Project	**IEEE 802.20 Working Group on Mobile Broadband Wireless Access** **<http://grouper.ieee.org/groups/802/20/>**
Title	**Partial proposal to support flexible, spectrally efficient multi-carrier mode**
Date Submitted	**2007-03-05 (March 5, 2007)**
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Re:	IEEE 802.20 Call for Proposal
Abstract	This document proposes the support of reduced channel spacing to improve the spectral efficiency of Mobile Broadband Wireless Access Systems in the multicarrier deployment mode.
Purpose	For consideration and adoption as a feature supported by 802.20 standard
Notice	
Release	
Patent Policy	

I. Introduction

This contribution provides further information on the support of quasi-guard subcarriers that can have different number than the quasi-guard subcarriers, in the Multicarrier ON mode. Related comments have been submitted through Letter Ballots 1 and 2 previously. Some initial simulation results [1] have also been discussed during the ballot comment resolution sessions in Jan '07 Interim meeting.

II. Description

In a conventional mobile cellular system with multi-carrier deployment scenario, guard bands are used to ensure the regulatory requirements on out-of-band emission are met. In addition, they are also used to reduce performance degradation due to adjacent channel interference.

It has been observed through some prior simulation studies [2] that the inherent multi-carrier nature of a coded OFDM signal lends itself to a spectrally efficient deployment of multiple carriers, each of which could be an independent, coded OFDMA system. This is because of the robustness of coded OFDM signal to adjacent channel interference which leads to less stringent requirements of guard bands between adjacent channels.

While the transmitted OFDM signal will still have to meet the out-of-block spectral emission through the use of guard subcarriers, which are not modulated with data, the other side of the signal spectrum that is located away from the block edge will not require the same number of guard subcarriers. In the current 802.20 standard draft [3], these guard subcarriers which are located between adjacent channels in the multi-carrier ON mode are known as the quasi-guard subcarriers. As we will see in the simulation results in the subsequent section, in the multi-channel deployment of coded OFDM systems, the requirements on the number of quasi-guard subcarriers can be significantly fewer than that for the guard subcarriers at the block edge, with insignificant performance degradation, especially when lower-order modulation, e.g., QPSK, is used in the edge subcarriers.

The original proposal for the 802.20 standard draft has been evaluated based on 32 guard subcarriers [4], which is one of the smaller numbers of guard subcarriers that is supported by the standard. Actually, the current 802.20 standard draft [3] supports 7 other values of guard subcarriers. For example, in the case of 512 FFT, the number of guard subcarriers for the superframe preamble can be 64, 128, …, or 448. According to the 802.20 specification [3], Section 6.5.6.1, the number of guard subcarriers for PHY frames should be the same as that for the superframe preamble, with a minimum of 64, when there is only one carrier for the sector. When 2 carriers are deployed in the same sector, the corresponding number of guard subcarriers in each PHY frame is 32, 96, 160, …, or 416, as described in more detail in Section V.

Therefore, if the number of quasi-guard subcarriers is allowed to have different values that the number of guard subcarriers, without significant performance degradation, the spectral efficiency of the spectral block can be improved significantly. This change is applicable to the guard subcarriers for both the superframe preamble and each PHY frame.

III. Simulation Models and Assumptions

The simulation results on the quasi-guard subcarriers that have been discussed during Jan '07 Interim meeting [1] had not included the non-linear effects of a power amplifier, which is a major cause of adjacent channel interference.

Further simulation results that include the effect of non-linearity are included in this contribution, as a study on the tradeoff between channel spacing and performance degradation as caused by adjacent channel interference, for the deployment scenario of 3 carriers.

The power amplifier (PA) model used is RAPP model for the AM/AM characteristics of a typical solid state PA. The AM/AM characteristics relate the output voltage levels to the input voltage levels, as shown in Figure 1. The model consists of two parameters: V_{sat} which represents the saturation voltage, and p which controls the degree of non-linearity at saturation, as shown in Equation 1.

