

# Computer Aided Planning of WLAN Access Networks

Sławomir Pluta, Jacek Pluta

**Abstract**—An Internet application was developed to support the design process of the WLAN access network. The whole program was designed as a desktop application using the following languages: HTML, CSS and JavaScript. The main task of the application facilitates the planning process of the WLAN access network, including the location of multiple base stations. There is an example of using the program in the WLAN network planning process. The main purpose of this application as the ability to carry out network planning using multiple base stations and provide radio coverage for the entire area served by Wireless Internet Service Provider, is obtained.

**Keywords**—planning, web application, WISP, WLAN, Internet access, radio coverage, co-channel interference, Google Maps API

## I. INTRODUCTION

THERE are many telecommunications carriers supplying Internet via WLAN. These companies are called WISP (Wireless Internet Service Provider). The WISP are competitors for large telecommunications operators. Solutions used in this area, operates in a point-to-multipoint (PTMP) system, with direct visibility of LOS (Line of Sight) antennas and a range of several kilometers. Typical WLAN standards used in these solutions are IEEE 802.11n and IEEE 802.11ac using MIMO techniques (Multiple Input Multiple Output) [1]. For use within the Europe frequencies of radio channels are usually selected in the range of 5470 ÷ 5725 MHz (channels 100 - 140 ) and they are allowed for outdoor application accorded to standard [2].

The CSMA / CA access is used in the link layer of the standard IEEE 802.11 and is intended for WLAN applications in hotspot systems and for indoor networks. This mode works correctly when a relatively small number of WLAN devices are close together. As more nodes join, more "collisions" occur, which results in a decrease in transmission speed and an increase in transmission delay.

A number of companies have developed WLAN access solutions for WISP. An example of a hardware supplier that is often preferred by WISP is Ubiquiti Networks. Ubiquiti Networks has developed airMAX series WLAN operator solutions [3] . The company uses a time-division multiple access system (TDMA) to ensure an appropriate level of QoS (Quality of Service). This solution is not compatible at the link layer with the IEEE 802.11 standard, as CSMA / CA access is not supported. Guaranteeing a given value of data transmission speed is done by allocating a channel gap of the required width in the time domain. The base station coordinates the allocation

of transmission time for individual subscribers. In this way, the occurrence of collisions of transmission frames has been eliminated. The airMAX Ubiquiti protocol allows to monitor which stations are active, and then the transmission time is divided only among those stations. This guarantees the transmission efficiency for each subscriber (guarantee of delivery of the ordered data transmission rate), provided that the level of received signal (RSL) is adequate. It is also necessary to eliminate inter-channel and co-channel interference. An appropriate signal-to-interference ratio (SIR or S/I) value is thus provided in accordance with system requirements. Typical C/I values for co-channel interference used in practice for digital systems are 13-15 dB. The guarantee of delivery of the ordered data rate takes place taking into account the qualitative parameters of individual transmissions in the PTMP system provided in the physical layer in accordance with the requirements of the IEEE 80211n,ac standard [1].

It is also possible to automatically support QoS using IEEE 802.1p priorities levels, which must be properly configured before entering data into airMAX devices and are delivered in the VLAN field in the header of the Ethernet frame [4].

There are several solutions in the form of web applications that support WISP designers. These applications provide the opportunity to support the planning process of WLAN access networks in urban or rural areas. The software is developed by companies that manufacture WLAN devices for WISP and is usual available as freeware / shareware. These are e.g. web applications: AirLink [5], RF Planner [6], Ligowave Link Calculator [7]. The impact of terrain on radio coverage and the height of the base station and user terminal antennas are considered. A wide selection of equipment from the manufacturer's catalogue is provided, which gives the possibility of automatically entering the parameters of the antennas. For some applications it is possibly to specify transmission performance parameters for the user terminal in a given point of the area. Free web applications cannot incorporate detailed land cover features in the form of vegetation and buildings (commercial applications provide this). Unfortunately, the applications listed above allow to installing only one base station.

In the program "WLAN Designer" [8] presented in article, due to the use of a very simple radio wave propagation model, most of these functionalities are not included. The main purpose of this application is, in turn, the ability to carry out network planning using multiple base stations and provide radio coverage for the entire area served by WISP. Frequency reuse or frequency planning is included as a technique for frequency and channel reuse in the communication system to improve spectral capacity and performance. The limitation for

S.Pluta and J. Pluta are with the Institute of Control, Opole University of Technology, Poland (e-mail:.s.pluta@po.edu.pl, j.pluta@opol.pl).



projects supported by WISP is the availability of locations for base stations, because of the economic factors.

