EUROPEAN COOPERATION
IN THE FIELD OF SCIENTIFIC
AND TECHNICAL RESEARCH

EURO-COST

COST 273 TD(03) 015
Barcelona, Spain
2003/Jan/15-17

SOURCE: **Communications Research Centre**
Ottawa
Canada

MICROCELLULAR MOBILE RADIO CHANNEL TRANSMISSION LOSS and TEMPORAL DISPERSION CHARACTERISTICS AT 1.9 GHz AND 5.8 GHz

Robert J.C. Bultitude
Communications Research Centre
3701 Carling Avenue
Ottawa, Ontario
K2H8S2
CANADA
Phone: 1-613-998-2775
Fax: 1-613-990-7987
Email: robert.bultitude@crc.ca

MICROCELLULAR MOBILE RADIO CHANNEL TRANSMISSION LOSS and TEMPORAL DISPERSION CHARACTERISTICS AT 1.9 GHz AND 5.8 GHz

R.J.C. Bultitude Communications Research Centre (CRC) 3701 Carling Avenue Ottawa, Canada, K2H 8S2 Email: robert.bultitude@crc.ca	T.C.W. Schenk Eindhoven University of Technology/CRC PO Box 513 5600 MB Eindhoven, The Netherlands, Email: t.c.w.schenk@tue.nl

Abstract

There is considerable interest in determining differences between radio channel characteristics in the currently allocated mobile radio frequency bands and bands that might be allocated for that purpose in the future. This document is therefore devoted to a determination and comparison of channel characteristics estimated from measurements on microcellular mobile radio channels at frequencies near 1.9 GHz and 5.8 GHz. Channel parameters that are considered include transmission loss, multipath spreads as well as various measures thereof, and frequency correlation characteristics.

INTRODUCTION

This document summarises two conference papers [1,2] that were written to report the results of propagation measurements, data analysis and modelling. The benefit of duplicating the information here is to make it more readily available to COST273 participants, and provide interpretations that were not possible when the original papers were written. However, not all material from the original papers is duplicated, and some is new.

The data that were analysed for this work were recorded during sequential CW and pseudo-noise channel sounding measurements. In both cases, transmission was from a biconical antenna mounted at 6m above ground level on a mast extended from the roof of a 1.8m high closed-in utility trailer that housed the transmitter (Tx) electronics. The trailer was parked near the curb in metered parking spaces on downtown Ottawa streets. Measurements at 1.9 GHz and 5.8 GHz (hereinafter referred to as 2 and 6 GHz for convenience) were made on different days. Though the transmit biconical had a wide enough bandwidth for operation at both frequencies, it was not considered suitable for use above the receive vehicle roof. Reception at each centre frequency was therefore via a tuned quarter-wavelength monopole mounted in the centre of the roof of a minivan. In-situ radiation patterns were measured to be omnidirectional within +/- 3 dB. The minivan was driven at normal traffic speeds throughout the urban centre. Off-air signals at the receiver (Rx) were down-converted to yield in-phase (I) and quadrature-phase (Q) baseband signals that were each sampled at either 10 MSamples/s, or 2 kSamples/s, depending on whether operation was in the wideband (psedo-noise), or CW mode, respectively. In the wideband mode, 511 chip PN sequences were transmitted at a rate of 5 Mchps. It is recognised that the resultant sounding bandwidth is too narrow for either recognition of off-line correlations with a reference sequence as radio channel impulse response estimates for applications that consider the wide bandwidths of cellular systems proposed for the future, or for an investigation of radio propagation physics. However, it is sufficient for an investigation of multipath spreads, defined as the maximum with of such cross-correlation estimates (XCEs), from the earliest relative delay of their emergence above noise, to the latest delay before they subside below noise. They are also considered suitable for use in the estimation of frequency correlation characteristics during fading [3]. Since all transmitter and receiver oscillators in the measurement systems were slaved to phase-coherent rubidium standards and all clocks ran continuously, the recorded data are suitable for time series analysis. During the wideband measurements, sampled data were stored in 4-sequence-length blocks. In post processing for the work presented herein, every 4th sequence length was cross-correlated with a reference sequence that was recorded when the Tx and Rx were connected back-to-back via a transmission line. This resulted in a time series of XCEs that had an effective sample rate of 450 XCEs/s, each of which could be used to model the convolution of the radio channel impulse response with an equivalent Tx-Rx RF filter that had a 10 MHz bandwidth. They are good estimates of the channel impulse response for applications in which symbol rates up to somewhere between 2 and 3 Msps are being considered. The same effective 450 sample/s XCE sample rate was used for operation at both frequencies and was designed to accommodate the higher fading rates expected at 6 GHz. This resulted in vehicular travel over approximately the same distance for files recorded at the two frequencies. It should be noted, however, that there would have been differences in such lengths as result of normal speed variations in urban traffic, the influence of which it was considered necessary to have present in the recorded data. The data collection system storage buffers were such that measurement runs having a duration of about 1 minute could be made before the vehicle had to be stopped to transfer the data to permanent storage. Distance travelled was not recorded during the wideband measurements. However, during the CW experiments, a Hall-effect device output was used to record the rate of revolution of one of the measurement vehicle's rear wheels every quarter of a second. Measurement runs in this mode were typically long enough to travel 1 km before recording was stopped to transfer data.

