Performance Evaluation of DVB-T2 Time Interleaving in Mobile Environments

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Abstract—**This paper investigates the performance of time interleaving in DVB-T2 in the context of mobile reception. By means of time interleaving it is possible to provide time diversity and improve the robustness of the transmitted information in mobile environments. DVB-T2 implements a highly flexible time interleaving that allows different trade-offs in terms of time diversity, latency and power saving. DVB-T2 also includes the possibility to particularize the transmission parameters on a service basis by means of multiple physical layer pipes. This way, it is possible to accommodate different use cases: fixed, portable and mobile, in the same frequency channel. This paper evaluates the time interleaving capabilities of DVB-T2 by means of physical layer simulations. The paper also proposes and evaluates a configuration that has been optimized for handheld reception.**

Keywords; DVB-T2, mobile TV, performance evaluation, FEC, time interleaving

I. INTRODUCTION

DVB-T (Digital Video Broadcasting – Terrestrial) has been adopted by many countries over the world for the provision of DTT (Digital Terrestrial TV) services. DVB-T was originally designed for fixed and portable reception, and it is not well suited for mobile scenarios due to the lack of power saving and more importantly time interleaving.

DVB-T2 (Digital Video Broadcasting – Terrestrial 2nd Generation) [1] is the second generation digital terrestrial transmission system developed by the DVB. It was finalised in June 2008. The first commercial transmissions of DVB-T2 began in the UK in December 2009. Finland is expected to become the second country to provide commercial DVB-T2 services in late 2010.

DVB-T2 was designed to provide a minimum capacity increase of 30% over DVB-T in order to accommodate HD (High Definition) TV channels. DVB-T2 incorporates the latest modulation and coding techniques in order to increase the robustness of the transmitted information. DVB-T2 also introduces physical layer pipes (PLPs) in order to achieve a per-service particularization of the transmission parameters. This characteristic allows the provision of different use cases in the same frequency channel: fixed, portable and mobile.

While DVB-T2 primarily targets fixed and portable reception, its enhanced robustness and high degree of flexibility is well suited to mobile environments as well. DVB-T2 implements a highly flexible time interleaving that can provide different trade-offs between time diversity, latency and power saving. Fixed services in DVB-T2 can sacrifice time diversity in order to reduce the latency whereas mobile services can benefit from increased time diversity or power saving at the expense of additional delay. Because of its superior performance and high flexibility, the physical layer of DVB-T2 is currently considered as a reference in the standardization process of the next generation mobile TV standard DVB-NGH (Digital Video Broadcasting – Next Generation for Handhelds) [2].

The mobile performance of DVB-T2 has been previously evaluated in [3], where certain parameters such as the guard interval, the FFT size or the utilization of rotated constellations were investigated by means of laboratory tests. In this paper we evaluate the performance of DVB-T2 time interleaving by means of physical layer simulations. Moreover, we propose and evaluate a configuration that has been optimized for the handheld scenario. This configuration provides adequate time diversity, latency and power saving levels according to the use case.

The paper is organized as follows. In Section II we describe the physical layer of DVB-T2 and the key technologies that have been included in the standard. Section III is dedicated to the time interleaver and the different configurations that are available in DVB-T2. Section IV details the simulation scenario whereas Section V is dedicated to the simulation results. We close the paper in Section VI with some concluding remarks.

II. DVB-T2 PHYSICAL LAYER

DVB-T2 incorporates a large number of new features over its predecessor in order to provide better robustness, capacity and flexibility [4]. OFDM symbols are arranged into T2 frames for transmission. Each T2 frame contains an entire number of OFDM symbols and can be configured with a length up to 250 ms. FFT modes with sizes of 1K, 4K, 16K and 32K OFDM sub-carriers have been added to the 2K and 8K modes in order to provide a wider selection of network configurations. The utilization of larger FFT sizes increases the capacity of the system but results in decreased Doppler performance due to the shorter separation between sub-carriers. DVB-T2 also allows the utilization of extended carrier modes that place additional sub-carriers in the edges of the OFDM symbols in order to increase the system capacity. Extended modes are allowed for 8K, 16K and 32K FFT sizes. Although the inclusion of additional sub-carriers extends the spectrum of the OFDM signal it also causes the rectangular part of the spectrum to roll off more quickly. This characteristic decreases the interference that is introduced in the adjacent bands and allows the utilization of extended carrier modes in a high number of scenarios.

