Methods for Estimating Consistency Intervals, and the Detection of Changes on Mobile Radio Channels

Robert J.C. Bultitude

Communications Research Centre 3701 Carling Avenue, Ottawa, Canada, Robert.bultitude@crc.ca

Abstract

For simulations, mobile radio channels are often assumed to be random and wide sense stationary, with unchanging stochastic parameters. Measurements, however, show that mobile channel characteristics change rapidly. This paper reports the detection of changes in measured radio propagation data by comparing cumulative distributions for angle of arrival and excess delay in consecutive time intervals. Results include time series showing correspondence between channel parameters and identified points of change, application of the results in the estimation of rms delay spreads, and the proposal of a method by which a model can be developed for controlling changes in channel parameters during simulations.

1. Introduction

It was recognised in [1] that for simulations, mobile channels are often assumed to be wide sense stationary (WSS), with unchanging stochastic parameters. However, mobile soundings show that channel characteristics change rapidly as either interacting objects, or the radio terminals, move. Both stochastic and physics-based approaches have previously been reported for the detection of such changes. Changes in the spatial structure of indoor MIMO channels have been investigated [2] by analysing cross correlations in MIMO channel matrices. More recently [3], work to identify intervals over which radio channels can be modelled as being WSS was reported.

The work in [1], and [4], were physics-based approaches. Although similar, they relied on different measures for the detection of changes. Both were based on the analysis of measured data to estimate the angles of arrival (AOAs) of multipath components (MPCs) using virtual linear aperture methods and the MUSIC algorithm. This paper reports more of this type of work using better equipment, and improved analyses. Immediate motivation arises from a need to estimate parameters from measured data that must be derived from averages over some interval. It is believed that the intervals over which channel characteristics remain consistent, herein referred to as Consistency Intervals (CIs), are the intervals over which such averaging should be done. Over CIs as defined herein, the distribution of MPC AOAs and excess delays remains almost constant. Channel variations within CIs are thus primarily the result of phase changes, over which propagation data are normally averaged. Averaging over greater intervals could involve the "mixing" of data from different channel processes (CPs), and yield misleading results.

2. Methodology

Kolmogorov-Smirnov (KS) tests can be used to decide whether or not two cumulative distribution functions (ECDFs) estimated from time series samples represent the same underlying process. Thus, if ECDFs can be estimated for radio channel parameters and compared for sequentially recorded data using KS tests, it should be possible to determine when changes in the associated CP take place. However, the requirement for multiple snapshots per high-resolution estimate limits time and distance resolutions. In addition, critical values for the required KS tests are obscure. This is because such values depend on the number of independent samples, but it is not clear how to estimate this number in cases where multiple parameters (e.g. multiple AOAs and excess delays) are estimated each time the channel is sampled. The problem arising from a need for multiple snapshots is mitigated herein by making running estimates of the channel parameters from multiple snapshot groups that differ by only one snapshot. Critical values are estimated by recognising and accounting for, extraneous factors that, in addition to true changes in the CP, can lead to distances between compared ECDFs. These factors include finite sample sizes, and errors in the processes used to generate parameter estimates. To account for these factors multiple ECDFs are estimated for channel parameters from multiple sample sets under conditions for which it is reasonably certain that there are no true changes in the CP. Critical values for the detection of true changes are then set equal to the maxima of ECDF distances resulting from the comparison of consecutive pairs of these ECDFs, which would be identical, were it not for the above-mentioned extraneous factors.

CIs can be estimated by estimating AOA and excess delay ECDFs from snapshot sets, centred on snapshots herein called reference snapshots. Then, ECDFs associated with each reference snapshot are compared with ECDFs associated with reference snapshots previous to and following it until compared ECDF distances are greater than the critical values. The forward and reverse intervals between a selected reference and reference snapshots for which comparisons exceed the critical values are herein referred to as forward and reverse intervals of consistency (IoCs), and their sum for any selected reference snapshot is termed a CI.

3. Measurements and Data Analyses

Propagation data were recorded in microcells in downtown Ottawa. A portable 2.25 GHz transmitter (Tx) was established sequentially on selected streets and transmitted a BPSK signal modulated with a 255 chip, 50 Mchps PN sequence from a vertical quarter-wavelength monopole supported at a height of 8.3 metres. The receive system was installed in a minivan with a 32 element uniform circular array (UCA) in the centre of its roof. Its receiver (Rx) was connected sequentially to each antenna array element for just longer than 1 PN sequence length, during which complex base-band samples were recorded at 100 Msps. Snapshots of just over 32 sequence lengths of data samples were recorded every 4 ms as the minivan was driven at speeds of 10-20 kph.

