Capitalizing on Cellular Technology – opportunities and challenges for Environmental Monitoring

Messer H.

School of Electrical Engineering, Tel Aviv University, ISRAEL

e-mail: messer@eng.tau.ac.il

Abstract

The use of existing measurements from a commercial wireless communication system as virtual sensors for environmental monitoring has gained attention in the last decade. In particular, measurements of the received signal level (RSL) in the backhaul communication microwave network (CMN) of cellular systems are considered as opportunistic sensors for precipitation monitoring. Research results have demonstrated the use of the suggested technique for estimating and mapping of rain, as well as of monitoring other-than- rain phenomena. However, further advancement toward implementation and integration in e.g., meteorological systems and models, are heavily dependent on multidisciplinary collaborations: Communication and networks engineers are needed to enable access to the existing measurements; Signal processing experts can utilize the diverse data for improving the accuracy and the tempo-spatial resolution of the estimates; Atmospheric scientists are responsible for the physical modeling; Hydrologists, meteorologists and others can contribute to the end uses; Economists can indicate on the potential benefits; etc. etc. In this paper I will review recent results and open challenges, demonstrating the benefit to the public-good from utilizing the opportunistic-sensing approach, and as an IoT application.

Keywords: Environmental monitoring, commercial microwave links, rainfall estimation.

1. Introduction

The relation between the rain intensity R (in mm/hr) and the attenuation of a microwave wireless signal A traveling in the atmosphere is relatively simple:

$$A = aR^bL , \qquad (1)$$

where A is in dB, L is the path lenth of the link and a, b are constants, depending on the frequency and the polarization of the signal, as well as on the drop size distribution (DSD) of the rain, which is considered as typical to an area. This relation, which becomes linear ($b = 1$) for a certain choice of signal parameters, has raised the idea to use microwave links (MLs) for rainfall measurements in the early 90's [53]. However, as the installation of dedicated Microwave Links (MLs) is costly, in combination with their limited coverage and questionable accuracy, this technology has not become commercial. On 2006, Messer et. al. [52] have suggested to take advantage on the existing widely spread cellular communication technology, and to use the MLs which are part of its backhaul network for environmental monitoring. While the relation (1) still forms the basis for this idea, the use of Commercial Microwave Links (CMLs) instead of dedicated MLs brings in opportunities, as well as challenges. The major opportunity is obvious: the availability of millions of potential virtual meteorological sensors almost everywhere on earth, with no costs for installation, maintenance or communication. However, the fact that during the 11 years since it first introduced this technology has not yet commercialized indicates on the challenges in implemented it. In this paper I will review the state of the art of the CML technology and the future direction for becoming an operational environmental monitoring system.

2. The first decade

Since first introduced in 2006, research groups from different disciplines have started to study this technology, and tens of peer-reviewed papers have been published. References [1]-[54] include selected publications, all are based on CMLs measurements. In general, these papers can be divided into four groups:

1. Papers in which the capabilities of the CML technology for environmental monitoring have been demonstrated (see Table 1). Naturally, the first foremost potential the near-ground rainfall monitoring capability. Several papers demonstrated the CML as a rainfall sensor, and a CMN as a sensors network, capable of 2D rainfall mapping. Later, other papers have demonstrated the use of CMLs for monitoring other-than-rain phenomena, including humidity, fog, dew, snow and sleet, and even wind and air pollution (indirectly).
2. The next step was, naturally, to study the accuracy of CMLs as virtual rainfall sensors. Table 2 presents a summary of the major contribution to errors and uncertainties analysis. Generally speaking, the uncertainties can be put in two groups: one which is related to physical effects, e.g., wet antenna which causes attenuation that may mis-read a higher rain-intensity value in (1) if not properly handled. The second group is human-made and is related to the CML technology, and will further be discussed in Section 3.

