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Enhancing Power Line Communication Utilization by an Enhanced Hybrid Bandwidth Allocation Scheme

Tin-Yu Wu[1,*], Wei-Tsong Lee[1], Chia-Fan Lin[1], Jhih-Siang Huang[1], and Yu-San Lin[2]

[1]*Department of Electrical Engineering, Tamkang University, Taiwan, R.O.C.*
[2]*Chung-Shan institute of Science and Technology, Taiwan, R.O.C.*

Thanks to the rapid development of the Internet in the past ten years, all kinds of wideband services have been proposed and adopted successively and power line network, which offers an environment of low cost deployment, is no exception. Because power lines have existed in every corner of the world, its deployment cost is comparatively low compared with other types of networks. Generally speaking, power line communication (PLC) and wireless network use the same transmission medium and their channels must be allocated for users to use simultaneously. However, there are still some differences between them. For example, compared with wireless network, the migration rate of power line communication users is more stable. Due to the physical characteristics of the transmission medium, users not only use the same transmission medium, but also share the contents of the medium. In this paper, by extending the concept of hybrid algorithms to power line communication, we modify and adjust the scheme based on the features of power line communication. With the simple synchronization, every node can calculate the optimal bandwidth proportion for transmission on its own and the functions of power line network thus can be further optimized.

Keywords: PLC, CSMA/CA, TDMA, Hybrid Algorithm.

1. INTRODUCTION

Because of the fast development of the Internet over the past ten years, various wideband services have been released and adopted sequentially and power line communication (PLC) that offers an environment of low cost deployment is no exception. Since power lines have existed in every corner of the world, its deployment cost is comparatively low compared with other types of networks. Power line communication also provides many kinds of applications, like VoIP, multimedia transmission, intelligent appliances control, power management, and so on Refs. [1–3].

Numerous recent power-line-related researches have suggested power line communication using the frequency ranging from 1.6 MHz to 30 MHz bandwidth for transmissions, and classified the possible noise disturbances into background noise, narrowband noise, and impulse noise.[4,5] Furthermore, because the distribution of power lines is complex, the interference caused by multipath effect is usually taken into consideration.[6,7] Multipath channel and echo model have been proved to fit real world networks.[8,9] In previous researches, OFDM[10] has already been regarded as one efficient solution to deal with impulse noises and multipath effect.[11] Error-Correcting Codes, like Turbo Code,[12] are adopted to handle terrible channels.

Power line communication and wireless network generally use the same transmission medium and their channels must be allocated for users to use simultaneously, but there are still some differences between them. For instance, compared with wireless network, the migration rate of power line communication users appears to be more stable and users not only use the same transmission medium, but also share the contents of the medium. At present, most power line communication modules manage the bandwidth by integrating the features of TDMA (Time Division Multiple Access) and CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance), which will be briefly explained below.[13,14] In the initial phase, the coordinator node (usually the first node that connects to the power line) allocates the timeslots to each node for each node to transmit packets according to the allocation. The foregoing process is the same as traditional TDMA algorithm, but with the increase of available bandwidth, it is very possible that all nodes complete the transmission in their allocated timeslots and enter meaningless waiting time. Therefore, the aim of our proposed hybrid algorithm is to release the bandwidth during the waiting time for other nodes to contend in the way similar to CSMA/CA algorithm. The bands that might be

*Author to whom correspondence should be addressed.

wasted originally can be utilized to improve the efficiency of the system.

In this paper, by extending the concept of hybrid algorithms to power line network in the MAC (Medium Access Control) layer, we modify and adjust the proposed scheme based on the features of power line communication. In the same way, the transmission channel is divided into several frames, which are moreover classified into negotiation window and data transmission window. By introducing the transmission features of power line communication, all nodes are able to allocate the channels by themselves without an extra coordinator.

This paper is divided into five sections. In addition to this section, the rest of this paper is organized as follows: Chapter Two reviews related works and analyzes the effects and solutions of multi-channel in wireless environments in terms of Signal-to-Noise Ratio (SNR) of different signals in Direct Sequence Spread Spectrum (DSSS) modulation and Ergodic Chaotic Parameter Modulation (ECPM). Chapter Three introduces our proposed scheme, which uses synchronization for every node to calculate the optimal bandwidth proportion for transmission and enhance the performance. The performance evaluation is given in Chapter Four to prove our scheme. Finally, Chapter Five concludes this paper.

