# PERFORMANCE EVALUATION OF INTERFERENCE CANCELLATION TECHNIQUES USING ADAPTIVE ANTENNAS

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Abstract[1]: In this paper, two array-based algorithms, which jointly exploit or compensate for the spatial and temporal characteristics of the propagation channel, are proposed for intercell interference suppression in UMTS scenarios. The first one is the array extension of the Viterbi algorithm and is referred to as Vector Viterbi algorithm (VVA). The second algorithm, known as Filtered Training Sequence Multisensor Receiver (FTS-MR), belongs to a class of algorithms in which a narrowband beamformer is placed prior to the MLSE detector. In order to assess performance of the proposed schemes, a set of link-level computer simulations adopting FRAMES' proposal for UMTS air-interface as well as realistic channel models for third generation communication systems is provided. Simulation results reveal gains, in terms of C/I, of 7-10 dB for the VVA with respect to the conventional VA and even higher for the FTS-MR.

## I. INTRODUCTION

A major challenge for wireless communication systems is the limited radio frequency spectrum to be shared by the users. This leads to the situation that, in practical systems, the capacity is mainly determined by the impact of the co-channel interference (CCI). In CDMA scenarios, CCI is a result of low cross-correlations among users spreading codes (Multiple Access Interference, MAI), whereas in TDMA systems co-channel interference is a result of frequency reuse.

In present days, the third generation mobile radio system (UMTS) undergoes standardization in Europe. The higher bit rate services (up to 2 Mb/s) together with increased flexibility in defining customized services are the major differentiating factors of third generation systems with respect to second generation [1,2]. Both CDMA and TDMA multiple access schemes have been investigated in the projects of the European Research Program RACE II, CODIT (COde DIvision Testbed) and ATDMA (Advanced TDMA). Within the ACTS (Advanced Communications Technologies and Services) program, the FRAMES (Future RAdio wideband Multiple accEs System) project [3] have developed a proposal for the UMTS air interface which integrates both access techniques in a single C/TDMA framework. On the other hand, the TSUNAMI II (Technologies in Smart antennas for Universal Advanced Mobile Infrastructure - Part two) project is involved in the incorporation of adaptive antennas (AA) in third generation systems [4]. One of the benefits being important reductions in intracell/intercell interference which allows more users to be allocated.

In this paper, some link-level simulation results for the Vector Viterbi Algorithm (VVA) and the Filtered Training Sequence Multisensor Receiver (FTS-MR) algorithm are presented. Both schemes have been applied to the uplink of a cellular system using FRAMES Mode 1 Non-spread speech burst-2 format. They employ standard vehicular and pedestrian channel models as specified by FRAMES, which have been modified to incorporate realistic angular description. The angular spread model has been derived in the channel sounding activities carried out within TSUNAMI (II).

## II. AN OVERVIEW OF FRAMES PROPOSAL FOR UMTS AIR-INTERFACE

Two multiple access schemes, namely, Wideband TDMA with or without spreading features (WB-TDMA/CDMA, Mode 1) and Wideband CDMA (WB-CDMA, Mode 2) have been identified by FRAMES in order to meet UMTS requirements (c.f. [3]). In this paper, however, we will only consider Mode 1 (Fig.1) where a 4.615 ms frame is deployed. Depending on the environment and service, the frame and the burst can be dynamically adapted with link adaptation. There are two burst formats for the 1/8 slot, one format for the 1/16 slot and two burst formats for the 1/64 slot. In particular, we will adopt the Mode 1 *Non-spread speech burst-2* format. This burst type is made up of two data blocks carrying OQPSK-modulated symbols with a cyclically extended 20-bit training sequence in-between. Since in Mode 1 without spreading features symbol duration equals 384 ns, this reverts in 72 μs speech bursts. For the range of velocities under consideration (less than 100 km/h), the propagation channel is approximately time-invariant for the whole burst duration. Mode 1 uses slow power control, with a 50 dB dynamic range, with an option to use faster power control on a burst basis.

