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ASSESSMENT OF THE POSSIBILITY OF USING POINT-TO-POINT RADIO LINKS IN THE MIMO SYSTEM FOR CONSTRUCTING THE LOCAL AREA NETWORK BACKBONE

ABSTRACT

The article presents the results of the research conducted to assess the possibility of replacing the wiring in the connection system of the local network backbone for constructing backup connections or for the localizations where architectonic conditions do not allow performing installation works related to structural wiring of a building. Testing laboratory environment has been developed using radio devices operating in the IEEE 802.11n standard. The paper reports the results of the transmission tests in the systems of point-to-point links using the MIMO technique to determine parameters of the data transmission performance-throughput and latency. The transfer tests in the MIMO system were conducted in the indoor and outdoor environment.

Key words:
MIMO, data transmission performance, point-to-point link, IEEE 802.11n, indoor environment, WLAN, network backbone.

INTRODUCTION

Current indoor teleinformatic networks are usually constructed using copper UTP/FTP wires of the 5e and 6 category in the systems of structural horizontal wiring, and optical fibres in the systems of structural vertical wiring comprising the network

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backbone. The WLAN wireless solutions usually only complement the wire systems giving the mobile users a possibility of connecting to the Internet/Intranet network, however, the connection usually shows unstable and unforeseeable values of the transfer efficiency parameters in individual areas of the building coverage with the radio signal.

During the installation of structural wiring in certain class of buildings and facilities such as listed monuments, industrial facilities, glazed facilities (entertainment arenas, sports arenas, airports), stadiums, tunnels, mine workings, we can encounter many difficulties of an administrative (e.g., monuments conservation), technical (e.g., no possibility of distributing the cable channels), economical (e.g., high costs of the wiring distribution), and exploitation (e.g., frequent risk of damages of the cable path) nature. Thus, a question arises whether it is possible to replace the cable connection in the LAN/campus network backbone with the connection established through the wireless PTP (Point-to-Point) link. Such links can be also installed to maintain backup connections in a building (redundancy of the connections in the structural network backbone) and in indoor systems of the wireless mesh networks.

WLAN devices for the needs of the WISP (Wireless Internet Provider) allow to build radio lines/bridges of the transfer reliability and efficiency previously unseen in this price range. Big improvement of the wireless WLAN network coverage and bandwidth has been ensured by new techniques of the IEEE 802.11n standard, such as the MIMO (Multiple-Input Multiple-Output) technique, including the reception diversification MRC technique, the transmission diversification TB technique, and the equipment of the radio network node in the radio modules with multiple outputs having own power amplifiers and dedicated antennas. The MRC (Maximum Ratio Combining) technique significantly improves the signal-to-noise ratio (SNR) especially in the environments of high degree of multipath propagation. The TB (Transmit Beamforming) technique allows signal proper shaping before its emission from the transmitting antenna in a way allowing to obtain required beams reflecting current state of the radio channel.

Using several antennas for the Spatial Multiplexing increases the channel capacity in comparison to the one-antenna solutions. Channel capacity, thus, the throughput linearly increases with the increase of the number of antennas. The IEEE 802.11n standard also allows to use increased channel width (up to 40 MHz) and to introduce higher speed of modulation what is related to the usage of different modulation techniques and different FEC (Forward Error Correction) levels. Also the efficiency of the MAC layer through introducing frame aggregation and blocked acknowledgement (Block ACK).

Typical WLAN devices operating in the IEEE 802.11n standard are able to use two spatial streams in the channel of 20 or 40 MHz width, what allows to achieve the throughput in the band 5 GHz: 150 or 300 Mb/s, respectively (for the configuration of MIMO 2x2). For the configuration of MIMO 4x4, in the channel of 40 MHz width, it is possible here to obtain the bandwidth even of 600 Mb/s. Such data transmission rates allow the PTP systems to compete with the wire FastEthernet connections (100 Mb/s) and to come close to the performance of the Gigabit Ethernet wire link (1 Gb/s). The maximum lengths of the radio PTP links in the IEEE 802.11n standard usually reach 10 km (in the open area). This value allows the PTP links to beat the Ethernet IEEE 802.3 transfer in the UTP/FTP cables (100 Mb/s, 100 BaseTX, 100 m) in this subject, and almost equals the optic fibre links made in the multimode technique (e.g., 1 Gb/s, 1000 BaseSX, 500 m) and the economical solutions made in the single-mode technique (e.g., 1 Gb/a, 1000 BaseLX, 5 km).