2. BACKGROUND AND RELATED WORK

The specification of PLC is IEEE-P1901 (Broadband Over Power Line) that can be divided into HomePlug Power-line Alliance, (HPA) and Universal Power-line Association (UPA), both of which are currently the members of IEEE-P1901 group.[15] Founded in March 2000 and established by a group of enterprises including Cisco, HP, Motorola and Intel, HPA first published the HomePlug 1.0 specification in June 2001. The latest specification of HPA, HomePlug AV, was published in 2005. On the other hand, established in May 2004, UPA's specifications cover not only PLC commercial markets and applications but also certified products that conform to agreed specifications. The members of UPA include DS-2, Itochu, Ilevo, Buffalo, Toshiba Electronics Europe, Power Monitors and so on Ref. [4]. Investigated the PLC performance for the receivers of DSSS modulation and ECPM and analyzed the SNR of the two techniques. The performance evaluation reveals that the SNR of both DSSS and ECPM is similar in a power line environment dominated by narrowband or impulsive noise. EPCM is found to be less robust to low-frequency interference while the implementation of DSSS is more complex.

The MAC protocols can be generally classified into three categories: pre-allocation protocols, reservation-based protocol, and contention-based protocol. Pre-allocation protocols are originally used to process voice traffic streams that are either silent or active (talkspurt). In a silent period, the data is not delivered, which not only wastes the bandwidth but also decreases the bandwidth. While the demand for other data types increases, the pre-allocation protocols designed to handle voice streams cannot conform to the diversity and dynamics of the traffic demands anymore and become inefficient. TDMA and FDMA (Frequency Division Multiple Access) both belong to pre-allocation protocols.

To utilize the bandwidth dynamically, reservation-based protocol were therefore proposed. Packet Reservation Multiple Access (PRMA), for instance, is one of the reservation-based protocols. In PRMA, the bandwidth is gathered according to the active state (talkspurt). At the beginning of the active state (talkspurt), the reservation requests are allocated by the contention channel. When the reservations are made successfully, many slots will be allocated by the talkspurt until the end of the active state. Compared with TDMA, the channel utilization of PRMA is improved obviously. Nevertheless, when packet collisions occur in the contention channel, the talkspurt for receiving reservation request successfully will be unlimited and result to the discarding of the previous packets. Though improved and enhanced by many researches, to guarantee the limited transmission delay but waste the bandwidth, or to utilize the channels efficiently but lead to immeasurable reservation delay remains to be the question.

Thus,[13] proposed an integrated and self-adjusted MAC protocol, which combines the concepts of TDMA protocols, reservation-based protocols, and contention-based protocols. In the HAMAC (Hybrid Adaptive Media Access Control) protocol, the contention channel can be used for data transmission and for dynamic and efficient bandwidth allocation in multimedia wireless environments. Moreover, by using a preservation technique, the HAMAC protocol enhances the QoS of voice and video. The more distributed bandwidth, the more efficient the HAMAC protocol will be.

In a multi-channel MANET (Mobile Ad Hoc Network), the multi-channel hidden terminal problem is usually solved by a transceiver to reduce hardware cost. Many previous researches have proposed to divide the beacon interval into channel negotiation and data transmission to avoid the multi-channel hidden terminal problem. In the MMAC protocol, the Announcement Traffic Indication Message (ATIM) window is added at the beginning of every beacon interval and the channels are classified into three statuses: high, medium and low. Before every turn of data exchange, the common channels are monitored to acquire every node's traffic indication messages, which are used to maintain each node's Preferable Channel List (PCL) for channel selection. Nevertheless, the transmissions cannot launch until the end of the ATIM period because of the fixed size of the ATIM window, which limits the network throughput. In a light loaded network, channel utilization is inefficient.

Therefore,[14] proposed Traffic Aware Multi-channel Medium Access Control (TAMMAC) protocol, which adopted a dynamical ATIM and added a network traffic condition-based dynamic regulated scheme for channel negotiation and data transmission with the aim to optimize the channel utilization and improve the whole network throughput. The TAMMAC protocol allows the host to have different negotiations with the receiver at the same time.

