Adaptive Filter Bank Modulation for Next Generation Wireless In-Home Networks

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Abstract. In this paper we investigate the deployment of filtered multitone (FMT) modulation over in-home wireless channels. We propose the adaptation of parameters (overhead factor) to the channel condition. Optimal and sub-optimal approaches are described. Comparisons with orthogonal frequency division multiplexing (OFDM) show that FMT provides significant improvements both in single user and multi user (based on frequency division multiplexing) cases.

Key words: OFDM, Filtered Multi-Tone, OFDMA, WLAN, IEEE 802.11, Adaptive Cyclic Prefix, Adaptive Overhead.

1 Introduction

In multi carrier modulation (MCM) systems, a broadband signal is split into M narrow band signals such that each of them experiences a near flat frequency response. This idea simplifies the equalization task, namely, the mitigation of the inter-symbol interference (ISI) caused by the channel frequency selectivity, and allows approaching the channel capacity making use of bit and power loading techniques [1]. Beside, considering the multi user scenario, the M sub-channels of a MCM scheme can be optimally partitioned among the network users realizing the so called frequency division multiple access (FDMA).

A MCM system can be described using a filter bank architecture [2]. In such a case, at the transmitter side, the M parallel data signals are interpolated by a factor $N = M + \beta$, filtered with a modulated prototype pulse and transmitted over the channel. The interpolation factor (IF) N, or equally the overhead (OH) β, and the modulated prototype pulse determine the type of MCM scheme, e.g., OFDM or FMT. On the other hand, the IF also affects the achievable rate of the system. As an example, in OFDM, the IF determines the duration of the cyclic prefix (CP). As it is well known, if the CP is longer than the channel duration, the received signal will be neither affected by inter-carrier interference (ICI) nor by ISI [3]. Nevertheless, this benefit is paid in terms of a loss in achievable rate and in signal over noise ratio (SNR) of a factor $M/(M+\beta)$, with β equal to the CP duration.

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In our previous work [4], we have found that over typical WLAN channels, the CP has not to be necessarily long as the channel duration to maximize the achievable rate, or with an abuse of terminology, to maximize capacity. Furthermore, for each channel class of the IEEE 802.11n WLAN channel model [5], we have found a near optimal value of CP designed according to the statistic of the capacity-optimal CP duration. We have shown that capacity improvements for the WLAN standard are attainable adapting the CP to the experienced channel class, this is true for both the single and the multi user cases. Moreover, for the multi user case, we have found that the CP adaptation to the channel class improves the aggregate network rate either with the use of orthogonal FDMA (OFDMA) or with the use of time division multiple access (TDMA).

In [6] it has been shown that for the single user case, over typical power line channels, FMT provides significant gains in terms of achievable rate w.r.t. OFDM. This statement is true considering both FMT and OFDM with OH adapted to the channel conditions.

Inspired by the above results, in this paper we are interested on extending to the FMT the approach followed in [4] to design the OH in OFDM. That is, in this work we find a limited set of OH values for FMT using the statistic of the capacity-optimal OH. The set of OH values is used to adapt the system to the channel conditions. We call such a system adaptive-FMT. We compare adaptive-FMT with adaptive-OFDM presented in [4] and we show that further capacity improvements to the IEEE 802.11 standard could be obtained adopting the former scheme.

Regarding the multi user case, we focus on the downlink channel where the access point (AP) signals to the N_U users of the network. Considering this scenario, we propose for FMT-FDMA a sub-channel allocation algorithm jointly with the adaption of the OH duration. We then compare adaptive-FMT-FDMA with adaptive-OFDMA (presented in [4]) and we show that the former scheme significantly outperforms the latter.

The paper is organized as follows. In Section 2 we introduce the general MCM scheme as a filter bank architecture. Thus, considering a single user scenario, in Section 3 we compute the optimal and the sub-optimal OHs for both FMT and OFDM. In Section 4, we extend the OH adaptation to the multi user case, namely, to FMT-FDMA and to OFDMA.

Extensive numerical results that compare FMT and OFDM in both single and multi user cases are presented in Section 5. Finally, the conclusions follow.

