RECENT RESULTS OF RAINFALL MAPPING FROM CELLULAR NETWORK MEASUREMENTS

Hagit Messer (1) , Oren Goldshtein (1), Asaf Rayitsfeld (2) and Pinhas Alpert (2)

(1) School of Electrical Engineering; (2) Department of Geophysics and Planetary Sciences,
Tel Aviv University, Tel Aviv 69978, ISRAEL

ABSTRACT

Electromagnetic waves are known to be influenced by atmospheric conditions. Therefore, wireless communications, in which electromagnetic signals carry the information, can be used in environmental studies. In a recently published paper, it has been demonstrated that received signal level (RSL) measurements from fixed terrestrial line-of-sight microwave links, deployed by cellular operators, can be used to estimate space-time rainfall intensities [1]. In this follow-up paper we present recent real data results based on a rigorous algorithm which converts received signal level measurements from a set microwave links in an arbitrary geometry, lengths and frequencies into a two dimensional rain map. As such, the great potential of using globally spread wireless communication systems for accurate two dimensional rainfall monitoring has is exploited.

Index Terms— **Rainfall estimation, environmental monitoring, microwave links, RSL measurements, rain field reconstruction.**

1. INTRODUCTION

Though radio wave propagation impairments caused by scattering and absorption of precipitation have been extensively studied for years, the main focus was to provide reliable wireless communication system design and planning. Many studies have investigated the temporal dynamic aspects of electromagnetic propagation effects for design of adaptive fade mitigation techniques in order to produce a more reliable radio link acquiring less power resources. This precipitation "problem", however, can be considered as a great opportunity for using wireless communication networks for rainfall estimation, as first suggested in 2006 [1].

The idea of attenuation measurements of microwave electromagnetic fields for rainfall estimation using specially designed equipment was already explored in the past. A tomographic technique which uses received signal level (RSL) measurements from a set of microwave links with specific, predefined geometry, transmitting on a specially selected frequency, has been proposed by Dino Giuli in 1991 [2]. The MANTISSA (Microwave Attenuation as a New Tool for Improving Storm-water Supervision Administration) Project [3] involving a few European universities, explored the use of dual frequency microwave links to estimate rainfall, and demonstrated it on a special designed system [4]. However, the use of **existing** wireless communication systems for rainfall monitoring brings in great opportunities, together with demanding challenges: the frequency of the signals, as well as the geometry of the links, their lengths and the RSL measurements protocols, were designed to optimize the communication tasks, and cannot be optimized for environmental monitoring purposes.

In this paper we present results of an algorithm which converts RSL measurements from a set of microwave links in an arbitrary geometry, lengths and frequencies into a two dimensional rain map. The method has been implemented on records from existing commercial cellular communication network (Pelephone LTD). Each link in the monitored system has a transmitter and a receiver situated at the edges of the microwave path. Time series of RSL data from each link in the monitored area have been transmitted to a central processing facility. The new method is used to process the multiple path RSL measurements to derive a two-dimensional map of the rainfall intensity field. It provides accurate estimates in high temporal and special resolution, which cannot be achieved by other existing methods.

The rest of the paper is organized as follows: the actual monitored system and area is detailed in section 2, while the proposed algorithm is sketched in section 3. Section 4 provides some results and discuss the.

2. THE MONITORED AREA

The results reported in this paper are based on data records from an actual system composed of fixed terrestrial line-of-sight microwave links network, employed for transmission purposes by "Pelephone" (an Israeli cellular communication operator company). The tested network comprised of 22 fixed line-of-sight microwave links deployed in an area of about 15 km^2 (see Fig.1). Each link has its own carrier frequency; all frequencies are in the rage between 17 GHz and 23 GHz.

The RSL has been recoded from each link in the monitored system, every minute, onto a central server. The RSL is displayed in dBm units, with 1 dB resolution. The communication equipment produces the RSL from the receiver's IF-AGC output voltage and the ambient temperature of the antenna. The IF-AGC is the receiver's Automatic Gain Control that controls the dynamic range of the receive signal, its output voltage is translated to power measurements according to predefined tables of voltage and measured ambient temperature (the tables are build based on pre calibration).

Some fixed microwave links include a fade mitigation capability called Adaptive Transmit Power Control (ATPC): a mechanism that is used to improve the spectrum efficiency of the fixed links by limiting the transmit power to that required to maintain a constant bit error rate (BER) regardless of the propagation conditions. The ATPC automatically controls the transmitted power through indication of the received power. In this study we used information with link with no ATPC. To deal with ATPC one needs to record and analyze the transmitted power in the link instead of the received power.