In order to increase the number of bits per sub-carrier, the 256QAM constellation has been added to the 64QAM, 16QAM and QPSK constellations that were already included in DVB-T. While DVB-T employed a single pilot patter,

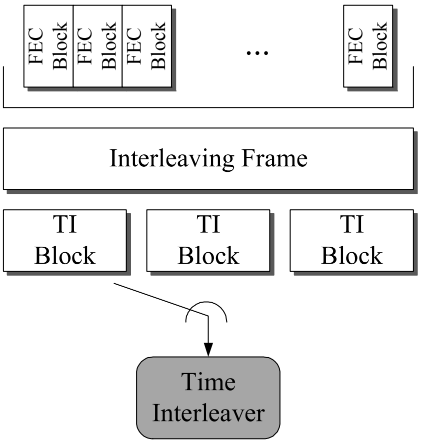

Figure 1. Time interleaving implemented in DVB-T2. In the Figure one interleaving frame is partitioned into three TI blocks.

DVB-T2 defines 8 different pilot patterns depending on the selected FFT size and guard interval. This allows the provision of sufficient channel estimation according to the reception scenario while minimizing the pilot overhead. The overhead due to pilot sub-carriers has been reduced in DVB-T2 compared to DVB-T from 10.6% down to 1.35%, 2.35%, 4.35% or 8.35%, depending on the selected pilot pattern. By means of larger FFT sizes, extended carrier modes, higher order constellations and reduced pilot density, DVB-T2 can transmit more information per OFDM symbol and achieve better spectral efficiency than the legacy DVB-T.

Regarding channel coding, DVB-T2 inherits the same concatenation of LDPC (Low Density Parity Check) and BCH (Bose Chaudhuri Hocquenghem) codes that were included in the DVB-S2 (Digital Video Broadcasting – Satellite 2nd Generation) standard. DVB-T2 supports six different code rates (1/2, 3/5, 2/3, 3/4 and 5/6) and two different FEC code word lengths (16200 and 64800 bits). The combination of LDPC and BCH coding provides better robustness than the convolutional and Reed Solomon codes used in DVB-T [5]. This increased robustness can be traded for higher capacity by means of higher code rates, larger FFT modes or higher order constellations. A bit interleaving and a bit-to-cell demultiplexer are placed after the FEC channel coding in order to assign the less protected bits of the FEC word to the more robust positions in the constellation points of 16QAM, 64QAM and 256QAM constellations. This way it is possible to compensate the unequal bit protection performed by the LDPC code. DVB-T2 also includes rotated constellations in order to improve the robustness. The constellation points are rotated in the complex and imaginary plane so that it is possible to recover the transmitted symbol with only the real or the imaginary part. After this, the imaginary part of each complex symbol is cyclically delayed with respect to the real part. By doing this, the real and imaginary part of each symbol end up being assigned to different cells and are transmitted in different sub-carriers. After the symbol mapping, cell, time and frequency interleavers are placed in order to ensure an uncorrelated error distribution inside the FEC code words in time or frequency selective propagation channels.

While DVB-T was entirely based on the transmission of MPEG-2 transport streams (TS), DVB-T2 also supports generic streams (GS) as input format. The utilization of GS provides a more efficient encapsulation of IP packets and results in less overhead due to packet headers. TS or GS packets are encapsulated inside baseband frames (BB frames) before being modulated and transmitted over the air. Each BB frame constitutes a FEC code word that is independently encoded by the LDPC and BCH encoders. The FEC blocks that results from the LDPC and BCH encoding have a constant size of 16200 or 64800 bits depending on the selected FEC word length.

DVB-T2 introduces the utilization of physical layer pipes (PLPs) in order to provide per-service configuration of transmission parameters such as constellation size, code rate or time interleaving. Each PLP carries a data stream (e.g. TS or GS) and can be transmitted with a particular set of transmission parameters. Different PLPs are multiplexed in time inside the T2 frames. The period of time inside a T2 frame that corresponds to a contiguous portion of information from the same PLP is referred to as sub-slice. Sub-slices carrying information from different PLPs are placed one after another in the T2 frames. By transmitting multiple PLPs it is possible to accommodate in the same frequency channel multiple services targeted to different use cases.