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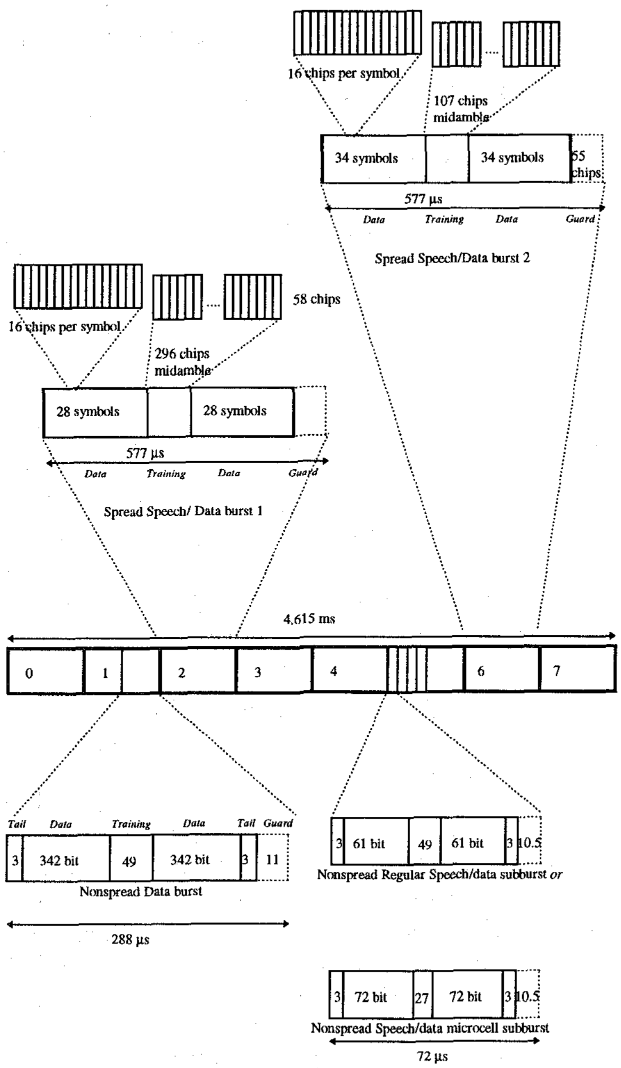


Fig. 1: FRAMES proposal for UMTS air interface Mode 1 (reproduced with the permission of the FRAMES consortium)

## III. SIGNAL MODEL

We consider a model for the general asynchronous multiple-access channel being observed through a $P$ sensor array allocated in the base station (BS). The uplink signal received by sensor $p$=1,..,$P$ is given by,

$$r_p(t)=\sum_{n}\sum_{k=1}^{K}s_k[n]\,h_{kp}(t-nT,t)+\sigma\, w_p(t) \tag{1}$$

where $s_k$[n] is the sequence of symbols transmitted by user $k$, $w_p(t)$ is normalized temporal and spatially white Gaussian noise, and $h_{kp}(t-nT,\ t)$ is the overall complex channel impulse response of user $k$ at sensor $p$. Such a channel response, given by the convolution of the physical channel and the transmitting and receiving filter impulse responses, incorporates the amplitude and the delay for user $k$ at sensor $p$ and its duration is assumed to be smaller or equal to $L$ symbol periods. The vector received signal is sampled at the symbol rate ($1/T$) to obtain the $P\times 1$ snapshot $\mathbf{r}[n]=[\mathrm{r}_1[n],\ldots,\mathrm{r}_P[n]]^T$. Using vector notation and neglecting the contribution from the noise term, we can rewrite

$$\mathbf{r}[n]=\sum_{k=1}^{K}\sum_{l=0}^{L-1}\mathbf{h}_{kl}[n]\,s_k[n-l] \tag{2}$$

where $\mathbf{h}_{kl}[n]=[h_{k1}(lT,nT),\ldots,h_{kP}(lT,nT)]^T$ are the multidimensional channel taps for user $k$. A generic model for the angular characterisation of propagation channels is the Gaussian Wide-Sense Stationary uncorrelated scattering (GWSSUS) model. In this model, it is assumed that the radio wave from user $k$ propagates through a number of scatterers with gains $\tilde{h}_m$, delays $l_{k,m}/c$ and azimuth angles $\theta_m$ (as seen from the base). The scatterers are grouped into $C$ *uncorrelated* clusters, $\Omega_c$, with delay differences *within* each cluster that cannot be resolved for the selected transmission bandwidth (see [4]). In this situation, the multidimensional channel taps, $\mathbf{h}_{kl}$, can be expressed as

$$\mathbf{h}_{kl}[n]=\sum_{c=1}^{C}\sum_{m\in\Omega_c}\tilde{h}_m e^{-j\left(2\pi f_o\frac{l_{k,m}}{c}+\beta\right)}p\left(lT-\tau_{k,c}\right)\mathbf{a}\left(\theta_m,f_o\right) \tag{4}$$