The "WLAN Designer" application has a simple graphical interface and the operation is intuitive. The application is intended for WISP designers who locate many base stations in a given area. It will also be helpful for students developing a project in the area of wireless WLAN networks. The designer himself sets the location for individual base stations, and the program performs analysis for the detection of co-channel interference. In this case, the designer moves those base stations that are responsible for co-channel interference. This creates a new coverage design that differs from the original hexagonal network coverage model. As mentioned earlier, WISP operators do not have extensive options for choosing the location of base stations due to the low-cost operating model.

## II. DESIGN ASSUMPTIONS OF THE "WLAN DESIGNER" PROGRAM

The "WLAN Designer" application was created with the help of HTML, CSS and JavaScript, which allow creating websites and web applications. Area maps of the WLAN network operation are downloaded from Google Maps [9]. Google Maps API allows to inserting a map to any web page and calculate the distance between points on the map.

The following design assumptions were made:

- network coverage: the availability of locations for placing base stations is a limitation, radio coverage: until the RSL drops to -95 dBm,
- selection of the type of WLAN network: capacitive network, QoS quality parameters are provided, such as bit rate, transmission error rate, value and delay variation, which forces the installation of more base stations,
- characteristics of the design area: LOS (Line On Sight) type propagation area,
- number and location of users: up to 30 users in a omnidirectional cell,
- network traffic profile: Internet access service, VoIP phone,
- determining the number of base stations (access points): according to the required coverage area,
- location of base stations: in accordance with available location possibilities,
- specificity of the base station antenna solution: omnidirectional antenna,
- channel width: 40 MHz,
- size of the cell cluster size  $N = 4$  (the repeating regular pattern of cells is called cluster),
- allocation of radio channels: cell No. 1 - channel 100 + 104, cell No. 2 - channel 112 + 116, cell No. 3 - channel 124 + 128, cell No. 4 - channel 136 + 140.

The main functional requirements are as follows:

- the program should accurately (to the first decimal number) calculate the distance  $D$  between the centres of cells having the same radio channels (distance between the centres of two co-channel cells),
- the program should enable the creation on map of a base station in accordance with the location indicated by marking the geographical position on the map with the mouse and the introduced parameters: radius of the cell ( $R$ ), receiver antenna gain ( $GR$ ), RSL and Effective Isotropical Radiated Power (EIRP),

- the program should enable calculating the RSL value on the basis of  $GR$ ,  $R$  and EIRP values,
- the program should display an error signal if the distance between the locations of stations with the same set of radio channels is smaller than the assumed distance  $D$ ,
- the program should enable the coverage of a given area with a radio signal in accordance with the given parameters of the base station and cell as well as the assumed frequency reuse model  $N$  of 4.

## III. CALCULATIONS IMPLEMENTED BY THE PROGRAM

### A. Calculation of the Received Signal Level for a Given Value of the Cell Radius and $GR$

In order to perform calculations, first the FSL (Free Space Loss) attenuation should be calculated. The FSL value was determined using (1) [10]:

$$FSL = 92,4 + 20 \cdot \log_{10}(f) + 20 \cdot \log_{10}(d) \quad (1)$$

where:

FSL - free space loss [dB],

$f$  - system operating frequency [GHz],

$d$  - distance between antennas "base station - user terminal" [km].

For the 5,4 GHz frequency, the FSL value is calculated based on a simplified relationship (2):

$$FSL = 106 \text{ dB} + 20 \cdot \log_{10}(d) \quad (2)$$

More accurate calculations should be ensured in the next version of the application, by using the ITU-R P.1411 model recommended in [11] for determining propagation attenuation in city access systems.

The basis for calculating the range of the radio link: "base station - user terminal" is the radio link budget, which allows determining the RSL value in accordance with the relationship (3):

$$RSL [\text{dBm}] = TSL - CLT + GT - FSL + GR - CLR \quad (3)$$

$$EIRP [\text{dBm}] = TSL - CLT + GT \quad (4)$$

where:

EIRP [dBm] - Effective Isotropical Radiated Power,

TSL [dBm] - transmitter output signal power,

RSL [dBm] - received signal power,

FSL [dB] - free space loss,

GT [dBi] - transmitter antenna gain,

GR [dBi] - receiver antenna gain,

CLT [dB] - transmitter losses (feeder, connectors),

CLR [dB] - receiver losses (feeder, connectors).

