# 38-GHz Wide-Band Point-to-Multipoint Measurements Under Different Weather Conditions

Hao Xu, Theodore S. Rappaport, *Fellow, IEEE*, Robert J. Boyle, and James H. Schaffner

***Abstract*—This letter presents 38-GHz wide-band point-to-multipoint measurement results from various weather events. 73 963 measured power delay profiles indicate that multipath can occur due to the foliage and the reflection from wet surfaces during rain. The received signal strength during rain varies according to a Rician distribution with a $K$ factor inversely proportional to the rain rate. The measured rain attenuation exceeds Crane model prediction by several decibels. The results may aid in design of broadband millimeter-wave communication systems.**

***Index Terms*—38 GHz, broadband wireless, LMDS, MBS, millimeter-wave propagation, rain attenuation.**

## I. Introduction

UNTETHERED, broadband multimedia services of the future will include local multipoint distribution services (LMDS), mobile broadband systems (MBS), and next generation internet (NGI). The millimeter-wavebands of 30–60 GHz are uniquely suitable for these applications due to the large available bandwidth and frequency reuse potential. However, little research has been done to study effects of weather on the multipath and time-varying nature of millimeter-wave channels. This letter summarizes results of extensive wideband measurements conducted on fixed point-to-multipoint links at 38 GHz.

## II. Hardware System and Site Description

Power delay profiles (PDP's) were captured using a *sliding correlator channel measurement system*. The system has a null-to-null radio frequency bandwidth of 200 MHz (providing a multipath time resolution of 10 ns [1]), a multipath dynamic range of 25 dB, a measurement speed of 50 PDP's per second, and two modes of operation: *spread spectrum mode* for wideband measurements, and *continuous wave (CW) mode* for system alignment and calibration.

Antennas were selected to represent antenna systems proposed for emerging LMDS links. The transmitting (hub) antenna was a horn with a maximum gain of 19 dB and half power beamwidths of 45° and 6.5° in azimuth and elevation, respectively. The receiver (subscriber) antenna was a parabolic reflector with a maximum gain of 39 dB and half power beamwidths of 1.5° in both azimuth and elevation. Vertical polarization was used. Careful records of local rain were taken via a portable tipping-bucket rain gauge.

TABLE I
SUMMARY OF MULTIPATH OCCURRENCE AND MAXIMUM OBSERVED MULTIPATH (MP) LEVEL (W.R.T. LOS) VIA THREE LINKS: L1–LOS, 605 m; L2–OBSTRUCTED PATH, 262 m; L3–PARTIALLY OBSTRUCTED PATH, 262 m;

| Link | Date | $R$(mm/h) | # PDPs | % of PDPs with multipath > $\Delta P$ | | | | | Max MP |
|---|---|---|---|---|---|---|---|---|---|
| Threshold: $\Delta P = P_{MP} - P_{LOS}$(dB) | | | | -10 | -12 | -14 | -16 | -18 | (dB) |
| L1 | 4/23 | clear | 190 | 0 | 0 | 0 | 0 | 0 | <-18 |
| | | 0–15.2 | 100 | 0 | 0 | 0 | 0 | 0 | <-18 |
| | 5/1 | 0–39.6 | 60 | 1.7 | 53 | 67 | 67 | 67 | -9.1 |
| | | hail | 58 | 1.7 | 1.7 | 1.7 | 1.7 | 6.9 | -5.2 |
| | 5/3 | clear | 10 | 0 | 0 | 0 | 0 | 0 | <-18 |
| | | 0–45.7 | 620 | 0 | 0 | 0 | 3.7 | 27 | -14.2 |
| L2 | 5/27 | clear | 4400 | 0.068 | 0.14 | 0.20 | 1 | 27 | -9.0 |
| | | 0–15.2 | 3000 | 0.83 | 2.4 | 8.6 | 21 | 28 | -9.3 |
| L3 | 5/30 | clear | 800 | 0.25 | 0.25 | 0.25 | 0.25 | 21.8 | -4.5 |
| | | 0–15.2 | 8350 | 0.08 | 0.12 | 0.74 | 7.7 | 21 | -4.75 |
| | 6/2 | clear | 7550 | 0.066 | 0.066 | 0.066 | 0.12 | 0.49 | -3.1 |
| | | 0–213.4 | 16850 | 0.17 | 0.22 | 0.81 | 4.7 | 17.6 | -2.6 |
| | 6/3 | clear | 2000 | 0.05 | 0.05 | 0.55 | 11 | 52 | -6.9 |
| | | 0–45.72 | 4300 | 0.047 | 0.047 | 0.12 | 1.8 | 11 | -1.4 |

Measurements were conducted via three links across the Virginia Tech campus from April to June 1998. The first link, L1, provided a 605-m unobstructed LOS path. The second link, L2, provided a 262-m obstructed path due to the dense canopy of a large oak tree. The third link, L3, provided a 262-m partially obstructed path due to nearby oak tree leaves that would obstruct the LOS path during windy conditions. Out of the 73 963 PDP's collected during the campaign, 36 338 were collected during rain events and hail storms.

## III. Measurement Results

*Multipath Statistics:* Table I summarizes the multipath statistics for different rain rates, $R$ (mm/hr), and multipath threshold levels, $P_{\mathrm{MP}} - P_{\mathrm{LOS}}$, where $P_{\mathrm{LOS}}$ is the power of LOS component and $P_{\mathrm{MP}}$ is the power of multipath component. On link L1, multipath was detected during rain but not during clear weather. On links L2 and L3, multipath was present for both clear and rainy days, which is due to the scattering by tree leaves and branches.

Fig. 1 compares measured PDP's during different weather events. On May 1, multipath occured during heavy rain right before and after the hailstorm. This may be caused by the sharp edge of the hailstorm cell. In [2] it was shown that multipath could occur at the edges of very intense rain cells. On the other hand, the change of the electromagnetic properties of the surface or the formation of standing water surfaces during rain may increase the reflected power and result in multipath. On May 3,

Manuscript received February 8, 1999. The associate editor coordinating the review of this letter and approving it for publication was Prof. Y. Bar-Ness.

The authors are with the Bradley Department of Electrical and Computer Engineering, Mobile and Portable Radio Research Group, Virginia Tech University, Blacksburg, VA 24061 USA (e-mail: haoxu@vt.edu).

Publisher Item Identifier S 1089-7798(00)01189-3.