Impact of Heavy Rain on Signal Propagation in the UK and Mexican 4G and 5G Networks

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***Abstract*— Wireless sensor networks are a current area of interest for many researchers, however surprisingly few have actually been deployed. In this paper we present preliminary results from a series of experiments designed to assess the viability of using existing mobile phone networks in developing countries to create flood warning systems. Creation of a flood warning network involves placing wirelessly connected nodes on all significant tributaries of a river system often over several hundreds of square kilometres. Rain is one of the principal causes of signal change in mobile networks. To assess the effect of the above on associated Internet of Things (IoT) flood alert systems, measurements were conducted in the UK and Mexico to determine the attenuation of line of sight (LOS) and ground multipath propagation due to either rain or excess surface water. Both components are analysed using ray tracing simulation software in addition to the real-time field measurements with the mobile hand set 'app' G-NetTrack Pro. Measurement experience gleaned from the UK campaign has been used to formulate a more comprehensive hand set based strategy in the Colima flood zone in Mexico, the results of which are also summarized in this paper. It is believed that both the above measurement and ray trace modelling exercises may be used to further optimize protocols required to address the propagation needs of future 4G/5G networks.**

Index Terms*—*Ray tracing and numerical simulation techniques, Propagation experimental methods and campaigns, Cellular networks and 5G, Connected objects (IoT and WSN).

I. INTRODUCTION

Flooding is the most prominent of natural disasters regarding the loss of life and long-term adverse social consequences. Unlike the UK, which has a sophisticated flood defense system, many developing countries are unable to afford the technology and have an inadequate response to flooding. However, most countries have a developed mobile network, which is upgrading for the 5G Internet of Things [1]. One of the practical solutions is to design a flood warning system based on the mobile network.

Floods occur when rain falls exceeds a threshold volume over a catchment zone. However, floods may also occur when combinations of parts of a catchment zone receive rain. IoT flood warning systems are being designed to collect data to allow researchers to assess which areas and combinations of areas contribute to floods. Some long-range IoT sensor networks typically use a cellular network to carry their data to a fusion server in the cloud [2]. However, such IoT networks need to be robust to extreme weather events during which path loss and Doppler perturbation may be significantly greater than typical means and variances [3].

In this paper, we have focus on the impact of heavy rain on mobile signal propagation within the IoT flood warning network.

The structure of the paper may be summarized as follows: section two analyses the sensor network in both the UK and Mexico and compares the respective communication strategies according to designated guidelines [4]. In section three, we undertake ray-tracing simulations of our experimental area via Wireless Insite software. Finally, we present the measurements undertaken with the G-NetTrack Pro software within the same area to assess the 4G received signal strength under varying rainfall conditions. The conclusions comprise further discussions of the impact of heavy rain on signal propagation and introduce future work programs in this field.

II. SYSTEM NETWORKS

A. Proposed Sensor Networks

The proposed UK-based sensor network will form part of the proposed Emergency Water Information Network (EWIN) flood detection system. [4]. It lies within the Soar river catchment zone covering an area of approximately 476 km^2. The network contains 14 riverbank nodes along with some water based 'drifter' nodes. It is located south of Loughborough and covers part of the city of Leicester as displayed in Fig 2.1.

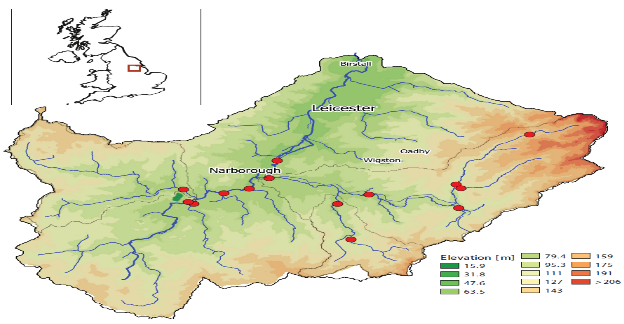

Fig. 2.1 Proposed Soar river sensor network with 14 nodes (red circles). Elevation data is provided by the UK Environment Agency.

