A fair scheduling for power line communication network

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Abstract

Power line Communications (PLC) has gained a lot of interest for the last mile or access because the normal electric power line is utilized for transmission also communication signals. Considerable research effort has been extended on investigating the technologies. But the transmission scheduling is still a key design problem in the PLC networks. In this paper, a transmission scheduling for providing fairness (FTRS) between users is proposed. It assigns the users time slots with special reuse and makes them achieve fair transmission speed. So that the users can achieve the goal of a relative high throughput, as well as the fairness of channel share. FTRS is an appealing concept for PLC networks, since there is always a manager controlling the network, and PLC networks are often master slave structure with tree topologies. The simulation results show that the proposed protocol can achieve a trade-off between the high throughput and the fairness of channel share in PLC networks.

Keywords: power line communication (PLC) networks, transmission scheduling, resource reuse, fairness

1 Introduction

The application of power line communication (PLC) technology to the medium voltage (MV) network offers many advantages. It an alternative low cost but high performance solution for telecommunication networks in the access area [1, 2]. Considerable research effort has been extended on investigating the technologies about the physical (PHY) layer and the medium access control (MAC) layer [2]. In the standard IEEE P1901, orthogonal frequency division multiplexing (OFDM) system is used to confront the multipath fading channel, and the hybrid scheme with time division multiple access (TDMA) and the carrier sense multiple access with collision avoidance (CSMA/CA) is used in MAC layer to assure the different quality of service (QoS) guarantee for each type of service in accordance with its requirements [2-4].

However, the problem of the schedule arises when there is not enough available transmission capacity to satisfy all the requests from the users at the same time [3-6]. And it is challenging to design efficient scheduling strategies, which did not have specified in the standard IEEE P1901.

In [3], a low-complexity cross-Layer resource allocation is proposed to solve the problem with the channel allocation at the PHY layer and scheduling scheme at the MAC layer. In order to improve the performances of the power line system under impulsive noise, an efficient resource allocation is proposed in [4]. By adapting power transmitted in each cycle, the proposed resource allocation technique utilizes sub-channel ordering to obtain a higher throughput and tolerable bit error rate of the power line system. In [5], by focusing the problem of sub-channel and power allocation for indoor PLC networks with multiple links employing power spectral density limitations, an efficient multiuser loading algorithm is proposed for indoor PLC networks. In [7], an approach to schedule a limit of resource (transmission capacity in a frame) for a dynamic resource sharing system is proposed. In the method, it allocates different number of resource to satisfy the different QoS requirement to all users. So the overall benefit of the networks achieves higher with the scheduling strategies.

In [8], a channel allocation protocol is proposed for in PLC networks. It takes the individual channel quality of each user into account while calculating the necessary transmission resource. So that it can make the users in the networks achieve the same average transmission throughput between users in the networks. In order to obtain a high throughput, a transmission scheduling is proposed in [9]. By assigning the users time slots with special topology of PLC networks, the proposed method improves the throughput of the PLC networks. In [10], in order to minimize the time usage for total data delivery, a bandwidth guaranteed routing and time slot assignment method is proposed for multi-hop PLC networks. The numerical experiments results show that the proposed approach obtains significant performance improvement on network resource usage. In [11], the maximum weighted-sum-rate problem for an orthogonal frequency division multiple access (OFDMA) PLC system is used and the problem is solved by sequential convex programming through iterative convex approximations. It is a nearly optimal solution. But it focuses on the total power consumption, and does not account for QoS.

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There is a large variety of scheduling algorithms for MAC protocols, considering point-to-point or broadcast traffic and different collision and fairness constraints [12, 13]. But the PLC network is usually a master slave system, where a HE controls all the medium accesses of its slaves. The scheduling method in the PLC networks differs from those mentioned above.

In the paper, we propose a transmission scheduling for providing fairness (FTRS) between users, which make HE assign time slots for the nodes in the cell with spatial reused. By reducing the packets collision between the nodes, the FTRS can improve the performance of networks significantly in multi-hop PLC networks.

The rest of this paper is organized as follows. In section II, we formulate the problem in PLC networks we aim to solve. In section III, the FTRS for PLC networks is illustrated. In section IV, simulations are carried out, and the performance of the FTRS is analyzed. Section V gives the conclusions and future work.

2 System model and problem statement

A PLC access network (cell) usually consists of a HE (Head End), zero to several repeaters, and several CPEs (Customer Premises Equipment), as specified in the IEEE P1901. The cell is connected to the backbone network via an optical link or via PLC over MV lines, as shown in Figure 1. Since CPEs are end user modem in the PLC networks and users usually access the networks via CPEs, the fairness between users is achieved, when the fairness between CPEs is achieved.

