

Channel modelling activities related to the satellite navigation channel in the SatNEx project

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Abstract— The research work within the European Satellite Communications Network of Excellence Phase II (SatNEx II) is organised in various joint actions (JA). JA2310 is dedicated to “Channel Modelling and Propagation Impairments Simulation” and encompasses 4 focus topics (FT). This contribution refers to the work in focus topic FT4 which deals with the satellite navigation channel. Contributing institutions to FT4 are CNES, DLR, ESTEC, ONERA, Politecnico di Milano, University of Surrey, and University of Vigo. FT4 is led by DLR.

The contribution gives an overview about recent advances in modelling the multipath behaviour of the satellite navigation channel. The main activities focus on indoor and rural environments and also address complexity aspects of the channel models.

I. INTRODUCTION

An important task of a satellite navigation receiver is to estimate the time it takes for the navigation signal to travel from the transmitter (satellite) to the receiver. The estimated time can be directly translated into distance. The simultaneous reception of navigation signals from 4 and more satellites allows estimating the position of the receiver.

The navigation signal is subjected to various effects while travelling through the Earth’s atmosphere. The ionosphere causes a delay of the propagation time. The same holds for the troposphere. These propagation delays vary slowly with time; both spontaneous solar activity as well as the day and night rhythm have the main effect on this delay. Finally, multipath reception, diffraction and scattering of the navigation signal due to buildings, vegetation and other obstacles and items in the proximate vicinity of the receiver very much deteriorate the synchronisation process in the receiver. Multipath propagation varies fast with time. In addition to multipath, blockage of the signal may occur which disables signal reception and, consequently, any position fix.

In order to cope with multipath fading and to improve the accuracy, appropriate receiver algorithms have to be

developed. They have to be optimised and tested which is done via computer simulations. These, in turn, require channel models which realistically simulate the multipath behaviour.

The paper is organised as follows: Section II reviews the state-of-the art in modelling of the satellite navigation channel. The section concentrates on urban, sub-urban and aeronautical environments. Section III covers ongoing channel modelling for the satellite-to-indoor and rural environments. Section IV addresses implementation aspects and treats the question whether it is feasible to simplify some of the proposed channel models in order to allow an easier hardware implementation.

II. STATE-OF-THE ART IN CHANNEL MODELLING FOR SATELLITE NAVIGATION

In the last years new wideband models for the satellite navigation channel have been developed. This has been motivated by the high demand to accurately simulate the performance of satellite navigation receivers in different environments. Applications span from mass market receivers in rural, urban, and indoor environments to commercial receivers in aeronautical, maritime, and other environments.

Commonly, the basis of a detailed channel model is a measurement campaign. In a measurement campaign the transmit signal is known to the receiver and the channel impulse response can be measured precisely. As the application is satellite navigation it is common practice to install the experimental transmitter on a flying platform such as an aircraft [1], helicopter [1], [2] or Zeppelin [3] or on a highly elevated platform [4], [5], [6].

Various models for the different environments have been published and standardised:

- Aeronautical channel model: published in [1] and standardised by ITU as ITU-R 682-2. A MATLAB implementation can be downloaded from [7].

- Land-mobile channel model for urban environments and car users: published in [8] and approved for standardisation as ITU-R 681-6. A MATLAB implementation can be downloaded from [7].
- Land-mobile channel model for sub-urban environments and car users: published in [9] and planned to be submitted to ITU-R.
- Land-mobile channel model for urban and suburban environments and pedestrian users: first findings are in [10]; the paper on final results is submitted to ENC GNSS 2009.

Results on a detailed satellite-to-indoor channel model for satellite navigation have been published in [2]. As the subject is rather complex due to very different building structures channel modelling is still ongoing evaluating recent measurement campaigns.

The rural channel model is under development and is based on an exhaustive measurement campaign carried out in 2002.

Not yet covered by highly accurate measurement campaigns are environments such as rail and maritime. Both require a detailed knowledge of the propagation medium as applications also belong to the safety-of-life category. Both environments are very challenging as the surroundings typically consist of strong reflectors. Both environments are very much different than the ones described above so that an assessment of the propagation behaviour without detailed measurement campaigns is very difficult not to say impossible. However, such campaigns are not planned at the moment as far as the authors know.

