Crosstalk Identification and Cancellation Algorithm in xDSL Systems

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Abstract: - In this paper we propose a sample algorithm for offline identification and cancellation of crosstalk in xDSL modems using impartial third party concept [2]. The crosstalk identification technique includes the following three procedures: 1) The transmitted and received signals from each DSL modem for a predefined time period are collected and sent to the third party; 2) The signals are resample according to the clock rate of the receiver of interest; 3) The signals timing differences are estimated by cross correlation and crosstalk coupling functions are estimated using the variance comparing method. The practical problems expressed and solution for them are explained, And finally crosstalk signal identified and then removed based on some sample information from each modem and assumption for coefficients in real crosstalk domain. Finally, results are compared with other related studies, and flexibility and power of the algorithm in different conditions are shown. MATLAB 6.5 package is used for programming of the algorithm. The written program is applicable for sample production appropriate with any kind of xDSL modems. Furthermore, the used coefficients for crosstalk are chosen from real measured lab information. Number of investigated samples is adjustable in mentioned time span.

Key-Words: - crosstalk, xDSL modem, power spectral density

1 Introduction

DIGITAL subscriber line (DSL) technology uses the existing unshielded twisted pairs of telephone lines to provide high-speed data transmission services to both the residential and business customers. There are many types of DSL, which are generically referred to as xDSL, including basic rate DSL (ISDN), HDSL (high-bit-rate DSL), HDSL2 (second generation HDSL), SDSL (single-pair, symmetric DSL), SHDSL (single-pair, high-speed DSL), ADSL (asymmetric DSL), and VDSL (very-high-bit-rate DSL). At present several million telephone lines between the central offices and subscribers are deployed with xDSL technology at the world, and the number of the subscribers is rising rapidly. One of the major impairments of the current xDSL systems is the severe crosstalk among the telephone lines in the same or neighboring bundles. The severe crosstalk not only limits the maximum data rate of any individual line but can also degrade the existing services if a new service is added to the bundle. Thus, in the currently deployed system, the worst crosstalk scenario is assumed to prevent the breakdown of the system. However, this assumption is often too pessimistic in a real scenario and, hence, limits the overall performance of the system.

According to the importance of crosstalk in xDSL systems and its impact on the speed and accuracy of the information and also daily increasing of DSL modem users (which causes increase in crosstalk amount) crosstalk identification and cancellation methods have special importance. Several studies on this concept have been published [2-6] which are using telephone line crosstalk concept and in multi-user system, crosstalk function estimated and then cancelled. In a relatively complete work [2] with consideration of practical assumptions, an algorithm to crosstalk cancellation proposed that is applicable in different conditions. Weakness of this method is based on the assumption that signals from different modems are completely uncorrelated but in real this condition violated. When the correlations between various modem signals are increased; the estimation error is increasing strongly. In the proposed algorithm in this paper the weakness of these algorithms are improved. Efforts are made to make the proposed algorithm applicable in common communication structures.

2 Formulation

The generic crosstalk model of the xDSL systems for a given receiver is shown in Fig.1. The objective is to identify the crosstalk functions for the receiver. The crosstalk includes the near-end crosstalk (NEXT) and the far-end crosstalk (FEXT). Generally in the presence of NEXT, its value is much larger than FEXT. Therefore, in ADSL and VDSL systems, frequency-division duplexing is used to avoid NEXT. Nevertheless, NEXT may still exist because of other types of services like ISDN, HDSL, HDSL2, SDSL, and/or SHDSL. It is much easier to identify the crosstalk if the transmitted signals and the received signals are both known. Based on this observation, an impartial third-party site is proposed in which the transmitted signals and the received signals during a given time span from all modems are available for the coupling function identification. This level of coordination is necessary and can be achieved by setting up a standard, which suggests that each operator captures the data that flows through each modem during a predefined time period and sends them to the third party. For example, in the central office site, all service operators have their own DSL access multiplexers (DSLAMs) which can be used to collect the transmitted and received data in each modem during a certain time period. The collected data is then sent to the third-party site via internet or some other means for processing. In the customer site, the modem has to store the transmitted and received data packets and send them to the third-party site. Because the line characteristics do not change very much, these data packets can be sent either offline when the modems are idle or via low-speed diagnostic channels currently used in most DSL modems. The location of the third-party site is not confined to the central office. In return, the crosstalk functions obtained from the third-party site are fed back to different service operators who may use this information for various purposes, such as spectral management, system diagnosis, or expansion. These identified crosstalk functions also provide an essential initial condition for a multi-user detector to track the crosstalk response. The time stamp of each modem from different operators relies on the central office clock. Unfortunately, these time stamps are not accurate and the difference can be as large as several milliseconds. Consequently, the predefined time spans from different modems are not strictly aligned together. Besides, the propagation delays are not equal from different crosstalk sources to the receiver of interest and this effect should also be included in the timing differences, although the differences of the propagation delays are generally much smaller than the differences of the time stamps. Without loss of generality, all transmitters are assumed to have nonnegative timing difference. Note that the timing difference d_i is represented in terms of the clock cycles of the receiver and it has an integer value. The fractional portion of the delay is absorbed into the channel/crosstalk response.

