Are IEEE 802 Wireless Technologies Suited for Fire Fighters?

Philipp Hofmann [1], Koojana Kuladinithi [2], Andreas Timm-Giel [2], Carmelita Görg [2], Christian Bettstetter [3], François Capman [4] and Christian Toulsaly [5]

[1] DoCoMo Communications Laboratories Europe GmbH, Munich, Germany
hofmann *at* docomolab-euro.com

[2] University of Bremen, tzi ikom, Bremen, Germany
{koo|atg|cg} *at* comnets.uni-bremen.de

[3] University of Klagenfurt, Klagenfurt, Austria
christian.bettstetter *at* uni-klu.ac.at

[4] Thales Communications, Paris, France
francois.capman *at* fr.thalesgroup.com

[5] Brigade de Sapeurs Pompiers de Paris, Paris, France
christian.toulsaly *at* pompiersparis.fr

***Abstract* - Ad hoc networks are considered to provide flexible and robust communication in emergency scenarios like fire fighting. However, for the time being, it is not clear how existing digital wireless communication technologies perform in environments with fire, smoke and vapour. To investigate this issue, we carried out several experiments at the training facilities of the Paris fire brigade. Our goal was to evaluate the performance of standard wireless communication systems in a real fire fighting scenario. The main result is that wireless communication is not affected much by fire and smoke but is indeed affected by vapour. Technologies operating in the 2.4 GHz frequency achieve a higher communication range than those with 5 GHz in our setup.**

1. Introduction

A particularly challenging emergency scenario with respect to communication is fire fighting. Coordination and collaboration is crucial to reduce risks and to increase efficiency of fire fighters. For the time being, fire fighters either do not communicate per voice at all or use conventional analogue radios. However, analogue radios only enable low quality voice communication. Transmission of additional status information (e.g., image of a thermal camera or position of fire fighters) is not possible. Furthermore, the range of single hop communication may not be sufficient in certain environments, e.g., tall buildings with several floors or tunnels [1]. All those problems could be solved by introducing modern digital communication systems with multihop technology.

The development of such systems is one of the main goals of the European *wearIT@work* project [2], including applications, protocols and hardware platform. However, concerning the wireless communication hardware only standard technologies will be considered. To the best of our knowledge, it is still an open issue how current digital wireless communication technologies perform in fire fighting environments, e.g., in fire, smoke and vapour. The goal of this paper is to test the feasibility and performance of wireless communication in such harsh environments. To do so, we performed several experiments at the facilities of the Paris fire brigade.

The remainder of this paper is structured as follows. Chapter 2 introduces the setup of the experiments, including hardware, software and the location. The results are discussed in Chapter 3. We conclude the experiments in Chapter 4.

2. Experiment Setup

2.1. Tested Wireless Technologies

For the experiments only commercial-off-the-shelf components with standard wireless communication technologies are used, as listed in Table 1.

Technology	Nominal data rate	Freq. band	Brand
IEEE 802.11a	54 Mbit/s	5 GHz	Cisco
IEEE 802.11b	11 Mbit/s	2.4 GHz	Orinoco
IEEE 802.11n (pre)	108 Mbit/s	2.4 GHz	Belkin
Bluetooth (Class 1)	723 Kbit/s	2.4 GHz	Acer
IEEE 802.15.4	250 Kbit/s	2.4 GHz	Moteiv

Table 1: Tested wireless technologies

The IEEE 802.11 technologies [3] are tested in infrastructure mode only. An access point connected via Ethernet to a laptop is used as transmitter. A second laptop equipped with a WLAN PC card is used as receiver. The Belkin devices employ MIMO (Multiple Input Multiple Output) technology. The access point and WLAN card are each equipped with three antennas to increase achievable data rate and communication range. The use of MIMO technology for communication in WLANs will be defined by the upcoming IEEE 802.11n standard. Hence, Belkin specifies their devices as pre-N-compliant. They are compatible with IEEE 802.11b and g. The 802.11b WLAN cards are additionally tested together with an external antenna that provides 5 dBi gain. Personal area network technologies are evaluated using Bluetooth [4] and IEEE 802.15.4 [5] compliant devices (Telos motes [6]).

IEEE 802.11a operates in the 5 GHz band, all other technologies operate in the 2.4 GHz frequency band.

