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Increasing the throughput of HomePNA

Aurelio Amodei Junior, Luís Henrique M. K. Costa* and Otto Carlos M. B. Duarte

GTA/COPPE/Poli – Federal University of Rio de Janeiro
P.O. Box 68504 - 21945-970 - Rio de Janeiro - RJ - Brazil
{*aurelio,luish,otto*}*@gta.ufrj.br*

SUMMARY

In this paper we propose a new medium access mechanism for HomePNAv2 and HomePNAv3 standards. This mechanism uses a priority aggregation mechanism to avoid collisions, increasing these protocols throughput. Furthermore, this mechanism does not require modifying standards, since it can be implemented over their actual MAC sublayers. Simulation results show that the proposed mechanism is able to increase the throughput up to 44% for HomePNAv2, and 36% for HomePNAv3. Moreover, we also show how this mechanism affects network delay, analyzing average delay and jitter for all protocols presented. Copyright © 2006 John Wiley & Sons, Ltd.

KEY WORDS: Home networks, HomePNA, medium access control.

1. Introduction

Nowadays there are different technologies available for home networks. One commercial solution uses 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 commercially available version, and HomePNA version 3, the new high performance version. HomePNAv2 uses Carrier Sense Multiple Access with Collision Detection (CSMA/CD) for medium access and transmission rates up to 32 Mbps. Differently from version 2, HomePNAv3 standard [3] defines two Medium Access Control (MAC) modes: synchronous (SMAC) and asynchronous (AMAC) [4]. HomePNAv3 provides transmission rates up to 128 Mbps, with an extension up to 240 Mbps in the synchronous mode [5]. For fair comparison, in this paper we only consider HomePNAv3 AMAC, whose access mechanism is similar to HomePNAv2.

In this paper, we propose a mechanism that increases the throughput of HomePNAv2 and v3 protocols in asynchronous mode (AMAC). The key idea is to aggregate a fixed number,

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*Correspondence to: GTA/COPPE/Poli – Federal University of Rio de Janeiro, P.O. Box 68504 - 21945-970 - Rio de Janeiro - RJ - Brazil. e-mail: luish@gta.ufrj.br

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AS (Aggregated Slots), of 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 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 [6]. In this work, we show that our mechanism can be used for both versions of HomePNA, comparing results for all protocols presented. Additionally, we analyze the impact of the proposed mechanism on average delay and jitter, for both protocols.

This paper is organized as follows. Related work is presented in Section 2. Section 3 describes HomePNAv2 and v3 protocols. We present a HomePNA throughput analysis in Section 4. In Section 5, we present the proposed mechanism. Simulation results are presented in Section 6. Finally, Section 7 concludes the paper.

2. Related Work

Bisaglia *et al.* [7] propose a model for the HomePNA channel and analyze its physical layer. Bisaglia and Castle [8] also analyze a receiver architecture for HomePNA and equalization techniques. These works concentrate on the physical layer.

Concerning the medium access control sublayer, Chung *et al.* [9] present a mathematical analysis of the saturation throughput of HomePNAv2 MAC. Kim *et al.* [10] make a similar analysis for 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.* [11] present an analysis of HomePNAv2 MAC protocol and its collision resolution mechanism. They show that the number of slots used for collision resolution, as defined by the standard, is not optimal for some scenarios. Then, they suggest that the number of slots should be larger in order to increase network efficiency, according to network load.

3. HomePNA MAC Protocol

HomePNAv2 MAC protocol is based on CSMA/CD. Additionally, HomePNAv2 defines eight levels of priority for Quality of Service (QoS) support. Classes of traffic are labelled with priorities from 0 to 7, with 7 being the highest. Medium access operation is as follows. After a frame transmission, there is no transmission for a period of time corresponding to an inter-frame gap (IFG), which is equal to 29 μs. After IFG, stations can try to access the medium, but each station must wait for a period of time corresponding to the priority of the frame that it wants to transmit.

As shown in Figure 1, time intervals are organized in decreasing order of priority. 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.

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

All stations monitor the medium to detect collisions. Idle stations detect a collision through

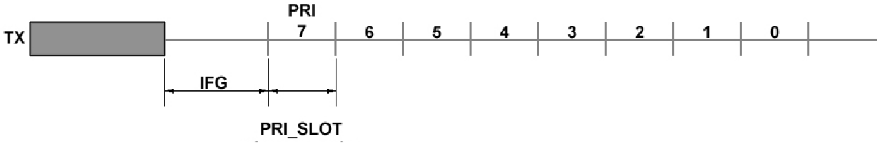

Figure 1. HomePNAv2 priority slots.

Figure 2. Collision resolution signaling slots.

the transmission duration. Minimum duration of a valid frame is 92.5 μs whereas 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, allowing other stations to detect the collision. Any frame fragment which is too short, or too long, indicates 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 that only one station is at BL 0, being able to acquire the channel. After a successful transmission, all other stations decrement their BL, and new station(s) at BL 0 try to transmit. All stations, including idle ones, shall monitor activity on the medium to keep track of the Maximum Backoff Level (MBL). Stations that did not collide are not allowed to contend for medium access until all stations that collided have transmitted one frame successfully. The only exception is when a station has a frame with priority higher than the priority slot where the collision occurred.

As shown in Figure 2, after a collision has occurred, there are three special collision resolution signaling slots (S0, S1, and S2) before the priority slots. Counters BL and MBL are determined by using these signaling slots, which have a duration of 32 μs each.

After a collision, active stations - the ones involved in 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 signaling slot. Therefore, 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 trailer of the HomePNA frame are transmitted at 4 Mbps basic rate. On the other hand, the payload can adaptively use rates from 4 to 32 Mbps, according to channel conditions.

