Perez -Francisco, M.; Boronat-Perez, P.; Manzoni, P.; Tavares De Araujo Cesariny Calafate, CM.; Cano Escribá, JC. (2014). Rumours and Good Practices in Community Networks Wireless Links. IEEE COMMUNICATIONS SOCIETY. doi:10.1109/ICUFN.2014.6876822.

Rumours and good practices in (community networks) wireless links

Miguel Pérez-Francisco[1], Pablo Boronat[2], Pietro Manzoni[3],
Carlos T. Calafate[3], and Juan-Carlos Cano[3]

[1] DICC, Universitat Jaume I, Spain
`mperez@uji.es`,
[2] DLSI, Universitat Jaume I, Spain
`boronat@uji.es`,
[3] DISCA, Universitat Politècnica de Valencia, Spain
{`pmanzoni,calafate,jucano`}`@disca.upv.es`

Abstract. In wireless community networks, backbone point-to-point links concentrate most of the traffic. Thus, these links are crucial for the overall performance of the network. Network managers have to constantly test and maintain these links to optimise their performance, but their decisions are often based upon rumours or a purely theoretical knowledge of the technologies being used. These sources of information can be very biased and can lead to incorrect decisions in such complex systems.

In this work we provide the guidelines to help in wireless links optimization by covering the most common mistakes or questions, and by addressing the critical factors one by one using a real scenario. In our experiments we analyse critical characteristics such as the interference among links, the relation between channel bandwidth and throughput, the impact of output power, and the effect of antenna proximity.

We are well aware that the efficiency of wireless networks is very variable and dynamic, therefore this work provides useful hints on how to better deploy an efficient wireless community network.

Keywords: Community networks, point-to-point wireless links, WiFi radio interference, wireless links capacity, 802.11n

1 Introduction

In community networks, and more generally in wireless networks, the channel capacity is strongly related to the quality of links. There are different environmental factors, as well as configuration options, which determine the effective bandwidth. These factors become critical in urban scenarios in which the frequency spectrum is heavily saturated. Consequently, network designers and managers are continuously trying to improve the quality and stability of the links. To this end, they take into account their previous experience, but also rumours coming from both colleagues or the Internet. Unfortunately, there are many factors to be considered that often limited observations lead to wrong conclusions.

As active supports of the guifi.net[1] community network, in this work we try to shed some light and formalise the issues which are commonly discussed not only by network participants, but also by skilled professionals. In addition, our experiments also attempt to provide configuration guidelines which can help to improve the performance of community networks.

Many works (e.g., [1–9]) study different characteristics of WiFi in practice, but still more practical tests and a larger set of experiments are needed. For example, most of the works are focused only on the 2.4 MHz band or only study a reduced set of aspects of the 5GHz band.

Probably the most referenced work was presented by Shrivastava et al. [10], where the authors study the performance of the new capabilities introduced in the 802.11n standard, such as PHY-diversity, channel bonding (i.e. 40 MHz channels) and frame aggregation. This work shows how the use of 40 MHz channel or a 802.11g link can lead to a throughput degradation; the former can be mitigated using frame aggregation. Also they demonstrate experimentally that MIMO technique improves the throughput in the absence of line of sight or in presence of interference, the relation of distance and throughput and the effect of using coincident or adjacent channels. In [11] the authors make an exhaustive work focusing their experiments on the interference between different non-overlapping channels. They use 802.11b and 802.11g devices in the 2.4 GHz band in a indoor scenario. They show that even in non overlapping channels there is important loss due to the proximity of antennas. This work is specialized in one of the aspects we have checked and confirms results obtained in an outdoor realistic scenario.

