Rapid Estimation Method for Data Capacity and Spectrum Efficiency in Cellular Networks

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***Abstract* — System level simulations for deriving data capacity and spectrum efficiency of cellular wireless networks require complex modeling and a considerable computational effort. In this paper a combined analytical / geometric approach has been proposed allowing rapid performance estimation in cellular packet data networks. This is accomplished by mapping measured or simulated link level curves onto measured or simulated cell C/I distributions. Two different scenarios have been studied related to two generic traffic models widely used in the literature. The first traffic model assumes a fixed average packet data call duration whereas the second one assumes a fixed average packet data volume per subscriber. Based on these models the first scenario provides very optimistic while the second one more pessimistic performance results. Both GSM/EDGE and the upcoming new IEEE 802.16 WiMax system have been studied in 1x3 frequency reuse, showing a considerable difference of nearly 50-60% in terms of spectrum efficiency between both traffic models. The comparison of WiMax with GSM/EDGE reveals a moderate performance advantage for the new broadband OFDM system in the order of 20-40% higher spectrum efficiency.**

Keywords — Spectrum Efficiency, Performance, IEEE802.16, WiMax, EDGE

I. Introduction

A combined analytical / geometric method for rapid estimation of the packet data channel capacity and spectrum efficiency in cellular wireless systems is introduced. The proposed method has been applied to two scenarios corresponding to two generic traffic models leading to totally different performance results.
The first scenario assumes equal packet call duration for all subscribers. In cellular environment this leads to considerably different data volumes transferred during the fixed time interval since subscribers under good radio conditions enjoy considerably higher data rate than subscribers under poor radio conditions. The resulting cell throughput and consequently the spectrum efficiency are too optimistic. In reality such user behavior might be justified in cases, where subscribers just spend a certain fixed time period e.g. with web-browsing in the Internet.
The second scenario assumes an equal data volume per subscriber. Such user behavior is observed e.g. with download applications such as FTP service or Audi-Video-Streaming in drive tests. In this case subscribers under poor radio conditions with low data rate occupy radio resources disproportionately leading to too pessimistic capacity and spectrum efficiency results. Obviously in a real system implementation a certain mixture of both traffic models is expected inducing performance results in between those provided by the studied traffic models.
The proposed method is based on geometric mapping of the measured or simulated link level performance curves on the measured or simulated cell C/I distribution. Approximating the link level curves by stair-case functions simplifies the analytical formulas used in the performance analysis.
Detailed results for GSM/EDGE [1], [2] as well as for broadband IEEE 802.16 MAN (WiMax, [3], [4]) are provided.
However, there are some factors like power control, admission control as well as specific scheduling techniques, which cannot be taken into account by the proposed analytical method. But at full system load downlink power control has only minor influence on the cell C/I Cumulative Distribution Function (CDF). Admission control blocks subscribers under very poor radio conditions avoiding allocation of channel resources in case of bad radio conditions. Furthermore the spectrum efficiency can be significantly affected by means of sophisticated scheduling techniques. For example a maximum C/I scheduler gives preference to subscribers under good radio conditions at the expense of those under moderate radio conditions thus increasing cell throughput and spectrum efficiency whereas a proportional fairly weighted scheduler improves the throughput of subscribers under poor radio conditions thus degrading the overall spectrum efficiency.
The paper is structured as follows. Section II describes the theoretical background used for derivation of analytical formulas for the two scenarios under study concerning channel capacity and spectrum efficiency. In Section III a GSM/EDGE system deployed in 1x3 frequency reuse has been analyzed based on measured link level and simulated C/I CDF. Section IV presents the data capacity and spectrum efficiency achieved by a state-of-the-art IEEE 802.16 WiMax system assuming the same frequency reuse, simulated link level and simulated C/I CDF. Finally the main conclusions are drawn in Section V.

