Reducing Power Consumption in Body-centric Zigbee Communication Links by means of Wearable Textile Antennas

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***Abstract*—Smart-fabric interactive textile systems have been studied intensively during the last decades and are ready to penetrate the market. Such systems are being tested in different application domains, such as health monitoring, coordination of military and emergency operations monitoring, sports and gaming. To make such systems attractive to consumers, they need to be low cost, low weight, flexible and primarily energy-efficient. We experimentally evaluate the deployment of efficient textile patch antennas in fire fighter garments to reduce the transmit power in a wireless sensor node network. The measurements performed in an advanced testbed setup, demonstrate the potential of on-body textile patch antennas to increase the power received at the nodes of a wireless sensor network and reduce the packet loss in the network, compared to using a rigid integrated PCB antenna with the same transmit power. The additional margin in received power may be exploited to reduce the transmit power while maintaining the same packet, resulting in a reduced energy consumption, paving the way towards smaller, lower-weight and less expensive consumer products.**

Keywords—textile antenna, on-body antenna, body-centric communication, energy-efficient, cooperative

I. Introduction

Wireless body-centric sensor networks received increasing interest in the last decade. At first, these systems were very complex, high-cost and dedicated to professional applications such as monitoring of military, law enforcement officers and rescue workers by means of, for example, the intelligent fire fighter suit developed in the FP6 Proetex Integrated Project. Nowadays, such systems are ready to penetrate the market for all kinds of consumer applications, given their potential in personal communications, gaming, sports and healthcare. In order to be successful and to achieve high market penetration, besides offering the required performance, these systems must be low-cost, light-weight, comfortable to wear and highly energy-efficient, as, especially in wearable applications, heavy batteries and frequent recharging should be avoided.

In this contribution, we demonstrate how the power required for off-body wireless communication may be reduced by making use of more efficient antennas. The key idea consists of exploiting the large area available in a garment to deploy a flexible textile antenna that provides high gain and large radiation efficiency while being seamlessly integrated in the garment. In particular, we make use of the RM090 transceiver module [10] to study the potential reduction in transmit power while maintaining the wireless link quality by replacing a simple printed PCB antenna by a wearable textile antenna. In addition, we study the effect of antenna polarization on link quality.

In current literature, the experimental characterization of textile patch antennas for different applications is mainly performed in terms of Signal-to-noise ratio (SNR) and bit error rate (BER) for uncoded data transmission relying on basic modulation schemes [1-4]. In this paper, measurements are performed following the IEEE 802.15.4 standard. In particular, we experimentally evaluate a wireless cooperative network, where a mobile node deployed on the human body serves as a hop, relaying data between the fixed nodes of the sensor network.

The article is organized as follows: Section II provides a complete description of the measurement setup, whereas Section III discusses the measurement results.

II. Measurement Setup

A. w-iLab.t testbed setup

To assess the potential in terms of transmit power reduction when deploying textile patch antennas, instead of simply using small printed PCB monopole antennas for off-body communication, we integrated different types of textile antennas into a professional fire fighter jacket and connected them to the RM090 transceiver modules. We then compare link quality obtained when using these wearable antennas connected as external antenna to the transceiver with the link quality provided by the internal transceiver antenna. Therefore, a fire fighter equipped with the wireless modules walks at normal walking speed along a fixed path, shown in green (walked from right to left) on Fig. 1, in the *w-iLab.t* *testbed* [9] indoor office environment. The testbed is deployed in an office building of 18x90m and spreads out over three floors. It consists of 200 node locations at fixed locations at the iMinds office premises, including meeting rooms, classrooms, offices and corridors. For this setup, only the nodes on the third floor are used, as shown in Fig. 1.

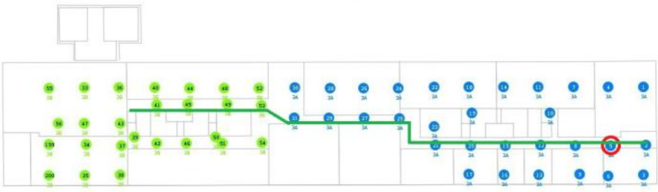

Figure 1: The w-ilab.t testbed, 3th floor

While the fire fighter is walking along the fixed path, in the first time slot of the frame, one fixed node (marked by the red circle Fig. 1) broadcasts to all fixed nodes as well as to the two RM090 mobile nodes. The two latter nodes are mounted together with their antennas in the shoulder sections of a professional fire fighter jacket, as shown in Fig. 2. In the two subsequent time slots of the frame, the two mobile nodes modify the packet received at time slot 1 by inserting their own specific node ID and RSSI-value into the packet, while maintaining the packet length. The two mobile nodes alternately broadcast their adapted packets to all fixed nodes in the *w-iLab.t testbed*. Both mobile nodes apply the same transmit power.