TRANSMISSION LOSS

Based on a comparison of the effective apertures of identical receive antenna types at the two frequencies, if effective radiated powers are identical, in free space, the difference in received power at the two frequencies should be $20 \cdot \log_{10}(\lambda_2 / \lambda_6)$, or 9.5 dB, where λ_i, i = 2,6 represents the wavelength at operating frequencies of 2 or 6 GHz. This is considered to have been the primary difference in measured results for the two frequencies, as reported later. However, other observations are also useful for characterising propagation in microcells.

Comparison of the 40 wavelength running averages of received CW power at the two frequencies showed no obvious differences for streets with different orientations. It was also not possible to obtain meaningful and consistent results from any deterministic comparisons based on location of the receiver. It was observed, however, that, considering the fact that traffic conditions were almost certainly different when the sequential measurements were carried out at the two frequencies, the fading patterns in the running averages are remarkably similar. This indicates that significant power trends are greatly influenced by the fixed layout of buildings in the urban core, which can best be described as a Manhattan-type grid. Fig. 1 shows an example of measured results for both frequencies on a street that ran perpendicular to the line-of-sight (LOS) street, 7 blocks from the Tx location.

In order to report generally-applicable information on power loss at the two frequencies, the difference between received power, every metre along each street in the measurement area, including both LOS and non-LOS (NLOS) cases (e.g. on streets that ran parallel and perpendicular to the LOS street for each Tx site) was calculated. An experimentally-determined estimate of the cumulative probability distribution

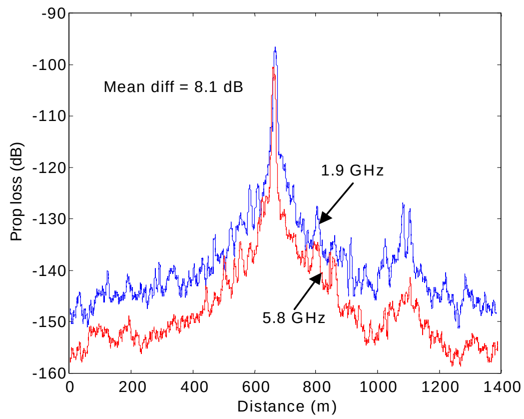

Fig. 1*: Comparison of measured power loss at frequencies near 2 GHz and 6 GHz on a street that ran perpendicular to the LOS street.*

(ECDF) for these differences (in dB) was then found. For measurements with one Tx site, the ECDF was found to compare well with a Gaussian distribution, having mean of 12 dB and a standard deviation of 4 dB. For another Tx site, one city block to the west on a perpendicular street, the appropriate model (again, for all measured data, LOS or NLOS) was also Gaussian, with standard deviation of about 4 dB, but it had a mean of 7 dB.