2.2. Performance Parameters and Tools

To evaluate the performance of the IEEE 802.11 and Bluetooth devices we measure throughput, jitter and round trip time (RTT) on the network layer. The traffic generator *iperf* [7] is used to obtain throughput and jitter by using UDP. The well-known tool *ping* is employed to measure the RTT. With the IEEE 802.15.4 devices we only test whether any communication is possible or not, while at the same time measuring temperature and humidity.

2.3. Premises

The experiments are carried out in a tunnel system at the training facilities of the Paris fire brigade (BSPP – Brigade de Sapeurs Pompiers de Paris) in Villeneuve St Georges close to Paris, as illustrated in Figure 1. The tunnel is about 1.5 m wide, 2 m high, made of stone and covered with earth and grass. The transmitting device is stationary placed at position T, which can be accessed via entrance 2. The receiving device is moved between positions R_1 and R_3, accessible via entrance 3. The fire is started in between transmitter and receiver at position F. The distance from the transmitter to the fire is about 25 m and the maximum distance between transmitter and receiver about 50 m.

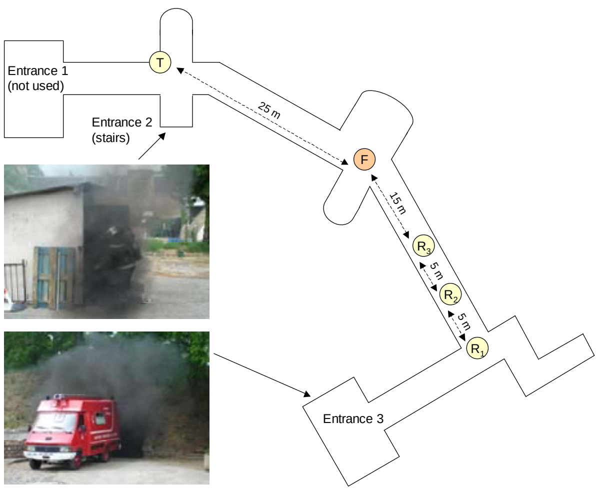

Figure 1: Tunnel system of BSPP training facilities

3. Performance Results

Measurements are performed in three Phases: (I) without fire, (II) with fire and smoke and (III) during the fire extinction, i.e., with smoke and vapour.

3.1. Reference Measurements

The initial measurements are performed without fire to obtain reference values for later comparison. At first we are interested in the communication range of the different communication technologies in the tunnel system. Therefore, the receiver is placed close to the transmitter, iperf is started and the receiving laptop is moved away from the transmitting laptop with a speed of about 1 m/s until position R_1 is reached.

All systems operating in the 2.4 GHz frequency band (IEEE 802.11b and n, Bluetooth, IEEE 802.15.4) are capable of communicating at the maximum distance of 50 m. In contrast, IEEE 802.11a only achieves a communication range of approximately 25 m. Due to the bad performance of IEEE 802.11a in the tunnel system it has been decided not to consider it for the later tests in fire. Furthermore, it turns out that the external antennas for the 802.11b WLAN cards do neither increase throughput nor the communication range.

Figure 2 shows the achievable throughput measured for IEEE 802.11b and 802.11n during this test. We have set the transmission rate of iperf to the nominal data rate of the tested wireless devices, i.e., 11 Mbit/s for 802.11b and 108 Mbit/s for 802.11n, respectively. The maximum achievable throughput of 802.11b is about 6.5 Mbit/s. It degrades in three steps to less than 1 Mbit/s at the maximum distance of 50 m, which has been reached after 55 s. The achievable throughput of 802.11n is close to 35 Mbit/s and degrades to less than 1 Mbit/s at the maximum communication range, too.

