RECOVERY EFFECT IN CELLULAR RADIO SYSTEMS

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ABSTRACT

A new expression for the attenuation of a radio wave propagating over a mixed land-sea path successfully predicts the recovery of field strength over the sea path. An initial series of measurements has been made in the Auckland area to determine whether recovery effect is a significant factor at cellular radio frequencies. Some evidence for this has been obtained.

INTRODUCTION

Cellular radio systems use multiple base stations, each serving mobiles in a clearly-defined local area or "cell". Frequencies are re-used in nearby areas. As communications traffic increases, cell sizes are reduced so that frequency re-use can occur over shorter distances. To avoid co-channel interference, system planners need to know where cell boundaries are located, and this leads to the need for precise information on propagation of mobile radio signals [1].

Recovery effect is a propagation phenomenon in which radio field strength changes as the signal passes over a non-homogeneous surface, such as a land-sea boundary. Millington (1949) noted that field strength would diminish as one moved away from a transmitter, but predicted using a semi-empirical approach that at a land-sea boundary, it would rise again as one continued to move away from the transmitter [2]. This seemingly unlikely result was subsequently confirmed by experiment [3]. In measurements across an estuary and across the English Channel, recoveries of the order of 12dB were noted, together with a corresponding fall as the far land-sea boundary was crossed. For a transmitter at Slough, the signal strength at Dieppe, 200km away, was stronger than that at Newhaven, less than 100km away.

Okumura (1968) proposed a correction factor K for mixed land-sea paths, in which K gave the deviation of the measured median field strength from a reference value. The reference was taken to be the urban field strength median in a quasi-smooth terrain. Empirically-derived curves were given showing the variation of K with β, where β was the percentage of the sea in the path. Although some of the curves appear to be drawn through a small number of points, in all cases there is an increase in received signal strength when there is a sea component in the path. Increases obtained vary between 3 and 15dB. Measurements were made at several frequencies between 450 and 1950 MHz [4].

Rowe (1984) made measurements at 465MHz over mixed land-sea paths in the Auckland area. Following Okumura's approach, comparisons were made between conditions in which the water was (a) closer to the receiver or (b) approximately mid-path (Okumura had also considered the case of water closer to the transmitter). In all cases signal enhancement was noted; however the degree of enhancement was found to be significantly greater (between 3 and 23 dB) than that predicted by Okumura. The Okumura model was found to have a mean error of 11.9 dB with an rms deviation about the mean of 4.6 dB. A model based on free-space propagation (together with a previously-derived 'clutter factor' for the suburban environment in

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which measurements were made) gave the best fit to the measured results, with a mean error of -1.1 dB and an rms deviation of 3.3 dB[5], [6].

If recovery effect is a significant factor in the propagation of cellular radio signals, and is not taken into account in system planning, the possibility arises of interference between cells using the same frequencies and separated by a mixed land-sea path. Such a situation might arise in a city built around a large natural harbour, as for example Auckland. This problem could be aggravated as cell-splitting brings co-channel cells closer together.

THEORETICAL DEVELOPMENT

Wu, Maclean and others (1988) have developed an integral equation for the attenuation factor of a radio wave propagating over an inhomogeneous irregular surface. This allows arbitrary terrain shapes, such as cliff edges, to be treated. In laboratory tests at 9.6 GHz over a model terrain, very good experimental confirmation of this theory and others has been obtained [7], [8].

The theoretical treatment of Wu and Maclean has recently been extended to cover land-sea propagation. For a planar inhomogeneous propagation path, this work predicts [9] that the attenuation of the radiowave is given by an attenuation function

$$W(B) = 2 - \left[\frac{j\,d}{\lambda}\right]^{\frac{1}{2}} \Delta_s \int_0^{d_1} 2\left[1 - j\,(\pi p)^{\frac{1}{2}} \exp\,(-p)\,\mathrm{erfc}\,(jp^{\frac{1}{2}})\right] \frac{dy_1}{\left[y_1(d-y_1)\right]^{\frac{1}{2}}} \quad \ldots (1)$$

where d, d_1, y_1 are given in Figure 1, Δ_s is the normalised surface impedance between A and C, λ is signal wavelength,

and $p = -j\,k\,y_1 \dfrac{\Delta_s^2}{2}$.

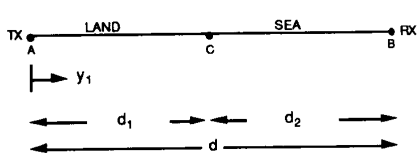

Figure 1: Planar Inhomogeneous propagation path ACB

Equation (1) has been used to confirm Millington's 1950 results. Good correspondence between theoretical and practical results has been obtained [9].

EXPERIMENTAL WORK

Millington's measurements were made at 3.13 MHz. The question arises as to whether the theory will also predict propagation at current cellular radio frequencies (800-900 MHz).

During 1989 an initial series of measurements was made in the Auckland area, using a recently-developed measurement facility known as the mobile laboratory. This consists of a Rohde and Schwarz ESVP receiver mounted in a large station-wagon, together with a Hewlett-Packard Vectra computer which controls the receiver via an IEEE Bus connection and acts as a data logger. A tacho device attached to the vehicle's gearbox produces distance-related pulses which trigger the receiver's fast analog-to-digital converter. Sample values are stored in expanded computer memory and subsequently transferred to floppy disk. Up to 1,000 samples per second of the received signal strength may be made. For most measurements the receiving antenna was a standard commercial cellular radio antenna, mounted on an aluminium groundplane just above the roof of the vehicle[10].