There is consistency in the standard deviations of the results from the two sites. However, the means of the best-fit models are considerably different from each other, and from the expected value of 9.5 dB. This difference can be explained by observation of the difference in the fading patterns of the running means as a function of distance along the street at the two frequencies. This pattern occurs over distances on the order of a few metres, and is often referred to as shadow fading. It is a result of both multipath interference and the obstruction of impinging waves (whether directly from the transmitter or via multipath sources) by obstacles. It is considered [4,5,6] that the term shadowing and the mechanisms that cause large-scale fading are often misunderstood. Shadow fading, or large-scale fading evidenced by variations in average received signal power from one local area to another should not only be associated with variations in obstruction to LOS between the Tx and Rx antennas. The comparison, shown in Fig. 2, of the results from a simple two-ray model, comprising a direct path and a ground reflected one, is a clear example of the difference in large-scale (shadow) fading at the two frequencies studied herein, in the absence of any obstruction losses, fixed or variable. The mean difference in this example is 13 dB and the standard deviation is 7 dB. The distribution for these differences, however was not found to compare well with a Gaussian model.

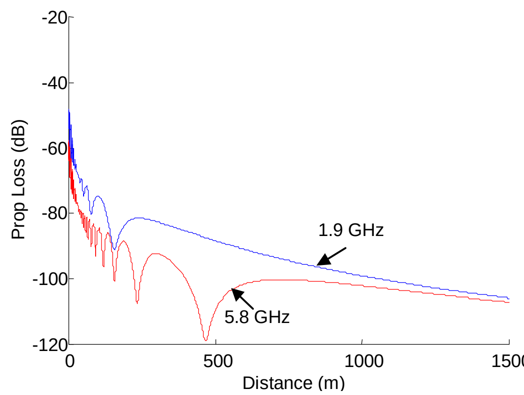

Fig. 2 *: Comparison of two-ray model results for the same transmit/receive geometry at frequencies near 2 GHz and 6 GHz.*

In the real world environments where the measurements were made, the multipath situations are considerably more complicated than those associated with the two-ray model. It therefore seems reasonable to conclude that the 5 dB disparity in the mean differences for measurements centred on the two Txs results from the difference in multipath patterns associated with the local environments of the transmit antennas and the difference in street orientations. To further substantiate these conjectures, more comparisons are planned for different Tx configurations, and at different operating frequencies. However, it is considered reasonable to conclude that in typical urban environments, radio propagation phenomena are such that there is no real difference in average propagation losses at 2 and 6 GHz. If transmit antenna gains and line losses are about equal, transmission loss, the consideration of which includes accounting for both propagation loss and transmission line/antenna affects, differs only because of the difference in the effective apertures of receive antennas. (In the reported measurements, approximately 5 m of RG214 was used at the Tx and about 3 m of RG52 was used at the receiver). The authors have recently been reminded, however [7] that first Fresnel zones on obstructed paths over which individual multipath components travel, are smaller at higher frequencies. It is considered that at the frequencies under study herein, this might lead to a small decrease in average propagation loss at 6 GHz, but it is likely reflected more by the difference in standard deviations of transmission loss from its mean.