Relations of this part expressed based on crosstalk structure. Received signal in receiver modem that composed of main signal, crosstalk signals and noise was shown in Fig.1.

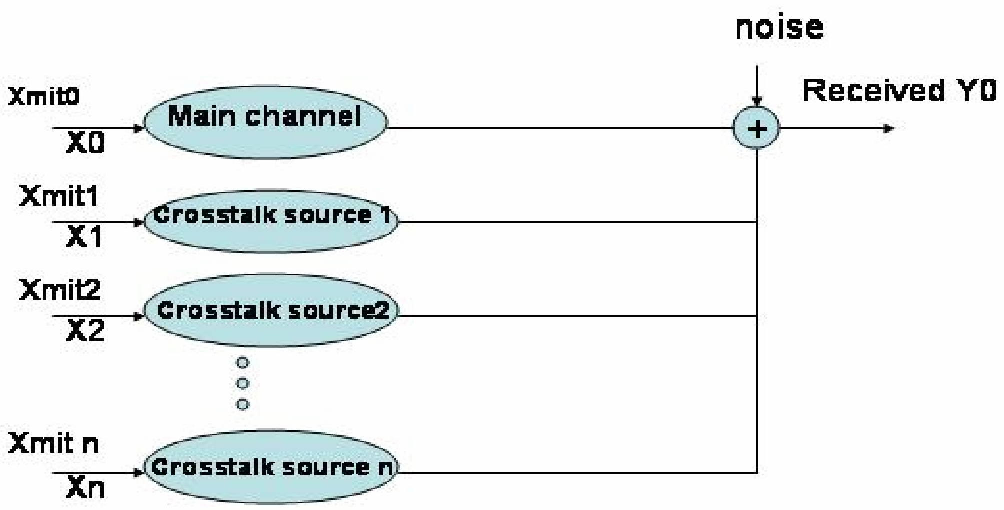

Fig.1: Network model of xDSL for one receiver

$$y(m) = \sum_{i=0}^{k}\sum_{j=0}^{n} a_{i,j} x_i (m - j + d_i) + n(m)$$ (1)

Where

m Number of received symbols;

k Number of crosstalk source;

$a_{i,j}$ Amount of (m-j) symbol effect on m symbol of main signal;

d_i Timing difference between cross talker and main modem;

n(m) Gaussian noise;

In practical systems, value of d0 always is zero because main transmitter and receiver are synchronized. Weights of main channel (a_{0j}) which is related to frequency response of main transmitted signal have higher level than other $a_{i,j}$ because crosstalk signal has less value compared to main signal. Effective $a_{i,j}$ on a definite channel if caused from a similar modem, their weights will be nearest together and the only main difference between them caused by the location of cross talker wire and main wire in binder that in implementation difference was around 5dBm.