Running wireless experiments is a task far from easy since, from one day to the other, and using the same platforms and scenarios, results will typically experience slight variations. We anyway consider that the results presented in this paper are useful to better understand the differences between experiments. We focus our attention in backbone point-to-point links supporting these community networks. We have designed the experiments necessary to cover issues like: whether it is interesting to use as much output power as possible, or if it is worth using 40MHz channels, or if WDS (Wireless Distribution System) based links are worse than common access point-client ones. Moreover we investigated how a link is affected by overlapped or adjacent busy channels, which is the relation between channel bandwidth and throughput, and finally whether it is a good idea to adjust antenna positions in order to reduce interference from other networks. It must be noticed that sometimes the issue is not only on how to improve our own network, but also on how to limit our impact on foreign networks, or how to use physical resources more efficiently in order to leave additional bandwidth for nearby wireless links.

The rest of this paper is organized as follows: Section 2 describes the overall scenario used for the experiments. Section 3 provides a description of the different experiments along with experimental results. Finally, in section 4 we summarise our conclusions and discuss those issues to be studied in the future.

---

[1] http://guifi.net

2 The scenario of the experiments

Figure 1 shows the structure of the scenario we used for the experiments. We used four 5GHz 802.11n MIMO (vertical and horizontal polarity) routers and Ubiquiti Nanostation M5 with Airos 5.5.2. This hardware is of widespread use in community networks and particularly in guifi.net. If not otherwise stated, we have used default configuration values. Some neighbor networks were detected with weak signals. A spectrum analysis showed that the radio-frequency environment was quite clean but we have to consider the possibility of interference and biased results. More specifically:

- The measured link had a signal intensity around -72 dBm (-76 dBm in Horizontal and -74 dBm in Vertical), with a Noise Floor of -90 dBm, a Transmit CCQ of 99%, a TX rate of 130 Mbps and a RX rate of 104 Mbps.
- For the noise link the signal intensity was slightly worse. It had -79 dBm (-81 dBm in Horizontal and -82 dBm in Vertical), with a Noise Floor of -91 dBm, a Transmit CCQ of 100%, a TX rate of 78 Mbps and a RX rate of 78 Mbps. In some experiments we have incremented a bit the output power in this link in order to have similar capacity to the measured one.

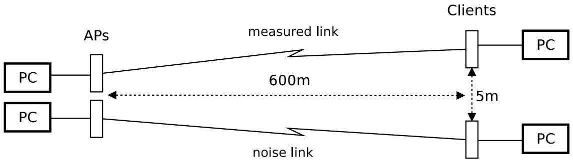

Fig. 1. Scenario of the experiments.

Performance tests have been done with the Iperf application version 2.05 (using TCP traffic and default configuration) running in GNU-Linux notebooks connected by Ethernet to each end of the wireless links. Each experiment had a duration of 10 seconds and was repeated to obtain a 95% of representativity; the experiments were repeated in both directions to take into account links' asymmetry. Iperf has also been used for the interfering links (the noise links) with its own Iperf server. That is, the notebooks and the traffic generated with Iperf was independent for each link. The output power configured in most of the tests in both links' endpoints was 2 dBm. When different emission powers have been applied it will be indicated in the text. We also verified that the notebooks were not becoming the bottleneck.

In most of the tests, the access points (APs) were on the same mast. This mast and those of the clients were 600 meters far. The clients were separated by 5 meters using different masts (see Figure 1). The effect of using just two masts, one for APs and one for clients, is also one of the aspects that we have tested.

In the experiments we checked the interference generally between two links; one link being the actual data link, which we called the *measured link*, and another link used to create perturbation to the measured link; we called it the *noise link*.

3 Experiments

The following subsections describe the different experiments we did, by specifying first the objectives of the specific experiment, detailing the results obtained and eventually stating the conclusions derived from the results obtained.

3.1 Distance of the radios in a single node

It is well known that if the radios in the same node are too close, they will generate considerable interference among them. However nodes in community networks usually have little room for the antennas. In this experiment determine how important is the interference due to the proximity of radios in a mast, and not only when using the same channel but in adjacent channels. Even if WiFi channels do not overlap in 5GHz band, some interference is produced because wireless emissions are not perfectly suited to the configured channel (see [3, 5]).

