Evaluation of WiFi for Kart Racing Monitoring

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Abstract. The focus of this paper is to study the throughput and jitter performances of the IEEE 802.11-2012 standard based solution for monitoring young kart racing drivers. At the low-level of kart racing, the speed of a kart is about 80 km/h. The PropSim channel emulator is applied to study performance of standard compliant radios in a vehicular environment. We will also study the impact of interference and shadowing on the system performance. The results indicate that it is feasible to use low-cost radios based on the IEEE 802.11 standards for this specific application if the need for bandwidth is not in Mbps.

Keywords: Communication, Karting, WiFi.

1 Introduction

Kart racing is a form of motorsport where vehicles are open and four-wheeled, namely karts. It is the most popular motorsport among youngsters and used commonly as the stepping stone to higher and more expensive classes of motorsport. The Finnish Formula One champions, Keke Rosberg, Mika Häkkinen and Kimi Räikkönen, all started their careers in kart racing. There are several classes covering different age groups in karting. It is typically started at the age of 6-7 years; and, after the age of 10, the first national competitions are available. At this level, the karts are reaching top speeds of about 80 km/h. The top-level of karting is KF1 which is open to the best drivers aged 15 and up. It is possible to reach top speeds up to 140 km/h and 70 km/h, on average, with this level of karts depending on the racing circuit layout. [1]

The length of homologated circuits varies between 748 m and 1700 m and is typically compacted into a small area. For example, the karting circuit located in Pori, Finland has a circuit length of 1045 m and outer dimensions of about 250 m x 200 m. [2]

At the lowest level of karting, driving skills are the most valuable asset because the karts are very similar to each other in terms of performance. By analyzing driver's actions when entering and exiting a curve, development of a young driver can be enhanced. Since the first classes of karting are the most low-budgeted, a need for an affordable, easy-to-deploy, reliable and portable monitoring system is present.

WiFi based on the 802.11 standards is a mature technology providing reliable communication and broad coverage with reasonably priced commercial components,

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and availability of the components makes fast adaptation possible. The schema of the monitoring system is depicted in Fig. 1. A karting circuit is typically an open-space without any major blocking objects. By using WiFi, one access point (AP) can basically cover a whole kart racing circuit. If connection is lost, the driving information is stored locally and transmitted right after a connection recovery. An analysis of the driver's performance is performed in a service area or pit.

The 802.11 physical (PHY) layer, i.e., orthogonal frequency division multiplexing (OFDM) defined in [3] has shown its strength as a PHY layer for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. The 802.11a amendment was used as a basis for the 802.11p amendment which is applied as a PHY layer of wireless access in vehicular environment (WAVE) applications [4]. WAVE uses the 5.9 GHz frequency band dedicated for road safety, and includes V2V and V2I communications [4]. The 802.11p amendment uses licensed 5.9 GHz frequency band [4].

Due to price and use of licensed frequency band of the 802.11p, it is not feasible to low-cost driving analysis application. The present study focuses on the performance of commercial, affordable, off-the-shelf (COTS) WiFi radios in a vehicular environment. The paper is organized as follows: Section 2 presents the related work, Section 3 introduces the measurement setup, and Section 3 continues with the discussion on measurement parameters. In Section 4, the results from the measurement campaign are presented and analyzed. Finally, the paper is concluded in Section 5.