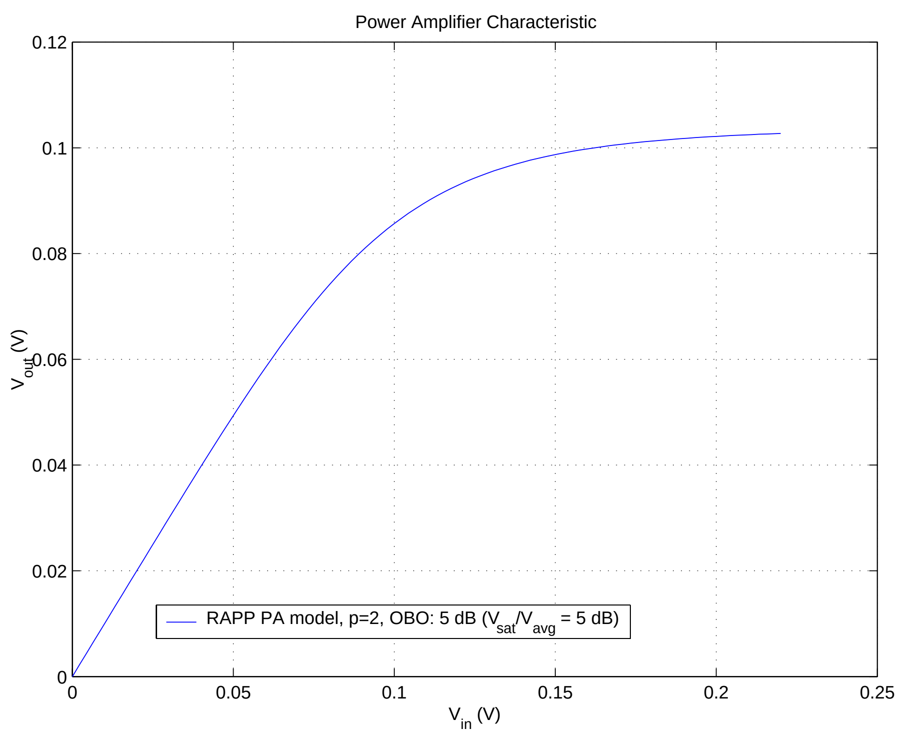

Figure 1 AM/AM characteristics of the RAPP PA model, p=2

$$V_{out} = \frac{V_{in}}{\left(1 + \left(\frac{|V_{in}|}{V_{sat}}\right)^{2p}\right)^{\frac{1}{2p}}} \quad , p = 2$$

Equation 1 RAPP's model for AM/AM characteristic, p = 2.

The simulation is performed at the physical link level. The simulated transmitter consists of randomly generated information bits, followed by convolutional encoding, modulation, interleaving, IFFT computation, appending cyclic prefix, filtering and computing the PA output. Adjacent channel interference is modeled by a similar transmitter chain that consists of independently generated random information bits. The modulated transmit signals from the adjacent channel interferers are spaced at ±Δf from the desired channel, the transmission from which is eventually demodulated and decoded by the receiver model. Transmit signal from the desired channel and the two adjacent channels are combined before passing through the PA model [5], [6], [7]. A block diagram of the simulation model is shown in Figure 2.

