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FOUR CHANNEL ASSIGNMENT SCHEMES FOR WIFI IN 2.4 GHZ BAND

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Abstract

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Nowadays, WiFi is mostly operating in 2.4 GHz band, which allows only 3 non-overlapping channels. For deployment in building it could be a problem to repeat only three channels. In this paper we compare standard three channel scheme (channels 1, 6 and 11) with four channel schemes. The most promising scheme is with channels 1, 5, 9 and 13, which involves overlapping channels, but the overlap is minimal and in certain distances (power levels) is possible to use this scheme. The problem could be in some countries which do not allow usage of 13 channels. We also compare other schemes, with overlapping channels, but they have a much lower throughput than scheme with channels 1, 5, 9 and 13.

Keywords: WiFi, four channels, channel scheme, channel assignment, throughput

INTRODUCTION

Recently, the wireless connection became very popular way of connection to Internet. The main reason is user's convenience while the reliability and speed is sufficient. WiFi technologies based on IEEE 802.11 standard family are the most used nowadays for this purpose. WiGLE.net (2015) provides statistic that the most used (94%) frequency spectrum for WiFi is around 2.4 GHz and therefore nowadays is considered as highly utilized and overcrowded. Another cause for this is that 2.4 GHz band is also used by cordless phones, small home appliances (baby monitors, remote controllers), IEEE 802.15 devices and others. The second reason is that for WiFi it offers only 3 non-overlapping channels. In the paper we discuss the possibility to use more channels and we show the problems which arises with using partially overlapped channels.

In the first part of paper is the theory about usable frequency spectrum used for WiFi and information about usable overlapping and non-overlapping channels in 2.4 GHz band. Follows the related work, where we discuss previous works in this field. The next section describes measurement methodology to allow others repeat our measurement. The most important part contains our measurement results together with discussion about their implications for practice. In the end of paper is stated a conclusion and our future work in this field.

WiFi Theory

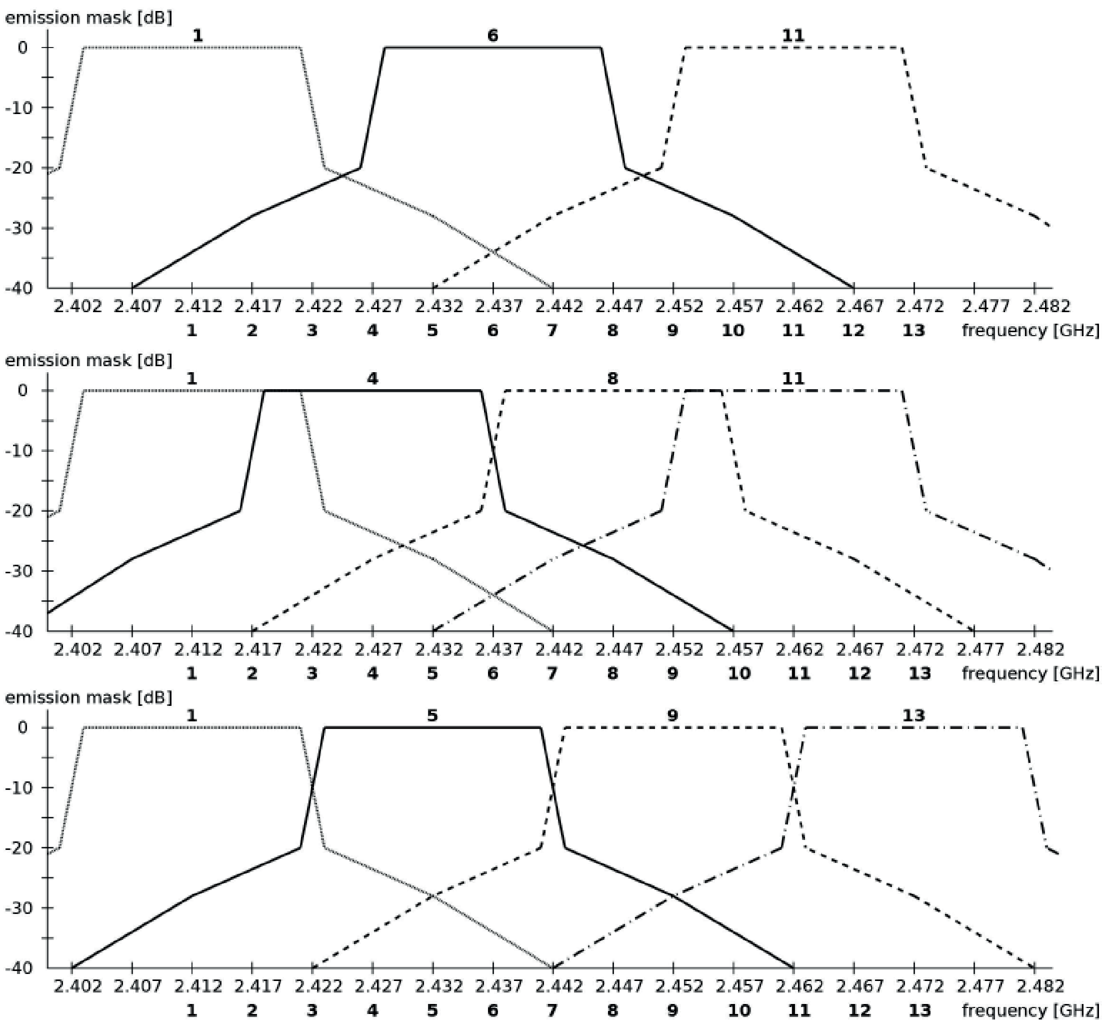
Most of today's WiFi network devices operate in the 2.4 and 5 GHz unlicensed bands. These bands are under the control of the European Telecommunications Standards Institute (ETSI) in the European regulatory domain. ETSI (2012b) stipulates frequency range of 2.4–2.4835 GHz with the maximum RF output power of 20 dBm for other types of wide band modulations such as DSSS or OFDM. This frequency range is divided into 13 partially overlapping channels with a normal channel width of 20 MHz or extended 40 MHz channel width. In the 5 GHz band, the frequencies 5150–5350 MHz and 5470–5725 MHz are permitted by ETSI (2012a), the maximum RF output power depends on the frequency band and ranges from 20 to 30 dBm. The norm also stipulates that the Transmit Power Control (TPC, power mitigation) and the Dynamic Frequency Selection (DFS, radar detection) are required for the devices operating above the frequency 5250 MHz. Czech regulation by ČTÚ (2010) follows the European norms, specifies the maximum power output in mW instead of dBm, and the frequency range 5150–

