The Diffuse Multipath Component and Multipath Component Visibility

Dana Porrat
School of CS and Engineering
The Hebrew University of Jerusalem
91904 Israel
dana.porrat@huji.ac.il

***Abstract*—This work studies the effect of spatial variation of the multipath structure on the diffuse multipath component (DMC). The DMC is quantified in simulated and measured channels, using two versions of SAGE. Using a 'classic' implementation of SAGE, the DMC increases as the visibility regions of multipath components decrease in size. An implementation of SAGE that takes into account visibility regions of multipath components achieves lower DMC over both simulated and measured channels.**

I. Introduction

The diffuse multipath component (DMC) is a relatively recent addition to multipath channel models, aimed to account for the part of the channel that is not described in a satisfactory manner by specular multipath components (MPCs). The DMC is the residual part of the channel, that remains after subtracting the specular components from measured channel responses that were taken with an angular or spatial variation of transmitter and/or receiver antennas.

The DMC accounts for a significant fraction of measured channel power in both indoor and outdoor settings. Analysis of indoor measurements showed 20% - 80% fractional DMC power [1], [2], and outdoor measurements showed results between 10% - 90% [3]. Results in [1], [2], [3] are based on measurements with a 100 - 200 MHz band around a center frequency between 2 and 4 GHz. A graphical representation of a high DMC is shown in Figure 1 of [4] and Figure 4 of [5].

Indoor channel measurements from a single transmit antenna to a receiver array, taken with a bandwidth of 17 GHz exposed the details of the multipath structure, and [6] showed that a significant feature of NLoS indoor channels is the apparent small visibility regions of the constituent multipath components. By MPC 'visibility region' we mean the area of MPC visibility when the receiver antenna moves. The observation of spatial dynamics in [6] leads to a possible explanation of the DMC. The Space Alternating Generalized Estimate Maximize (SAGE) algorithm [7] inherently assumes that multipath components are visible over the entire range of terminal movements used for collecting measurements. We suggest that the DMC is at least partly the result of the modelling inaccuracy that results from not taking into account the spatial characteristics of multipath components.

Quitin et al. recently observed [1] that the angular power spectrum of the DMC is similar to the angular spectrum of the clustered multipath of the same measurement. This observation fits nicely with the idea of the DMC being composed of 'short-lived' multipath components, visible to the receiver (or from the transmitter) over only part of its trajectory.

Two implementations of SAGE are presented in Section II. Analysis results of simulated channels are presented in Section III, they demonstrate the connection between the visibility regions size and the residual power that remains in the DMC after SAGE channel estimation. Section IV brings analysis results of measured channels.

II. SAGE Channel Estimation

This work compares two implementations of the SAGE algorithm, developed to process channel measurements taken between a single transmit antenna and a linear array of receive antennas.

- A 'classic' or spatially–unaware SAGE, that assumes MPC visibility regions that extend over the entire receiver antenna array.
- A 'spatially-aware' SAGE that allows for visibility regions that extend over a section of the receiver array.

The research was supported by Israeli Science Foundation grant number 235/10. This work is expected to be published in EuCAP 2011.

SAGE is based on iterations between an Estimation (E) step and a Maximization (M) step.

E-step: In the l^{th} E-step the channel response due to the l^{th} MPC is estimated over the entire receiver array using the current value of MPC delays, angles of arrival (AoA), amplitudes and possibly visibility regions:

Estimated Response due to l^{th} Path =
Measured Response −
Esimated Response with the l^{th} MPC excluded

Our implementation does not iterate over a fixed number of MPCs. Rather, it adds MPCs until their energy falls below a threshold. Together with the initial conditions we used, this amounts to an E-step that simply outputs the remaining channel, after subtraction of the current channel estimate.

M-step: The M-step estimates the l^{th} MPC by finding the most energetic component of the E-step output. The MPC is estimated via its delay, angle of arrival and amplitude in the spatially-unaware version, and also the visibility region in the spatially-aware version. The M-step is essentially a straight–forward search over delays, angles of arrival and, in the case of the spatially–aware version of SAGE, the start and end positions of the visibility region. For each value of the delay, AoA and visibility regions parameters, that constitute a candidate MPC, the measured channel at the corresponding delays is phase shifted according to the angle of arrival, and then summed over the appropriate range of receiver antenna positions. The accumulated (complex) amplitude of the candidate MPC is then normalized (divided) by the length of its visibility region, i.e. the apparent amplitude of the candidate MPC is calculated. The amplitudes of all candidate MPCs are them compared, and the MPC with the maximal amplitude (in absolute value) is returned as the M-step output.