For the frequencies used in the 5470 ÷ 5725 MHz range, the EIRP value, determined by (4) may not exceed 30 dBm for outdoor operation [2]. If EIRP = 30 dBm then TSL has the highest value in accordance with the restrictions given in the standard [2]. Modern WLAN equipment for WISP usually integrates the antenna within the base station module or the subscriber's terminal. For this reason, CLT and CLR losses are often negligible.

Substituting the assumed value of radius  $R$  (in place of  $d$ ) to (2), the RSL value reached at the cell border is determined using (3).

Usually, the purpose of planning will be to determine radio coverage with an RSL level greater than  $-70$  dBm. This ensures efficient operation of wireless devices, especially in HT (IEEE 802.11n) and VHT (IEEE 802.11ac) standards [10]. The coverage areas will be plotted on the map in the form of circles corresponding to RSL boundary values.

Minimum input sensitivity (MIS) is defined as the lowest power level at which a receiver can achieve the prescribed PER (Packet Error Rate) criteria. The minimum PER that a receiver must achieve is 8% for DSSS and 10% for OFDM, HT, and VHT standards. Thus, the minimum sensitivity of the receiver for the IEEE 802.11 standard is the required "minimum signal level at which the receiver detects and demodulates a signal with a PER value of 10% or less." In other words, it is the minimum value of RSSI (Received Signal Strength Index) ensured correct decoding for a given type of modulation and coding speed (MCS index) with PER below 10%. Table 5 in [12] shows relation between MCS Index, number of Spatial Streams Modulation Stream 1/2/3/4, Coding Rate, Data Rate, Guard Interval. Table 4.3 in [13] shows relation between Modulation Scheme, Code Rate and Minimum Sensitivity for 20/40/80/160 MHz bandwidth. If we combine the information from these two tables together, we will get Table I. In this table we find information about value of the minimum value of the input sensitivity to ensure a specific data transmission speed in a given channel width. Table I contains the summary for the IEEE 802.11n (HT) standard for one and two spatial streams. This is a typical solution used by WISP. By binding MIS given in the Table I with the RSL calculated by program in given cell, it can be assessed whether the receiver is capable of providing the data rate expected by the designer.

Full sets of tables binding MIS, SNR, data rate and other parameters are presented in [14].

#### B. Determination of the Radius of the Cell for a Given Value of the GR and RSL

It has been assumed that according to the permitted EIRP level the relationship (4) takes place. Then from (3) and (4) we get (5):

$$FSL = EIRP - RSL + GR \quad (5)$$

The relationship (2) is placed in the formula (5) instead of FSL, as  $d$  is taken as  $R$ , which gives (6), (7), (8).

$$106 \text{ dB} + 20 \cdot \log_{10} R = EIRP - RSL + GR \quad (6)$$

$$\log_{10} R = (EIRP - 106 \text{ dB} - RSL + GR)/20 \quad (7)$$

$$R = 10^{(EIRP - 106 \text{ dB} - RSL + GR)/20} \quad (8)$$

#### C. Determining the Distance Between Co-channel Cells

To reduce co-channel interference, co-channel cells must be physically separated by a minimum distance to provide sufficient isolation due to propagation. It has been assumed

that the value of the co-channel interference reduction factor  $Q$  is calculated by the relationship (9) [15]:

$$Q = \frac{D}{R} = \sqrt{3N} \quad (9)$$

where:

$D$  - distance between the centres of two co-channel cells,

$R$  - cell radius,

$N$  - cell cluster size .

Despite the complexity of the propagation process, it is typical to depict the coverage area of a cell as hexagonal. Presenting a cell in the form of a hexagon is required to perform the above calculations using the geometric properties of hexagons [15], from which the relationship (9) results. In the "WLAN Designer" size  $N = 4$  was adopted, hence the value of  $D$  is given by (10):

$$D = R \sqrt{12} \quad (10)$$

It is assumed that for a given  $R$ , co-channel interference is negligible if the value of  $D$  is determined by (10). In the "WLAN Designer" program, the cell area will be graphically marked as a circle. This corresponds more to the actual characteristics of the cell coverage area in the absence of terrain. The  $R$  values must be the same for all cells, so they cannot be changed by individually changing the TSL value of a given base station.

#### IV. AN EXAMPLE OF OPERATION OF THE "WLAN DESIGNER" PROGRAM

After starting the application, the appropriate option is selected from the drop-down list in the "RSL" tab. If we want the RSL level to be calculated automatically on the basis of the cell radius ( $R$ ), we choose the option "Calculate RSL from radius" (Fig. 1.).

