Site Diversity Against Rain Fading in LMDS Systems

Csaba Sinka and János Bitó

***Abstract*—Local Multipoint Distribution Services (LMDS) system is a fixed cellular radio based point-to-multipoint technology in the microwave band providing broadband services. These systems need very accurate network planning method because of the variable carrier-to-interference ratio (*C/I*) in the whole service area and high sensitivity for meteorological phenomena especially for precipitation. The effects of a moving rain cell over an LMDS system was analyzed and site diversity as one possible countermeasure technique is demonstrated. The location dependent *C/I* in the LMDS service area under rainy conditions with and without site diversity technique was calculated applying a rain shower profile.**

***Index Terms*—Broadband communication, diversity methods, radio propagation, rain.**

I. Introduction

THE number of possible services is extending rapidly with the capability of transferring high-speed data. New broadband networks and services are developed continuously to serve the different demands, e.g., Internet, mobile Internet, broadcasting, telephony, e-commerce, Video on Demand, etc. Point-to-multipoint wireless system could be a promising solution to connect the users to the backbone network instead of broadband wired networks because of its cost efficiency, easy and fast installation, and re-configurability; however due to the time and location variable channel conditions the system should apply fade mitigation techniques to reach the QoS requirements. Local Multipoint Distribution Services (LMDS) system is a fixed cellular radio based point-to-multipoint technology for local broadcast and interactive broadband multimedia services operating in the millimeter wave frequency band [1]. Duplex communication is used between the Base Stations (BS) and the Terminal Stations (TS). Although downlink communication is a point-to-multipoint communication the uplink direction is a point-to-point one. The intra- and intersystem interference and fading phenomena reduce the capacity of wireless systems therefore system planning should optimize the *C/I* conditions at each locations of the service area and efficient fade mitigation techniques should be included.

II. Rain Effect in Cellular LMDS Systems

Because of the application of high carrier frequencies the channel quality highly depends on precipitation causing *C/I* fluctuation which is transformed to BER fluctuation in the application level depending on modulation, coding, etc. Our goal was to simulate the effect of a moving rain-cell over an LMDS system. *C/I* conditions on the down- and the uplink directions were investigated in our previous work [2]. A moving rain-cell causes different attenuation in different links that is changing continuously because of the motion of the rain-cell and rain intensity time variation. From the *C/I* point of view three basically different situations can be determined according to the position of the rain-cell over the service area of the LMDS system:

A. Rain Induced C/I Degradation

Rain-cell covers significant part of the desired signal (*C*) path while the interferer signal (*I*) paths mostly are outside the rainy area. So the *C/I* have been degraded radically.

B. Rain Induced C/I Improvement

Rain-cell covers part of the significant interferer signal (*I*) paths while the desired signal (*C*) path is mostly free of rain. In these cases the *C/I* will be higher.

C. No C/I Change

The rain-cell causes mostly equal attenuation on the desired (*C*) and the interferer (*I*) signal paths. So very low variance of the *C/I* can be obtained independently from the rain intensity. This situation can be occurred even in slight rain or at heavy rain events.

C/I maps were calculated for the nonrain case and for different rain-cell positions to investigate the effects of moving rain-cell in the LMDS service area. Finally the effects of the listed three *C/I* fluctuation situations can be obtained.

III. System Assumptions

C/I conditions in up- and downlink directions are obtained. A frequency-sectored LMDS system applying 4-frequency and 90° sectorization with TDMA are investigated in the 40 GHz band. The frequency sectorizations and the dominant interference situations are depicted in Figs. 1 and 2 for down- and uplink, respectively. The frequency duplex distance is 1.5 GHz between up- and downlink according to [3]. The different frequencies ($f_1 - f_4$ respectively) are signed by different grey shades. The investigated system contains nine BSs in a regular 3×3 BS configuration. The LMDS cell in our simulation has a size of 6×6 kms; therefore an LMDS sector has a size of 3×3 kms realizing an 18×18 kms LMDS coverage area. The used antennas are a sharply directed (3°) antenna in case of TS and a 90° space sectored antenna in case of BS.

Please observe from Figs. 1–2 the down- and uplink interference situations, respectively where transmitters (BS/TS) in the second neighbor cells operating at the same frequency transmits dominant intereferer signals. Downlink interference situa-

Manuscript received February 4, 2003; revised April 23, 2003. This work was supported by the European Commission under the IST-EMBRACE Project [7]. The review of this letter was arranged by Guest Editor Roberto Sorrentino.

The authors are with the Department of Broadband Infocommunication Systems, Budapest University of Technology and Economics, Budapest H-1111, Hungary (e-mail: csaba@docs4.mht.bme.hu; bito@mht.bme.hu).

Digital Object Identifier 10.1109/LMWC.2003.815702

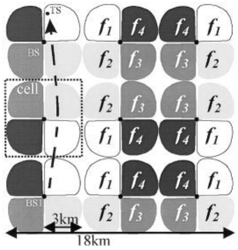

Fig. 1. Downlink frequency allocation plan and interference scenario.