The Mexican experimental network area is centered around the Colima river catchment zone located in the north of the Colima state as shown in Fig. 2.2, where the green markers denote the sensor node locations. The Colima River originates on the slopes of the Colima volcano and forms one of the tributaries of the Armeria River. It is also of interest to this project as it has rapid growing, diverse foliage along its riverbank [5], which would affect the signal transmission in the wet season.

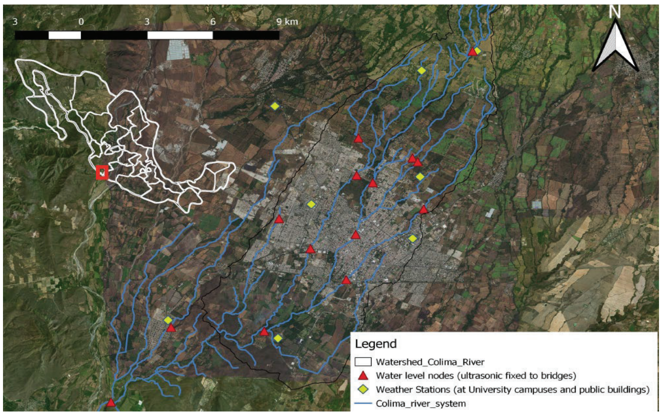

Fig. 2.2 Proposed Colima river sensor network for real time flood detection (Note white outline represents Mexico indicating position of Colima).

B. *Comparison between the two networks*

Table 2.1 compares the topographical and climatic statistics for both the UK and Mexican equi-numbered nodal networks illustrated in Fig. 2.1, 2.2. A study of which highlights the geographical differences which influence both the fixed node network design and the inter-nodal propagation. For example, most nodes in the Mexican network are gathered around Colima, where good base station to node signal strength may be possible. However, during the rainy season the node sites become overgrown with dense tropical foliage. There are also security problems in Mexico meaning that towers, to improve Line of Sight and solar panels to assist with power budgets, are not useable since they may be stolen. The task is to attempt to wirelessly connect nodes to each other and to towers through dense vegetation and in heavy rain using low cost off-the-shelf radio solutions. There are no suitable models available and a new one is therefore being researched as part of this work.

TABLE 2.1 COMPARISONS BETWEEN UK AND MEXICAN SENSOR NETWORKS

	UK network	Mexico network
Node amount	14	14
Catchment area	476 km^2	770 km^2
Average distance to the server	7.887 km	7.647 km
Mean elevation	84 m	519 m
Humidity	85 %	78 % (98% rain)
4G band frequency	800/1800/2600MHz	1700/2100MHz
Average temperature	13-19 C^o	23-29 C^o

Fig 2.3 shows the rainfall in the UK and Mexico and highlights the radically different rainfall conditions in the two locations. The UK network exhibits minimal fluctuation in the mean monthly rainfall that contrasts sharply with the cyclical Mexican rainfall characteristics; which comprise a pronounced maximum in the summer and minimal levels throughout the rest of the year.

The project's strategy is to research the UK network performance first then duplicate the experiments in Mexico during the rainy season. In line with the well documented relationship between rainfall and signal propagation loss [6], it should then be possible to offer real-time predictions of heavy rain in potential flood areas.