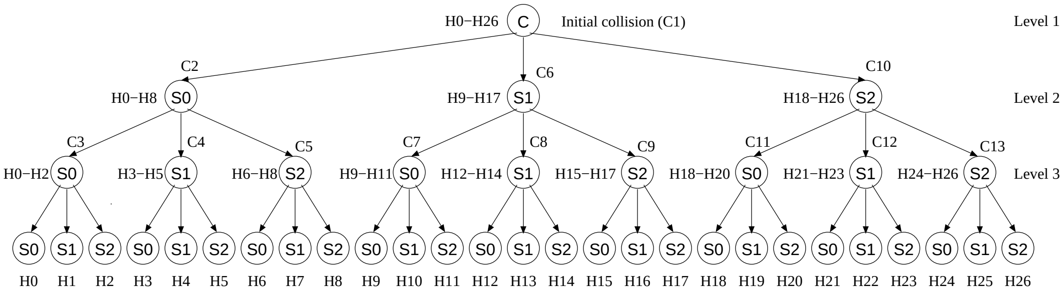

Figure 3. Collision resolution between 27 nodes in HomePNAv3.

3.1. HomePNAv3

HomePNAv3 MAC has two modes of operation, synchronous (SMAC) and asynchronous (AMAC). While HomePNAv2 has a maximum transmission rate of 32 Mbps, HomePNAv3 supports rates of up to 128 Mbps, with an optional extension to 240 Mbps [5]. To reach this rate HomePNAv3 uses larger frequency bandwidth and larger QAM constellations. Furthermore, the new version uses a packet aggregation technique to increase MAC protocol efficiency [4] [12]. This technique increases maximum payload size and aggregates several packets into a single MAC frame, reducing header and trailer control overhead.

Synchronous mode was created to provide better QoS guarantees. SMAC uses a synchronous medium access technique under control of a master node which manages the transmission of all other nodes. The master node also implements admission control and resource reservation, guaranteeing QoS requirements fulfillment.

Asynchronous mode (AMAC) is similar to HomePNAv2 and compatible with it. Nevertheless, HomePNAv3 introduces a new collision management technique to reduce the number of collisions. Each node has a set of three collision resolution slots (A, B, C), that is defined when the node enters the network. Each slot A, B, and C can be defined as S0, S1, or S2, as shown in Section 3. When a frame first collides, the node uses slot A for collision resolution. If this frame produces a second collision, then the station chooses slot B, and in case of a third collision, slot C. As there is no other node in the network with the same slot set (A, B, C), the maximum number of collisions per frame is limited to three. This technique reduces collisions and improves 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 be 27 nodes at most.

Figure 3 represents a collision resolution process between 27 nodes, the maximum possible number. Nodes are labelled from H0 to H26 whereas C1 to C13 represent collisions in order of occurrence. Slot sets for each node are represented in the collision sequence. Thus, the set for H15, derived from Figure 3, is (S1, S2, S0). Note that in HomePNAv3 a collision is resolved after 3 interactions at most, guaranteeing that no frame collides more than 3 times.

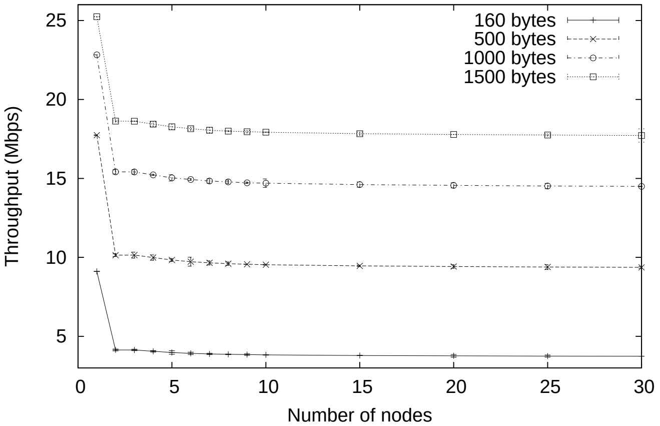

Figure 4. Throughput analysis at 32 Mbps.

4. Throughput Analysis

Chung *et al.* [9] have mathematically analyzed HomePNA saturation throughput. They assume that all transmitting nodes always have a frame to transmit immediately after a successful transmission. We have implemented a HomePNA module in the *ns-2* simulator [13], repeated the analysis through simulation, and compared the results obtained. We have used a physical layer model similar to Ethernet.

All simulations last for 100 seconds, and use 4 frame sizes, 160, 500, 1000, and 1500 bytes. The scenario is composed of one receiver node for all transmitters. The results have confidence intervals of 95% relative to the average, represented by vertical error bars in the graphs.

Figure 4 plots results for 32 Mbps data rate and 1 to 30 nodes. The behavior is similar to the theoretical analysis of [9], except that in [9] the throughput increases when the number of nodes changes from 2 to 3. This happens because in [9], total transmission time of a collision resolution cycle includes preceding and following IFGs, but only one of those should be accounted for. If preceding IFG is included, following should not be as it would be included as the next frame preceding IFG.

Figure 5 plots the same results for a transmission rate of 4 Mbps. MAC protocol efficiency at 4 Mbps is greater than at 32 Mbps. For lower rates, the payload transmission time is greater, therefore the time spent with header, trailer, IFG, and priority slots represents a smaller fraction of total transmission time.

We also analyze the influence of frame size on throughput. Figure 6 plots results for a scenario with 1 transmitting node, where frame size varies from 50 to 1500 bytes. Data transmission rate is 32 Mbps, and we use the same condition where the transmitter always has a frame ready for transmission. For shorter frames, payload transmission time is shorter, reducing efficiency.