III. TIME INTERLEAVING IN DVB-T2

In Figure 1 it is shown the time interleaving mechanism of DVB-T2. As can be seen in the figure, FEC blocks belonging to the same PLP are grouped in interleaving frames for time interleaving purposes. Time interleaving in DVB-T2 is performed on time interleaving blocks (TI blocks). Each TI block contains a dynamically variable integer number of FEC blocks that are interleaved before transmission. It should be noted that no interleaving exists between FEC blocks pertaining to different TI blocks. Due to fact that only one interleaving frame can be transmitted in each T2 frame, it may be necessary to partition the interleaving frames into several TI blocks in order to fit the TI memory. This is the case of high data rate PLPs that result in bigger interleaving frames than the available TI memory in the time interleaver. In the figure, the interleaving frame is partitioned into three different TI blocks that will be interleaved by the time interleaver and transmitted one after the other.

The interleaving depth in DVB-T2 is defined as the period of time that passes from the first and last OFDM symbol carrying information from the same TI block. The maximum interleaving depth that can be provided in DVB-T2 is limited by the TI memory. The available TI memory in DVB-T2 receivers has been set in the standard to approximately 2^{19} cells as a compromise between performance and hardware complexity. The maximum interleaving depth that can be provided in DVB-T2, I, can be computed as follows:

$$I \approx \frac{2^{19} \times CR \times \log_2[\mu]}{R_b} \tag{1}$$

where CR is the code rate, μ is the number of symbols in the QAM constellation (e.g., 4 for QPSK), and R_b is the service data rate. Because of the limitation in the available TI memory, long interleaving depths in DVB-T2 are only possible in the case of low data rate services. Higher order constellations and higher code rates also facilitate the provision of longer time interleaving.

After the TI blocks have been interleaved, the interleaving frame is mapped to T2 frames for transmission. DVB-T2 can

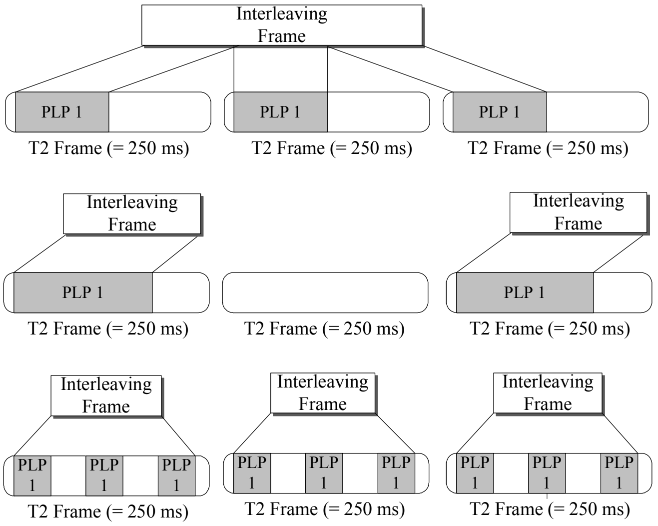

Figure 2. Frame mapping options in DVB-T2: multi-frame interleaving (top), frame hopping (center) and sub-slicing (bottom).

perform *multi-frame interleaving*, *frame hopping* and *sub-slicing* when mapping the information into T2 frames. The three options are illustrated in Figure 2.

Multi-frame interleaving is accomplished when one interleaving frame is carried over multiple T2 frames. This allows the provision of time interleaving depths beyond the duration of one T2 frame. It must be noted that the maximum interleaving depth is always limited by (1). In Figure 2 it is shown how an interleaving frame is mapped to three different T2 frames. The utilization of multi-frame interleaving increases the time diversity at the expense of additional latency and longer channel switching times. Although latency can be tolerable in certain transmissions like non-live events, the channel switching time is considered as a key parameter in TV usability. In [6] it is stated that channel switching times shorter than 500 ms are seen as instantaneous whereas more than 2 seconds are felt as annoying. Since the channel switching time is proportional to the interleaving depth, the utilization of multi-frame interleaving can result in channel switching times above tolerable values.

Frame hopping consists in the mapping of interleaving frames to non-consecutive T2 frames. This way, the information of one PLP is only carried in a sub-set of T2 frames regularly spaced over time. The separation between frames carrying information from one PLP is referred to as the *frame interval*. A frame interval of two T2 frames is illustrated in Figure 2. DVB-T2 receivers can perform power saving by switching off their front ends during the portions of time where no information of the PLP is transmitted. By means of frame hopping receivers can sleep during entire T2 frames and achieve better power saving. On the other hand, frame hopping results in an increase of the average channel switching time that is proportional to the frame interval. When switching to a new PLP, the receiver has to wait a period of time until the arrival of the first T2 frame carrying information of the PLP. This period of time is on average equal to half the duration of the frame interval.