2 System Model

We consider the downlink channel from the AP to the N_U users of the network. The M parallel data signals of user u are denoted with $a^{(u,k)}(\ell)$, $k = \{0, \ldots, M-1\}$, $\ell \in \mathbb{Z}$. Each data signal is interpolated by a factor N, filtered with a sub-channel pulse $g(n)$, and modulated by the k-th sub-carrier $f_k = k/M$. For both OFDM and FMT the sub-carrier modulation is accomplished via an exponential function. Therefore, the base-band discrete-time multicarrier signal for user u can be written as the output of a synthesis filter bank, i.e.,

$$x^{(u)}(n) = N \sum_{k \in \mathbb{K}^{(u)}} \sum_{\ell \in \mathbb{Z}} a^{(u,k)}(\ell) g(n - \ell N) e^{j2\pi f_k n}, \quad (1)$$

where $\mathbb{K}^{(u)}$ denotes the set of sub-channels indices assigned to user u. Clearly, $\mathbb{K}^{(u)} \subseteq \{0, \ldots, M-1\}$.

The signal is transmitted from the access point to the user u over a channel that has an equivalent complex impulse response $g_{ch}^{(u)}(n, d)$, where d denotes the distance between the transmitter and the receiver. As it was assumed in our previous work [4], also here we use the IEEE 802.11 TGn channel model [5]. We just recall that this model generates channels belonging to five classes labeled with B,C,D,E,F, and that each class is representative of a certain environment, e.g., small office, large open space/office with line of sight (LOS) and non LOS (NLOS) propagation, and so on. For a description of the channel model used through this work, please see [4], [5].

The received signal $y^{(u)}(n) = x^{(u)}(n) * g_{ch}^{(u)}(n, d)$ is analyzed with a filter bank having sub-channel pulses $h(n)$. The outputs are sampled with period N. Therefore, before equalization, the signal received by user u in the k-th sub-channel is given by

$$z^{(u,k)}(\ell) = a^{(u,k)}(\ell) g_{TOT}^{(u,k)}(0) + ISI^{(u,k)}(\ell) + ICI^{(u,k)}(\ell) + \eta^{(u,k)}(\ell) \ . \quad (2)$$

In (2), $g_{TOT}^{(u,k)}(0)$ denotes the complex amplitude of the data of interest, whereas, $ISI^{(u,k)}(\ell)$, $ICI^{(u,k)}(\ell)$, and $\eta^{(u,k)}(\ell)$ respectively denote the ISI, the ICI and the noise term experienced by user u in sub-channel k. The interference terms are in general present when transmitting through a frequency selective channel. They can be mitigated with some form of equalization. The filter bank design aims at reaching a tradeoff between ISI and ICI. While the presence of both ISI and ICI requires a multi-channel equalizer, the presence of only ISI allows using sub-channel equalization. In our analysis we consider the use of sub-channel equalization only. Therefore, the signal after the sub-channel equalization can be written as

$$z_{EQ}^{(u,k)}(\ell) = a^{(u,k)}(\ell) g_{EQ}^{(u,k)}(0) + ISI_{EQ}^{(u,k)}(\ell) + ICI_{EQ}^{(u,k)}(\ell) + \eta_{EQ}^{(u,k)}(\ell) \ , \quad (3)$$

where we use the subscript EQ to denote the dependence from the equalizer. The terms $g_{EQ}^{(u,k)}(0)$, $\eta_{EQ}^{(u,k)}(\ell)$, $ISI_{EQ}^{(u,k)}(\ell)$ and $ICI_{EQ}^{(u,k)}(\ell)$, respectively denote the peak of the overall impulse response, the noise term and the interference terms at the k-th sub-channel equalizer output.

In the next sub-sections we derive the OFDM and the FMT MCM schemes.