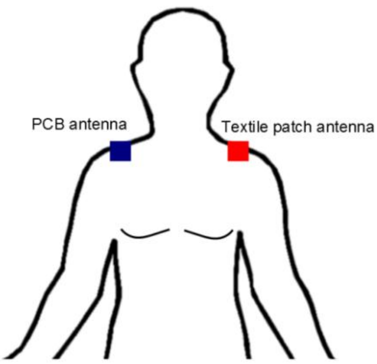

Figure 2: Mobile node setup on the fire fighter jacket

B. *Textile patch antenna*

By means of the experiment described above, textile antennas exhibiting different kinds of polarization are studied. One of these textile antennas is a *dual polarized* textile patch antenna [5], as shown in Fig. 3. The two ports of this antenna transmit and receive two signals along *orthogonal linear polarizations*. The antenna is implemented on a flexible protective foam substrate commonly found in protective garments for rescue workers. The foam protects vulnerable body parts such as elbows, shoulders and knees. The flexible closed-cell foam is fire-resistant, water-repellent, and regains its original form after deformation. The patch and ground plane were realized in the low-cost e-textiles FlecTron and ShieldIt, respectively. The rectangular slot in the antenna patch ensures impedance matching and provides the bandwidth required to cover the 2.45GHz ISM band.

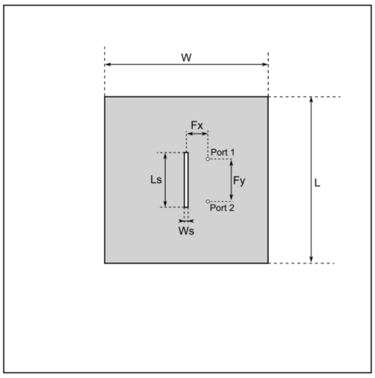

Figure 3 : Dual polarized patch antenna

TABLE I: TEXTILE PATCH ANTENNA PARAMETERS

Antenna specifications (see figure)		
Antenna dimensions [mm]	*L*	*45.32*
	W	*44.46*
	Ls	*14.88*
	Ws	*1*
	Fx	*5.7*
	Fy	*11.4*
	Substrate Height h	*3.94*
Substrate parameters	*Permittivity* ε_r	*1.53*
	tan δ	*0.0012*

In the experiments we also consider *circularly polarized textile patch antennas* implemented on an Aramid substrate. These textile antennas were developed within the FP6 Proetex Integrated Project [6,8]

III. MEASUREMENT RESULTS

Table II presents the total packet loss on each of the 51 receive nodes, when the fire fighter walks along the fixed path shown in Fig. 1. In this measurement, node 5, indicated by the red circle in Fig. 1, is the fixed transmitter node. The first row shows the packet loss of the complete dual-hop link (transmit node-mobile node-receive node), where the packets are forwarded by the mobile node with a wearable *circularly polarized textile antenna*. The second row of the table shows the total packet loss from the transmit node 5 to all receive nodes, along the dual-hop link (transmit node-mobile node-receive node), where packets are forwarded by the mobile node with the small printed PCB antenna. The last row shows the packet loss for the direct link from the transmit node to the receive nodes, without forwarding the packets by a mobile node on the fire fighter jacket. The small distance between some of the fixed receive nodes in the testbed and the fixed transmitter node 5, explains the low values of the packet loss for these fixed nodes.