$$=\sum_{c=1}^{C}\mathbf{v}_{k,c}\,p\left(lT-\tau_{k,c}\right)$$

where $f_o$ is the uplink carrier frequency, $p(t)$ is given by the convolution of the modulation pulse shape and the receiver filter response, and $\mathbf{a}(\theta_m, f_o)$ is the vector of receive antenna gains and phases in azimuth direction $\theta_m$ at frequency $f_o$. When the mobile moves, the propagation delay changes this causing the taps $\mathbf{h}_{kl}$ to be time-varying (Doppler-fading). In the second expression, $\mathbf{v}_{k,c}$ is given by the superposition of the steering vectors belonging to cluster $c$ associated to user $k$, i.e.

$$\mathbf{v}_{k,c}=\sum_{m\in\Omega_c}\tilde{h}_m\, e^{-j\left(2\pi f_o\frac{l_{k,m}}{c}+\beta\right)}\mathbf{a}\left(\theta_m,f_o\right) \tag{5}$$

For a number of scatterers, the vectors $\mathbf{v}_{k,c}$ can be regarded as zero-mean complex *Gaussian-distributed wide-sense stationary* random processes with a limiting multipath covariance matrix given by [4]:

$$\mathbf{R}_c=E\left[\mathbf{v}_{k,c}\mathbf{v}_{k,c}^H\right]=\sum_{m\in\Omega_c}\left|\tilde{h}_m\right|^2\mathbf{a}\left(\theta_m,f_o\right)\mathbf{a}^H\left(\theta_m,f_o\right) \tag{6}$$

Assuming the number of scatterers within each cluster is infinite (Fig.2), several power distributions with respect to the azimuth $\theta$ can be devised in order to match those commonly observed. Departing from the well-known approach that employs a truncated Gaussian Angle of Arrival (GAA) distribution [4], a Laplacian Angle of Arrival (LAA) pdf will be considered here. As shown in [5], the power azimuth distribution is well modelled with the Laplacian function in a variety of environments where the Gaussian distribution fails in reproducing the sharp peak at 0°. In practice, the distribution will be restricted to the range $\theta_m\pm 2\sigma$, where $\theta_m$ is the mean DOA and $\sigma$ stands for the corresponding standard deviation (angular spread). Typical values for the latter parameter lie in the range 2°-8°.

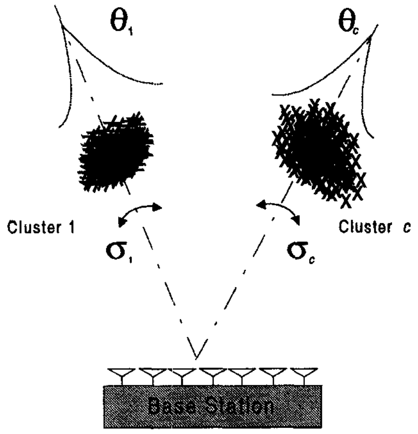


Fig. 2: LAA propagation model.

### A. *Angular Characterisation of Standard Test Channels*

In order to obtain wideband channel models characterised both in the angular and delay domains, two approaches can be considered: adopting a scatterers' deployment (with resolvable delays) such that this matches both distributions or, alternatively, applying the narrowband models of the previous section to each tap in the delay profile to be generated. The latter strategy, which relies on the assumption that azimuth and delay dispersions are not coupled, will be considered in the sequel. In particular, two tapped-delay lines proposed in [6] are taken into account (Fig. 3)

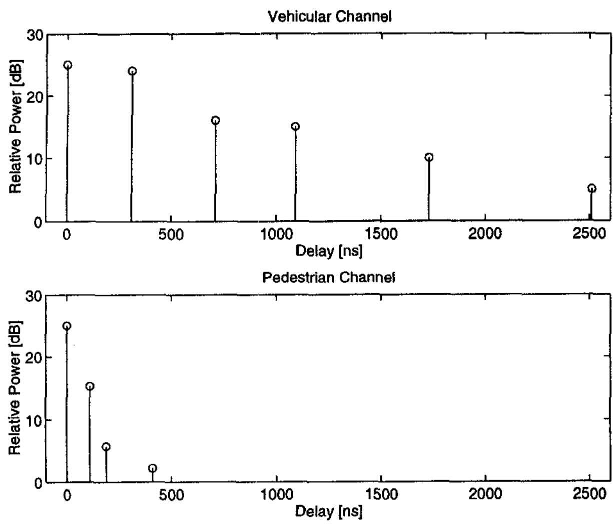


Fig. 3: Tapped-delay lines for the pedestrian and vehicular channels.

