An Efficient Medium Access Control Mechanism for HomePNA

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Abstract— **We present a new medium access mechanism for the HomePNAv2 and HomePNAv3 MAC protocols. The proposed mechanism uses a priority aggregation technique to avoid collisions that causes the increase of the throughput. We implement, in the ns-2 simulator, the versions 2 and 3 of the HomePNA protocols with and without the proposed mechanism to compare the performance. Results show a gain in performance where the throughput increases up to 44% for HomePNAv2, and 36% for HomePNAv3. Moreover, we analyze the average delay and the jitter for all the presented protocols.**

I. INTRODUCTION

Nowadays there are different technologies available for home networks. One commercial solution uses the phone lines, which does not require installing a new cabling infrastructure. Home phoneline networks are defined by the HomePNA standard (Home Phoneline Network Alliance) [1], [2].

This paper focus on HomePNA version 2, the commercial available version, and HomePNA version 3, the new high performance version. HomePNAv2 uses the Carrier Sense Multiple Access with Collision Detection (CSMA/CD) mechanism to access the medium and transmission rates that achieve 32 Mbps. Based on the second version [3], the alliance created HomePNAv3, with two Medium Access Control (MAC) modes: synchronous (SMAC) and asynchronous (AMAC) [4]. HomePNAv3 was conceived to attain a transmission rate of 128 Mbps, with a possible extension up to 240 Mbps in the synchronous mode [5]. For comparison purposes, this paper only considers the HomePNAv3 AMAC, whose access mechanism derives from HomePNAv2.

Bisaglia et. al. [6] propose a model for the HomePNA channel and analyze its physical layer. Bisaglia and Castle [7] also analyze a receiver architecture for HomePNA and equalization techniques. Several other works concentrate on the physical layer. Concerning the medium access control sublayer, Chung et al. [8] present a mathematical analysis of the saturation throughput of HomePNAv2 MAC. Kim et al. [9] make a similar analysis for the HomePNAv3 AMAC. The saturation throughput is defined as the maximum network throughput for a given number of nodes, when every node always has frames ready to be transmitted. Kangude et al. [10] present an analysis of the MAC protocol of HomePNAv2 and its collision resolution mechanism. They show that the number of slots used in the collision resolution, as defined by the standard, is not optimal in some scenarios. Therefore, they suggest that the number of slots should be larger in order to increase the network efficiency, according to the network load.

In this paper, we propose a mechanism that increases the throughput of the HomePNAv2 and v3 protocols in asynchronous mode (AMAC). The key idea is to aggregate a fixed number, AS, of the higher priority slots into a larger highest priority period of time composed of AS slots. Then, the outgoing high priority frames are randomly assigned to one of these priority slots. Since we spread the high priority frames over more than one priority level, many collisions are avoided, especially at high network load condition. This mechanism was proposed for HomePNAv2 in [11]. In the current work, we show that the mechanism can also be used for HomePNAv3, comparing the results for all the protocols presented. Additionally, we analyze the impact of the proposed mechanism on the average delay and jitter for both protocols.

This paper is organized as follows. Section II describes HomePNAv2 and v3 protocols. In Section III, we present the proposed mechanism. Simulation results are presented in Section IV. Finally, Section V concludes the paper.

II. THE HOMEPNA MAC PROTOCOL

A. HomePNAv2

The HomePNAv2 MAC protocol is based on the CSMA/CD mechanism. HomePNAv2 includes a priority mechanism with eight levels of priority for Quality of Service (QoS) support. Different classes of traffic can be labeled with priorities from 0 to 7, where 7 is the highest one. After a transmission the medium becomes free and there is no transmission for a period of time corresponding to the inter-frame gap (IFG) which separates the frames. The IFG lasts 29 μs. After the IFG, every station can occupy the medium but they must wait for a period of time corresponding the priority of the frame it want to transmit.

As shown in Fig. 1, the time intervals are organized in decreasing order of priority. Thus, higher priority flows start transmitting earlier, without contending with lower priority traffic. The duration of each priority slot, PRI_SLOT, is 21 μs. Stations must transmit their frames at the beginning of a slot whose number is equal to or less than the frame priority.