In these tests we made a comparison of three spatial distributions of masts and antennas, namely: 1) APs in the same mast and clients in the same mast, 2) APs in the same mast and clients separated horizontally 5 meters, and APs separated horizontally 2.5 meters and clients separated horizontally 5 meters. In all of them the distance between APs and clients was 600 meters. The measured link is in channel 5280 MHz and the noise link in 5260 MHz.

Figure 2 shows the downlink performance of these three configurations for the measured link as a function of the output power of the noise link. In the figure it can be seen that the line corresponding to clients in the same mast has a considerable lower throughput than the other two lines, in which clients are in different masts separated 5 meters.

Figure 3 has been obtained with a similar scenario but the two links used channels separated by a gap of 20 MHz. In this case, the links should have similar performances as if they were alone. However, again it can be seen that when clients are in the same mast, there is still an important inference between the two links.

The separation of the APs does not seem to be a main factor, but nevertheless when using adjacent channels it is also preferable to separate the APs as a degradation can be observed when increasing the output power (Figure 2).

We must say that our scenario is probably worse than a real one. The APs point to the same direction, which is not common in real scenarios. Besides, the antennas have a beam-width of 45° and antennas for point-to-point links usually are narrower.

A conclusion can be extracted from this experiment. Point-to-point links usually become the bottleneck of the network, as they concentrate most of the

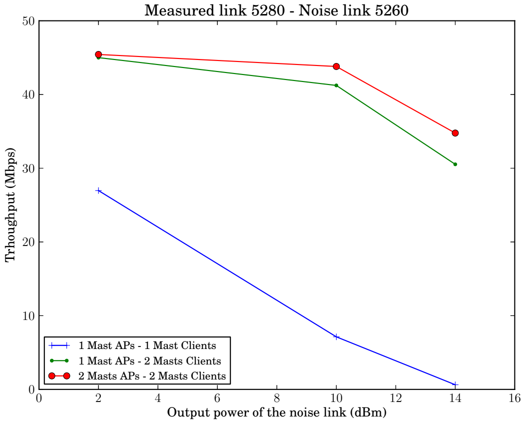

Fig. 2. Throughput of a link in presence of a noise link in an adjacent channel as function of the output power of the noise link. Three different spatial distributions of the antennas in masts are compared.

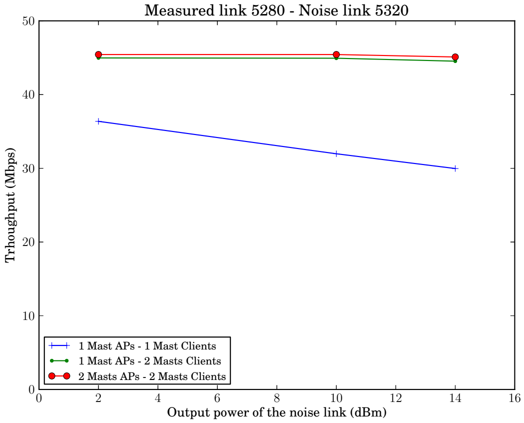

Fig. 3. Throughput of a link in presence of a noise link in a different (not adjacent) channel as function of the output power of the noise link. Three different spatial distributions of the antennas in masts are compared.

clients' traffic. A good solution is the replication of these links (i.e. channel bonding). However, this experiment shows that distance between antennas in the same node is a main factor, specially for links connecting the same locations.

3.2 Importance of the channel

Another interesting point is to know if there are significant differences among the channel we use; supposing the absence of noise (channels are free). In fact there are and especially in the 5 GHz band the particular regulations of each country may impose differences. For instance, some channels could be allowed to use more power than others and some could be forced to use Dynamic Frequency Selection (DFS) to prevent interference with other devices such as radars.