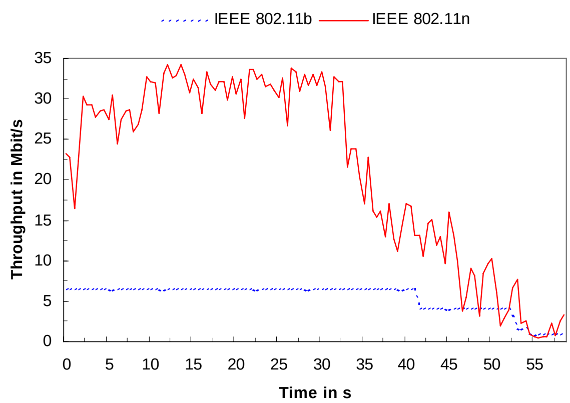

Figure 2: Throughput of IEEE 802.11b and 802.11n

Figure 3 illustrates the jitter that has been measured for IEEE 802.11b and 802.11n during this test. With short distances, the jitter is on average 3.5 ms for 802.11b and below 1 ms for 802.11n. With increasing communication range, the jitter increases for both technologies. The maximum measured jitter is 10 ms for 802.11b and 18 ms for 802.11n. Note that a high jitter usually is a consequence of an overloaded channel.

When configuring iperf with a transmission rate of 700 Kbit/s, the maximum achievable throughput with Bluetooth is on average 630 Kbit/s close to the transmitter and decreases to about 120 Kbit/s at a distance of 50 m. The jitter is varying between 5 and 20 ms for short communication ranges and goes up to 80 ms at the maximum distance.

Additional measurements are performed with 802.11n to obtain reference values of throughput, jitter and RTT at positions R_1, R_2 and R_3. The results are presented in the next Section in comparison with the performance in fire.

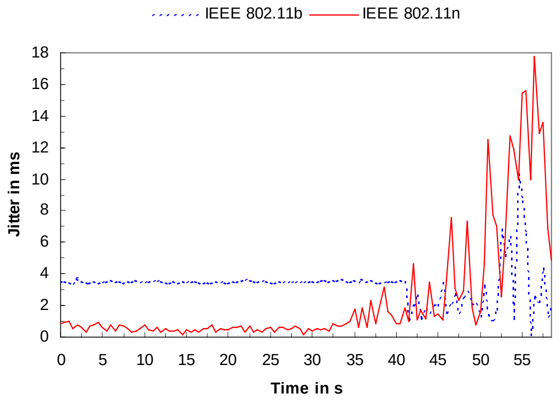

Figure 3: Jitter of IEEE 802.11b and 802.11n

3.2. Fire and Smoke

For Phase II, a fire is started at position F and the tunnel is completely filled with smoke after a short time. This is a typical situation for fire fighters. The receiving laptop is carried by a fire fighter and measurements are performed with IEEE 802.11n at positions R_1, R_2 and R_3 (each for 60 s). For the throughput and jitter measurements the data rate of iperf is now set to 6 Mbit/s.

The achieved average throughput without fire is nearly 6 Mbit/s and independent of the distance between transmitter and receiver, as shown in the first row of Table 2. The further rows show minimum, maximum, standard deviation and deviation for a confidence interval of 95 %. For comparison, the throughput in fire and smoke is shown in Table 3. It is only slightly smaller than the throughput without fire and smoke, so the main result of this experiment is that fire and smoke do not reduce the throughput considerably.

	Avg.	Min.	Max.	Dev.	Conf.
R_1	**5.97**	4.96	7.06	0.32	0.05
R_2	**5.97**	4.77	7.46	0.17	0.03
R_3	**5.57**	1.69	6.84	0.86	0.15

Table 2: Throughput of IEEE 802.11n in Mbit/s without fire

	Avg.	Min.	Max.	Dev.	Conf.
R_1	**5.73**	3.06	7.10	0.68	0.12
R_2	**5.47**	0.00	7.55	1.57	0.26
R_3	**5.98**	5.08	6.91	0.14	0.01

Table 3: Throughput of IEEE 802.11n in Mbit/s with fire and smoke

The measured average RTT is between 3 and 5 ms and independent of the communication range, as shown in row one of Table 4. The further rows again show minimum, maximum, standard deviation and deviation for a confidence interval of 95 %. Table 5 proves that the RTT is not affected by fire and smoke either. As already illustrated in Figure 3, without fire the jitter of IEEE 802.11n is below 1 ms as long as the distance is not too high (at position R_3 and R_2). It increases to an average of 3.8 ms at position R_1 with a distance of 50 m to the transmitter. Furthermore, the jitter is slightly increased by fire and smoke, e.g., going up to 5.3 ms at position R_2.