3 Assumptions

In practice a series of primary assumptions is necessary for cancellation of crosstalk. At first, the frequency response of main channel is known and in crosstalk calculation didn't applied. Suppose that there is impartial third party which identification of crosstalk, calculation and transmit of $a_{i,j}$ coefficients to modems for cancellation of crosstalk are done in this center. In time span that signals are processed cross talker modems and main receiver send their last received and transmitted information in impartial third party. So in formula (1) unknowns summarized in ($a_{i,j}$) s and ($a_{i,j}$ d_i) s.

d_i Or time difference is because of asynchronous operation of main modem and cross talkers has special importance because the place of effected sample from cross talker on main sample is a fundamental factor for correct weight estimation of $a_{i,j}$ filter coefficients which is related to cross talker. In general if we have N samples, d_i will be an integer between 0 and N.

Also $a_{i,j}$ is related to the type of modem, frequency, signal strength and cable characteristics [1]. Modems that have different frequency response does not affect receiver and automatically are removed of the algorithm.

Because value of Fext is too less than Next, so it is not used in calculations, and argued impartial third party only identify and cancel the Next. Of course algorithm also has ability of identification and cancellation of Fext.

The system is working in offline mode, namely, modem weights are fixed after calculations and are used in a period of time in modems.

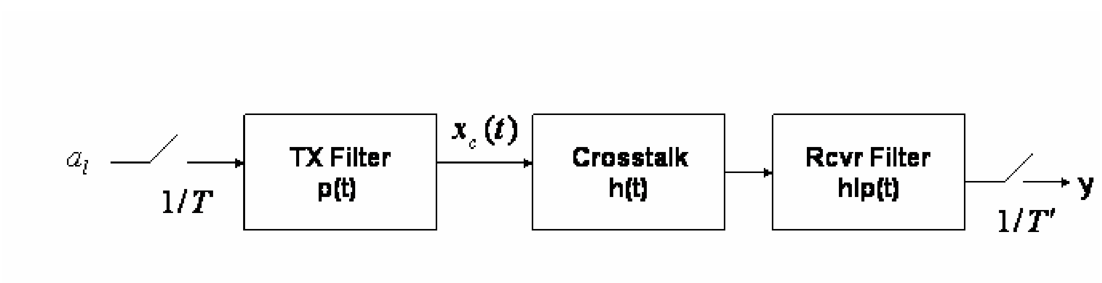

Fig.2: typical base band crosstalk diagram in the xDSL systems

4 Resampling

As mentioned in the introduction, many different services exist in the same bundle of the telephone lines that have different sampling rates. Therefore, the discrete (sampled) crosstalk function will vary with time if the receiver and the crosstalk transmitter belong to different services and have different symbol rates. However, if we can resample the transmitted signals with the same clock as in the receiver, the crosstalk function is stationary because it reflects the physical configuration of the lines.

Fig. 2 shows a typical base band crosstalk diagram in the xDSL systems, where $p(t)$, $h(t)$ and $h_{lp}(t)$ are the transmit filter, the crosstalk response, and the receiver low pass filter respectively.

The sampling rates for the transmitter and the receiver are $1/T$ and $1/T'$, respectively.
The transmitted continuous time signal is:

$$(2)\quad x_c(t) = \sum_{L=0}^{N-1} a_l \delta(t - lT - \tau) * p(t)$$

Where

T Sampling period;

a_l Discrete data stream;

N Total number of data symbols to be transmitted;

τ Fractional delay in terms of the receiver clock;

The received signal before sampling is:

$$y_c(t) = \sum_{L=0}^{N-1} a_l \delta(t - lT) * \underbrace{p(t-\tau) * h(t) * h_{lp}(t)}_{q(t)} + n(t)$$

$$= \sum_{l=0}^{N-1} a_l \delta(t - lT) * \frac{1}{T'} \sin c(\frac{t}{T'}) * q(t) + n(t)$$

$$= \underbrace{\frac{1}{T'} \sum_{l=0}^{N-1} a_l \sin c(\frac{t - lT}{T'})}_{x(t)} * q(t) + n(t)$$

(3)