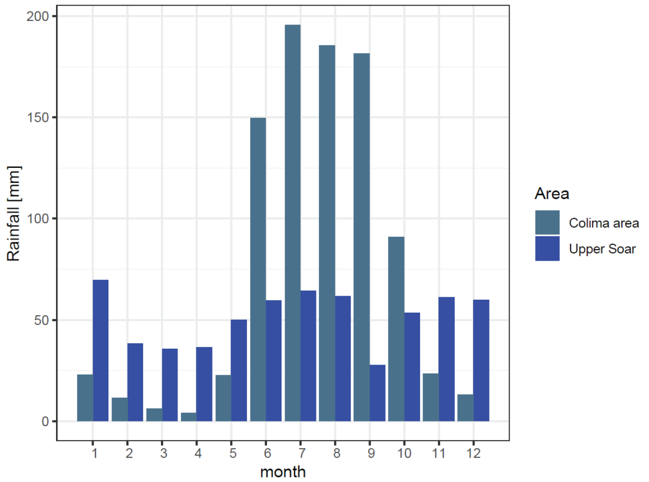

Fig. 2.3 Average monthly rainfall in Colima (Mexico) and upper Soar catchment area (UK)

III. WATERSIDE SURVEY USING EXPERIMENTAL NODES

The aim of this section is to assess the impact of heavy rain on LOS / water reflected multipath using both mobile handsets at the location indicated in Fig 3.1 along with Ray tracing modelling. The ray tracing simulations were performed using Wireless Insite and the mobile handset-based field measurements derived using the G-NetTrack Pro 'app', which provided both transmission and received signal power for 2G/3G and 4G. On viewing the measurement location on the River Soar, quite close to Loughborough, (see Fig. 3.1), it may be seen that two base stations are in close proximity: namely the 'Three' company tower at the head of a triangular island and the other located within the spire of St. James church. As this site is close to the river, it offers the added benefit of being able to monitor both LOS propagation and water reflection simulations.

Fig. 3.1 Experimental node positions used for River Soar Waterside survey

A. *Ray tracing simulation*

Ray tracing simulations fulfil an important role in radio propagation research, especially when practical measurements are hampered by an undulating or cluttered topography. The Wireless Insite software is a commercial product developed by the Remcom Inc. Its ability to simulate complex irregular terrain, emulate environmental and RF transmit / receive characteristics and estimate propagation path loss (using its X3D algorithm) makes it particularly apt for modelling the flood alert system network in the UK.

The Insite Ray tracing operation screenshots for the aforementioned River Soar area modelling are shown Fig. 3.2 and 3.3. Referring to Fig. 3.2 first, the 'Tx1' box denotes the base station of the 'Three' operator and the 'Tx2' box the base station of O_2 and Vodafone, whereas 'Rx1' denotes the measurement site C. After defining the Base Station transmission parameters, the simulations were performed, and the resulting modelled received powers recorded as a function of water coverage surface area in Table 3.1.

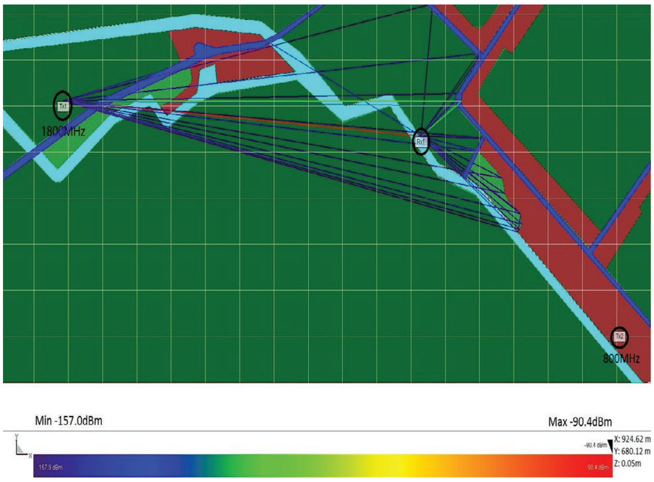

Fig. 3.2 Raytracing simulation of 1800 MHz with no ground water. This figure shows the area shown in Fig 3.1. Green – grass covered ground, blue – rain water covered ground.