AOAs in azimuth for MPCs within each 10 ns delay interval were estimated with a resolution near 6 degrees using UCA ESPRIT. Groups of 11 snapshots were used to estimate each Power-AOA spectrum. Results from a set of 29 overlapping 11-snapshot groups were then analysed to estimate power-weighted ECDFs for AOAs, and excess delays with respect to the power-delay centroid in each set. The 20^{th} snapshot in each set was taken as the reference, and all results were associated with the time at which this snapshot was recorded. Estimation of the critical values for the KS tests was also conducted using sets of 29 11-snapshot spectra. Time series of ECDFs for nearest neighbour sets were compared under the assumption of no change in the CP between nearest neighbours. At the vehicle speeds that were used, the distance travelled between 4-ms spaced nearest neighbour snapshots was about 2.4 cm. Both the values of 4 ms and 2.4 cm are considered sufficiently small to justify this assumption.

4. Results

Fig. 1(a) shows AOAs for a measurement run that began in LOS, then turned left onto a NLOS street. The 29 estimates of power in each 6-degree azimuth interval were summed, giving a result identical to a power-weighted pdf for AOAs before normalisation. It can be seen that initially, most of the power arrived from ahead, the direction towards the Tx. Then at snapshot 1500, just before the left turn, the concentration of power started to swing from 360 degrees toward lower AOAs. The angular dispersion widened near the middle of the turn because of the NLOS conditions. Fig 1(b) shows the corresponding time series of ECDFs for AOA. The shade at the upper right hand side of the subplot indicates the value of unity. Between snapshots 500 and 1200, one can note changes of the maxima from being between 0-6 degrees to 354-360 degrees. Then at snapshot 1500, the occurrences of the maxima begin to change from near 360 degrees to lower AOAs. The increased angular dispersion towards the end of the turn is seen to cause smearing beyond snapshot 2500. This good comparison between the ECDFs in Fig. 1(b), and the AOAs in Fig 1(a), establishes the necessary link between the ECDFs used to detect changes in the CP, and physics. Fig 1(c) shows results from comparing the ECDFs of AOA estimates. The bars indicate the number of consecutive snapshot sets over which a decision to reject the hypothesis of no change based only on AOA estimates could not be justified. Where there are no changes in the AOAs, these IoCs are long in the forward (positive) direction at the beginning of the interval, and diminish towards the change point. Similarly, the IoCs start out to be short in the reverse direction (negative), and lengthen towards the change point (e.g. at snapshot 420). One can also see that after the turn began at snapshot 1500, the IoCs are shorter because of the constantly changing AOAs.

Fig. 2(a) shows the corresponding time series of powers sums for MPCs in each excess delay interval. The minimal dispersion during the LOS portion of the trajectory and its rapid increase when NLOS conditions began at around snapshot 2000 are to be noted. Notable also is the correspondence between these occurrences, the ECDFs in subplot 2(b) and minima in the IoCs determined by comparison of ECDFs for excess delay only, in subplot 2(c).

Fig. 3 shows a bar plot of CIs determined by terminating each forward or reverse IoC when either the critical value for azimuth or excess delay comparisons is exceeded. The pattern of IoCs reported earlier can again be observed. The median interval between change points at local minima was found to be approximately 32 snapshots.

Knowledge of CIs can be applied in the estimation of rms delay spreads by conducting the needed averaging over the CI associated with each reference snapshot. This is proposed as an alternative to averaging over arbitrarily chosen intervals. Results are shown in Fig. 4. The four curves include results from: (i) spatial averaging of impulse response estimates from the 32 antenna elements of the UCA in 1 snapshot, (ii) averaging over the CI associated with the reference snapshot at each distance, (iii) averaging over 1 s, and (iv) no averaging. It can be seen that the instantaneous results have the largest and most frequent changes. Spatial averaging is seen to provide considerable smoothing. Averaging over CIs also provided smoothing, but results followed the general trend of the instantaneous results very well. The 1 s averaging provided too much smoothing and departed often from this trend. The median of the instantaneous results was 43 ns, whereas the medians for the other three results were about 39 ns.

