Interference of WiFi and Bluetooth Low Energy

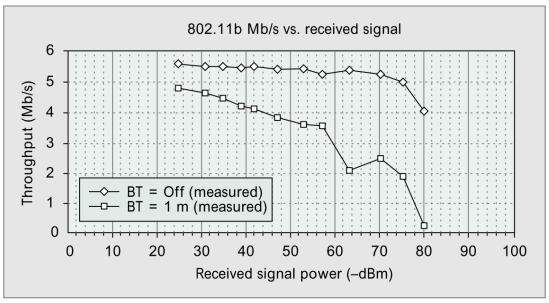


Figure 1: Measured throughput of Wi-Fi in the presence of Bluetooth [1].

(a) Position of BLE beacons

(b) Testbed setting

Figure 2: Testbed installation.

I. Introduction

The goal is to measure the influence of Bluetooth Low Energy (BLE) on an existing WiFi network. Both wireless technologies use the same frequency of 2.4 GHz. The work of [1] measured the throughput of Wi-Fi in the presence of Bluetooth. Figure 1 shows to what extent the throughput is influenced with activated Bluetooth in 1 m distance.

A small delay of device discovery might occur depending on which WiFi channels are used, since BLE advertisers typically use three advertising channels randomly [2]. A more serious issue can be the decrease of the actual WiFi throughput. The paper [2] found two best practices. Randomly use available WiFi channels, if only low data rates have to be achieved. When high data rates need to be maintained, it is best to avoid WiFi channel 4 when a lot of BLE broadcasters are present. This choice ensures high WiFi throughput in presence of BLE devices.

II. Testbed

We established two different testbeds to measure the influence of BLE devices on a WiFi network. We use BLE beacons as BLE devices to enable indoor positioning and other proximity-based services. In both testbeds we simulate a worst case scenario by placing the BLE beacons around the access point to achieve a maximum disturbance.

The first testbed was installed at home in the basement without any discoverable WiFi network to measure only the influence of BLE beacons. The second testbed was installed at the university in a meeting room with many (approximately 110) nearby WiFi access points. Figure 2 shows the testbed installation. The distance between access point and client was 4 m. Table I presents the difference between the two testbeds is the setting of the BLE beacons and and the test duration of the benchmark tool.

A. Hardware

- 1 x WiFi access point
  - Linksys WRT 1900AC[1]
  - SSID: tum-info
  - Protocol: 802.11n
  - Security: WPA2-Personal
  - Network frequency: 2.4 GHz
  - Network channel: 1, 6
- 1 x Apache Webserver (wired gigabit)
  - Sony Vaio Pro 13
  - CPU: Intel Core i5-4200U (1.6 GHz)
  - RAM: 8 GB
- 1 x Client (wireless)
  - MacBook Pro Mid 2015
  - CPU: Intel Core i5-5287U (2.9 GHz)
  - RAM: 16 GB
  - Network adapter: Broadcom 802.11ac
- 10 x BLE beacons
  - iBeek Sensor Beacon[2]

B. Software

- Apache Webserver 2.4.23[3]
- wrk benchmark tool[4]

C. Testbed Setting

Figure 3 presents the general testbed consisting of a server client architecture. The Apache web server is connected via cable to the WiFi access and offers six dummy files: 1 MB, 10 MB, 50 MB, 100 MB, 500 MB and 1 GB which are used for the benchmark. The client uses a 2.4 GHz wireless connection to the access point and runs the wrk benchmark tool which uses the six dummy files from the Apache web server to measure the performance of the wireless connection. Listing 1 shows the wrk benchmark script. We have in total ten rounds

[1] http://www.linksys.com/us/p/P-WRT1900AC/(visitedon2016/12/27)
[2] http://bluvision.com/wp-content/uploads/2016/12/Specs-iBEEK1.6.pdf (visited on 2016/12/27)
[3] http://www.apachelounge.com/ (visited on 2016/12/27)
[4] https://github.com/wg/wrk (visited on 2016/12/27)

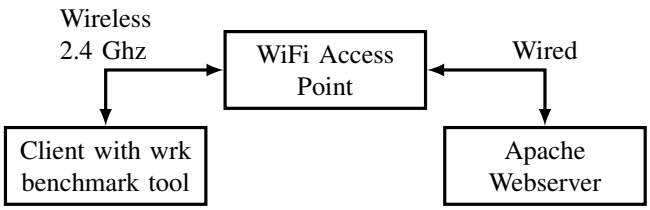


Figure 3: Testbed with WiFi access point using only 2.4 GHz wireless connection.