Where $q(t)$ is the aggregated crosstalk function of concern and $x(t)$ is the reconstructed transmitted signal. The second equation above follows from the fact that $y_c(t)$ is not changed by multiplying by another low-pass filter $\frac{1}{T'}\sin c(\frac{1}{T'})$ if the receiver low pass filter h_{lp} is ideal. The bandwidth of the crosstalk function $q(t)$ is determined by the smallest one of $p(t)$, $h(t)$, and $h_{lp}(t)$. In other words, the identifiable band of the crosstalk is limited by the smallest frequency band of the crosstalk signal, the crosstalk channel response, and the receiver filter. After sampling at a rate of $\frac{1}{T'}$, we obtain the discrete received signal

$$y(m) = x(m) * q(m) + n(m)$$

where

$$(4)\quad x(m) = \sum_{l=0}^{N-1} a_l \sin c(m - \frac{lT}{T'})$$

Since both $x(t)$ and $q(t)$ have a bandwidth less than $\frac{1}{2T'}$, there is no aliasing after sampling. The resampling function (sinc) is not unique; many other functions (e.g., the raised cosine) can be used as the alternative resampling function.

If main modem and crosstalk source belong to different DSL services so we have different sample rate, example1 illustrate this topic.

example1: The receiver of interest is assumed to be a ADSL modem with 276Kbps sampling rate and the cross talker is an ISDN modem with rate 80Kbps. in predefined time if ADSL modem has 500 sample ,in same time ISDN modem will send 145 sample that affect 500 sample of ADSL modem. So impartial third party should produce 500 samples from 145 samples of ISDN to investigate effect of ISDN modem over ADSL modem. So we use following equation for resampling:

$$(5)\quad x_{new}(m) = \sum_{l=0}^{N-1} x_{old}(l) \sin c(m - \frac{lT}{T'})$$

Where

N Total number of resample data; (145 in example1)

T Predefined time for transmit of signal; (1/80 Kbps in example1)

T' Predefined time for receiver; (1/276 Kbps in example1)

m Number of new samples; (a number between 0 and $\frac{NT}{T'}$)

x_{old} And x_{new} is old and new samples;

5 Identification and Canceling of Cross Talkers

Based on assumptions in previous sections after exercising practical conditions, main signal component can be subtracted from the received signal(Y) and only the crosstalk and noise signals are considered, and all data packages from various modems, have the same number of samples it is equal to N. Now, unknown $a_{i,j}$ and d_i must be found with the use of known parameters Xi and Y, that were sent before to the impartial third party. In other words, in predefined time span, all transmitted and received data in modems, are available in impartial third party.

Crosstalk function is a causal finite impulse response (FIR) and Crosstalk effect over one data sample can be caused from eight preceding samples of cross talker [1].so we can rewritte (1)

$$y_m = \sum_{i=0}^{k}\sum_{j=0}^{7} a_{ij} x_i (m - j + d_i) + n(m) \quad (6)$$

5-1 Timing Difference Distinction

Cross correlation technique is used for identification time difference for main cross talker, correlation between received signal Y and main cross talker will have much correlation than other cross talkers. Assume that the transmitted signals from different users are independent and uncorrelated. If correlation between various signals increases, the algorithm can't detect the time difference of main cross talker correctly, but in practice correlation between various signals is less than critical value and we can use this algorithm properly. In [2] it is assumed that all transmitted signals are uncorrelated, and based on this assumption time difference d_i calculated for all modems, but in real condition we can't achieve to this level of non correlation. In this work we have calculated time difference d_i related to main cross talker modem only, because it have clear peak value in contrast with other cross talkers. After identification of main cross talker, it is subtracted of received signal Y and algorithm uses remained Y signal for identification of other cross talkers, and this method is on the contrary of [2], that identify d_i for all modems in the same time. In this paper, at first, only d_i of main cross talker is identified and other timing differences will be found in other steps of the algorithm.

5-2 Main Cross Talker Time Difference Identification

After recognition of main cross talker with the use of correlation technique, rewrite (6) again in a way that main cross talker is isolated from other cross talkers.

$$y_m = \sum_{j=0}^{7} a_{0j} x_0 (m - j) + \sum_{i=1, i\neq 0}^{k}\sum_{j=0}^{7} a_{ij} x_i (m - j + d_i) + n(m) \quad (7)$$

Where

0 Number of main cross talker

X0 Received main cross talker signal after adjustment of time difference d_i;

If autocorrelation function of X0 is impulse function and other cross talkers are uncorrelated with main cross talker (0) then:

$$R_{x0,x0} = k$$
$$R_{ym,x0} = a_{00} k$$
$$R_{ym,x(0+1)} = a_{01} k$$
$$\vdots \quad (8)$$

