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Load Dependent Interference Margin for Link Budget Calculations of OFDMA Networks

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Abstract—Link budget calculations are essential in the planning of wireless networks to get a reliable estimate of maximum cell radius and guaranteed signal to interference plus noise ratios at the cell border. In future networks using orthogonal frequency division multiple access, the interference introduced by co-channel cells depends on the amount of subcarriers utilized in the interfering as well as in the considered cell. If distributed subcarrier allocation is applied, frequency diversity and interference averaging effects can be obtained. A method is derived in this paper to consider load dependent margins for interference from co-channel cells in the link budget calculation. This margin makes the estimation of the maximum cell radius more accurate.

Index Terms—Interference margin, link budget calculation, orthogonal frequency division multiple access.

I. INTRODUCTION

LINK budget calculations are the first step in the network planning process. By considering gain and loss during transmission and assuming a required signal to noise ratio (SNR_{req}) at the receiver and a maximum transmit power at the sender a maximum pathloss can be determined. This leads to a maximum cell radius for that the assumed SNR can still be guaranteed at the cell border [1, 2]. To compensate for slow or fast fading, margins can be added in the link budget calculation. If the pathloss is known, the achievable SNR at the cell border can be adjusted by changing the transmit power or the maximum cell radius taking only thermal noise into account. In scenarios where the inter-cell interference is larger than the thermal noise changing the cell radius will have no influence on the signal to interference ratio (SIR). Improved SIR conditions at the cell border can only be achieved by increasing the distance to co-channel interfering cells with a higher frequency reuse [3].

A promising multiple access schemes for future mobile communication systems is Orthogonal Frequency Division Multiple Access (OFDMA) [4]. OFDMA is considered for 4th Generation wireless networks and is currently used for broadband wireless access networks according to the IEEE 802.16e standard [5]. OFDMA provides frequency diversity and interference averaging if distributed subcarrier allocation is considered [6]. If subcarriers are not utilized in neighboring cells, the effective interference experienced by a user is

reduced. This effect should also be considered when planning wireless networks.

In networks using code division multiple access (CDMA), it is state of the art to consider a load dependant margin for the intra- and inter-cell interference [7]. There is no intra-cell interference when using OFDMA due to orthogonality among the subcarriers. Nevertheless, there is inter-cell interference which depends upon the load, i.e. the amount of utilized subcarriers, in the co-channel cells. In this paper a load dependant interference margin (IM) for wireless networks using OFDMA with distributed subcarrier allocation is derived. Compared to a noise limited scenario the maximum pathloss is reduced by the IM so that still a given required signal to interference plus noise ratio (SINR) is guaranteed to the user at the cell border.

This paper is organized as follows. In section II, the system model is described that is used throughout this investigation. The IM due to partial load is derived in section III. Section IV provides results obtained from link level simulations. Finally, conclusions are drawn in section V.

II. SYSTEM MODEL

A wireless network using OFDMA is considered. The subcarrier allocation to users is performed in a distributed fashion. In that case, subcarriers allocated to a single user are distributed over the whole available bandwidth. Users in co-channel cells utilize different sets of subcarriers. The allocation procedure is cell dependant. Coding and interleaving is performed over a set of subcarriers. Convolutional codes are used. Therefore, interference averaging and frequency diversity can be obtained [6].

A regular hexagonal cell grid with omnidirectional antennas is assumed. The transmit power per subcarrier is constant. The SIR at the cell border depends on the reuse distance D and can be approximated by

$$\text{SIR} = 10 \log_{10} \left(\frac{S}{I} \right) = 10 \log_{10} \left(\frac{R^\alpha}{(D - R)^\alpha} \right) \quad (1)$$

with S the received power density, I the interference power density at the receiver, α the pathloss coefficient and R the cell radius [3]. The reuse distance D is a linear function of R so that the SIR is independent of R .

A set of subcarriers \mathcal{A} is utilized in the considered cell. The co-channel interfering cells utilize a set of subcarriers \mathcal{B} with $\mathcal{B} \subseteq \mathcal{A}$. This is achieved if co-channel interfering cells are not fully loaded and therefore not all subcarriers are needed for transmission. A measure for the load l is given by the ratio of the cardinalities of \mathcal{B} and \mathcal{A} given by

$$l = \frac{|\mathcal{B}|}{|\mathcal{A}|} \quad (2)$$

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with $0 \leq l < 1$. For $l = 0$, the system is noise limited and there is no co-channel interference. For $l = 1$, the system would be interference limited and all subcarriers are interfered by co-channel interfering cells. Due to assumption of a constant SIR, no optimization can be performed in that case.

It is assumed that the interference power density, is larger than the spectral noise power density $I \gg N$. Therefore subcarriers with index $k \in \mathcal{A} \setminus \mathcal{B}$ experience an SNR_{nl} which depends on the cell radius, subcarriers with index $i \in \mathcal{B}$ experience an SIR given by (1). Interference power as well as noise power is assumed to be Gaussian distributed [6].