II. Theoretical Background

A. *Spectrum Efficiency*

In a cellular network the spectrum efficiency η given in [bps/Hz/cell] is defined by:

$$\eta = \frac{C_{Cell}}{r \cdot B_{CH} \cdot N_{CH}} = \frac{C_{CH}}{r \cdot B_{CH}} \qquad (1)$$

with C_{Cell} the cell/sector throughput in [kbps], N_{CH} the number of configured channels per cell, B_{CH} the channel bandwidth in [kHz] and r the frequency reuse. The cell throughput C_{Cell} is the total of the N_{CH} individual channel throughputs C_{CH}.
In a cellular radio network radio frequency channels are allocated to cells with a certain reuse factor r characterizing

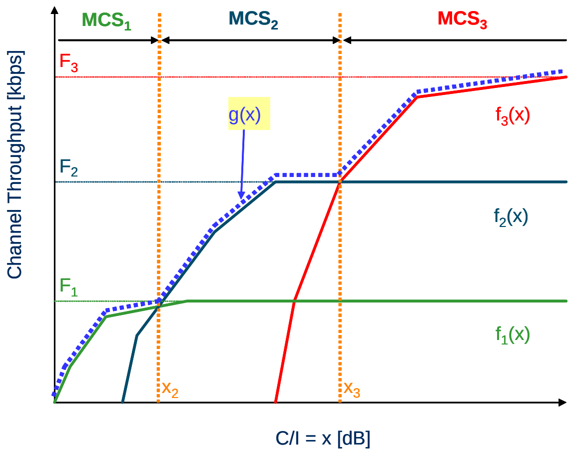

Fig. 1. Example for a link level performance with three MCS.

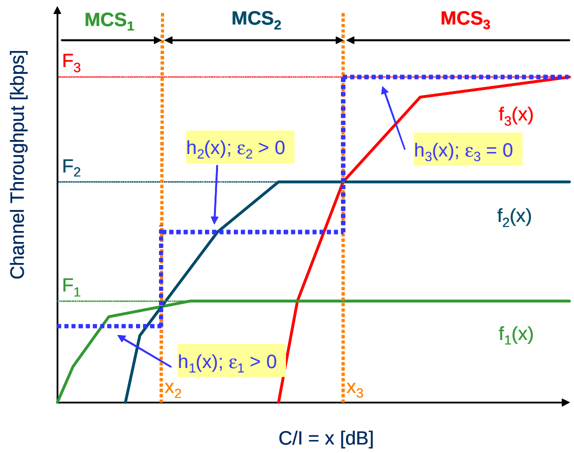

Fig. 2. Approximation of $f_i(x)$ by step function $h_i(x)$.

the robustness of the system against co-channel interference. The quantity used to describe the quality of the radio link is the Carrier-to-Interference-Ratio (C/I) given in dB. Depending on the multiple access scheme of the radio technology deployed in the network a radio frequency channel features a well defined structure fixed by the standard. Typically the structure of the radio frequency channel reflects the way it is designed to accommodate one or multiple communication channels, in the following termed channel.

Typically a channel consists of e.g. TDMA timeslots and frames carrying resource units. A GPRS/EDGE Packet Data Channel (PDCH) carries a radio block, a WiMax OFDM frame consists of OFDM symbols. The resource units are assigned by a scheduler to different users multiplexed on the same channel in the cell. Typically the resource units for an individual user are associated with a certain modulation and coding scheme (MCS) experiencing a certain error rate $\varepsilon(C/I)$ depending on the quality of the individual radio link.

Link Adaptation (LA) is usually applied to adjust the MCS to the varying radio conditions maximizing the user throughput. Hence in general each particular resource unit of the channel carries different payload. The total channel capacity (channel throughput) is the ratio of the average effective (related to ε) payload of the channel resource units and the transmission time per resource unit.

Obviously the highest channel throughput and consequently the highest spectrum efficiency is obtained in a system with 100% channel utilization, i.e. all resource units of the channel are permanently busy carrying traffic data.

B. Link Level Performance

State of the art multi-rate systems support different modulation and coding schemes MCS_i with i=1,…,M. Fig.1 shows an example with three MCS. Let's define a function $f_i(x)$ describing the throughput of a channel exploiting MCS_i at a carrier to interference ratio $C/I = x[dB]$ assuming 100% channel utilization. The function $f_i(x)$ can be written as:

$$f_i(x) = F_i \cdot (1 - \varepsilon_i(x)) \qquad (2)$$

with F_i the nominal throughput ($\varepsilon_i(x \to \infty)$) of a channel utilizing MCS_i and $\varepsilon_i(x)$ being the error rate of MCS_i at $C/I = x$.