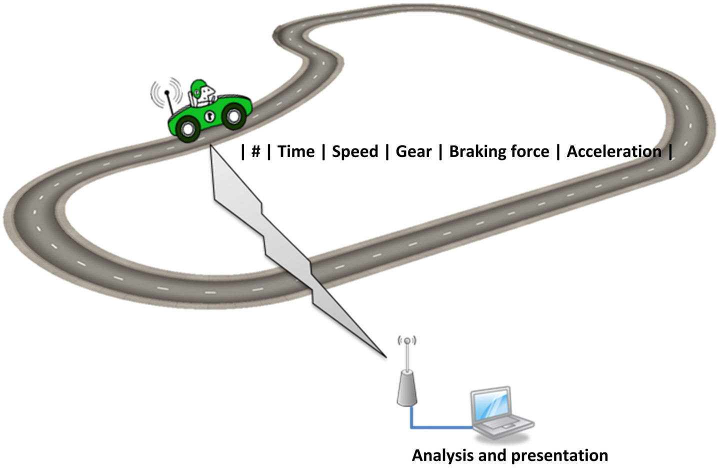

Fig. 1. Schema of the kart monitoring system

2 Related Work

In [5], it is studied the throughput efficiency and the average delay performance of the IEEE 802.11 by using a Markov chain model. The OPNET simulations were carried out with the packet size of 1500 bytes having the channel bit rate of 11 Mbps. The results show that the throughput efficiency is 57.7 % for two stations with the contention window (CW) size of 32. Doubling the CW size decreases the throughput efficiency 3.5 percentage points. When the number stations are increased from 2 to 6, it has a slight influence on the throughput efficiency.

An analytical model for the enhanced distribution channel access (EDCA) mechanism in the IEEE 802.11p MAC layer is proposed in [6]. The model is validated against simulations. The model takes into account different features of EDCA, such as CW, different access classes (AC) and internal collisions. The normalized throughput was approximately 45% in the simulations where the packet payload was 512 bytes and the channel rate was 6 Mbps The measurements where the suitability of the IEEE 802.11 standard for the V2I communication is evaluated are presented in [7]. The user datagram protocol (UDP) throughput was measured with 802.11g and 802.11b also comparing different packet sizes. A fixed access point (AP) was passed with a car speeding up to 120 km/h. The authors concluded that the throughput is slightly smaller with this speed than in a static case showing that IEEE 802.11 is feasible for such velocities.

The WAVE performance measurement results for a V2I link are given in [8], where frame success ratio (FSR) is measured with various modulation-coding schemes, packet lengths and velocities. The maximum coverage of 700 m was reported for FSR > 0.25 at the data rate of 3 Mbps.

The V2I measurement results where the IEEE 802.11a and 802.11p are compared are reported in [9]. The packet size was set to 100 bytes. The connection time between a roadside unit (RSU) and a car was much longer when 802.11p was used, mainly because 802.11p does not require any authentication process, whereas it is needed to 802.11a to establish connection. In addition, it was found out that the packet losses of 802.11p were lower than 802.11a. The measurement devices applied the nominal channel bandwidths which are 10 MHz and 20 MHz for 802.11p and 802.11a, respectively. The selection of smaller bandwidth doubles the timing parameters of 802.11 improving the system performance in channels with a high delay spread. It is also possible to use 10 MHz bandwidth with 802.11a [3].

In our study, the focus is to evaluate if the affordable COTS WiFi radios are capable to perform in a vehicular environment.

3 Measurement Setup

The measurement setup contains commercial off-the-shelf (COTS) WiFi radios, a PropSim channel emulator [10], and laptops as illustrated in Fig. 2. One of the WiFi radios is tuned to work as an AP and another as a station (STA). Antenna connectors of the radios are connected to the PropSim so that 2x2 multiple-input multiple-output (MIMO) channels for an uplink and a downlink are formed. The throughput and jitter performance are measured by using the Iperf network testing tool installed in each laptop which, in turn, are connected to each radio with Ethernet cables. The WiFi radios are compliant with the IEEE802.11-2012 standard without optional features such as space-time block coding (STBC).