Table I: Testbed settings

	Beacons		Benchmark		
Testbed	Adv. rate	Range	Threads	Conn.	Duration
Worst case (home)	0.1 s	80 m	1	1	30 s
Realistic settings (university)	2.5 s	12 m	1	1	60 s

for each of the six dummy files and calculate the average performance.

Table I shows all relevant testbed settings. The advertisement rate and range of the BLE beacons mainly influences the disturbance of the WiFi. These settings were used for beacon packets including S Beacon, Eddystone URL, Eddystone UID and Eddystone TLM (day and night mode). For the wrk benchmark tool we used only one thread and one connection. The test duration was firstly 30 s in the worst case scenario and then extended to 60 s in the real settings scenario. The reason was that the latency and requests are zero for bigger files (≥ 50 MB) because the benchmark tool wrk was not able to finish the tests in the specified test duration due to the larger file size.

III. Evaluation Results

The evaluation of the transfer size reflects best how the BLE beacons influence the WiFi performance. Figure 4 shows that the transfer size is smaller in the presence of the BLE beacons. The testbed with realistic settings[5] has smaller negative impact on the WiFi performance. However, the scenario with realistic beacon settings is still a worst case regarding the beacon placement, because the WiFi access point is surrounded by ten beacons in very short distance (few centimeters) which does not reflect the real testbed setting, in which the beacons have a distance of some meters. Thus, the effect of the BLE beacons is smaller.

Table II shows the transfer size for the six dummy files in the two different testbeds. In the worst case scenario the transfer size is decreased by 1.91 to 2.30 MB/s (average: 2.05 MB/s) and in the realistic setting scenario by 0.46 to 0.71 MB/s (average: 0.61 MB/s). These results show that the amount of advertised beacon packets and transmission strength (range) have a major impact on the WiFi performance. The ratio between the worst case and realistic settings is 3.36 regarding the transferred data.

[5]less advertised beacon packets and smaller range

```
#!/bin/sh

i=1
param="-t1 -c1 -d30s http://192.168.1.218/"
sleep_time="30s"

while [ "$i" -lt 11 ]
do
  echo "Round $i"

  file="file_1_MB"
  echo ${file}
  wrk ${param}${file} > result_${i}_${file}
  sleep ${sleep_time}

  file="file_10_MB"
  echo ${file}
  wrk ${param}${file} > result_${i}_${file}
  sleep ${sleep_time}

  file="file_50_MB"
  echo ${file}
  wrk ${param}${file} > result_${i}_${file}
  sleep ${sleep_time}

  file="file_100_MB"
  echo ${file}
  wrk ${param}${file} > result_${i}_${file}
  sleep ${sleep_time}

  file="file_500_MB"
  echo ${file}
  wrk ${param}${file} > result_${i}_${file}
  sleep ${sleep_time}

  file="file_1_GB"
  echo ${file}
  wrk ${param}${file} > result_${i}_${file}
  sleep ${sleep_time}

  sleep 1m
  i=$((i + 1))
done
```

Listing 1: Benchmark script

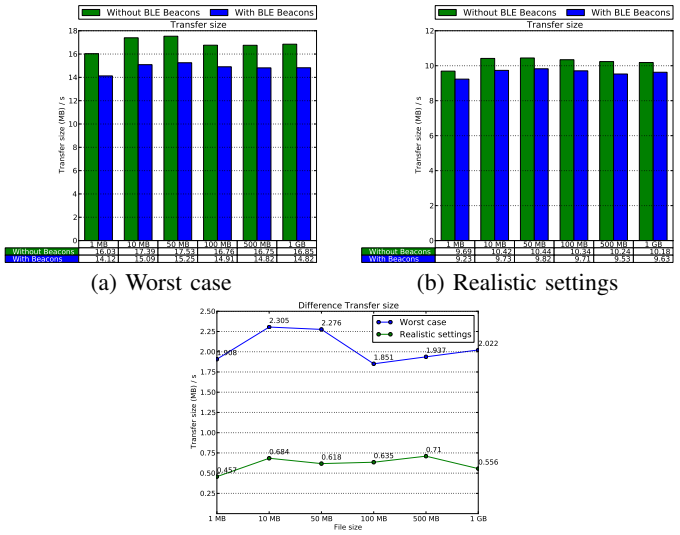
Appendix A
Testbed Installation

A. Installation of wrk Benchmark Tool

```
sudo apt-get install build-essential libssl-dev git
git clone https://github.com/wg/wrk.git
cd wrk
make
# move the executable to somewhere in your PATH
sudo cp wrk /usr/local/bin
```

B. Installation of Ubuntu Bash on Windows

1) Update and security: activate developer mode



(a) Worst case (b) Realistic settings

Transfer size in presence of BLE beacons and without BLE beacons.

