COMPARISON OF WLAN MULTICARRIER DS-SS PHYSICAL LAYER CONFIGURATIONS IN MEASURED INDOOR ENVIRONMENT

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The new generation of multimedia laptop and palmtop computing devices is strongly pushing industry towards the development and the implementation of high speed Wireless Local Area Networks (WLANs). This task is not trivial, since the mobility feature has to be provided in a challenging transmission medium such as the indoor radio channel. In this framework the only standards delivered by regulatory bodies are the IEEE 802.11 and the ETSI HIPERLAN [1][2]. Interference and multipath fading are the most significant problems that affect WLANs. WLAN applications often use bands where electronic devices radiate RF energy (e.g. ISM band). In such an environment the interference rejection properties of the Spread Spectrum (SS) technique are precious [3]. Because of this reason the SS technique has been adopted in the IEEE 802.11, both in Direct Sequence (DS) and Frequency Hopping (FH) configurations. Moreover, the adoption of the SS technique allows to gain an intrinsic diversity of the signal in order to cope with the effects of multipath fading. In this paper we show the convenience to combine the SS signaling with the Multicarrier Modulation (MCM), in order to support indoor WLAN applications. The MCM was considered by the ETSI for the HIPERLAN standard, although Decision Feedback Equalization (DFE) was finally adopted. The MCM approach permits to displace the equalization problems from the time domain to the frequency domain; when combined with the SS technique, it leads to some feasible technical solutions that exploit the strong issues of both techniques, such as frequency diversity, full channel equalization by means of a Complex-valued Automatic Gain Control (CAGC) at the receiver side, and rejection of the interference [4][5]. An MCM-DS-SS radio subsystem for WLAN must be designed taking account of the special issues of such an application.

In typical WLAN environment a CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) access scheme is adopted [1], so the Spread Spectrum technique is only devoted to the rejection of interference and to provide a proper diversity order [6]. Since a good value of throughput has to be guaranteed also for short packets and for MAC messages handshake, a great care must be observed in the strategy adopted for the channel estimation and equalization, by preferring easy to implement techniques which allow to obtain small values of the processing delay.

More in detail, in this paper we propose two different MCM-DS-SS physical layer configurations for WLANs and evaluate their performance in terms of bit error rate and frame error rate by using measured channel delay profiles, in different indoor environments. By comparing the obtained performance with the results of the DS-SS physical layer of the IEEE 802.11 standard, we point out the potential performance limiting factors.

Figures 1 and 2 show the base-band schemes of the proposed MCM-DS-SS modems. For the sake of brevity, the detailed description of each block is not reported in this summary.