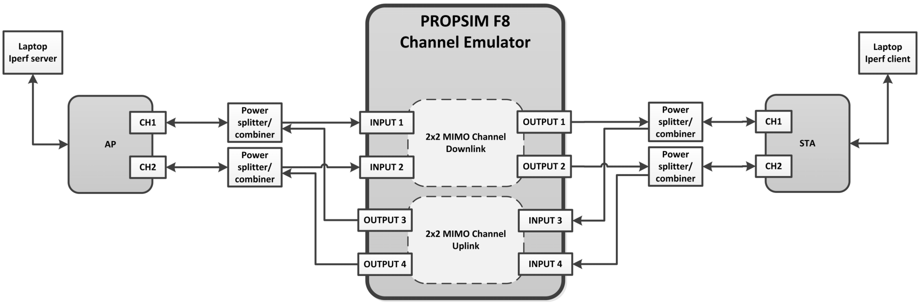

Fig. 2. Measurement setup

3.1 Ipert Network Testing Tool

The Iperf client generates 300 bytes user datagram protocol (UDP) data packets with a specified rate of 10 Mbps in this study. The packet size covers the data to be transmitted at the application layer. The Iperf server computes throughput, jitter and packet loss at an application layer. It counts lost datagrams based on an ID number of each datagrams. The size of the UDP packet varies between 8 – 65 535 bytes and usually consists of several internet protocol (IP) packets. Losing one IP packet will lose the whole UDP packet. The UDP packet size was set to 300 bytes. When the maximum transmission unit (MTU) is 1500 bytes, we can call a datagram as a packet, and the number of lost datagrams is equal to lost packets. [11]

3.2 PropSim Channel Emulator

A channel emulator is applied to model a wireless channel for studying performance of real hardware. Complex set-ups can be built in a laboratory environment so as to closely emulate a real scenario. The emulation is based on pre-calculated files, i.e., channel impulse response and other related parameters. The PropSim channel emulator includes several standard channel models; but, it is also possible to create a unique channel model when needed parameters are known. [10]

A work flow with PropSim starts by defining a channel impulse response tap by tap. For each channel tap, properties such as delay, amplitude distribution, Doppler spread, correlation, etc. can be adjusted. The next step is to connect a generated channel to RF inputs and outputs. Finally, the channel is emulated and measurements can be done.

V2I Channel Model

Our V2I channel model is based on the roadside-to-vehicle (RTV) Expressway channel model at 5.9 GHz presented in [12]. All parameters needed for channel emulation are presented in Table 1.

Table 1. Channel model for RTV-Expressway

Tap no.	Path no.	Tap power [dB]	Relative path loss [dB]	Delay value [ns]	Rician K [dB]	Frequency shift [Hz]	Fading Doppler [Hz]	LOS Doppler [Hz]	Fading spectral shape
1	1	0.0	0.0	0	-5.3	769	70	770	Round
1	2	0.0	-36.4	1	n/a	-22	600	n/a	Round
1	3	0.0	-30.0	2	n/a	535	376	n/a	Round
2	4	-9.3	-12.3	100	n/a	754	117	n/a	Round
2	5	-9.3	-21.7	101	n/a	548	424	n/a	Round
2	6	-9.3	-24.9	102	n/a	-134	530	n/a	Flat
3	7	-20.3	-24.3	200	n/a	761	104	n/a	Round
3	8	-20.3	-25.4	201	n/a	88	813	n/a	Classic 3 dB
4	9	-21.3	-26.8	300	n/a	37	802	n/a	Classic 6 dB
4	10	-21.3	-28.5	301	n/a	752	91	n/a	Round
5	11	-28.8	-31.2	400	n/a	16	807	n/a	Classic 6 dB
5	12	-28.8	-41.8	401	n/a	-755	329	n/a	Round

Interference

In PropSim, there is also functionality to internally generate an interfering signal. A preliminary interference test was done by adding the filtered additive white Gaussian noise (AWGN) with constant signal-to-noise power ratio (SNR) for each received antenna.

Shadowing

It is also possible to add slow fading to the channel emulating the effect of obstacles in the signal path. A shadowing feature of PropSim was applied to test the system response when an attenuation of a channel is increased. The channel gain was decreased with 0.1 s time intervals to -35 dB or -50 dB. After a breakpoint, the gain was increased back to 0 dB.

4 Measurement Parameters

During measurements, the radios were adjusted to use the 802.11a+n radio protocol with 5745 MHz channel center frequency and 5 dBm transmitted power which was the minimum available power level. Single-input single-output (SISO) and MIMO setups were applied. The radios did not have a support for STBC or other diversity methods. The transport protocol was UDP with a packet size of 300 bytes and a bandwidth of 10 Mbps. During a 3-minute measurement run, about 750 000 UDP packets were transmitted. In an interference measurement, a possible interference source is co-located exactly in the channel of a victim system covering the victim frequency band completely or partially. Two values of the maximum shadowing attenuation were applied, namely 35 dB and 50 dB. All the parameters are summarized in Table 2.