Where R is correlation function and X(0+1) is received signal from cross talker No 0 that is shifted .

$$\frac{R_{ym,x0}}{R_{x0,x0}} \approx a_{00} \quad (9)$$

In practical conditions autocorrelation function is not an impulse, and received signals are not completely uncorrelated. So we can't use (8) and based on (9) we can calculate the rang of weights, by dividing $R_{ym,x0}$ by $R_{x0,x0}$ .By the direct use of this weights, the error will increase because of the correlations between signals. For exact estimation of weights ($a_{i,j}$) and decreasing the error we use an intermediate algorithm. To explain the details of this intermediate algorithm we rewrite (7) again:

$$y_m = \sum_{j=0}^{7} a_{0j} x_0 (m - j) + y_{remain} \quad (10)$$

y_{remain} is sum of the remain crosstalk signal and noise

(11)

$$y_m = a_{00} x_0(m) + a_{01} x_0(m+1) + ... + y_{remain}$$
$$y_k = y_m - k x_0(m)$$

If we subtract $kx_0(m)$ from y_m and if k is equal to number of a_{00} then we have:

(12)

$$y_k = a_{01} x_0(m+1) + a_{02} x_0(m+2) + \cdots + y_{remain}$$

Cross correlation function between y_k and x_0 will have very little value in all points if x_0 correctly removed from y_k and if there were any difference between k and a_{00} that we named it er so we have(note that value of er can be positive or negative):

$$y_k^{'} = er x_0(m) + a_{01} x_0(m+1) + \cdots \quad (13)$$

Cross correlation function between $y_k^{'}$ and x_0 because of $erx_0(m)$ is similar to y_k and only difference between is the term $erx_0(m)$. If there were a criterion in algorithm to identify the positive or negative value that is added to a sample of cross correlation function between y_k and x_0, then we can found a value for k that will exactly be equal to a_{00}. After testing various criterions, the value of variance was the best criterion that we can use for finding a_{00}.

Based on above explanations we expand an algorithm that is used to find a_{00} weights:

$$\begin{aligned} & for \quad \mathrm{k} = \text{-}a\frac{\mathrm{R}_{\mathrm{ym,x0}}}{\mathrm{R}_{\mathrm{x0,x0}}} : step : a\frac{\mathrm{R}_{\mathrm{ym,x0}}}{\mathrm{R}_{\mathrm{x0,x0}}} \\ (14) \quad & y_k = y_m - kx_0(m) \\ & A = \mathrm{var}(R_{yk.x0}) \end{aligned}$$

The minimum value for A refers to value k that is exactly equal to a_{00}. The suitable value for a is equal to 2.5 based on different simulation results and negative value for scan is used because of the probability of negative value for weights.

After calculating, exact value for a_{00} is achieved and we subtract $a_{00}x_0(m)$ from y_m. For calculating of a_{01}, we shift x_0 and repeat this procedure to find a_{01} and only $x_{(0+1)}$ are used instead of x_0 in all calculations.

All 8 weights related to main cross talker can be found by repeating this algorithm and remained y_m will be equal to y_{remain} in (8) in ideal case.

If we subtract the weights related to main cross talker from y_m and replace y_{remain} instead of y_m and repeat algorithm again we can find weights for second main cross talker modem. From nine unknown parameter for each cross talker at first, d_i and then, weights will be found with respect to their importance respectively. All unknowns are equal 9K and K refers to number of cross talkers.

6 Error Estimation

Definition of cross talk error can be explained in two ways. One of them is the ratio between remained crosstalk power to the primary cross talk power that is used in many practical systems. In second method, which is used in [2], error defined as difference between calculated weights for filter and real weights. In this case, summation of weights square level difference, will compare with summation of the weights and result will present in percents. Second criterion define error more accurate than the former.

7 Simulation and Results

In this section, we show the simulation results of crosstalk identification in the upstream direction (from the subscriber to the central office). The receiver of interest is assumed to be an ADSL modem. To reflect typical crosstalk environment, the number and the type of the cross talkers are assumed to be

- Four basic rate ISDNs (BRIs);
- Four HDSLs;
- Five ADSLs.