A note on the implementation of the spatially–aware version of SAGE: The comparison of the amplitudes of the candidate MPC is a choice we made after testing other metrics. We tried comparing the accumulated amplitude, and also tried normalizing it by various roots (powers smaller than one) of the visibility length. Normalization by the length, i.e. comparison of MPC amplitudes, gave the lowest DMC.

The algorithm iterates between the E-step and the M-step, where the index l increases by one at each iteration.

Initialization: After some experimentation with initialization we settled simply on initializing all MPC delays, angles of arrival and amplitudes to zero.

Convergence: Convergence is determined by a threshold on the energy accumulated by the l^{th} estimated MPC. The energy of each MPC is defined as its squared amplitude multiplied by the length of its visibility region. SAGE is stopped when the l^{th} MPC is 20 dB below the strongest MPC, i.e. the one found in the first iteration.

Search Resolution: The accuracy of SAGE is strongly affected by the resolution of the search in the M-step. We used a high resolution in the delay and AoA domains, the delay resolution was 0.3 nsec and the angular resolution was $\Delta\theta \approx \Delta \sin\theta = 0.09$, determined from the delay resolution and the array length. In the spatial domain, the search over visibility region edges was done with a coarse resolution, dictated by the long run-time of the spatially-aware version of SAGE in Matlab. The resolution equals one quarter of the length of the receiver array, in the simulations and most measurements this equals 25 cm.

The Diffuse Multipath Component: The DMC is the difference between the measured (or simulated) channel and its reconstruction generated from the MPCs returned by SAGE. The DMC power delay profile has a shape that loosely follows the measured channel, i.e. it decreases with delay.

III. Analysis Results for Simulated Channels

Overview of this section: Multipath channels with a single cluster were simulated with MPC visibility regions with diameters that are log-normally distributed as suggested by [6]. See an example of a simulated channel in Figure 1. After filtering to a 100 MHz band around 3.6 GHz (Fig. 2) and applying SAGE, we show that the energy of the DMC resulting from the spatially-unaware version of SAGE depends strongly on the average diameter of the visibility regions of MPCs. The DMC becomes stronger as the visibility regions of the constituent MPCs become smaller. The power delay profile of the DMC decreases with delay in all cases, this decrease appears to reflect the power delay profile of the channel response.

A. Channel Simulation

Channel responses were simulated between a single transmit antenna and a one meter linear receiver array with elements separated by 4 mm. The channel was simulated over a wide band with temporal resolution of 0.3 nsec, and MPCs that occupy a single temporal bin, as in Figure 1. After generating the impulse responses over the array, they were filtered to a 100 MHz band

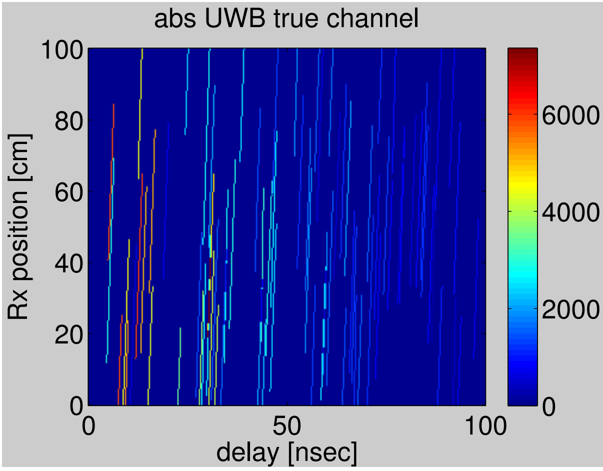

Fig. 1. A simulated UWB channel composed of a single cluster of 81 MPCs. The horizontal axis holds delay and the vertical receiver positions along a linear array. Note the finite visibility regions of the MPCs. The figure shows the real-values impulse responses of the channel.