Table 2. Measurement parameters

Parameter	**Value**
Radio protocol	802.11a+n
Frequency channel	5.745 GHz (#149)
Channel bandwidth	20 MHz
Transmitted power	5 dBm
Transport protocol	UDP
UDP packet size	300 B
UDP bandwidth	10 Mbps
Velocity	10, 50, 100 or 140 km/h
Interference center frequency	5.745 GHz
Interference bandwidth	5 or 20 MHz
SNR in interference measurement	10 or 15 dB
Maximum attenuation in shadowing measurement	35 or 50 dB

The link quality given by the software driver of the WiFi board was recorded before emulation to confirm operation of the setup. As it can be seen from Table 3, connections were perfectly functional in SISO and MIMO setups.

Table 3. Link quality before channel emulation

Setup	**SISO**	**MIMO**
Link quality	70/70	70/70
Bit rate	65 Mbps (MCS7)	130 Mbps (MCS15)
Signal level	-34 dBm	-35 dBm

5 Results

The results of the measurements are discussed in this chapter. The throughput and jitter performances of the system were measured at the application layer. The impact of velocity, interference and shadowing were studied to have a comprehensive understanding of the system performance.

5.1 Velocity

The performances of SISO and MIMO setups were measured by using velocities of 10, 50, 100 and 140 km/h. The corresponding maximum Doppler shifts are 53, 266, 531 and 745 Hz. The measurement results are presented in Fig. 3 and Fig. 4. A line represents an average result, whereas a bar depicts a standard deviation. For both setups, it is clear that when the velocity increases from 10 km/h to 50 km/h, the throughput performance degrades dramatically. In the end, the MIMO setup gives the mean throughput of 1199 kbps with 140 km/h, and correspondingly 491 kbps for SISO. The jitter performance is in reasonable range in the case of MIMO for all studied velocities, whereas it varies strongly for SISO. The IEEE 802.11-2012 standard defines the subcarrier spacing of the 20 MHz OFDM PHY to be 312.5 kHz [3]. With velocity of 50 km/h, the intercarrier interference (ICI) starts to have an impact on the system performance. An extensive study on the effect of Doppler spread on the OFDM system performance can be found, e.g., in [13].

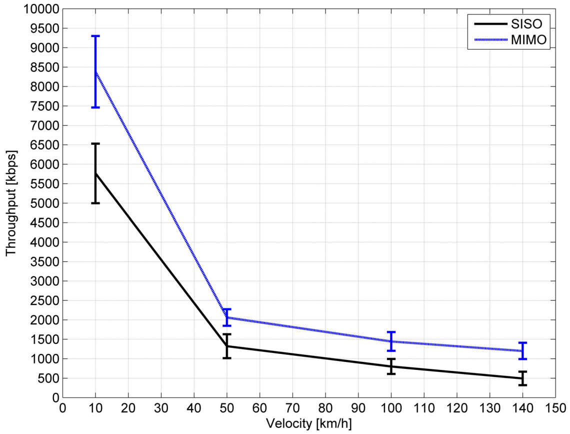

Fig. 3. Impact of velocity on the system throughput performance

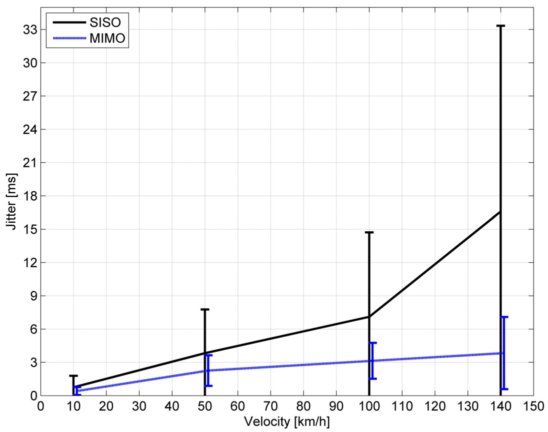

Fig. 4. Impact of velocity on the system jitter performance

5.2 Interference

In public spaces such as a karting circuit, there may also exist other WiFi devices or other equipment using the same frequency band. These introduce interference to the desired system. The performance of the system was measured by using two possible interfering systems having the channel bandwidth of 20 MHz and 5 MHz. The interference was modeled as a band-limited white Gaussian noise. Table 4 gives the mean results and standard deviation values (σ) of the measurements for different the signal-to-interference power ratios (SIR). The results show that the system manages interference overlapping communication bandwidth completely better than partially overlapping interference.