LA automatically selects the most suitable MCS for certain $C(t)/I(t) = x(t)$ at time instant t for a particular radio link thus providing optimum throughput even for a time varying channel [5]. The optimum throughput curve is given by the envelope of all $f_i(x)$:

$$g(x) = \max\{f_i(x)\},\ i = 1,\ldots, M. \qquad (3)$$

There are (M – 1) switching points x_i due to LA corresponding to the intersection points of the functions $f_i(x)$:

$$f_{i-1}(x_i) = f_i(x_i),\ i = 2,\ldots, M. \qquad (4)$$

Hence according to LA, MCS_i is in use in a C/I range of $x_i \le x < x_{i+1}$, $i = 2,\ldots,M$. Since by this notation both the lower bound for MCS_1 and the upper bound for MCS_M are not specified in the following it is assumed that MCS_1 is used from x_2 down to some limited lower C/I value while MCS_M is used from x_M up to an arbitrary high C/I. To facilitate further analytical approach let's introduce the 'virtual' switching points $x_1 \to -\infty$ and $x_{M+1} \to +\infty$, defining the lower bound for MCS_1 and the upper bound for MCS_M, respectively. To allow for simple calculations each function $f_i(x)$, $i = 1,\ldots,M$ reflecting the channel throughput utilizing coding scheme MCS_i has been approximated over the respective C/I interval $x_i \le x < x_{i+1}$, $i = 1,\ldots, M$ by a step (Heaviside) function $h_i(x)$ as follows (refer also to Fig. 2):

$$h_i(x) = F_i \cdot (1 - \varepsilon_i) = H_i = const. \quad \text{for } x \ge x_i \text{ and} \qquad (5)$$
$$h_i(x) = 0 \quad \text{for } x < x_i.$$

Obviously the accuracy of approximation in (5) and hence the value of H_i strongly depends on the constant error rate ε_i chosen to represent the real one over the relevant C/I interval for the respective MCS. As suggested by Fig. 2 the best approximation result will be achieved using the expectation value (average error rate $\overline{\varepsilon_i}$, refer to Section D) of $\varepsilon_i(x)$ over the interval $x_i \le x < x_{i+1}$.

C. Cell C/I Distribution

Fig. 3 illustrates an example for a CDF of C/I obtained by system level simulations for a hexagonal cell deployment in 1x3 reuse (r = 3) at 100% channel utilization. The CDF

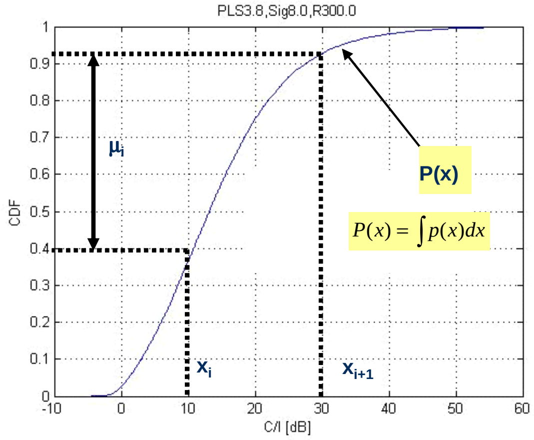

Fig. 3. Cell C/I CDF (300 m cell radius, 1x3 reuse, 3.5GHz band, 100% channel utilization, downlink power control off).

depends mainly on cell geometry, antenna configuration (height and pattern) as well as the propagation model. The RF output power plays no role in interference limited scenarios in tight reuse, if there are no coverage problems. Table I gives an overview of the essential parameter settings.

In the following the cell C/I CDF is denoted by $P(x)$ and the corresponding probability density function by $p(x)$.

Mapping the LA switching points x_i on the cell C/I CDF gives the portion μ_i of users (assuming an uniform user distribution over the cell area) able to use a certain MCS_i:

$$\mu_i = \int_{x_i}^{x_{i+1}} p(x)dx = P(x_{i+1}) - P(x_i)\,, \quad i=1,\ldots, M. \tag{6}$$

In particular μ_1 is given by $P(x_2)$ and μ_M by $1.0 - P(x_M)$ since as above defined $x_1 \to -\infty$ and $x_{M+1} \to +\infty$. Note that μ_i is not necessarily equivalent to the portion of channel resource units having a certain MCS_i. This heavily depends on the assumed traffic model as demonstrated in the following two simulation scenarios.

