International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 14 Issue 3 ǁ March 2026 ǁ PP. 20-26

Proficient Access Control Orders for Home Area Networks

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Abstract
The rapid growth of smart homes and Internet of Things (IoT) devices has increased the need for secure and efficient access control mechanisms within Home Area Networks (HANs). Traditional access control schemes often suffer from high computational overhead, scalability issues, and vulnerability to security threats. This paper proposes an efficient access control scheme tailored for HAN environments that ensures secure authentication, fine-grained authorization, and low resource consumption. The proposed model leverages lightweight cryptographic techniques and role-based policies to enhance security while maintaining system performance. Security analysis demonstrates resistance against common attacks such as unauthorized access, replay attacks, and impersonation. Performance evaluation shows that the scheme achieves reduced computation and communication costs, making it suitable for resource-constrained smart home devices.
Keywords: *BPLC,MACProtocol,CSMA,Beacon, IBFD*

Date of Submission: 01-03-2026 Date of Acceptance: 10-03-2026

I. Introduction

Develop some efficient access control schemes to address two problems that arise when broadband powerline communication (BPLC) are employed in EHANs. On one hand, the physical (PHY) data rate is not efficiency translated into throughput in the media access control (MAC) layer. In this regards, we propose two new techniques that take advantage of in band full duplex (IBFD) to improve the MAC efficiency. Specifically, we propose CFP to eliminate superfluous random back-off stages and, we propose mutual preamble detection (MDP) to avoid lengthy collision recovery. On the other hand, an interface to accommodate heterogeneous network traffic generated by various application running over power line communication EHANs is not yet available. In this aspect, we propose an interface that uses network traffic prioritization to accommodate their different quality of service (QoS) requirements and traffic shaping to realize centralized bandwidth management and admission control. The format of home plug green physical (HPAV) media access control (MAC) frame transmission in carrier sense multiple access collision avoidance (CSMA/CA) mode. All the other time intervals without data payload are MAC overheads impending the MAC efficiency. Note that in case of a collision, the transmitted data payloads corrupt each other thus all the time intervals are also MAC overheads [5]. With the goal of bringing practical values of η as close as possible toηmax, we attempt to reduce the total time duration of these MAC overheads as much as possible. Specifically, we propose contention free pre sensing (CFP) to eliminate the redundant back-off stage and mutual preamble detection (MDP) to avoid the lengthy collision recovery.

II. Problem Formulation and Proposed Method

2.1 Problem Formulation

In a EHANs, despite the high physical (PHY) layer data rate supported by the HPAV protocol, it remains a challenge to effectively translate this data rate throughput in the medium access control (MAC) layer. The efficiency of HPAV, MAC protocol is largely confined by various kinds of MAC overheads. The CSMA with collision avoidance (CSMA/CA) operation is associated with the lengthy collision recovery. Regardless of this, the HPAV protocol implements CSMA/CA because collision detection (CD) generally requires in band full duplex (IBFD) operation. Moreover, in order to avoid collision, each CSMA/CA transmission is associated with a random back-off stage, which further restricts the achieved MAC throughput. We need to reduce these MAC overheads caused by contention and collision to improve the MAC efficiency. In order to, accommodate heterogeneous network traffic generated by various applications running over PLC, EAHNs, [1]an interface with quality of service (QoS) differentiation is required. The HPAV uses multiple priority levels to prioritize the network traffic. Yet, a specific traffic prioritization scheme for EHANs needs to be proposed. To better manage the network resource utilized by each priority level, in particular, to prevent lower priority starvation, a traffic shaping schemes is required. Thus, we need to propose an interface with network traffic prioritization and traffic.