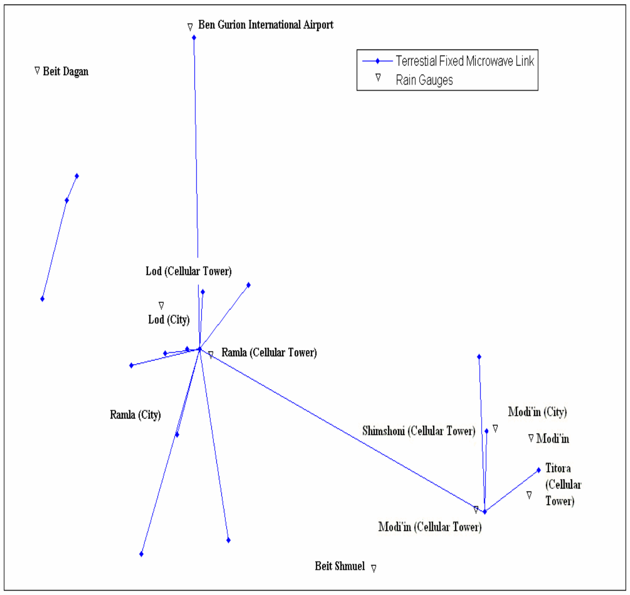

Fig. 1: The monitored area in the center of Israel. Lines represent microwave links and a inverse triangles represents rain gauges.

To validate the results of the proposed methods we used rain gauges. During the winter of 2006-7, six high-resolution rain gauges have been positioned in the surrounding area of microwave antennas. In the region of the first site (Ramla, approximately 20km SW from Tel Aviv) three high-resolution rain gauges were deployed. In the second region (Modi'in, approximately 15km east from Ramla), three high-resolution rain gauges have been used for the investigation. Another three high-resolution rain gauges are taken into account in the surrounding area (Ben Gurion International Airport, Bait Dagan and Kfar Shmuel).

3. THE ALGORITHM

Let $link_1, link_2, \ldots, link_N$ be the set of a given N terrestrial microwave links, where $link_i = \left(Lat_{i1}, Long_{i1}, Lat_{i2}, Long_{i2}, \underline{A}_i\right)$. Each i^{th} link, $i = 1,2,.....,N$, is identified by its two edges latitude and altitude coordinates - $\left(Lat_{i1}, Long_{i1}, Lat_{i2}, Long_{i2}\right)$ and includes an observation vector - $\underline{A}_i$ containing time series samples of the received power values in [dB]. Each link's received power observation vector, $\underline{A}_i$ is converted into rain rate vector, $\underline{R}_i$, using the relation:

$$A\left(dB\right) = aR^b L_{eff} \qquad (1)$$

Where $R[mm/h]$ denotes the rain rate along the link, $L_{eff}[km]$ is the effective path length, and a and b are functions of mainly the frequency but also of rain temperature and Drop Size Distribution (DSD). Though the relation is regarded as empirical, a strong theoretical justification exists for this choice, See [5], [6] for example.

The proposed method then spatially represents each microwave link by at least three, equally spaced, data points (Fig. 2). The spatial conversion is form a given set of N terrestrial microwave links to a set of M data points containing rainfall rate vectors as follow: each j^{th} data point, $j = 1,2,.....,M$, is defined by its location and a time series rain rate vector: $\underline{R}_j = \underline{R}(x_j, y_j)$, (all points on the same link assume the same rain rate measurements).

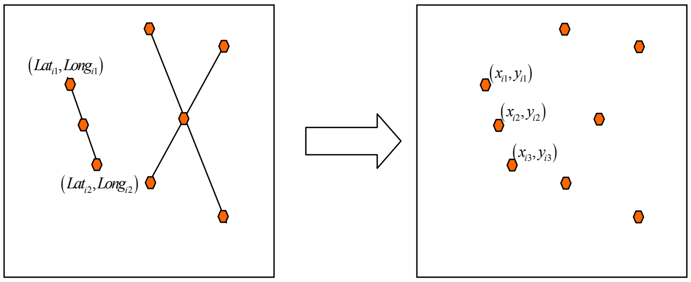

Fig. 2: Illustration of inks converted to data points

The monitored area is marked by an $n \times n$ regular grid, so that each grid point is attributed with a region of influence and can be spatially analyzed. Around each grid point a circle is drawn, called "the radius of influence" (Γ_i), and the area circumscribed is called "the region of influence".