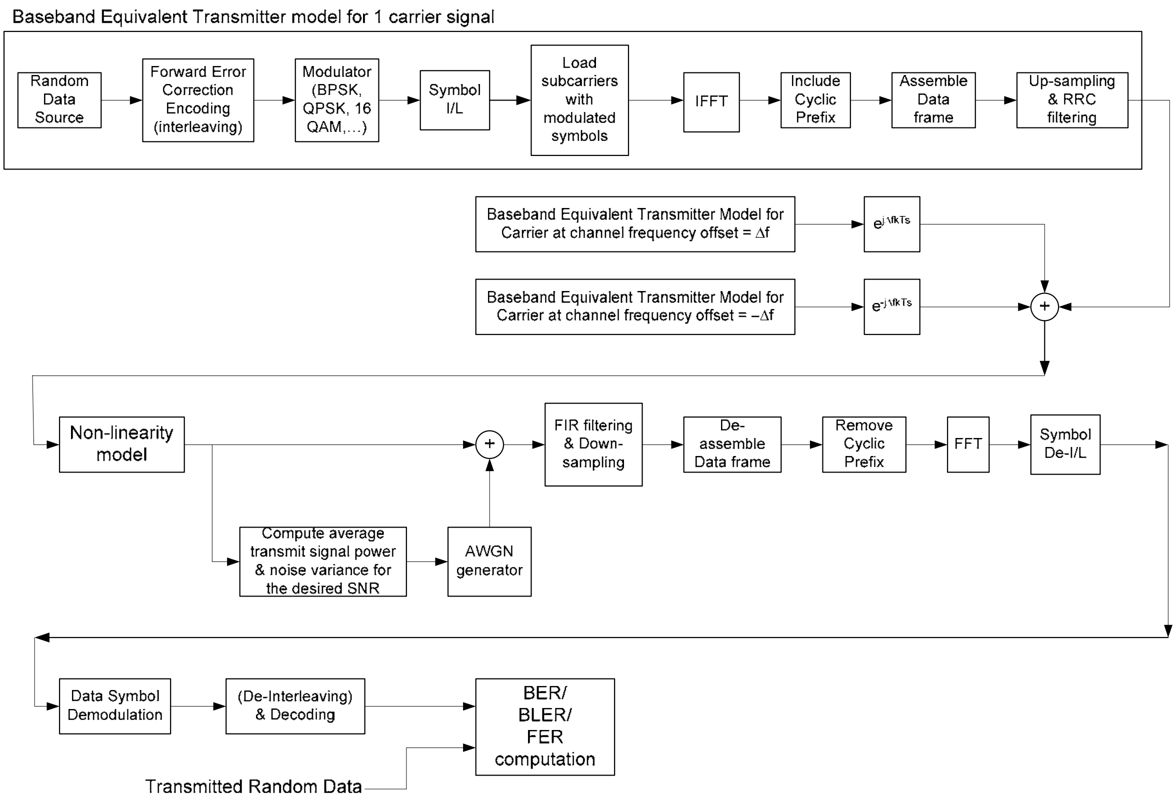

Figure 2 Block Diagram of the simulation model

The simulated OFDM signal uses 512 FFT, with tone spacing of 9.8 kHz. Although the number of guard subcarriers in the simulated waveform is set to 86, but the number of quasi-guard subcarriers is varied between several smaller values that are shown as the effective values of channel spacing between the adjacent channels.

IV. Simulation Results

The power spectrum (PSD) of the simulated transmit signal is plotted in Figure 3. The desired channel in the center and its two adjacent channels can be seen distinctively, as this is the case for Δf = 5MHz. The spectral re-growth as caused by the PA model can be observed by comparison with the PSD of the signal at the input of the PA.

Uncoded bit error rate (BER) performance for various values of channel spacing with QPSK modulated signal is shown in Figure 4. It can be observed that an error floor appears when the channel spacing is reduced to 0.82 Δf. With channel coding and interleaving, this error floor is reduced to a performance degradation of 0.3 dB at 10^{-3} BER in the coded bit error rate results shown in Figure 5 for QPSK modulated signal. However, with the same channel spacing, Figure 6 shows that the corresponding degradation is 2.25 dB for 16-QAM modulated signal. This degradation can be further reduced to 1.0 dB when the channel spacing is at 0.86 Δf. In the absence of the PA non-linearity, the degradation at such channel spacing is about 0.6 dB. Note that the degradation due to in-band distortion only is about 0.3 dB, even in the absence of adjacent channel interference.

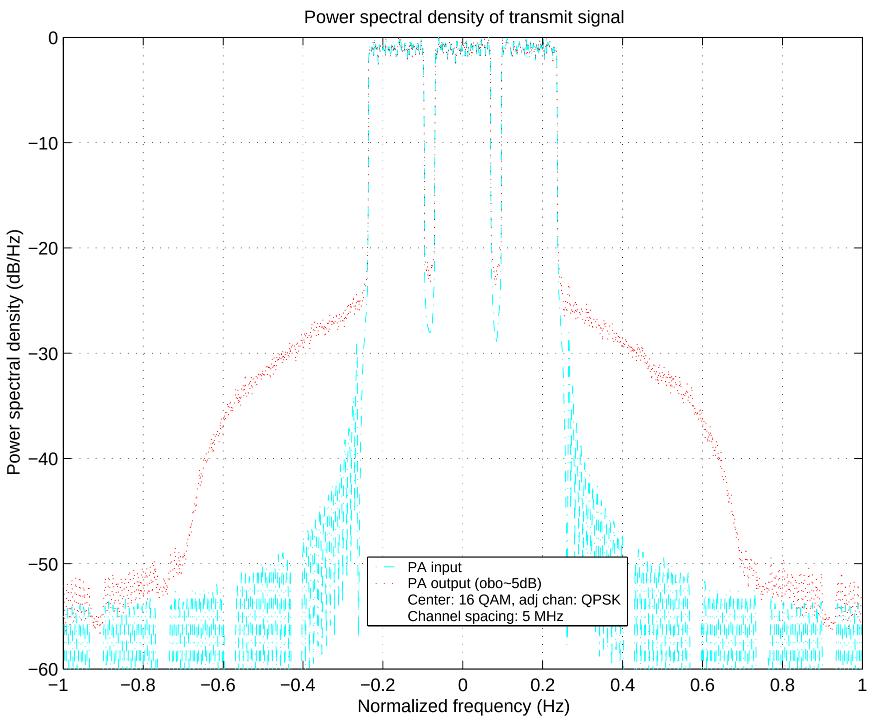

Figure 3 **Power spectral density of transmitted signal with three adjacent OFDM channels (each with 512 FFT size) with spacing at 5 MHz**