The first one, Outdoor to Indoor and Pedestrian test channel (Channel A), models an environment characterised by small cells and low power base and mobile stations. Base stations with low antenna heights are located outdoors whereas pedestrian users are located both on streets and inside buildings. The second model, Vehicular test Channel (Channel A), is more appropriate to model situations where larger cells and higher transmitted power are used. In all cases, a single-cluster LAA distribution has been assumed for the leading taps whereas an omnidirectional angular distribution has been adopted for the last (pedestrian model) or the last two taps (vehicular model). This way, reflections of distant scatterers are embedded in the channel model. Since only link-level simulations are presented in this paper, propagation models do not include slow-fading or path-loss effects. In accordance with [7,8], these phenomena should be taken into account in system-level simulations.

## IV. ALGORITHM DESCRIPTION

Two array processing algorithms have been employed to generate the link-level results presented in this paper. They represent a family of algorithms which jointly exploit or compensate the spatial and temporal characteristics of the propagation channel. Therefore they are only applicable to the uplink of a cellular communication system.

The first one, VVA (Vector Viterbi Algorithm) is the natural extension of the VA for the array observation case (Fig. 4). The implementation of the Viterbi algorithm implies estimation of the temporal channel of the user of interest. If, furthermore, an array of sensors is employed this temporal domain characterisation is required for every sensor in order to supply the Vector MLSE detector with those estimates [9].

The theoretical foundations of the Viterbi algorithm make it optimum in the presence of Gaussian noise only. It is nevertheless recognised that the Viterbi MLSE receiver is sub-optimal in the presence of co-channel interference where joint detection receivers represent the optimal strategy. The same can be said in general with respect to the VVA detector. Unless extended as a multi-user receiver, i.e. all active users are detected, it does not guarantee attainment of the most likely sequence for low SIR.

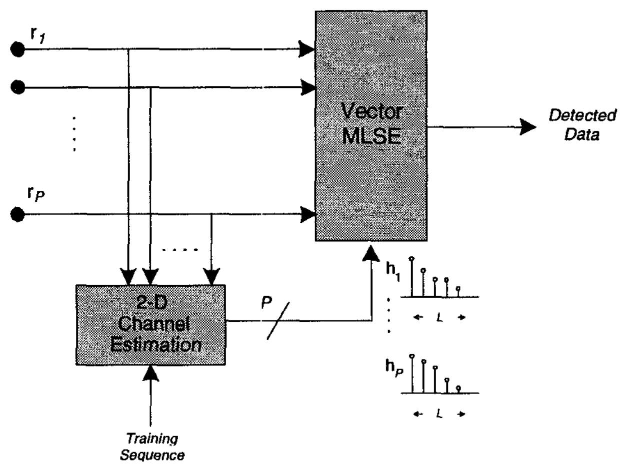


Fig. 4: Vector Viterbi Algorithm.

The second algorithm, known as Filtered Training Sequence Multisensor Receiver (FTS-MR) [10,11] belongs to a class of algorithms in which a narrowband beamformer, **w**, is placed prior to the detection stage (see Fig. 5). The complex baseband components corresponding to each of the antenna elements are combined into a single complex signal, which is fed into a conventional MLSE receiver. This way, both spatial and temporal signal processing are taken into account: spatial filtering in order to remove CCI and a MLSE detector to *remove* the remaining ISI. For the design of the beamformer, weights, the following expression is minimized:

$$J(\mathbf{w},\mathbf{h}) = E\left[ \left\| \mathbf{w}^H \mathbf{r}[n] - \mathbf{h}^H \mathbf{s}[n] \right\|^2 \right] \quad (7)$$

where **h** is the $L\times1$ channel response for the user of interest after spatial filtering (to be estimated along with the beamformer) and $\mathbf{s}[n]$ is a vector made up of the last $L$ transmitted symbols. Minimization is carried out with the restriction $\mathbf{h}^H\mathbf{h}=1$ so as to avoid the trivial solution. After some algebra, it can be obtained that the channel estimate, $\mathbf{h}_{mse}$, is given by the eigenvector associated to the smallest eigenvalue of the matrix

$$\mathbf{F} = \mathbf{R}_{ss} - \mathbf{R}_{rs}^H \mathbf{R}_{rr}^{-1} \mathbf{R}_{rs} \quad (8)$$