In the indoor environment the radio link in the IEEE 802.11n standard operate in the low and centre frequencies of the unlicensed band of 5 GHz, where EIRP cannot exceed 200 mW (23 dBm), and the maximum coverage can still equal the coverage of the indoor wire links because using the MIMO technique allows realisation of the PTP transmission in the propagation conditions of the LOS environment with the first Fresnel zone obviously covered or in conditions of the NLOS environment. Proper installation of such radio links should ensure such arrangement of the antennas to avoid the absorption of the radio waves by persons that can shade the main propagation path.

DESCRIPTION OF THE TESTBED AND METHODS

Conducting the tests of the MIMO system properties required development of the laboratory station. The test station comprises of two identical sets of devices of the radio station equipped in suitable elements required for the wireless signal transmission in the MIMO technique. The station enables modification of the components, such as wireless network card and antenna, and ensures software setup of the system parameters of the radio transfer.

The possibility of using antennas of different polarisation and changing the intervals between the antennas was assured. This allows testing the influence of typical methods of the diversity reception on the transfer efficiency. In an indoor scenario multiple reflections at the walls gives a rich scattering environment and the fades between the antennas will be uncorrelated as long as the antenna spacing is sufficiently large. Setting the distance between the antennas of the MIMO system is important because the transfer efficiency of such system is the higher the lower the correlation between the individual paths of the multi-path reception. This lack of correlation is directly dependent on the angle separation of the received signal paths assessed at the reception antenna side. The requirement of the angle separation allows to determine the interval between the antennas. The minimum interval between the antennas depends on the radio wavelength and on the propagation environment. There are widely varying results found in the literature. Theoretical investigations have revealed significant improvements in throughput for a fading environment when multiple transmitter and receiver antennas are deployed [2]. In [1], based on ray tracing simulations, it was found that increasing the antenna spacing at both the Tx and the Rx to 3 λ will help to achieve higher capacity. A significant drop in capacity for the interval between the antennas smaller, then 5 λ and 4 λ is determined for indoor scenarios in [3, 5, 6]. Usually the mobile networks use the interval of 3–7 λ, for the WLAN system (according to CISCO [4]) an optimal interval is 1–4 λ. The theoretically determined interval between the antennas of the MIMO system can be modified in practice, depending on the propagation environment and the degree of the radio wave distraction and often is determined according to the designers and installers experimental experience. Certain set interval between the antennas is recommended in order to decrease the influence of the interference of signals coming from the mutual coupling. So the interaction between the two transmit antennas can't be neglected.

The wavelength for the 5.5 GHz frequency is 0.055 m. The possibility of realisation of the antennas system for the diversity polarisation reception using the antennas of different orthogonal polarisations, spatial diversity reception with intervals between antennas from 3.5 λ to 14.5 λ (0.2–0.8 m) and combinations of both those techniques. During the tests, the antennas were arranged on the testing station plate in 0.2 m and 0.8 m intervals.

The tests were conducted for two scripts: in the indoor environment (main tests) and free propagation space (verifying tests). Due to the article spatial limitation, only the most significant results will be presented. The article presents only the results of using the UDP protocol for the data transmission. Analogical tests were conducted also for the TCP protocol and its results are characterized by lower values of the link capacity parameters what is caused by the influence of the techniques of controlling the data rate and by the retransmissions on the value of the bandwidth.

The assessment of the transmission quality was conducted indirectly, through the measurement of the CCQ parameter. The value of the CCQ (Client Connection

Quality) parameter indicates how efficiently the throughput of the radio link in comparison to the nominal data rate is used. The lower the CCQ value the more retransfer of frames is present in the radio link, what indirectly allows the assessment of the frame error rate.

Figure 1 shows the station view during the tests, on the fourth floor of the Faculty of Electrical Engineering, Automatic Control and Informatics (FEEACI) of the Opole University of Technology. The frame of the test station of the radio station with antennas in the MIMO 2x2 system has been designed and constructed, enabling conduction of the tests of data transmission using different antennas systems. The drawings show the frame with the antennas backplane (dimensions: 200 x 90 x 60 cm). The backplane also enables fast installation and deinstallation of the antennas and the radio station in order to modify the setup in different intervals and for different polarisations.

