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Localization of rainfall and determination its intensity in the lower layers of the troposphere from the measurements of local RF transmitter characteristics

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Abstract: The article deals with a method of acquiring the temporal and spatial distribution of local precipitation from measurement of performance characteristics of local sources of high frequency electromagnetic radiation in the 1–3 GHz frequency range in the lower layers of the troposphere up to 100 m. The method was experimentally proven by monitoring the GSM G2 base stations of cell phone providers in the frequency range of 920–960 MHz using methods of frequential and spatial diversity reception. Modification of the SART method for localization of precipitation was also proposed. The achieved results allow us to obtain the timeframe of the intensity of local precipitation in the observed area with a temporal resolution of 10 sec. A spatial accuracy of 100 m in localization of precipitation is expected, after a network of receivers is built. The acquired data can be used as one of the inputs for meteorological forecasting models, in agriculture, hydrology as a supplementary method to ombrograph stations and measurements for the weather radar network, in transportation as part of a warning system and in many other areas.

Key words: precipitation, RF transmitter, SART method, radar measurements, hazardous weather phenomena

1. Introduction

Natural climate changes that arose gradually and lasted from thousands to millions of years differ from the current climate change when there have been significant climate changes almost within one to two decades. Opponents of the theory of climate change argue that, in particular, according to satellite data, the troposphere of our planet is warming significantly more

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slowly than shown by the results of processing the measured temperature data from ground meteorological stations. The current warming is not only in terms of absolute value, but also from its speed unlike any form of warm period known to history. The current climate development in recent years, is not natural for our Earth. This is the fastest unprecedented warming within a century and the trend continues.

It is obvious that the energy potential of the troposphere has been increasing in the last few decades. Due to this observation, we see also in continental Europe increased incidence of unusually intensive convection effects, which penetrate to the stratosphere and are accompanied on the Earth's surface by heavy hail, torrential rain, storms and tornadoes. These phenomena are typical for its meso- and micro-range borders, relatively short existence. Weather radars and data from geostationary and polar satellites are commonly used to detect and monitor them.

This paper aims to briefly state the characteristics of hazardous weather phenomena associated with convective processes and present a new method of measuring the spatial distribution of rainfall and its intensity by measuring the attenuation of the transmission communication paths.

2. Overview of extensive meso- and micro-spatial convection effects

Wind squalls – occur before the passing of a cold front (frontal squall), or just before a storm or heavy rain in unstable air masses, especially in the afternoon during the summer semester. This phenomenon was observed in the past before climate change. During a squall strong gusts of wind occur with speeds of up to 45 ms^{-1}, and often change direction. This is caused by strong upward and downward movement of cumulonimbus, characterized by whirls with a horizontal axis.

A microburst – is a small scale phenomenon with a horizontal diameter of not more than 4 km. If the effect size is larger than 4 km it is called a macroburst. The destructive wind usually lasts for 2–15 minutes and reaches speeds up to 75 ms^{-1}. It is characterized by the strong wind shear, which means higher increase of the gradient of the speed and/or wind direction. The detection of this phenomenon is very difficult, often impossible because of its short duration and small dimensions. This phenomenon is particularly dangerous for aviation, where it has already caused a series of serious aircraft accidents at take offs and landings of aircraft and helicopters.

Derecho – is a phenomenon characterized by the territory in which there are reported wind damage and/or wind impact must reach at least 25 m/s on the major axis, which is 400 km long and reporting of the damage caused by wind and wind gusts must have a chronological order. Derecho must be related to the advance of a convective system in one or more bands of instability. A distinction is made between low-end derecho, moderate derecho – within the range of damage over a length of not less than 64 km are at least three wind gusts of 33 m/s and high-end derecho with at least three wind gusts with intensity of 38 m/s.

Supercell – is a conventional storm of heavy intensity, which consists of a single highly significant convective cell. Its life lasts up to several hours with the influence of a single vigorous convection current, which is typically strongly rotating and vertical speeds can reach up to 50 m/s. Its rotation and vertical velocity is associated with complicated flow structure and is the cause of specific symptoms such as – occurrences of tornadoes, relatively long hail occurrence and creation of enormous hailstones. A supercell development can lead to multicell, and vice versa. Supercell may also be present as a part of the line of instability.