Results from the 2 GHz CW measurements were also used to evaluate various microcellular channel propagation loss models [8,9,10]. In addition, some new model extensions were proposed. The reader is referred to [2] for details on the modelling. On line of sight streets, the best fits to 40 wavelength running averages of received power were obtained using the modified two-ray model reported in [8]. This model extends the basic two-ray model by using what the authors refer to as a visibility factor (s) to account for obstruction of the direct and ground reflected rays by other vehicles on the street, and signs, etc. It also makes allowance for the case that the secondary ray might come from a vehicle roof, rather than the road surface, by considering the average height of the receive antenna to be lower than it actually is, becoming a factor denoted as (h_0). Although these factors are given a physical interpretation, it is difficult to determine them other than by comparing experimental transmission losses with those predicted through use of the model with different parameter values and choosing the best fit results. For the system configuration reported herein, with the actual receive antenna about 1.8m above ground, best fits were obtained for values of h_0 ranging between 0.6 and 1.6 metres and s between 0 and 0.005. The median value for s was .0025, and that for h_0 was 1.2m. Eighteen line of sight street sections having lengths between 300 and 400 metres were studied. Variations of the experimentally determined running average power with respect to the modelling results were also determined. The rms values of these ranged between 2.6 dB and 4.7 dB, although there was an outlier at 6.8 dB. The median was 3.9 dB. Invariably the distribution of these variations was found to compare reasonably well with Gaussian distributions having means that ranged between –1.3 and +1.4 dB and standard deviations that were very similar to the reported rms deviations from the model. A lognnormal model is therefore considered reasonable for modelling purposes, but currently there is no accepted physical explanation for this. Fits to a double Rayleigh distribution [6] were not studied, but this is considered to be an important topic for further investigation. In addition to finding the best-fit models for the 18 street sections, a general model was recommended that gave reasonable fits in all cases. The parameters for this were found to be h_0=1.2m and s=0.001. Rms deviations of the experimental results from this model were similar to standard deviations for Gaussian distributions for differences with respect to the model that had means that ranged between –4 dB and + 14 dB, and had standard deviations between 3 and 9 dB. The median value for the means was 2 dB and that for the standard deviations was 5 dB.

Good models for the parallel and perpendicular NLOS streets were more difficult to find. On perpendicular NLOS streets, reasonable success was obtained for distances from the LOS street of up to 300m using the virtual source model reported by El-Sallabi [9]. The same process as that described for the LOS streets was used to arrive at a "generalised" model for perpendicular NLOS streets. Parameters for this generalised model were {W_s=20m, x=2m, r_s as per the area map, and $\alpha = 0.2$}, where W_s represents the width of the perpendicular NLOS street, x represents the distance of the base station antenna from the adjacent building wall, r_s represents the distance in metres from the base station to the centre-line of the perpendicular street, and α is a model parameter described in [9]. Using this model on 15 different trajectories for streets within 5 city blocks of the Tx sites resulted in rms variations of experimentally-determined local means (determined over 40 wavelengths) with respect to the model that ranged between 2.5 dB and 9 dB. The best Gaussian fits to ECDFs for these variations had means that ranged from –8 to +5 dB and standard deviations that ranged from –3 to + 4 dB. The median of the means was 0 dB, and the median of the standard deviations was 3.2 dB.

A modified virtual source model was tested for parallel NLOS streets. The modifications were such as to allow for propagation through and between buildings. Results with about the same accuracy as those reported for the other streets were eventually obtained for each street section. However, no consistencies were found that would allow for the reporting of a "generalised" model as for the other street types.

MULTIPATH DISPERSION

Time dispersion resulting from multipath propagation is often parameterised by rms delay spread. However, this measure can be significantly influenced by noise spikes at long excess delays. To reduce the influence of these, during the analysis reported herein, a probability of false alarm algorithm [11] was used to establish a threshold power below which XCE samples were assumed to be noise and zeroed. The threshold used was such that one noise spike could be mistaken as a multipath component in every 100 XCEs. The same effective radiated power was used during experiments at the two centre frequencies. However, it is known from the foregoing that transmission loss is greater by about 10 dB at 6 GHz because the ratio of effective receive antenna apertures for quarter-wavelength monopoles at the two frequencies is 10 dB. Therefore received SNRs would have been 10 dB lower at 6 GHz, and the noise exclusion threshold would automatically be set higher in data recorded at that frequency, resulting in some degree of scepticism regarding rms delay spread comparisons. Nevertheless, such comparisons were made and considered along with other results in order to draw conclusions. These were estimated from average power delay profiles (APDPs) computed from 500-estimate XCE time series. Though measurements at the two frequencies were conducted on different days, channel characteristics were estimated using data from approximately the same street sections to result in what is considered to be equivalent representation within the two data pools. This document reports the analysis of data recorded in two consecutive 500-XCE measurement runs on ten different street sections within 1 city block of the Tx. It is acknowledged that this yields a somewhat limited 20 street section (20 sample) pool of data for each frequency. However, this did include 100,000 instantaneous XCEs, and because of the above-mentioned careful selection of time series, reliable comparisons are considered to have been achieved. Fig. 3 is a comparison of rms delay spread results.