The case of channel spacing at Δf, i.e., 5 MHz in the simulation, is equivalent to the case when the number of quasi-guard subcarriers is identical to the number of guard subcarriers. The simulation results show that it is not necessary for these two parameters to be identical. The number of quasi-guard subcarriers can be smaller than that of the guard subcarriers.

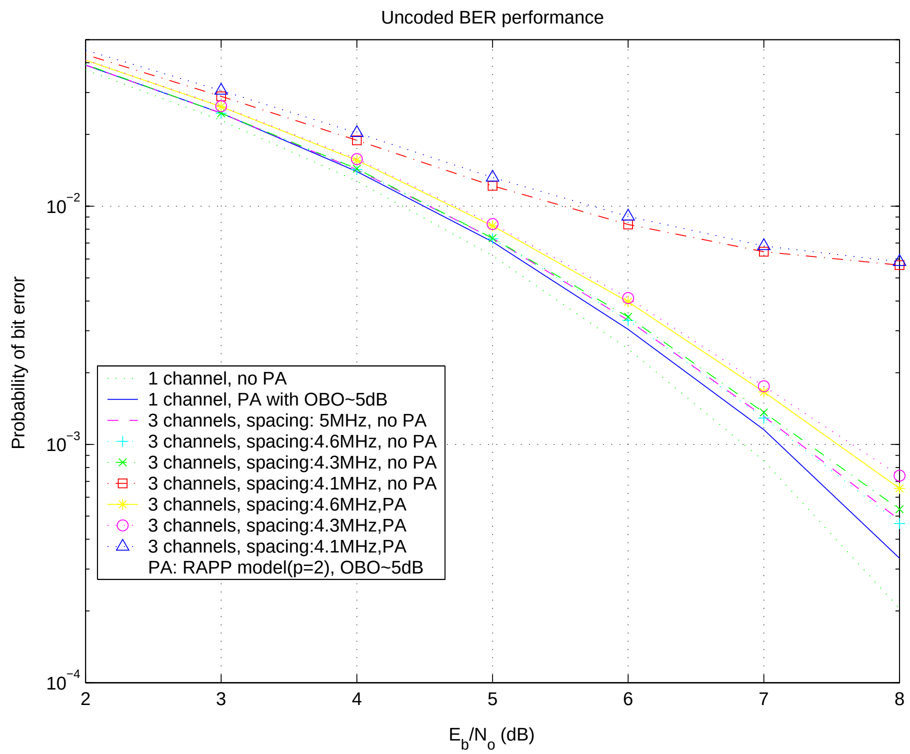

Figure 4 **Uncoded BER performance for various values of channel spacing, with QPSK modulation.**