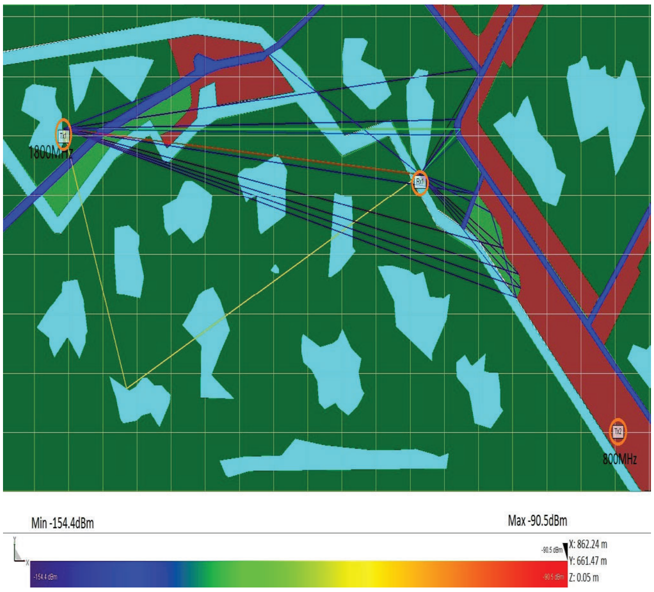

Fig. 3.3 Raytracing simulation with 50% ground water. Green – grass covered ground, blue – rain water covered ground

TABLE 3.1 Received power (dBm) as a function of measurement site water coverage area

Frequency	No water	25% cover	50% cover	75% cover
800MHz	-80.64	-80.26	-79.46	-78.10
1800MHz	-94.81	-93.6	-92.94	-91.23

A study of the table reveals a strong correlation between the water coverage areas and the modelled received power for both 800 and 1800 MHz bands. As well as rain, standing water is of interest. Initial experiments indicate that in general, more standing water leads to less multipath but stronger reflections. The contents of the water may also change the conductivity, and this also alters the propagation loss. Similar effects have previously been cited in [7].

B. *Signal measurement with G-NetTrack Pro in the UK*

Recently a number of phone applications have appeared that allow a user to measure and record some of the channel quality signals used in 2G/3G and 4G technologies. They are a useful way of recording signal strength over extended periods of time using 'app' data deposited at a server and of taking indicative signal levels. In this work we have used G-NetTrack Pro and OpenSignal Apps. The test configuration shown in Fig. 3.4, along with its key dimensions in Table 3.2, comprised four Samsung S6, hand-sets with pre-installed G-NetTrack Pro, OpenSignal Applications on a wooden support close to the ground to avoid any perturbative effects from human interaction. OpenSignal is used to locate the base station, whilst the G-NetTrack Pro provides the required network performance metrics. After installing all phones on the support, the G-NetTrack Pro logging software was run for ten minutes with a 2 second data sampling interval. The mean of the recorded data was then calculated and recorded for further analysis.

Table 3.2 Dimensions displayed in Fig. 3.4

Number	Length	Number	Length	Number	Length
1	50.0mm	2	112.5mm	3	210.0mm
4	30.0mm	5	60.0mm	6	27.5mm
7	200.0mm	8	390.0mm	stand	129cm

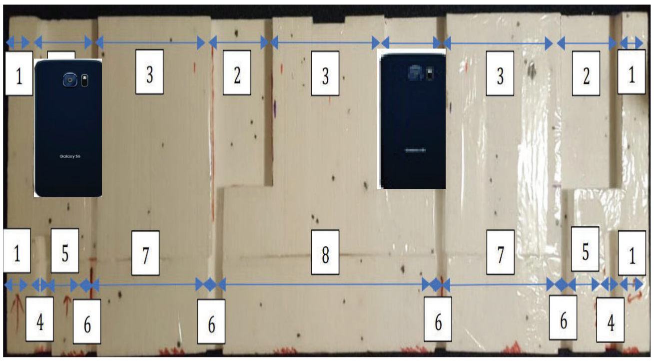

Fig 3.4 Design of the support were the phones are secured

Table 3.3 details the recorded mean RSRP of the four operators for varying daily rainfall levels along with its associated functional dependence as plotted in Figure 3.5 below. The rainfall amount on the given measurement day is taken from [8]. A study of this table shows a decrease in RSRP with increasing rainfall as predicted by:

$$\gamma_R = k \cdot R^{\alpha} \quad (1)$$

Where γ_R the specific attenuation, is obtained for the rain rate R (mm/day) using the ITU-R P.838-3 power law relationship of [9], where the values of the coefficients k and α are frequency dependent functions. In the 4G band, for example, the rain loss would follow an exponential function curve, which forecasts a proportionally higher attenuation when the rain is heavier.