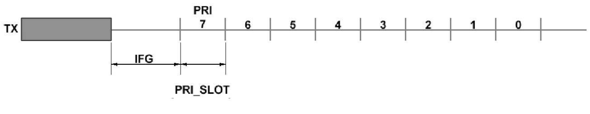

Fig. 1. HomePNAv2 priority slots.

Stations with frames to transmit shall sense the carrier and defer the transmission if any carrier is detected before the time slot corresponding to the frame priority. In this case, the time slot counting is restarted.

All stations monitor the medium to detect collisions. Inactive stations detect a collision through the transmission duration. The minimum duration of a valid frame is 92.5 μs and the maximum duration is 3122 μs. Additionally, a transmitting station can detect a collision by sensing the medium. Any station that detects its own frame collision shall cease transmission no later than 70 μs. After the beginning of this frame, so that other stations can detect the collision. Therefore, any frame fragment too short or too long is considered as a collision. If there is a collision, all stations start a distributed collision resolution algorithm called Distributed Fair Priority Queuing (DFPQ) [3]. After the algorithm execution, all stations involved in the collision are ordered in Backoff Levels (BL), which indicate the order these stations will transmit. The desired outcome is for only one station to be at BL 0, enabling it to acquire the channel. After a successful transmission, all other stations decrement their BL, and the new station(s) at BL 0 attempt to transmit. All stations, even the idle ones, shall monitor the activity on the medium to keep track of the Maximum Backoff Level (MBL). By monitoring the MBL, stations that did not collide are not allowed to contend for access to the medium until all stations that collided have transmitted one frame successfully.

As shown in Fig. 2, after a collision occurs, there are three special collision resolution signaling slots (S0, S1, and S2) before the priority slots. The BL and MBL counters are determined through these signaling slots. These slots have a duration of 32 μs, and are used only after a collision.

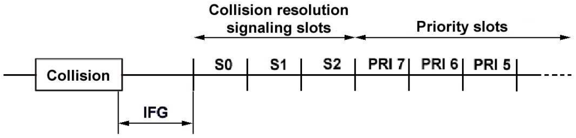

Fig. 2. Collision resolution signaling slots.

After a collision, active stations - the ones involved on the collision resolution - randomly choose one of the three signaling slots to transmit a backoff signal. More than one station can transmit a backoff signal in the same signal slot. Therefore, the stations are organized in three groups according to the chosen slot, and these groups are reorganized in three other groups, until there is only one station in each group.

The header and the trailer are transmitted at basic rate of 4 Mbps. On the other hand, the payload can adaptively use rates from 4 to 32 Mbps, according to the channel conditions.

B. HomePNAv3

HomePNAv3 adopts two operation modes in the MAC sublayer, synchronous (SMAC) and asynchronous (AMAC). In the physical layer, the main difference is that HomePNAv3 supports rates of up to 128 Mbps, with a possible extension to 240 Mbps in SMAC mode [5].

The synchronous mode was created to provide better QoS guarantees. SMAC mode uses CSMA/CA (CSMA with Collision Avoidance) in a master-slave mode with admission control and resource reservation techniques. Furthermore, SMAC uses a packet aggregation technique to increase the MAC protocol efficiency [4], [12].

The asynchronous mode is similar to HomePNAv2, and maintains compatibility with the previous version. But HomePNAv3 introduces a new collision management technique. Each node has a set of three collision resolution slots (A, B, C), that is defined when the node enters the network, and it can not be the same for two nodes. Each of the slots A, B, and C, can be defined as S0, S1, or S2, as shown in Section II. When a frame first collides, the node uses slot A for collision resolution. If this same frame collides again, then it chooses slot B, and in case of a third collision, slot C. As there is no other node in the network with this same slots set (A, B, C), this technique limits to three the maximum number of collisions per frame. This technique reduces the number of collisions and improves the network efficiency, but, on the other hand, it imposes a restriction to the maximum number of nodes in the network. As we can only have 27 different slots sets (3^3), there can only be 27 nodes at most.

III. THE PROPOSED MECHANISM

An important property of the eight priority levels of HomePNA is that different priority frames do not have to contend for the medium after a frame transmission, because each priority level has its corresponding transmission slot. A highest priority frame is transmitted first, followed by lower priority frames, in order of priority, without colliding. Thus, if three priority 7 stations want to transmit their frames, these will collide until the collision is resolved and the three frames can be transmitted in a random order. Suppose now that these three frames were randomly given different priorities, for example, 7, 6, and 5. In this case the three frames would also be transmitted randomly ordered without colliding. Therefore, the collision time could be saved just by adding some extra priority slots to some frames. This makes the network more efficient, and that was the motivation for this work.