Sub-slicing is used when each PLP is transmitted inside several sub-slices per T2 frames. Sub-slices from different PLPs are placed regularly one after the other inside the T2 frames in order to cover the entire duration of the frame. The maximum time diversity is achieved when the number of sub-slices is equal or higher than the number of OFDM symbols in the T2 frame and PLPs are continuously transmitted over time. In Figure 2 an example of sub-slicing is shown where the interleaving frame is transmitted in three sub-slices. Due to synchronization issues, receivers must wake up before the actual reception of each sub-slice. Because of this, the period of time in which receivers can maintain their RF components off decreases with the number of sub-slices. Unless frame hopping is used, power saving cannot be achieved if the information is continuously transmitted inside the T2 frames. It should be noted that only certain values of sub-slicing are allowed in the standard. This is due to undesirable interactions with the frequency interleaver that may result in the loss of frequency diversity.

TABLE I. SIMULATION PARAMETERS

System Parameters	Value
Bandwidth	8 MHz
Transmission mode	SISO
FFT size	8K
Guard interval	1/4
T2 frame length	250 ms
Constellation	16QAM
Rotated constellations	Yes
Channel estimation	Perfect
QAM demapping	Genie Aided
FEC code word length	16200 bits
FEC blocks per T2 frame	43
Channel Model	TU6
QoS criterion	BBFER 1%
Simulation length	300 T2 frames

IV. PERFORMANCE EVALUATION

Table I shows the system parameters chosen for the simulations. Each T2 frame carries only one PLP whereas the rest of the frame is assumed to be filled with dummy data and is not taken into account for the error computation. We have considered the transmission of 43 FEC blocks per T2 frame in order to maintain the same PLP data rate for every time interleaving configuration. In this case, the PLP data rate is about 2.8 Mbps. The service data rate is obtained after multiplying this value by the code rate.

We have selected the BBFER (Baseband Frame Error Rate) 1% as QoS criterion in the simulations. Bit error ratios (BER) were used to evaluate the system performance in the standardization process of DVB-T2. More specifically, the QoS criterion followed was a BER of 10^{-4} after LDPC decoding [7]. However, BER criterions only indicate the percentage of erroneous bits and do not take into account the bit error correlation. DVB-T2 relies on the BCH error detection capabilities to detect and discard erroneous BB frames. Due to the fact that one single erroneous bit is enough to corrupt an entire BB frame, the final performance of the system depends highly on the bit error correlation. Because of this, BBFER criterions are better representatives of the QoS seen by the upper layers in mobile wireless channels.

In order to evaluate the performance of DVB-T2 in mobile scenarios we have employ the 6-taps typical urban (TU6) channel model. This model was used for the performance

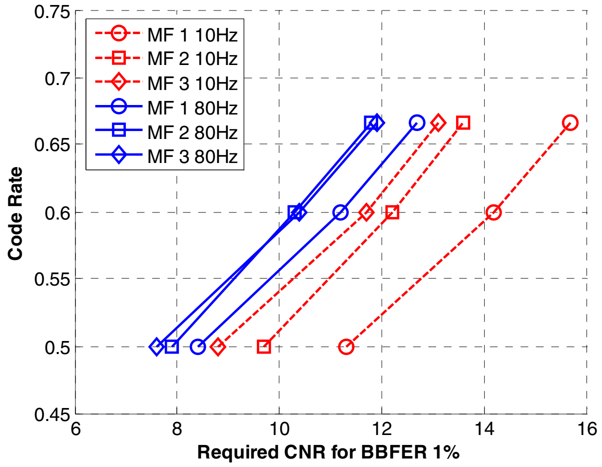

Figure 3. Comparison of different multi-frame interleaving (MF) configurations in the TU6 channel model.