Antennas are usually adjusted for particular radio-frequency bands and they do not perform exactly the same in different channels of the target band. We have performed some experiments to check this aspect and significant differences have not been observed. The results can be seen in Figure 4. In this experiment the channels have a 20 MHz width. The only difference to be pointed out is that with the 5700 MHz channel we obtained less bandwidth when the Iperf server is in the client side (downlink).

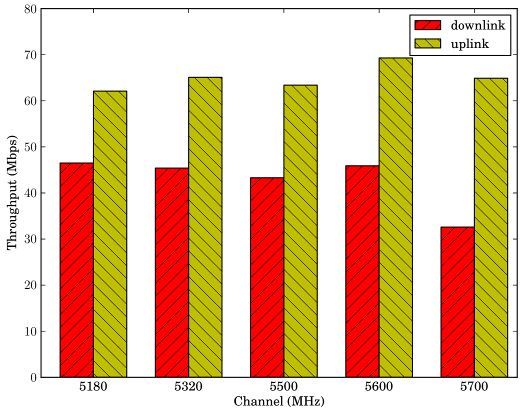

Fig. 4. Performance comparison a link in different 20 MHz channels.

From this test, we can conclude that these antennas can be used in any channel with similar performance. The last channel (5700 MHz) is the only one in which these antennas seem to start losing bandwidth, but even in this channel the performance is acceptable. That is, if channels are free, the selected channel does not seem an important factor.

3.3 Channel bandwidth and throughput

To determine the relation between bandwidth and throughput we evaluated a “free” channel (a channel not being used by any other nearby links), and compared different channel bandwidths. This experience can be of interest for urban scenarios in which all available radio-frequency bandwidth are in use. In these cases it could be a good choice to use smaller channels looking for more robust links with a more reduced data loss. Also it could allow a better sharing of this physical resource with other networks. In further experiments it can be seen that when channels overlap, the biggest one has not always the better throughput (Subsection 3.5), and in addition, it produces bigger interference on the other links. Figure 5 shows the throughput obtained in a link using free channels of different widths in MHz. The two lines corresponds to the direction of the test (uplink or downlink).

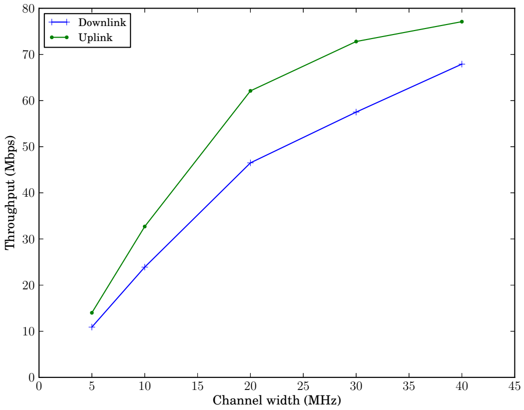

Fig. 5. Throughput of a link as a function of the channel bandwidth.

From this experiment it is interesting to remark that for channels below 20 MHz width, using twice frequency bandwidth also provides twice throughput. However, when comparing channels between 20 MHz and 40 MHz, this behaviour is not maintained; the throughput is lower than expected.

We can therefore conclude that, when channels are quite free it can be a good choice using bigger channels. The case when channels are occupied is evaluated in Subsection 3.5 where we analyse the behaviour of overlapping 20 MHz and 40 MHz links.

3.4 Interference between different 20 MHz links

In urban scenarios it is difficult to find free channels. In their absence, network administrators choose channels which are less used and with fewer signal power. However, it is interesting to have an idea about how efficient is a link using the same channel than another or even how much interference adjacent ones will induce. In fact we usually assume that in the 5 GHz band, channels do not overlap. But as emitters are not perfect, some interference is produced in neighbour channels ([3, 5]).