TABLE II: PACKET LOSS MEASUREMENT 1

Node:	**1**	**4**	**5**	**6**	**7**
Patch	20.27%	20.27%	16.28%	29.24%	16.94%
PCB	25.91%	24.92%	24.92%	34.88%	21.59%
TX	0.66%	20.60%		0.33%	13.95%
8	**9**	**10**	**11**	**12**	**13**
17.28%	23.92%	26.58%	18.60%	17.61%	23.59%
25.25%	29.90%	36.54%	23.26%	24.58%	29.24%
1.33%	1.33%	15.95%	3.65%	1.99%	0.33%
14	**15**	**16**	**17**	**19**	**20**
17.94%	17.94%	17.61%	17.28%	21.93%	15.61%
21.59%	21.59%	26.58%	22.59%	28.24%	21.93%
0.33%	0.33%	0.33%	1.33%	0.33%	0.33%
21	**22**	**23**	**25**	**26**	**27**
15.61%	18.60%	15.28%	19.27%	20.60%	16.61%
21.26%	19.60%	20.60%	21.26%	20.60%	22.26%
10.30%	0.66%	1.33%	1.66%	12.29%	0.33%
28	**29**	**30**	**31**	**33**	**34**
21.93%	22.59%	25.58%	23.26%	58.47%	40.86%
22.92%	24.92%	24.92%	24.58%	48.17%	38.87%
2.66%	9.97%	13.29%	10.63%	98.67%	25.25%
35	**36**	**37**	**39**	**40**	**41**
49.17%	51.50%	35.22%	58.14%	45.18%	37.87%
40.20%	42.19%	31.56%	46.51%	39.53%	37.87%
54.15%	99.67%	22.59%	28.24%	54.82%	46.84%
43	**44**	**45**	**46**	**47**	**48**
57.81%	50.17%	35.22%	28.57%	62.13%	35.55%
45.85%	42.52%	34.55%	27.24%	46.84%	36.88%
87.04%	95.68%	57.48%	23.92%	100.0%	63.12%
49	**50**	**51**	**52**	**53**	**54**
34.22%	47.84%	27.91%	32.89%	26.25%	23.26%
37.21%	36.88%	30.56%	35.22%	27.24%	37.87%
51.50%	25.58%	7.97%	19.27%	30.56%	29.24%
55	**56**	**199**	**200**		
59.14%	59.47%	32.89%	46.84%		
46.84%	46.18%	30.90%	37.21%		
55.48%	100.0%	17.28%	62.79%		

Table II demonstrates that relaying data by means of the mobile node with the textile patch antenna reduces the total packet loss observed at the majority of the receive nodes, compared to the rigid PCB antenna. This result is consistent with Fig. 4-5, showing the RSSI levels at fixed nodes 8 and 9. For most of the packets, the mobile node with the textile patch antenna provides a larger RSSI value compared to the mobile node with the printed PCB antenna.

The received power on the mobile nodes was also recorded. The node equipped with the textile patch antenna exhibits significantly larger RSSI levels than the node with the printed PCB antenna, as shown in Fig. 6.