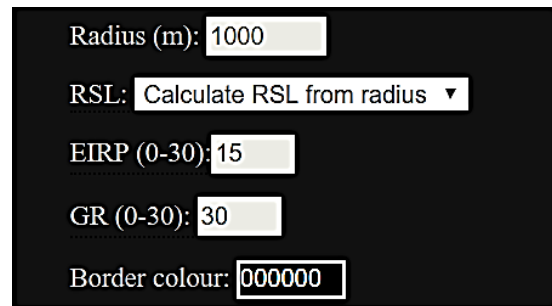


Fig. 1. Screen image for the "Calculate RSL from radius" option and selection of base station and cell parameters.

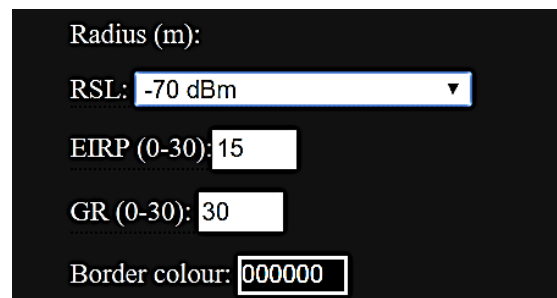


Fig. 2. Screen image for the "Calculate radius from RSL" option and selection of base station and cell parameters.

The second option is to choose the calculation of the R cell radius for the assumed RSL value (selection: "Calculate radius from RSL", Fig.2.).

After selecting the R or RSL, EIRP, GR values and the colour of the cell circle border for a given base station, you can proceed to arrange them. The location where the given station is to be built (Fig. 2, Fig. 3) is indicated on the map using the mouse.

The geographical position of the station and the cell radius R of the cell are displayed in meters at the top of the application desktop, after clicking on the marker indicating the base station. After selecting the "Calculate" button, coverage areas are determined with an RSL interval of 5 dBm, which is shown in Fig. 3.

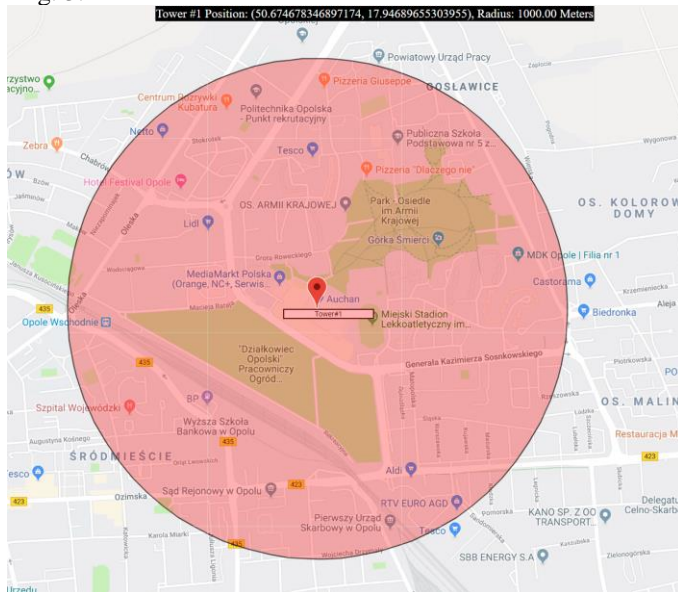


Fig. 3 Screen image illustrating the determination of the range by means of circles defining individual RSL power levels, for R = 1 km, EIRP = 20 dBm, GR = 25 dBi.

Fig. 4.shows screen image representing the creation of a base station with an omnidirectional cell for RSL = -70 dBm, EIRP = 20 dBm, GR = 25 dBi which gives R = 2.818 km. Cells are created on the map in turn according to the colour pattern: red, blue, green, grey. Each of the four colours indicates a different set of WLAN radio channels (Fig. 5.).

Checking if base stations interfere with each other is made after placing five (or more) stations on the map. Calculations are started by selecting the "Calculate" button (Fig. 4), which is located in the upper left corner of the screen. If the calculated D value is too small for stations with the same set of radio channels, an error messages is displayed with a red colour (for two or more co-channel cells). This is illustrated in Fig. 5. Then the markers corresponding to base stations listed in the message are moved to a greater distance, using the mouse. The stations are correctly arranged if the error disappears after moving the station further away and clicking the "Calculate" button. It is possible to arrange base stations so that the coverage covers the entire area of the selected city and the surrounding area, assuming an example limit value of RSL = -70 dBm (R = 2.818 km) and EIRP = 20 dBm, GR = 25 dBi. This is shown in Fig. 6.