In this section we check how a 20 MHz link is affected by another one. The measured link is in channel 5280 MHz with 2 dBm of emission power in both edges of the link. For the noise link we have used channels 5260, 5280, 5300 and 5320 MHz. In each of these channels, the following emission powers were applied: 0, 2, 6, 10 and 14 dBm. We have measured the throughput in both ways. As we obtained similar profiles, for the sake of simplicity in the following graph the data corresponds to the uplink case (each link has its own Iperf server).

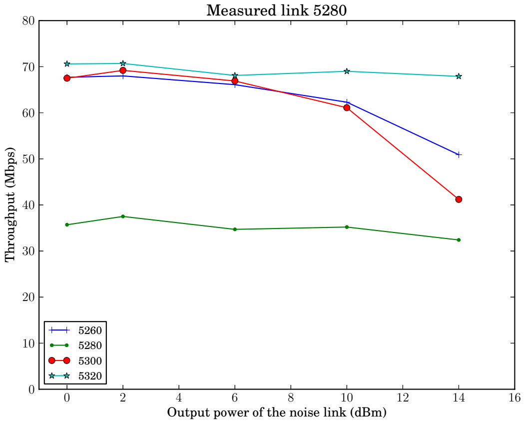

Fig. 6. Throughput of a 20 MHz link (in channel 5280 MHz) in presence of a noise link as function of the output power of the noise link. Different channels have been used for the noise link.

Figure 6 shows that when the output power of the noise link is increased, the throughput of the measured link decreases. This influence is more important when using the channels adjacent to the measured link (in our case, channels 5260 and 5300). If there is a 20 MHz gap between the two links, the influence is quite reduced. In fact, the line representing channel 5320 can be taken also to represent the throughput obtained by the measured link without noise.

The worse impact is obviously when both links use the same channel (line of channel 5280). However, this result is not so bad because the channel seems acceptably shared among the two links, independently of the output power of the noise link.

From this experiment we can conclude that we should choose the channel in which we detect the less signal power, but we have also to take care of the power of the adjacent channels. Even if we are lucky and we detect a free channel, we should always use as few power as possible, given that our link will produce some interference in neighbour channels.

Another way to present the results of this experiment is to see how throughput changes as a function of the output power in the measured link when the noise link uses constant output power. This is shown in Figure 7. In this figure, there is a line by channel as a function of the output power. Lines correspond to 5260, 5280, 5300 and 5320 channels, all of 20 MHz width. A fixed noise link in channel 5280 with output power 2 dBm is applied in the experiment.

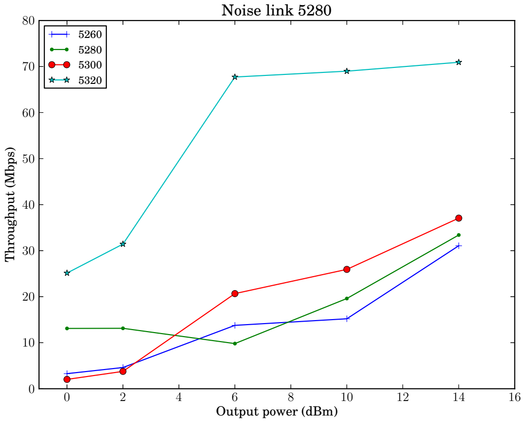

Fig. 7. Throughput of a 20 MHz link in presence of a noise link (in channel 5280 MHz) as function of the output power of the measured link. Different channels have been used for the measured link.

It is interesting to remark the poor data rate obtained when there is low output power when using adjacent channels to the noise link. It can even be worse to use an adjacent channel if there is not enough signal power than using the same channel of the other link. In the figure it can be seen that with less than 4 dBm of output power, the throughput of the links in adjacent channels is lower than using the same channel in both links.

As seen before (see Figure 6), with a 20 MHz gap between the two links, interference is not significant as indicated by the line of channel 5320. Again, this line is similar to that of the throughput of a link without noise. In this case, the line of channel 5320 shows another interesting aspect. It can be seen that using more output power than 6 dBm has no interest in this case. However, if more power is applied, we would affect other links unnecessarily.