2.2 Proposed Method

In this section, we propose our first scheme called contention free pre sensing (CFP) to detect a CFC during the priority resolution period (PRP) and second scheme mutual preamble detection (MDP). Section below we are going to describe our method one by. A contention free condition (CFC) is identified by a network node when it does not detect any other network node transmitting with the same or higher priorities during the priority resolution period (PRP). To detect a CFC, we equip network nodes with in band full duplex (IBFD) capability and allow them to detect priority resolution slot (PRS) transmitted by other nodes while transmitting a PRS themselves

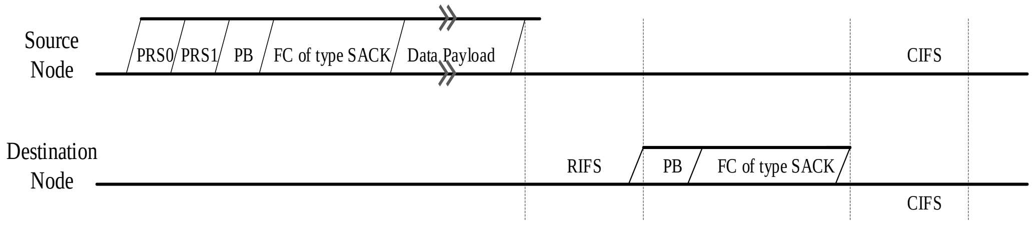

Figure.1 the MAC Frame Transmission with CFP when a CFC Successfully Detected

- **Detecting CFC using IBFD in CFP**

Consider a network of K nodes, where N of those nodes contend to transmit a frame, with priority levels pn associated with each of the n=1, 2.., N nodes. A CFC occurs when only one of the N nodes transmits a message of the maximum priority level of all transmitting nodes, maxp_n, with 0<max $p_n \leq p_{std}$ where $p_{std} = 2^m$-1(m $\epsilon \mathbb{Z}^+$)is the highest support priority level of a message in the operating standard. For example, in the IEEE 1901.1 and HPAV standard, m=2. In order to provide upward compatibility for future standards that may decide to support a great number of priority levels to effective serve traffic of varied nature, we present an analysis of our proposed CFP procedure for general m. We designate a p_x-CFC to arise when only one network node transmits a message with max $p_n = p_x$. Our CFC scheme is aimed to successfully detect such p_x-CFCs, for all 0 <$p_x \leq p_{std}$. Every priority level p_n can be express as.

- **Detection Error and False Alarm Rates of the CFP**

We denote the false alarm and detection error rates of the CFP at a network as and, respectively to aid our derivations, we define following the three events at a given network node.

- E_0 : The node transmits a PRS.
- E_1 : The node detects the presence of at least one PRS signal transmitted by another node in the network.
- E_2 : At least one node other than the consider node actually transmits a PRS.

We can now present $P_{\text{DE}} = P(E_0 \cap (\overline{E_1} \mid E_2))$, where $\overline{E_n}$ represent the nonoccurrence of the event. In order to calculate P_{FA} and P_{DE} , we consider a network with two nodes A and B, with node A continuously transmitting PRSs, while node B either transmits a PRS or remains silent.

- **Network Operation with Mutual Preamble Detection (MPD)**

Now we introduce our second access control enhancement called Mutual preamble detection (MDP) where we use the medium aware transmission ability provided by the IBFD capability to avoid lengthy collision recovery by predicting a future frame collision. Through MPD, we essentially propose a practical scheme to realize carrier sensing multiple access collision detection (CSMA/CD) in BPLC networks by detecting the overlapping preamble signals.

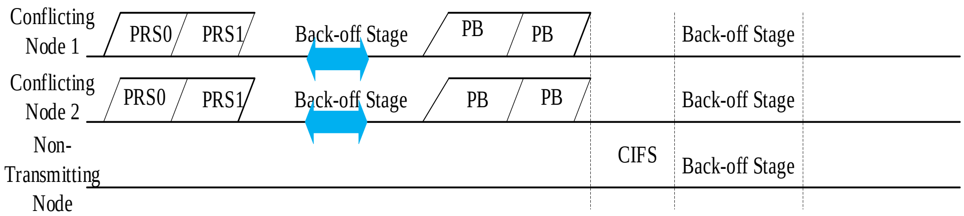

Figure.1 Activity on the Medium in case of a Collision with the Deployment of MPD

Under such circumstance, we compel these conflicting nodes to transmit another preamble signal subsequently. This acts as a jamming signal to ensure that all network nodes are made aware of a potential collision.