The last option is related to the use of information from the table in the right side of the application desktop (Fig. 4, Fig.5.). The table lists the MIS values and their corresponding data rate values from Table I for 40 MHz channel width. This allows the designer to quickly assess what data rate is offered at a given cell location. The given rate value corresponds to the maximum value achieved in the physical layer for duplex transmission.

In many cases, the provider does not have to get the full coverage of this area due to the lack of potential customers or the inability to install the base station (no location available for WISP).

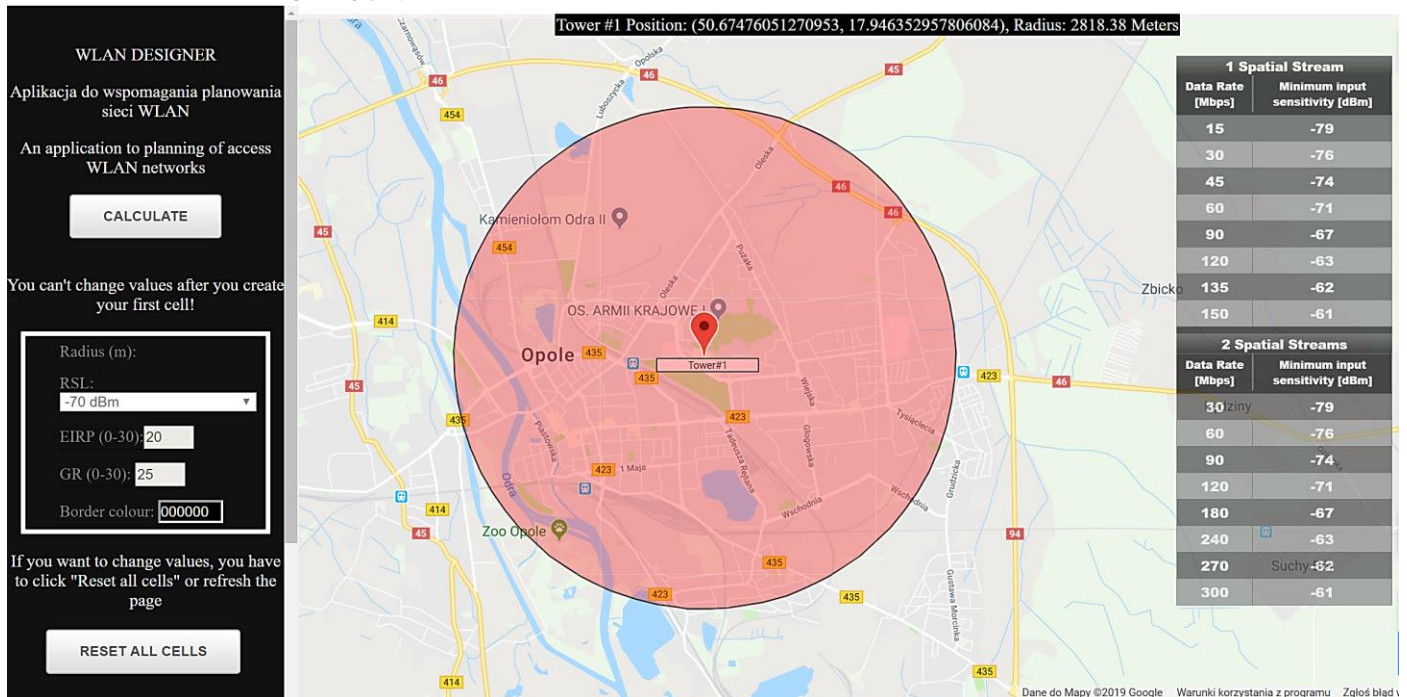


Fig. 4. Screen picture showing the creation of a base station with an omnidirectional cell for RSL = -70 dBm, EIRP = 20 dBm, GR = 25 dBi, R = 2.818 km.