III. RECENT ACHIEVEMENTS IN SATELLITE NAVIGATION CHANNEL MODELLING

This paper covers recent contributions in channel modelling concentrating on the satellite-to-indoor and rural channel model.

A. The satellite-to-indoor channel

Four satellite-to-indoor measurement campaigns to assess the wideband satellite navigation channel have been carried out since 2002 in L, S and C band [2], [11], [5], [6]. The detailed modelling is still ongoing. First results have been published [2], [11], [12]. An overview of further channel modeling activities which are also well suited for satellite communication applications is given in [13]. Here recent results on the penetration loss at C band and the power delay profile at L and C band are presented.

At 5 GHz the penetration loss into a building are presented to show how the penetration loss changes with the incidence angle. The results were obtained by simulation based on the method of physical optics. The geometry of the situation is shown in Fig. 1.

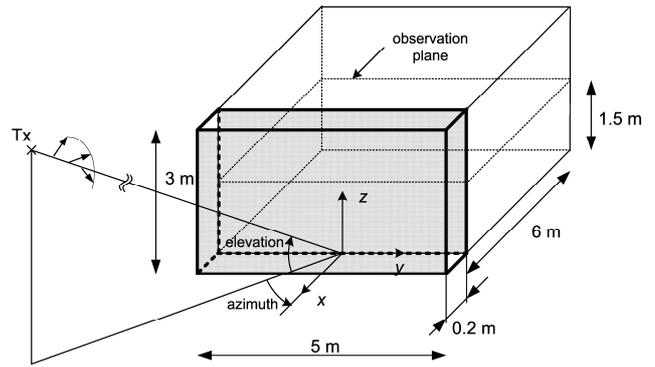


Fig. 1 Building geometry.

There is a circular right-handed polarized wave propagating towards the external wall of the building. The field on the inner side of the wall is calculated using the incident field and transmission coefficient and dielectric slab model. The field is then reradiated into the room behind the wall. Only the effect of the external wall is taken into account, i.e. the reflections from the internal walls of the room are not considered.

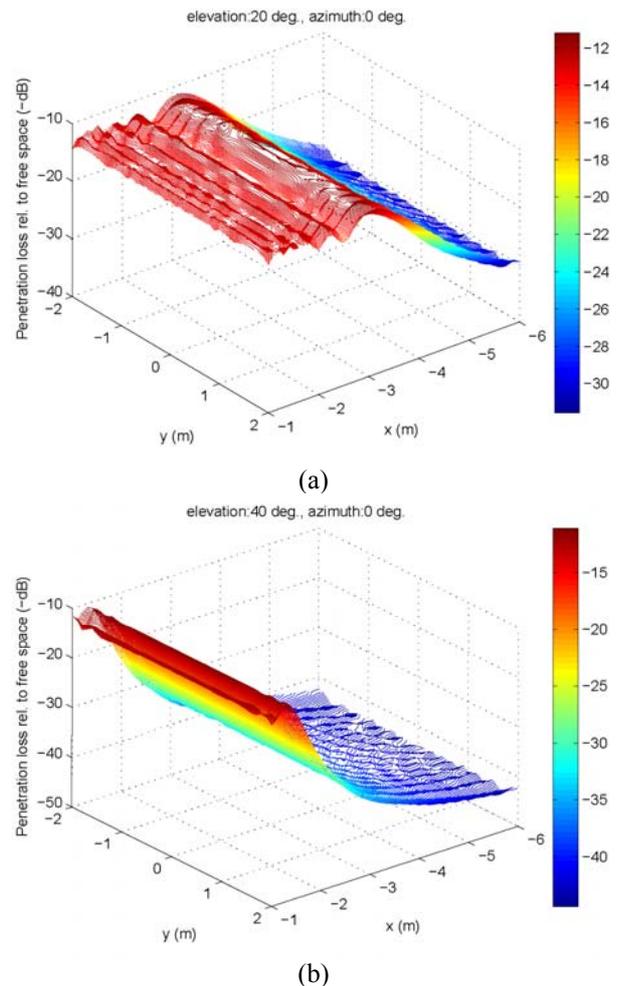


Fig. 2 Penetration loss for 20 deg. (a) and 40 deg. (b) elevation.