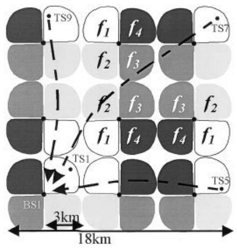

Fig. 2. Uplink frequency allocation plan and interference scenario.

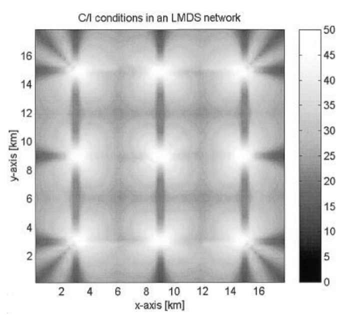

Fig. 3. Downlink C/I map [dB] without rain.

tion can be observed in the *C/I* map of the whole coverage area on Fig. 3. The critical areas can be observed in *C/I* maps illustrated with dark color. The countermeasure techniques for the highly interfered coverage locations in both up- and downlink cases play the key role in LMDS network planning.

The variance of the *C/I* situations against the nonrain cases was investigated using a rain-cell model applying a circularly symmetric Gaussian shaped rain shower cell profile with maximum rain intensity value of $R_{max} = 50\ \mathrm{mm/h}$. Calculating the rain attenuation a_{rain} over a link using the following expression validates the model [4], [5]

$$a_{rain} = \int_0^1 k \cdot R(x)^a dx\ [\mathrm{dB}] \tag{1}$$

where the values of k and α are the known frequency and polarization dependent parameters, $R(x)$ is the variable rain rate *[mm/h]* at position x along the path [2], [6].

Here, we focus our attention on the investigation of site diversity method in case of moving rain-cell over BFWA system.

IV. Site Diversity

Applying a frequency allocation plan given in Figs. 1–2 TSs in the outermost part of the sector from its BS can suffer very high *C/I* degradation described in *case A* in Section II. The degradation due to these quite general rain situations can be decreased by site diversity. Site diversity temporarily gives the opportunity to the TSs for switching to other BS than its original one reaching better *C/I* level during the rain period. Site diversity needs a switching algorithm and in case of measured *C/I* at the receiver under a pre-defined *C/I* threshold (this threshold is based on the type of modulation and the required BER, in our simulation $C/I_{th} = 20\ \mathrm{dB}$) value the TS tries to find a BS from the nearest BSs with better *C/I*. The switchover is made for the BS with the highest *C/I*. The *C/I* threshold detection process must have hysteresis for optimal performance in order to avoid tilting between BSs around the *C/I* threshold.

The grade of *C/I* degradation in down- and uplink is different in a given rain-cell position therefore the need for site diversity is different also for both directions. The consequences of up- and downlink switchover to another BS are totally different. While downlink switchover means simply only better *C/I* from another BS from the receiver (TS) point of view, the uplink switchover is much more complicated. When an uplink switchover happens the switcher TS becomes a new interference source for BSs using the same frequency. Therefore the direct effect of switchover at site diversity can be measured at the switching TS in downlink but in uplink the total effects of switchover can be determined by calculating the additive interference load caused by the switcher TS at the BSs in the given frequency. In real implementation parallel down- and uplink *C/I* calculations are needed taking the different download/upload requirements into consideration, respectively. The general traffic need is asymmetric in the radio path that means the download speed requirements are typically higher than the upload one. From the quality point of view radio path availability in downlink is more important than in uplink. Certainly accurate frequency and capacity management is required in site diversity.

V. Simulation Results

Effects of a moving rain-cell over the investigated LMDS system were calculated and presented in [2] and [5], here the downlink analysis with the result of site diversity simulation is presented. A simulated rain-cell was moved along a straight path and the additional rain-attenuation was calculated for each link with and without site diversity as described in the previous sections. The simulation results are depicted on Figs. 4–5 at one critical rain-cell position where the center of the rain-cell is located between the BS located in the center of the BFWA service area and the farthermost corner of its right bottom sector. Black circle on the diagram signs the contour and the center of the rain-cell. The *C/I* map with rain effect is illustrated on Fig. 4. Please observe that the TSs located in the right bottom corner of the sector, where the center of the rain-cell is located, have the highest *C/I* degradation effect (q.v. *case A* in Section II.). Site diversity improvement can be realized on Fig. 5. The critical TSs which have *C/I* under the given threshold are plotted on Figs. 6–7 with lines to their original and the switched-to BSs, respectively.

Average *C/I* values were calculated for five different areas (See illustration of the areas on Fig. 6) of the LMDS service area to compare the effects of rain and site diversity in rain and given in Table I. The areas are narrower and narrower from the

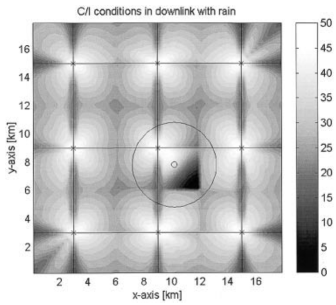

Fig. 4. Downlink C/I map [dB] with rain.