Sput/Trombe – is a whirl in the atmosphere with a non-horizontal, mostly vertical axis and a diameter in the order of units and tens of metres, exceptionally in hundreds of metres. A trombe has the shape of a funnel or elephant's trunk that runs from the lower base of convective storms (cumulonimbus), mostly from a supercell. The peripheral speed of whirls can reach up to 100 m/s as a result of the strong rotation.

Tornado – is the name for a large trombe. They usually occur in unstable moist tropical air that creates the warm sector of a cyclone. If a large trombe touches the ground, we are talking about a tornado.

Short-term rainfall properties and their intensity are commonly recorded by raingauge (ombrograph). When processing the intensities we look at the relation between the affected area and duration of rainfall, as well as the relation of intensity and the probability of exceeding at a certain time duration. Intensity fluctuation depending on the time is recorded by a raingauge in the shape of a summation line. The various degrees of rainfall intensity are distinguished as *very weak*, inmeasurable quantity, *light* (0.1 mm/h to 2.5 mm/h), *moderate* (2.6 mm/h to 8.0 mm/h), *strong* (8.1 mm/hr to 40.0 mm/h) and *very heavy* (above 40.0 mm/h).

3. Meteorological radar measurement properties

Meteorological radars (wavelength $\lambda = 0.8$ to 10.0 cm) acquire qualitatively new information on atmospheric precipitation, clouds and the phenomena that are associated with them, in the form of spatial display on the area of up to 150 thousand km^2 from one point in a few minutes.

Radar information about precipitation is a result of the spatial and time averaging (in a pulse volume – on a measurement area with quantum of data) and depends on the nature of the averaged value fluctuations, which indicate the characteristics of the dropout precipitation over time and space.

Generally, radar measurement of precipitation is carried out by measuring its equivalent reflectance $\mathrm{Z_e}$, at the minimum non blocked angle of the antenna – from the ground layer of the atmosphere or by measuring the dual polarization moments $\mathrm{Z_{dr}}$, $\mathrm{K_{DP}}$.

When measuring the amount and intensity of rainfall, we consider the radar a relative device that does not have continuous calibration to obtain absolute results. Nowadays, when the observatory grid is equipped with telemetric rain gauges, we have the ability to unify the data obtained with the data from the meteorological radar to establish the correlation coefficient for selected periods of time, such as 30 minutes or 1 hour and the like, in relation to the duration of the rainfall.

Rainfall intensity I in the given level, meaning the water mass which is falling on a unit area per time unit, depends on the concentration of raindrops, their range of dimensions and the velocity of their fall relative to the surface of the Earth. For practical calculation it is assumed that the liquid precipitation is uniform in time and space, and the vertical movements of the surface of the Earth are non existent.

The Slovak radar network currently consists of four meteorological radars, operating at a wavelength of 5 cm (C band) type SELEX METEOR 735

CDP with peak power more than 400 kW and are all dual polarization radars equipped with doppler mode to measure the radial velocity. The dual polarization option enhances the measurement of precipitation intensity and makes possible the categorization of different types of hydrometeor like drizzle, rain, hail and snow. Meteoradars METEOR 735 CDP are located on the Malý Javorník (Bratislava), Kubínska hoľa, Kojšovská hoľa and Španí Laz, Fig. 1.

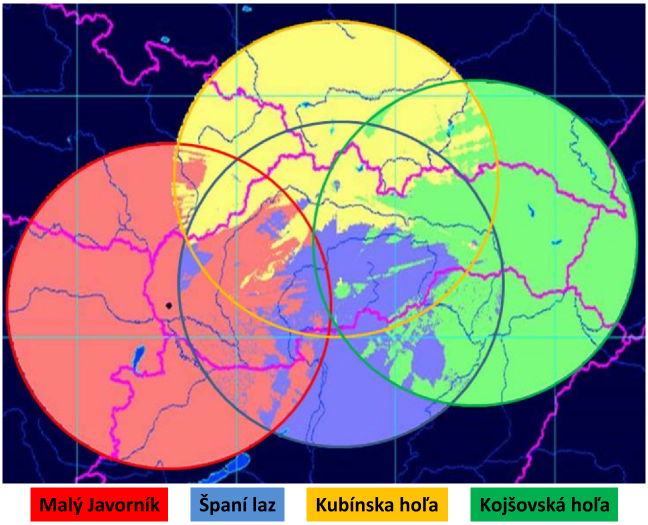
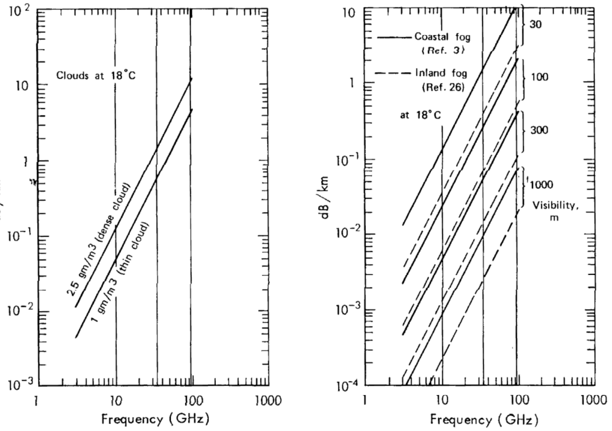