5350 MHz is permitted for indoor use only. The main WiFi operational characteristics are specified by the well-known IEEE 802.11 standards, details related to MAC and physical layer can be found in IEEE (2012).

While in 5 GHz band can be used up to 19 non-overlapping channels, the 2.4 GHz band offers us only 3 non-overlapping channels. Because the most used devices support only 2.4 GHz band, the wireless deployments are using only 3 channels. This could be problem, when is necessary to repeatedly use all channels, for example to provide sufficient signal in large (multistory) building. Then it leads to graph coloring problem, where three colors are not enough in a lot of cases. Our paper tries to find out if it is possible to use any four channel combination, which would provide similar or better throughput as classic three channel assignment (channels 1, 6 and 11). On the other hand the advantage of this scheme is that uses channels allowed in most countries in world. The usage of 4 channels in same band width as in classic channel assignment leads to use channels 1, 4, 8 and 11 and as can be seen in Fig. 1 the channels partially overlap. Our idea is to use the whole spectrum which is allowed in Europe (channels 1–13) and employ channels 1, 5, 9 and 13. We consider this channel scheme as promising, because the channels overlap minimally as can be seen in Fig. 1.

Related Work

Since the first IEEE 802.11 standard some works dealing with channel deployment in 2.4 GHz band were published. The study (Cisco, 2004) compares two ways of four channel deployment. The first scheme uses partially overlapped channels 1, 4, 8 and 11, second uses non-overlapping channels with using one twice (e.g. 1, 1, 6 and 11). The performance was compared on average throughput per channel with resulting the second scheme had almost two times higher throughput. The reason is that during transmission on the same channel, the CMSA/CA technique detects other traffic on the channel and can delay current transmission to avoid collisions and lower the interference. The recommendation from Cisco (2004) is to use only non-overlapping channels. On the other hand Fuxjager (2007) describes that even previously