TABLE I. ESSENTIAL PARAMETERS OF THE RADIO NETWORK MODEL

Parameter	Value
Number of sites	16 wrapped around on torus, 3 sectors per site, hexagonal deployment
Site-to-site distance	900 m (300 m cell radius)
Frequency reuse pattern	1x3
Frequency band	1.8 GHz / EDGE; 3.5 GHz / WiMax
User distribution	uniform, random positioning
Pathloss slope	38 dB per decade
Propagation Model	COST-231
BS RF TX power	20 W / EDGE; 2 W / WiMax
BS antenna	65°, 17.5 dBi, 35 m above ground, no down-tilt
Mobile antenna	Omni, 0 dBi; 1.5 m above ground
Power control (PC)	Downlink PC switched off
Slow fading std. deviation	8 dB

D. *Scenario 1: Channel Capacity for equal mean Packet Call Duration per User*

In the first scenario a traffic model is assumed, where all users occupy the channel resources for the same average time period independent of the individually assigned MCS_i and the experienced error rate ε_i. The scenario is similar to a conventional voice traffic model having a fixed mean call holding time. The drawback of the model is given by the fact, that different users obtain different data volumes, e.g. users at the cell edge suffering from poor radio conditions get significantly less data volume than users close to the base station. The advantage of the model is its simplicity.

Obviously the C/I distribution of the channel resource units $p_{RU}(x)$ is identical to the C/I distribution of the users $p(x)$ and consequently the portion α_i of the channel resource units having MCS_i corresponds to the portion μ_i of users able to use MCS_i :

$$\alpha_i = \int_{x_i}^{x_{i+1}} p_{RU}(x)dx = \int_{x_i}^{x_{i+1}} p(x)dx\,. \tag{7}$$

Using (6) it follows: $\alpha_i = \mu_i = P(x_{i+1}) - P(x_i)$. The average error rate $\overline{\varepsilon_i}$ for MCS_i over the interval $x_i \le x < x_{i+1}$ is:

$$\overline{\varepsilon_i} = \frac{1}{\alpha_i} \int_{x_i}^{x_{i+1}} p(x) \cdot \varepsilon_i(x)dx\,. \tag{8}$$

The channel capacity C_{CH} in (3) is derived by mapping the envelope $g(x)$ of the throughput functions $f_i(x)$ on the cell C/I CDF:

$$C_{CH} = \int_{-\infty}^{+\infty} p(x) \cdot g(x)dx = \sum_{i=1}^{M} \int_{x_i}^{x_{i+1}} p(x) \cdot f_i(x)dx. \tag{9}$$

Using (2) and (8) yields:

$$C_{CH} = \sum_{i=1}^{M} \int_{x_i}^{x_{i+1}} p(x) \cdot F_i \cdot (1-\varepsilon_i(x))dx = \sum_{i=1}^{M} \alpha_i \cdot F_i \cdot (1-\overline{\varepsilon_i}). \tag{10}$$

Applying the step function approximation for the throughput vs. C/I curves from (5) the following easy calculation formula has been obtained:

$$C_{CH} \approx \sum_{i=1}^{M} \alpha_i \cdot H_i = \sum_{i=1}^{M} \mu_i \cdot H_i. \tag{11}$$

Example: assume two user types sharing the same fully loaded channel, user type "a" with μ_a = ½ and $g(x_a) = H_a = 10$ *kbps* and type "b" with μ_b = ½ and $g(x_b) = H_b = 20$ *kbps*. With (11) the channel capacity is given by the arithmetic mean and results in C_{CH} = ½ * *10 kbps* + ½ * *20 kbps* = *15 kbps*.

Given the nominal payload $L_{RU,i}$ of a resource unit utilizing MCS_i the average data payload $\overline{L_{RU}}$ of the resource units on the channel is given by:

$$\overline{L_{RU}} = \sum_{i=1}^{M} \alpha_i L_{RU,i}(1-\overline{\varepsilon_i}) \approx \sum_{i=1}^{M} \alpha_i H_i T_{RU} = \sum_{i=1}^{M} \mu_i H_i T_{RU} \tag{12}$$

with T_{RU} the time duration of the resource unit.

E. *Scenario II: Channel Capacity for equal mean Packet Call Data Volume per User*

The second scenario is based on a traffic model with a fixed mean data volume V per packet call independent of the radio link quality of the different users. The C/I distribution of the users is still given by $p(x)$ and the portion of users having

MCS_i is defined by μ_i according to (6). The distribution $p_{RU}(x)$ of the channel resource units, however, is not equal to the C/I distribution of the users $p(x)$ anymore, because users under poor radio conditions require significantly more channel resources than users e.g. close to the base station in order to transfer the same data volume V. An example with user type "a" at $C/I = x_a$ and user "b" at $C/I = x_b$ leads to the required number of channel resource units $N_{RU,a}$ and $N_{RU,b}$ respectively:

$$N_{RU,a} = \frac{V}{g(x_a) \cdot T_{RU}} \quad N_{RU,b} = \frac{V}{g(x_b) \cdot T_{RU}} \quad \text{and} \quad \frac{N_{RU,a}}{N_{RU,b}} = \frac{1}{g(x_a) / g(x_b)} . \tag{13}$$