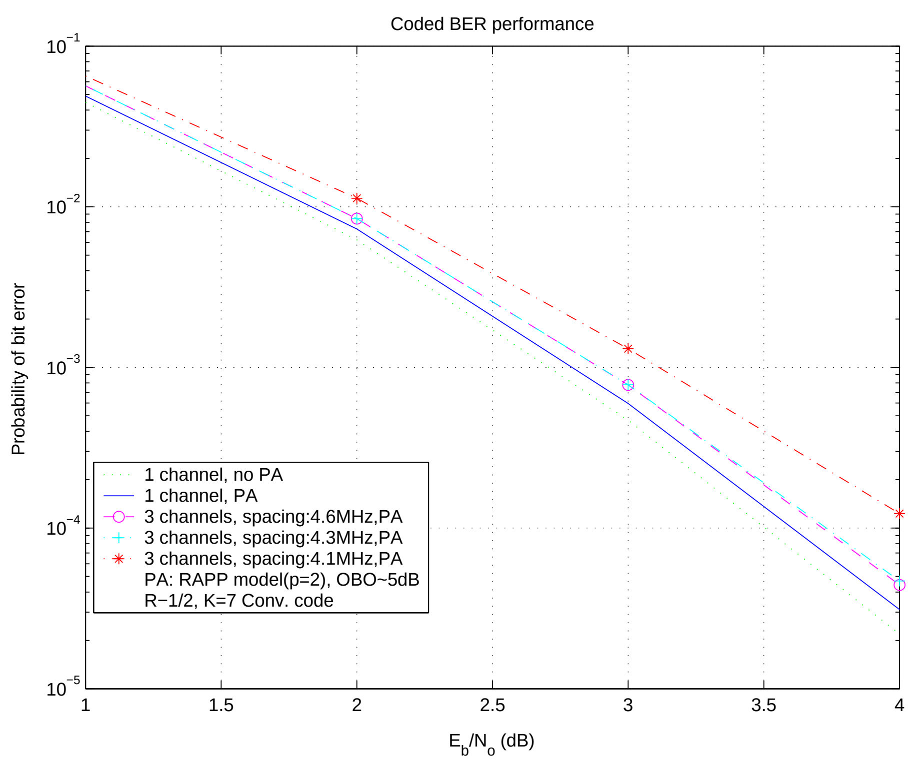

Figure 5 **BER performance for various values of channel spacing, with QPSK modulation**

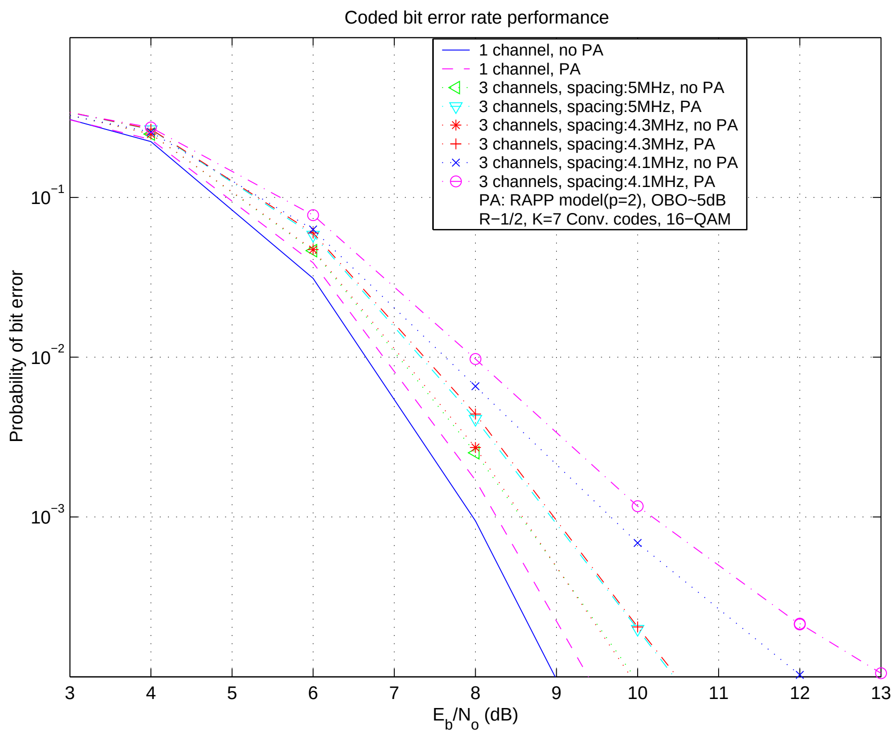

Figure 6 **Coded BER performance for case of 16-QAM, for various values of channel spacing**

V. Required Changes to the current Standard Draft

In the current version of the 802.20 standard draft, the number of guard subcarriers is transmitted as a parameter in the SystemInfo block, which is transmitted in F-pBCH0:

NumGuardSubcarriers = $N_{Guard,PR}$ -32*n, where n = number of carriers in the sector-1

$N_{Guard,PR}$ = Number of guard subcarriers in the superframe preamble
= N_carrier_size/8 to 7*N_carrier_size/8, as defined in Section 8.1.11, Numeric constants.

For 512 FFT, $N_{Guard,PR}$ = 64, 128, 192, …, 448 subcarriers. This number of guard subcarriers in the superframe preamble will be set by the access network.

Thus, NumGuardSubcarriers = $N_{Guard,PR}$, when the number of carriers = 1;

When number of carriers = 2, n = 1 => NumGuardSubcarriers = 32, 96, 160, …, 416 subcarriers.