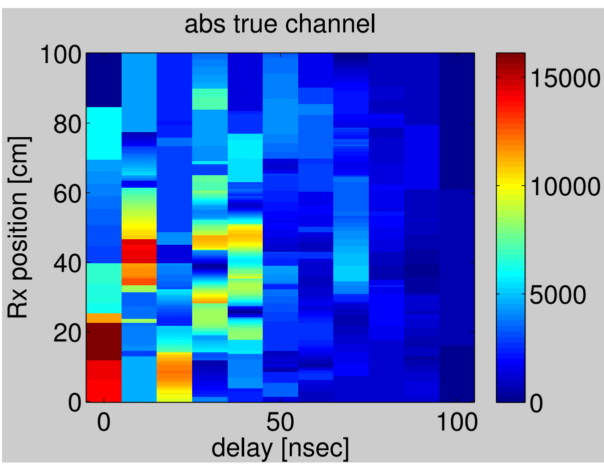

Fig. 2. The simulated channel from Figure 1, filtered to a 100 MHz band around 3.6 GHz. The plot shows the absolute value of the complex channel.

around 3.6 GHz, with a temporal resolution of 10 nsec, see an example in Figure 2.

Simulated channels contained a single cluster with MPC arrival rate of 1/2.09 nsec, taken from the IEEE 802.15.4a channel model for office NLoS scenarios [8]. The standard deviation of the angle of arrival was set to 24°, as indicated by [9]. The MPCs had independent visibility regions, i.e. regions over the receiver array where they were seen. The center of each visibility region was uniformly distributed over the receiver array, and its length was log-normally distributed with a standard deviation of 0.16 m as indicated by [6]. The mean visibility diameter was set at different simulations to values between 0.1 and 0.7 m, or to a large value corresponding to a multipath model where all MPC visibility regions cover the entire receiver array.

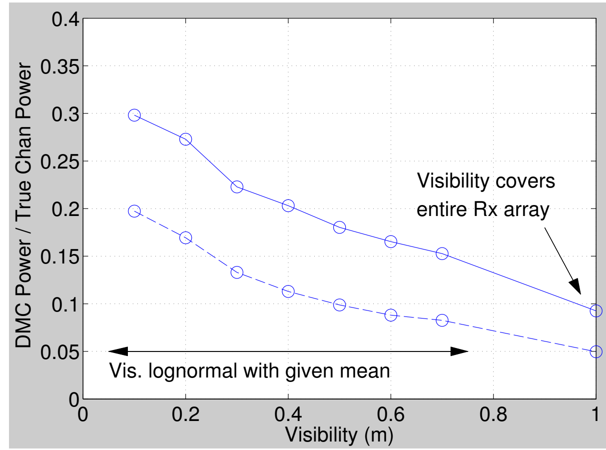

Fig. 3. The DMC energy normalized by the energy of the actual channel, and averaged over at least one hundred simulated experiments. Top: classic SAGE, bottom: spatially aware SAGE. Visibility diameters are log-normal with standard deviation 0.16 m for all but the rightmost point in the graph. For the rightmost point visibility regions of all MPCs span the entire receiver array. This plot shows DMC power for the two versions of SAGE, the spatially-aware and the classic one.

White Gaussian noise was added to each simulated channel, with variance that was set to 50 dB below the channel energy.

At lease one hundred channel realizations were generated per each value of the mean visibility region and SAGE was run on each, the results presented below are averaged over these realizations.

B. Analysis Results of Simulated Channels

Short visibility diameters mean that the channel model implicitly assumed by classic SAGE is inaccurate, and results in a large DMC. To present the results, the energy of the resulting DMC is divided by the energy of the simulated channel, and then averaged over all experiments with the same mean visibility diameter to give the results shown in Figure 3.

Both versions of SAGE result in a DMC that gets stronger as the visibility diameter increases. However, the added spatial degree of freedom of the spatially-aware version lets it achieve significantly smaller DMC, the average reduction in DMC power is 43%. Improvement of the spatial resolution (set here at 25 cm) is expected to further reduce the DMC in the spatially-aware version of SAGE.

IV. Results on Measured Channels

A. Channel Measurements

Equipment: The measurement setup was based on an Agilent N5230 network analyzer, connected to two omni-directional antennas (Electro-Metrics EM-6865) in the 1-18 GHz band with suitable amplifiers. The receive antenna was placed on a meter long linear motorized positioner with sub-millimeter accuracy that was moved between measurements but was kept immobile during the collection of each channel response. The transmit antenna was placed on a cart that was moved to different locations for different measurements, but was immobile during each measurement. Measurements were normally performed during nights, when movement of people around the system was minimal. One antenna was characterized in an anechoic chamber to verify its response.