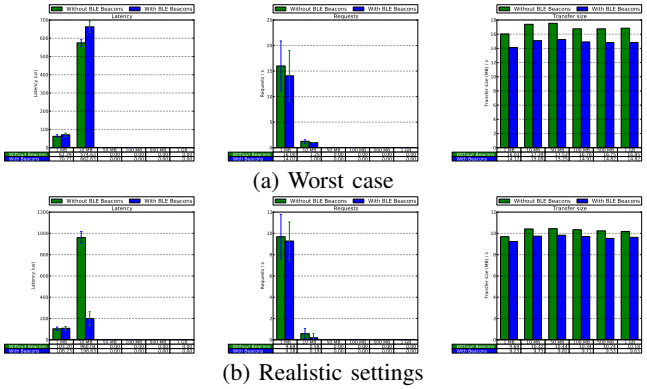
Figure 4: Evaluation results: Transfer size.

Table II: Evaluation results: Transfer size

Testbed	Setting	File size 1 M	10 M	50 M	100 M	500 M	1 G
		Transfer size (MB) / s					
Worst case	- BLE	16.03	17.39	17.53	16.76	16.75	16.85
	+ BLE	14.12	15.09	15.25	14.91	14.82	14.82
	Abs.	**1.91**	**2.30**	**2.28**	**1.85**	**1.94**	**2.02**
	Rel.	11.90	13.25	12.98	11.04	11.56	12.00
Realistic settings	- BLE	9.69	10.42	10.44	10.34	10.24	10.18
	+ BLE	9.23	9.73	9.82	9.71	9.53	9.63
	Abs.	**0.46**	**0.68**	**0.62**	**0.64**	**0.71**	**0.56**
	Rel.	4.72	6.57	5.92	6.14	6.94	5.46

2) Control panel: install windows subsystem for Linux (beta)
3) Restart
4) Search after bash and install

Appendix B
Full Evaluation Results



(a) Worst case

(b) Realistic settings

Table III: Full evaluation results.

Table IV: Evaluation results: Latency

Testbed	Setting	File size 1 M	10 M	50 M	100 M	500 M	1 G
		Latency (us)					
Worst case	- BLE	62.39	574.63	0	0	0	0
	+ BLE	70.77	662.63	0	0	0	0
	Abs.	8.38	88.00	0	0	0	0
	Rel.	13.44	15.31	0	0	0	0
Realistic settings	- BLE	103.20	960.04	0	0	0	0
	+ BLE	108.23	198.63	0	0	0	0
	Abs.	5.02	761.40	0	0	0	0
	Rel.	4.87	79.31	0	0	0	0

Table V: Evaluation results: Requests

Testbed	Setting	File size 1 M	10 M	50 M	100 M	500 M	1 G
		Requests / s					
Worst case	- BLE	16.00	1.25	0	0	0	0
	+ BLE	14.07	1.00	0	0	0	0
	Abs.	1.93	0.25	0	0	0	0
	Rel.	12.06	19.87	0	0	0	0
Realistic settings	- BLE	9.68	0.58	0	0	0	0
	+ BLE	9.28	0.19	0	0	0	0
	Abs.	0.40	0.38	0	0	0	0
	Rel.	4.16	66.26	0	0	0	0

References

[1] J. Lansford, A. Stephens, and R. Nevo, "Wi-Fi (802.11b) and Bluetooth: Enabling Coexistence," *IEEE Network*, vol. 15, no. 5, pp. 20–27, 2001.

[2] J. Wyffels, J.-P. Goemaere, B. Nauwelaers, and L. de Strycker, "Influence of Bluetooth Low Energy on WIFI Communications and Vice Versa," in *Proceedings of the European Conference on the Use of Modern Information and Communication Technologies (ECUMICT)*, 2014, pp. 205–216.