5. Summary, Discussion, and Conclusions

The method proposed herein for estimating when changes occur on mobile radio channels involves estimating consecutive angular and delay spectra for MPCs received at a mobile, then employing KS tests to determine when ECDFs for these spectra differ sufficiently enough to no longer represent the same random population of MPCs. Several values had to be chosen, including: the number of snapshots (N_{sn}) used to estimate the spectra, the number of spectra (N_{sp}) used for each ECDF, and the critical values for the KS tests. To obtain results presented herein, intuition, as well as some software trials were used to make these choices. The choices of N_{sn} and N_{sp} are tradeoffs between accuracy and resolution in the identification of changes. The choice of critical values herein was empirical, based on an assumption of no change in the CP over 4 ms. Each of these values could change with environment, method of AOA estimation, or sounder implementation. For the critical values, both maxima and 95th percentiles of nearest neighbour ECDFs were used, but the maxima were found to give the best correspondence between changes observed in the spectra, and the declaration of the end of an IoC. There is additional work to be done, however, before definitive results can be reported. Relevant theory can be sought, simulations can be done and larger data pools can be analysed. However, results reported here are intuitively pleasing, and the method is believed to be promising. It is also believed that averaging over CIs is a better choice than no averaging, or averaging over arbitrary intervals to approximate expectations, although work is needed to determine what averages over the shortest of CIs represent and how they can be used. It is anticipated that the observed pattern of IoCs can be exploited for modelling changes by determining the intervals between local minima. A model ECDF for these intervals would to be estimated for use in controlling change points during simulations. IoCs could then be derived as increasing and decreasing ramp functions between change points. Changes in AOA and excess delay could initially be random, but this could be fine tuned by comparison of rms delay and azimuth spreads estimated over simulated CIs with those estimated over CIs in measured data.

6. Acknowledgements

The work of Guorui Zhang, Dr. Yvo de Jong, Ghassan Dhaman and Hong Zhu in helping with the analysis tools, the equipment, and the measurements is gratefully acknowledged.

7. References

1. R.J.C. Bultitude, G. Brussaard, M.H.A.J. Herben, and T.J. Willink. “Radio channel modelling for terrestrial vehicular mobile applications,” Proc., ICAP/JINA Millennium Conference on Antennas and Propagation, Davos, Switzerland, April 9-14, 2000.

2. M. Herden and E. Bonek, “A MIMO correlation-based metric for characterising nonstationarity,” Proc., IST Mobile and Wireless Conference, Lyon, France, June, 2004.

3 T.J. Willink, “Wide sense stationarity of mobile MIMO radio channels,” To be published, IEEE Trans. Vehicular Technol., March, 2008.

4. R.J.C. Bultitude, T.J. Willink, M.H.A.J. Herben, and G. Brussaard., “Detection of changes in the spectral characteristics of measured mobile radio data for space wave modelling applications,” Proc. Queens University Bienniel Symposium on Communications,” Kingston, Canada, May 28-31, 2000, pp. 90-94.

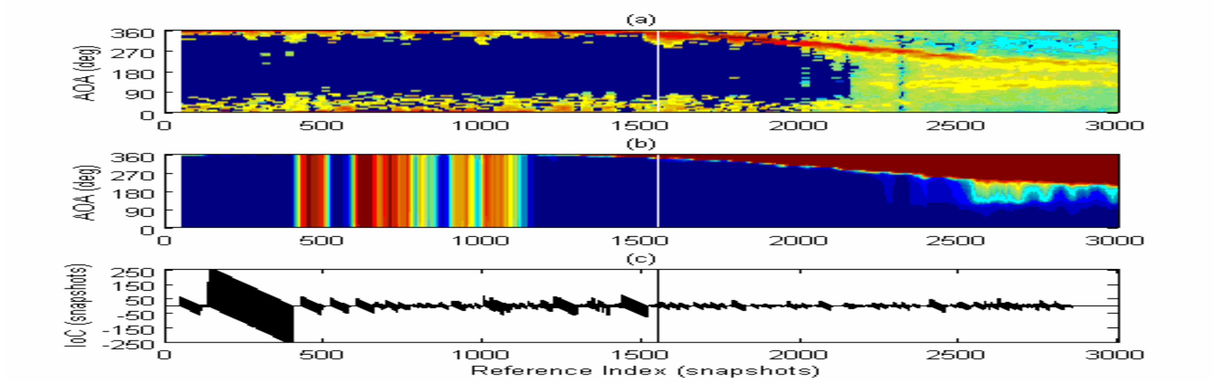

Fig. 1. AOA time series (a) sum of the powers per resolution interval, (b) power-weighted ECDFs for AOA, (c) IoCs if ECDFs compared for AOA only.