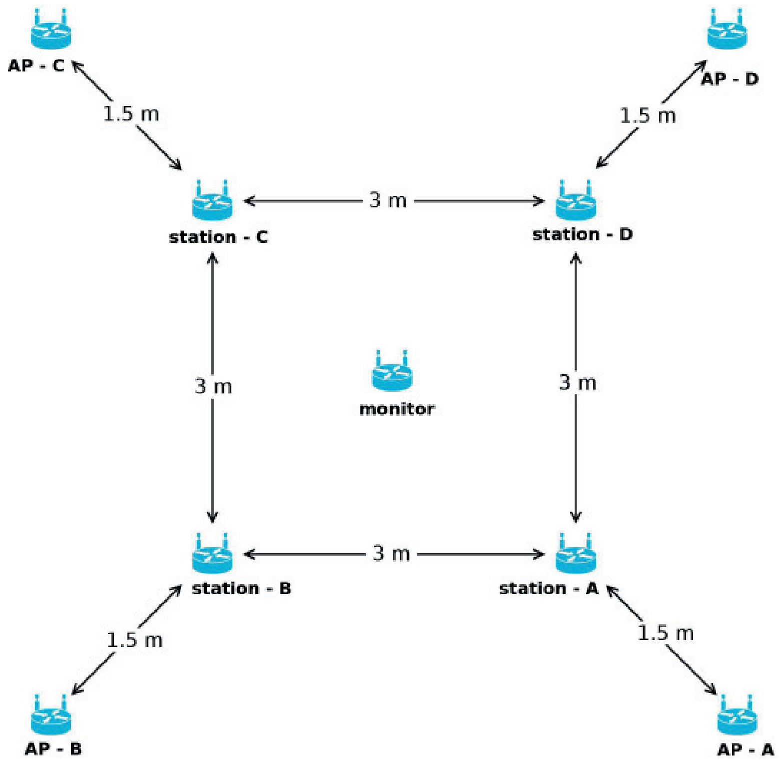
1: *Transmit spectrum masks for various channel combinations* mentioned non-overlapping channels influences themselves. But this is true only when the nodes are in proximity and there is sufficient signal strength. In contrast Mishra (2005) showed that even partially overlapped channels can coexist and reliably work. The performance of partially overlapping channels depends on the signal strength (distance between devices). With rising channel distance the noise which affects the original signal lowers. For example the interference on fifth channel from other device is maximally 39% power level of interfering divice (Mishra, 2005). Chieochan (2010) solves a problem of assigning channels to APs (Access Points), but uses only 3 non-overlapping channels. Although we searched in all main databases we did not found any paper about using channels 1, 5, 9 and 13. In the Internet we found an article, where Coleman (2012) discusses possibility to use these channels in Europe, but without belief in it.