TABLE 3.3 Mean RSRP of 4 Mobile network operators under varying rainfall conditions

	4G Frequency (MHz)	Mean RSRP variation with rainfall (dBm)			
		No rain	30mm/ day*	50mm/ day*	80mm/ day*
Oper. 1	1800	-99.3	-100.5	-101.8	-102.4
Oper. 2	2600	-104.1	-104.7	-105.3	-105.4
Oper. 3	800	-91.7	-93.1	-95.4	-96.9
Oper. 4	800	-91.4	-92.9	-94.2	-97.4

*the rainfall amount cited from [7]

In the next experiment we used a mobile handset 'app' to collect large data sets for our radio propagation analysis. A technique which surpasses other methods which cannot provide the decoded signal metrics provided by the GNet Track application.

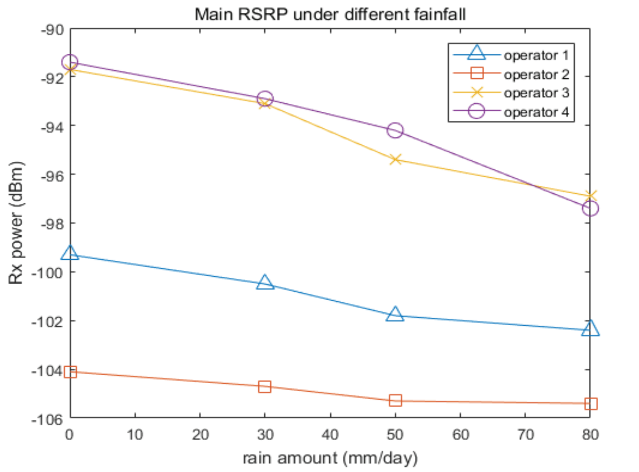

Fig. 3.5 Mean RSRP under different rainfall conditions for the four mobile network operators in the River Soar area

C. *Signal Measurement with mobile network tools and Spectrum Analyser in Mexico*

Unlike the UK, Mexico may have less cellular coverage due to its mountainous terrain and neighboring volcano. In order to assess the extent of the mobile network coverage here for the salient 900/1800 MHz GSM bands, RSS power measurements were made at coarse angular intervals across a 700 to 1000 MHz range using a spectrum analyzer to generate the frequency versus azimuth map plotted in Fig. 3.6. From the figure it is evident that the area is subject to strong 4G (850-880MHz) signals, and that there are multiple base stations particularly in the azimuth region from 150-200 degrees. Future comparative measurements using this technique in heavy rainfall should provide a basis for assessing the global effect of rain induced attenuation on emitters across the Mobile network spectrum. The method could also help us understand how the network parameters change dynamically when the flooding occurs.

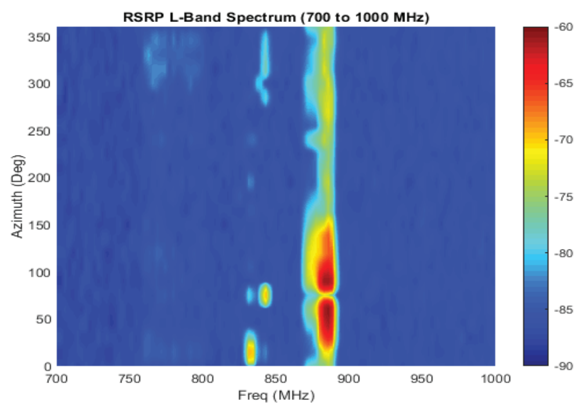

Fig. 3.6: Map of RSRP for Mobile emitters in the 700MHz to 1000MHz frequency range as a function of measurement bearing (Azimuth) in the Colima district.