TABLE I  
 IEEE 802.11N DATA RATES AND MIS REQUIREMENTS

MCS Index	Modulation	Cod	20 MHz				40 MHz			
			Data Rate (Mbps)		Min. SNR (dBm)	MIS (dBm)	Data Rate (Mbps)		Min. SNR (dBm)	MIS (dBm)
			GI = 800 ns	GI = 400 ns			GI = 800 ns	GI = 400 ns		
<b>1 Spatial Stream</b>										
0	BPSK	1/2	6.5	7.2	2	-82	13.5	15	5	-79
1	QPSK	1/2	13	14.4	5	-79	27	30	8	-76
2	QPSK	3/4	19.5	21.7	9	-77	40.5	45	12	-74
3	16-QAM	1/2	26	28.9	11	-74	54	60	14	-71
4	16-QAM	3/4	39	43.3	15	-70	81	90	18	-67
5	64-QAM	2/3	52	57.8	18	-66	108	120	21	-63
6	64-QAM	3/4	58.5	65	20	-65	121.5	135	23	-62
7	64-QAM	5/6	65	72.2	25	-64	135	150	28	-61
<b>2 Spatial Streams</b>										
8	BPSK	1/2	13	14.4	2	-82	27	30	5	-79
9	QPSK	1/2	26	28.9	5	-79	54	60	8	-76
10	QPSK	3/4	39	43.3	9	-77	81	90	12	-74
11	16-QAM	1/2	52	57.8	11	-74	108	120	14	-71
12	16-QAM	3/4	78	86.7	15	-70	162	180	18	-67
13	64-QAM	2/3	104	115.6	18	-66	216	240	21	-63
14	64-QAM	3/4	117	130.3	20	-65	243	270	23	-62
15	64-QAM	5/6	130	144.4	25	-64	270	300	28	-61