MATERIALS AND METHODS

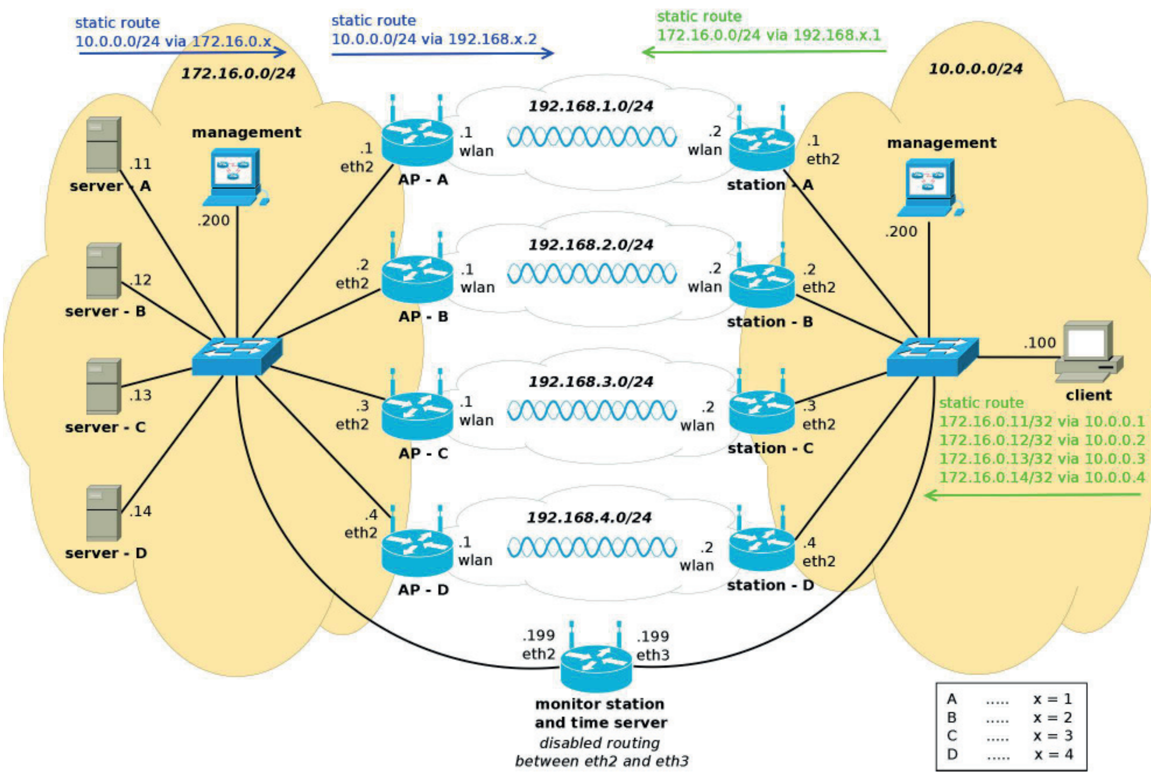
The wireless device placement was inspired by Mishra (2005) – pair of measurement nodes close together with a certain distance from other measurement pair. For our purposes we used four pairs of wireless devices (AP and station) which were 1.5 meters apart. The wireless clients were placed in the corners of imaginary square with side length about 3 meters, APs were 1.5 meter further from the corner. In the middle of square were placed a wireless device which monitored wireless activity. In Fig. 2 can be seen the physical placement of nodes. The experiment took place in our laboratory in the basement room, where the wireless signal from other APs is very low.

Logically we divided measurement network into two parts both connected by wires. The server part contained four HTTP servers (one for each test pair), ethernet interfaces of wireless APs, NTP server interface, management station and it was all connected via switch (Cisco Catalyst 2960 in default configuration). In the client part were client PC, ethernet interfaces of wireless stations, interface of time server, management station and all together it was connected through switch (again Cisco Catalyst 2960 in default configuration). The connection between these two parts is done via four wireless links. Each server uses different link for own communication. E.g. to test wireless link A (between AP – A and station – A) is necessary to download file from server A. The management stations were used to control wireless APs or stations. Complete topology is depicted in Fig. 3.

Wireless links were established on MikroTik technology, for both APs and stations was used Mikrotik router 951-2n with RouterOS in version 6.15. On wireless card was set: 802.11n, SSID to match AP only with particular station, WPA2 security and the regulatory domain was set to Czech Republic (allows channels 1-13 and maximum transmit power is 20dBm EIRP). We used a time server to assure the same time on end devices (servers and client), because we needed synchronized times to evaluate transmission delay. The time server was running



2: *Physical wireless devices placement*



3: *Measurement test logical topology*

on MikroTik router (951-2n), which we also used to monitor wireless spectrum.

The methodology of throughput measurement was inspired by Cisco (2004), where 50 MB file was repeatedly downloaded using FTP. Instead of using FTP we used the file download via HTTP, but the file size remained same. Both client and servers were Linux CentOS stations virtualized on Oracle VirtualBox. On servers were uploaded testing 50 MB zip file and started http daemon. For each measurement was launched script which repeatedly downloaded file from selected server until defined time. Before each measurement we cleaned up stations' environment to avoid software buffering affects the measurement results. The schedule of measurement was to firstly test independently throughput of individual channels (one wireless pair on, other off) – the 50 MB file was downloaded as many time as it was possible in 45 seconds. After testing all individual pairs was started group measurement where all wireless pairs were active and client simultaneously downloaded files from all servers for 180 seconds (again as many time as it was possible). The throughput was calculated as average of all successfully downloaded files.