All twisted pairs are assumed to be 26-gauge (0.4 mm) and 9000-feet (2744 m) long. The dominant crosstalk signals consist of NEXTs from BRIs and HDSLs. There is no NEXT from ADSL because most of the deployed ADSL modems use frequency-division duplexing scheme [5]. We are used related PSD for next in modeling the effect of each modem. PSD can found in [5] and a variable coefficient is (up to5db) used for place of twisted pair in bundle. Crosstalk signal with respect to the upper practical parameters is used in simulation. In order to investigation of algorithm efficiency in any simulation, time differences and weights are chosen randomly from authorized domain. Simulator uses 20 different cross talker with fixed number of data to achieve more accurate result and finally the mean of errors that occurred, is reported as the error. Fig.3. shows the identification of main cross talker from all cross talkers. Fig.4. contains the error result with respect to data samples and level of error. If we denote M for unknown parameters (72 in this example) doubling the number of the data symbols reduces the error by 3 dB. However, the error grows rapidly when the number of data is less than 2M. This result is exactly as same as other works.

8 Conclusion

Crosstalk is a major impairment of xDSL systems, which significantly limits the data rate and the reach of the twisted pairs. For both ILECs and CLECs, it is invaluable to identify the crosstalk environment for each pair and, thus, offer better services to more users. However, because of the competitive nature of ILECs and CLECs, there is little coordination between them so far. In this paper, an impartial third-party concept is proposed to process the data from all service operators and estimate the crosstalk functions for them. In comparison with the same works, using the variance concept has good results for crosstalk identifications also idea for time difference identification in each procedure of crosstalk identification cause that the sensitiveness of algorithm to correlation between signals becomes less than the same algorithms and has better results.

Error estimation results are shown and we noted that by choosing the appropriate number for data sample, error will be less than 2 percent. In the example used in algorithm there were worst case and modems have similar conditions and we expect better results in real practical conditions.

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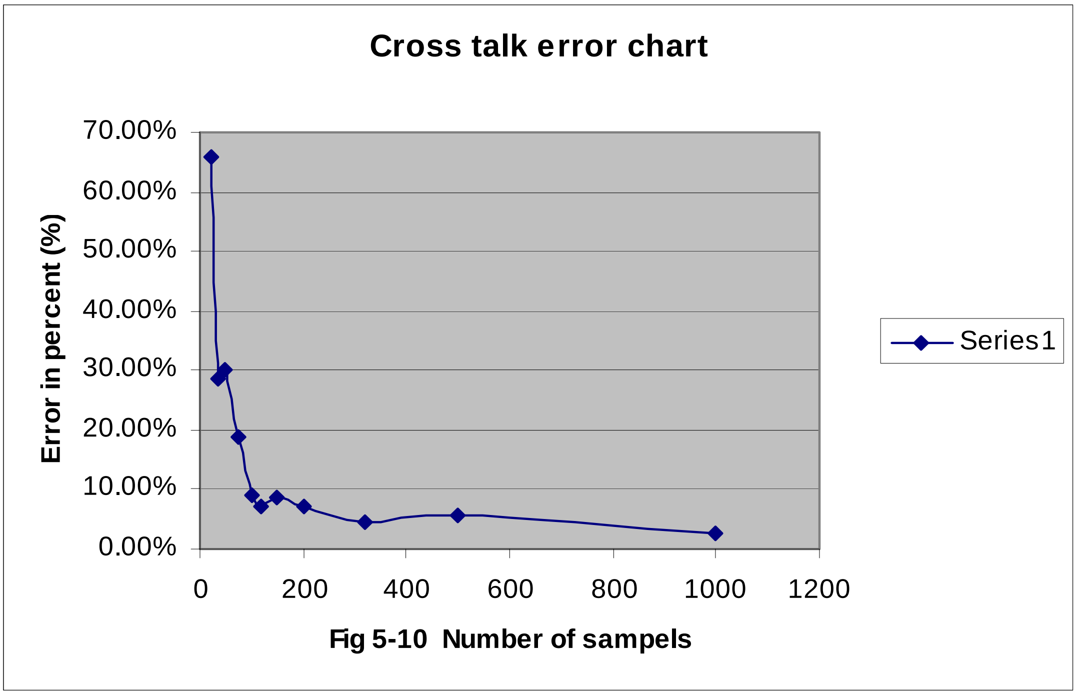