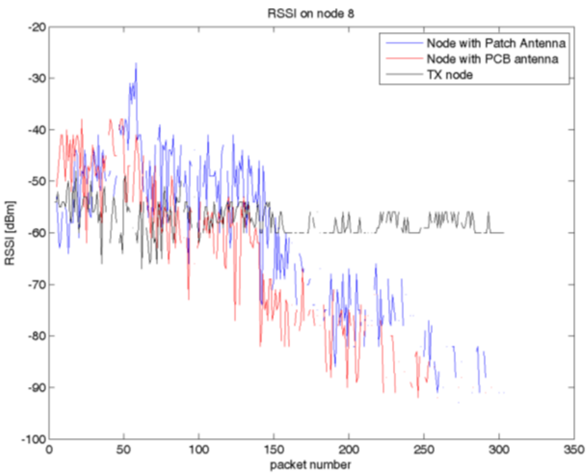

Figure 4 : RSSI levels at fixed node 8

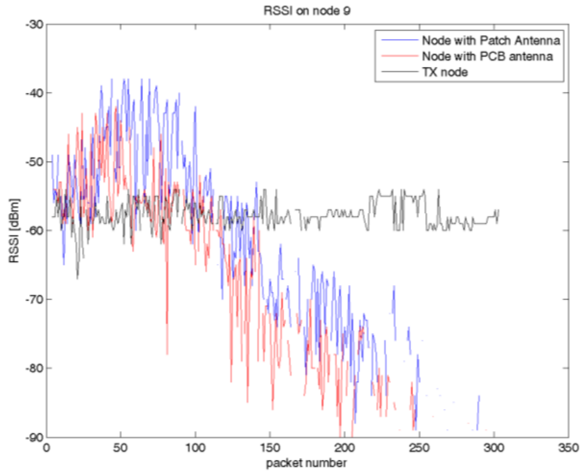

Figure 5 : RSSI levels at fixed node 9

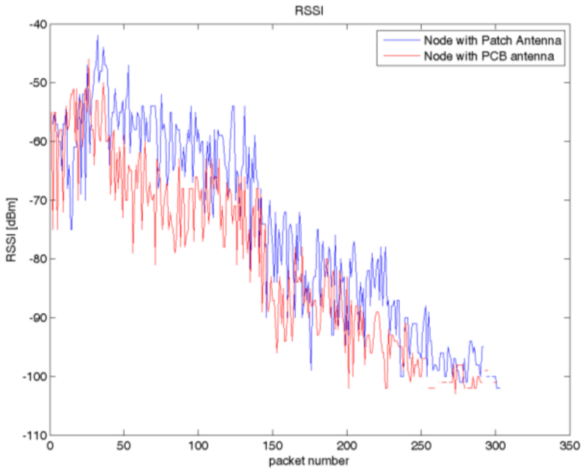

Figure 6 : RSSI levels at mobile nodes

The same results are obtained when using the *dual polarized textile patch antenna*. During the experiment with this antenna, one of the two ports is terminated with a load impedance, to ensure impedance matching over the required bandwidth at the port connected to the transceiver node.

Although the straightforward experimental approach of attaching textile antennas to the RM090 transceiver modules external antenna input by means of a small flexible coaxial cable provides some indication about the potential benefits of textile antennas over integrated PCB antennas, this measurement setup does not provide an entirely fair comparison between both types of antennas, as the integrated PCB antennas is attached directly to the transceiver's RF port, thereby avoiding the cable losses encountered by the external textile patch antenna. Therefore, the straightforward measurement protocol was refined to ensure that both antennas encounter the same amount of losses in the RF patch between the antenna and transceiver. This new measurement protocols corrects for the additional insertion loss introduced by the coaxial cable, which was measured to be 1.57dB. In addition, it also includes the extra losses in the lossy RF signal path on the transceiver PCB, connecting the RF pin of the transceiver to the connection point for the external antenna.

To calibrate out these losses, a printed PCB antenna, identical to the one found on the RM090 wireless sensor node, is isolated on a separate printed circuit board, having the same size and shape of the mobile node, including the same ground plane size. This printed PCB antenna is then connected to the external antenna output of the wireless sensor node by means of the same type of coaxial cable as used for the textile patch antenna.

Applying this new measurement protocol, Table III represents the total packet loss on each of the 51 fixed receive nodes, when the fire fighter walks along the same fixed path as the previous measurement setup. Node 5 again serves as the fixed transmitter node. The figures of merit shown in Table III are the same as in the previous measurement (Table II).

TABLE III: PACKET LOSS MEASUREMENT 2

Node:	1	4	5	6	7
Patch	40.20%	17.94%	28.57%	23.92%	32.56%
PCB	47.51%	47.84%	43.19%	48.84%	47.84%
TX	19.60%	0.33%		0.33%	0.66%
8	**9**	**10**	**11**	**12**	**13**
13.29%	19.27%	37.87%	60.47%	12.62%	53.49%
48.84%	44.85%	56.15%	45.18%	43.85%	46.18%
0.33%	3.99%	0.66%	2.33%	0.33%	12.62%
14	**15**	**16**	**17**	**19**	**20**
17.94%	28.90%	14.29%	13.95%	24.25%	14.29%
44.85%	44.52%	44.52%	44.85%	51.16%	42.86%
3.65%	1.00%	0.66%	1.33%	29.90%	0.33%
21	**22**	**23**	**25**	**26**	**27**
53.82%	49.83%	13.62%	15.95%	19.27%	13.95%
42.86%	47.18%	42.19%	43.19%	47.18%	42.52%
0.33%	3.32%	6.98%	0.33%	11.96%	2.99%
28	**29**	**30**	**31**	**33**	**34**
17.94%	16.94%	25.58%	22.26%	56.15%	23.92%
44.52%	44.19%	48.17%	45.51%	78.07%	47.51%
12.29%	1.00%	11.96%	11.30%	80.07%	13.62%
35	**36**	**37**	**39**	**40**	**41**
43.52%	57.14%	23.26%	58.47%	47.51%	37.21%
58.14%	71.76%	48.50%	52.49%	71.76%	57.14%
41.53%	46.18%	9.97%	46.51%	63.12%	49.50%
43	**44**	**45**	**46**	**47**	**48**
46.51%	44.19%	32.89%	19.27%	57.48%	27.24%
56.81%	62.46%	58.14%	45.51%	60.47%	51.50%
26.25%	46.51%	70.76%	1.66%	95.68%	64.45%
49	**50**	**51**	**52**	**53**	**54**
27.24%	61.46%	16.94%	21.59%	21.26%	18.27%
54.15%	57.14%	45.85%	56.15%	48.84%	46.51%
14.62%	11.63%	2.33%	22.92%	16.61%	7.31%
55	**56**	**199**	**200**		
57.48%	59.80%	30.56%	40.53%		
75.75%	69.10%	54.49%	58.47%		
100%	88,04%	12.96%	16.94%		