RESULTS AND DISCUSSION

The experiment took place in the laboratory room, where we could not place devices in distances as it would be in usual deployment. Therefore we made a few measurement with different output power, which would simulate a higher distances between nodes. By Rappaport (2001) the attenuation of wireless signal due to propagation in free space can be calculated by

$$FSPL = 20\log_{10}\left(\frac{4\pi}{c}df\right).$$

The free space path loss (*FSPL*) is attenuation in dB over a distance (*d*) in meters. The attenuation is also dependent on the signal frequency (*f*) in Hz. The *c* is a speed of light in vacuum (299 792 458 m/s). If we set output power of all wireless devices to 7 dBm instead of maximum 17 dBm, it would be like increasing the distances between devices three times (with rounding attenuance to 10 dB instead of 9.54 dB). Setting output power to 3 dBm would act as increasing distances ten times. To prove that lower signal is still sufficient to affect other devices we made measurement with switched places of stations – the position of station A was switched with station C and position of station B was switched with station D (according to Fig. 2). This increased physical distance between AP and station to 5.7 m, with –3 dBm output power to 57 m.

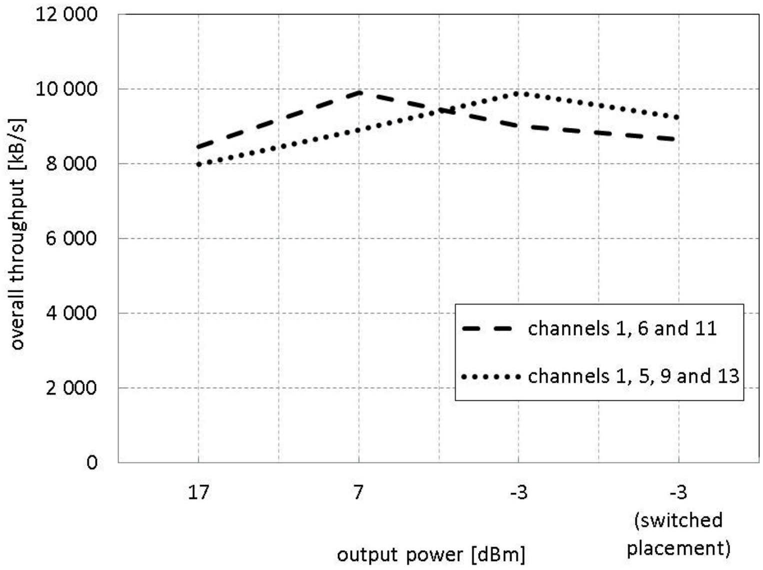
Firstly we compared the influence of output power on throughput of individual channels and overall throughput of all channels. For each output power level (17 dBm, 7 dBm, –3 dBm and –3 dBm with switched places) we tested two channel schemes – classical 1, 6 and 11 and four channels usable in Europe 1, 5, 9 and 13. For each combination of output power and channel scheme we performed four individual measurements, which differed in channel assignment to wireless pairs (e.g. Measurement 1: A – channel 1, B – channel 6, C – channel 11, D – off. Measurement 2: A – channel 6, B – channel 11, C – off, D – channel 1). In Tab. I are average and median results per each combination of output power and channel scheme.

The throughput per one channel for channels 1, 6 and 11 is around 3 MB/s and the best performance is not with highest power but with output power 7 dBm. The four channels scheme has a lower throughput per channel and with decreasing power the throughput rises, which would be caused by decreasing interference from neighbor channels. In middle columns are relative speeds of channel in reference with measurement without other channels. Here can be seen that even non-overlapping channels influence themselves, because the throughput with neighbor channels is higher than without in all cases. For non-overlapping channels 1, 6 and 11 is relative speed around 94%, for 1, 5, 9 and 13 it rises with lower output power. The average values from the last columns are in Fig. 4 to compare performance of channels schemes in contrast with output power. We could say, that overall throughput (all three or four channels) together is in all cases between 8 and 10 MB/s and for output power 17 dBm and 7 dBm combination of channels 1, 6 and 11 has about 0.5–1 MB higher throughput, for lower transmit output it is vice versa. The reason why partially overlapping channels are better with lower power would be that in channel distance 5, the interference is maximally 39% and with lower power output would not the channels interfere themselves.