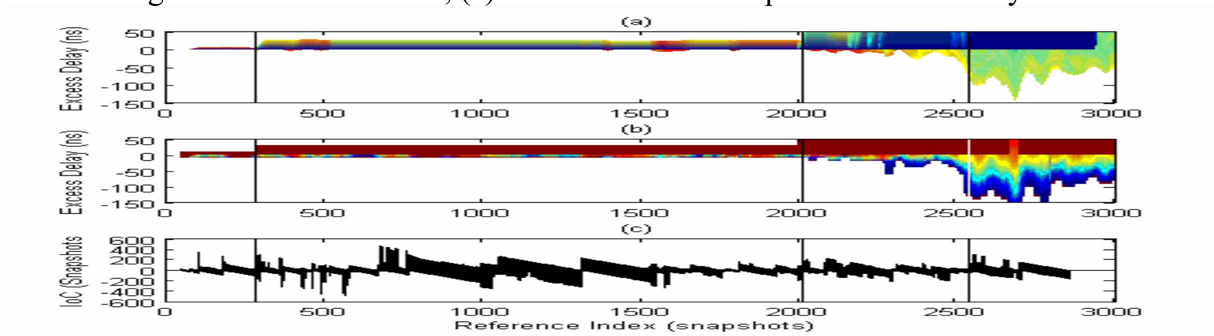

Fig. 2. Excess delay time series (a) sum of the powers per 10 ns interval (b) power-weighted ECDF for excess delays, (c) IoCs if only ECDFs for excess delay compared.

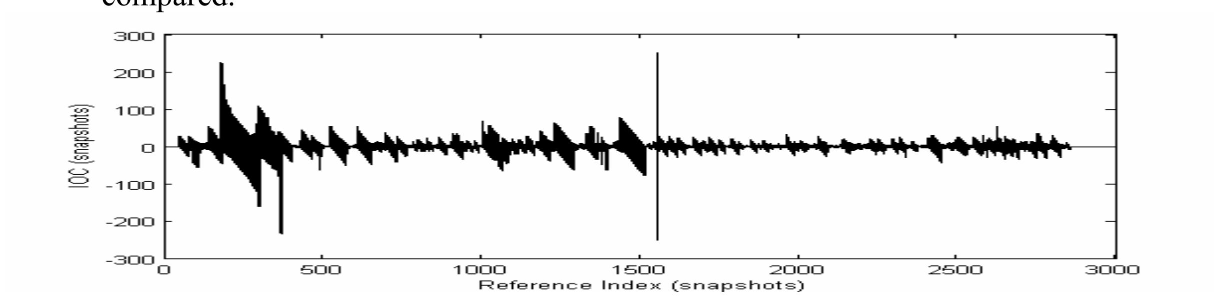

Fig 3. IoCs estimated by considering both AOA and excess delay ECDF comparisons.

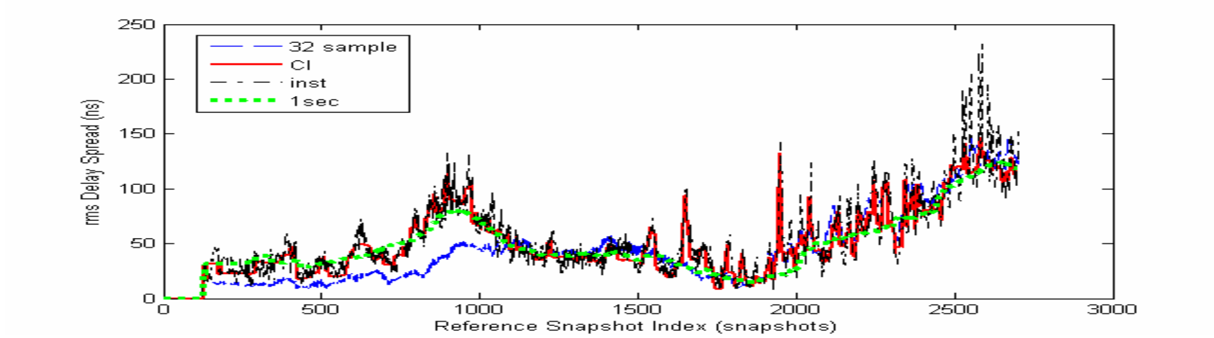

Fig.4. rms delay spreads estimated by averaging over different intervals: “32 sample” - average of IREs from all 32 UCA elements (1 snapshot), “CI” – average of IREs from antenna 1 over CIs, inst” - instantaneous result for the IRE from antenna 1, and “1 sec” – average of single IREs from antenna 1.