Hence the distribution $p_{RU}(x)$ of the resource units can be derived from $p(x)$by the following probability transformation:

$$p_{RU}(x) = \frac{p(x)}{g(x) \cdot Z} \quad \text{with} \quad Z = \int_{-\infty}^{+\infty} \frac{p(y)}{g(y)} dy . \tag{14}$$

The portion α_i of the channel resource units having MCS_i leads to:

$$\alpha_i = \int_{x_i}^{x_{i+1}} p_{RU}(x) dx = \int_{x_i}^{x_{i+1}} \frac{p(x)}{g(x) \cdot Z} dx = \frac{1}{Z} \int_{x_i}^{x_{i+1}} \frac{p(x)}{f_i(x)} dx = \frac{1}{Z} \int_{x_i}^{x_{i+1}} \frac{p(x)}{F_i \cdot (1 - \varepsilon_i(x))} dx. \tag{15}$$

Applying the step function approximation from (5) and using (8) the following easy calculation formula has been obtained:

$$\alpha_i = \frac{\mu_i / (F_i (1 - \overline{\varepsilon_i}))}{\sum_{k=1}^{M} \mu_k / (F_k \cdot (1 - \overline{\varepsilon_k}))} \approx \frac{\mu_i / H_i}{\sum_{k=1}^{M} \mu_k / H_k} . \tag{16}$$

The capacity of the shared channel with fixed mean data volume is then defined by:

$$C_{CH} = \int_{-\infty}^{+\infty} p_{RU}(x) \cdot g(x) dx = \frac{1}{Z} \int_{-\infty}^{+\infty} p(x) dx = \frac{1}{Z} . \tag{17}$$

The step function approximation according to (5) leads to:

$$C_{CH} = \frac{1}{\sum_{k=1}^{M} \mu_k / (F_k \cdot (1 - \overline{\varepsilon_k}))} \approx \frac{1}{\sum_{k=1}^{M} \mu_k / H_k} . \tag{18}$$

The average data payload per resource unit is given by:

$$\overline{L_{RU}} = \frac{1}{\sum_{k=1}^{M} \mu_k / (L_{RU,k} \cdot (1 - \overline{\varepsilon_k}))} \approx \frac{T_{RU}}{\sum_{k=1}^{M} \mu_k / H_k} . \tag{19}$$

The example in Section D with two types of users sharing the same fully loaded channel — user type "a" with μ_a = ½ and $g(x_a) = H_a = 10$ *kbps* and type "b" with μ_b = ½ and $g(x_b) = H_b = 20$ *kbps* — leads with (18) to a channel capacity of $C_{CH} = (½ / 10 \text{ kbps} + ½ / 20 \text{ kbps})^{-1} = 13.33$ *kbps*.

With (16) α_a = *½ / 10 kbps x 13.33 kbps = 0.66* and α_b = *½ / 20 kbps x 13.33 kbps = 0.33,* thus, in contrast to the example above with fixed mean packet call duration, the MCS utilization per resource unit with the fixed mean data volume model is not equal. The ratio $\alpha_a / \alpha_b = 2 / 1$ is reciprocal to the ratio H_a / H_b of the assumed nominal data rates.

III. NUMERICAL RESULTS FOR GSM/EDGE

GSM/EDGE supports M = 9 modulation and coding schemes MCS_1, …, MCS_9 utilizing both GMSK and 8-PSK and providing RLC data rates up to 59.2 kbps per PDCH. Fig. 4 on the right hand side shows the measured end-to-end application throughput per PDCH vs. C/I for all MCS. Application throughput means that all overhead including TCP/IP and LLC headers are included reducing the peak user data rates by roughly 3-5%. The measurements have been conducted on downlink static/stationary AWGN channel with commercially available handset and a GMSK modulated co-channel interferer with random payload. Link level results based on other channel models such as TU3 or TU50 have been published in [6] and could also be used. In addition the static/stationary throughput vs. C/I curves have been optimistically approximated (assuming ε_i = 0) by step functions H_i as outlined in Section II. Mapping the eight LA switching points x_i onto the cell C/I CDF for 1x3 reuse in Fig. 4 on the left hand side provides the portions μ_i of users to which LA will assign MCS_i according to the experienced C/I at the particular cell location. All data necessary for the calculations of channel capacity and spectrum efficiency by using (11), (18), and (1) have been collected in Table II. Obviously the 8-PSK MCS_i (MCS_5, …, MCS_9) are dominantly in use with more than 75% vs. 25% GMSK modulation even for tight 1x3 frequency reuse.