The figure shows that the estimated rms delay spreads were most often greater at 2 GHz. Although there are too few data for acceptable statistical significance, ECDFs were also constructed using the data from the figure.

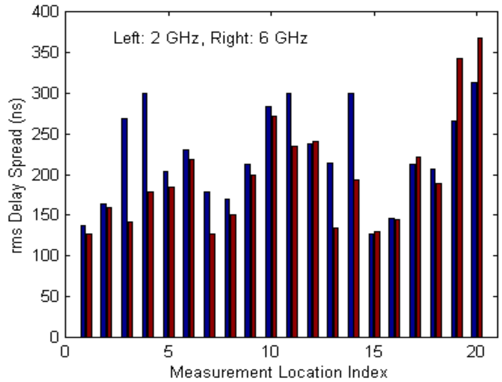

Fig. 3. *rms delay spreads at 2 GHz (blue) and 6 GHz (red) on 20 different street sections.*

The medians given by the ECDFs were 213 ns and 184 ns at 2 GHz and 6 GHz, respectively. The corresponding 90th percentiles, which can reasonably be considered to be the worst instances of multipath dispersion, were 297 ns and 271 ns. The ratio of the medians is 0.86, and the ratio of the 90th percentiles is 0.91. These differences could have been caused by differences in the characteristics of the measurement systems used at the two frequencies, which had different receiver front ends and different receive antennas. Back to back measurement results are therefore shown in Fig. 4 for use in evaluating the effect such differences

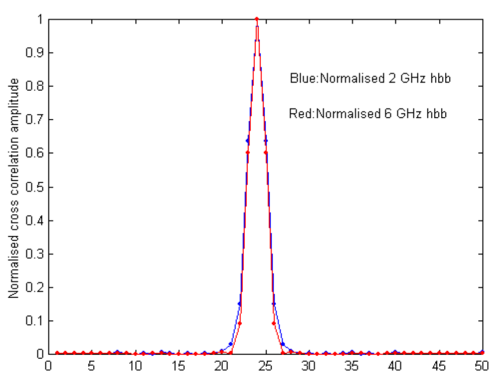

Fig. 4 *Comparison of back-to-back cross-correlation results for the 2 and 6 GHz wideband measurement systems.*

It can be seen in the figure that the back-to-back XCEs differed slightly. They had rms delay spreads of 70.2 ns and 67.4 ns at 2 GHz and 6 GHz, respectively. These values were calculated using a –30 dB noise exclusion threshold. Their ratio is 0.96, showing that the difference between back-to-back results is less than difference in propagation measurement results, and indicating that there may actually be a reduction in temporal dispersion as operating frequency increases. However, it is recognised that nonuniformities in the antenna characteristics across the applicable bandwidths (which would not have influenced the back-to-back results as they had to be made without the antennas) could also have been responsible.

Comparisons of multipath dispersion can also be made using Statistical Impulse Response Models (SIRMs) [12]. These are models constructed from ECDFs for the excess delay of the precursors and postcursors APDPs at specific relative powers with respect to their peaks.

Fig. 5 is a plot of SIRMs for the medians and 90th percentiles of excess delays in APDPs constructed from the measured data. The figure shows, for example, that at a relative power of – 15 dB with respect to peak APDP powers, the ratio between the width of the SIRM at 6 GHz and that at 2 GHz is 0.83. The fact that the data (APDP) pool was limited to 20 samples, however, indicates there is a rather large error region associated with the ECDFs used to construct the SIRMs.

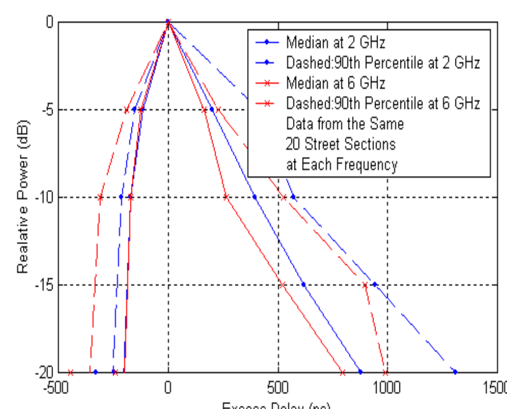

Fig. 5 SIRMs for the 50th and 90th percentiles at 2 and 6 GHz.