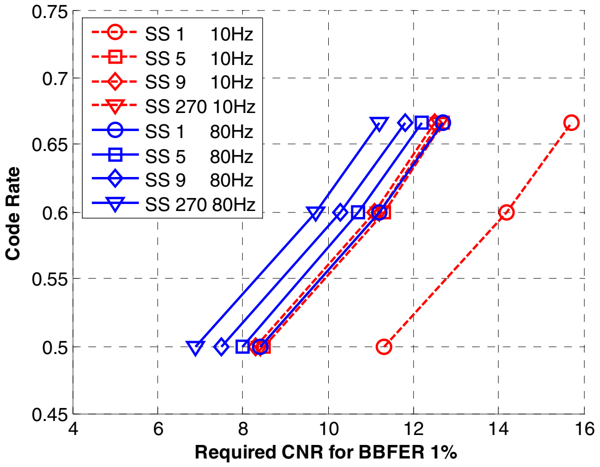

Figure 4. Comparison of different sub-slicing (SS) configurations in the TU6 channel model.

evaluation of mobile TV systems like DVB-H [8]. It has been also used for the performance evaluation of DVB-T2 in mobile environments [3]. The TU6 channel model is representative of mobile reception in fast fading scenarios for Doppler frequencies above 10 Hz.

In the simulations we have considered three different configurations of time interleaving referred to as *reference*, *handheld*, and *maximum diversity*. The *reference* configuration does not employ multi-frame interleaving, frame hopping or sub-slicing. This configuration provides the shortest channel switching times and the best power saving levels at the expense of reduced time diversity.

The *handheld* configuration is optimized for handheld reception. In the handheld scenario, it is important to provide good time diversity and power saving while maintaining the channel switching time below tolerable levels. Since multi-frame interleaving results in a significant increase of the channel switching time, time diversity is improved by means of sub-slicing. The number of sub-slices is configured to the maximum value of 270 which result in continuous transmission inside the T2 frames. In order to achieve good power saving, frame hopping is used in conjunction with sub-slicing. The frame interval in this case determines the power saving and channel switching time. For example, a frame interval of 3 T2 frames results in a power saving of 66% and an average channel switching time of 625 ms (for a T2 frame of 250 ms).

The *maximum diversity* configuration represents the upper bound in the time diversity that can be provided in DVB-T2. This configuration achieves the maximum time diversity at the expense of latency and power saving. In order to accomplish this, multi-frame interleaving is used in conjunction with 270 sub-slices. The combination of long interleaving depth and continuous transmission aims to provide better time diversity in highly correlated channels.

V. SIMULATION RESULTS

In Figure 3 we represent the performance achieved by different configurations of multi-frame interleaving. Specifically, we have evaluated the multi-frame interleaving over 1, 2 and 3 T2 frames. It must be noted that although the number of FEC blocks per T2 frame is fixed in order to maintain the data rate constant, the usage of the TI memory increases with higher values of multi-frame interleaving. In this case, a multi-frame interleaving of 1, 2 and 3 T2 frames corresponds to a TI memory usage of 43, 86 and 129 FEC blocks respectively. 129 FEC blocks correspond to approximately 2^{19} cells when using the 16QAM constellation and a FEC code word length of 16200 bits. This represents the maximum possible utilization of the TI memory that is available for time interleaving purposes. In the figure, multi-frame interleaving shows and improvement up to 2.6 dB with 10 Hz of Doppler and up to 0.8 dB with 80 Hz of Doppler. Multi-frame interleaving achieves higher gains in low Doppler environments since longer interleaving depths are required in order to counteract the higher correlation of the propagation channel. In the figure it is seen that the utilization of multi-frame interleaving beyond 2 T2 frames provides no significant improvement in fast fading scenarios, especially in the case of high Doppler.

Figure 4 illustrates the performance achieved by different number of sub-slices per T2 frame. In particular, we have selected 1, 5, 9 and 270 sub-slices. These values are allowed in the standard for the configuration employed in the simulations. Similarly to multi-frame interleaving, sub-slicing achieves a greater improvement in the low Doppler scenario. The gain provided by sub-slicing is up to 3.1 dB with 10 Hz of Doppler and up to 1.5 dB with 80 Hz of Doppler. Since sub-slicing provides a higher gain without a significant increase in the channel switching time or the TI memory utilization, it should be preferred over multi-frame interleaving for improving the performance in fast fading scenarios.