OFDM. The OFDM scheme can be obtained setting the synthesis and the analysis pulses respectively equal to

$$g(n) = \frac{1}{N} rect\left(n/N\right), \qquad h(n) = \frac{\sqrt{N}}{M} rect\left(-(n+\beta)/M\right), \quad (4)$$

where $rect\,(n/A) = 1$ for $n = \{0, 1, \ldots, A-1\}$ and zero otherwise. The factor β denotes the length of the CP. As previously said, when the length of the CP is greater than the channel duration, the received signal (2) is neither affected by ISI nor by ICI [3]. In such a case the equalization task reduces to a simple single tap zero forcing sub-channel equalizer. Through this work, when showing numerical results for OFDM, we assume the use of a simple single tap sub-channel equalizer. That is, each sub-channel equalizer multiplies the received signal (2) by $\left(g_{TOT}^{(u,k)}(0)\right)^{-1}$. We make this assumption to maintain simple the OFDM implementation.

FMT. FMT was originally proposed for application in very high speed digital subscriber lines (VDSL) [7]. Then, studied for multi user wireless communications in [8]. Recently, it has been investigated for power line channels [6, 9]. In FMT the sub-channel symbol period is N and the analysis pulse is matched to the synthesis pulse, i.e., $h(n) = g^{(*)}(-n)$. A distinctive characteristic of FMT is that the prototype pulse is designed to obtain high frequency confinement [7]. Therefore, qualitatively we can say that in FMT the ICI term is negligible, and thus the equalization task focuses on deleting the ISI term. This observation justifies our assumption of considering only sub-channel equalization.

When showing numerical results for FMT, we consider MMSE fractionally spaced sub-channel equalization [10]. Furthermore we deploy truncated root-raised-cosine pulse with rolloff equal to $(N-M)/M$, and length 10 symbols to obtain good frequency confinement.

3 Adaptive Overhead: The Single User Case

In this section we first recall the method used in [6] to optimally adapt the OH of OFDM and FMT to the channel realization. Then, we briefly recall the method proposed in [4] to adapt the CP of OFDM to the experienced channel class of the 802.11n channel model [5]. Finally, making the proper adjustments, we extend this last method to FMT.

3.1 Optimal OH Adaptation

In order to evaluate the impact of the OH duration on the system performance we compute the capacity assuming parallel Gaussian channels. That is, we assume additive white Gaussian noise, independent and Gaussian distributed input signals, which renders ISI and ICI also Gaussian (cf. e.g. [3]). The capacity in bit/s for the link of user u and for a given channel realization is given by

$$C^{(u)}(\beta) = \sum_{k \in \mathbb{K}^{(u)}} C^{(u,k)}(\beta), \tag{5}$$

with

$$C^{(u,k)}(\beta) = \frac{1}{(M+\beta)T} \log_2 \left(1 + SINR_{EQ}^{(u,k)}(\beta)\right), \quad (6)$$

where $SINR_{EQ}^{(u,k)}(\beta)$ denotes the signal over interference plus noise ratio, after sub-channel equalization, experienced by user u in sub-channel k when we transmit using an OH of β samples. Details on its computation, for OFDM, can be found in [11].

In (5), the factor T denotes the system sampling period. Through this work we assume to transmit power across sub-channels at a constant level given by a constraint on the power spectral density (PSD).

From (5), we can see that the capacity of both OFDM and FMT is a function of the OH duration β. Therefore, considering a single link communication, the optimal approach to adapt the OH to the channel realization is to choose β as such value that maximizes capacity (5), i.e.,

$$\beta_{opt}^{(1)} = \underset{0 \le \beta < \nu^{(1)}}{\text{argmax}} \left\{ C^{(1)}(\beta) \right\}, \quad (7)$$

where we have denoted with $\nu^{(1)}$ the channel duration in samples.

Since the argument of (7) is generally not convex, the implementation of the optimal approach to adapt the OH to the channel realization requires an exhaustive search which is complex.

A significant simplification that assures the feasibility of the OH adaptation to the channel realization, is to pre-compute a limited amount of OH values, and then adapt the OH over this small set of values. This is discussed in the next sub-section.

3.2 Simplified OH Adaptation

In this section we are interested at finding a finite set of OH values over which perform adaptation. The method that we use is based on the evaluation of the statistic of the capacity-optimal OH (7). As it will be clarified in the following, since the statistic of the capacity-optimal OH depends on the used MCM scheme, in the following we distinctly describe the simplified OH adaptation for OFDM and FMT.

