[2], i.e., the desired signal $d(n)$ is given by

$$d(n) = \sum_i w_i(n) * u_i(n) + \sigma_\eta \qquad (2)$$

where $u_i(n)$ is the signal transmitted on pair i, $w_i(n)$ is the time-domain crosstalk function between pair i and the considered pair, and σ_η is additive Gaussian noise.

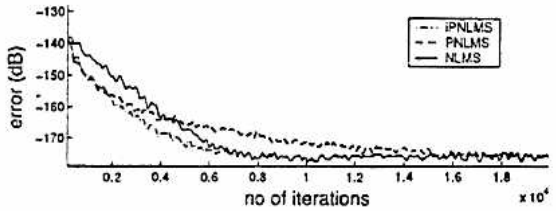

Fig. 2. Plot of the error at $\sigma_\eta = -176$dBm.

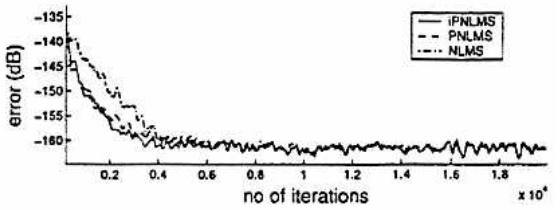

Fig. 3. Plot of the error at $\sigma_\eta = -161$dBm.

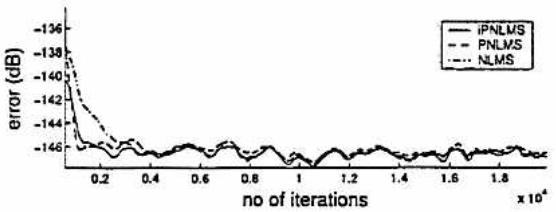

Fig. 4. Plot of the error at $\sigma_\eta = -146$dBm.

A. *Convergence rate in an HDSL2 environment*

When all the twisted pairs in a bundle are of a single DSL type, NEXT cancellation does not require resampling of the transmitted input signals. In the HDSL2 system, the input signal is also passed through a scrambler. Thus the input signal tends to have a low eigenvalue spread, which helps in increasing the convergence rate of the adaptive filter.

The NEXT cancellation in each adaptive algorithm is performed under different noise conditions. Figs. 2, 3, and 4 show the plots of the error versus the number of iterations under different noise conditions. From the plots, it can be seen that at low σ_η, the i-PNLMS algorithm has the fastest convergence and the PNLMS algorithm exhibits the slowest convergence. However as the noise floor σ_η increases, the performance of the PNLMS algorithm improves over that of the NLMS algorithm. In all the noise conditions, the i-PNLMS algorithm exhibits the fastest convergence for the same mean-residual error.

B. *Convergence rate in a mixed environment*

For the mixed environment, three DSL types were simulated, namely, HDSL2, HDSL, and ISDN. The simulations used a bundle consisting of 7 twisted pairs of gauge 26 AWG and length of 7600 feet. HDSL2 was simulated on three pairs, with two pairs each for HDSL and ISDN, as specified in the T1E1.4 draft for HDSL2, HDSL and ISDN standards [9][10][11]. The transmitted data from all the lines were made available to each line for the purpose of crosstalk cancellation. They were accordingly resampled if the other line had a different DSL type.

For this paper, the NEXT cancellation was performed on the pairs with HDSL2. The adaptive filters used for performing the NEXT cancellation were of length 100. Note that HDSL2 has the highest sampling rate among the three DSL mentioned, and due to the higher eigenvalue spread of the resampled input signals for the other DSL systems, it represents the most critical case when compared with HDSL and ISDN.

Figs. 5, 6, and 7 show the plots of the error of the adaptation system under different noise conditions. From the plots it can be seen that the PNLMS algorithm shows a faster initial convergence compared to the i-PNLMS algorithm. But as the adaptation progresses, the PNLMS algorithm slows down and the i-PNLMS algorithm overtakes the PNLMS algorithm. As the noise floor σ_η is increased the PNLMS algorithm tends to converge slightly faster than the i-PNLMS algorithm for the same mean-residual error.

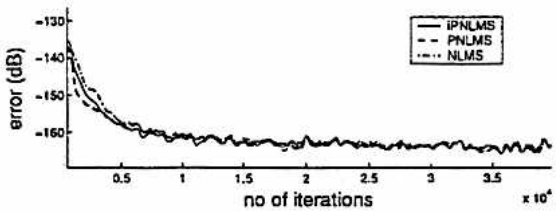

Fig. 5. Plot of the error at $\sigma_\eta = -174$dBm.

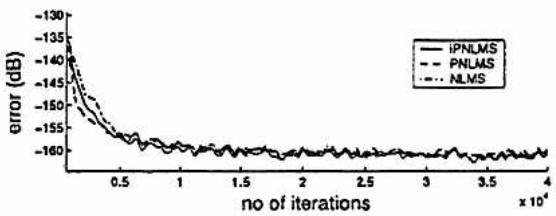

Fig. 6. Plot of the error at $\sigma_\eta = -159$dBm.

C. *Tracing the convergence path of a filter tap*

In Fig. 8, the convergence path of a single adaptive filter tap for each of the adaptive algorithms is shown. As can be seen, for the NLMS algorithm the value of the filter tap oscillates about the optimum as it converges. The same tap value shows a gradual increase towards the optimum for both the PNLMS

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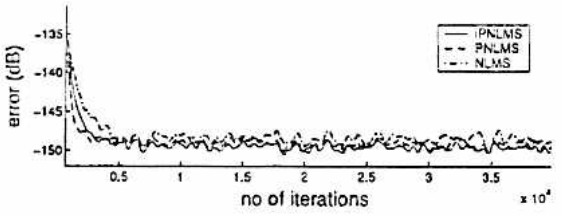

Fig. 7. Plot of the error at $\sigma_\eta = -144$dBm.

and i-PNLMS algorithms. However, the tap weight of the i-PNLMS algorithm exhibits the smallest oscillation among the three algorithms as it converges. This implies that the tap weight in the i-PNLMS algorithm contributes the least amount to the mean-square error and thus significantly increases the convergence rate.

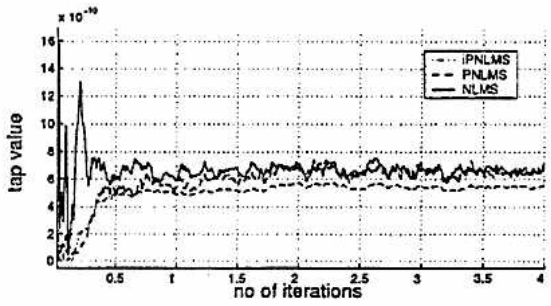

Fig. 8. Plot of a filter tap of an adaptive filter versus the no. of iterations for the various algorithms.

IV. Conclusions

Simulation experiments were performed to examine the convergence rate of the NLMS, PNLMS, and i-PNLMS algorithms in the context of NEXT cancellation in xDSL system. From the simulations it was observed that for a slight increase in computational complexity over that required by the NLMS algorithm, the i-PNLMS algorithm gives, on the whole, better improvement especially when the noise floor is small. The i-PNLMS algorithm also exhibits a greater improvement over the PNLMS algorithm when the NEXT cancellation is done in the HDSL2 environment rather than in a mixed environment with different DSL types.

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