In the simulation scenario used for HomePNAv3 analysis, there is also one receiver to which all sources transmit. The number of sources ranges from 1 to 27. The set of slots that each node uses for resolution of collisions is randomly chosen in each simulation run. Simulations consider

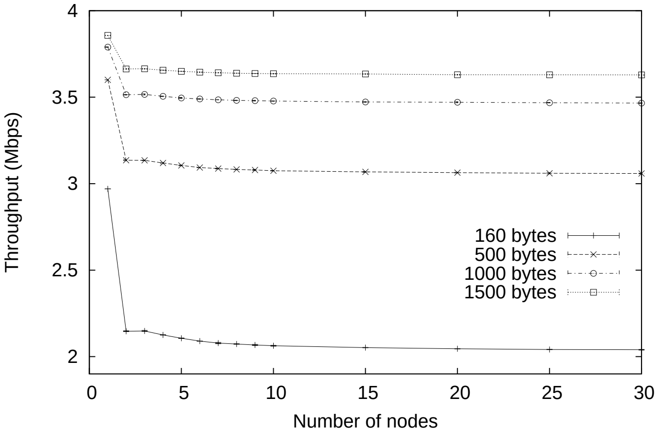

Figure 5. Throughput analysis at 4 Mbps.

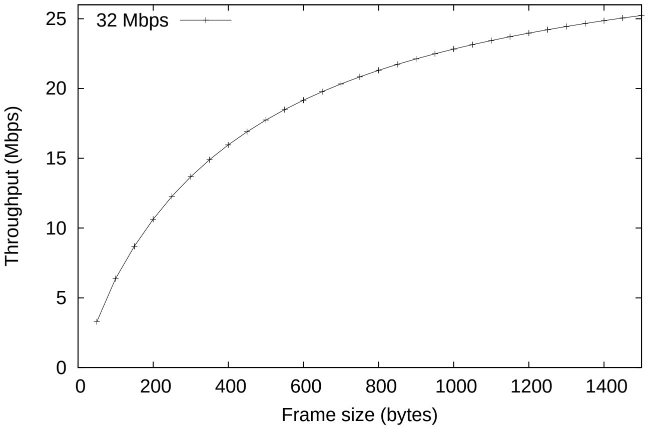

Figure 6. Frame size influence at 32 Mbps in HomePNAv2.

128 Mbps PHY rate. Each run simulates 100 seconds. Nodes have priority 7, the priority which yields the highest throughput. All sources transmit continuously, therefore, when the medium gets idle, all sources try to transmit, causing a collision and triggering the collision resolution procedure.

Figure 7 plots the throughput for varying number of sources using 1500-byte frames. Note that for HomePNAv2 the aggregated throughput tends to stabilize for a large number of nodes, whereas for HomePNAv3 the throughput increases with the number of nodes. This is due to the collision management technique used in HomePNAv3, which actually reduces the collisions per frame for larger numbers of nodes. The parameter C/n represents the average

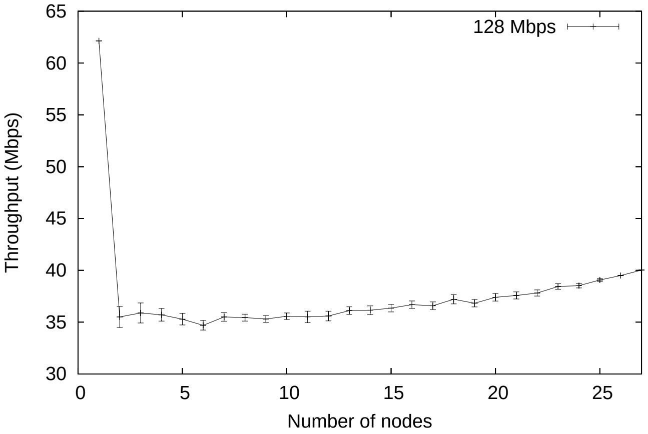

Figure 7. Throughput of HomePNAv3 using priority 7 1500-byte frames.

number of collisions per frame transmitted. The smaller C/n, the more efficient is the medium access. For HomePNAv2, C/n tends to 0.93 for more than 15 nodes. Figure 3 shows what happens for HomePNAv3 with 27 nodes. After the first collision involving 27 nodes, these are divided into 3 groups with 9 nodes each, which themselves produce 3 additional collisions. Then, groups of nodes split again into 9 3-node sets, which produce 9 additional collisions before completing the transmission of all frames. Thus, a total number of 13 collisions were needed for the transmission of 27 frames, yielding a C/n equal to 0.48. HomePNAv3 is more efficient than v2 since it produces less collisions per frame transmitted.

Figure 7 shows a high difference between nominal transmission rate and maximum throughput obtained. For 128 Mbps PHY rate, with only 1 sender, maximum throughput is 62.1 Mbps, yielding an efficiency of 48.5%. For more nodes transmitting, throughput falls down to about half the maximum throughput, or 34.7 Mbps. The huge difference between PHY rate and throughput obtained is explained by the 4 Mbps rate used to transmit header and trailer of data frames. Indeed, for 128 Mbps PHY rate, the additional time spent with one collision is larger than the time needed to transmit one data frame.

Figure 7 plots the throughput obtained for varying frame size. For the smallest 160-byte frames, network throughput of is as low as 5 Mbps. Note that the network performance depends on the number of collisions, which is itself a function of the number of nodes (Figures 7 and 8). Therefore, for a specific scenario, changing the transmission rate or changing the frame size, the throughput obtained changes, but not the network behavior.