Simplified OH Adaptation in OFDM. To determine the limited set of CP values for OFDM, in [4] we have proposed an approach based on the evaluation of the cumulative distribution function (CDF) of the capacity-optimal CP (7). The numerical results (see Section 5) show that the capacity-optimal CP value depends on the specific channel realization and therefore, in general, it relies on the channel class and on the distance between the AP and the user. However, we have noted that the CP value variations are more pronounced among classes than within a given class. That is, the variation of the CP for the channel realizations of a given class for various distances is not as significant as if we draw channels from different classes. Hence, we have proposed to choose a single value of CP for all channel realizations that belong to a certain channel class. For a given class and distance, the specific CP length is chosen to be the value of β for which the CDF of (7) is 99%. Then, to obtain a single CP value associated to that class we pick the largest CP among those obtained for the considered set of distances, say from 3 m to 60 m. The set of the obtained CP values for the five classes is denoted with $\mathbb{P}_{OFDM} = \left\{\beta^{(99\%)}_{B,OFDM}, \beta^{(99\%)}_{C,OFDM}, \beta^{(99\%)}_{D,OFDM}, \beta^{(99\%)}_{E,OFDM}, \beta^{(99\%)}_{F,OFDM}\right\}$.

Clearly, once the devices know the scenario in which they are working, or equivalently the experienced channel class, the CP adaptation reduces to pick the corresponding value of CP from the set $\mathbb{P}_{OFDM}$.

Simplified OH Adaptation in FMT. To determine the limited set of OH values for FMT, we use a method similar to the one above described for OFDM.

Looking at the capacity-optimal OH CDFs of FMT (see Section 5), we notice that its variations are more pronounced within a given class than among different classes. In other words, the capacity-optimal OH CDF of FMT strongly relies on the distance between transmitter and receiver. Whereas, for a given distance, the dependence among classes is negligible. Therefore, for FMT we choose to define the limited set of OH values based on the distance between transmitter and receiver. In order to have a limited set of OH values, we compute the capacity-optimal OH CDF only for four values of distances, i.e., 3 m, 10 m, 30 m, 60 m. Now, for each value of distance, we choose a near optimal OH as the value of OH that renders the corresponding capacity-optimal OH CDF equal to 99%. The corresponding set of OH values is $\mathbb{P}_{FMT} = \left\{\beta^{(99\%)}_{3,FMT}, \beta^{(99\%)}_{10,FMT}, \beta^{(99\%)}_{30,FMT}, \beta^{(99\%)}_{60,FMT}\right\}$.

Differently from OFDM, in this case even if the devices know the scenario where they are working (or equally the experienced channel class) the choice of the OH requires an exhaustive search over the values of OH belonging to $\mathbb{P}_{FMT}$. Therefore, $\beta^{(1)}_{opt} = \text{argmax}_{\beta \in \mathbb{P}_{FMT}} \left\{C^{(1)}(\beta)\right\}$.

It is worth noting that for FMT, if we chose for each channel class, the smallest value of β such that all the OH CDFs are lower than 0.99, as we did for OFDM, we would obtain the same OH value for all the channel classes. Thus, this method could be used to design a single value of OH in FMT.

4 Adaptive Overhead: The Multi User Case

Since we have already shown in [4] that OFDMA outperforms OFDM that deploys time division multiple access, to assess the performance of multiuser FMT we consider a network where multiplexing is accomplished via FDMA. Therefore, depending on the considered MCM scheme we have FMT-FDMA and OFDMA. We focus on the downlink channel from the AP to the N_U users of the network. Since the channels experienced by the users are different, the AP allocates the sub-channels and the OH according to a fair principle based on maximizing the aggregate network rate but assuring that all users exceed a minimum rate.

In the following we extend to the case of FMT-FDMA the optimal and the sub-optimal OH and sub-channels allocation algorithms that we have described in [4] for OFDMA.