Since the above-mentioned papers are chiefly applied to wireless environments, we make a comparison between power line network and wireless network. In a wireless environment, the same single transmission medium is used and thus the channel must be allocated for data transmission so that users can transmit and receive information of different channels simultaneously. Different from wireless network, the mobility of power line network users is comparatively low. In a power line environment, when one of the nodes sends out the packets, the other nodes in the environment can monitor the status, which means that packets in a power line environment are transmitted in the way of broadcasting. In addition, it is worthy mentioning that power line network outperforms wireless network in audio/video transmission when there is no interference.

It occurs to us that packet broadcast of power line network is applicable to the movement of wireless network before packet

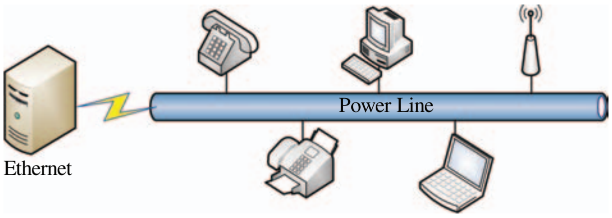

Fig. 1. Architecture of power line network and its applications.

transmission. For this reason, we transfer the techniques originally applied to wireless environment to power line environment. To further present the better performance of power line network in transmitting audio/video packets, we regulate the weight according to different data types with the aim to attain better audio/video transmission.

3. THE PROPOSED HYBRID BANDWIDTH ALLOCATION SCHEME

Because the transmission medium in power line communication is shared to whatever connected, the packets sent by either node will be monitored by other nodes in the same network. In other words, every single packet is also a broadcasting package itself. As shown in Figure 1, this characteristic allows the bandwidth of power line network to be shared by all connecting nodes and our proposed algorithm is designed in terms of the characteristic.

The classification of this algorithm is based on the frames and the usable channels. As illustrated in Figure 2, a frame is divided into data transmission window and negotiation window, which is separated into two parts based on the functions.

Two beacons in negotiation window are sent by the bridge. It is assumed that the first bridge to connect to the power line is taken as the main coordinator whose responsibility is to send node detection beacon and weight announcement beacon in the coordination phase. However, not every frame executes the two steps.

After several frame durations, the main coordinator sends a detection beacon that includes the numbers of all nodes up to now to negotiation window so that new joining nodes can respond and get their own serial numbers to join in the next contention queue of data transmission window.

By monitoring the weight announcement beacon sent by the coordinator, all nodes broadcast the weight of the accumulated data so far and simultaneously monitor the weight sent by other nodes for further calculation. In light of the calculation result, each node's available time in data transmission window will be

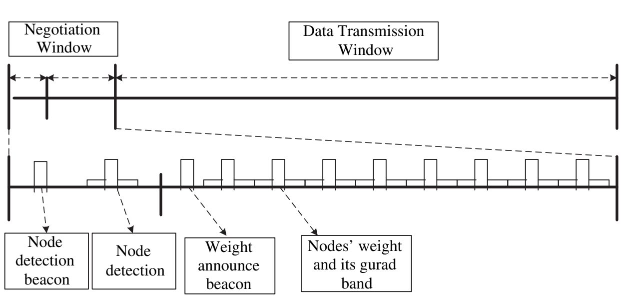

Fig. 2. The frame structure for weight announcement beacon and its guard band.

Table I. Packet classification and the corresponding weight.

Packet classification	Weight
Voice	Extra high
Video	High
Best effort	Medium
Background	Low

allocated proportionally. Since the beacon includes the message of synchronization, even without extra coordination, all nodes can make good use of data transmission window to achieve the optimal channel utilization. Because the number of connecting nodes is already known in the node detection phase, the length of this window differs with the number of nodes.

To consider the insufficient frame length and the delay, our proposed algorithm increases the weight of a packet according to the number of delays and the equation thus can be given by:

$$D_w = \sum_{k=D} \{D_n \times (1 + 0.2 \times k)\}, \quad 0 \leq n \leq 5 \qquad (1)$$

Where D_w denotes the total weight of the delayed data and D_n refers to the data that has been transmitted for the nth time. It is revealed that the longer the data is delayed, the faster its weight is increased to accelerate the transmission rate. Besides the original weight of data (D), our algorithm gives different weight to different types of data. Also, for the timeliness of data and the applicability of channels, when a packet has been delayed for more than five times, this packet is regarded as invalid and expired, and will be discarded. The purpose of this step is to ensure that the data that has been delayed for too long will not obtain too high weight to transmit data that might be expired already and the channel utilization can be enhanced.