FREQUENCY CORRELATION

Frequency correlation functions (FCFs) for fading channels, the random characteristics of which can be shown to satisfy a Zero-Mean- Gaussian-Wide-Sense-Stationary-Uncorrelated-Scattering model, can be derived through Fourier transforms of APDPs for the channels of interest. In such cases, there is an inverse relationship between rms delay spread and correlation bandwidth, which has been shown to have a lower bound [13]. However unless it can be verified that all the cited model criteria are satisfied, correlation bandwidths cannot be inferred from rms delay spreads. It is more reliable to estimate FCFs through time series analysis, as reported in [3]. FCF estimates by this method are influenced less by the differences in measurement system characteristics at the two frequencies and more dependent upon differences in random variations across the channel bandwidths as time evolves. They are therefore considered ideal for use in the comparison that is the subject of this report, and were estimated for all time series under study.

When fading has Rician characteristics, the deterministic component in the signal prevents frequency correlation from deteriorating significantly across very large bandwidths. Hence, on Rician channels, the influence of noise at the band edges of the sin(x)/x shaped sounding spectrum of the measurement system often becomes significant before actual decorrelation on the radio channels is greater than about 10 percent. Thus, bandwidths at which correlation is reduced to 50% are either such that there is significant noise-related decorrelation, or they are wider than the 10 MHz bandwidth of the sounder. Hence, 50% correlation bandwidths from soundings on Rician channels cannot be compared. However, many of the measured channels exhibited Rayleigh fading at both frequencies. A bar plot of their 50% double-sided correlation bandwidths is shown in Fig 6. Rician fading existed on the street sections having indexes where there are no bars in the figure.

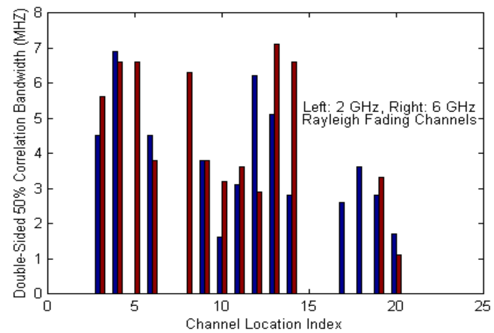

Fig 6 *Double-sided 50% correlation bandwidths on Rayleigh fading channels.*

It can be seen that on many street sections, correlation bandwidths were greater at 6 GHz. However, the medians are approximately the same, that at 2 GHz being 3.6 MHz, and that at 6 GHz being 3.8 MHz. The best and worst cases are also approximately the same, being 7 MHz and 1.5 MHz, respectively. It should be noted that because of the two-sided nature of the method by which the FCFs were estimated, these values are twice those that would normally be reported based on Fourier transforms of ADPs.

Another measure of frequency correlation can also be used for this comparison, and can include results from the Rician channels. This measure is the volume [3] defined by the 3-D FCF that results from effecting time-series estimates using every spectral line across the measurement bandwidth, in turn, as the correlation reference. This procedure must be used when uncorrelated scattering is not a good assumption, but is also applicable in cases when the effects of scattering and other multipath phenomena during measurements were uncorrelated.

When radio channels are being characterised for a specific application it is recommended that this volume be computed over the RF bandwidth to be occupied in proposed systems, and normalised to the square of that bandwidth. An ideal, flat-fading channel would therefore have a normalised FCF volume equal to unity. In IMT2000-type systems, which are to be the standard of the 3rd generation, bandwidths will be 3.85 MHz. Results for 4 MHz bandwidth were therefore estimated and are shown in Fig. 7 for the channels under study.

