Modelling, Characterisation and Performance of the Home Phoneline Network

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HPL-1999-86
16th July, 1999*

HomePNA,
TCP,
phoneline network

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EDICS: CL1.5 Transmission

July 15, 1999

Abstract

We present experimental results characterising the home phoneline network, and a model which allows both time and frequency domain representations. Using these results we provide performance measurements for the HomePNA version 1.0 technology on the specified HomePNA test network, and show that under particular channel conditions the performance of the system can be seriously degraded.

1 Introduction

The home segment of the networking marketplace is poised for rapid growth, and in order to meet this demand networking specifications are currently under development for intra-home local area networking. The Home Phoneline Networking Alliance (HomePNA) [1] is an industrial organisation formed to develop specifications for interoperable home networked devices. These specifications are based on existing home telephone wiring, which is shared by other devices [2]. These devices include POTS devices (telephones, modems, fax machines) and also possibly the broadband digital subscriber line service G.Lite. These devices are designed to coexist without interference on the same wire pair. HomePNA have defined a version 1.0 [2], which operates at a carrier frequency of 7.5MHz, occupies 4MHz of bandwidth and provides transmission rates of 1Mbit/s. The choice of carrier frequency for version 1.0 is based on a number of factors including coexistance with DSL services, which occupy the frequency range 25kHz to 1.1MHz. The specification is based on IEEE802.3 with a modified physical layer for operating over the home phoneline network [2].

The purpose of this letter is to present experimental results and a channel model for the transfer function of the HomePNA test network (HPTN). Furthermore, we describe a typical deployment scenario where the performance of HomePNA version 1.0 technology can be seriously degraded, and provide experimental results to support these findings.

2 Background

The modulation scheme in [2], is a form of differential pulse position modulation, where the data is encoded onto the modulation symbol using a run-length code. This code operates by encoding upto 6-bit sequences into 25 pulse positions, and each pulse position has a period of $116.67ns$. As a time dispersion countermeasure, each modulation symbol is separated by a blanking interval of approximately $3.26\mu s$. The pulse shape of the transmitted waveform is obtained by passing 4 cycles of a 7.5MHz square wave through a $5th$ order bandpass butterworth filter with a passband of 5.5MHz to 9.5MHz. This shaping ensures the spectral mask for coexistance with other services. The reader is referred to [2] for a more detailed description.

3 Modelling

Consider the HPTN shown in Fig.1, where all dimensions are in feet. It conists of two correctly terminated phone jacks at either end of the network, and four unused cables in shunt. These unused shunt cables are generally referred to as bridged taps, and in this example network all are open-circuited.

We define the transmission line in terms of the primary constants: C, the shunt capacitance per unit length, R, the resistance per unit length, L, the inductance per unit length, and G, the shunt conductance per unit length. The secondary constants per unit length of cable are specified as

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)} \tag{1}$$

$$Z_o = \sqrt{\frac{(R + j\omega L)}{(G + j\omega C)}} \tag{2}$$

where γ is the propagation constant and Z_o is the characteristic impedance. We characterise the line using the transmission parameters, A, B, C, and D, for a general linear reciprocal two port network. In terms of the secondary constants, the ABCD parameters in matrix notation are given by

$$\mathbf{S} = \begin{pmatrix} A_s & B_s \\ C_s & D_s \end{pmatrix} = \begin{pmatrix} cosh\gamma l_s & Z_o sinh\gamma l_s \\ \frac{1}{Z_o} sinh\gamma l_s & cosh\gamma l_S \end{pmatrix} \tag{3}$$

where l_s is the length of the transmission line. Similarly, it is straightforward to show that the equivalent ABCD parameters for a bridged tap (unused cable) are given by [3]

$$\mathbf{B} = \begin{pmatrix} A_b & B_b \\ C_b & D_b \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ \frac{1}{Z_o} tanh\gamma l_b & 1 \end{pmatrix} \tag{4}$$

where l_b is the length of the unused cable. In matrix form, the cascaded connection of a line and a bridged tap is simply the matrix multiplication $\mathbf{T} = \mathbf{SB}$ [3]. By repeated application of this operation the general transmission parameters can be computed for any number of two port networks in cascade. Therefore, from Fig.1 we can write the transmission parameters for the complete HPTN as

$$\mathbf{T} = \prod_{i=0}^{N-1} \mathbf{S}_i \mathbf{B}_i = \begin{pmatrix} A & B \\ C & D \end{pmatrix} \tag{5}$$

where i denotes the section of line or bridged tap in the HPTN and N is the number of cascaded sections. We use the RLCG functions for category 5 (CAT5) cabling given in [5] to determine (1) and (2) across the frequency range of interest. For completeness, these functions are shown below:

$$R(f) = 1.81 \times 10^{-22} f^3 - 4.11 \times 10^{-14} f^2 + 4.57 \times 10^{-6} f + 31.48 \tag{6}$$

$$G(f) = 2.37 \times 10^{-26} f^3 - 5.09 \times 10^{-18} f^2 + 5.11 \times 10^{-10} f + 0.00261 \tag{7}$$

$$L(f) = e^{-1.3 log f - 4.2} + 4.38 \times 10^{-5} \tag{8}$$

$$C(f) = 4.59 \times 10^{-9} \tag{9}$$

It is straightforward to show that the transfer function of the HPTN is given by [3]

$$H(f) = \frac{Z_L + Z_s}{A(f)Z_L + B(f) + C(f)Z_s Z_L + D(f)Z_s} \tag{10}$$

where Z_s and Z_L are the source and load impedances respectively, and the ABCD parameters have been modified to denote their dependency on frequency.

The measured transfer function for the HPTN is shown in Fig.2 and the computed values using the channel model are shown in Fig.3. In the model, the HPTN has $N = 5$ cascaded sections, where $\mathbf{B}_4 = \mathbf{I}$, the identity matrix. It can be seen that Fig.2 and Fig.3 are in good agreement. Moreover, since the channel model is complex, it can also provide a realistic time domain characteristic. We also have similar results for the lower quality quad silver satin (QSS) cabling, however, in the interests of conciseness we have not presented these results.

4 Performance

It is apparent that the test network is highly frequency selective, and the notches occur at locations given by [4]

$$f_b = \frac{1.5 \times 10^8}{l_b} \tag{11}$$

We recall that the HomePNA specification version 1.0 operates at a carrier frequency of 7.5MHz. From (11), an unused cable of approximately $l_b = 20$ft, will place a notch in the bandwidth of interest. We now consider the performance of version 1.0 HomePNA over 2 networks which are both based on the HPTN of Fig.1. The first network is the same as Fig.1, but only the first unused cable is left unterminated. The remaining unused cables are terminated with 100Ω resistors. The second network is identical to that of Fig.1. Both networks have version 1.0 HomePNA nodes connected to the phone jacks and both networks are standalone, i.e. disconnected from the access network.

Table I shows the TCP (Transmission Control Protocol) throughput performance of both networks for QSS and CAT5 cabling, measured using publically available performance benchmarking software [6, 7]. The lower quality QSS is virtually unusable, whereas on the CAT5, the HomePNA technology appears to cope well with network 1, but struggles with network 2. It should be stressed, the throughput over the HPTN with all unused cables correctly terminated into 100Ω was measured at 810kbit/s for both QSS and CAT5. In addition we found that network 1 with QSS cabling was able to achieve 810kbit/s when we shortened the unused cable such that $l_b \leq 17ft$ ($f_b \geq 8.8$MHz).

5 Conclusion

The HomePNA specification version 1.0 is the latest standard for wired networking in the home. It relies on using existing phoneline wiring in the home to connect devices and coexists with existing services. We have presented experimental performance results of HomePNA version 1.0 technology and a channel model for the transfer function of the HPTN. More importantly, we have shown that the performance of version 1.0 equipment can be seriously degraded under certain channel conditions. Specifically when there are multiple unterminated cables in the network. This is particularly the case when QSS cabling is employed. Finally, we remark that these issues will not affect HomePNA version 2.0 technology, which has been designed to cope with the frequency selectivity observed on typical networks to enable higher transmission rates.

References

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[6] "Netperf: A network Performance Benchmark, Revision 2.0", Information Networks Division, Hewlett-Packard Company, Feb. 1995.