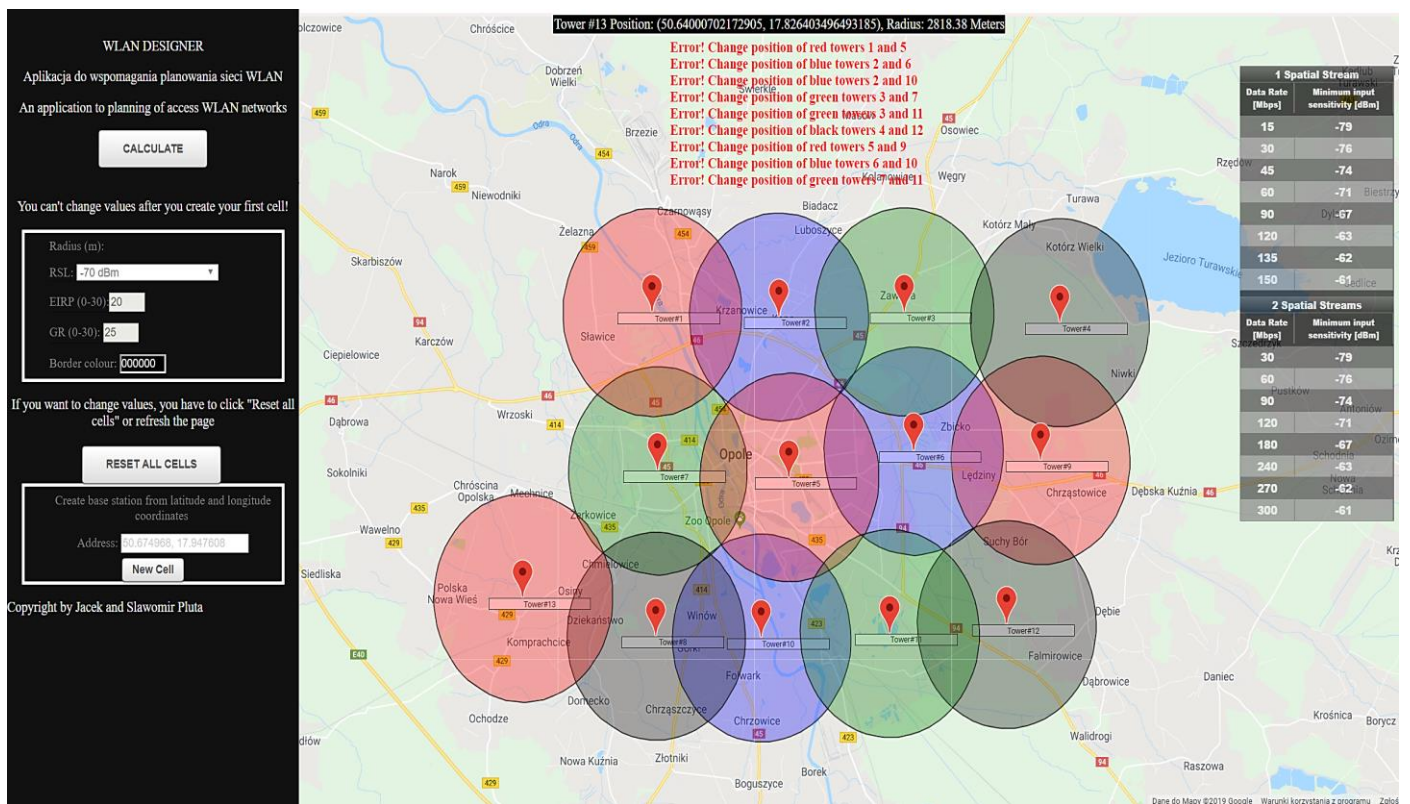


Fig. 5. Screen picture showing the wrong location of a base stations with an omnidirectional cell, RSL = -70 dBm, EIRP = 20 dBm, GR = 25 dBi, R = 2,818 km.

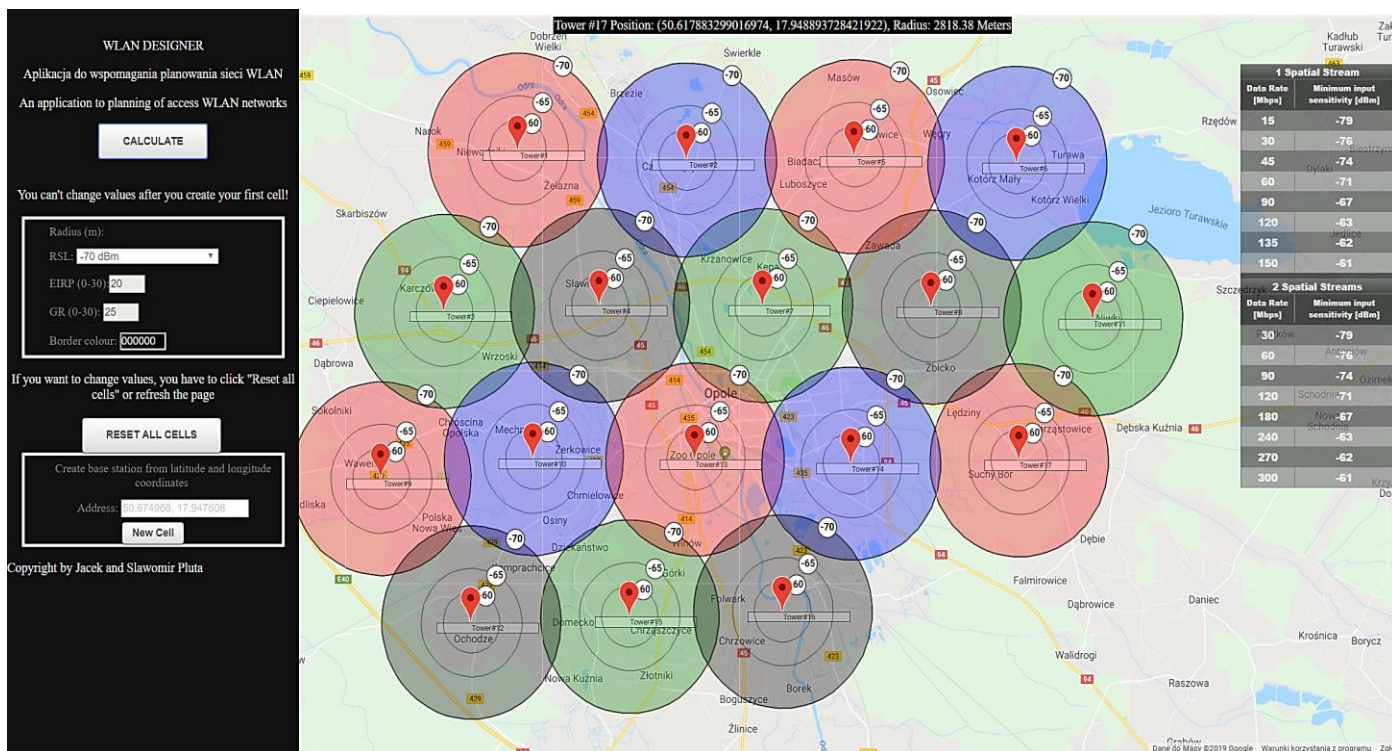


Fig. 6. Screen image for proper location of 15 base stations in Opole and the surrounding area for an omnidirectional cell, RSL = -70 dBm, EIRP = 20 dBm, GR = 25 dBi, R = 2,818 km.