Let θ denotes the rainfall rate at a spatial grid point coordinates (x, y) and let $[R_1, R_M]$ be a series of M spatial distributed rain rate data point values at a given time, processed from measurements of microwave links RSL. A basic method for estimation of rainfall rate out of scattered data points is commonly called "Shepard's method" Inverse Distance Weighted (IDW) interpolation [7] which is commonly used technique for interpolation of scattered points:

$$\theta = \frac{\sum_{i=1}^{M} W_i \times R_i}{\sum_{i=1}^{M} W_i} \qquad (2)$$

Where W_i is a weighting function, calculated using a search radius and is given by:

$$W_i(x, y) = \begin{cases} \dfrac{\left(1 - \dfrac{l_i}{\Gamma}\right)^2}{\left(\dfrac{l_i}{\Gamma}\right)^2} & ; \dfrac{l_i}{\Gamma} \le 1 \\ 0 & ; \dfrac{l_i}{\Gamma} > 1 \end{cases} \qquad (3)$$

Where l_i denotes the distance between the required estimated grid point θ at location (x, y) and sampled data point d_i, Γ is the radius of influence. The results in the following section derived using a more sophisticated choice of W_i which, takes into consideration the quantization error in the RSL measurements [8].

4. RESULTS AND CONCLUSION

Fig. 3 presents a typical time series of the measured RSL (the raw data) over about two hours. Measurements from 14 links are shown, where in some cases there are double links (one for each direction) between two points. In those cases, the measurements from the two links are presented in the same frame. All links are at different frequencies and beside these cases, they are at different lengths.

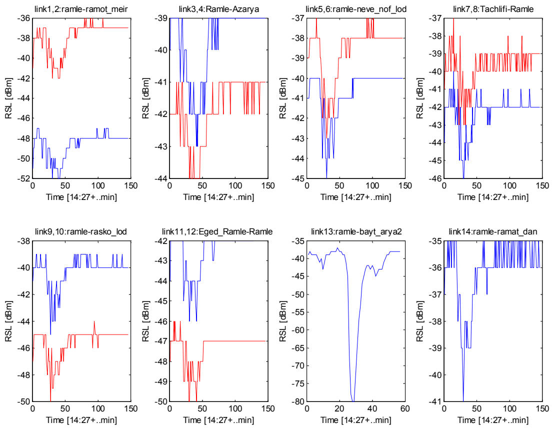

Fig. 3: Example for RSL data for several monitored microwave links

On December 26-27, 2006, a cold front moved from the North West to South East of Israel. Measurements of RSL from 22 links in the monitored area of Fig. 1 have been recorded at a temporal resolution of 1min. From that data, at two-dimensional rain map has been created using the method of section 3, minute by minute, for the two days period. For meteorological feasibility a high resolution in time (one minute sample) and in space ($1\,km^2$) are a giant advancement in the understanding the fine structure and the behavior of rain cells in a micro scale, which can not be resolved by using only rain gauge or Radar.

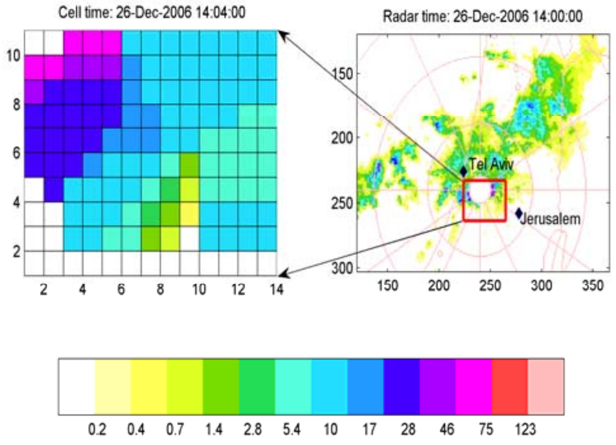

Fig. 4: Rain map of the monitored are, as created by the proposed method (left) and from Mekorot's Radar data (right).

One snapshot of the rain map created by our method is presented in Fig. 4. It shows the two-dimensional rain level map in pixels of 1 km^2, which demonstrate that a rain rate pick as high as 84 mm/hr can be localized at one pixel. For comparison and orientation, the radar map of the same instant is also presented in Fig. 4. Besides the fact that our monitored area happened to be partially within the blind spot of the Radar, it is obvious that the later cannot provide similar resolution.