Table 1 Demonstrations of capabilities

	Reference
Rainfall sensing	15, 44,51, 52
Rainfall mapping	48, 52
Humidity sensing	45
Fog sensing	10, 24
Precipitation classification	17
Dew	11
Wind	32
Air pollution	3

Table 2 Errors and uncertainties analysis

	Reference
General	13, 39, 41, 47, 50
Dry/Wet	25,37, 40
Wet Antenna	7, 27
Calibration	6
Quantization bias	55
Non-linear Preprocessing	19

3. In Table 3 a list of paper suggesting algorithm for rainfall monitoring is presented. As the main opportunity in the CML technology is in near ground, bottom-up rain mapping, most algorithms are focused on it. The naïve approach is to treat each CML as a local point measurement and to interpolate local measurements to a grid, based on standard spatial interpolation techniques. Based on this approach, open software tools were developed ([8],[9]). More advanced algorithms have been developed by signal processing experts, on which the tempo-spatial resolution of the rainfall maps, their accuracy and their coverage has dramatically improved. Different authors used different approaches, such as: an iterative approach in which variability of the rain along the links as exploited [48]; compressed sensing approach [20],[22]; model based, parametric approach; tomographic approach [1]; and dynamic mapping [4], [42]. The main future challenge is to improve CML rainfall maps by merging with other measurements, where these exist.
4. Table 4 details a partial list of applications. In all papers in this table, actual CML measurements were employed and empirical results were presented and validated over time, in different climatological areas.

Lately, after about a decade of expanding research, the proposed approach has finally gained the attention of the private sector. First, Ericsson initiated a pilot [56], and lately a startup company has been formed[1].

[1] www.climacell.co

Table 3 Algorithms and tools

	Reference
Instantaneous rain mapping	20,22,43, 46, 48, 49
Dynamic rain mapping	4, 42
Heavy rain detection	30
Merging with other measurements	21, 23,
Rainfall tomography	1
Accumulated Precipitation	14
Open software tools	8, 9

Table 4 Applications

	Reference (year)	Area/comments
Large scale rainfall estimation/mapping	2, 29	Holland
Rainfall measurements	5,16 33 34,36 35	Africa Israel Germany Holland
Flood Prediction	26 30	Israel
Calibration of other sensors	28	
Hydrology	31, 38	urban drainage

3. The main challenge: Availability of CML measurements

The CML weather monitoring technology depends on the availability of measurements of the Received Signal Level (RSL) and the Transmitted Signal Level (TSL) from the microwave backhaul network of a cellular communication system. As in most countries a cellular company owns the infrastructure, the required measurements are owned by a private company. While the use of measurements of the transmitted/received signal levels is of no risk to neither the communication services nor to the privacy of the users, most cellular providers are reluctant of providing access to their intra-network for a 3rd party. On the other hand, researchers interested in the CML technology have approached cellular companies and success affords can be put in two groups:

3.1 The Passive Approach

Manufacturers of the backhaul transmission networks have implemented tools into their systems, which monitor and log the signal levels of all links in the network. The tool, known as the Network Management System (NMS), produces RSL and the TSL indicators which are automatically logged by the network operators (i.e., the cellular providers). *The passive approach relies on the use of the already existing NMS records as input for the CML weather monitoring technology*. The major advantage of the passive approach is that it puts neither burdens nor risks to the cellular providers, so it is relatively simple to get them to share this data. However, as the NMS data is kept for network monitoring, and in particular, for monitoring the actual link budget, the RSL (and TSL) signals in the NMS go through highly nonlinear process. Typically, only the minimal and the maximal RSL (and TSL) values, from the measurements taken over a window of 15 minutes, are stored. Moreover, these values are quantized at a 0.1-1dB resolution. Furthermore, as they are mostly used for analysis, the NMS records are rarely available in real time. An example of a typical RSL time series from an NMS record is depicted in Fig. 1.

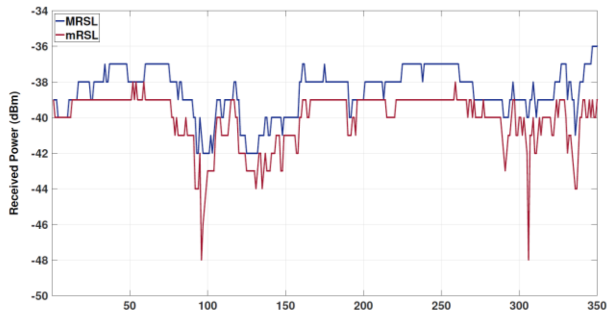

Figure 1: Typical time series of the minimal/maximal RSL, extracted from NMS records, at 15-minute intervals.