802.11e has defined to give different transmission priority to different types of data. Therefore, in addition to maintain a high of quality of QoS, our scheme proposes a similar weighting method as displayed in Table I.

With the packet classification, the equation is further revised into:

$$D_w = \sum_{k=D} \{D_n \times D_{type} \times (1 + 0.2 \times k)\}, \quad 0 \leq n \leq 5 \qquad (2)$$

D_{type} means the weight according to data types. Our scheme gives different extra weight to different data types to increase the channel utilization. As real-time transmission, the weight of VoIP packets is thus set to extra higher than other types. In fact, compared with other networks those share the transmission medium (like Wi-Fi, Ad hoc Network, WiMAX and so on), users usually do not connect to the power line communication repeatedly and the utilization of power line communication is comparatively stable.

Moreover, to increase the whole transmission efficiency, our algorithm does not detect the nodes in every frame but every specific time period. Whenever a new node joins in, the node must be monitored for at least one period to use the power line communication. The flowchart of the proposed scheme is illustrated in Figure 3.

4. PERFORMANCE EVALUATION

To differentiate the proposed algorithm, the proposed algorithm without weight calculation, and a commonly-seen hybrid algorithm that integrates TDMA with CSMA/CA this section focuses

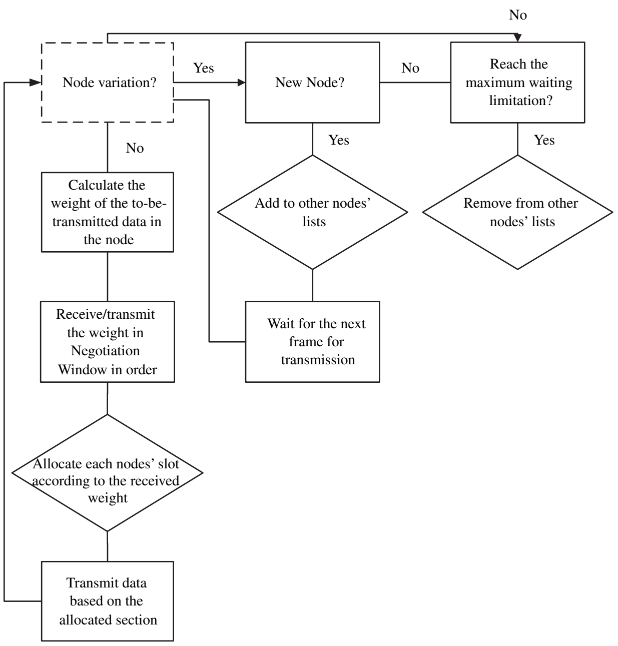

Fig. 3. Flowchart of the proposed algorithm.

Table II. Simulation Parameters.

Parameters	Value
MAC protocol	Proposed algorithm
Rate of node variation detection	400 (ms)
Channel capacity	200 Mb/s
Frame size	0.1∼10 Mbits
Negotiation frame duration	5 (ms)
Frame duration	100 (ms)
Number of nodes	50
Expiration time	500 (ms)
Platform	MATLAB 7

on the comparison of the MAC throughput and the delay of the four different data types: Voice, Video, Best-effort and Background, where real-time voice transmission is 128 bits/s, video transmission is 3.2 Mbits/s (H.264), and aside of them,

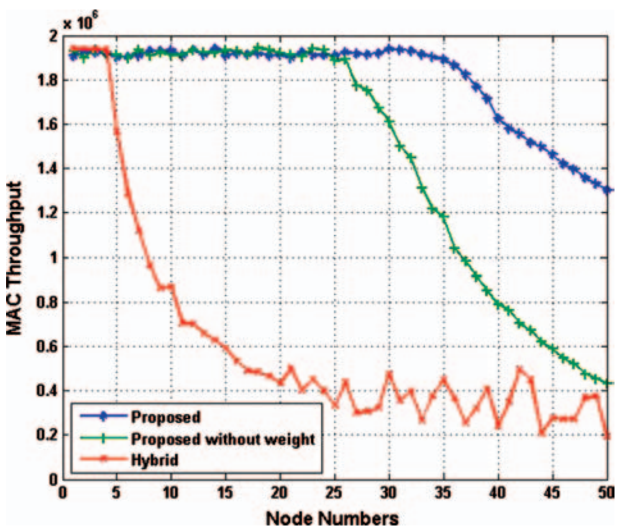

Fig. 4. Comparison chart of MAC throughput.