In the above expression, $\mathbf{R}_{ss}$, $\mathbf{R}_{rr}$ and $\mathbf{R}_{rs}$ stand for the autocorrelation and cross-correlation matrices for the transmitted and received data. Finally, the beamformer weights are computed from the recently obtained channel estimate:

$$\mathbf{w}_{mse} = \mathbf{R}_{rr}^{-1} \mathbf{R}_{rs} \mathbf{h}_{mse} \quad (9)$$

The only requirement for the FTS-MR algorithm is the knowledge about the training sequence for the user of interest.

Again, no optimality claims can be made with respect to the performance of the scheme in any practical situation in which interferences are not completely cancelled. Nevertheless, the algorithm has shown good behaviour under realistic simulation tests and experimental data [10].

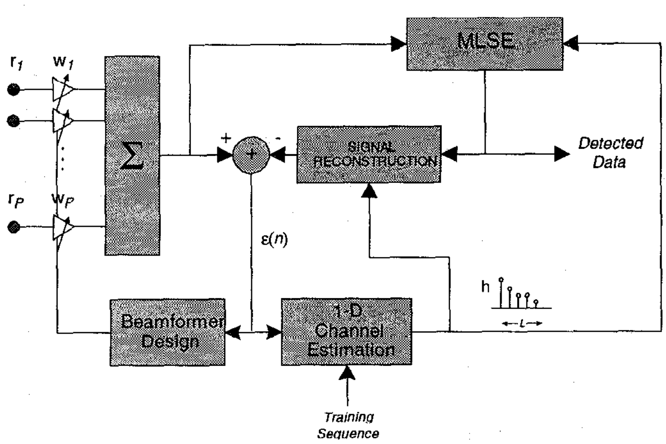


Fig. 5: Filtered Training Sequence Multisensor Receiver.

## V. LINK-LEVEL SIMULATION RESULTS

The received signal impinged on a $\lambda/2$-spaced Uniform Linear Array (ULA) with $P$=8 sensors. A uniform distribution within the range {-60°,...,60°} was adopted for the mean DOAs of both desired and interfering users. That is, a 120° sectorization was assumed. Regarding angular spread, two cases were considered: low azimuth spread equal to 2° for the Vehicular test channel and, moderate azimuth spread equal to 8° for the Pedestrian test channel. Additionally, two interfering scenarios were simulated for *each* channel model depending on the existence or not of a dominating interferer. For the first case, a single interferer was simulated whereas five interferers were generated in the second case. In all situations, the SNR for the AWGN noise was 20 dB.

Apart from the algorithms under study (VVA and FTS-MR) a Viterbi-based detector with single-sensor observation (no antenna diversity) was introduced for comparison purposes. For this reference scheme, channel estimation was performed as in GSM receivers, that is, by cross-correlating the received midamble with the original training sequence.

Performance curves are presented in Fig. 6 where the uncoded (raw) BER is depicted as a function of the instantaneous (in-burst) signal to interference ratio. Several conclusions can be drawn. First of all, in the situations with a dominating interferer (plots on the left), the FTS-MR algorithm is able to cancel it out completely. For a SNR=20 dB, this leads to the situation that measured error rates are lower than the confidence thresholds corresponding to the number of simulations performed (which vary depending on the C/I ratio). Consequently, no curve has been plot for this algorithm. Secondly, for the cases with 5 interferers, the FTS-MR algorithm offers an additional gain with respect to the VVA detector of 3 dB in the range C/I= -5, ...0 dB. This range of signal to interference ratio would probably be the most interesting operating point for the FTS-MR scheme. Conversely, there is no substantial difference in terms of performance between the FTS-MR and the VVA for C/I ratios larger than 3-5 dB (depending on the channel model). Both the FTS-MR and VVA curves merge beyond that point. Performance of the FTS-MR approach is only slightly worse for the vehicular test channel. Since both test channels provide sufficient temporal diversity, the only effect of propagation through longer channel impulse responses (8 symbols vs. 2 symbols in the Pedestrian channel) is degradation in the channel response estimates, thus reverting in higher bit error rates.

## VI. CONCLUSIONS

Simulation results indicate substantial gains, on the order of 7-10 dB, for the Vector VA with respect to the conventional VA (assuming this employs no antenna diversity) and even higher for the FTS-MR for standard pedestrian and vehicular channels in the range of interest for the raw BER.