Corresponding to a normal link budget calculation, a noise limited scenario with $l = 0$ is assumed. An SNR_{req} can be achieved at the cell border by adjusting, e.g., the cell radius. In a second scenario, interference from neighbouring cells is considered on part of the subcarriers thus $0 < l < 1$. The performance at the cell border of the scenario including interference should match the performance at the cell border of the noise limited scenario. Therefore, it is obvious that the SNR_{nl} at the cell border has to be readjusted if $\text{SIR} \neq \text{SNR}_{\text{req}}$. The difference between SNR_{nl} and SNR_{req} gives the interference margin that has to be considered in the link budget calculation to get reliable maximum cell radius estimations for the network planning.

III. INTERFERENCE MARGIN

To determine the performance at the cell border, the channel capacity [8] is used throughout this paper. The channel capacity may be expressed in the form

$$I(X; Y) = h(Y) - h(Y|X) \quad (3)$$

with X and Y the input and output signal, respectively, using a certain modulation and $h(\cdot)$ the entropy function [8]. The channel capacity for PSK and QAM modulation can be obtained using the Monte Carlo method [9]. It is not possible to give a closed form solution for the relationship between SNR and channel capacity for QPSK and 16QAM modulation, so that we will use the expression

$$C = f(\text{SNR}) \quad (4)$$

throughout this paper. The function can be found in Fig. 1.

In a noise limited scenario with $l = 0$ an average capacity per subcarrier

$$C_{\text{req}} = f(\text{SNR}_{\text{req}}) \quad (5)$$

can be guaranteed at the cell border by adjusting the transmit power and the cell radius. The SNR achieved at the cell border in this configuration is termed SNR_{req} .

The average capacity per subcarrier achieved in a scenario where $l \cdot |\mathcal{A}|$ subcarriers are interfered by co-channel cells is given by

$$C(l) = C_{\text{nl}} \cdot (1 - l) + C_{\text{il}} \cdot l \quad (6)$$

where C_{nl} is the capacity achieved on subcarriers interfered by noise and C_{il} the capacity achieved on subcarriers interfered by co-channel cells. To get the required average capacity C_{req} , C_{nl} has to be adjusted so that

$$C_{\text{nl}}(l) = \frac{C_{\text{req}} - l \cdot C_{\text{il}}}{1 - l}. \quad (7)$$

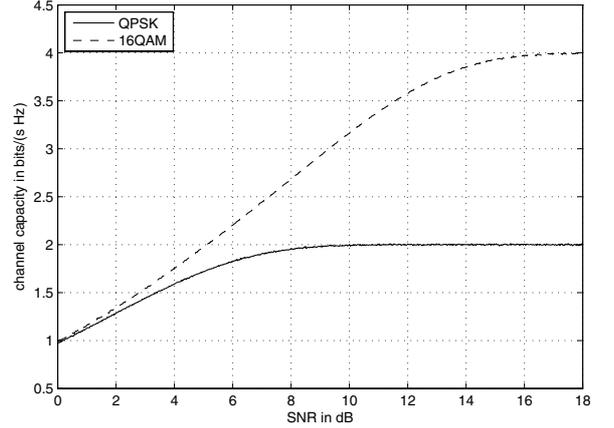


Fig. 1. channel capacity as function of the SNR for QPSK and 16QAM modulation.

TABLE I
SIMULATION PARAMETER

Parameter	Value
System bandwidth	10 MHz
Subcarrier spacing	11.16 kHz
symbol duration	95.2 μ s
Channel Model	Additive White Gaussian Noise
SIR	0 dB (reuse 1); 8 dB (reuse 3)
Modulation and coding	QPSK 1/2, 16 QAM 1/2, 16 QAM 3/4

It should be noted that for $l = 1$, C_{req} is limited by C_{il} which is assumed to be independent of the cell radius in this work. The minimum SNR at the cell border in a scenario with interfering co-channel cells is given by the inverse function of f which is valid for channel capacities smaller than the maximum achievable channel capacity with that modulation:

$$\text{SNR}_{\text{nl}}(l) = f^{-1}(C_{\text{nl}}(l)). \quad (8)$$

The IM depending on SNR_{req} and l is given by

$$\text{IM}(l) = \text{SNR}_{\text{nl}}(l) - \text{SNR}_{\text{req}}. \quad (9)$$

IV. SIMULATION RESULTS

Link level simulations according to the IEEE 802.16e standard [5] are performed. In this section, the results will be compared to the IM model developed in section III. The convolutional code of [5] is considered. Decoding is performed using the Viterbi algorithm [10]. 288 bits are coded and interleaved together in one code block according to [5]. In each code block a fraction l of the subcarriers experiences a predefined SIR. The SNR experienced on the remaining subcarriers is variable. The IM is the difference in SNR between a scenario with $l = 0$ and $l \neq 0$ when the same performance for the user can be achieved. The performance is measured as transmitted bits per code block based on the achieved bit error performance. The main simulation parameters can be found in Table I.