The mechanism we propose aggregates some of these priority levels in the highest priority. The outgoing high priority frames are then mapped in one of these priorities randomly. Thus, this mechanism works like a random backoff inside the priority 7, where this small delay of the frames can avoid many collisions, depending on the number of priority levels that were aggregated in the high priority.

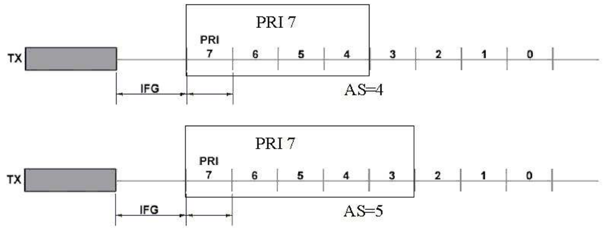

Fig. 3. The proposed mechanism for AS=4 and AS=5.

The number of aggregated slots is called AS (Aggregated Slots). The AS value ranges from 2 to 7, to keep at least two different priority levels. Fig. 3 shows an example of the priority aggregation mechanism using $AS = 4$ and $AS = 5$. In this paper, we propose this mechanism for HomePNAv2 and v3, as both use the same priority scheme. Moreover, we also determine the optimum AS value for each case, which results in the best network throughput.

An important characteristic of the proposed mechanism is that it does not need any change to the HomePNAv2 and v3 standards. The proposed modifications can be done in a sublayer above the MAC sublayer. This sublayer works as a priority-mapping interface. The priority mapping can be done in any convenient way, as long as the AS number is respected.

IV. SIMULATION RESULTS

This section presents the simulation results of HomePNAv2 and v3 with the proposed mechanism using the *ns-2* simulator. The modified versions of HomePNA were called HomePNAv2+ and HomePNAv3+, respectively.

A. HomePNAv2+

We analyze the efficiency of the mechanism and discover the best value of AS [11] considering a data transmission rate of 32 Mbps. We assume that all stations transmit 1500-byte frames with the same priority, 7, and we vary the number of transmitting nodes from 1 to 30. We analyze the throughput under saturation, where all nodes always have a frame to transmit all the time. This condition leads to the maximum utilization of the network, referred to as the saturation throughput [8], [9]. The confidence interval of the measures is 95%, represented by vertical error bars.

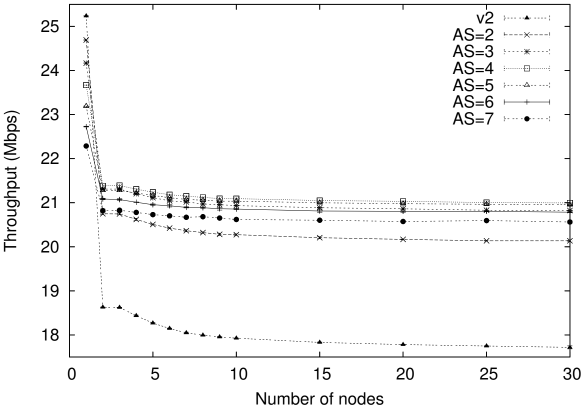

Fig. 4. Throughput of HomePNAv2+ with 32 Mbps transmission rate.

Fig. 4 shows the results for up to 30 nodes with transmission rate of 32 Mbps. The results show the throughput attained by HomePNAv2 and HomePNAv2+, for AS values ranging from 2 to 7. Note that for more than one sender, the throughput increases for every value of AS. Moreover, there is a small throughput decrease for one node, which was expected, since in this case there are no collisions.

Fig. 5 presents the same throughput values normalized by the throughput of HomePNAv2. In this figure we find the best value for AS, 4. For $AS = 4$, we obtain a 14.8% gain for 2 nodes, and 18.5% for 30 nodes, which are larger than the gains obtained for other AS values, for any number of nodes.