5. 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. Highest priority frames are transmitted first, followed

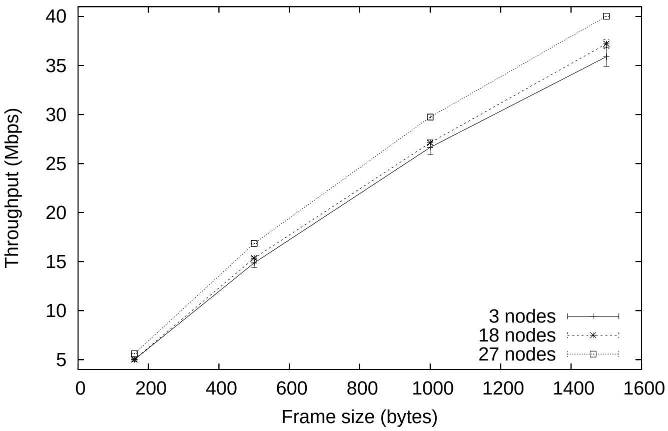

Figure 8. Frame size influence at 128 Mbps in HomePNAv3.

by lower priority frames, in order of priority, without colliding. While isolating different-priority traffic, the fixed slot reservation for eight classes of service may lead to network underutilization. For example, if three priority-7 stations want to transmit their frames, they will collide until the collision is solved and the three frames can be transmitted in a random order. The priotity-7 collision occurs even if priority-6 to 0 slots are idle. Suppose now that these three frames were randomly given different priorities, e.g., 7, 6, and 5. In this case, the three frames would also be transmitted randomly ordered, without colliding. Therefore, the time spent with collisions could be reduced by adding extra priority slots to some frames, increasing network efficiency. Therefore, the main objective of the mechanism we propose is to reduce the network underutilization and to avoid collisions involving the highest-priority frames.

The proposed mechanism aggregates some priority levels into the highest priority. The key idea is that the traffic mapped in the new highest-priority class has less chances of producing collisions, since the highest priority has n instead of 1 time slot available. Outgoing high priority frames are then randomly mapped in one of these highest-priority slots. The mechanism works like a random backoff inside priority 7, where a small additional delay can avoid collisions, depending on the number of priority levels that were aggregated to form the high priority.

The number of aggregated slots in the proposed mechanism is called AS (Aggregated Slots). AS value ranges from 2 to 7, because the mechanism keeps at least two different priority levels. Figure 9 illustrates the operation of the priority aggregation mechanism using $AS = 4$ and $AS = 5$. With $AS = 4$, there are 5 priority levels, namely, 7 and from 3 to 0. The highest-priority class of service, 7, has 4 time slots. Thus, priority-7 frames are randomly transmitted during one out of the 4 time slots, reducing their collision probability. The proposed mechanism can be used with HomePNAv2 and HomePNAv3 AMAC, as both use the same priority scheme. A key issue it to determine the AS value which yields the highest network throughput.

An important characteristic of the proposed mechanism is that it does not need any change to HomePNAv2 and v3 standards, but can be implemented above the MAC sub-layer. Priority

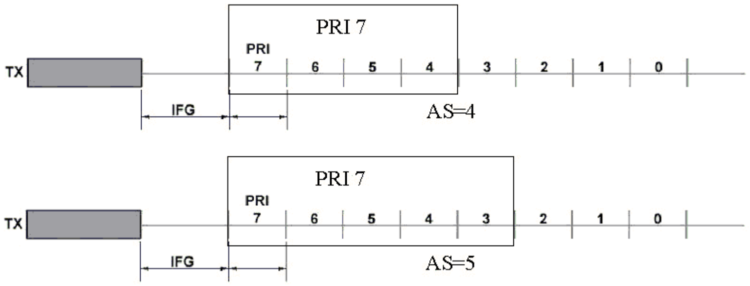

Figure 9. Proposed mechanism with AS=4 and AS=5.

Table I. Example of priority mapping with AS=4.

Actual priority	Priority in HomePNA
7	7 6 5 4
6 5	3
4 3	2
2 1	1
0	0

mapping can be done in any convenient way, as long as the AS number is respected. Table I gives an example of such a mapping, using $AS = 4$.

On the other hand, other priorities may experience performance loss, since different priority flows can be mapped in the same slot. In the example of Table I, flows of priorities 6 and 5 contend for the medium in the same priority slot, 3. In this case, if priorities 6 and 5 are used simultaneously, more collisions can occur inside this slot. Furthermore, there is no isolation between these priorities. A possible solution to this problem is a new mapping of network priorities, in order that concurrent priorities are not used. A priority 5 flow can be mapped to priority 4 or 3, so that it does not use the same priority slot as priority 6. In the example of Table I there can be 5 different priorities without performance losses.

In the home networking environment, interactive applications such as voice over IP or interactive television [14] shall be assigned the highest priority whereas background applications such as air-conditioning control can use one of the lower-priority classes. Furthermore, the number of classes of service to be used remains an implementation choice, depending on the mix of applications running in the home network.

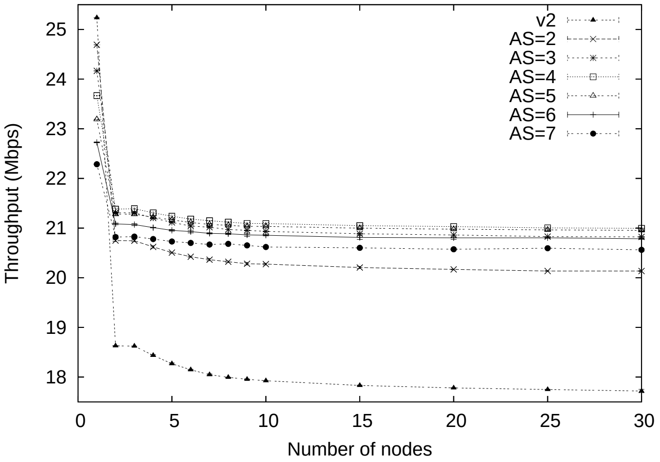

Figure 10. Throughput of HomePNAv2+ with 32 Mbps transmission rate.