TABLE II. ESSENTIAL EDGE DATA FOR FURTHER PROCESSING

MCS	x_i [dB]	μ_i	H_i [kbps]
1	NA	0.05	8.0
2	1	0.07	11.0
3	4.5	0.06	14.0
4	6.5	0.07	17.0
5	7.5	0.05	21.0
6	9.5	0.2	28.0
7	13.0	0.1	43.0
8	16.0	0.2	52.0
9	21.0	0.2	56.0

A. *Traffic Model with fixed mean Packet Call Duration*

Inserting the data from Table II into equation (11) the channel capacity of an EDGE PDCH is obtained for the traffic model with fixed mean packet call duration:

$$C_{PDCH} \approx \sum_{i=1}^{9} \alpha_i \cdot H_i = \sum_{i=1}^{9} \mu_i \cdot H_i = 35.75 kbps.$$

The average data payload per resource unit is calculated according to (12) using EDGE radio blocks with four TDMA frame rectangular interleaving duration T_{RU} of 20 ms to:

$$\overline{L_{RU}} = C_{PDCH} \cdot T_{RU} = 35.75 kbps \cdot 20 ms = 715 bit.$$

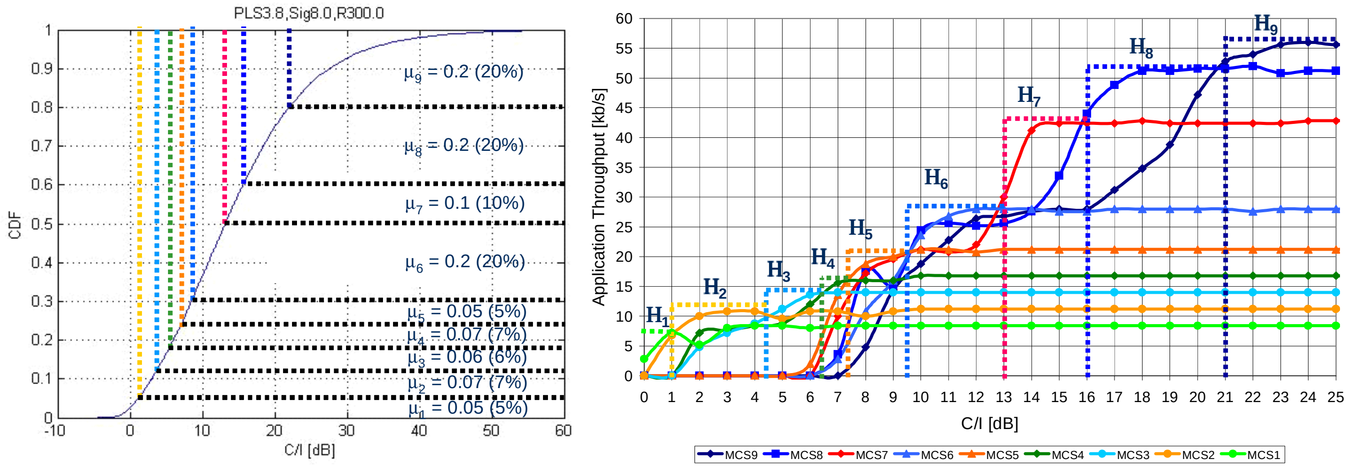

Fig. 4. Mapping of a measured GSM/EDGE link level with approximation by step functions (right) on the cell C/I CDF for 1x3 reuse (left) at full load.