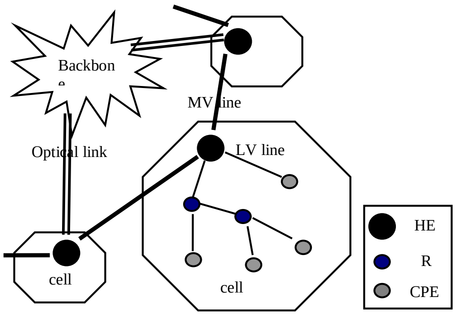

FIGURE 1 PLC Network architecture

The HE has to find the best solution to divide the limited network transmission capacity to grant access right to all the users, in accordance with the QoS requirements of the services. A repeater is placed between the HE and the CPEs in order to extend the coverage. When a repeater receives the data token from the HE, it has to organize an access scheme for all of its slaves within the given transmission duration. Several repeaters can be connected to form a multi-hop networks to support for longer distance transmissions. The PLC network usually has a tree topology.

The time slot is limited resources in conventional TDMA. So the time slot should be more efficiently used by applying the concept of spatial reuse well known from multi-hop networks. Spatial reuse TDMA is an appealing concept for PLC networks. First, PLC networks are often tree topologies with master slave structure. They are usually not fully connected. In such cases, some nodes can transmit simultaneously without causing collisions of their signals. Second, there is always a controlling station, the HE, managing the cell in PLC networks. The important information about the cell, such as the topology, the traffic load situation and the access duration of the nodes, can be known to the HE, associated with all nodes within the cell. The HE can manage the cell, such as synchronizing the nodes, and assigning the time slot for each node, effectively. Moreover, the collisions of the packets in networks can be defined as primary conflicts and secondary conflict. The former is that a node cannot receive a packet while transmitting in a given slot. The latter is that a node cannot receive more than one packet in a time slot [12].

However, it is important for users, both in the narrowband and broadband PLC networks, to achieve the same transmission throughput. It means that, the HE, in the PLC networks, has to transmit and receive the same amount of data from every user (electricity meter). So that it is important to keep the fairness between CPEs in the PLC networks [6, 7].

In the paper, a transmission scheduling for providing fairness (FTRS) between users is proposed in the multi-hop PLC networks. In the FTRS, the fairness between the users is achieved for using the cost function and throughput is increased for reusing the time slots between the users.

3 The transmission scheduling method

When a CPE initializes a new service, it sends a request to its HE and waits for the new bandwidth assignment. If the service is initialized from the HE, the request will be passed to the schedule. After the bandwidth broker allocates additional bandwidth for the new service, the HE will inform the CPE about the new bandwidth allocation and the transmission for the traffic of the new service will begin.

A. Resource Unit Definition.

Generally, a resource unit is defined as an amount of frequency band and time duration. This resource unit is the smallest transmission unit which can be allocated into a node. In TDMA in the PLC networks, the resource unit is defined as a time slot (T_S) in a time frame (T_F). Each node can utilize the whole available frequency band in the allocated time slots for the transmissions. The repetition of a resource unit in different time frames is also called channel. A time frame starts with a control beacon time slot, using for the synchronization between the nodes.

In the PLC networks, a node has to avoid using the same channels with its neighbours for avoiding packets collision. When the nodes are not neighbouring, they can use the same channel, called channel spatial reuse. It is also assumed that the interference between the neighbour nodes is so strong that all the connections in the neighbour nodes have to use different channels for their transmissions.

B. Resource Utilization.

With the main objective to maintain the fair throughput between the CPEs in the networks, it is necessary that all the CPEs will be scheduled to have the same transmission speed. Assumed that the TDMA scheme is applied in the cells, we calculate the fair transmission speed between a HE and its CPEs in the time frame when we apply the fair scheduling. This fair scheduling transmission speed, called "fair speed" for short, represents an amount of data a CPE can transmit in the whole time frame. With the same fair speed, each CPE can transmit and receive the same amount of data with its HE in a time frame. Calculation for the fair speed is divided into two steps as presented in Figure 2.

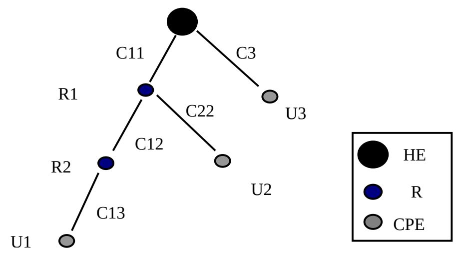

FIGURE 2 Network topology with 2 repeaters and 3 CPEs

Step1: calculation of the individual speed presents the individual transmission speed between a CPE and its HE in a given transmission time.