Radio Stations Setup

Below the equipment of the single bridge radio station is listed:

- RouterBOARD433AH board manufactured by Mikrotik;
- metal casing prepared for installation of the RouterBOARD433AH board;
- miniPCI Techniclan cards complying with the IEEE 802.11n standard and of up to 300 Mb/s bandwidth with the possibility of connecting two external antennas;
- two panel antennas manufactured by Interline of 5 GHz frequency, of 19dBi gain; with the possibility of using vertical and horizontal polarisation, of the horizontal/vertical beam radiation width of (–3dB) 16°, FBR (Front to Back Ratio) >30dB, XPD (cross-polar discrimination) >27dB;
- metal frame and plane for installation of the antennas.

Setup of the first station aims at constructing wireless, transparent radio bridge for connecting the second station. Option of the access point as the 'AP Bridge' (Access Point Bridge). Setup of the radio interface card in the MIMO system was conducted assuming using two antennas for the transmission. The HT Tx Chains and HT Rx Chains are responsible for the two transfer beams of the transmitted and received signal. For that, the available HT Rx/Tx Chains fields were activated. Other options are responsible for:

- HT AMSDU — the amount of data transferred in the Ethernet frame, assumed 8192 B;
- HT Guard Interval — time between the sent symbols; in the 802.11n the *any* option increases the throughput to 11% in comparison to the *long* option;

– HT AMPDU Priorities — the value of the transmitted packet priority; all of the values 0–7 were set as active in order to maximize the data transmission efficiency.

The next parameter that needs to be setup is MCS (Modulation and Coding Scheme). This parameter is responsible for the selection of the data rate and the modulation type adjusted to this process, aiming at ensuring synchronisation of the connection and its maintenance. Such factors like the signal power, time between the sent symbols, link quality, allow to set the link bandwidth from the value of 6.5 Mb/s (MCS 1) to even 300 Mb/s (MCS 15) for the channel width of 40 MHz. Marking all of the available options since MCS 1 to MCS 15 allows automatic reaction in the moment of appearing the transfer disruptions in a form of sustaining the connection with negotiated, gradually lowered value of the MCS. Such setup enabled conducting all of the planned tests without any breaks in a form of disconnecting wireless bridge. The last parameter needed for the link setup, is the transmit power expressed in the Winbox software as the Tx Power. The default value of power of 2dBm was assumed. Optimal parameters of the transmission efficiency were reached for the link of the coverage of about 100 m.

Fig. 1. View of the laboratory station during the tests

In order to set the radio channel centre frequency for the needs of the test, the 5 GHz band was scanned. Thanks to that, the possibility that the channel set for the transfer will overlap with the channels used by other devices/systems was eliminated. In the free space environment, during the test, channels of the 5240 MHz and

5520 MHz frequencies were occupied only in the range of several percent of the channel full usage. The second environment, located in the building of the FEEACI, shows the usage of 3.7%, 4.8% and 9.9% for the channels of the centre frequency of 5260 MHz, 5300 MHz, 5580 MHz, respectively. Due to low value of the noise coefficient (Noise Floor) on the level of –120 dBm, we decided to choose the first 2 channels of the 5 GHz band of the centre frequency of 5180 MHz and 5200 MHz, respectively.

For the second station, in order to enable initiation of the connection with the first device, it is necessary to set the Mikrotik device in the 'station bridge' mode. Then, the station adjusts the setup of work parameters according to the settings assumed by the station No. 1.

TESTS OF THE PERFORMANCE OF MIMO TRANSMISSION IN THE INDOOR ENVIRONMENT

The test in the building of the FEEACI, in the indoor environment was conducted as the first one. Figure 2 shows the arrangement of the laboratory testbed on the fourth floor of the building. The total length of the building floor is 73 m and the laboratory stations were located at 60 m intervals. The transmission is conducted in the LOS conditions, in the narrow hall introducing spatial limitations for the radio waves propagation and giving good possibilities of obtaining multiple-path transmission (beneficial considering the MIMO system).