		Avg.	Min.	Max.	Dev.	Conf.
R_1	RTT	**3.28**	1.00	14.00	3.64	1.14
	Jitter	**3.83**	2.89	8.61	0.53	0.08
R_2	RTT	**4.59**	1.00	26.00	6.24	1.80
	Jitter	**0.37**	0.00	3.88	0.91	0.14
R_3	RTT	**3.60**	1.00	21.00	5.11	1.49
	Jitter	**0.85**	0.00	3.38	0.80	0.14

Table 4: RTT and jitter of IEEE 802.11n in ms without fire

		Avg.	Min.	Max.	Dev.	Conf.
R_1	RTT	**4.13**	1.00	24.00	6.24	1.93
	Jitter	**1.64**	0.00	3.99	1.56	0.28
R_2	RTT	**4.35**	1.00	29.00	6.01	1.43
	Jitter	**5.30**	2.51	68.73	6.83	1.15
R_3	RTT	**4.77**	1.00	34.00	7.14	1.92
	Jitter	**2.02**	0.00	5.36	1.71	0.10

Table 5: RTT and jitter of IEEE 802.11n in ms with fire and smoke

No detailed measurements have been performed with IEEE 802.15.4 in this Phase but communication generally is possible.

3.3. Smoke and Vapour

Measurements during Phase III (fire extinction) are only performed with IEEE 802.11b devices. iperf has been configured to transmit UDP packets with a data rate of 6 Mbit/s. The measured throughput is shown in Table 7. For comparison, the throughput without vapour is shown in Table 6. If the receiver is placed at position R_3 (i.e., 40 m distance), the throughput is not decreased compared to Phase II. However, when moving the receiver further away from the transmitter, the vapour indeed affects the throughput. At position R_2, the vapour reduces the achievable throughput considerably to an average of 4.3 Mbit/s and temporary reduces it to zero, as shown in Table 7 and Figure 4. When moving further to position R_1, communication is even not possible any more.

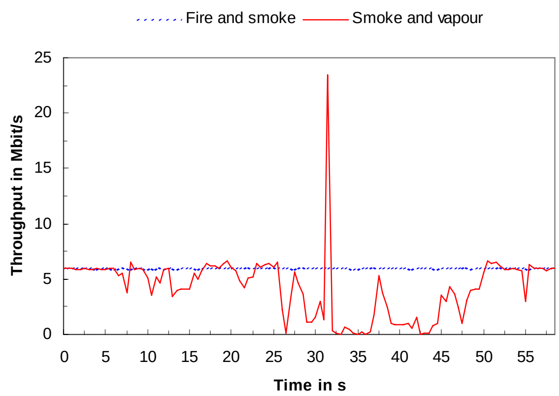

Figure 4: Throughput of IEEE 802.11b at position R_2

	Avg.	Min.	Max.	Dev.	Conf.
R_1	**5.98**	5.74	6.04	0.06	0.01
R_2	**5.99**	5.86	6.04	0.05	0.01
R_3	**5.65**	0.73	6.73	1.02	0.09

Table 6: Throughput of IEEE 802.11b in Mbit/s with fire and smoke

	Avg.	Min.	Max.	Dev.	Conf.
R_1	**Failed**[1]	-	-	-	-
R_2	**4.27**	0.00	23.50	2.86	0.52
R_3	**N/A**[2]	-	-	-	-

Table 7: Throughput of IEEE 802.11b in Mbit/s with smoke and vapour

The vapour has a similar impact on the jitter. While there is only a minor increase of the jitter at position R_3, it is significantly higher at position R_2 – up to 105 ms, as illustrated in Figure 5 and Table 9.

The RTT however is not affected by vapour at all. For comparison, Table 8 shows RTT and jitter without vapour.