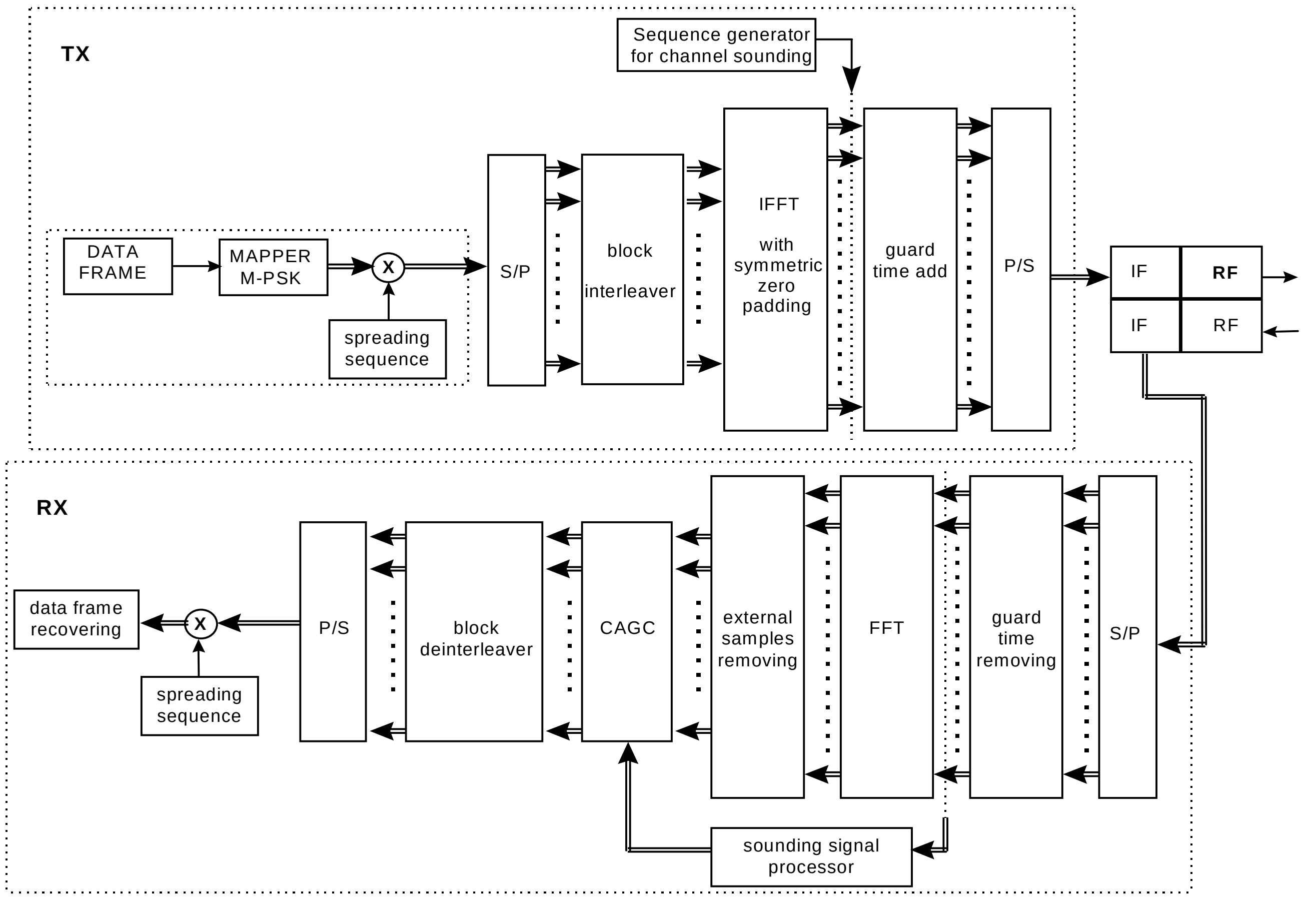

Fig. 1 *Basic schemes of the TX and RX base-band sections of the first MCM-DS-SS modem (System A). Double lines indicate complex-valued signals.*