The behaviour of the line of channel 5260 should be similar to that of the channel 5300, but it was less than expected due to external noise to our experiment.

It must be said that the effect of the noise link can be more important than a real case, as this link is busy all the time of the tests. A link which is idle most of the time has negligible performance effect on other links.

3.5 Is it worth using 40 MHz channels?

With the standard 802.11n, among other improvements, an increment of data transfers can be obtained by using more than one antenna for the same link (usually using the same channel with two polarities) and also 40 MHz width channels. However, these big channels obviously reduce the number of available channels to a half. It is interesting to know how much throughput increase would be obtained by using a 40 MHz channel compared to using a 20 MHz channel with low or no noise. Moreover, it is important to know the impact of using big channels when the frequency spectrum is crowded. In other words, it is important to determine how much will be the benefits and how will be the interference due to these big channels.

We run a set of experiments for 40 MHz channels coexisting with 20 MHz ones. In this experiment we used 4 dBm of output power in the noise link in order to have similar quality than the measured link. The results of these experiments can be seen in Table 1. Units in the table are in Mbps.

		Measured link 20 MHz		**Measured link 40 MHz**	
		uplink	downlink	uplink	downlink
A	No noise	46,5	62,1	67,9	77,1
B	Noise channel 20 MHz (low)	16,8	30,1	2,8	42,9
C	Noise channel 20 MHz (high)	44,0	58,3	19,8	40,4
D	Noise channel 40 MHz	12,3	16,7	33,8	51,1
E	Two 20MHz noise channels	-	-	3,0	21,9

Table 1. Comparison of the throughput (in Mbps) of a 20 MHz and a 40 MHz links for different conditions of noise links.

Table 1 summarizes the results of the experiments. Looking first at row A, it can be seen that even using competing channels without signals, 40 MHz channels does not provide twice the throughput obtained with 20 MHz channels (row A). However, it is true that it is cheaper than the installation of two 20 MHz separate links.

In rows B and C the noise channel has a 20 MHz width. In case B the noise channel overlaps the 20 MHz measured channel and the low half of the 40 MHz measured channel. In both cases an important asymmetric loss is produced. For the 20 MHz channel, the loss is more than a half, but what it is surprising is the impact on the 40 MHz channel for the uplink. In this case it seems better to use a 20 MHz channel. Probably this important impact is due to the MAC protocol mechanism to coexist with 20 MHz channels. To use a 40 MHz channel the CTS mechanism is applied to both halves of the channel. It seems that losing a bit of time for this procedure, gives some advantage to the 20 MHz noise channel. This phenomenon is magnified when the sources of traffic are close and the 20 MHz channel is the first half. In row C the 20 MHz noise link is in the upper half of the 40 MHz measured link. In this row we can see that the loss in the 40 MHz link is important but it is not so important on the uplink as when the overlapping link is in the first half of the channel.

Row D shows the case in which the noise link is in a 40 MHz channel. As expected, it has bigger impact on the 20 MHz link as both the measured channel and the adjacent channels are busy. However, for the 40 MHz link, the impact is less than when it overlaps with 20 MHz links. This is probably due to the mechanism CSMA/CA which in this case has less spurious carrier sensing and less frames are corrupted ([2,3]).

Finally, in row E we can see how a 40 MHz link is affected by two 20 MHz links. Obviously, the impact is more important than all other cases.

As a conclusion from these experiments, it seems interesting to 40 MHz channels when the radio-frequency spectrum is clean, or if all links were of this width, evven if this information is hard to get. Anyway, in typical scenarios, it does not seem a good idea, given that the throughput obtained will be far from the expected and moreover it will have a bigger impact on close by 20 MHz links.

3.6 AP-WDS links and AP-client links

In some community networks the standard wireless backbone links have both sides configured as AP-WDS. As both sides of the links are symmetric, new links can be added and also when scanning for new possible links more data can be obtained. For instance new possible links, anomalies or busy channels can be more easily detected.