For a CPE U_i which requires one or several repeaters to be reached from its HE, the effective speed (C_i) is defined as the ratio of the data length to be transmitted and the time spent for this transmission. Assumed that there are I_j links (I_j -1 repeaters) between the CPE U_i and its HE, the effective speed is calculated as a function of the transmission speed C_{ij} in each link j, and in accordance with:

$$C_i = \frac{1}{\sum_{j=1}^{I_j} \frac{1}{c_{ij}}} . \tag{1}$$

As shown in Figure 2, the value of the variable C_i, the individual effective speed between the HE and CPE U_1 can be written as follows:

$$c_1 = \frac{1}{\frac{1}{c_{11}} + \frac{1}{c_{12}} + \frac{1}{c_{13}}} . \tag{2}$$

Step2: calculation of the fair scheduling transmission speed between the HE and its CPEs.

When applying the fair scheduling, each CPE is allowed to transmit the same amount of data (L) in the time frame. If there are I CPEs in a cell, the weight cost of the CPEs transmitting their data packets to the HE can be calculated from the effective speed between these CPEs and the HE, as shown in Equation (3).

$$w_i = \frac{1}{c_i} . \tag{3}$$

It can be seen from the Equation (3) that, if each CPE to transmit the same amount of data over the time frame (both uplink and downlink), the cost is different. So that if there is M channels that HE can allocate to the CPEs in the cell, in order to make each CPE transmit the same amount of data to the HE, the channels allocated to each CPE can be written as follows:

$$m_i = \frac{w_i}{\sum_{i=1}^{I} w_i} M . \tag{4}$$

This transmission speed depends on the network structure, including the number of CPEs and the qualities of the links. The fair scheduling speed between the HE and one of its CPEs during a time frame is

$$s_i^f = c_i m_i Ts . \tag{5}$$

C. Fairness Index.

For evaluation the fairness between the CPEs in the networks, the Jain's fairness index is used. Assume there are I CPEs in the network, the fairness index is calculated based on the fair speed of the CPEs

$$f = \frac{(\sum_{i=1}^{I} s_i^f)^2}{I \cdot \sum_{i=1}^{I} (s_i^f)^2} , \tag{6}$$

where the fair scheduling transmission speed is evaluated for all the CPEs by applying Equation (5). When the fairness index is higher, the fair speeds of different CPEs are nearer. The maximum fairness index is one when all the fair speeds are equal.

D. Resource Reuse.

The core idea of the resource reuse is shown as follows.

1) The conventional TDMA protocol as an underlying common protocol with node as designated node for time slot, referred to as the slot node, is used.

2) The nodes that can transmit during the same slot without causing packet collisions are adaptively identified. These nodes are referred to as joining nodes for this time slot. The classification of the network nodes is performed in an ad hoc fashion. The node, called in the section, can be any devices in the PLC networks, including the HE, repeater or CPEs.

It is important to note that if a node is using a TDMA allocation for both transmitting and receiving, its TDMA schedule information contains a corresponding entry in both TDMA transmit schedule and TDMA receive schedule. The following example illustrates how TDMA allocations can be selected for transmission and reception of data between stations. The topology is shown in Figure 3. There are four nodes, A, B, C, D, in the network.

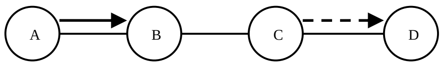

FIGURE 3 Network topology with four nodes

When node A is transmitting at time X and receiving at time Y, as well as node D is transmitting at time Z and receiving at time R. The allocation about the time slots can be shown in Figure 4. Node B can only transmit to node C at the time slot, when node B can transmit, as well as node C can receive. So that node B can transmit to node C at the time slot X, R, and S. At the same way, node C can only transmit to node B at the time slot, when node C can transmit, as well as node B can receive. So that node C can transmit to node B at the time slot Y and S.

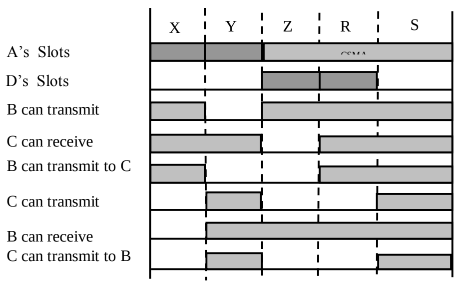

FIGURE 4 Time slots assignment about the four network topology

The resource reuse factor is defined as the ratio of the sum of all the time slots used in the whole network by the available number of time slots. The resource reuse factor is calculated by

$$r = \frac{\sum_{i=1}^{I} m_i}{\sum_{i=1}^{I} f_i}. \quad (7)$$

The higher the resource reuse factor, the more the resource is reused between the nodes. In a cell, the resource reuse factor is less than one when the time slots are not reused between the nodes.