4.1 Sub-channels and OH Adaptation

In order to allocate the sub-channels to the network users, for a certain value of β, the AP can solve the following optimization problem

$$R(\beta) = \max_{\underline{\alpha}} \quad \sum_{u=1}^{N_U} \sum_{k\in\mathbb{K}} \alpha^{(u,k)} C^{(u,k)}(\beta), \qquad \text{s.t.} \sum_{u=1}^{N_U} \alpha^{(u,k)} = 1, \quad k \in \mathbb{K},$$
$$\sum_{k\in\mathbb{K}} \alpha^{(u,k)} C^{(u,k)}(\beta) \geq p^{(u)} \sum_{k\in\mathbb{K}} C^{(u,k)}(\beta), \quad u = 1, ..., N_U. \tag{8}$$

In (8), $\alpha^{(u,k)}$ denotes the binary sub-channel coefficient equal to 1 if sub-channel k is allocated to user u, and to zero otherwise, and $\underline{\alpha} = \{\alpha^{(u,k)}$, for $u = 1, \ldots, N_U$; and $k \in \mathbb{K}\}$. $p^{(u)}$ are quality of service coefficients, each indicates the percentage of achievable rate that the u-th user has to achieve w.r.t. the one that it would achieve in the corresponding single user scenario. $R(\beta)$ denotes the aggregate network rate when deploying an OH of β samples. $\mathbb{K}$ denotes the set of available sub-channels, e.g., for the WLAN standard [12], it corresponds to $M = 64$ sub-channels deployed in a frequency band of 20 MHz. Problem (8) can be solved using integer programming (IP) [13]. In order to diminish the computational complexity, we solve (8) via linear programming (LP) followed by rounding the coefficients $\alpha^{(u,k)}$ to the nearest zero or one integer. Consequently, for each value of β the set of sub-channels assigned to user u is given by $\mathbb{K}^{(u)} = \{k : \alpha^{(u,k)} = 1\}$. The optimal value of β is obtained by the maximization: $\text{argmax}_\beta \{R(\beta)\}$.

The exhaustive search of the OH values renders the algorithm complexity relatively high. A significant simplification is obtained if we solve (8) with LP only for the finite set of OH values that has been pre-determined in the single user case according to the criteria of Section 3.2. That is, the optimal OH is respectively given by $\beta_{\text{opt}}^{OFDMA} = \text{argmax}_{\beta\in\mathbb{P}_{OFDM}} \{R(\beta)\}$ for OFDMA, and by $\beta_{\text{opt}}^{FMT-FDMA} = \text{argmax}_{\beta\in\mathbb{P}_{FMT}} \{R(\beta)\}$ for FMT-FDMA.

It is worth noting that for the case of OFDMA, if the environment where the devices operate is known, or in other words, the AP knows the channel class of its network, the set $\mathbb{P}_{OFDM}$ of the CPs reduces to one value. Therefore, for OFDMA, the allocation of sub-channels to the network users consists in solving (8) only for a single value of β.

5 Numerical Results

To obtain numerical results, we have chosen the following system parameters that, considering OFDM, are essentially those of the IEEE 802.11 standard [12]. The MCM systems use $M = 64$ sub-channels with a transmission bandwidth of 20 MHz. The signal is transmitted with a constant power spectral density (PSD) of -53 dBm/Hz. At the receiver side, we add white Gaussian noise with PSD equal to -168 dBm/Hz. Thus, the signal to noise ratio (SNR), without path loss and fading, on each sub-channel is 115 dB. The baseline systems use an OH of 0.8 μs that corresponds to the value of CP employed in the IEEE 802.11 standard [12].

Fig. 1 shows the capacity (5) as a function of the OH duration for both OFDM and FMT for 100 class B channel realizations. The distance between transmitter and receiver equals 10 m. As we can see in both cases an optimal OH that maximizes the capacity (5) can be found for each channel realization. Furthermore, we can see that in general the capacity is not a convex function of the OH, this is especially true for FMT, but in general it can also happen for OFDM. This observation justifies the exhaustive search (7) over the values of OH to find the optimal OH value to be used for each channel realization. On the other hand, we can see that the capacity curves are relatively flat around the optimal OH value. Therefore, the choice of an OH close to the optimal one will not dramatically change the capacity value w.r.t. the maximum. These observations justify our proposal to design the OH according to the capacity-optimal OH CDF as described in Section 3.2. From Fig. 1 we can also notice that the OH adaptation significantly improves the system performance w.r.t. the baseline system that deploys an OH of 0.8 μs.