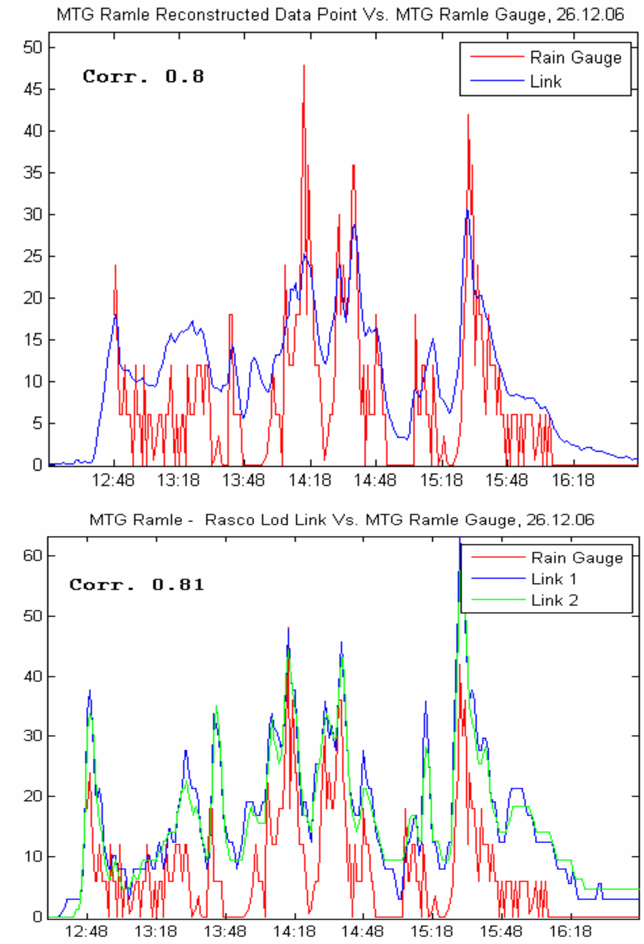

Fig. 5: Rain rate estimates (in mm/hr) from a single link and measurements from a close-by rain gauge (a 4 hours sample from two days period). The X-axis represents time in minutes (starting from 12:27 PM) and the Y-axis represents rain rate (in mm/hr).

To infer on the accuracy of the method we compared the estimated rain rate with measurements from the rain gauges located close to the links. Fig. 5 shows two examples which compare the rain rate estimate in two links connected to the Ramle switch grid point to the measurements of the rain gauge located in the middle of the grid (see Fig. 1), during 4 hours. While seeing very good match between the curves, they certainly do not coincide. We have calculated the correlation coefficients between the estimated and measures rain rate in different links using all available observation time. Our results show that the **point** correlation coefficient is about 0.8, which is considered to be a very good match, by meteorological standards. Note that this correlation coefficient is different (more demanding) from the one achieved by correlating the rain measurements over area, in which a typical correlation coefficient between rain gauges and Radar is about 0.6.

5. ACKNOWLEDGMENT

This project could not be done without the collaboration of Pelephone, who provided the data, and particularly of A. Shilo, E., Moshayov and Y. Shachar. We are much grateful to them. The authors like to thank their colleagues Artem Zinevich, Noam David and Amit Firesten for many fruitful discussion and help. We also thank D. Dreamler (IEC LTD), Y. Levy (Shacham/Mekorot) for radar data and A. Arie (Meteo-Tech).

7. REFERENCES

[1] Hagit Messer, Artem Zinevich, Pinhas Alpert, "Environmental Monitoring by Cellular Networks", Science, 312. 713 (2006).

[2] Dino Giuli, A. Toccafondi, G. Biffi Gentili, and A. Freni, "Tomographic reconstruction of rainfall fields through microwave attenuation measurements," J. Appl. Meteorology, vol 30, no. 9, pp. 1323-1340, 1991.

[3] http://prswww.essex.ac.uk/mantissa/

[4] Graham J. G. Upton, Rob J. Cummings, Anthony R. Holt, "The Potential of Mocrowave Links for Providing Information Concerning the Amount and Type of Precipitation", in IEEE Proceeding of the ICASSP'2008.

[5] "Specific attenuation model for rain for use in prediction methods," The Radio communications Agency of The International Telecommunications Union, ITU-R Recommendation P.838-1, 1999.

[6] Roderic L. Olsen, David V. Rogers, Daniel B. Hodge, "The aR^b Relation of Rain Attenuation", IEEE Trans. On Antennas and propagation, Vol. AP-26, No. 2, March 1978. pp. 318-328

[7] Shepard D.,"A two-dimensional interpolation function for irregularly spaced data" In Proceedings of 23rd National Conference (New Yark, 1968), ACM, PP 517-523.

[8] Oren Goldshtein, Estimating Space-Time Rainfall Intensity Using Measurements from Existing Network of Fixed Terrestrial Microwave Links, M.Sc. thesis, School of Electrical Eng, Tel Aviv University, 2006.