Fig. 1. Slovak radar network.

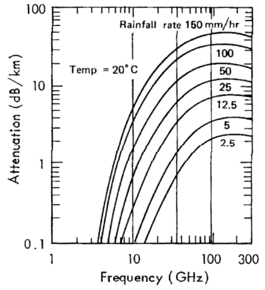
The combined radar information of SR is generated from radar data from all radars every 5 minutes at a central processing unit. This information also enters into a network of international exchange CERAD (Central European radar network). Volume data from all radar are sent to Odyssey (Operational radar data centre) EUMETNET OPERA program (European radar network), where a Europe wide composite is generated every 15 minutes.

4. Utilization of high-frequency electromagnetic radiation sources

Attenuation of electromagnetic radiation in the atmosphere and rainfall impact on the parameters of communication lines is a phenomenon that has been studied and monitored since the first experiments in this area in the 1930s. Attenuation values for the band from 1 to 1000 GHz taken from the common publications (*Chen, 1975*) are shown in Fig. 2.



(a) Clouds (b) Fog



(c) Rain

Fig. 2. Signal attenuation values for the frequency range from 1 to 1000 GHz for clouds, fog and rain (*Chen, 1975*).

These effects of attenuation of electromagnetic radiation by rainfall at directional link connections in the 10 GHz band, were experimentally verified in meteorology in experimental projects in the Netherlands (*Overeem et al., 2011*) and Sweden[1]. Directional microwave paths are by their nature suitable for determining the integral value of attenuation along the connection path as a result of local meteorological conditions. However, microwave

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[1] https://www.ericsson.com/mobility-report/microweather-unlocking-potential

paths do not create a coherent network/grid, and due to bandwidth and price their users tend to prefer optical cable routes. Attenuation of microwave connections is continuously monitored in real time by operators, but for commercial reasons this information is usually not widely available.

Besides the above mentioned sources of microwave radiation in our environment, many other sources of RF energy exist. Typical representatives are the base stations of mobile operators BTS, DVB-T transmitters for radio and TV, data communications (WiFi), satellite TV broadcasting, GPS and others. Most of these sources operate below 3 GHz and according to the published data, (Fig. 2), that this frequency band suffers from very little loss of communication path due to rainfall, fog and water steam, so it is generally neglected in the analysis and design of communication paths. It is obvious that a simple observation of the attenuation characteristics of the signal path between the source and the receiver will not be sufficient for the rainfall detection.

4.1 Properties of the communication path

Communication path properties are described by parameters of the environment dominantly affecting the first Fresnel zone[2] in Fig. 3. In telecommunication engineering it distinguishes between the signal spread in the direct optical visibility (LOS – Line of Sight) or without direct optical visibility. Interference effects caused by obstacles in the first Fresnel zone (moving vegetation, vehicles...) and changes in the environment itself (e.g. change of the refractive index of air due to temperature gradients) cause leakage (fading) of the signal at the place of its reception. Fading can be significant even over a relatively short distance from the source and can vary significantly when moving one of the connection parties, for example, a cell phone user. Fading character can be statistically described by (LOS) Rician- or Rayleigh-distribution[3].