When the total interference power is constant, the smaller bandwidth interference interferes less sub-carriers with at higher power than with the higher interference bandwidth. It should be pointed out that any interference increases the standard deviation in throughput almost 100 %. In the jitter performance, there is no significant impact when the interference bandwidth is 20 MHz.

Table 4. Impact of interference on the MIMO system performance

Parameter	**No interference**	**Interference BW=20 MHz**		**Interference BW=5 MHz**	
SIR	∞	10 dB	15 dB	10 dB	15 dB
Mean throughput [kbps] (σ)	8337 (868)	6934 (1742)	8701 (1519)	3256 (1574)	5559 (1372)
Mean jitter [ms] (σ)	0.42 (0.39)	0.44 (0.26)	0.40 (0.54)	2.75 (8.50)	0.91 (2.85)

5.3 Shadowing

This MIMO measurement case simulates a situation where a signal is blocked by an obstacle and a received SNR decreases. The signal is totally blocked by using 50 dB or partially blocked with 35 dB maximum attenuation. Fig. 5 depicts the throughput results, where dashed lines are mean values of measurements. The upper figure is the case where the maximum attenuation is 50 dB, and the lower one is for 35 dB. The jitter performance is given in Fig. 6. By using 50 dB, the radio link is totally blocked and there is no communication between AP and STA. When attenuation is low enough, the link is established quickly. For lower maximum attenuation, the radio is able to keep the connection up.

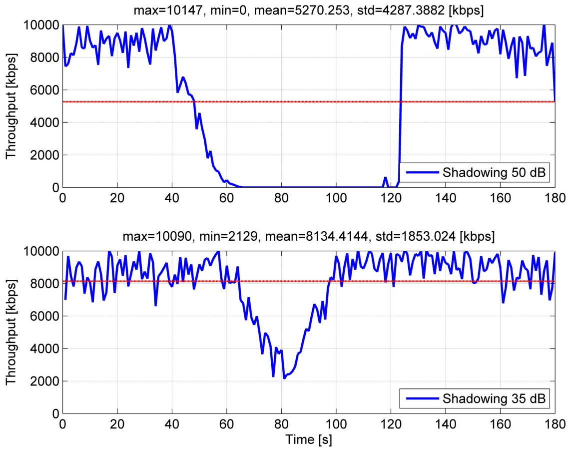

Fig. 5. Impact of shadowing on the system throughput performance

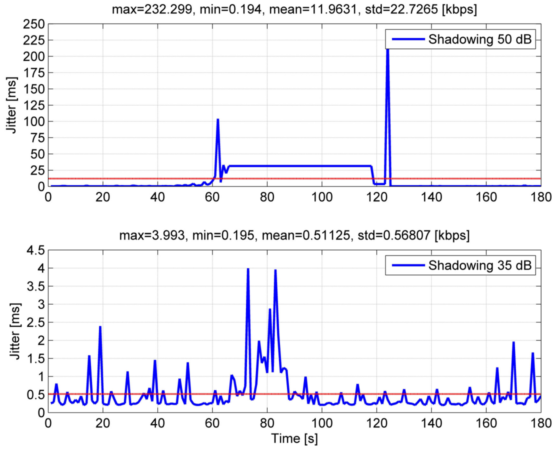

Fig. 6. Impact of shadowing on the system jitter performance

6 Conclusion

This paper presented the measurement results where radio system performance was studied in the vehicular environment. The karting monitoring system is needed to provide a possibility to monitor and analyze performance of young drivers in the early stages of their professional careers. The lower level of kart racing has the lowest budget, and hence costs should be minimal. The radio system based on WiFi allows the opportunity for monitoring and analysis by providing affordably priced hardware options.

The measurement results showed that a standard-based WiFi, without any optional features, cannot manage high velocity scenarios if the throughput requirement is several Mbps. But, this could be solved by using local data storage in a kart where information is stored to be transmitted when a channel is in order. Nevertheless, when transmitting status information only, the bandwidth need is much less and the radios can operate up to 140 km/h.

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