In Figure 5 we show the performance of the *reference* configuration with a different number of FEC blocks per T2 frame. This is done in order to evaluate the effect of the TI memory utilization in the system performance. Specifically we have considered 43, 86 and 129 FEC blocks per T2 frame. The utilization of the full TI memory (129 FEC blocks) achieves a gain up to 1.2 dB with 10 Hz of Doppler and up to 1 dB with 80 Hz of Doppler. While the TI memory utilization is the same as with multi-frame interleaving, the improvement in performance is significantly lower in the case of 10 Hz due to the reduced interleaving depth. Higher utilizations of the TI memory for a certain data rate can be achieved by means of frame hopping. If a frame interval of 2 is employed, twice as much information must be transmitted every 2 T2 frames. In this case, frame interval values of 1, 2 and 3 result in 43, 86

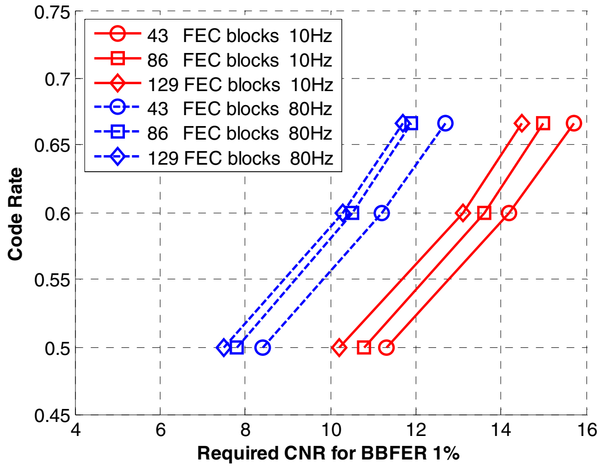

Figure 5. Comparison of different number of FEC blocks per T2 frame in the TU6 channel model.

and 129 FEC blocks transmitted per T2 frame. Another way of increasing the TI memory usage is to multiplex several services in the same stream in order to increase the data rate of the PLP. Since the transmission parameters cannot be particularized for each one of the services transmitted inside the same PLP, it is recommended to multiplex services that belong to the same use case.

In Figure 6 we compare the *reference*, *handheld* and *maximum diversity* configurations. As can be seen in the figure, the *handheld* and *maximum diversity* configurations achieve practically the same performance. The utilization of multi-frame interleaving provides little improvement when the number of sub-slices is 270 and the information is continuously transmitted inside the T2 frame. Nevertheless, the *maximum diversity* configuration achieves a gain up to 3.1 dB in the case of 10 Hz and up to 1.8 dB in the case of 80 Hz of Doppler with respect to the *reference* configuration.

VI. CONCLUSIONS

In the paper we have evaluated the performance of the DVB-T2 time interleaving in the TU6 channel model. The provision of multi-frame interleaving, frame hopping and sub-slicing allows different trade-offs in terms of time diversity, latency and power saving. The simulation results show that by means of these mechanisms it is possible to improve the mobile reception of DVB-T2 services up to 3.1 dB with 10 Hz of Doppler and up to 1.8 dB with 80 Hz of Doppler. We have also proposed a configuration optimized for the handheld scenario that achieves a performance close to the maximum gain while providing good power saving and tolerable channel switching times. However, due to limitations in the available TI memory, DVB-T2 may not provide sufficient time diversity in shadowing scenarios. The performance evaluation of the DVB-T2 time interleaving in the presence of shadowing is left for future work.

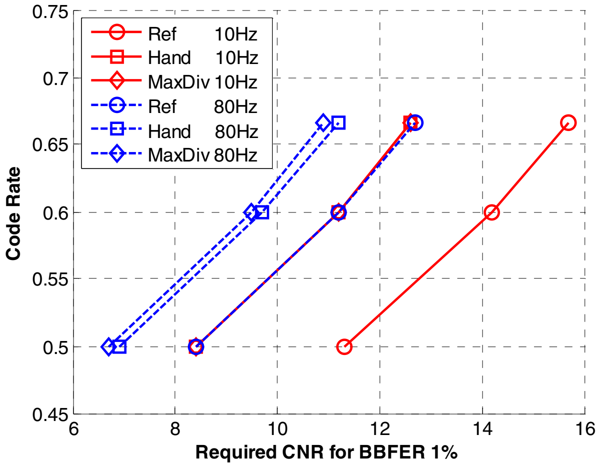

Figure 6. Comparison of the *reference*, *handheld* and *maximum diversity* configurations in the TU6 channel model.

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