Additionally, performance results show low sensitivity with respect to the angular spread and to the type of environment. Nevertheless, simulations were carried out assuming no implementation errors and should be employed with caution.

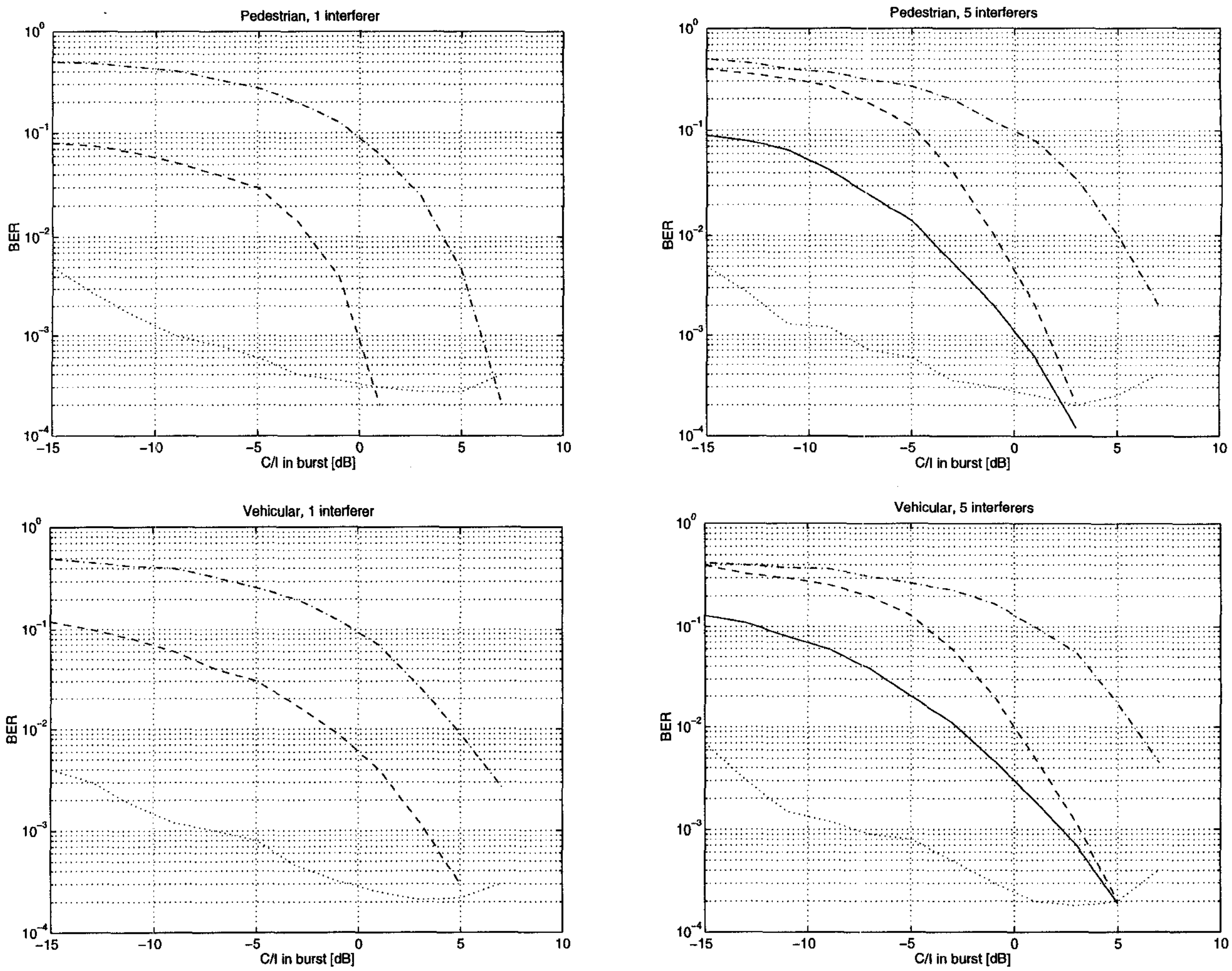


Fig. 6: BER vs. C/I for different test environments: FTS-MR algorithm (solid-line), VVA algorithm (dashed line) and VA with single sensor observation (dash-dot). The confidence ratio, defined as ten times the inverse of the number of symbols associated with each instantaneous C/I value, is represented by the dotted line.

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