- **The IBFD Preamble Detection**

To determine the success of an IBFD preamble detection, consider a BPLC network with two nodes, A and B with node, A continuously transmitting preambles slot by slot, while in each time slot, node B either transmits a preamble or not.We view the behavior of node B as a source continuously transmitting information bits using OOK, with the preamble signal being the transmission pulse. In every preamble time slot, node B transmits a bit '1' to send a preamble to node A, and a '0' when it has nothing to transmit. An IBFD enabled node A is able to continuously detect the information bit sent by node B in each time slot.

III. Implementation of CFP and MDP in a BPLC Device

3.1 Hardware Implementation Cost

The elementary requirement for implementing contention free pre-sensing (CFP) and mutual preamble detection (MDP) in power line networks is to incorporate broadband powerline communication (BPLC) modems with in band full duplex (IBFD) capability. Recent works have shown that adding IBFD capability to a BPLC devices requires minimal changes to the modem chipsets, with only an additional power consumption of about 0.1 w for the active hybrid circuit that is used at the power line modem interface.

- **Interoperability**

Our proposed CFP and MDP schemes are completely inter operable with half-duplex (HD) devices. For CPF an IBFD enabled node can detect a CFC when it is the only node transmitting the highest priority message regardless of whether the other nodes are IBFD enabled. However, ahalf-duplex (HD) node is unable to detect a CFC. For MDP when only a part of the network nodes are IBFD enabled, MDP still offers improvements in η, but with reduced effect compared to the case when all the network nodes are IBFD enabled.

3.2 Network Traffic Generated by EHAN Applications

(1) Home Automation Applications. Home automation traffic is typically short in duration but frequent in occurrence. It generally consists of data collected by various sensors liketemperature monitoring data or control commands sent by control units, like turning on/off a device. Due to the large number of sensors, controllers, and actuators in future in home environments, we expect the number of data packets to be also large. These data packets require in-time robust delivery.

(2) In Home Multimedia Applications. Multimedia data are generally AV streams that are for example generated by video, conference, in home gaming, or high definition AV streaming. These are bur sty in nature and have high data throughput requirements [7]. Concurrently, network traffic generated by in home multimedia applications are also required to be delivered robustly in time.

(3) PLC Network Management Function. EHANs also contain network management traffic that requires in time robust delivery.

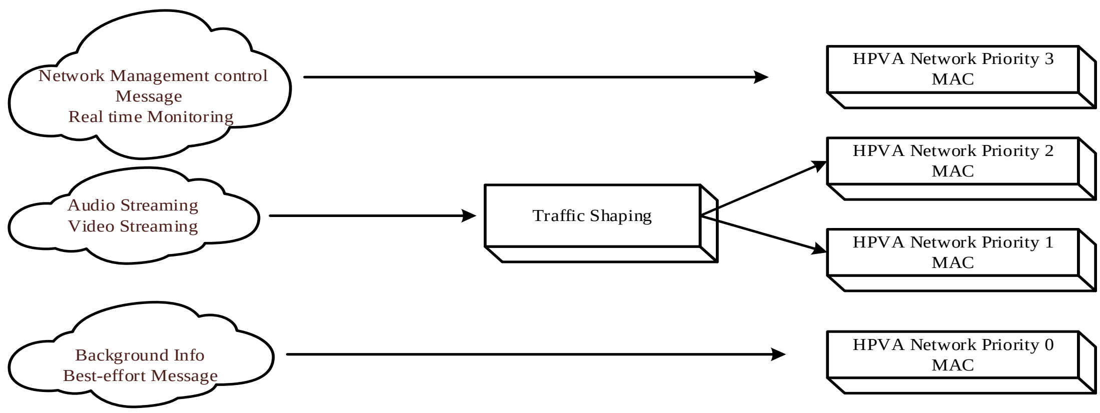

Figure. 2 Illustration of Prioritization and Traffic Shaping

- **The Prioritizing EHANs Traffic**

The heterogeneous network traffic generated by these applications require EHANs to provide QoS differentiation function. Since the HPAV protocol supports MAC frame transmissions with different priority levels, we propose a specific network traffic prioritization scheme for the EHANs.

(1) Priority 3. General control message typically require in-time robust delivery. Some of these messages are generated in a cyclic manner while some other are triggered event based. We express the average arrival rates of priority 3 MAC frames at the nth network node asλ_n, 3 which depends on the average message generation rates of general control messages.