The results in Tab. I show that in all power output setting the classical channel assignment scheme (1, 6 and 11) has similar throughput. Because in usual deployment APs are not placed next to each other but they are place separately (15 to 50 meters apart) to cover area with signal evenly. Therefore we set the output power to –3 dBm to simulate 30 m distance between interfering wireless devices. With these setting we measured four channels schemes tested in Cisco (2004). The first one was four channel scheme for US – channels 1, 4, 8 and 11 and the second

I: *Throughput measurement results for different power output and channel schemes*

Output power	Used channels	One channel throughput [kB/s]		Relative one channel throughput [-]		Overall throughput [kB/s]	
		Average	Median	Average	Median	Average	Median
17 dBm	1, 6 and 11	3058	2999	0.926	0.921	8464	9066
	1, 5, 9 and 13	1998	2115	0.592	0.624	7991	8099
7 dBm	1, 6 and 11	3302	3337	0.912	0.918	9905	9843
	1, 5, 9 and 13	2202	2232	0.616	0.649	8897	8885
–3 dBm	1, 6 and 11	3006	3073	0.938	0.943	9018	8984
	1, 5, 9 and 13	2475	2689	0.802	0.848	9899	9893
–3 dBm (switched placement)	1, 6 and 11	2880	2945	0.963	0.954	8641	8751
	1, 5, 9 and 13	2313	2414	0.802	0.896	9251	9080



4: *Overall throughput comparison for two channels combination in reference with transmit power*

II: *Throughput measurement results for various channels schemes (the output power was –3 dBm)*

Used channels	One channel throughput [kB/s]		Relative one channel throughput [-]		Overall throughput [kB/s]	
	Average	Median	Average	Median	Average	Median
1, 6 and 11 (3 wireless pairs)	3006	3073	0.938	0.943	9018	8984
1, 4, 8 and 11	1571	1632	0.442	0.433	6282	6307
1, 6 and 11 (one channel used twice)	2333	2485	0.746	0.909	9333	9357
1, 5, 9 and 13	2475	2689	0.802	0.848	9899	9893

III: *One-way delay statistic for channel schemes 1-6-11 and 1-5-9-13 with output power –3 dBm*

	1, 6 and 11 (3 wireless pairs)	1, 5, 9 and 13
Median delay [ms]	14.8	14.4
Average delay [ms]	15.7	15.1
Maximal delay [ms]	146.1	156.9

was classic scheme (channels 1, 6 and 11), but with using one channel twice. In Tab. II are all measured throughputs to compare performance of all channel schemes. The overlapping scheme (channels 1, 4, 8 and 11) has very poor throughput, which is caused by interference of neighbor channels. The channels 1, 4, 8 and 11 have distance between channels 3, which brings interference 66% of neighbor signal (Mishra, 2005). Interesting is comparison of two deployment of classical scheme (channels 1, 6 and 11), when in one case is the fourth wireless pair turned off and in second is set on used channel. The throughput of twice used channel is divided between both wireless pair (not equally), but despite this the overall throughput of four wireless pairs is higher. The best performance in this case has four channel scheme for Europe (1, 5, 9 and 13).

To find out if interference of partially overlapping channels influence transmission delay (for example due to retransmissions) we examined departure and arrival times of all packets. Tab. III contain statistic of delays for channels 1, 6 and 11 and channels 1, 5, 9 and 13 (output power was –3 dBm). The differences between delays are small and for TCP it is neglectable.

CONCLUSION

The aim of this paper was to show possibilities in usage four channel scheme for WiFi deployments in 2.4 GHz spectrum. Currently the most common channel deployment is using three non-overlapping channels 1, 6 and 11. The channel allocation planning is hard task when it is possible to use only three channels. We discussed usage of various channel combinations to gain more usable channels. The four channel scheme deploying channels 1, 5, 9 and 13 was promising because the overlap between channels is minimal (only on lower power level).

In laboratory we performed simultaneous file download through four wireless links, while each link tested one channel. The wireless devices were in proximity (3 m) to influence each other and to simulate higher distances we used different output power levels. The aim of measurement was to inspect throughput of various channel combinations. Nowadays the most used combination 1-6-11 (non-overlapping channels) had in all measurement almost same throughput – around 3 MB/s giving together around 9 MB/s. The four channel combination (1, 4, 8 and 11) mentioned in Cisco (2004) had the worst of all results (only about 1.5 MB/s per wireless link). Surprisingly the classic combination (1, 6 and 11) utilizing the same channel twice had slightly better results than the same combination with using only three wireless links. This is because CSMA/CA technique can detect traffic on the same channel and delay current transmission to avoid collisions and interference. In this case the wireless links using same channel divided maximal throughput on channel between themselves, other wireless links were not affected. The last, but promising four channel combination usable in Europe (1, 5, 9 and 13) showed with higher distances between wireless device (lower output power) the best results – 2.5 MB/s per channel, together around 10 MB/s. On the other hand when the wireless devices were in proximity (high output power) the throughput of individual channels was lower (around 2 MB/s) due to interference from partially overlapping channels. Nevertheless we expect that four channels 1, 5, 9 and 13 could be employed in some environments. Also we think, that four independent channels helps with wireless channel planning, because the four color map theorem could be used to solve problem of channel selection. In the environments, where channel 13 is not available due to law, we recommend to stick with 3 channels or use channels on 5 GHz band.

