users in MAC layer, and applies the priority function to divide users into two priorities. Then users are scheduled based on the priority and utility function. In the physical layer, equal power allocation method is used. The simulation results show that the proposed algorithm can take the latency and throughput into account and improve user's QoS.

## 6. Acknowledgements

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