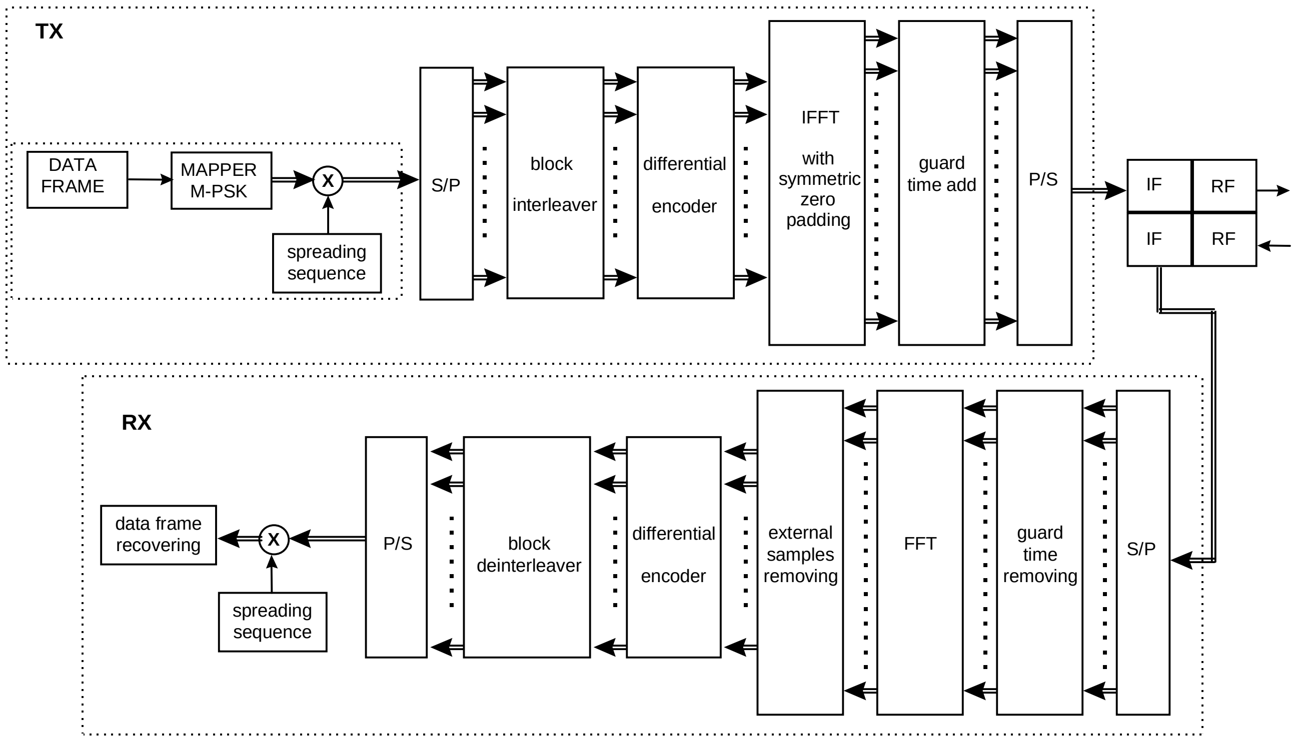

Fig. 2 *Basic schemes of the TX and RX base-band sections of the second MCM-DS-SS modem (system B). Double lines indicate complex-valued signals.*

The considered MCM-DS-SS schemes differ each other in the strategy adopted for the sounding and equalization of the channel.

In the first MCM-DS-SS scheme the sounding of the channel is obtained by interleaving a number of known pilot carriers, frequency-spaced, at least, by one half of the coherence bandwidth of the channel, in each MCM symbol. The receiver obtains an estimation of the channel frequency response by linearly interpolating the amplitude and phase values of the received pilot carriers. In the second MCM-DS-SS scheme the sounding of the channel is avoided by a differential encoding of the complex-valued data symbols, before the IFFT processing, at the transmitter side. At the receiver side a dual operation is performed in order to reverse the differential encoding and to recover the effects of the channel.

Table 1 shows the most significant system parameters of the considered configurations. In order to make a number of considerations and comparisons possible, in the following we will assume some of the system and frame parameters of the IEEE 802.11 Draft Standard [1] as a reference. By observing Table 1 the following issues should be pointed out:

- The proposed system configurations are characterized by the same *chip rate* and the same *spreading factor L* of the IEEE 802.11 DS-SS Physical Layer Specifications [1].
- The measured maximum *delay spread* is 1 μs, that leads to a *coherence bandwidth* of 1 MHz. By comparing these values with the *spreading factor L* and the *channel bandwidth* it is possible to

conclude that a full exploitation of the diversity order of the channel is achieved by the proposed systems.

- The *FFT length* is 512 samples for both *system A* and *system B* configurations. This value represents a good compromise among some aspects such as: efficiency with respect to the adoption of a circular prefix between adjacent MCM blocks, system throughput for short packets and for MAC messages handshake, implementation of a real-time FFT / IFFT processor.

MCM-DS-SS WLAN SYSTEMS PARAMETERS			
MAX DELAY SPREAD (s)	1,00E-06	CARRIER FREQUENCY (Hz)	2,40E+09
COHERENCE BANDWIDTH (Hz)	1,00E+06	MAX SPEED RX-TX (m/s)	1,00
CHANNEL BANDWIDTH (Hz)	1,10E+07	MAX DOPPLER SPREAD (Hz)	8,00
CHIP RATE (chip/s)	1,10E+07	CHANNEL COHERENCE TIME (s)	1,25E-01
CHIP DURATION (s)	9,09E-08		
CIRCULAR PREFIX LENGTH (chips)	11		

System A		System B	
FRAME MAX LENGTH (bytes)	2400	FRAME MAX LENGTH (bytes)	2400
FFT LENGTH (samples)	512	FFT LENGTH (samples)	512
SPREADING FACTOR	11	SPREADING FACTOR	11
DATA SYMBOLS / MCM SYMBOL	40	DATA SYMBOLS / MCM SYMBOL	43
DATA SYMBOLS MAPPING	8-PSK	DATA SYMBOLS MAPPING	8-PSK
BITS / MCM SYMBOL	120	BITS / MCM SYMBOL	129
BYTES / MCM SYMBOL	15	BYTES / MCM SYMBOL	16
EFFECTIVE BITS / MCM SYMBOL	120	EFFECTIVE BITS / MCM SYMBOL	128
MCM DATA SYMBOLS / FRAME	160	MCM DATA SYMBOLS / FRAME	150
DATA CARRIERS	440	DATA CARRIERS	474
PILOT CARRIERS	41	PILOT CARRIERS	0
VIRTUAL CARRIERS	31	VIRTUAL CARRIERS	38
MCM CARRIERS SPACING (Hz)	21484,4	MCM CARRIERS SPACING (Hz)	21484,4
PILOT CARRIERS SPACING (Hz)	252048,4	PILOT CARRIERS SPACING (Hz)	-----
GUARD BAND (kHz)	666,0	GUARD BAND (kHz)	816,4
MCM SYMBOL RATE (symbol/s)	21032	MCM SYMBOL RATE (symbol/s)	21032
DATA BLOCK RATE (blocks/s)	21032	DATA BLOCK RATE (blocks/s)	21032
MCM SYMBOL DURATION (s)	4,75E-05	MCM SYMBOL DURATION (s)	4,75E-05
CHANNEL ESTIMATION PERIOD (s)	4,75E-05	CHANNEL ESTIMATION PERIOD (s)	4,75E-05
BIT RATE (bit/sec)	2.523.840	BIT RATE (bit/sec)	2.692.096
SYMBOL RATE	841.280	SYMBOL RATE	897.365