Nevertheless, this configuration is frequently questioned under the belief that its performance is lower than a typical AP-client link. Table 2 shows the results of a comparison between three configurations: 1) a link with an AP and a client, 2) a link with both edges being AP-WDS and 3) one with an AP and a client with protocol WDS. In this table it is shown the throughput of 20 MHz link alone and with a 20MHz noise link in the same channel.

As can be seen from the table we can conclude that similar results are obtained in the three different configurations, both when the channel is free or when overlapping with a noise link. The only drawback of using the symmetric

	AP-Client		**AP-AP (WDS)**		**AP-Client (WDS)**	
	uplink	downlink	uplink	downlink	uplink	downlink
Single link	46,5	62,1	45,5	62,4	45	62,1
With noise	16,8	30,1	17,1	29,6	16,9	30,8

Table 2. Comparing the throughput in Mbps of a symmetric link (both edges in AP-WDS mode) and an asymmetric link (one edge in AP and the other in Client mode). The later, with and without WDS protocol.

configuration (both edges are AP-WDS) is that they have to be in the same channel. If one radio changes the channel (manually when tuning the link or automatically due to systems such as DFS) the link is lost. This makes changes more difficult to apply.

3.7 Effect of tuning the polarity of the radios

As a last experiment we wanted to evaluate the use of polarity modification to improve links performance. Due to the important competition for radio-frequency channels, network managers are starting to apply different improvised tunings. One practice we have observed is rotating the antennas 45° looking to avoid interference by using different signal polarisation. Typically antennas use vertical, horizontal or both polarities. We have made some experiments to check the effectiveness of this operations.

In Figure 8 we show the throughput resulting from two overlapping 20 MHz links as a function of the output power of the noise link. The antennas of the measured link have been turned 45° in the emission axis. This figure can be compared with Figure 6.

As it can be seen in the figure, if the measured and noise links are in the same channel, the behaviour is the same as that of the antennas in the normal position. In the case of using adjacent channels, if the output power is high in the noise channel, the loss of bandwidth in the measured channel is lower than the case of Figure 6. Then, perhaps this tuning can have some reduced benefits, but the installation of the antennas is more complex and in some cases it could affect the sealing of the device.

4 Conclusions and future work

In this work we analysed critical characteristics such as the interference among links, the relation between channel bandwidth and throughput, the impact of output power, and the effect of antenna proximity to provide the guidelines to help in wireless links optimization by covering the most common mistakes or questions, and by addressing the critical factors one by one. Using a realistic scenario we tested several configuration options.

From these experiments, we provided the following configuration guidelines:

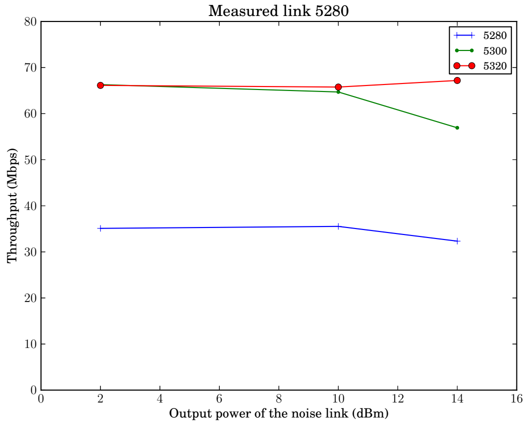

Fig. 8. Throughput of a 20MHz link (in channel 5280 MHz) with antennas turned 45° in presence of noise link (antennas in normal position) as a function of the output power in the noise link. Different channels have been used in the noise link.