From our point of view it is important, that signal fading due to the interference effects in two places in a dimension at a distance greater than one wavelength from each other, are mutually at the time uncorrelated variables. The same is true when using the same communication path at

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[2] https://en.wikipedia.org/wiki/Fresnel_zone

[3] https://en.wikipedia.org/wiki/Fading

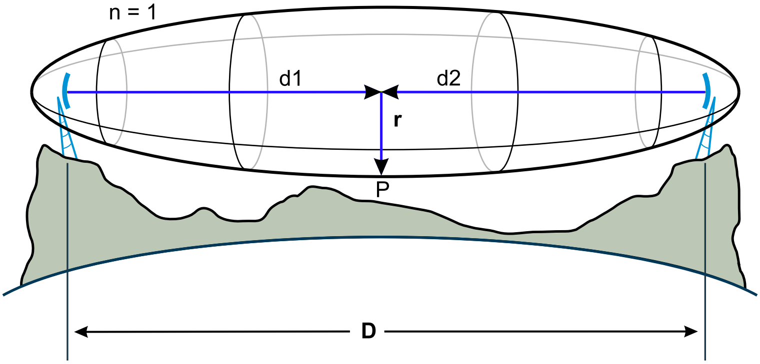

Fig. 3. First Fresnel zone, calculation of the parameters in `https://en.wikipedia.org/wiki/Fresnel_zone`.

different frequencies, the signal fading is an uncorrelated variable for individual frequencies. These effects are used in communication technologies to suppress fading by methods known as dimensional and frequency diversity reception[4].

It is obvious from the above, that the change of the communication path LOS characteristics that will affect the direct ray of the signal, is indicated in the dimensional and the frequency diversity reception as a correlated variable and can be used to quantify the parameters of the communication path environment. In the case of rainfall we get a correlated variable, corresponding to the total (integral) influence of the communication path along its entire length. In principle, we cannot distinguish one intense localized rain shower from weaker rainfall activity across the whole area within a single communication path.

4.2 Experimental verification of diversity reception

Within the experimental verification of the ideas presented above, we have used two mobile operator base stations (BTS) with operating frequencies (for synchronization signals CPITCH) at 928.8 Mhz and 950.9 MHz (downlink). The frequency spectrum of the BTS at frequency 928.8 MHz is shown in Fig. 4.

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[4] https://en.wikipedia.org/wiki/Diversity_scheme

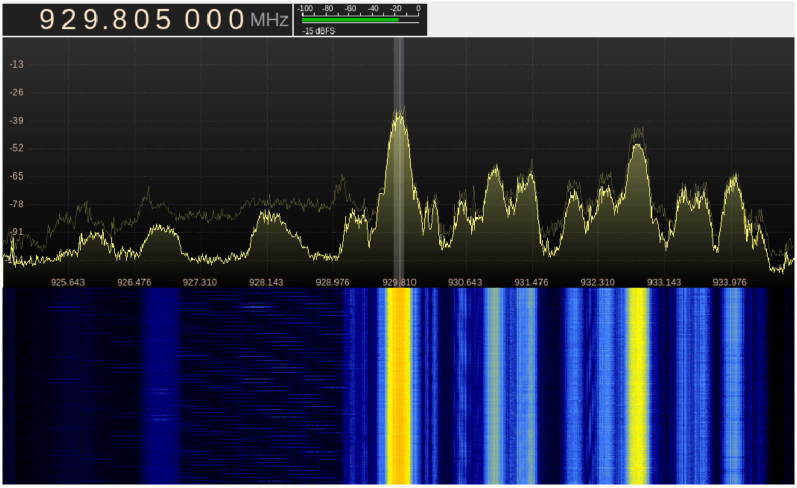

Fig. 4. Frequency spectrum and spectrogram of a BTS, pilot signal at 928.8 MHz.

BTSs are located relatively close to each other and approximately at the same height level. The receiver with an option of receiving on multiple frequencies was at a distance of approximately 400 m. Experiment layout is shown in Fig. 5. Green and red dot shows the position of BTSs, arrows show the main directions of antenna radiation diagrams, black dot shows the position of the receiving antenna.

During the passing of a significant cold front, the receiver controlled by a computer recorded the instantaneous signal intensity on BTSs frequencies. The situation from the SHMU weather radar is shown in Fig. 6. At the same time, the rainfall intensity was recorded as far as possible from the visual observations of the front transition.

The result of the experiment is shown in Fig. 7, which shows time courses of the signal intensities of both BTSs and detailed progress with commentaries from visual observation during rainfall. Values of signal fading does not exceed ±2.5 dB m, after evaluation by a correlation filter a noticeable influence of rainfall on the properties of the communication path is present.

Similar results were also obtained by the method of dimensional diversity reception using multiple receiving antennas separated by a few wavelengths and receiving the signal of one BTS. Both methods can be combined to obtain more accurate values of mutual correlation.