Fig. 2 shows the calculated penetration loss for 20° and 40° elevation. The observation plane is perpendicular to the z axis and is 1.5 m above the floor. Results for concrete wall are shown. The relative permittivity and conductivity of concrete are $\epsilon_r = 7.7$ and $\sigma = 0.1$ S/m. The thickness of the wall is 20 cm. It can be shown from the results presented that the entry loss increases significantly both for increasing elevation angles and when the receiver moves deeper into the building.

The DLR measurement campaign from June 2008 [6] allows for a comparison of the propagation behaviour in L and C band. Other insights are expected on the spatial correlation of the channel impulse response as the receiver changes its position. The findings on the latter issue are presented later this year.

The power delay profile obtained for L and C band is shown in Fig. 3. The building used for the measurements is a typical three-story office building. The receiver was located in the upper floor. It can be easily seen from the figure that considerably less power is received in C-band compared to L-band. Also the delay spread of the channel is smaller at L-band than at C band. More results are presented in [14].

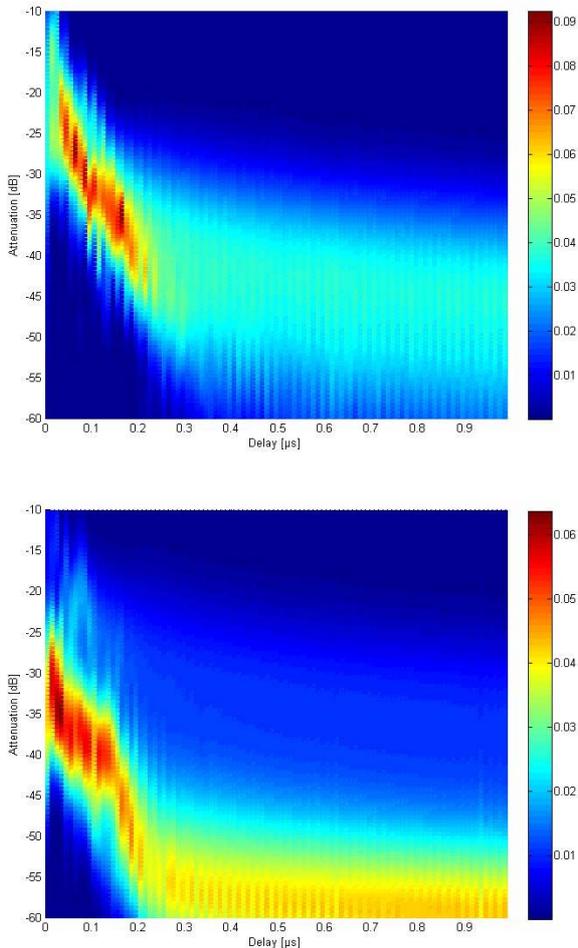


Fig. 3 PDF estimate for the power delay profile at elevation angles of about 10° for L-band (above) and C-band (below).

B. The rural channel

In 2002, DLR conducted high-resolution measurements in Munich's hinterland with a channel sounder at an L-band centre frequency of 1.51 GHz and a bandwidth of 100 MHz resulting in a time resolution of 10 ns. The transmitter was mounted on a Zeppelin which served as vibration-poor hovering platform resembling a satellite. The channel sounder's receiver was installed into a van which drove through a rural environment consisting of country roads and a freeway [3]. The channel impulse responses of several scenarios of different elevation angles were recorded.

The wave propagation effects caused by roadside trees, forests, and alleys are most intriguing to channel modelling aspects for GNSS applications:

- Trees which are close to the road and within the line-of-sight caused periodic deep fades of the sender's signal (the "satellite").
- Since trees are composed of structures in the size of the wavelength such as branches, forks, and leaves in a heterogeneous way, they show strong speckle-like backscattering in the channel impulse responses.

As both effects, the deep fades and the strong reflections of the satellites' signals, are combined in close proximity of the vehicle, it becomes clear that GNSS receivers are imposed to a demanding situation in rural surroundings dominated by vegetation. Consequently, the modelling of the GNSS rural radio channel will focus on shadowing, diffraction, and scattering of trees, forests, and alleys along the road.