- The distance between radios must be taken into account, specially if channel bonding is used (by channel bonding we refer to the accumulation of more than one link to connect two locations, and must not be confused with the use of 40 MHz channels in 802.11n).
- In the 5 GHz band, in similar conditions, we do not observe significant differences in the used channel. The antennas used in the tests seem to behave similarly in the entire band.
- Using channels wider than 20 MHz do not provide the expected bandwidth increase.
- When choosing a free channel it is highly important to also consider the signal strength of adjacent channels.
- An increment of the output power does not always provide significant improvements in the throughput and moreover it has negative impact on adjacent channels.
- The use of 40 MHz channels in 802.11n does not provide interesting results unless few channels are occupied.
- There is no performance difference between symmetric AP-WDS or AP-client in the case of point-to-point links.
- Varying antennas polarity shows a reduced benefit of throughput.

As future work we will evaluate the various configuration options for clients' connection radios (point-multipoint). Also the combination of these radios with point-to-point links will be analysed, being the latter scenario the usual composition of multi-radio nodes in community networks.

5 Acknowledgments

This work has been supported by project P1·1A2010-13 from the Universitat Jaume I, the project TIN2011-27543-C03-01 from "Ministerio de Ciencia e Innovación de España" and also by the ERDF of the European Union.

References

1. Selvam, T., Srikanth, S.: Performance study of IEEE 802.11n WLANs. In: Communication Systems and Networks and Workshops, 2009. COMSNETS 2009. First International. (Jan 2009) 1–6
2. Nachtigall, J., Zubow, A., Redlich, J.P.: The impact of adjacent channel interference in multi-radio systems using IEEE 802.11. In: Wireless Communications and Mobile Computing Conference, 2008. IWCMC '08. International. (Aug 2008) 874–881
3. Zubow, A., Sombrutzki, R.: Adjacent channel interference in ieee 802.11n. In: Wireless Communications and Networking Conference (WCNC), 2012 IEEE. (April 2012) 1163–1168
4. Raman, V., Vaidya, N.H.: Adjacent channel interference reduction in multichannel wireless networks using intelligent channel allocation. Technical report, University of Illinois at Urbana-Champaign (2009)
5. Angelakis, V., Papadakis, S., Siris, V., Traganitis, A.: Adjacent channel interference in 802.11a is harmful: Testbed validation of a simple quantification model. Communications Magazine, IEEE **49**(3) (March 2011) 160–166
6. Paul, U., Crepaldi, R., Lee, J., Lee, S.J., Etkin, R.: Characterizing wifi link performance in open outdoor networks. In: Sensor, Mesh and Ad Hoc Communications and Networks (SECON), 2011 8th Annual IEEE Communications Society Conference on. (June 2011) 251–259
7. Villegas, E.G., Lopez-Aguilera, E., Vidal, R., Paradells, J.: Effect of adjacent-channel interference in IEEE 802.11 WLANs. In: Cognitive Radio Oriented Wireless Networks and Communications, 2007. CrownCom 2007. 2nd International Conference on. (Aug 2007) 118–125
8. Abusubaih, M.A., Najem Eddin, S., Khamayseh, A.: Ieee 802.11n dual band access points for boosting the performance of heterogeneous wifi networks. In: Proceedings of the 8th ACM Workshop on Performance Monitoring and Measurement of Heterogeneous Wireless and Wired Networks. PM2HW2N '13, New York, NY, USA, ACM (2013) 1–4
9. Xhafa, A., Batra, A., Zaks, A.: On the coexistence of overlapping BSSs in WLANs. In: Vehicular Technology Conference, 2007. VTC-2007 Fall. 2007 IEEE 66th. (Sept 2007) 189–193
10. Shrivastava, V., Rayanchu, S., Yoonj, J., Banerjee, S.: 802.11n under the microscope. In: Proceedings of the 8th ACM SIGCOMM Conference on Internet Measurement. IMC '08, New York, NY, USA, ACM (2008) 105–110
11. Fuxjager, P., Valerio, D., Ricciato, F.: The myth of non-overlapping channels: interference measurements in IEEE 802.11. In: IEEE 4th Annual Conference on Wireless on Demand Network Systems and Services (WONS), 2007., Ieee (2007) 1–8