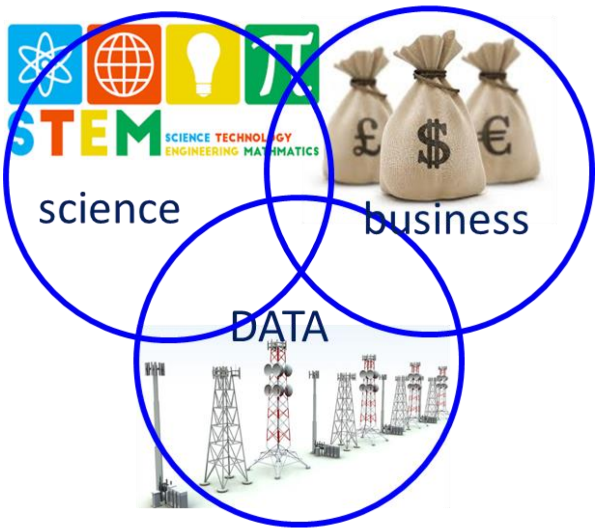

Figure 2: The future of environmental monitoring – capitalizing on existing communication technologies

Obviously, measurements collected by the passive approach are far from being "ready to use" for rainfall evaluation using (1). The instantaneous attenuation A required by (1) cannot be extracted from the min/max indicators of the TSL/RSL and the estimation of R from the available measurements calls for sophisticated signal processing [57].

3.2 The Active Approach

Modern microwave communication networks are remotely managed. That is, the network operators (i.e., the cellular providers) can access and inquire the status of the different CMLs remotely. Specifically, most CMLs hardware is connected to the provider's intra-net, and uses the Simple Network Management Protocol (SNMP) to submit queries to the CMLs, and receive the requested information. *The active approach is to use the SNMP to collect RSL measurements dedicated for weather monitoring.* A recent publication details this methodology, and establishes a set of open-source tools which can be used to *actively* access the CMLs of common manufacturers, and receive the instantaneous RSL (and TSL) samples [9]. With this approach RSL (and TSL) are available at real time as instantaneous samples, at sampling interval that can be as small as 10 seconds. Note however that in most cases, the RSL and the TSL samples collected by this approach still suffer from quantization, as the quantization process is a property (and a limitation) of the sampling hardware itself. Obviously, CML measurements collected by the active approach are most suitable for environmental monitoring, both because of the excellent temporal resolution and the lack of the highly nonlinear min/max processing of the NMS. Moreover, the availability of real time measurements is most attractive for applications as now casting and flood prediction. However, the active approach requires high level of involvement of the cellular provider including its permission to a 3rd partly to cross its firewall. Most providers are reluctant to allow it, as they see it as a potential risk to their main business – communication.

Table 5 summarizes the two approaches.

Table 5 Available CML measurements

	Passive	Active
Source of measurements	Existing NMS records	Designated data collection system
Temopral resolution	Minuts-days Typical – 15min	Seconds-minuts Typical – 10sec
Non-linear preprocessing	Typically min/max values over a given interval	non
Quantization	yes	yes
Major advantage	Simple acess, no risk for cellular operators	Real time
Major disadvanage	Not available in real time	Hard to get
Summary	Recommended for research purpose and for historic studies	Essensial for real time applications

4. Discussion

The CML environmental monitoring technology has started as an academic research, and is now on the verge of the next step in the journey – technology transfer for public good. By negotiating with local cellular providers, multidisciplinary research groups all over the world receive access to CML measurement in their countries, mostly for no cost, and are studying different aspects of this technology. Most of these groups are now collaborating and sharing experience, tools and knowledge in different ways, so a new scientific community has been built. This stage is most important for the sustainability and the future advancement of this emerging technology. On the other hand, the changes in the communication markets derive companies to look for new business, so they are more open to explore the potential of creating revenues from the CML technology. The 3rd part in the equation is the market itself, in which measurements and (big) data of any kind become valuable assets. Multinational companies such as IBM™ and Google™ are now interested in weather, and the CML technology is the best source for such data. Fig. 3 illustrates it. Recently, it has been mentioned as maybe one of the first IoT applications [58], which is now getting much attention.

While the conditions for the CML technology to become useful seems to be right, and we may see it soon in products as well as in public-good services, it also serves as a pioneering example of the new trend of capitalizing on existing technology by utilizing it for non-intended use.

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