6. Simulation Results

This section presents simulation results for HomePNAv2 and v3 using our proposed mechanism implemented in *ns-2* simulator [13]. The modified versions of HomePNA were named HomePNAv2+ and HomePNAv3+, respectively.

6.1. HomePNAv2+

We analyze the efficiency of our mechanism and determine the best AS value [6] considering a data transmission rate of 32 Mbps. All stations transmit 1500-byte frames of priority 7 and there are from 1 to 30 transmitting nodes. Again, we measure the saturation throughput, where all nodes always have a frame to transmit. The confidence interval of measures is 95%, represented by vertical error bars.

Figure 10 plots the throughput obtained with HomePNAv2 and HomePNAv2+, for AS values ranging from 2 to 7. Note that for more than one sender, throughput increases for every AS value. Moreover, there is a small throughput decrease for one node, because in this case there are no collisions.

Figure 11 presents the same results, normalized by the troughput of HomePNAv2. This figure indicates the best value for AS, 4. With $AS = 4$, we obtain a 14.8% gain for 2 nodes and 18.5% for 30 nodes, which are larger than the gain obtained with other AS values for any number of nodes.

Frame size also influences the gain that may be obtained. Figure 13 plots 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, consequently, the time spent with collisions represents a larger fraction of total transmission time. For 160-byte frames the gain obtained by HomePNAv2+ reaches 44%.

To analyze average delay and jitter, we used the same scenario, with 1 to 30 nodes, 1500-byte

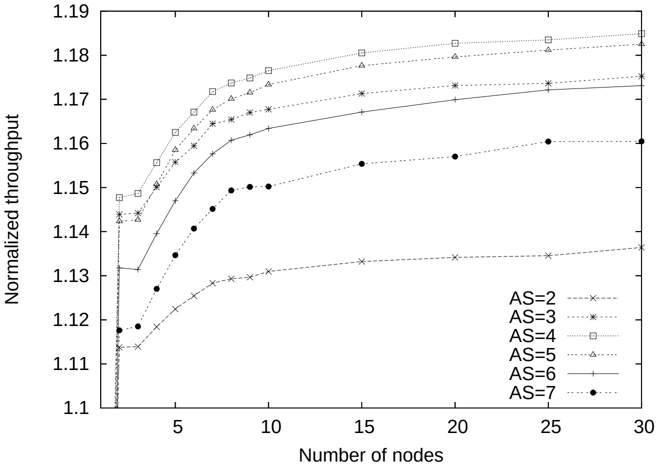

Figure 11. Normalized throughput of HomePNAv2+ with 32 Mbps transmission rate.

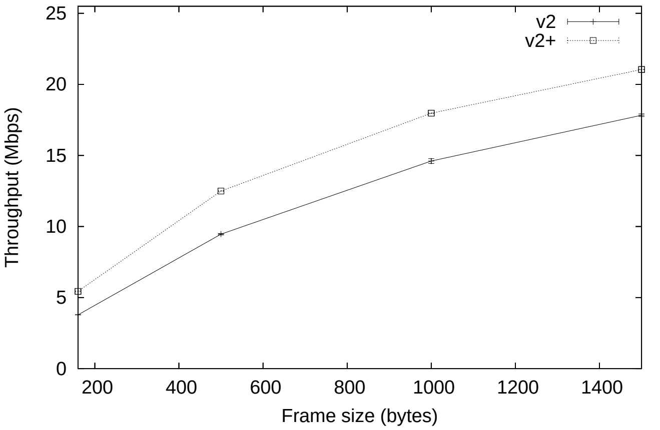

Figure 12. Throughput of HomePNAv2+ with 15 nodes and 32 Mbps rate.

frames, priority 7, and 32 Mbps data rate. Confidence interval is 95%. The analysis considers only the MAC sub-layer delay, i.e., the delay between the end of transmission of a frame and the end of transmission of the next frame from the same station. Figure 14 plots average delays for HomePNAv2+ and HomePNAv2. Note that HomePNAv2+ slightly decreases the average delay of the network. In spite of the medium access deferral caused by the random choice of aggregated slot, the time saved with collision avoidance is larger, then the average delay is smaller. With 30 nodes, HomePNAv2 has an average delay of 20.2 ms, while the average delay of HomePNAv2+ is 17.1 ms.

On the other hand, the proposed mechanism increases jitter, as shown in Figure 15. In

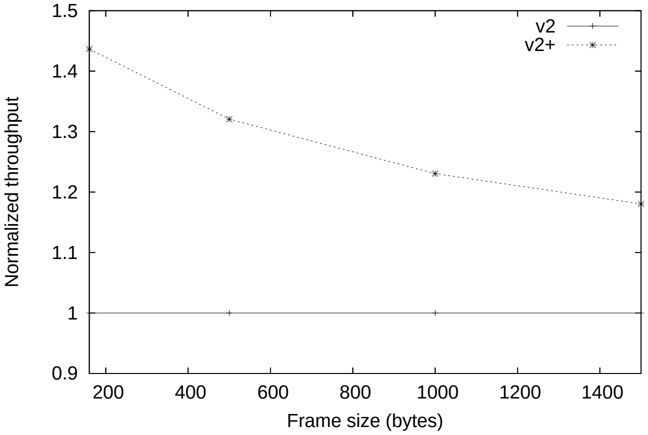

Figure 13. Normalized throughput of HomePNAv2+ with 15 nodes and 32 Mbps rate.