Calibration was performed using measured responses of the cables and amplifiers, i.e. their responses were removed from the channel responses used for analysis. The (mild) frequency dependent responses of the antennas were also removed, but we could not compensate for the slight deviation of the antenna patterns from the nominal omni-directional pattern. We also did not attempt to compensate for the vertical pattern of the antennas.

We tested the effect of the metallic receiver cart in two ways, by (1) comparing measurements with the cart covered with absorbing material to measurements taken with the cart exposed, and (2) by comparing measurements with the cart direction reversed (rotated by 180). No significant effects were seen.

Environment: The 44 measurements used in this paper were collected between 2006 and 2008 in two office buildings in the Givat Ram campus of the Hebrew University in Jerusalem and one in the Holon Institute of Technology, these buildings have a standard cement and cement block construction from the 1960s-1970s. We kept the equipment in a single floor of each building. Transmitter-receiver separation ranged from 3 to 28 meters. All measurement were non line of sight (NLoS).

B. Analysis Results

The two versions of SAGE were applied to the 44 measured channels, after filtering the measurements to a 100 MHz band around 3.6 GHz. The classic, i.e. spatially–unaware version of SAGE, found on average 67 MPCs, and resulted in a DMC that held 14% of the input energy. The spatially-aware version of SAGE found 14.5 more MPCs on average, and resulted in a DMC that was 30% lower on average. The DMC in this case held on average 9% of the input energy.

It is worth noting that in two of the measurements we had available, one of the versions of SAGE could not converge. In one case the classic version did not converge, and in the other the spatially–aware version did not converge.

Note that the spatial search resolution was very low, set at a quarter of the length of the receiver array. A higher spatial resolution (smaller step) is expected to reduce further the DMC of the spatially–aware version of SAGE.

References

[1] F. Quitin, C. Oestges, F. Horlin, and P. De Doncker, "Diffuse multipath component characterization for indoor mimo channels," in *Antennas and Propagation (EuCAP), 2010 Proceedings of the Fourth European Conference on*, Apr. 2010, pp. 1 –5.

[2] N. Czink, A. Richter, E. Bonek, J.-P. Nuutinen, and J. Ylitalo, "Including diffuse multipath parameters in mimo channel models," in *Vehicular Technology Conference, 2007. VTC-2007 Fall. 2007 IEEE 66th*, Oct. 2007, pp. 874 –878.

[3] A. Richter, J. Salmi, and V. Koivunen, "Distributed scattering in radio channels and its contribution to mimo channel capacity," in *Antennas and Propagation, 2006. EuCAP 2006. First European Conference on*, Nov. 2006, pp. 1 –7.

[4] ——, "An algorithm for estimation and tracking of distributed diffuse scattering in mobile radio channels," in *Signal Processing Advances in Wireless Communications, 2006. SPAWC '06. IEEE 7th Workshop on*, July 2006, pp. 1 –5.

[5] J. Medbo and J.-E. Berg, "Directional propagation characteristics at the base station," Nov. 2010, cOST 2100 12th MCM, Bologna, Italy.

[6] D. Porrat, A. M. Hayar, and Y. Serfaty, "Spatial dynamics of indoor radio wideband channels," *EURASIP Journal on Wireless Communications and Networking*, to appear.

[7] B. Fleury, M. Tschudin, R. Heddergott, D. Dahlhaus, and K. Ingeman Pedersen, "Channel parameter estimation in mobile radio environments using the SAGE algorithm," *Selected Areas in Communications, IEEE Journal on*, vol. 17, no. 3, pp. 434–450, Mar 1999.

[8] A. Molisch, K. Balakrishnan, D. Cassioli, C. Chong, S. Emanmi, A. Fort, F. Karedal, J. Kunisch, H. Schantz, U. Schuster, , and K. Siwiak, "IEEE 802.15.4a channel model - final report," IEEE, Tech. Rep. TG802.15.4a, 15-04-0662-08-004a, 2004.

[9] Q. Spencer, B. Jeffs, M. Jensen, and A. Swindlehurst, "Modeling the statistical time and angle of arrival characteristics of an indoor multipath channel," *Selected Areas in Communications, IEEE Journal on*, vol. 18, no. 3, pp. 347–360, Mar 2000.