Fig.4: Total crosstalk error estimation

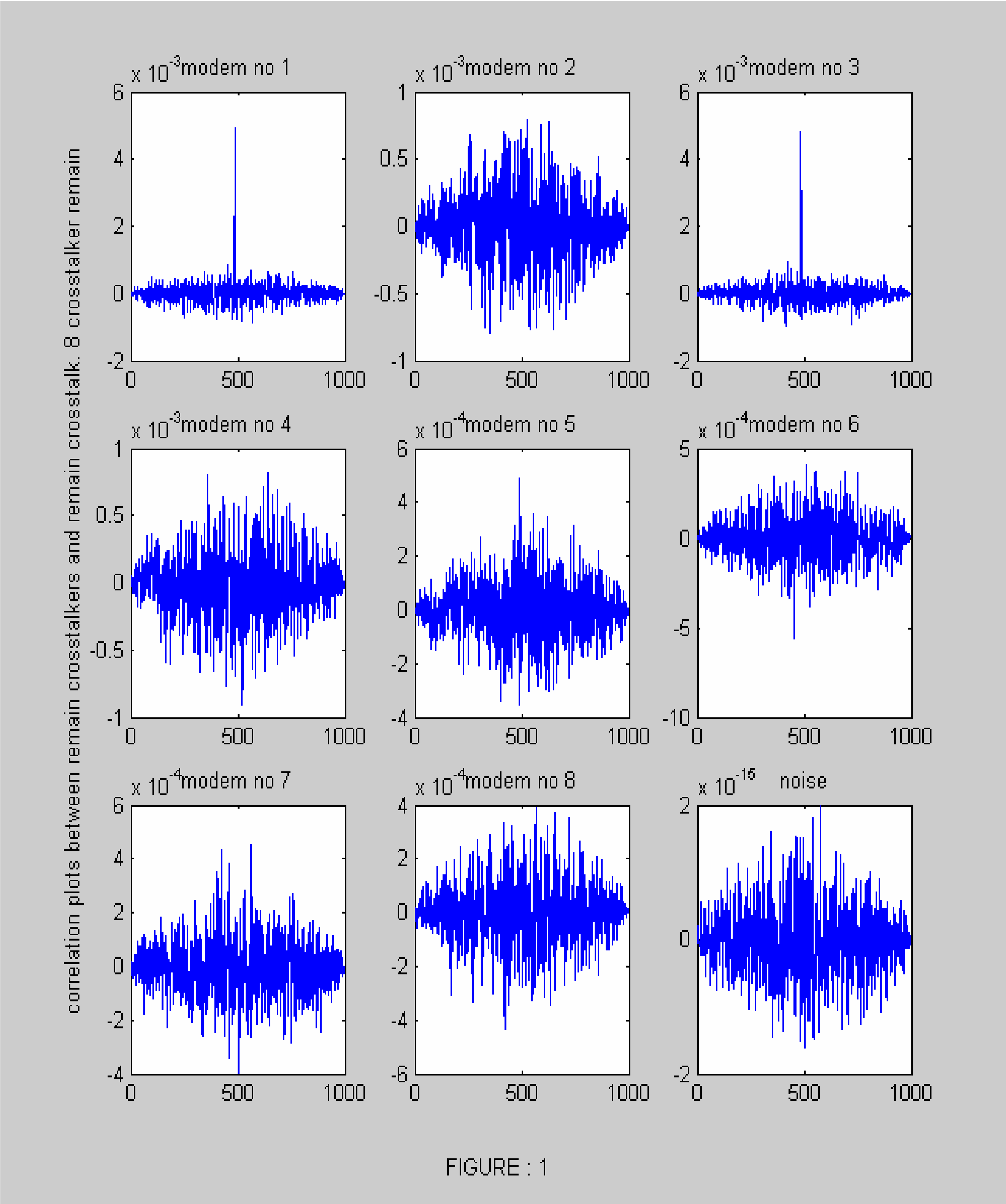

Fig.3: identification of main cross talker