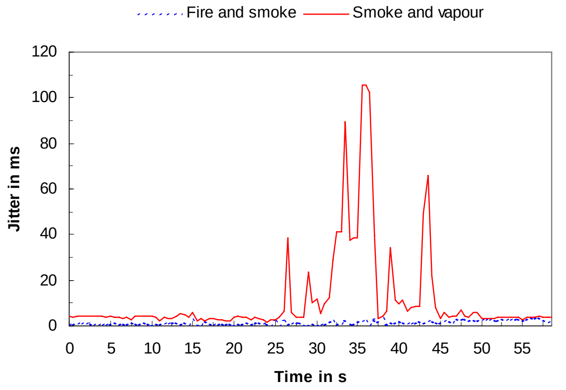

Figure 5: Jitter of IEEE 802.11b at position R_2

		Avg.	Min.	Max.	Dev.	Conf.
R_1	RTT	**N/A**[2]	-	-	-	-
	Jitter	**2.63**	0.11	4.01	1.30	0.16
R_2	RTT	**2.06**	2.00	4.00	0.31	0.08
	Jitter	**1.45**	0.11	3.58	0.91	0.16
R_3	RTT	**2.03**	2.00	3.00	0.17	0.04
	Jitter	**3.40**	0.00	13.14	1.45	0.12

Table 8: RTT and jitter of IEEE 802.11b in ms with fire and smoke

		Avg.	Min.	Max.	Dev.	Conf.
R_1	RTT	**Failed**[1]	-	-	-	-
	Jitter	**Failed**[1]	-	-	-	-
R_2	RTT	**2.15**	2.00	9.00	0.96	0.26
	Jitter	**11.55**	1.61	105.69	20.35	3.67
R_3	RTT	**2.00**	2.00	2.00	0.00	0.00
	Jitter	**N/A**[2]	-	-	-	-

Table 9: RTT and jitter of IEEE 802.11b in ms with smoke and vapour

[1] No communication possible
[2] No measurements performed

4. Conclusions

We have investigated the performance of wireless communication technologies in a typical fire fighting scenario. Measurements in a tunnel system with fire, smoke, and vapour led us to the following main conclusions:

- Technologies using the 2.4 GHz frequency band achieve a higher communication range than technologies using the 5 GHz band in the tunnel system.
- Fire and smoke do not severely affect the communication performance of devices operating in the 2.4 GHz band.
- Vapour reduces the transmission quality by decreasing throughput and range and increasing jitter.

Although vapour decreases the transmission range by about 20 %, communication was still possible at a distance of 40 m, which is considered to be sufficient for our application scenario. On the other hand, the jitter was increased significantly close to the maximum communication range, which can be problematic for voice applications. An application receiving voice packets can cope with high jitter in two ways, by either dropping received packets with high jitter or buffering them for a certain time before decoding. The disadvantage of the former approach is that the communication quality is reduced as information gets lost. The disadvantage of the latter approach is that the total communication delay is increased. Voice communication with very high quality is possible if the delay is below 150 ms and still possible with delays of up to 400 ms [8]. In our measurements however the jitter had a maximum value of "only" 100 ms in vapour. So even if the receiver would buffer packets for 100 ms there would still be enough time for transmitting and processing voice packets while maintaining very good communication quality.

Hence, in summary we can conclude that standard wireless communication technologies operating in the 2.4 GHz frequency band are suitable for communication in fire fighting scenarios.

REFERENCE

[1] A. Appelbaum, "Clearer Signals Through the Smoke", IEEE Spectrum Online, Feb. 2005, available at http://www.spectrum.ieee.org/WEBONLY/wonews/feb05/0205nnyceradio.html

[2] wearIT@work project, web page available at http://www.wearitatwork.com

[3] M. Gast, "802.11 Wireless Networks: The Definitive Guide, Second Edition", O'Reilly, Apr. 2005

[4] B. Miller and C. Bisdikian, "Bluetooth Revealed: The Insider's Guide to an Open Specification for Global Wireless Communications, 2nd Edition", Prentice Hall PTR, Nov. 2001

[5] J. Gutierrez, E. Callaway and R. Barrett, "Low-Rate Wireless Personal Area Networks: Enabling Wireless Sensors with IEEE 802.15.4", Standards Information Networks, IEEE Press, 2003
[6] Moteiv, "Telos B Data Sheet", available at http://www.moteiv.com/products/docs/telos-revb-datasheet.pdf
[7] A. Tirumala, F. Qin, J. Dugan, J. Ferguson and K. Gibbs, "Iperf: The TCP/UDP Bandwidth Measurement Tool", available at http://dast.nlanr.net/Projects/ Iperf
[8] International Telecommunication Union, "One-way Transmission Time", ITU Recommendation G.114, Feb. 1996