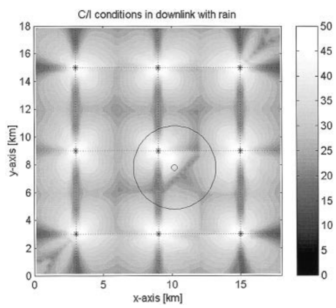

Fig. 5. Downlink C/I map [dB] with rain applying site diversity.

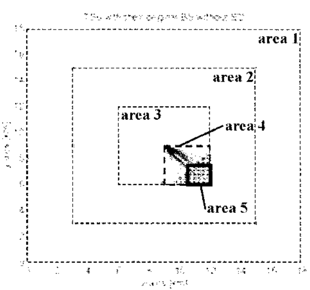

Fig. 6. TSs which switched to another BS with site diversity (with their original BS).

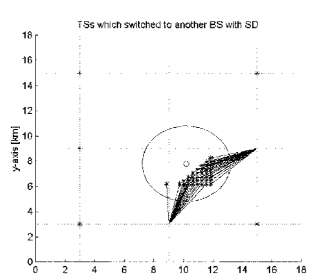

Fig. 7. Switchover maker TSs and the "new" BSs where they switched to.

full area (36 sectors) to the rain-induced most critical part (1/4 sector). The overall performance of the LMDS system is measured by average *C/I*. The second row in the Table I is for the central area of 16 sectors. The other rows mean average *C/I* for the worst cell (around the BS located in the center of the service area), the worst sector and the most critical area (1/4 part of the worst sector).

Average *C/I* calculated for large area is not suitable measure because it does not reflect well the variability of the *C/I*. The

TABLE I
AVERAGE C/I [dB] OF THE LMDS SERVICE AREA IN DOWNLINK

	Without Rain	With Rain, no Site Diversity	With Rain, and Site Diversity
all the service area[1]	34.613	35.481	35.489
central area[2]	35.816	36.455	36.464
worst cell[3]	35.446	36.324	36.361
worst sector[4]	35.822	35.417	38.505
critical area[5]	28.581	12.849	25.479

[1]All the LMDS service area, all the 9 cells(36 sectors).
[2]The central part of the service area without the outer sectors (16 sectors).
[3]The worst (central) cell where the rain-cell is located (4 sectors).
[4]The worst sector of the worst cell where the rain-cell is located (1 sector)
[5]The most critical area where C/I is mostly degraded by the rain-cell (right bottom quarter of the worst sector, ¼ sector)

investigated rain-cell causes high attenuation for major interference causing *C/I* improvement (q.v. *case B* in Section II) afar from the position of the rain-cell, e.g., mostly in the left upper and right bottom corner of the service area as lighter gray colors in the *C/I* map. This effect is experienced many places in the service area (please compare Fig. 3 with Fig. 4). This is why the first three rows show "average *C/I* improvement caused by rain."

Site diversity improvement can be obtained by comparison of the second and third column of Table I; average *C/I* is always higher with site diversity. The closer the area to the rain-cell the more system performance improvement can be measured. Observe that in the most critical area site diversity improvement is very significant (approximately from 13 to 25.5 dB).

VI. CONCLUSIONS

Generally, the fact that a rain-cell with high rain intensity can degrade the system performance very significantly in locations of BFWA area proves that estimating of fade margin against rain attenuation is also very important in BFWA network planning procedures.

Preventing the highest degradation of performance level in the corner of the cells site diversity can be applied. When the *C/I* value reaches the critical threshold caused by rain the TS can make a switch-over to the "rain-free" neighbor BS. Certainly the traffic will be larger in the switched-to cell however in average the quality of services will be higher in the whole service area.

REFERENCES

[1] A. Nordbotten, "LMDS systems and their application," *IEEE Commun. Mag.*, pp. 150–154, June 2000.
[2] Cs. Sinka *et al.*, "The effect of rain over LMDS system," in *Eur. Conf. Wireless Technologies ECWT 2002*, Milan, Italy, Sept. 2002, pp. 26–27.
[3] *European Standard Transmission and Multiplexing in the Frequency Band 40,5 GHz to 43,5 GHz; Part 1: General Requirements*, ETSI EN 301 997-1 V1.1.1, 2002–04.
[4] A. Paraboni *et al.*, "Spatial rain distribution models for the prediction of attenuation in point-to-multipoint and resource-sharing systems in the Ka and V frequency bands," in *Proc. URSI-F Symp. on Propagation and Remote Sensing 2002*, p. 6.
[5] Cs. Sinka *et al.*, "The effects of moving rain cell over LMDS systems," in *1st Int. Workshop*, Malvern, U.K., July 1–3, 2002.
[6] "Propagation Data and Prediction Methods Required for the Design of Terrestrial Line-of-Sight Systems," ITU, Geneva, ITU-R Recommend. P.530-7, 1997.
[7] EMBRACE—Efficient Millimeter Broadband Radio Access for Convergence and Evolution. [Online]. Available: http://www.telenor.no/fou/prosjekter/embrace/.