The spectrum efficiency is calculated for frequency reuse *r = 3* according to (1). The radio channel spacing in GSM is 200 kHz. Thus the channel bandwidth of the EDGE PDCH is $B_{PDCH} = 200\ kHz / 8 = 25\ kHz$, since the GSM carrier includes eight timeslots and one PDCH occupies one timeslot.

$$\eta = \frac{C_{PDCH}}{r \cdot B_{PDCH}} = \frac{35.75kbps}{3 \cdot 25kHz} = 0.47 bps/Hz/Cell\ .$$

B. Traffic Model with fixed mean Packet Call Volume

Using (18) and (19) and the data in Table II the EDGE channel capacity and average payload per radio block have been calculated in case of a fixed mean data volume per user as follows:

$$C_{PDCH} \approx \frac{1}{\sum_{k=1}^{9} \mu_k / H_k} = 24.82kbps \quad \text{and}$$

$$\overline{L_{RU}} \approx C_{PDCH} \cdot T_{RU} = 24.82kbps \cdot 20ms = 496bit.$$

Taking into account the PDCH bandwidth of 25 kHz (refer to the comments above) the corresponding spectrum efficiency is given by (1):

$$\eta = \frac{C_{PDCH}}{r \cdot B_{PDCH}} = \frac{24.82kb/s}{3 \times 25kHz} = 0.33 bps/Hz/Cell.$$

As expected the channel capacity as well as the spectrum efficiency for EDGE is significantly higher for the traffic model with fixed mean packet call duration than those obtained for the traffic model with fixed mean packet call volume. The difference in the results is nearly 50%.

The EDGE results for the traffic model with fixed mean packet call volume are fully in line with the system level simulation results provided e.g. in [6] - [9].

Note that the results described above are only valid for PDCH allocated on transceivers (TRX) in 1x3 reuse, i.e. PDCH allocation on a BCCH TRX has not been considered. The latter case would result in a lower overall spectrum efficiency.

IV. Numerical Results for IEEE 802.16 (WiMax)

IEEE 802.16 WMAN (WiMax) standard provides M=7 modulation and coding schemes $MCS_1, \ldots, MCS_7$ as shown in Fig. 5 on the right hand side. MCS_1 is based on BPSK modulation, $MCS_{2/3}$ on QPSK, $MCS_{4/5}$ on 16-QAM and $MCS_{6/7}$ on 64-QAM. Data rates ranging from 1.5 Mbps up to 11.5 Mbps are feasible in a 3.5 MHz channel.

Similar to Fig. 4 the static/stationary throughput vs. C/I curves have been optimistically approximated in Fig. 5 by step functions H_i (assuming $\varepsilon_i = 0$) as outlined in Section II. Mapping the six LA switching points x_i onto the cell C/I CDF for 1x3 reuse in Fig. 5 on the left hand side provides the portions μ_i of users to which LA will assign MCS_i according to the experienced C/I at the particular cell location. All data necessary for the calculations of channel capacity and spectrum efficiency by using (11), (18), and (1) have been collected in Table III.

TABLE III. Essential WiMax data for further processing

MCS	x_i [dB]	μ_i	H_i [Mbps]
1	NA	0.1	1.29
2	2.5	0.1	2.59
3	6.0	0.13	3.88
4	9.0	0.17	5.18
5	12.0	0.1	7.77
6	16.0	0.2	10.37
7	21.0	0.2	11.66

A. Traffic Model with fixed mean Packet Call Duration

Inserting the data from Table III into equation (11) the capacity of a WiMax channel is obtained for the traffic model with fixed mean packet call duration:

$$C_{WiMax} \approx \sum_{i=1}^{7} \alpha_i \cdot H_i = \sum_{i=1}^{7} \mu_i \cdot H_i = 6.95Mbps.$$

The average data payload per resource unit can be calculated according to (12) with an OFDM symbol duration T_{RU} of 68µs (including 4µs cyclic prefix) to:

$$\overline{L_{RU}} \approx C_{WiMax} \cdot T_{RU} = 6.95Mbps \cdot 68\mu s = 472bit.$$

The spectrum efficiency is calculated for frequency reuse *r = 3* according to (1). The radio channel spacing in WiMax is 3.5 MHz:

$$\eta = \frac{C_{WiMax}}{r \cdot B_{WiMax}} = \frac{6.95Mbps}{3 \cdot 3.5MHz} = 0.66 bps/Hz/Cell.$$