4 Simulation Results

To evaluate the performance of the proposed FTRS, simulations under different traffic load were carried out. The performance of the proposed FTRS is compared to that of the fairness time slot scheduling (FTS) and that of the conventional TDMA with proper robust schedule (PRS). The simulation results of the proposed FTRS, FTS and PRS are separately labeled as 'proposed FTRS', 'FTS' and 'PRS', in Figure 6 to Figure 10. In the simulation the nodes transmit CBR over UDP traffic, using 1500-byte packets. The physical bit rate is 200Mbps. It is assumed that all nodes transmit frames using the same channel access priority.

In order to obtain indicative performance results, the networks topologies are generated randomly. More specifically, the total number of the repeater is 4, and the total number of the CPE is 16. But the number of the CPE connect to each repeater is generated randomly. Here is an example of the topology is shown in Figure 5.

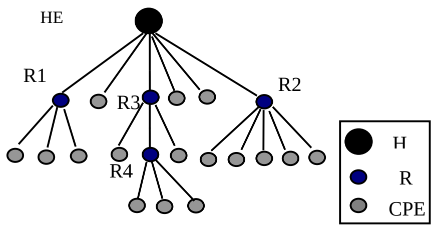

FIGURE 5 The network topology with 4 repeaters and 16 CPEs

A. Throughput.

Figure 6 shows the comparison of the throughput of the three methods. From Figure 6, we can observe that the throughput of three methods increases along with the increase of the traffic load when the traffic load is small, and it trends to a stable value when the traffic load increases. The maximum throughput of the proposed FTRS, PRS and FTS is 0.885, 0.988 and 0.489, when the traffic load is 16.67, 18.33 and 10.00 packets per second, respectively.

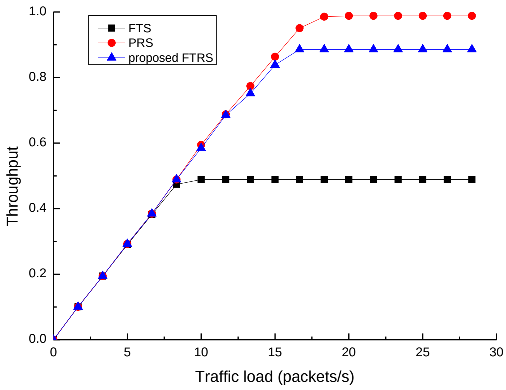

FIGURE 6 Throughput

The maximum throughput of PRS is the highest among three methods, since it is a contention-free method with time slot reused. The maximum throughput of the proposed FTRS is slightly smaller than that of the PRS, for keeping the fairness between the nodes. The maximum throughput of FTS is the smallest, since it focuses on the fairness between the nodes other than the time slot reused in the networks.

B. End to end delay.

The comparison of the end-to-end delay of the three methods is shown in Figure 7. From Figure 7, we can observe that the throughput of three methods increases along with the increase of the traffic load. The end-to-end delay of the PSR protocol increases much slower than other two methods, when the traffic load increases. The reason is that, the PSR method makes the packets wait less time for transmitting. The end-to-end delay of the proposed FTRS, PRS and FTS increases fast, when the traffic load is more than 16.67, 18.33 and 10.00 packets per second, respectively. The end-to-end delay of the FTS protocol increases fastest among these protocols. The reason is that it makes the packets wait too much time for transmitting. The end-to-end delay of the proposed FTRS protocol increases faster than that of the PRS, since it makes some time slots unused, in order to guarantee the fairness between the nodes.

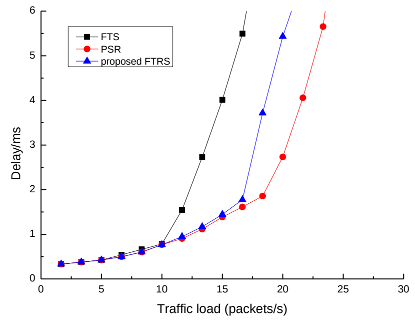

FIGURE 7 End-to-end delay

C. The packets drop ratio.

The comparison of the packet drop ratio of three protocols is shown in Figure 8. From Figure 8, we observe that the packet drop ratio of three protocols increases along with the increase of the traffic load. The packet drop ratio of the PRS protocol is the smallest among these protocols. This is because it improves the efficiency of the channel for improving the reusing of the time slot.