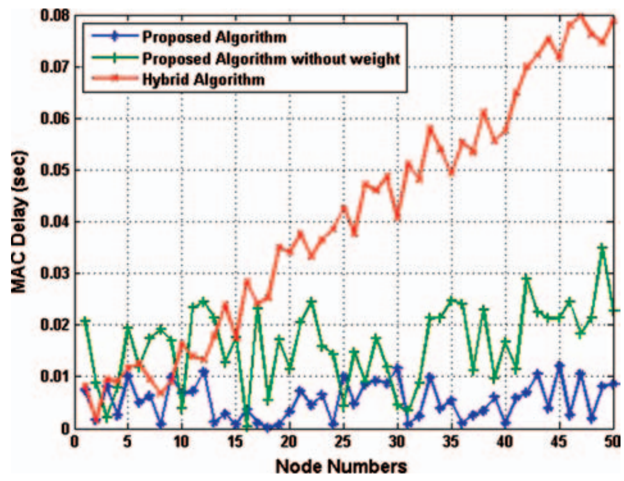

Fig. 5. Comparison chart of voice transmission delay.

best-effort and background transmission is limited to occur randomly between 0.1 and 7.5 Mbits/s. Table II shows the detailed parameters used in the simulation.

As given previously, our proposed algorithm without weight calculation simply allocates the available bandwidth proportionally and some real-time data might be delayed unexpectedly, which may decrease the efficiency and influence QoS. Without the weight calculation, the bandwidth allocation is inefficient and the performance certainly will be degraded.

To compare the MAC throughput in different number of nodes, Figure 4 shows that our proposed algorithm with four data types and weighting method is able to stabilize the transmission and maintain its own performance when the number of nodes keeps increasing. It is revealed that when the system is heavily loaded or needs to handle different data types, our algorithm obviously performs better than others.

The comparison chart of voice transmission delay displayed in Figure 5 shows that by giving weights to different data types, the performance of our algorithm on the MAC delay can be minimized. Figure 6 is the comparison chart of video transmission delay. Compared with voice packets, the data amount of video packets is huge and as a result, the MAC delay increases due to

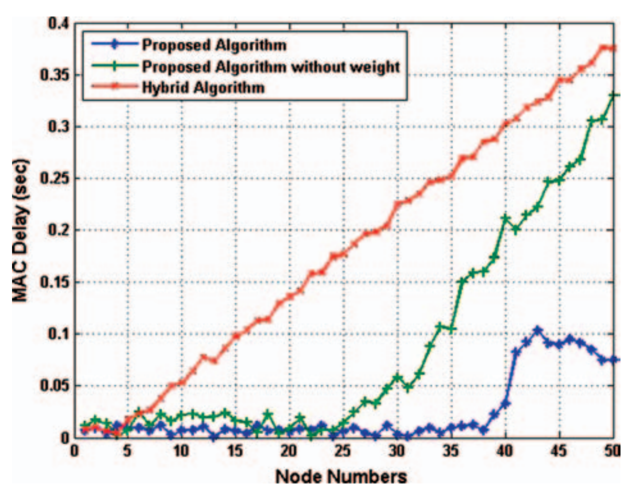

Fig. 6. Comparison chart of video transmission delay.