Fig. 2, 3 and 4 show the results of the IM as function of the required SNR at the cell border for transmission with QPSK 1/2, 16QAM 1/2 and 16QAM 3/4, respectively. It can be seen that the analytical model from section III fits well to the results gained from simulation if the required SNR is not

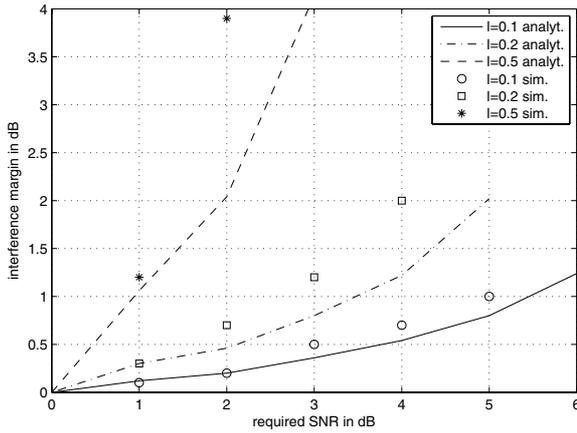


Fig. 2. Interference Margin for QPSK rate 1/2, reuse 1 (SIR = 0 dB).

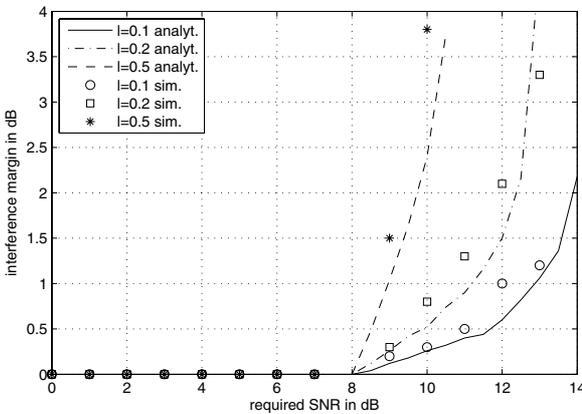


Fig. 3. Interference Margin for 16QAM rate 1/2, reuse 3 (SIR = 8 dB).

high compared with the SIR and l is small. Due to interleaving and coding over a certain number of bits, a high SNR on some symbols can compensate a low SIR on the other. But the interference of part of the subcarriers leads to an error floor in the bit error curves [11]. For instance, QPSK 1/2 requires an SNR of 5 dB to achieve a bit error rate less than 10^{-6} according to [5]. Therefore, QPSK 1/2 can be guaranteed at the cell border for a scenario with SIR equal to 8 dB. On the other hand QPSK 1/2 is not feasible in an interference limited scenario with SIR equal to 0 dB and $l > 0.2$ as seen in fig. 2. This is also covered by the developed model.

V. CONCLUSION

An analytical model to consider interference in the link budget calculation for OFDMA based wireless networks is proposed in this paper. In the considered scenario, it is assumed that some subcarriers are interfered by co-channel interfering cells while the remaining subcarriers experience only thermal noise. The same performance in terms of channel capacity can be guaranteed at the cell border as in a noise limited system if the SNR is improved by a reduction of the cell radius. Link level simulations for IEEE 802.16e OFDMA show that the results from the proposed model are accurate so that the influence of load in co-channel cells can be considered in the link budget calculation to get an estimate for the required SNR

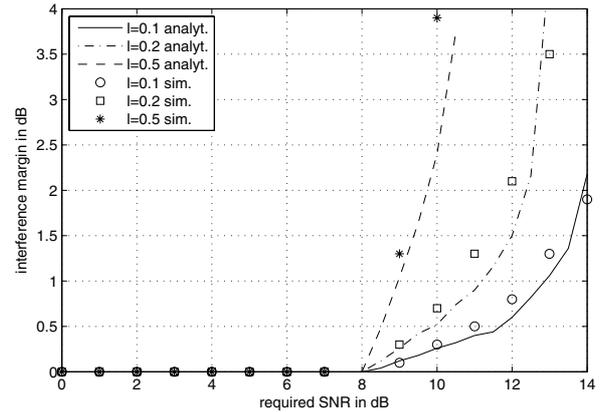


Fig. 4. Interference Margin for 16QAM rate 3/4, reuse 3 (SIR = 8 dB).

at the cell border. It was shown that a realistic margin can be given to achieve the same performance at the cell border in terms of channel capacity, if some subcarriers experience high interference from co-channel cells, as in a noise limited scenario. Of course, this performance cannot be achieved if the required SNR is high compared to the SIR, the load is high in co-channel cells and higher order modulation and coding schemes shall be used. This is also reflected in the proposed model. Due to the assumption of a constant SIR the model leads to lower bound results. If the interference power density gets close to the spectral noise power density an $\text{SINR} > \text{SIR}$ has to be considered in (7) which is no longer independent of the cell radius. Nevertheless, the proposed model helps to improve the link budget calculation due to taking load dependant inter-cell interference for OFDMA networks into account. The estimation of the maximum possible pathloss in the link budget calculation gets more accurate.

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