In Colima, we also performed a measurement of RSS versus distance at various positions from the source. Note, due to difficulties in navigating the terrain, these locations did not occupy a straight-line distribution. The measurement location in azimuth, and radial distance from the source are illustrated in Figure 3.7 for measured data at 3.5 GHz, the band proposed for the 5G network. The power loss increases as the distance extends – a phenomena attributable to elevation, foliage, and distance. Measurements were made using a R&S FHS4 spectrum analyzer under dry conditions for all positions apart from the 340 m, WP2.2.13 way-point, where heavy rain was experienced. Here the RSS was recorded for both wet and dry cases as illustrated in Figure 3.8. A study of which shows a pronounced reduction in signal strength between dry and wet conditions, a trend which concurs with the theoretical prediction provided by the rain loss model in (1).

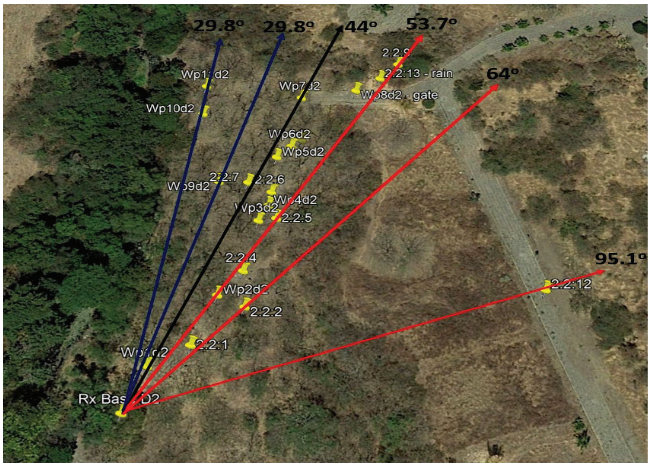

Fig. 3.7 Figure showing the radial and azimuthal measurement locations used for the RSS vs distance measurements in Colima.

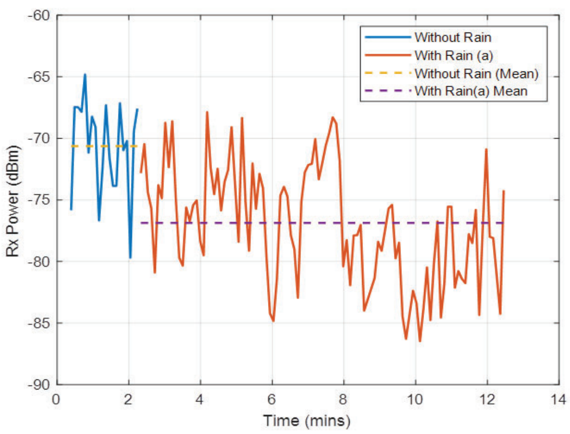

Fig 3.8 Recorded variation of received power (RSS) vs time at 'Waypoint 2.2.13' in Fig 3.7, with & without rainfall.

IV. Conclusions and Future Work

After analyzing the result of both measurements and simulations the following preliminary conclusions were drawn:

The level of signal attenuation is related to the amount of rainfall, with the theoretical rain induced attenuation exhibiting an exponential functional dependence. Within the mobile communication bandwidth, higher frequency signals suffer less rain loss than the low frequency ones.

Wireless Insite is quite useful for simulating radio propagation scenarios when practical measurements are hard to organize.

Future work would focus on similar measurements in the Mexican network during the rainy season in Colima where we will further investigate sudden heavy rain affects. Based on the propagation characteristics and data obtained, we will then formulate a suitable medium access control (MAC) protocol in readiness for the next measurement phase.

Acknowledgment

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