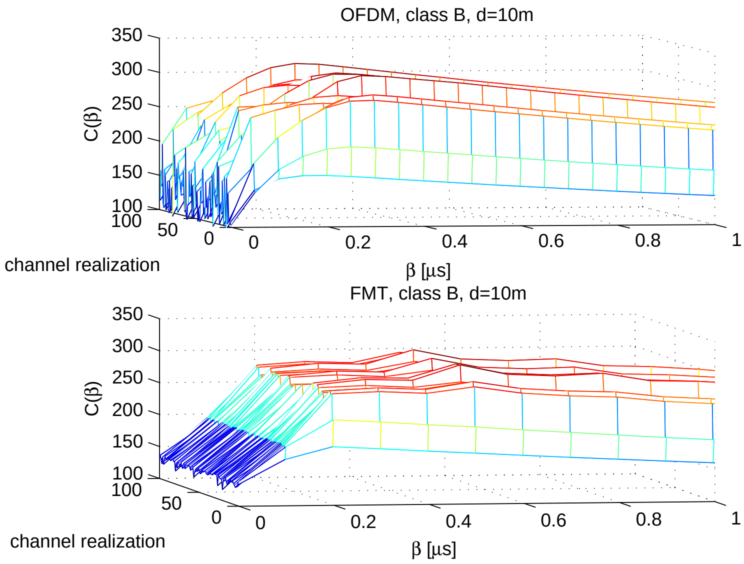

Fig. 1. Capacity as a function of the OH duration for 100 class B channel realizations using OFDM (top), and FMT (bottom). The distance between transmitter and receiver is set equal to 10 m.

Figs. 2,3 respectively show the capacity-optimal OH CDFs for FMT and for OFDM for each channel class and for different distances between transmitter and receiver. From Fig. 2 (see the first 5 sub-plots starting from the top), we

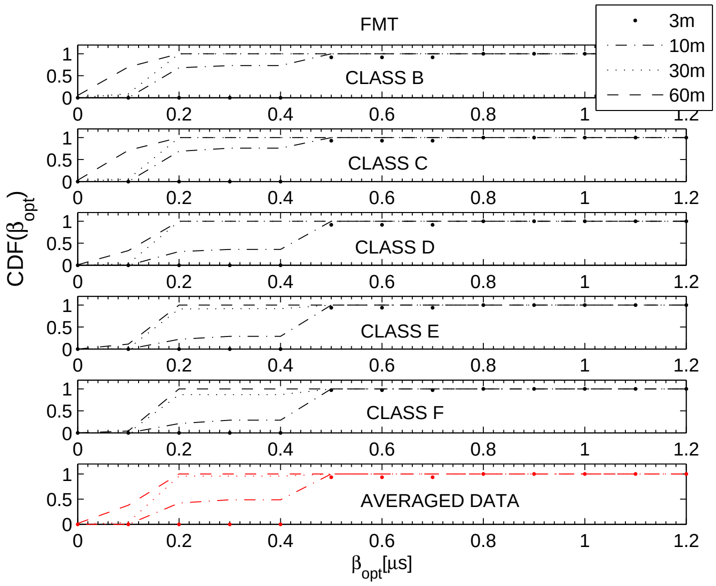

Fig. 2. Optimal OH CDF for FMT considering each single channel class, and all the classes together. The distances between transmitter and receiver are set equal to 3 m, 10 m, 30 m, and 60 m.