Table 1 *System parameters of the OM-DS-SS WLAN system.*

- The number of *data symbols*, 8-PSK mapped, in each MCM block is 40 and 43 for *system A* and *system B* respectively. This fact leads to slightly different values of spectral efficiency with *system B* being advantaged by the absence of pilot carriers in each block.
- The comparison of the *channel estimation period* of both configurations with the *channel coherence time* and of the *pilot carriers spacing* of the *system A* with the channel *coherence bandwidth* leads to the expectation of a good behavior of both the systems with respect to the estimation and tracking of the channel time-variant response.

• The maximum achievable *bit rate* is 2.523.840 bit/s for the *system A* and 2.692.096 bit/s for the *system B*. Taking into account the value of the *channel bandwidth* of 11 MHz it can be argued that the proposed system configurations show a maximum spectral efficiency value more than doubled with respect to the IEEE 802.11 (2 Mbit/s in one channel of 22 MHz).

Fig. 3 shows the frame structure of the proposed MCM-DS-SS physical layer configurations. In the *system A* a frame of 2400 bytes is segmented into 160 MCM symbols. The sounding signal is embedded in each MCM block containing 40, 8-PSK symbols corresponding to 15 bytes. Since no dedicated sounding block is required, the shortest allowed block is represented by a single 15 bytes data block. In the *system B* configuration a frame of 2400 bytes is segmented into 150 MCM symbols. The shortest allowed block is represented by a single 16 bytes data block.