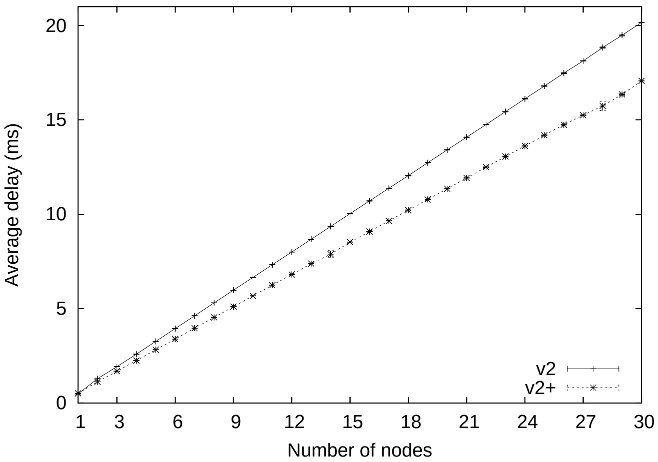

Figure 14. Average delay of HomePNAv2 and HomePNAv2+.

HomePNAv2 the jitter is 8.1 ms with 30 nodes, whereas in HomePNAv2+ it increases to 32 ms. Jitter increases because the proposed mechanism defers transmission of some frames in order to transmit more frames in higher priorities with less collisions. Hence, throughput and average delay are improved but the tradeoff is larger jitter.

6.2. HomePNAv3+

First, to determine the best AS value, we repeated the simulations of previous section with 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. Collision resolution slots sets

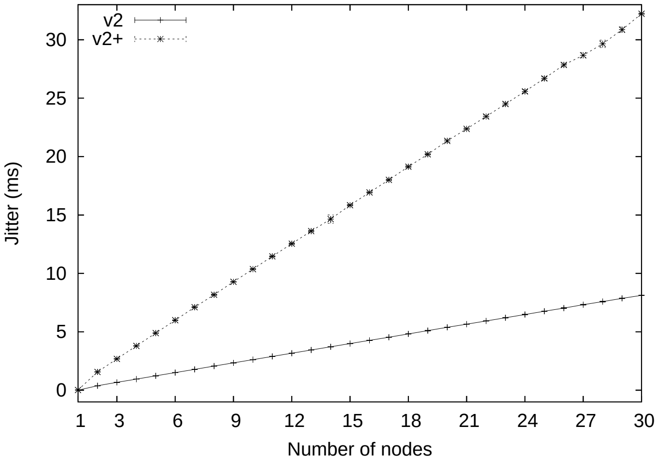

Figure 15. Jitter of HomePNAv2 and HomePNAv2+.

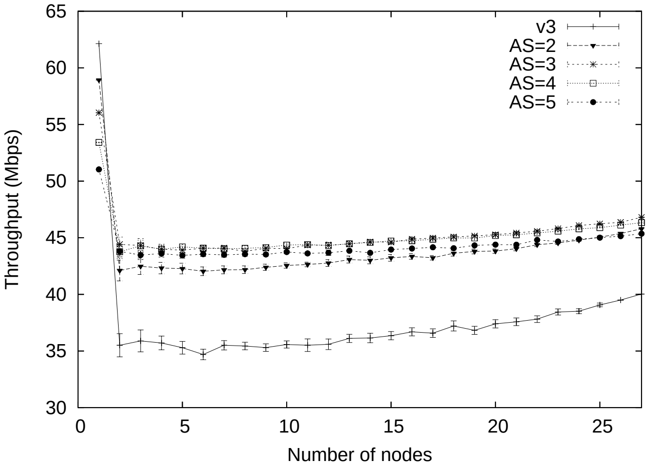

Figure 16. Throughput of HomePNAv3+ at 128 Mbps.

are randomly chosen. As HomePNAv3 has introduced a collision management which reduces the number of collisions as compared with HomePNAv2, we expect that the best AS value should be less than or equal to that found for HomePNAv2, because there are less collisions to treat. Therefore, we did not simulate AS values 6 and 7, because they are far from the best. We simulated with $AS = 5$ to track the behavior of different curves.

Figure 16 presents the throughput obtained with HomePNAv3+. Again, all AS values produced throughput gains compared to HomePNAv3, except for the scenario with one node. For HomePNAv3+, curves corresponding to $AS = 3$ and $AS = 4$ are very close. $AS = 2$ and $AS = 5$ are slightly below, therefore the best AS value is 3 or 4.

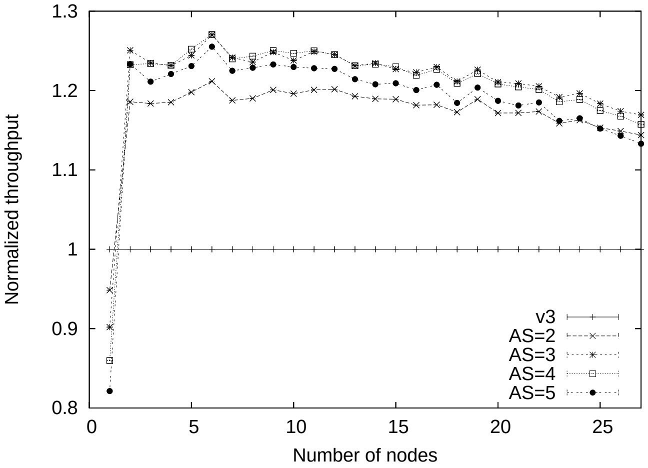

Figure 17. Normalized throughput of HomePNAv3+ at 128 Mbps.