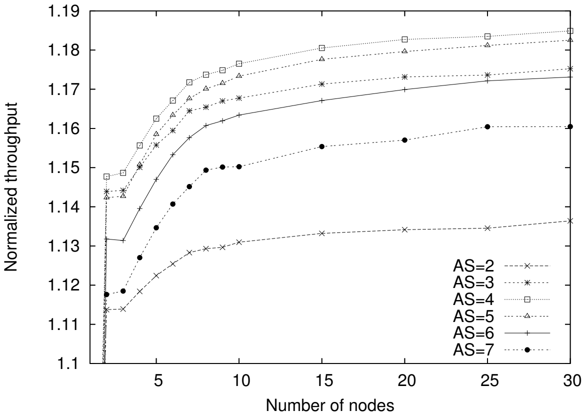

Fig. 5. Normalized throughput of HomePNAv2+ at 32 Mbps.

The frame size also influences the gain that may be obtained. Fig. 6 presents the normalized throughput of HomePNA with frame sizes varying from 160 to 1500 bytes, for 15 nodes. For HomePNAv2+, the best value of AS, 4, is used. Note that the throughput gain is larger for smaller frames because the payload transmission time is smaller and, hence, the time spent with collisions represents a larger fraction of the total transmission time. For 160-byte frames the gain obtained by HomePNAv2+ reaches 44%.

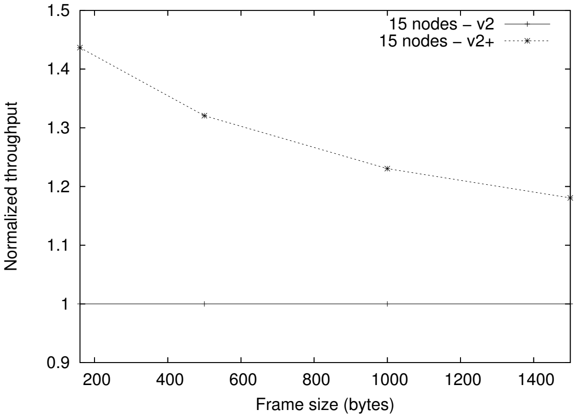

Fig. 6. Frame size influence on HomePNAv2+.

B. HomePNAv3+

First, to determine the best AS value, we executed simulations similar to the previous section for HomePNAv3+. The differences to the previous scenario are the number of nodes, limited to 27 in HomePNAv3, and the transmission rate, set to 128 Mbps. The collision resolution slots sets are randomly chosen. As the HomePNAv3 standard introduced a collision management technique which reduces the number of collisions compared with HomePNAv2, we expect that the optimal AS value be less than or equal to that found for HomePNAv2,

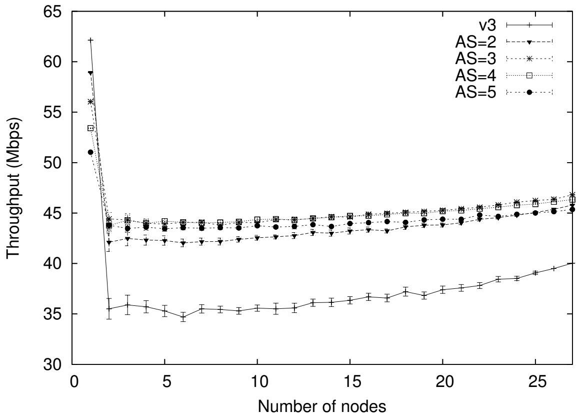

Fig. 7. Throughput of HomePNAv3+ at 128 Mbps.

because there are less collisions to treat. Then, we did not simulate the AS values 6 and 7 because they are anyway far from the best value. We simulated with $AS = 5$ to track the behavior of the different curves.

Fig. 7 presents the throughput obtained by HomePNAv3+. Again, all the AS values produced throughput gains compared to HomePNAv3, except for the scenario with one node. For HomePNAv3+, the curves corresponding to $AS = 3$ and $AS = 4$ are very close. The $AS = 2$ and $AS = 5$ are slightly below, therefore the best AS value is 3 or 4.

Fig. 8 plots the normalized throughput of HomePNAv3. For the aggregation factors equal to 3 and 4, the HomePNAv3+ throughput presents the highest values. For a small number of transmitting nodes in the network the throughput gains for $AS = 3$ and $AS = 4$ are almost the same. Nevertheless, for more than 15 senders the gain for AS=3 is slightly larger. Thus, the best AS value for HomePNAv3+ is 3. The throughput gains range from 16.9% to 27%, for 27 and 6 nodes, respectively.