The rural channel model will allow the definition of tree distributions and user vehicle trajectory parameters as well as the position of the satellite as input parameters. Statistical processes will then output channel impulse responses which will correspond to those which were measured during the campaign taking the actual wave propagation effects into account. We expect first results of the modelling to be available later this year.

IV. IMPLEMENTATION ASPECTS OF SATNAV CHANNEL MODELS

The treatment of the question which level of detail a satellite navigation channel model shall be able to simulate is very crucial. On the one hand, an accurate channel model describes the propagation medium in its very details. On the other hand its realization for computer simulations may cause time consuming simulations and - more severe - may even disable a hardware implementation in a signal generator due to its complexity.

To overcome the latter problem, one may think of modelling the channel in a less detailed way. However, a low complex channel model may yield wrong results as it might

not model relevant propagation details. It is assumed that navigation receivers are affected by a simplification of channel models very differently depending on how sophisticated these receivers are, i.e. how sensitive they are on the very details of the propagation medium. Advanced receivers which allow for multipath mitigation even under severe multipath conditions by sequential Bayesian estimation [15] may be more sensitive to channel details than conventional receivers.

A. Methods for Channel Model Reduction

Within the framework of JA2310 the impact and feasibility of a reduced DLR land mobile model [8] has been studied [16]. In general there are several reduction approaches to be distinguished, e.g. the objective can be to preserve some properties of the channel with respect to the temporal behaviour, the delay profile or the frequency domain. Spectral properties of the signal that gets transmitted through the channel may be taken into account as well as the architecture of the receiver, e.g. its reception bandwidth. Generally a limited bandwidth may allow for grouping several closely spaced taps into a representative tap. Furthermore the power and phase of the original taps may be expected to have a large impact. Given the channel model links the time-variant impulse response to specific reflectors it may be even possible to remove complete reflectors from the model.

The aforementioned study was restrained to reduction methods in the delay domain, which are independent of the receiver and the used signals, and which are purely based on the realization of the particular channel response, i.e. for each temporal consecutive realization of the channel response the reduction is applied independently, whereas two methods were considered:

- A simple method that just preserves the most powerful echoes of the original channel response (*selection method*) and
- an advanced method, which aggregates weak echoes coherently with their nearest neighbours with respect to the delay domain [*aggregation method*].

B. Effect of Model Reduction

The impact of model reduction on the channel characteristics is illustrated in Fig. 4. It can be seen that after simplification the number of long delay paths is reduced significantly. The mean delay is decreased and the mean power is increased (see Table 1).

| | Mean Delay [m] | Mean Power [dB] |
|--------------------|----------------|-----------------|
| Original Channel | 43,7 | -35,8 |
| Selection Method | 15,8 | -26,8 |
| Aggregation Method | 20,4 | -25,8 |

Table 1: Mean delay and power values according to Fig. 4.