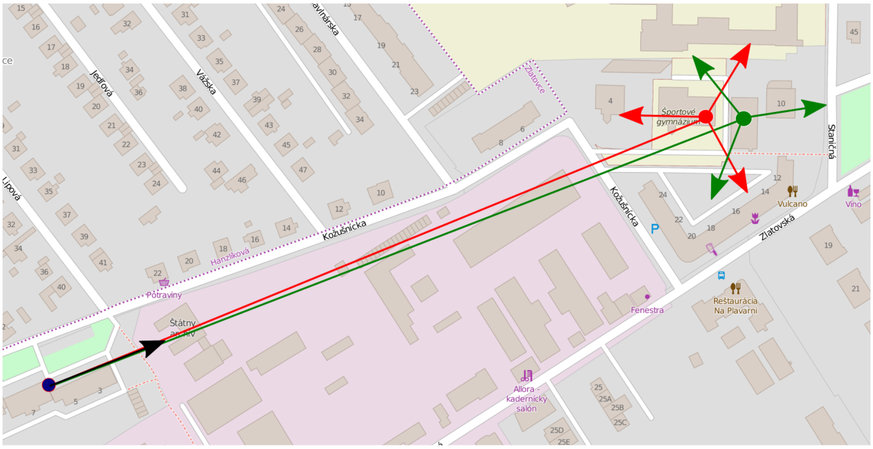

Fig. 5. Experimental layout for the frequency diversity receiving of two close BTSs, map sources are from the project OpenStreetMap (`https://www.openstreetmap.org/`).

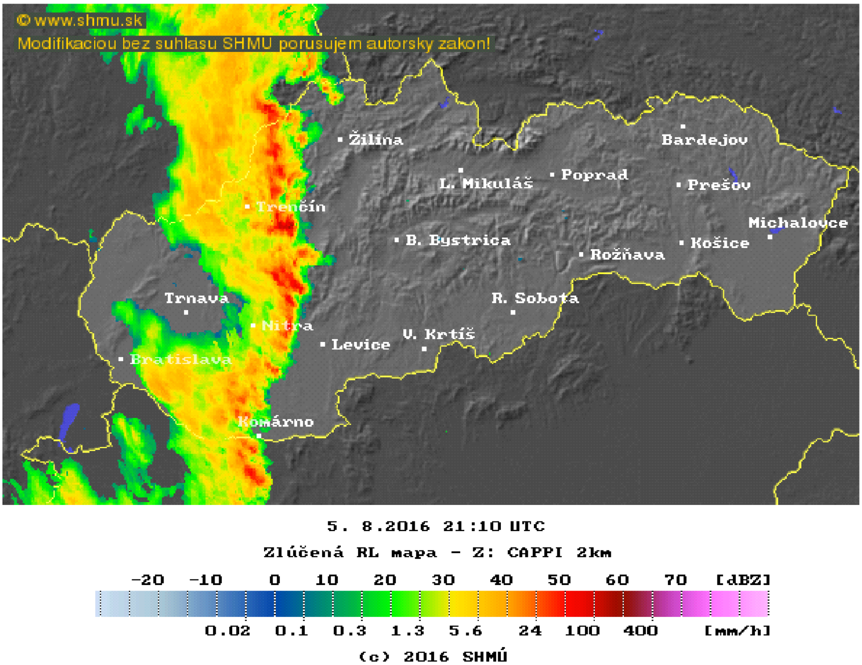

Fig. 6. Meteorological situation – passage of a cold front, image source: Slovak Hydrometeorological Institute (`http://www.shmu.sk`).