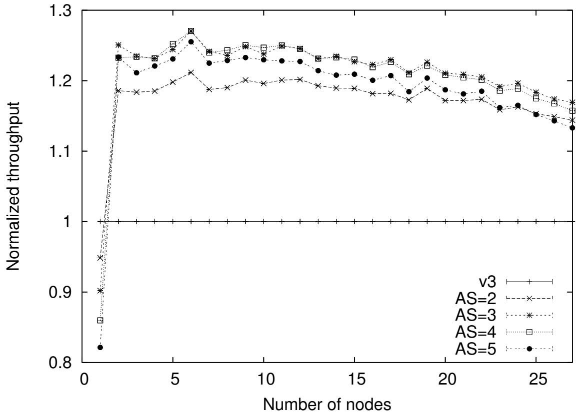

Fig. 8. Throughput of HomePNAv3+ at 128 Mbps.

The frame size influence is presented in Fig. 9. We use a scenario with 6 nodes because it obtained the highest gain in Fig. 8. Fig. 9 shows that HomePNAv3+ also performs better for smaller frames, similarly to HomePNAv2+. The gain varies from 27% to 35.8% for 1500-byte and 160-byte frames, respectively.

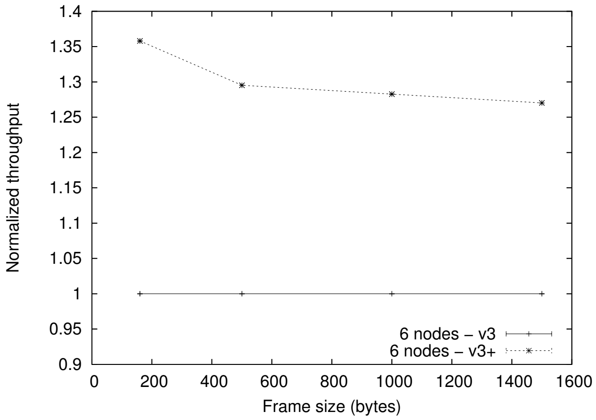

Fig. 9. Frame size influence on HomePNAv3+.

C. Average delay and jitter

The proposed mechanism causes some nodes to defer their transmission to avoid collisions, achieving higher throughput. Therefore, we investigate in this section the impact of the proposed mechanism on the average delay and jitter. For this analysis we consider the 32 Mbps transmission rate for HomePNAv2 and 128 Mbps for HomePNAv3, and 1500-byte frames transmitted with priority 7.

Fig. 10 plots the average delay of the network, showing that it is not affected by the use of the proposed mechanism. The average delays of HomePNA v2+ and v3+ are slightly lower than the delay of HomePNAv2 and v3, respectively.

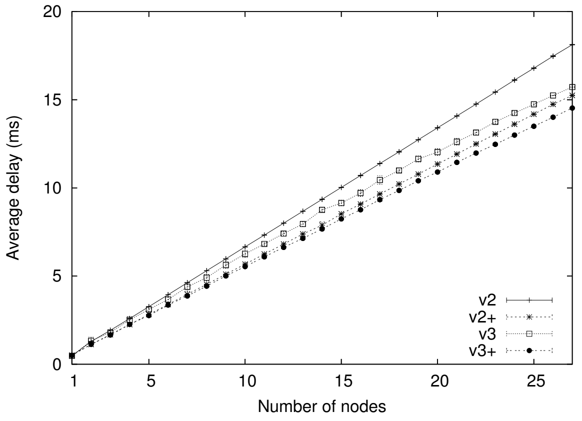

Fig. 10. Average delay.

On the other hand, the proposed mechanism increases the jitter of the network, as shown in Fig. 11. We can conclude that the random deferral of some frames affects the jitter. Therefore, there is a tradeoff between the jitter increase and the throughput gain.

D. Comparison of the MAC protocols

This section compares all the medium access control techniques analyzed so far, i.e., HomePNAv2, v2+, v3, and v3+, under the same conditions. We used the largest transmission rate common to all versions, 32 Mbps, and a scenario where the number of nodes varies from 1 to 27. The frames are 1500 bytes long and are transmitted with priority 7.