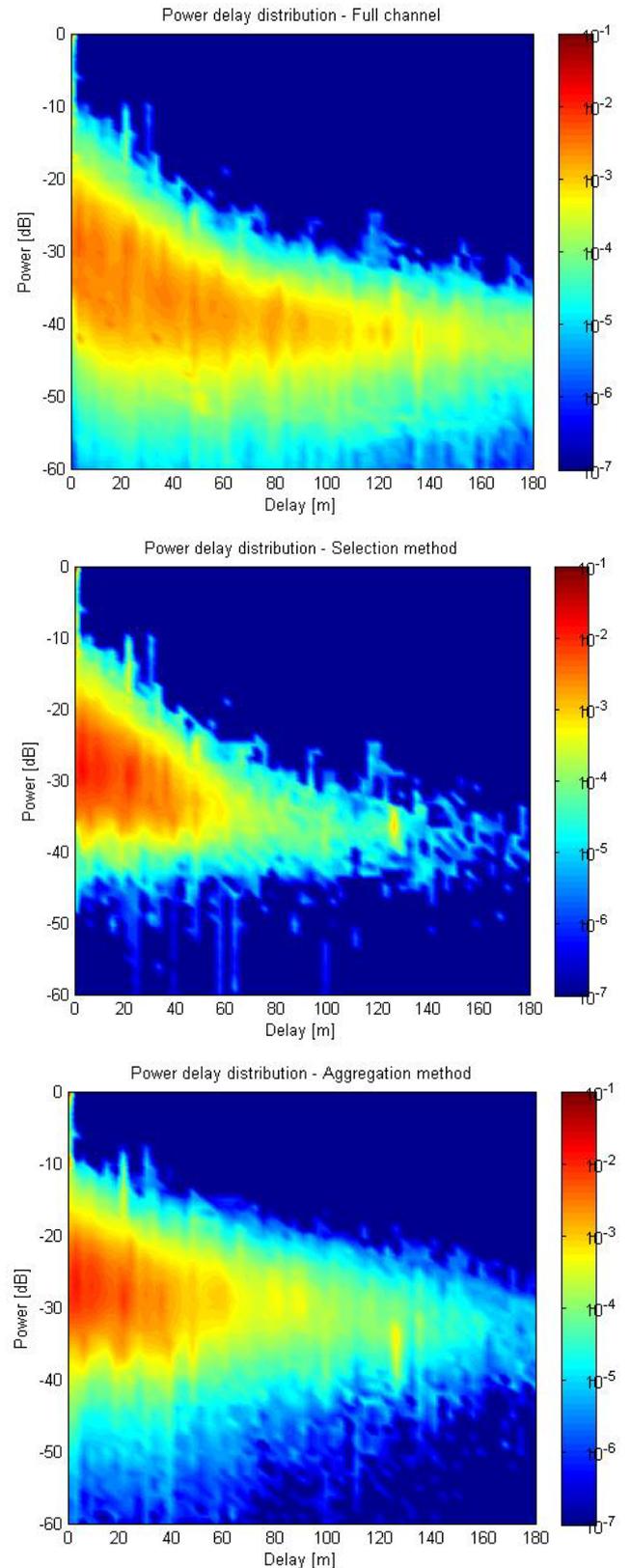


Fig. 4 Power delay distributions for the original channel (above), the channel reduced by selection method (middle), and the channel reduced by the aggregation method (below), reduction to a maximum of 7 simultaneous echoes.

As it can be seen in Fig. 5 the receiver behaviour for standard receivers is preserved for both reduction methods, whereas the aggregation method produces similar errors compared to the full model and the selection method tends to underestimate them. Interestingly, the preliminary results presented in [16] reveal that the errors in the receiver behaviour due to the model reduction increase for a decreasing signal-to-multipath ratio, i.e. in particular whenever the line of sight signal is strongly attenuated.

To alleviate this, future work in this context will focus on the definition of further simplification methods and the preservation of specific channel characteristics, in particular with respect to the frequency domain.

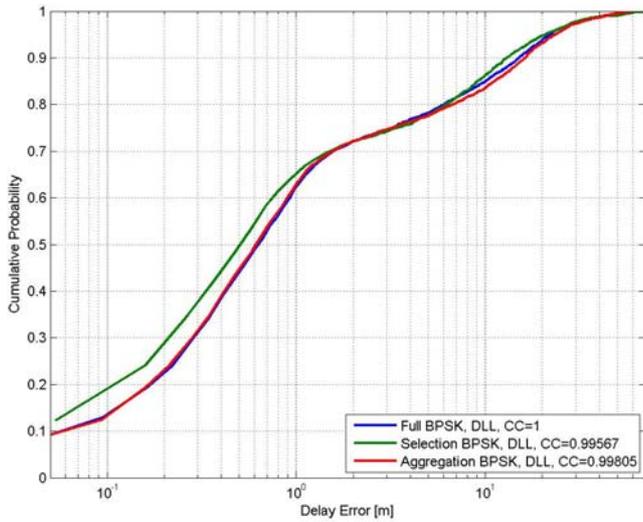


Fig. 5 Cumulative distribution of the tracking errors of a standard navigation receiver depending on the reduction method applied, original channel (blue), selection method (green), and aggregation method (red).

V. CONCLUSIONS

Channel modelling for satellite navigation is a relatively young subject. After the development of channel models for the aeronautical and land-mobile environments research concentrates now on rural and the challenging satellite-to-indoor environments. The subject is rather complex and profits from the cooperation of research teams.