(2) Priority 2 and 1. We reserve these priorities to multimedia traffic. The multimedia content is either stored locally at the source node or is retrieved from external sources typically the internet. [3]In either case, the source node pre fetches multimedia content into the buffer to ensure that there is always some AV streaming data ready to be transmitted beforehand. Such a prefetching also referred to in the literature as buffering or caching is required at the source node for the smooth delivery of multimedia streams.

(3) Priority 0. After serving the higher priority traffic, we tune the network nodes to utilize the remaining resources to transmit as many priority 0 MAC frames as possible. In order to transmit priority 0 MAC frames.

IV. Performance Evaluations

In order to verify the effectiveness of our proposed schemes, we simulate the in home PLC network and evaluate their performance in the different network settings using a discrete event simulator, Opnet 14.5 education version.

4.1 Simulation Model

The simulation network topology is shown in Figure 4. Several network nodes including the CCO are interconnected to each other through the power line medium in a star model. Out of these, only a set of N nodes are active with data to transmit. In our simulations, we assume

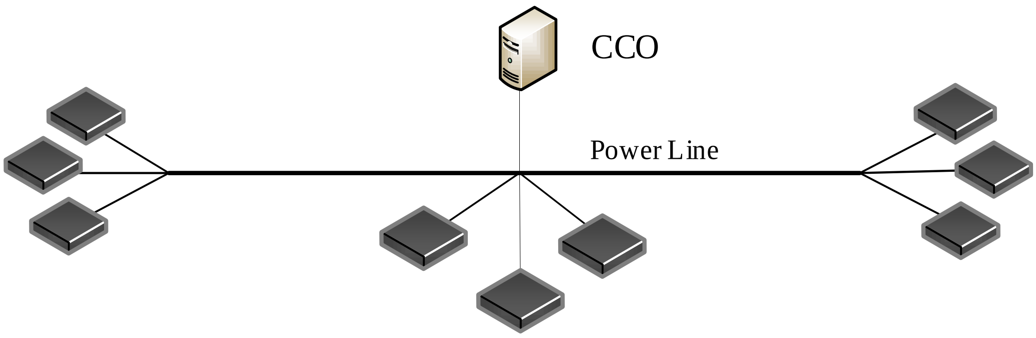

Figure. 4 Network Simulation Topology

Table 1.Simulation parameter for the EHANs

Parameter	Value
Simulation Time, Ts	30s
t_{CIFS}	100μs
PRS and Back-off slot time,tSLOT	35.84μs
t_p	35.84μs
t_{FC}	133.92μs
Max FL	2341.12μs
t_{RIFS}	140 μs
t_{EIFS}	2920.64μs

an identical time interval of the data payload,t_{FL}, regardless of its priority level. The simulation parameters are listed in Table 4.2 and are based on the HPAV specifications [6]. The significance of the simulation results is guaranteed by the sufficient simulation time,T_S where the resultant MAC efficiency of each simulation run is the average performance of several thousand of MAC frame transmission. By denoting the total number of transmitted MAC frames with successful acknowledgements asn_{ACK}, we compute the MAC efficiency, η, at the end of our simulation runs as

$\eta = \frac{n_{ACK}\ t_{FL}}{T_S}$(1)

Where T_S is the total simulation time see Table.1, We assume that physical layer uses a robust transmission mode [10] to transmit control sequences while we consider the multimedia streams with inherent data redundancy to be error tolerant. Therefore, for simplicity, we do not consider transmission errors as well as the associated retransmissions in our simulations. In such conditions n_{ACK} is simply equal to the number of frames transmitted without encountering collisions.

4.2 Performance of CFP with Single Node Flooding

For our first result, we use the following network setting to test the effectiveness of the CFP scheme. We set |N|=1 by letting the CCO be the only active network node that continuously transmits priority-3 MAC frames to all the other network nodes without channel idling. Under such a scenario, our proposed MPD scheme has no effect as no contention or collision occurs with this setting. The impact of varying t_{FL} on the archived MAC efficiency with and without CFP is shown in Figure 5. Since the network experiences no collision or idle time intervals, the power line medium is kept busy by continuous transmitting MAC frames shown in Figure 5. Under such conditions the MAC efficiency can also be represent as where,

$$\eta = \frac{t_{FL}}{(t_{\text{EIFS-MaxFL}}) + t_{FL} + (2 + \mathrm{E}[\eta_{BF}])t_{\text{SLOT}}} \qquad (2)$$

$\mathbb{E}[n_{BF}]$is the expected number of back-off time. Using the HPAV protocol without CFP the contention remains at the base stage of 0 as no node other than the CCO transmits packets and hence the transmission of these packets encounters no collisions or deferral.