When number of carriers = 3, n= 2 => NumGuardSubcarriers = 0, 64, 128, …, 384 subcarriers.

According to the interpretation of the current 802.20 standard draft, the number of guard subcarriers in the superframe preamble will have to be increased to at least 128, when n=2, to ensure that the deployed system will be compliant with regulatory requirements. Otherwise, the next smaller value for $N_{Guard,PR}$ will lead to ‘0’ guard subcarriers in this case, as computed above.

In Section 9.3.2.2.1, it is further specified that the number of guard subcarriers in each PHY frame shall be N_{guard}, as given by the NumGuardSubcarriers, which is sent as part of the overhead Message Protocol.

Changes to Section 8.1.11

To support the proposed feature, a new protocol constant can be added: $N_{QuasiGuard,PR}$, for use in the MultiCarrier ON mode.

Changes to Section 6.5.6.1

A new field can be added to the SystemInfo block: NumQuasiGuardSubcarriers. The new field needs to be transmitted in the SystemInfo block when the number of carriers per sector is greater than one, i.e., in the MultiCarrier ON mode.

Changes to Section 9.3.2.2.2

"… The set of quasi-guard subcarriers in the superframe preamble shall be the subcarriers numbered $N_{carrier\_size}$*m – $N_{QuasiGuard,PR}$ /2 through $N_{carrier\_size}$*m + $N_{QuasiGuard,PR}$ /2 – 1 where m =. 1, …, $N_{carriers}$ – 1. The set of quasi-guard subcarriers in each FL shall be the subcarriers numbered $N_{carrier\_size}$*m – $N_{QuasiGuard}$ /2 to $N_{carrier\_size}$*m + $N_{QuasiGuard}$ /2 - 1 where m =. 1, …, $N_{carriers}$ – 1. The quantity $N_{QuasiGuard}$ is given by the NumQuasiGuardSubcarriers parameters which is part of the public data of the Overhead Messages Protocol."

Changes to Section 9.4.1.2.2

"…The set of quasi-guard subcarriers in each RL shall be the subcarriers numbered $N_{carrier\_size}$*m – $N_{QuasiGuard}$ /2 to $N_{carrier\_size}$*m + $N_{QuasiGuard}$ /2 - 1 where m =. 1, …, $N_{carriers}$ – 1. The number of quasi-guard subcarriers $N_{QuasiGuard}$ for the reverse link shall be the same as the number of quasi-guard subcarriers on the reverse link, as given by NumQuasiGuardSubcarriers, which is part of the public data of the Overhead Messages Protocol for any sector…."

VI. Conclusion

By allowing the number of quasi-guard subcarriers to be a parameter that is different from the number of guard subarriers, the standard will be more flexible in supporting various system deployment scenarios so as to achieve higher spectral efficiency in a spectral block.

References

[1] C802.20-07/03, `Simulation data for letter ballot comments on quasi-guard subcarriers and reverse-link waveform', Jan 15, 2007.

[2] L. Tee, C. Rensburg, Y. Ding, 'Performance of a multi-channel OFDM system under the effect of adjacent channel interference', Proceedings of VTC '05 Fall conference, September 2005

[3] 'Draft Standard for Local and Metropolitan Area Networks - Standard Air Interface for Mobile Broadband Wireless Access Systems Supporting Vehicular Mobility - Physical and Media Access Control Layer Specification', IEEE P802.20/D2.1, May 2006.

[4] J. Tomcik, 'MBFDD Performance Report 1', C802.20-05/61r1, Jan 06, 2006.

[5] A. Tee, J. Cleveland, ‘Evaluation of 802.20 proposals with adjacent channel interference considerations’, C802.20-04/58, April 27, 2004
[6] A. Tee, J. Cleveland, ‘Evaluation of 802.20 proposals with adjacent channel interference considerations – Description text’, C802.20-04/68r1, Sept 3, 2004
[7] A. Tee, ‘Performance degradation caused by adjacent channel interference-simulation results’, March 14, C802.20-05/21, 2005

Appendix Relevant sections quoted from 802.20 standard draft V2.1 [3]