Measurements were made in a number of areas where the radiowave travels over a mixed land-sea path. Where possible, control channel signals radiated from the central-city BNZ tower were used as the signal source. The vehicle was driven away from the source along an approximately radial path, and values of received signal strength were recorded at approximately 4cm intervals.

RESULTS

Figure 2 shows a plot of received signal strength in dB above 1μV versus distance travelled in km. This was taken over a land-only path in urban Auckland travelling south-west along Queen Street and Dominion Road. Fading and shadowing effects are evident. At 1km from the transmitter the signal level is about 22dBμV, and at 2km it is about 10dBμV. These values may be compared with the curve derived from theory which is shown in Figure 3.

Figure 4 shows a typical run from the BNZ tower, north-east along Queen Street, and terminating at the end of Queens Wharf. The land-sea boundary is at about 765m. The steep rise in signal strength near this point may be due partly to absence of shadowing. At 1km from the transmitter the mean signal level is about 55dBμV.

Figure 5 shows the same transmission received on the far side of the Waitemata Harbour, with a sea path of almost 1.3km. The plot starts at 2.05km from the transmitter, and mean signal level here is about 25dBμV.

These results appear to indicate a "sea-gain" of about 33dB at 1km. This may be compared with 27dB predicted by the theory. Figure 6 shows the curve derived from equation (1) for a land-sea path with the boundary at 765m from the transmitter. The agreement at 2.05km is poorer: 37dB predicted and about 18dB measured. This may however be due to the fact that the measurements (Figure 5) were taken on land, and an inverse recovery effect may have occurred. A series of over-water measurements is planned, which may clarify this point.

CONCLUSIONS

The results presented are limited by the fact that they were taken in a 'real' environment rather than in controlled laboratory conditions. It is therefore difficult to eliminate unwanted variables, particularly the effects of clutter. Nevertheless the results do show consistently that signal enhancement occurs over a sea-water path at cellular radio frequencies. Further work is needed to determine the relative contributions of recovery effect and clutter, and this is proceeding.

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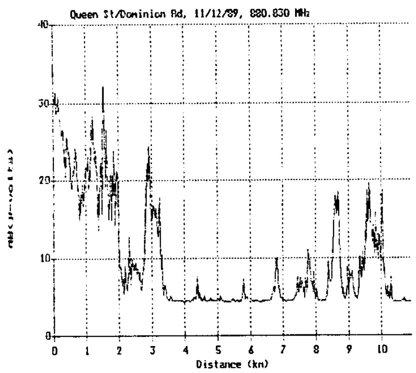

Figure 2: Land-only Path: Measured

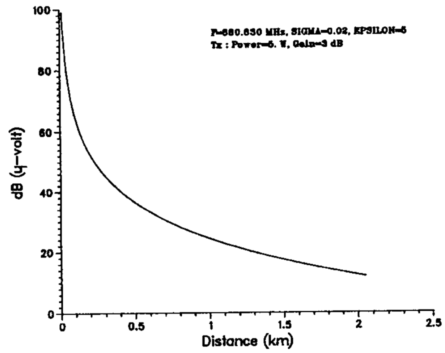

Figure 3: Land-only Path: Predicted

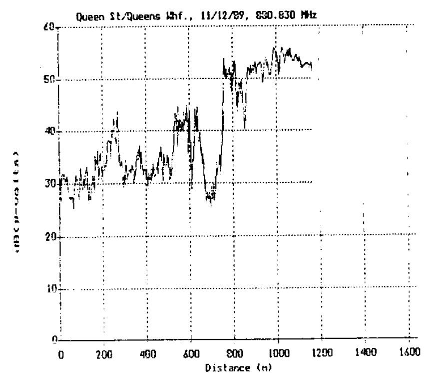

Figure 4: Land-Sea Path: Measured

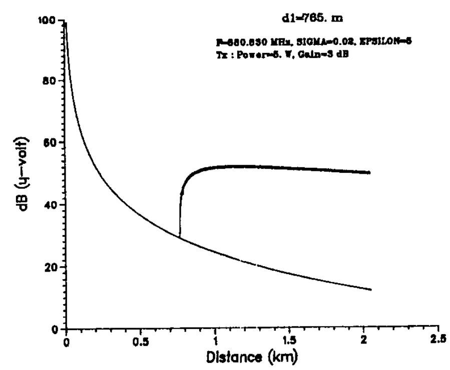

Figure 6: Land-Sea Path: Predicted

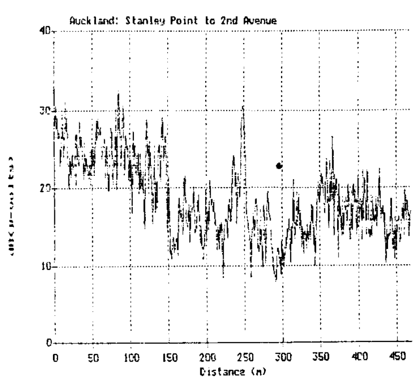

Figure 5: Land-Sea-Land Path: Measured

(abscissa starts at 2.05 km)