[7] http://www.netperf.org

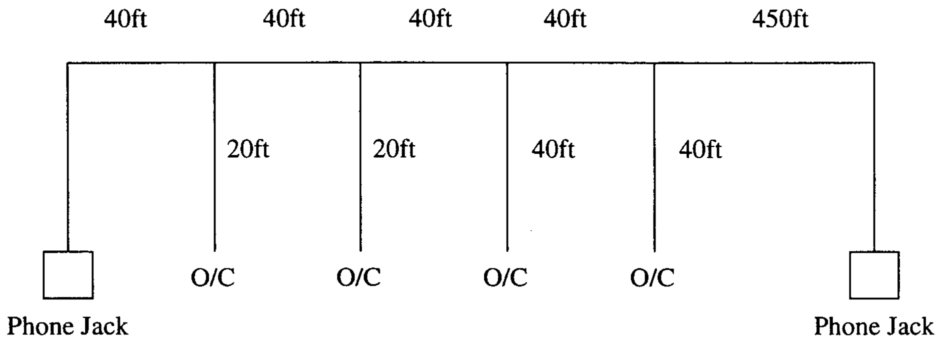

Figure 1: HomePNA Test Network

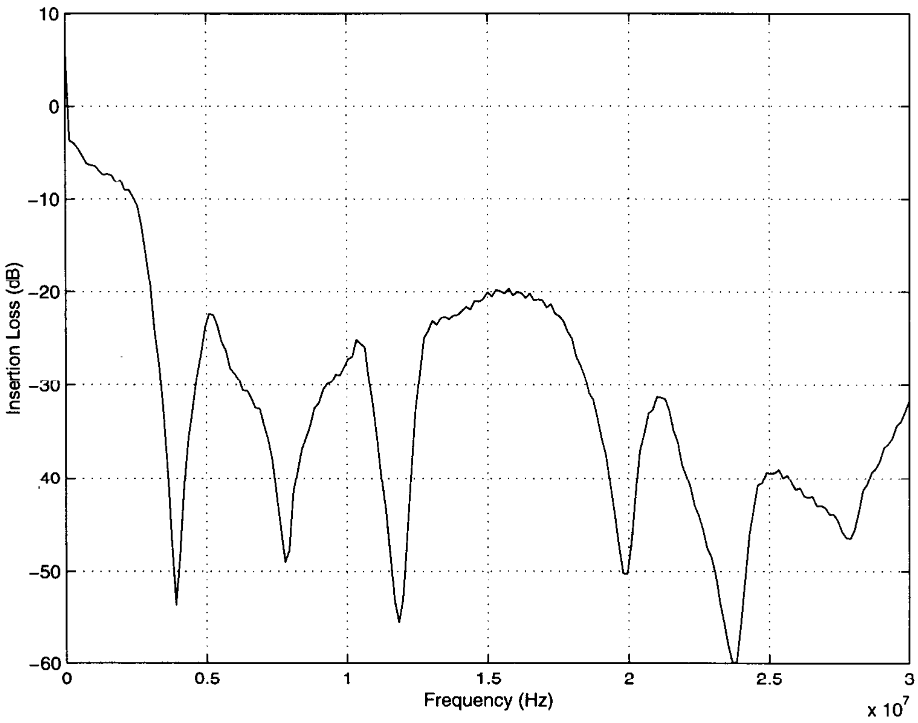

Figure 2: Measured Transfer Function for the HPTN using CAT5 cabling

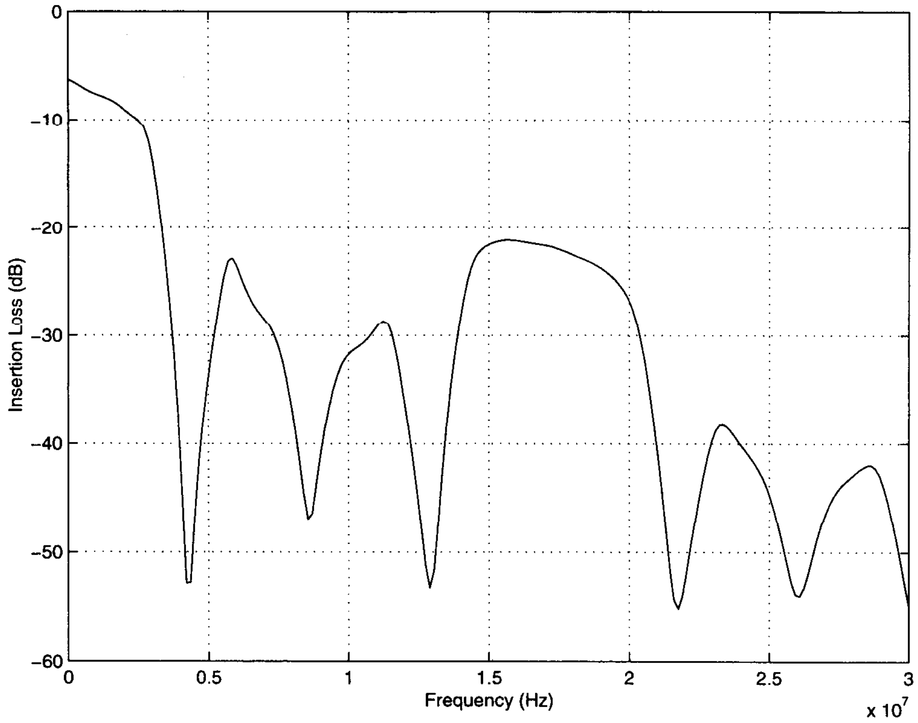

Figure 3: Computed Transfer Function for the HPTN using CAT5 cabling

	Network 1	Network 2
QSS	10kbit/s	10kbit/s
CAT5	810kbits	490kbit/s

Table I
Performance of HomePNA version 1.0 over the HPTN for QSS and CAT5 cabling