8.1.11 Protocol numeric constants and parameters

Constant	Meaning	Value
$N_{PHYPType}$	Type field for this protocol	Table 9~~Table 9~~
$N_{PHYPDefault}$	Subtype field for this protocol	0x0000
N_{FFT}	Number of subcarriers in an OFDM symbol	512, 1024, or 2048
T_{CHIP}	Basic unit of time for generating the OFDM waveform	Defined in Table 96~~Table 94~~ as a function of N_{FFT}
$N_{CARRIER\_SIZE}$	Number of subcarriers in one carrier	512 in MultiCarrierOn mode N_{FFT} in MultiCarrierOff mode
$N_{CARRIERS}$	Number of carriers	$N_{FFT}/N_{CARRIER\_SIZE}$ (= 1 in MultiCarrierOff mode)
$T_{CP,PR}$	Cyclic prefix duration for the superframe preamble	$N_{FFT}T_{CHIP}/4$
$N_{GUARD,PR}$	Number of guard subcarriers in the superframe preamble	Any multiple of $N_{CARRIER\_SIZE}/8$, ranging from $N_{CARRIER\_SIZE}/8$ through $7N_{CARRIER\_SIZE}/8$. This field shall be set by the access network, and is determined by the access terminal.
T_{WGI}	Duration of windowing guard interval	$N_{FFT}T_{CHIP}/32$
$N_{PREAMBLE}$	Number of OFDM symbols in the superframe preamble	8
$N_{FRAME,F}$	Number of OFDM symbols in a forward link PHY Frame	8
$N_{FRAME,R}$	Number of OFDM symbols in a reverse link PHY Frame	8
N_{BLOCK}	Number of subcarriers in a tile.	16 in BlockHopping mode (FL) 1 in SymbolRateHopping mode (FL) 16 for the RL
$T_{G,TDD,F}$	Guard time between a forward link PHY Frame and the subsequent reverse link PHY frames	$3N_{FFT}T_{CHIP}/4$
$T_{G,TDD,R}$	Guard time between a reverse link PHY Frame and the subsequent forward link PHY frames	$5N_{FFT}T_{CHIP}/32$
N_{pBCH0_Period}	Number of superframes over which F-pBCH0 is encoded	16
$N_{MaxErasureHopPorts,F}$	Maximum number of hop-ports to be used for transmitting a single erasure sequence on the forward link	16
$N_{MaxErasureHopPorts,R}$	Maximum number of hop-ports to be used for transmitting a single erasure sequence on the reverse link	16
$N_{CRC,pBCH}$	Number of CRC bits to be used for pBCH0 and pBCH1 packets.	12

6.5.6.1 SystemInfo block

The SystemInfo block shall be transmitted directly by the Control Channel MAC Protocol over the pBCH0 channel, and shall not pass through other sublayers. The SystemInfo block shall have the following format.

Field	Length (bits)
MaximumRevision	4
MinimumRevision	4
CarrierID	2
NumCarriers	2
SystemTimeLSB	12
CPLength	2
NumGuardSubcarriers	3
BlockHoppingEnabled	1
N_FLBurst	2
N_RLBurst	2
FLReservedInterlaces	4
NumFLReservedSubbands	4
RelaxedRetransmissionEnabled	1

MinimumRevision — This field shall be set to the minimum revision number that the sector can support.

MaximumRevision — This field shall be set to the maximum revision number that the sector can support.

CarrierID — This field shall be set to the CarrierID of the carrier this block is transmitted on.

NumCarriers — This field shall determine the number of carriers available at this sector. This parameter shall take the value (n+1).

SystemTimeLSB — This field shall be set to the twelve lower bits of the superframe number at the time the SystemInfo block starts transmission.

CPLength — This field shall determine the cyclic prefix length in units of chips. This parameter shall take the value N_{FFT}*(1+n)/16, where n is equal to the 2 bit field that takes the value 0, 1, 2 or 3.

NumGuardSubcarriers — This parameter shall take the value $N_{GUARD,PR}$ - 32*n. Here $N_{GUARD,PR}$ is a numeric constant of the Physical Layer Protocol.

BlockHoppingEnabled — This field shall be set to '1' if block hopping is enabled. This field shall be set to '0' if symbol rate hopping is enabled.

N_FLBurst — This field shall determine the number of forward link PHY Frames that comprise a forward link burst in TDD mode. This parameter shall take the value (n+1). This field shall be ignored in FDD mode.

N_RLBurst — This field shall determine the number of reverse link PHY Frames that comprise a reverse link burst in TDD mode. This parameter shall take the value (n+1). This field shall be ignored in FDD mode.

FLReservedInterlaces — This field shall determine what interlaces contain reserved bandwidth on the forward link.