The figure shows that 3-D FCF volumes at the two frequencies are approximately equal, but frequently, the 6 GHz volumes are slightly greater. It can also be observed that the volumes for the Rician channels (at location indexes where there are no bars in Fig. 6) are greater. The medians for all channels are 0.701 and 0.741 at 2 GHz and 6 GHz, respectively. The corresponding 90^{th} percentiles are 0.875 and 0.880.

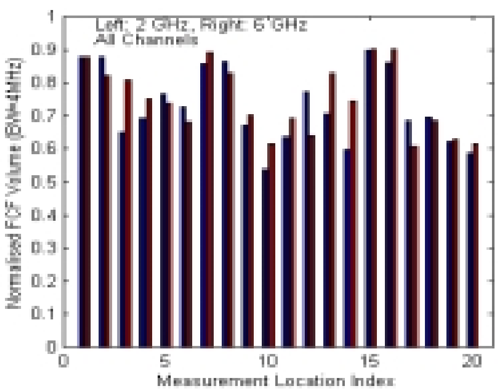

Fig. 7 *Normalised 3-D FCF volumes over a 4 MHz bandwidth.*

DISCUSSION AND CONCLUSIONS

Results from analyses of CW measurements reported herein leed to the conclusion that the difference between transmission loss at 2 GHz and 6 GHz can be modelled as having a Gaussian distribution, with a standard deviation of about 4 dB and a mean that is approximately equal to the difference in effective apertures of the receive antennas used at the two frequencies. It is also concluded that the mean difference varies for different base station configurations, because of large-scale fading related to the geometry of the operating environment.

It is believed that propagation loss by itself, in the absence the influence of antennas and transmission lines could still be slightly different at the 2 frequencies, as a result of small differences in scattering, reflection, and diffraction coefficients. In addition, it is considered possible that microcellular mobile system physical scenarios in vehicle-filled streets are such that obstruction losses are different at the two frequencies because first Fresnel zone radii are smaller at 6 GHz. However, these affects are almost certainly smaller than the influence of differences in the effective apertures of receive antennas.

Results herein from the analysis of wider bandwidth (10 MHz) measurements show that rms delay spreads estimated from measurements were consistently lower at 6 GHz, (by a factor of 0.86), compared with those estimated for the same street sections at 2 GHz. Statistical impulse response models also showed that multipath spreads down to relative power levels of -15 dB are consistently lower, (by a factor of 0.83) at 6 GHz. However, both these comparisons could have been influenced by differences in the characteristics of the measurement equipment used at the two frequencies. The latter differences resulted in a lower back-to-back measurement system rms delay spread by a factor of 0.96 at 6 GHz. Comparisons could also have been influenced by the limited size of the data pool, which was made up of only 20 averages (though these were from 10,000 instantaneous XCEs) at each frequency.

The influence of multipath dispersion was also compared by examining frequency correlation characteristics. This adds new information, since the usual Fourier transform relationship that links such estimates and rms delay spreads directly was avoided. Results from the FCF estimation method that was used are considered to be less dependent upon the measurement system characteristics than they are upon random channel variations. They showed that on 11 Rayleigh fading channels, correlation 50% bandwidths were more often greater at 6 GHz, although median values were approximately the same. A new measure (FCF Volume), from one of the cited papers also indicated slightly higher correlation over larger bandwidths at 6 GHz. Both these results are consistent with a conclusion that there is slightly less multipath dispersion at the higher frequency, and are in agreement with conclusions from the rms delay spread and multipath spread (SIRM) comparisons.

The differences in dispersion reported in this document would not result in significant differences in time-dispersion-related degradation to digital mobile link performance at the two frequencies. From an engineering perspective, it can therefore be concluded that, given the same values of SNR at receivers, unprotected performance would be slightly poorer at frequencies near 2 GHz on the worst channels and slightly better near 6 GHz on the best channels.