The results in Table III demonstrate clearly an additional improvement in terms of total packet loss for the textile patch antenna, compared to the PCB antenna. Now, the total packet loss for the link where the node with the textile patch antenna acts as relay is less than the packet loss along the link where the node with the PCB antenna acts as relay, for almost all fixed nodes. This result is consistent with Fig. 7-8, showing the RSSI levels at fixed nodes 8 and 9.

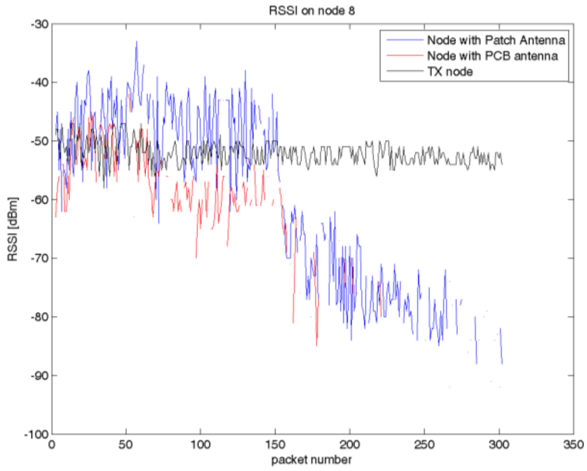

Figure 7 : RSSI levels at fixed node 8

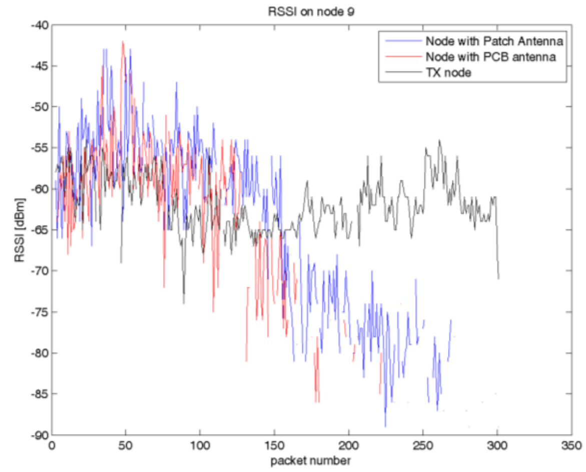

Figure 8 : RSSI levels at fixed node 9

The power received by the mobile nodes is shown in Fig 9. In this graph, it is clearly visible that the received power is larger for the node with the textile patch antenna. Even when the node with the printed PCB antenna is unable to decode the packets, the wireless node with the textile patch antenna still receives the packets at a reasonable RSSI level.

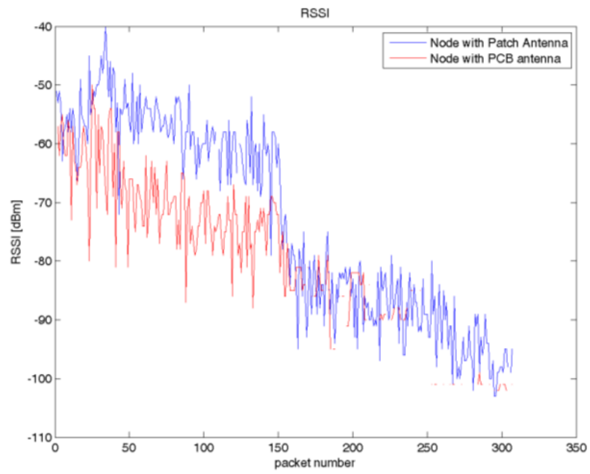

Figure 9 : RSSI levels at mobile nodes

Next, the new measurement protocol was repeated with all other textile patch antennas, leading to similar results. A small overview of the packet loss obtained during these measurements is given in table IV and table V.