In future we plan to implement four channels scheme to university wireless network to test performance in production network. Also we want to test if partially overlapping channels affect Quality of Service. The interference could raise the packet loss, which affect voice telephony or streaming media.

REFERENCES

CISCO. 2004. *Channel Deployment Issues for 2.4-GHz 802.11 WLANs.* [Online]. Available at: http://www.cisco.com/c/en/us/td/docs/wireless/technology/channel/deployment/guide/Channel.html. [Accessed: 2014, August 28].

COLEMAN, D. 2012. *Wi-Fi Back to Basics – 2.4 GHz Channel Planning.* [Online]. Available at: http://blogs.aerohive.com/blog/the-wireless-lan-training-blog/wifi-back-to-basics-24-ghz-channel-planning. [Accessed: 2014, August 28].

CHIEOCHAN, S., HOSSAIN, E. and DIAMOND, J. 2010. Channel assignment schemes for infrastructure-based 802.11 WLANs: A survey. *Communications Surveys & Tutorials, IEEE,* 12(1): 124–136.

ČESKÝ TELEKOMUNIKAČNÍ ÚŘAD. 2010. *Všeobecné oprávnění č. VO-R/12/09.2010-12 k využívání rádiových kmitočtů a k provozování zařízení pro širokopásmový přenos dat v pásmech 2,4 GHz až 66 GHz.* [online]. Available at: http://www.ctu.cz/cs/download/oop/rok_2010/vo-r_12-09_2010-12.pdf. [Accessed: 2014, August 15].

EUROPEAN TELECOMMUNICATIONS STANDARDS INSTITUTE. 2012a. *Broadband Radio Access Networks (BRAN); 5 GHz high performance RLAN; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive.* ETSI EN 301 893 V1.7.1 (2012-06). [Online]. Available at: http://www.etsi.org/deliver/etsi_en/301800_301899/301893/01.07.01_60/en_301893v010701p.pdf. [Accessed: 2014, August 15].

EUROPEAN TELECOMMUNICATIONS STANDARDS INSTITUTE. 2012b. *Electromagnetic compatibility and Radio spectrum Matters (ERM); Wideband transmission systems; Data transmission equipment operating in the 2.4 GHz ISM band and using wide band modulation techniques; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive.* ETSI EN 300 328 V1.8.1 (2012-06). [Online]. Available at: http://www.etsi.org/deliver/etsi_en/300300_300399/300328/01.08.01_60/en_300328v010801p.pdf. [Accessed: 2014, August 15].

FUXJAGER, P., VALERIO, D. and RICCIATO, F. 2007. The Myth of Non-Overlapping Channels: Interference Measurements in IEEE 802.11. In: *Fourth Annual Conference on Wireless on Demand Network Systems and Services, 2007. WONS '07.* 1–8.

INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC. 2012. *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. IEEE 802.11.* [Online]. Available at: http://standards.ieee.org/about/get/802/802.11.html. [Accessed: 2014, August 18].

MISHRA, A. et al. 2005. Exploiting Partially Overlapping Channels in Wireless Networks: Turning a Peril into an Advantage. In: *Proceedings of the 5th ACM SIGCOMM conference on Internet Measurement (IMC '05).* Berkeley, 19–21 October. Berkeley: USENIX Association, 29–29.

RAPPAPORT, T. 2001. *Wireless Communications: Principles and Practice*. 2nd ed. Upper Saddle River: Prentice Hall.

WIGLE.NET. 2015. *WiGLE stats: Octet Prefix, Channel, and File Stats*. [Online]. Available at: https://wigle.net/stats#octetstats. [Accessed: 2015, October 15].

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