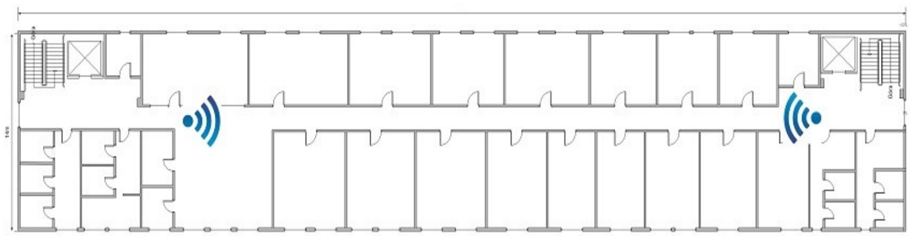

Fig. 2. Arragment of the laboratory testbed in the Faculty of Electrical Engineering, Automatic Control and Informatics of the Opole University of Technology (4th floor)

In order to present the properties of the radio transmission in the MIMO system, the test results were shown as table and graphs. Table contains abbreviations of the parameters names explained below:

– Rust — transmit data rate automatically set by the system software of the RouterBoard device on the radio stations;

– Rz — throughput of the PTP bridge measured in the system: station 1 — station 2 using the Winbox software (as a part of operational system RouterBoard).

The measurements were taken for the following modes: only transmission — Tx, only receiving — Rx, and for the mode of alternate transmission (two-way): Tx/Rx. The below listed values of the transmission performance parameters are calculated as the arithmetic means of 5 consecutive measurements carried out within 5 minutes. The measured RTT (Round Trip Time) value means the value of the total latency and is given for the individual measurements of the throughput. Influence of increasing the transmit power value in the range of 2–25 dBm on the transmission performance parameters was measured. Using exceeded levels of the power allows to determine the influence of the high level of the signal power on the possibility of the receiver lockout occurrence.

Figure 3a presents a graph showing significant decrease of the throughput for both modes: Rx and Tx in the conditions of overload. It can be concluded that properly set signal power is a crucial element in creating efficient wireless link. Dependence of the RTT delay on the transmitted signal power can be noticed in the figure 3b. The delay values are maintained on low levels. System of 2 antennas with vertical and horizontal polarisation and the 80 cm interval between the antennas for every radio station was used in the test.

Table 1 presents the results of the tests of the influence of the antennas polarisations and the interval between them on the parameters of the transmitted signal for the UDP protocol. The antennas were arranged in the vertical line, where: V — vertical polarisation, H — horizontal polarization. The transmitted signal power is 2 dBm. The best results for the tests of the bandwidth Rz of the PTP link in the two-way (Rx and Tx) mode were obtained in the HH 80 cm system.

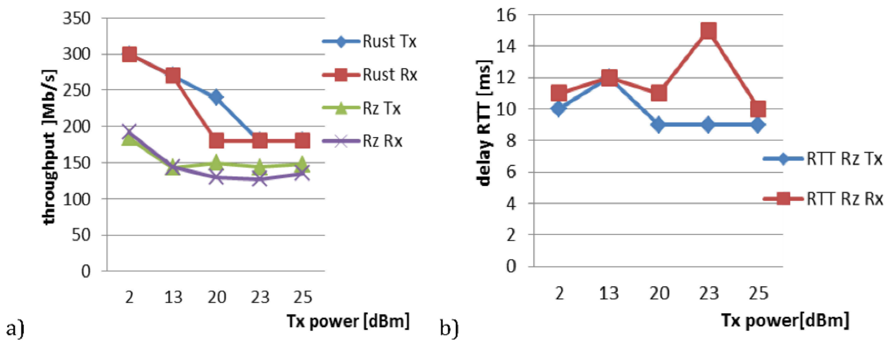

Fig. 3. Graph of the dependency of the throughput Rz and Rust on the transmitted signal power, for the Rx and Tx mode (a); graph of the dependency of the transmission delay on the transmit signal power, for the Rx and Tx mode (indoor environment, UDP protocol) (b)

Table 1. Results of the tests of the influence of different polarizations and intervals between the antennas on the parameters of the transmission for the protocol UDP in the indoor environment

Polarization/interval between antennas	VH/20cm	VH/80cm	VV/20cm	VV/80cm	HH/20cm	HH/80cm
Rust[Mbit/s]	243/300	300/300	240/300	270/300	270/300	300/300
Signal level Tx/Rx[dBm]	–53/–53	–51/–51	–40/–39	–42/–42	–39/–40	–37/–36
SNR [dB]	69	79	82	79	81	85
Tx/Rx CCQ [%]	84/99	96/99	88/100	81/100	83/98	87/100
Rz for Tx [Mb/s]	203	184	151	125	182	194
RTTz/Tx[ms]	12	10	11	10	10	10
Rz for Tx/Rx[Mb/s]	92/69	102/92	87/98	76/94	94/98	112/98
RTTz/ Tx/Rx [ms]	8	9	8	9	7	7
Rz for Rx [Mb/s]	198	192	213	193	214	214
RTTz/Tx[ms]	10	11	12	12	13	12