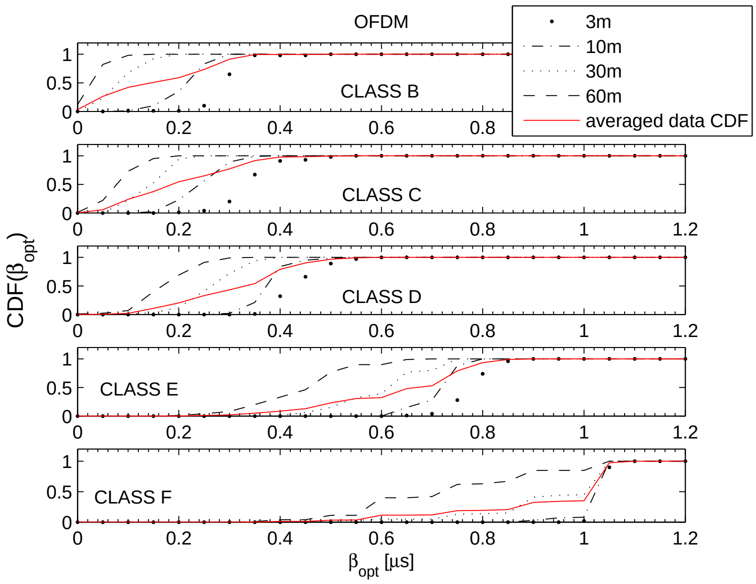

Fig. 3. Optimal CP CDF for OFDM considering channels of class B, C, D, E, and F. The distances between transmitter and receiver are set equal to 3 m, 10 m, 30 m, and 60 m.

can see that for FMT the optimal OH CDF does not appreciably depend on the experienced channel class but it shows a strong dependance on the distance between transmitter and receiver. Thus, as explained in Section 3.2 for each value of distance considered, we choose a near optimal OH value as such value that renders the optimal OH CDF equal to 0.99(obtained averaging the data across all the channel classes, see the last sub-plot of Fig. 2). The corresponding set of OH values is $\mathbb{P}_{FMT} = \{\beta^{(99\%)}_{3,FMT} = 0.8\mu s$, $\beta^{(99\%)}_{10,FMT} = 0.5\mu s$, $\beta^{(99\%)}_{30,FMT} = 0.2\mu s$, $\beta^{(99\%)}_{60,FMT} = 0.2\mu s\}$.

Regarding Fig. 3, we can see that for OFDM the optimal OH CDF depends more on the channel class than on the distance. Thus, as assumed in [4], for each channel class, we choose a near optimal value of OH (or equally CP) that renders the optimal OH CDF (obtained averaging the data over the distances) equal to 0.99. The corresponding set of OH values is $\mathbb{P}_{OFDM} = \{\beta^{(99\%)}_{B,OFDM} = 0.4\mu s$, $\beta^{(99\%)}_{C,OFDM} = 0.5\mu s$, $\beta^{(99\%)}_{D,OFDM} = 0.6\mu s$, $\beta^{(99\%)}_{E,OFDM} = 0.9\mu s$, $\beta^{(99\%)}_{F,OFDM} = 1.1\mu s\}$. It is worth noting that the application to FMT of the criterion used to compute the limited set $\mathbb{P}_{OFDM}$ for OFDM, would return a single value of OH equal to 0.8 μs. This is because, as shown in Fig. 2, the optimal OH of FMT does not depend on the channel class. Thus, for all the channel classes we would obtain the same value of β that renders all the CDFs equal to 0.99. This criterion could be adopted to design a globally acceptable value of OH for FMT.

The different behavior of the optimal OH CDFs for FMT and OFDM is due to the use of different sub-channel pulses and equalization scheme. In FMT the ICI is minimized via the design of the OH factor together with the sub-channel pulse, while the ISI is mitigated with the use of the sub-channel equalizer. In OFDM since we deploy a single tap equalizer, the OH (cyclic prefix) has to be designed such that we tradeoff between ISI+ICI and noise. Indeed, multichannel equalization is in principle applicable in OFDM in order to mitigate the ICI with a CP shorter than the channel response, which however, increases significantly complexity.

Let us now focus on the optimal OH CDF of OFDM (see Fig. 3). As previously observed, the optimal OH depends on the experienced channel class. This is because each channel class is characterized by a certain r.m.s. delay spread, and as it is well known, in OFDM the channel temporal dispersion that causes ISI is handled with the CP. Consequently, for each channel class a different value of OH (or equally CP) is needed to deal with the ISI term. Obviously, the for the ICI term considerations similar to the ones done for FMT are also valid for OFDM. Now, in Fig. 4 we report the complementary CDF (CCDF) of the capacity (5) obtained for FMT and OFDM with both the optimal OH value (7) and the sub-optimal ones above listed. The used channel classes are the B, D, and F. The distance between transmitter and receiver is set equal to 3 m, 10 m and 30 m. As we can see, in almost all the cases, FMT with OH optimized outperforms OFDM with OH optimized. This is true using either the optimal OH adaptation (7) based on the exhaustive search, or the simplified OH adaptation based on the limited search over the sets $\mathbb{P}_{OFDM}$ and $\mathbb{P}_{FMT}$. Note that, also if