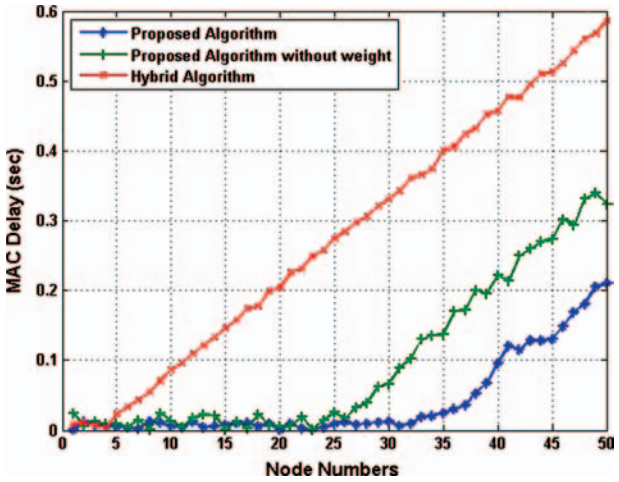

Fig. 7. Comparison Chart of Best-Effort Transmission Delay.

the larger size of packages. Therefore, for users to have the optimal utilization, the weight of video packets is set only second to voice packets.

Figure 7 displays the MAC delay in transmitting best-effort packets, which include most web-based activities, like browsing websites and downloading files. For this reason, best-effort packets occupy the biggest part of bandwidth and lead to higher latency. Nevertheless, compared with the above-mentioned voice and video packets, users' demands on this kind of latency are not so severe. Figure 8 displays the MAC delay in transmitting background packets. Although most users are not interested in this delay type, some background programs still have to exist and keep real-time, like synchronizing and keeping connected to the server.

We take down the maximal MAC delay of the two figures and find that the MAC delay in voice transmission is reduced from 0.08 s to 0.012 s, the MAC delay in video transmission is reduced from 0.375 s to 0.11 s, the MAC delay in best-effort transmission is reduced from 0.6 s to 0.21 s, and the MAC delay in background transmission is reduced from 0.2875 s to 0.225 s. The result reveals that the MAC delay of our proposed algorithm decreases the most in voice transmission and video the next. It proves that

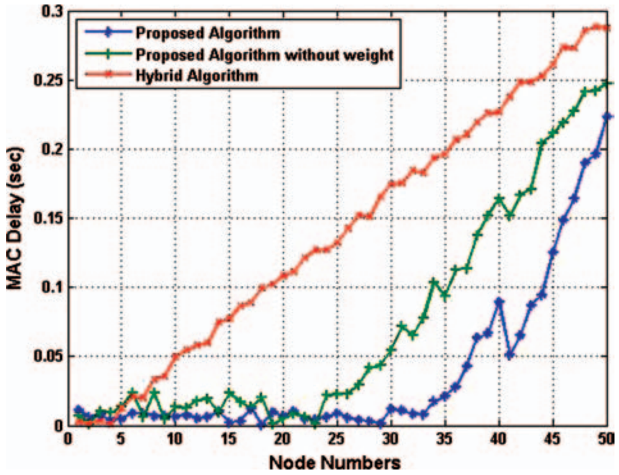

Fig. 8. Comparison chart of background transmission delay.

while transmitting different types of data, the hybrid algorithm uses preservation slot to enhance the audio/video quality, but our proposed algorithm outperforms the hybrid algorithm especially in voice and video transmission.

5. CONCLUSIONS

In this paper, we proposed an enhanced hybrid bandwidth allocation method that can attain high channel utilization because in the power line network, the same transmission medium is shared even at both the transmitter and the receiver. Therefore, when a node sends out packets, other nodes in the same network can monitor the information. Our method is improved from the multi-node transmission methods in multi-channel wireless network given in Refs. [13, 14]. Different from wireless network, the mobility of power line network users is comparatively low, and packets in a power line environment are transmitted in the way of broadcasting. The classification of our method is based on the usable channels and the frames and each frame is divided into negotiation window and data transmission window. The coordinator can gather the weight returned by each node for further calculation, allocate the bandwidth according to the calculation result, and determine the available time of each node at data transmission window proportionally. Moreover, to consider the insufficient frame length and the delay, our proposed algorithm increases the weight of a packet according to the number of delays.

Finally, in accordance with the features and popularization of audio/video transmission, we regulate the weight based on different data types in order to attain better audio/video transmission. Therefore, with a simple synchronization step, every node can calculate the optimal bandwidth proportion for transmission and betters the functions of power line network. With the attempt to achieve the optimal performance, our future target is to deal with the interference that household power line network may encounter and modify the calculation of the algorithm in terms of the utilization in different periods of time.

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