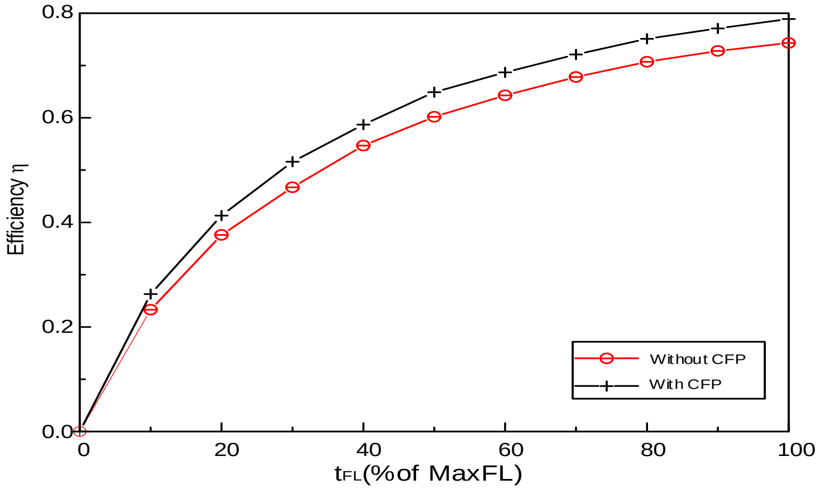

Figure. 3 MAC Efficiency as a Functional of t_{FL} under Single node Flooding

4.3 Performance Evolution with Multiple Active Nodes

To evaluate the network performance with multiple active nodes, we enable 1<| N | ≤ 25. From sub settings where we fix | N | =10 and vary t_{FL} in the first case, while we fix t_{FL}=MaxFL and vary | N | in the second.

- **Network Resource Allocation**

We calculate the average MAC frame interval at the nth network node in our simulations as,

$\mu_{n,i} = (t_{EIFS} - \text{MaxFL}) + t_{FL} + (2 + \mathbb{E}[n_{BF}]n, i)t_{SLOT}$ (3)

for the ith priority MAC frame, where $[n_{BF}]$ n,i represents expected number of back-off time slots at the nth network node for the ith priority data packet. Since the number of back-off time slots is hard to predict, we approximate $\mu_{n,i}$ as

$\mu_{n,i} \approx \mu = (t_{EIFS} - \text{MaxFL}) + t_{FL} + 2t_{SLOT}$ (4)

thus, by considering the above approximation, the admission control in our simulation can be expressed by re writing (4) as,

$$\mu\sum_{n=1}^{|N|}(\lambda_{n,}3+\lambda_{n,}2+\lambda_{n,}1)=k \qquad (5)$$

to account for the back-0ff time slots we ignored in our approximation of$\mu_{n,i}$, we choose a small K=0.65. By setting $\sum_{n=1}^{|N|}\lambda_{n,i}=\frac{k_i}{\mu}$, we allocate a certain portion of network resource.

4.4 Performance Evolutions with Varying t_{FL}

We first simulate the network with varying t_{FL} is shown in Figure 6. The curves essentially resemble those in single node flooding but with reduced η because of connections and collisions. However, all our proposed schemes improve the MAC efficiency compared to the standard HPAV protocol.