The packet drop ratio of the proposed FTRS, PRS and FTS increases fast, when the traffic load is more than 16.67, 18.33 and 10.00 packets per second, respectively. The packet drop ratio of the proposed FTRS protocol is slightly larger than that of the PRS protocol. This is because it makes some time slots unused for keeping the fairness between the nodes. The packet drop ratio of the FTS protocol is the largest among the three protocols, since it focuses on the fairness of the nodes and wastes too much time slot, leading to reducing the efficiency of the channel.

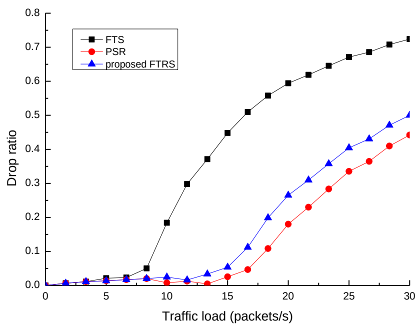

FIGURE 8 Packets drop ratio

D. Fairness index.

The comparison of the fairness index of three protocols is shown in Figure 9. From Figure 9, we observe that the fairness index of three protocols is almost one when the traffic load is low, and it decreases along with the increase of the traffic load. This is because the nodes drop no data packets when the traffic load is low, and the transmission speeds of the nodes are almost the same. When the traffic load increases, some nodes will drop the packets when the time slots assigned for the nodes are not enough, and the transmission speeds of the nodes will decrease.

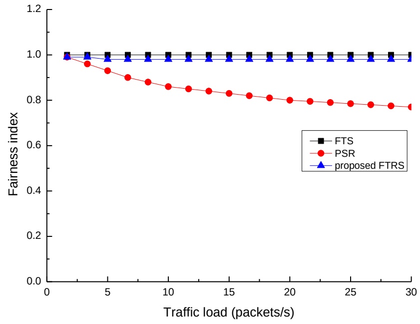

FIGURE 9 Fairness index

The fairness index of the proposed FTRS protocol is almost one, which is slightly lower than that of the FTS protocol. This is because it makes some time slots unused for keeping the fairness between the nodes. The fairness index of the PSR protocol is the smallest among these protocols. This is because it assigns more time slots for some nodes than the other nodes, in order to improve the reusing of the time slot in the networks.

E. Resource reuse factor

Figure 10 shows the comparison of the resource reused factor of the three methods. From Figure 10, we observe that the resource reuse factor of the three methods increases when the traffic load increases. This is because the nodes have not any packets to transmit even they can reuse the time slots with other nodes when the traffic load is low, the phenomenon will not happen when traffic load is high.

The maximum value of the resource reuse factor of the PSR is 1.99, and the maximum value of the resource reuse factor of the proposed FTRS is 1.78. This is because that, the proposed FTRS wastes some time slots which can be reused in some nodes for keeping the fairness between the nodes. The resource reuse factor of the FTS protocol is the smallest among these protocols, since the FTS focuses on the fairness of the nodes and wastes the time slots which can be reused.

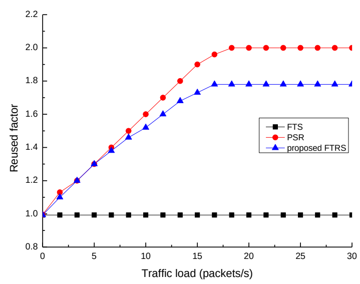

FIGURE 10 Resource reused factor

5 Conclusions

In this paper, a transmission scheduling for providing fairness (FTRS) between users has been proposed. It assigns time slots for the users in the networks with spatial reused. It is good for reducing collisions of packets, especially in the multi-hop PLC networks, and improving the performances of networks. It also provides fairness between users by making them transmit their packets with the same cost. The simulation results show that, the maximum throughput of FTRS is almost two times about that of the FTS protocol, while the fairness index is almost the same as that of the FTS protocol. The maximum throughput of FTRS is slightly lower than that of the PRS protocol, but the fairness index is much higher than that of the PRS protocol. The simulation results show that the proposed protocol can achieve a trade-off between the high throughput and the fairness, compared to the existing protocols.

Future work should be concentrated on the development of proper algorithm for multi-cell PLC networks with different physical bit rates. Moreover, the transmission scheduling with three-phase AC, and the approach to provide a more QoS guarantee to all users are also important issues that should be studied.

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