6.5.5.4.1.1 Procedure for transmission of the SystemInfo block

The SystemInfo block shall be transmitted every N_{pBCH0_Period} superframes. The SystemInfo block shall be carried by the Control Channel MAC Protocol over the pBCH0 physical channel, and shall not pass through the Signaling Transport. N_{pBCH0_Period} is defined in the Physical Layer Protocol. If the multi-carrier mode is MultiCarrierOn, the SystemInfo block shall be transmitted on each carrier, and all contents of the SystemInfo block except the CarrierID, FLReservedInterlaces and NumFLReservedSubbands shall be identical for all carriers. The multi-carrier mode is public data of the physical layer protocol.

Forward link:-

9.3.2.2.1 Guard subcarriers

Some of the available subcarriers in an OFDM symbol are designated as guard subcarriers and shall not be modulated, i.e., no energy shall be transmitted on these subcarriers. The number of guard subcarriers in the superframe preamble and in each FL PHY Frame shall be $N_{GUARD,PR}$ and N_{GUARD} respectively. The quantity N_{GUARD} is given by the NumGuardSubcarriers parameter which is part of the public data of the Overhead Messages Protocol. The set of guard subcarriers in the superframe preamble shall be the subcarriers numbered 0 through $N_{GUARD,PR}/2 – 1$ and the subcarriers numbered N_{FFT}-$N_{GUARD,PR}/2$ through N_{FFT}-1. The set of guard subcarriers in each FL PHY Frame shall be the subcarriers numbered 0 through $N_{GUARD}/2 – 1$ and the subcarriers numbered N_{FFT}-$N_{GUARD}/2$ through N_{FFT}-1.

9.3.2.2.2 Quasi-guard subcarriers

In MultiCarrierOn mode, additional sub-carriers within each OFDM symbol are designated as quasi-guard subcarriers and shall not be modulated, i.e., no energy shall be transmitted on these subcarriers. The set of quasi-guard subcarriers in the superframe preamble shall be the subcarriers numbered $N_{CARRIER\_SIZE}$*m- $N_{GUARD,PR}/2$ through $N_{CARRIER\_SIZE}$ *m + $N_{GUARD,PR}/2 – 1$ where m = 1, …,$N_{CARRIERS}$-1. The set of quasi-guard subcarriers in each FL PHY Frame shall be the subcarriers numbered $N_{CARRIER\_SIZE}$*m- $N_{GUARD}/2$ to $N_{CARRIER\_SIZE}$ *m + $N_{GUARD}/2 – 1$ where m = 1, …,$N_{CARRIERS}$-1. Subcarriers that are not guard or quasi-guard subcarriers are also referred to as usable subcarriers.

[*2] Guard hop-ports are always mapped to guard or quasi-guard subcarriers and are not modulated by any of the physical layer channels. These hop-ports are present since the assignments that are made by FTC and RTC MAC protocols span all N_{FFT} subcarriers.

Reverse-link –

9.4.1.2.1 Guard subcarriers

Some of the available subcarriers in an OFDM symbol are designated as guard subcarriers and shall not be modulated; i.e., no energy shall be transmitted on these subcarriers. The number of guard subcarriers in each OFDM symbol shall be N_{GUARD}, and the set of guard subcarriers shall be the subcarriers numbered 0 through $N_{GUARD}/2 – 1$ and the subcarriers numbered N_{FFT}-$N_{GUARD}/2$ through N_{FFT} - 1.

The number of guard subcarriers N_{GUARD} for the reverse link shall be the same as the number of guard subcarriers on the forward link, and is given by NumGuardSubcarriers, which is part of the public data of the Overhead Messages Protocol for any sector. The AT shall use the value corresponding to any sector in AS_{SYNCH}. (All sectors in AS_{SYNCH} have the same value of N_{GUARD}.)

9.4.1.2.2 Quasi-guard subcarriers

In multi-carrier mode, additional sub-carriers within each OFDM symbol are designated as quasi-guard subcarriers and shall not be modulated, i.e., no energy shall be transmitted on these subcarriers. The set of quasi-guard subcarriers in each RL PHY Frame shall be the subcarriers numbered $N_{CARRIER\_SIZE}$*m- $N_{GUARD}/2$ through $N_{CARRIER\_SIZE}$ *m + $N_{GUARD}/2 – 1$ where m = 1, …,$N_{CARRIERS}$-1.

Any subcarrier that is not a guard or a quasi-guard subcarrier is referred to as a usable subcarrier.