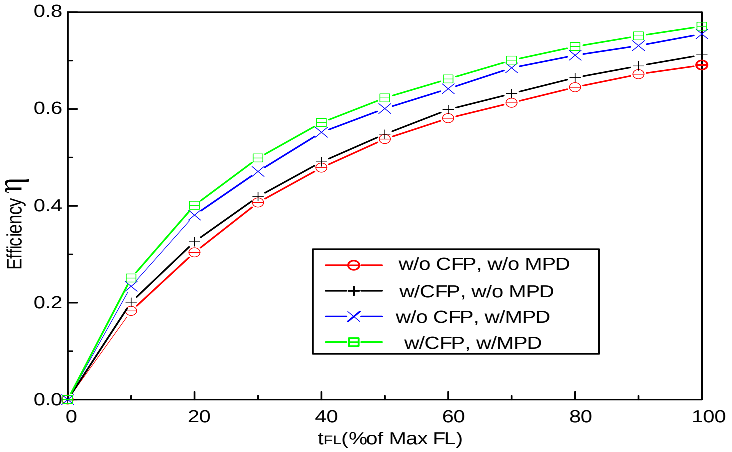

Figure. 4 The MAC Efficiency as a Function of t_{FL}

We observe that simultaneous deployment of CFP and MDP yields an η=76.80 %, which archives 98.16% of the optimal MAC efficiency, η_{max} = 78.24%. At the same time, we notice that a conventional HPAV protocol without CFP and MPD only manages to provide η=69.43%.

4.5 Performance Evaluations with Varying Number of Active Nodes

For our final results, we simulate the network with varying | N | and a fixed t_FL= MaxFL. The simulation results of this sub setting are shown in Figure7. We observe that without our MDP scheme η decreases as the number of active nodes increases due to the increased collision rate as well as the lengthy collision recovery time. We achieve a stable η across different number of nodes with MPD since our proposed MPD scheme virtually achieves CD. With our MPD scheme the potential collisions can be successfully detected and avoided which brings the cost of a potential collision to the minimum.Because of this as the number of network nodes increases although the collision rate is increased, we do not observe a degradation of MAC efficiency when our MPD Scheme is applied.

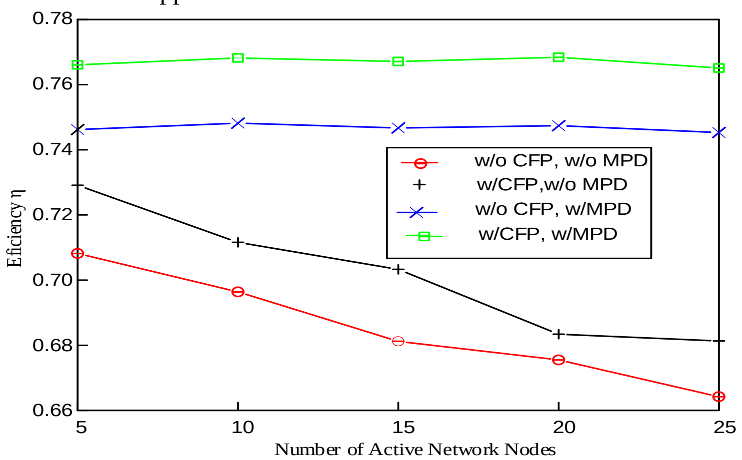

Figure. 5 The MAC Efficiency as a Function of the Number of Active nodes

- **Discussion on Metrics Used in Evaluations**

In this section, we aim to improve the MAC efficiency through the adoption of our proposed schemes. Thus, we evaluate the network performance under various conditions using MAC efficiency. Another network metrics to our interest is the latency of network traffic with nonzero priority level. However, we use admission control to ensure that messages of first three priority levels can be emptied from time to time. The probability of a message with non-zero level staying in the network goes exponentially small as the staying time increases. Thus, we do not present latency data in our EHANs performance evaluations.

V. Conclusion

In this part, we have proposed some efficient access control schemes for BPLC in EHANs. In order to efficiently translate physical data rate onto the MAC throughput, we have leveraged IBFD to propose two novel schemes CFP and MPD. CFP eliminates the redundant back-off stages while MPD avoids the lengthy collision recovery. To accommodate heterogeneous network traffic generated by various applications running over PLC for EHANs, we have proposed an interface with network traffic prioritization and traffic shaping. We have presented simulation results showing under single network node flooding and maximal MAC frame size conditions, CFP works well with MPD to considerably increase the MAC efficiency close to optimal value each scheme standing alone can also provide MAC efficiency improvements over the original HPAV protocol.

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