TESTS OF THE PERFORMANCE OF MIMO TRANSMISSION IN THE FREE SPACE ENVIRONMENT

In order to verify the results received in the indoor environment, tests were conducted in the free space, for the LOS conditions and 60 m interval between stations. Improvement of the transmission performance in comparison to the results of the tests for the indoor environment, and also obtaining maximum bandwidth of the bridge of 300 Mb/s (according to the data for the IEEE 802.11n standard) is visible in the figure 4. The value of delay RTT is 10 ms for all measurements.

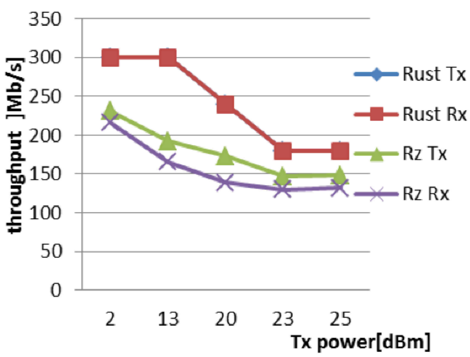

Fig. 4. Graph of the throughput Rz and Rust (UDP protocol) dependence on the transmit signal power, for the Rx and Tx mode (free space environment)

CONCLUSIONS

The aim of the first part of the study was to evaluate the influence of the power radiated by the antennas on the transmission performance parameters. In the tests, we assumed 5 values of the transmit power. Increase of the transmit signal power of 10 dBm over the 2 dBm value, introduced transfer disruptions due to the receivers overload and/or to the interference of signals coming from the mutual coupling. This was manifested by the decrease of the throughput (automatically set to lower values through modifications of the MCS parameter), and also by the increase of the delay. Next tests regarded the influence of selecting certain polarization of the antennas, and also the interval between them, on the signal transmission. It has been shown that the devices with the antennas installed at the 80 cm interval usually allow to reach higher values of the throughput for the UDP and TCP protocol and lower values of the RTT delay in relation to the 20 cm arrangement. The 'Bandwidth Test' software enabled testing full bandwidth of the wireless network card for the UDP protocol. In the indoor environment, the maximum value of 203 Mb/s (Tx or Rx) was reached. The maximum throughput for the two-way transmission was Tx = 112 Mb/s, Rx = 98 Mb/s, respectively, with CCQ = 87%/100%. The TCP trafic in two-way transmission oscillated on the level of Tx = 46 Mb/s and Rx = 46 Mb/s. These results enables replacement of the wire links of the Ethernet standard with the radio WLAN bridge while ensuring installation of the radio station antennas adjusted to certain character of the indoor propagation environment.

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OCENA MOŻLIWOŚCI WYKORZYSTANIA ŁĄCZY RADIOWYCH PUNKT-PUNKT W UKŁADZIE MIMO DO REALIZACJI SZKIELETU SIECI LOKALNEJ

STRESZCZENIE

W artykule przedstawiono wyniki prac badawczych prowadzonych w celu oceny możliwości zastąpienia okablowania w układach połączeń szkieletu sieci lokalnej dla realizacji połączeń rezerwowych lub dla lokalizacji z uwarunkowaniami architektonicznymi, które nie zezwalają na prace instalacyjne w zakresie okablowania strukturalnego budynku. Opracowano badawcze środowisko laboratoryjne z wykorzystaniem sprzętu radiowego działającego w standardzie IEEE 802.11n. Przedstawiono ponadto wyniki badań transmisji w układach łączy punkt-punkt z zastosowaniem techniki MIMO przeprowadzonych w celu określenia parametrów wydajności transmisji danych w postaci przepustowości oraz opóźnienia transmisji. Badania transmisji w układzie MIMO zostały wykonane w środowisku wewnątrzbudynkowym i w wolnej przestrzeni.

Słowa kluczowe:

MIMO, wydajność transmisji danych, łącze punkt-punkt, IEEE 802.11n, środowisko wewnątrzbudynkowe, WLAN, szkielet sieci.