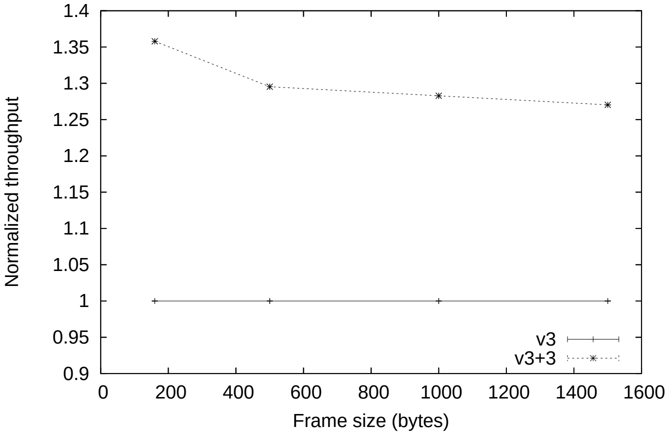

Figure 18. Normalized throughput of HomePNAv3+ with 6 nodes and 128 Mbps rate.

Figure 17 plots the normalized throughput of HomePNAv3+. For a small number of transmitting nodes 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. Throughput gains range from 16.9% to 27%, for 27 and 6 nodes, respectively.

Frame size influence is represented in Figure 18. We use a scenario with 6 nodes because it has shown the highest gain in Figure 17. Figure 18 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.

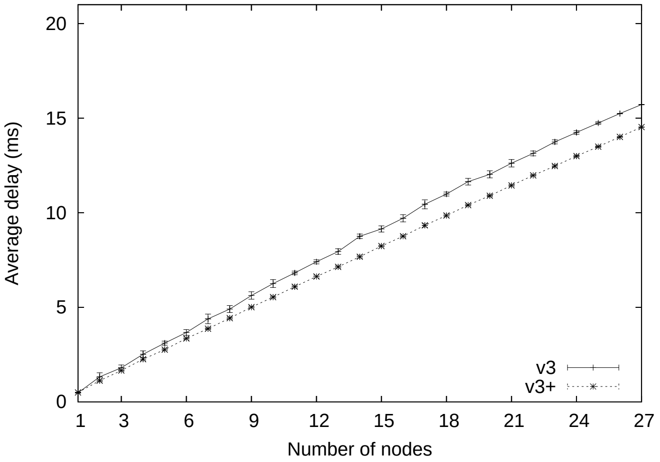

Figure 19. Average delay of HomePNAv3 and HomePNAv3+.

Average delay and jitter were analyzed in a similar scenario, with 1 to 27 nodes, 1500-byte frames, and priority 7. We used 128 Mbps PHY rate, the highest rate of HomePNAv3. Figure 19 plots average delays with HomePNAv3+ and HomePNAv3. As for HomePNAv2+, average delay for HomePNAv3+ is lower than for HomePNAv3. Comparing the 27 nodes case, HomePNAv3+ average delay is 14.5 ms against 15.7 ms for HomePNAv3.

The jitter for HomePNAv3+ and HomePNAv3 are shown in Figure 20. Again, we note that the proposed mechanism increases jitter. For HomePNAv3 the jitter is close to zero in this scenario, because the transmission sequence for all nodes is already defined by their collision resolution slots sets. Therefore, the delay between two frames of the same station is always the same. When we use the proposed mechanism, jitter increases to 20.2 ms.

6.3. Comparison of the different versions

This section compares different versions of HomePNA, namely, HomePNAv2, v2+, v3, and v3+, under the same conditions. We use the largest transmission rate common to all versions, 32 Mbps, and a scenario where the number of nodes varies from 1 to 27. Frames are 1500 bytes long and all nodes use priority 7. Confidence interval of measures is 95%, represented in the graphs by vertical error bars.

Figure 21 presents the comparison results. HomePNAv3+ has shown the best efficiency, achieving a throughput of 22.2 Mbps. Nevertheless, the disadvantage of the v3 and v3+ versions of HomePNA is that the number of nodes in the network is limited to 27. HomePNAv2+ and v2 have no such limitation.

It is interesting to compare HomePNAv2+ with HomePNAv3. Figure 21 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 employed by HomePNAv3, also allowing more than 27 nodes in the network. Nevertheless, both mechanisms can be combined, which is the most efficient alternative.

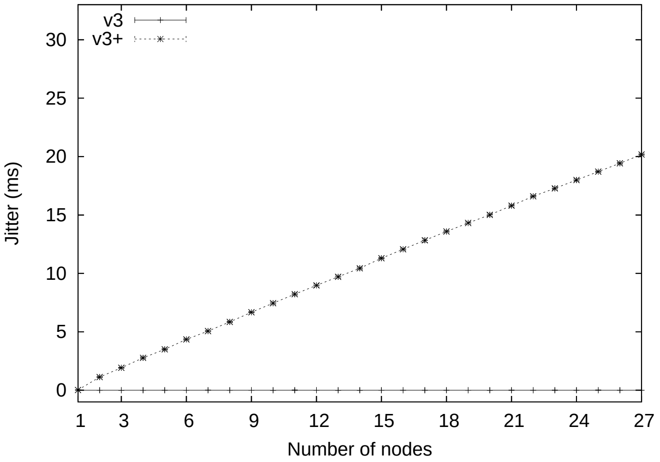

Figure 20. Jitter of HomePNAv3 and HomePNAv3+.