CONCLUSION

During the development of the program implementation concept, the use of open-source solutions using the Geographic Information System (GIS) was abandoned in favor of a completely own solution in this area. The "WLAN Designer" application was created using Google Maps and Google Maps API. This solution provides significant simplification of the designer activities in the field of using geographical information, which significantly speeds up the WLAN planning process. Used coverage calculations for collision-free PTMP transmission provided by operator-class WLAN equipment do not require an advanced mathematics.

The main purpose of this application as the ability to carry out network planning using multiple base stations and provide radio coverage for the entire area served by WISP, is obtained. The MIS values and their corresponding data rate values presented on screen allows the designer to quickly assess what data rate is offered at a given cell location.

The application can be modernized in the future. It is planned to apply radio coverage calculations taking into account information on: terrain, height of base station antenna and user terminal antenna and on base station antenna radiation characteristics. The use of sector antennas is also planning. More accurate results will also be determined by determining the type of propagation environment.

REFERENCES

[1] IEEE 802.11-2016 - IEEE Standard for Information technology-- Telecommunications and information exchange between systems Local and metropolitan area networks--Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, [Online; accessed 20-Sept-2019]. [Online]. Available: [https://standards.ieee.org/standard/802\\_11-2016.html](https://standards.ieee.org/standard/802_11-2016.html).

[2] ETSI EN 301 893 V2.1.1 (2017-05) 5 GHz RLAN; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU", [Online; accessed 20-Sept-2019]. [Online]. Available: <http://www.etsi.org>.

[3] airMAX, [Online; accessed 20-Sept-2019]. [Online]. Available: <https://www.ui.com/products/#airmax>.

[4] airMAX - QoS and Prioritization, [Online; accessed 20-Sept-2019]. [Online]. Available: <https://help.ubnt.com/hc/en-us/articles/205231750-airMAX-QoS-and-Prioritization>.

[5] airLINK, [Online; accessed 20-Sept-2019]. [Online]. Available: <https://link.ui.com>.

[6] Ligowave, [Online; accessed 20-Sept-2019]. [Online]. Available: <https://linkcalc.ligowave.com>

[7] RF Planner, [Online; accessed 20-Sept-2019]. [Online]. Available: <http://wisptools.net/rfplan>.

[8] WLAN-Designer. [Online; accessed 20-Sept-2019]. [Online]. Available: <http://wlan-designer.opol.pl>.

[9] Google Help, [Online; accessed 20-Sept-2019]. [Online]. Available: <https://support.google.com/maps/>.

[10] J.Unger, "Deploying License-Free Wireless Wide-Area Networks", Cisco-press.com, 2003, [Online; accessed 20-Sept-2019]. [Online]. Available: <https://pdfs.semanticscholar.org/f63a/1b90a624094ba7ab17a6737ef9f93a65db87.pdf>

[11] P.1411: Propagation data and prediction methods for the planning of short-range outdoor radio communication systems and radio local area networks in the frequency range 300 MHz to 100 GHz, [Online; accessed 20-Sept-2019]. [Online]. Available: <https://www.itu.int/rec/R-REC-P.1411/en>.

[12] WLAN 802.11n: From SISO to MIMO Application Note, [Online; accessed 20-Sept-2019]. [Online]. Available: [https://scdn.rohdeschwarz.com/ur/pws/dl\\_downloads/dl\\_application/application\\_notes/1ma179/1M\\_A179\\_10e\\_WLAN80211n\\_from\\_SISO\\_to\\_MIMO.pdf](https://scdn.rohdeschwarz.com/ur/pws/dl_downloads/dl_application/application_notes/1ma179/1M_A179_10e_WLAN80211n_from_SISO_to_MIMO.pdf).

[13] Introduction to Wireless LAN Measurements. From 802.11a to 802.11ac, [Online; accessed 20-Sept-2019]. [Online]. Available: [http://download.ni.com/evaluation/rf/Introduction\\_to\\_WLAN\\_Testing.pdf](http://download.ni.com/evaluation/rf/Introduction_to_WLAN_Testing.pdf).

[14] MCS Index for 802.11n and 802.11ac Chart, [Online; accessed 20-Sept-2019]. [Online]. Available: <https://www.wlanpros.com/resources/mcs-index-802-11ac-vht-chart/>.

[15] W.C.Y. Lee, "Elements of Cellular Mobile Radio Systems", *IEEE Trans. Vehicular Technology*, vol.35, no 2, pp. 48-56, 1986.