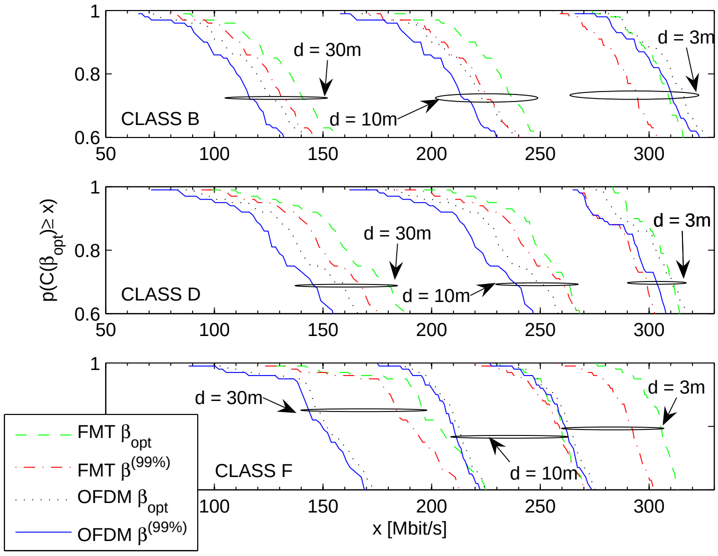

Fig. 4. CCDF of capacity using OFDM and FMT with optimal and limited OH adaptation. The used channel classes are the B,D, and F. The distances between the transmitter and the receiver are set equal to 3 m, 10 m, and 30 m.

not shown for space limitation, the CCDF of the capacity for OFDM and FMT with OH equal to 0.8 μs would give worse performance than the showed one. As for instance see the CCDF of the baseline OFDM system in [4].

Finally, in Fig. 5 we show the CCDF of the aggregate network rate obtained using the algorithm exposed in Section 4 for both FMT-FDMA and OFDMA. Also shown are the CCDF obtained using the baseline systems that deploy an OH equal to 0.8 μs. The network is composed by 4 users. The weights $p^{(u)}$ are equal to 0.25. Therefore, we have considered a proportional fair resource allocation. The users experience channels belonging to the same class, the channel class is randomly selected, and the distance between each user and the AP is drawn randomly between 3 m and 60 m. As we can see, the limited OH adaptation to the channel condition improves the performances of both FMT-FDMA and OFDMA w.r.t. the baseline system that deploys an OH equal to 0.8 μs. More precisely, with probability equal to 0.9, the limited OH adaptation respectively improves the aggregate network rate of about 7% for OFDMA, and of about 12% for FMT-FDMA. From Fig. 5, we also notice that the use of adaptive FMT-FDMA, with probability equal to 0.9, improves the aggregate network rate of about 27% w.r.t. the use of OFDMA with a fixed CP value equal to 0.8μs.

6 Conclusions

The use of adaptive FMT could further improve the WLAN standard capacity w.r.t. the use of adaptive OFDM. This is true for both the single user case and the

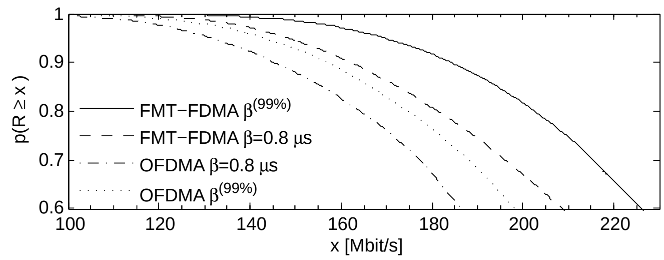

Fig. 5. CCDF of the aggregate network rate obtained using the limited OH adaptation for both OFDMA and FMT-FDMA. Also plotted are the CCDFs obtained using FMT-FDMA and OFDMA with a fixed OH of 0.8 μs.

multi user case that deploys FDMA. Ongoing work is assessing the complexity implications and the approaches to reduce it.

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