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- [1] A. Steingass, A. Lehner, F. Pérez-Fontán, E. Kubista, B. Arbesser-Rastburg, "Characterization of the aeronautical satellite navigation channel through high-resolution measurement and physical optics simulation", *International Journal of Satellite Communications and Networking*, Vol. 26, 2008, John Wiley & Sons, Ltd., pp. 1 - 30, DOI: 10.1002/sat.891.
- [2] F. Pérez-Fontán, B. Sanmartín, A. Steingass, A. Lehner, J. Selva, E. Kubista, B. Arbesser-Rastburg, "Measurements and Modeling of the Satellite-to-Indoor Channel for Galileo", in *Proc. of the Institute of Navigation National Technical Meeting ION NTM 2004*, Jan. 26-28, 2005, San Diego, CA (USA).
- [3] A. Steingass, A. Lehner, "Measuring Galileo's multipath channel", in *Proc. of the European Navigation Conference ENC-GNSS*, Graz, Austria, April 22-25, 2003.
- [4] J. Goldhirsch and W. Vogel, "Handbook of Propagation Effects for Vehicular and Personal Mobile Satellite Systems", NASA, 1998.
- [5] G. Hein, M. Paonni, V. Kropp, and A. Teuber, "GNSS Indoors, Fighting the Fading, Part 1", *InsideGNSS*, vol. March/April, pp. 43-52, 2008.
- [6] T. Jost et al., "Satellite-to-Indoor Broadband Channel Measurement Campaign at 1.51 GHz and 5.2 GHz", *ESA Propagation Workshop*, Dec. 3-5, 2008, Noordwijk, The Netherlands.
- [7] <http://www.kn-s.dlr.de/satnav/index.html>
- [8] A. Lehner, A. Steingass, "A novel channel model for land mobile satellite navigation", in *Proc. of the ION GNSS 2005*, ION GNSS, pp. 2132-2138, September 13-16, 2005, Long Beach, California, USA.
- [9] A. Steingass, A. Lehner, "Navigation in Multipath Environments for Suburban Applications", in *Proc. of the ION GPS 2007*, ION GPS, Fort Worth, Texas (USA).
- [10] A. Lehner, A. Steingass, "Measuring Galileo's Channel - The Pedestrian Satellite Channel", *Satellite Navigation Systems: Policy, Commercial and Technical Interaction, Proc. of an Int. Symposium ISU 2003*, Kluwer Academic Publishers, The Netherlands, pp. 159 - 166, Strasbourg, France, May 26-28, 2003, ISBN 1-4020-1678-6.
- [11] F. Pérez-Fontán, V. Hovinen, E. Kubista, R. Wack, M. Schönhuber, and R. Prieto-Cerdeira, "Characterization of the Satellite-to-Indoor Channel at S-Band", in *Proc. of the EUCAP*, 2007.
- [12] F. Pérez-Fontán, V. Hovinen, M. Schönhuber, R. Prieto-Cerdeira, F. Teschl, J. Kyrolainen and P. Valtr, "Broadband channel modeling of the Satellite-to-indoor propagation channel at S-band", *2nd SatNex Propagation workshop*, April 17-18, 2008, Oberpfaffenhofen, Germany.
- [13] F. Pérez-Fontán et al., "Overview of activities carried out within SatNex on land mobile satellite and satellite to indoor channel modeling", in *Proc. of EuCAP 2009, Berlin, Germany*, March 2009.
- [14] T. Jost et al., "Satellite-to-Indoor Broadband Channel Measurements at 1.51 GHz and 5.2 GHz", in *Proc. of EuCAP 2009, Berlin, Germany*, March 2009.
- [15] M. Lentmaier, B. Krach, and P. Robertson, "Bayesian time delay estimation of GNSS signals in dynamic multipath environments," *International Journal of Navigation and Observation*, vol. 2008, Mar. 2008.
- [16] B. Krach and G. Artaud, "Performance Assessment of Navigation Signals in Realistic Multipath Environments," in *Proc. of the 4th ESA Workshop on Satellite Navigation User Equipment Technologies (NAVITEC 2008)*, Noordwijk, The Netherlands, Dec. 2008.
- [17] C. Mehlhauer, M. Rupp, "Approximation and resampling of tapped delay line channel models with guaranteed channel properties," in *Proc. of the 2008 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP 2008)*, Las Vegas, Nevada, USA, Mar./Apr. 2008, pp. 2869 - 2872.