From a physical perspective, however, it appears justifiable to conclude that multipath dispersion is slightly lower at the higher frequency. Since the dispersion parameters that were compared depend on relative powers, this cannot be attributed to the 10-dB difference in transmission loss at the two frequencies. Also, since the size of obstacles, such as buildings and vehicles in the environment, in comparison with either wavelength, is very large and material properties do not change significantly over the frequency difference involved, it is difficult to reason that scattered and reflected powers would be significantly different at the two frequencies. Diffraction losses, however, have not yet been quantified in modelling and it is believed that an answer might lie in the study of these. Closely related is the fact highlighted in [7] that first Fresnel zones are smaller at 6 GHz. This means that at 6 GHz a larger percentage of multipath waves could propagate on their way to and from reflecting and scattering objects without suffering any diffraction loss by smaller objects close to their propagation paths. This would make the relative powers of some 6 GHz components greater than those of 2 GHz waves received over the same paths with the same delays. If the powers of only the dominant multipath components at the shortest delays were greater because of this, rms delay spreads would be lower at higher frequencies. However, if most multipath components at higher frequencies had greater powers because of this, rms delays spreads would be greater in the higher frequency bands. As a topic for further study it is desirable that measurements and sebsequent comparison of transmission losses at even higher frequencies be made. This could reveal a trend that would help in the desired explanation.

References

1. Bultitude, R.J.C., “A comparison of multipath-dispersion-related microcellular mobile radio channel characteristics at 1.9 GHz and 5.8 GHz,” Proc., Symposium on Antenna Technology and Applied Electromagnetics (ANTEM 2002), Montreal, July 31-Aug 2, 2002, pp. 623-626.
2. Schenk, T.C.W., Bultitude, R.J.C., Augustin, L.M., van Poppel, R.H., and Brussaard, G., “Analysis of propagation loss in urban microcells at 1.9 GHz and 5.8 GHz,” Proc. URSI Commison F Open Symposium on Radiowave Propagation and Remote Sensing, Garmisch-Patenkirchen, Germany, February 12-15, 2002.
3. Bultitude, R.J.C., “Estimating frequency correlation functions from propagation measurements on fading radio channels: A critical review,” IEEE Journal on Selected Areas in Communications, Wireless Communications Series, Special Issue on Channel and Propagation Models for Wireless Design, August 2002, pp. 1133-1143.
4. Bryant, G.H., Bultitude, R.J.C., and Neve, M.J., “A spatial field model for mobile radio,” Proceedings, 8th URSI

Commission F Triennial Open Symposium on Wave Propagation and Remote Sensing, Aveiro, Portugal, September 22-25, 1998, pp. 220-223.
5. Bach Andersen, J., and Kovacs, I., "Power distributions revisited," COST273 Temporary Document TD(02)004.
6. Bach Andersen, J., "Statistical distributions in mobile communications using multiple scattering," Proc. URSI General Assembly, Maastricht, The Netherlands, Session CBF, August 21, 2002.
7. ITU-R WP 3K, Document 46E, submitted from Japan and proposed as a revision to ITU-R Report P 1411-1.
8. Oda, Y., Tsunekawa, K., and Hata, M., "Advanced LOS path-loss model in microcellular mobile communic-ations", IEEE Trans. Vehicular Techn., vol. 49, (6), Nov. 2000, pp. 2121 – 2125.
9. El-Sallabi, H.M., "Fast path loss prediction by using virtual source technique for urban microcells", IEEE VTC 2000-Spring Tokyo, pp. 2183 – 2187.
10. Zhang, W., and Moayeri, N., "Explicit expressions for the prediction of micro-cellular mobile radio propagation in urban street grid environments", Proc., IEEE Antennas and Propagation Society International Symposium 2000, pp. 1118 – 1121.
11. Sousa, E.S., Jovanovic, V.M., and Daignault, C., "Delay spread measurements for the digital cellular channel in Toronto," IEEE trans., Veh. Technol., vol. 33, Nov., 1994., pp. 837-847.
12. Bultitude, R.J.C., "A statistical model for the squared envelope of radio channel impulse response functions," Proc. ISAP, Sapporo, 1993, pp.85-88.
13. Fluery, B.H., "New bounds for the variation of mean-square-continuous wide-sense-stationary processes," IEEE Trans. Information Theory, Vol. 41, No. 3, May, 1995, pp. 849-852.