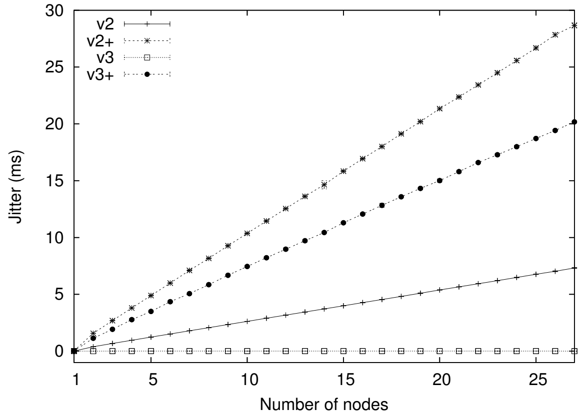

Fig. 11. Jitter.

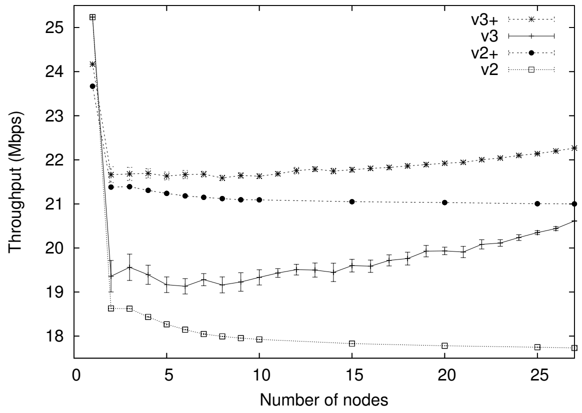

Fig. 12. Comparison of the different HomePNA versions at 32 Mbps.

Fig. 12 presents the results of the comparison. HomePNAv3+ presented the best efficiency, achieving 22.2 Mbps. Nevertheless, the disadvantage of HomePNAv3+ and HomePNAv3 is that the number of nodes in the network is limited to 27. HomePNAv2+ and v2 have no such limitation.

An interesting aspect is the comparison between HomePNAv2+ and v3. Fig. 12 shows that HomePNAv2+ performed better than HomePNAv3 for any number of nodes. Thus, we conclude that, if used separately, our mechanism is more efficient than the collision management technique used by HomePNAv3, and it also allows more than 27 nodes in the network. Nevertheless, both mechanisms can be combined, which is the most efficient alternative.

V. CONCLUSIONS

In this paper we proposed a new mechanism to improve HomePNAv2 and v3 MAC protocols. This mechanism aggregates some priority slots into one priority, spreading the high priority frames on these slots. Thus, the number of collisions decreases, what consequently increases the throughput.

First, we determined the best number of aggregated slots (AS) to be used in the mechanism for each of the standards. The modified versions of the protocols were called HomePNAv2+ and v3+. For HomePNAv2+, we analyzed AS values ranging from 2 to 7 and discovered that $AS = 4$ maximizes the throughput. HomePNAv2+ had a throughput increase as large as 44% compared with HomePNAv2, for 32 Mbps transmission rate and 160-byte frames. The proposed mechanism is more efficient for higher transmission rates and smaller frames.

On the other hand, for HomePNAv3+ we found that $AS = 3$ was the best value. The results showed that HomePNAv3+ also performed better than HomePNAv3, achieving a throughput gain of 35.8%, for 128 Mbps transmission rate and 160-byte frames.

Then, we also analyzed the average delay and jitter of the network using the proposed mechanism. We found that our mechanism increases the jitter, indicating a tradeoff between jitter and throughput gain. On the other hand, the average delay of the network was not affected.

Finally, we compared all the medium access control mechanisms analyzed under the same conditions. The same transmission rate was used for all versions of HomePNA. HomePNAv3+ presented the best performance. Nevertheless, HomePNAv3+ and HomePNAv3 limit the number of nodes in the network to 27. Moreover, HomePNAv2+ performed better than HomePNAv3, which shows that the mechanism proposed in this paper produced a larger throughput increase than the collision management technique introduced in HomePNAv3, for any number of nodes.

ACKNOWLEDGMENT

This work was supported by CNPq, CAPES, FAPERJ, FINEP, RNP, and FUNTTEL.

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