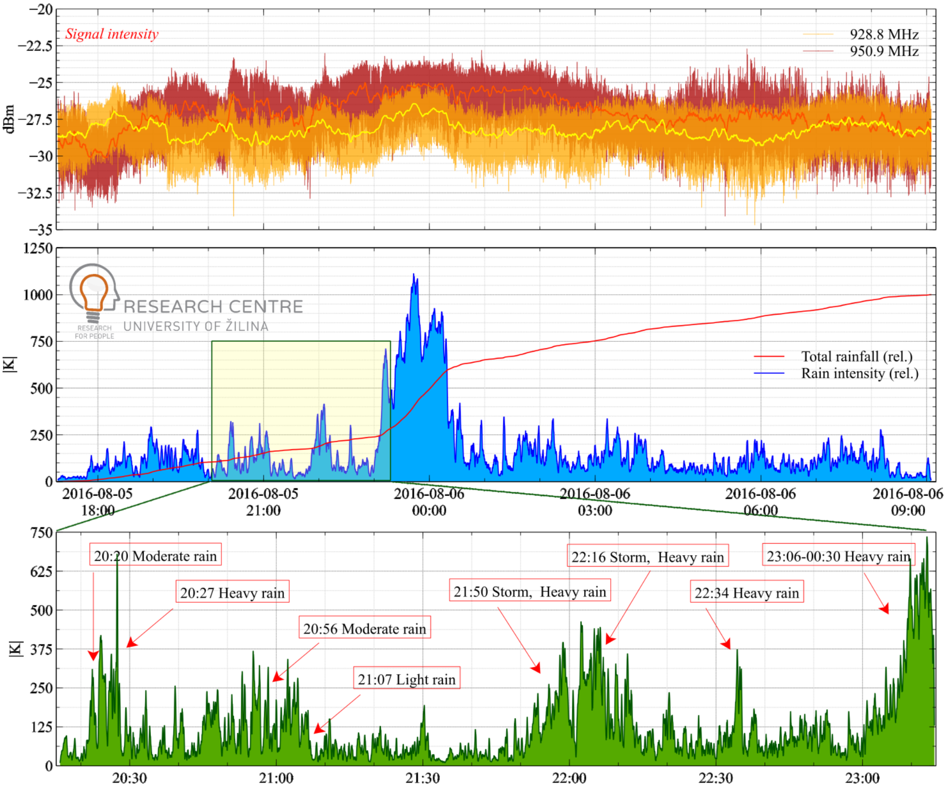

Fig. 7. Time record of BTSs signal intensities BTS (upper) and their mutual correlation.

4.3 Algorithm design for dimensional rainfall localization

It is obvious that obtaining quantity proportional to the integral value of rainfall along the communication path is not sufficient to locate rainfall, or it can be considered proportionate to rainfall values only for short routes in the order of hundreds of metres. For rainfall localization, for example, within urban areas, we can use a set of communication paths consisting of several receivers receiving signals from different BTSs, which are commonly available in such areas in large numbers. A model situation is shown in Fig. 8. For correct functionality of the proposed algorithm, it is necessary that the various paths mutually intersect each other.

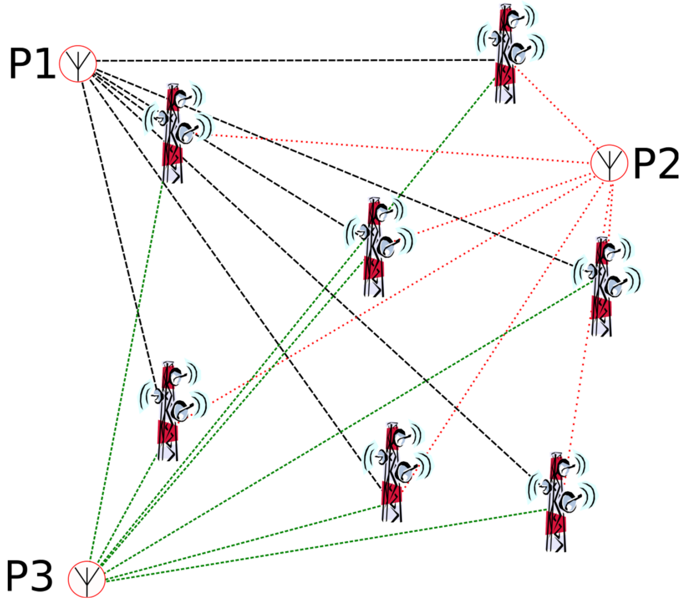

Fig. 8. Example of communication path mesh configuration with multiple BTSs and receivers P1–P3.

In the case that we know the positions of the individual BTSs and their frequencies, and we know the correlation values for each route, we can then use solution of a set of equations based on the Lambert-Beer's law to obtain the same parameter values at the intersections of the paths – points of network which are proportional to the actual amount of rainfall. The algorithm has been verified by a computer simulation, for practical verification it is necessary to build a network of the necessary number of receivers.

5. Conclusions

The presented paper outlines the possibilities of using statistical parameters of communication paths in the range 1–10 GHz for monitoring rainfall in the lower layers of the troposphere. The method utilizes passive diverse parameters monitoring of electromagnetic radiation sources and their evaluation using the correlation algorithms. The principle was demonstrated in an experiment with BTS GSM G2 mobile network by monitoring synchronization signals of BTS. The method does not require decoding of data streams transmitted by sources. In the case of spatial diverse reception, the sources may not even transmit with constant power.

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