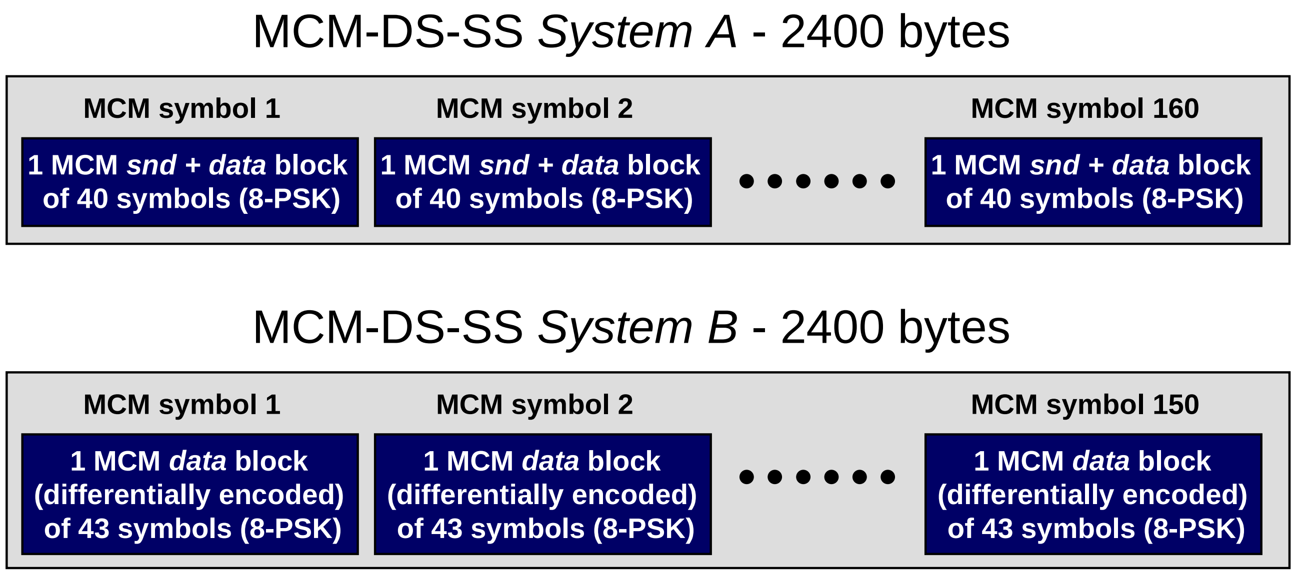

Fig. 3 *Frame format of the MCM-DS-SS physical layer configurations.*

Taking the sounding and equalization techniques into consideration, we report the bit error rate performance in terms of bit error rate and frame error rate. As already mentioned, the analysis is based on measured sets of indoor channel delay profiles, in different indoor environments. The wide-band (20 MHz) measurements of the channel, carried out at Centro Studi e Laboratori Telecomunicazioni (CSELT) in Turin, were performed inside a covered parking area and in an office environment in Line of Sight (LOS) and No Line of Sight (NLOS) conditions. During the measurements, the receiving antenna was moved along a track perpendicular to the line covering TX and RX. Figure 4 shows the geometrical arrangements of the measurement sets.

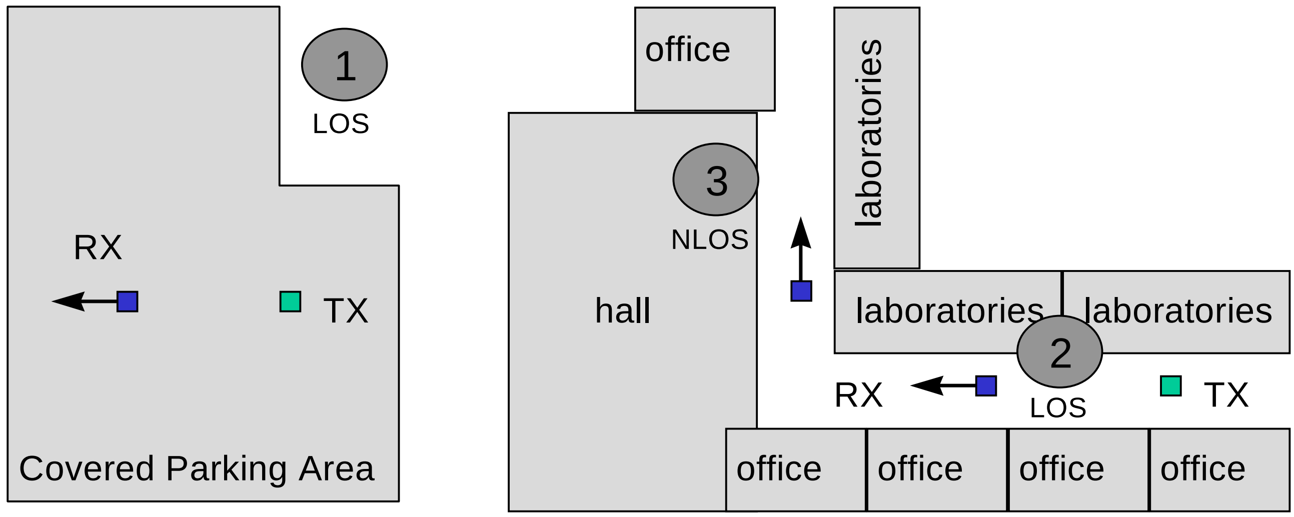

Fig. 4 *Representation of the geometrical arrangements during the measurements.*

In the analysis performed, a number of interesting results were found, but the brevity of this summary does not allow us to make an exhaustive description of them. Nevertheless the following issues emerged :

- The considered MCM-DS-SS radio access schemes perform well, both in LOS and NLOS conditions.
- The first MCM-DS-SS configuration exhibits better performance in terms of channel sounding, with respect to the second one, but it requires more processing power in the RX section of the modem due to the estimation of the channel frequency response.
- From a comparison of the MCM-DS-SS configurations with the DS-SS physical layer of the IEEE 802.11 standard a significant performance improvement emerges, particularly in NLOS conditions. This performance margin of the MCM-DS-SS schemes with respect of the DS-SS physical layer of the IEEE 802.11 can be exchanged with an increase of the operating area or/with a reduction of the transmitted power. Moreover the configurations proposed show a maximum spectral efficiency value more than doubled with respect to the IEEE 802.11

In conclusion, the proposed MCM-DS-SS physical layer configurations show good performance in terms of BER and a good capacity for counteracting multipath fading thus making the MCM-DS-SS an interesting technique to be adopted for WLAN applications.

References

[1] IEEE 802.11/D1, "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications", Draft Standard, 1 December 1994.

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