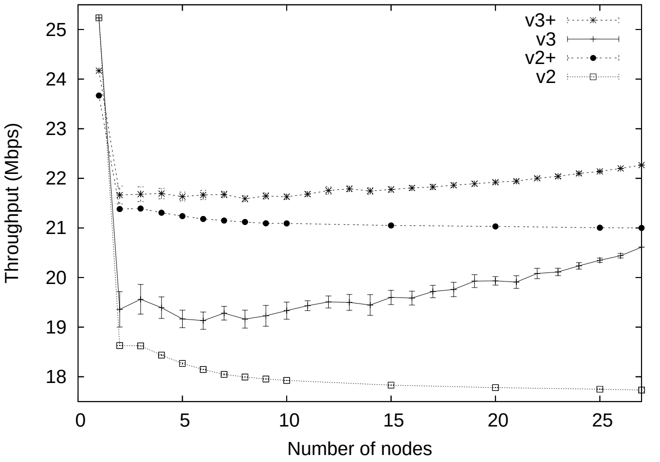

Figure 21. Comparison of the different HomePNA versions with 32 Mbps transmission rate.

7. Conclusions

In this article we have proposed a new mechanism to improve HomePNAv2 and HomePNAv3 MAC protocols. The mechanism aggregates some priority slots into one priority, spreading high priority frames on these slots. The number of collisions decreases consequently increasing the throughput.

First, we have determined the best number of aggregated slots (AS) to be used in the mechanism for each standard. The modified protocol versions were named HomePNAv2+ and HomePNAv3+. For HomePNAv2+, we have analyzed AS values ranging from 2 to 7 and discovered that $AS = 4$ maximizes the throughput. HomePNAv2+ provided a throughput increase as large as 44% compared with HomePNAv2, using 32 Mbps PHY rate and 160-byte frames. The proposed mechanism is more efficient for higher transmission rates and smaller frames.

For HomePNAv3+ we have found out that $AS = 3$ was the best value. The results have shown that HomePNAv3+ also performs better than HomePNAv3, achieving a throughput gain of 35.8%, using 128 Mbps PHY rate and 160-byte frames.

Then, we have also analyzed network average delay and jitter using the proposed mechanism. We have found out that our mechanism increases jitter, which is its tradeoff. On the other hand, network average delay was not affected.

Finally, we have compared all the medium access control mechanisms analyzed under the same conditions. HomePNAv3+ has presented the best performance. Nevertheless, HomePNAv3+ and HomePNAv3 limit the number of nodes in the network to 27. Moreover, HomePNAv2+ performs better than HomePNAv3, which shows that the proposed mechanism produces a larger throughput increase than the collision management technique introduced in HomePNAv3, for any number of nodes.

We expect that the traffic encountered in home networks will have a mix of video and audio flows, for example produced by television applications, low bit-rate flows produced by automation applications, for example temperature sensors, and other legacy Internet applications which will be carried on using a shared Internet access, such as peer-to-peer or e-mail. Among those applications, video flows are currently the most bandwidth demanding. The video transmission rate actually depends on the codec used but today a high-quality video can be transmitted using around 5 Mbps, which allows for approximately 4 simultaneous flows using HomePNAv3+. This is a worst-case scenario, considering that in our simulations we have analyzed the saturation throughput.

REFERENCES

1. http://www.homepna.org, 2006. Accessed September 2006.
2. Home Phoneline Network Alliance, "Interface specification for HomePNA 2.02.7 10M8 technology." HomePNA 2.0 Standard, 1999.
3. E. H. Frank and J. Holloway, "Connecting the home with a phone line network chip set," *IEEE Micro*, vol. 20, no. 2, pp. 27–38, Apr. 2000.
4. R. Sterenson, "Guaranteed QoS in the home network environment," tech. rep., CopperGate Communications, 2003.
5. ITU-T, "G.PNT: PNT3 proposal overview." Draft document MC-107R1, Aug. 2003.
6. A. Amodei Jr., L. H. M. K. Costa, and O. C. M. B. Duarte, "Increasing the throughput of the HomePNA MAC protocol," in *29th IEEE Conference on Local Computer Networks - LCN'2004*, (Tampa, USA), pp. 294–301, Nov. 2004.
7. P. Bisaglia, R. Castle, and S. H. Baynham, "Channel modeling and system performance for HomePNA 2.0," *IEEE Journal on Selected Areas in Communications*, vol. 20, no. 5, pp. 913–922, June 2002.
8. P. Bisaglia and R. Castle, "A comparison of equalizer structures for frequency diverse QAM," Tech. Rep. HPL-2001-186, Hewlett-Packard Laboratories, 2001.
9. M. Y. Chung, H. C. Kim, and T.-J. Lee, "HomePNA 2.0 - saturation throughput analysis," *IEEE Communications Letters*, vol. 7, no. 11, pp. 558–560, Nov. 2003.
10. H. C. Kim, M. Y. Chung, T.-J. Lee, and J. Park, "Saturation throughput analysis of collision management protocol in the HomePNA 3.0 asynchronous MAC mode," *IEEE Communications Letters*, vol. 8, no. 7, pp. 476–478, July 2004.
11. S. Kangude, J. Copeland, and M. Sherman, "An analysis of the Home PNA collision resolution mechanism," in *28th IEEE Conference on Local Computer Networks - LCN'2003*, (Bonn/Konigswinter, Germany), Oct. 2003.

12. ITU-T, “The proposed MAC for PNT3.” Draft document PF-042, Aug. 2003.
13. K. Fall and K. Varadhan, *The ns Manual*. UC Berkeley, LBL, USC/ISI, and Xerox PARC, Nov. 2007. Available at http://www.isi.edu/nsnam/ns/ns-documentation.html.
14. M. E. M. Campista, I. M. Moraes, P. M. Esposito, A. A. Jr., D. de Oliveira, L. H. M. K. Costa, and O. C. M. B. Duarte, “The ad hoc return channel: a low-cost solution for brazilian interactive digital TV,” *IEEE Communications Magazine*, vol. 45, no. 1, pp. 136–143, Jan. 2007.