TABLE IV : PACKET LOSS OVERVIEW

	Circ. Pol. Patch antenna		Dual Pol. Patch antenna	
	Avg. loss Patch	Avg. loss PCB	Avg. loss Patch	Avg. loss PCB
Meas. 1	30.8%	31.2%	27.4%	31.4%
	26.2%	28.4%	27.2%	31.4%
Meas. 2	31.0%	52.0%	24.5%	31.8%
	29.1%	33.6%	34.9%	51.0%

TABLE V : PACKET LOSS IMPROVEMENT

	# nodes with less packet loss than PCB antenna	
	Circ. Pol. Patch antenna	Dual Pol. Patch antenna
Meas. 1	31 (60%)	27 (53%)
	36 (71%)	40 (78%)
Meas. 2	45 (88%)	48 (94%)
	41 (80%)	44 (86%)

IV. CONCLUSION

A way to reduce the power required for off-body wireless communication by making use of more efficient antennas is experimentally validated. By replacing the integrated PCB antenna by a textile patch antenna, the quality of the wireless link may be improved both in receive and transmit mode. This may be exploited to reduce transmit power at the mobile nodes while guaranteeing the same amount packet loss.

To further reduce the power consumption, we need to improve the transceiver design such that cable and interconnect losses are avoided in the RF circuitry. This may be implemented by directly integrating the transceiver onto the textile patch antenna, following the design methodology outlined in [7]. A second path for future research consists in integrating two or more textile patch antennas into the professional fire fighter jacket and combining their signals by means of a power combiner. An optimal position for two antennas could be on opposite sides of the fire fighter jacket (for example, one antenna integrated in the back-section and one in the front-section of the jacket). This setup may be further extended to one or more dual polarized textile patch antennas, where each of the antenna ports is connected to two wireless nodes. This allows two wireless nodes to transmit and receive along orthogonal linear polarizations on a single antenna.

[1] P. Van Torre, L. Vallozzi, H. Rogier & J. Verhaevert, “Diversity textile antenna systems for firefighters.” *Proceedings of the fourth European Conference on Antennas and Propagation*. Presented at the 4th European conference on Antennas and Propagation (EuCAP 2010), Piscataway, NJ, USA: IEEE.

[2] Sang-Hun Han, Sang Kyu Park, "Performance analysis of wireless body area network in indoor off-body communication," *IEEE Trans. Consum. Electron.*, vol.57, no.2, pp.335,338, May 2011

[3] L. Vallozzi, P. Van Torre, C. Hertleer, H. Rogier, M. Moeneclaey, and J. Verhaevert, “Wireless Communication for Firefighters Using Dual-polarized Textile Antennas Integrated in Their Garment.” *IEEE Trans. Antennas Propag.* 58 (4): 1357–1368, 2010

[4] P. Van Torre, L. Vallozzi, C. Hertleer, H. Rogier, M. Moeneclaey, J. Verhaevert, "Indoor Off-Body Wireless MIMO Communication With Dual Polarized Textile Antennas," *IEEE Trans. Antennas Propag.*, vol.59, no.2, pp.631,642, Feb. 2011

[5] L. Vallozzi, H. Rogier and C. Herteleer “Dual Polarized Textile Patch Antenna for Integration Into Protective Garments,” *IEEE Antennas Wireless Prop*. Lett., vol. 7, pp. 440-443, 2008.

[6] C. Hertleer, L. Van Langenhove, H. Rogier and L. Vallozzi, „A textile antenna for fire fighter garments,” Proceedings Autex 2007 , Tampere, Finland, 2008.

[7] F. Declercq and H. Rogier. “Active Integrated Wearable Textile Antenna with Optimized Noise Characteristics.” *IEEE Trans. Antennas Propag.* 58.9 3050–3054, 2010

[8] http://www.proetex.org/

[9] http://www.crew-project.eu/wilabt

[10] http://www.crew-project.eu/portal/wilab/rm090