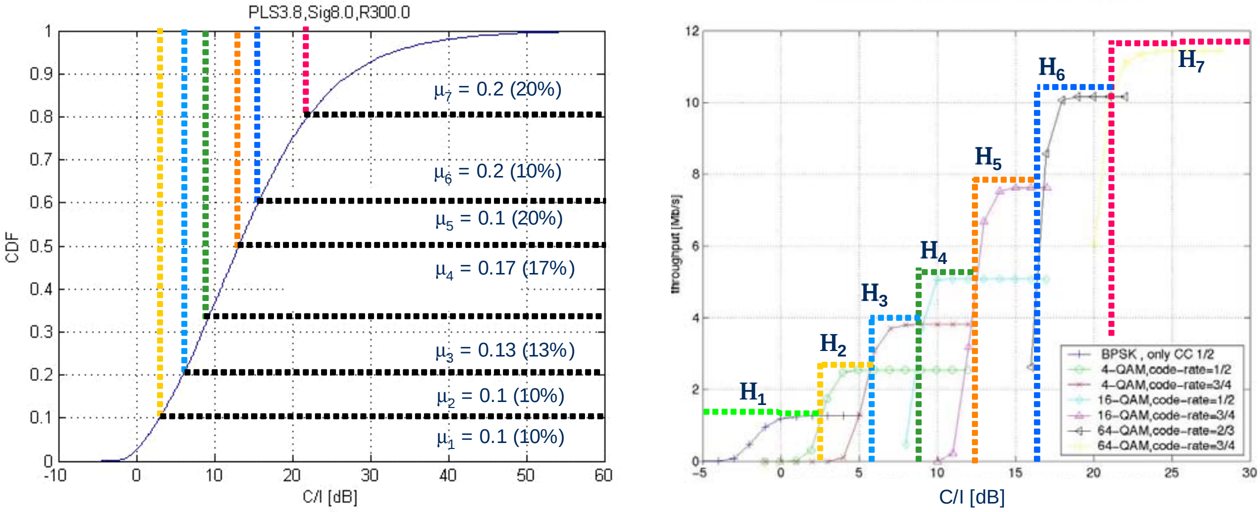

Fig. 5. Mapping of a simulated IEEE 802.16 (WiMax) link level with approximation by step functions (right) on the cell C/I CDF for 1x3 reuse (left) at full load.

B. Traffic Model with fixed mean Packet Call Volume

Using (18) and (19) and the data in Table III the WiMax channel capacity and average payload per OFDM symbol have been calculated in case of a fixed mean data volume per user as follows:

$$C_{WiMax} \approx \frac{1}{\sum_{k=1}^{7} \mu_k / H_k} = 4.31 Mbps, \quad \text{and}$$

$$\overline{L_{RU}} \approx C_{WiMax} \cdot T_{RU} = 4.31 Mbps \cdot 68 \mu s = 293 bit.$$

The corresponding spectrum efficiency is given by (1):

$$\eta = \frac{C_{WiMax}}{r \cdot B_{WiMax}} = \frac{4.31 Mbps}{3 \times 3.5 MHz} = 0.41 bps/Hz/Cell.$$

As expected the channel capacity as well as the spectrum efficiency for WiMax is significantly higher for the traffic model with fixed mean packet call duration than those obtained for the traffic model with fixed mean packet call volume. The difference in the results is nearly 60%.

The WiMax results for the traffic model with fixed mean packet call volume are fully in line with the system level simulation results provided in [10] and [11].

The direct comparison of WiMax with EDGE shows that about 40% higher spectrum efficiency is obtained by WiMax applying the traffic model with fixed mean packet call duration and about 20% applying the traffic model with fixed mean packet call volume. Nevertheless it shall be pointed out, that especially under good radio conditions WiMax allows for a significantly higher user throughput than EDGE due to the higher order modulation schemes (64-QAM for WiMax vs. 8-PSK for EDGE) and due to the larger channel bandwidth (e.g. 3.5 MHz for WiMax vs. 25 kHz for EDGE).

V. Conclusions

A quasi-analytical rapid estimation method for channel capacity and spectrum efficiency in wireless packet data networks has been derived. The method is essentially based on mapping simulated or measured link level curves of an arbitrary radio access technology on a measured or simulated cell C/I CDF. The approximation of the link level performance curves by simple step functions allows for a very easy-to-use calculation procedure. The proposed approach has been manifested on two generic traffic models assuming packet calls either with fixed duration or fixed volume. The results obtained are in line with state-of-the-art system level simulation results recently published in the literature. The channel capacity and spectrum efficiency have been estimated for a widely established technology like GSM/EDGE and an upcoming new technology such as WiMax. It has been clearly stated that irrespective of the radio technology under evaluation the performance indicators like channel capacity and spectrum efficiency show significant difference of 50-60 % depending on the traffic model. Future work will be focused on the evaluation of an appropriate mixture of the generic traffic models to cope with realistic user behavior in wireless networks.

References

[1] 3GPP TS 44.060, “General Packet Radio Service (GPRS); Mobile Station - Base Station System Interface; Radio Link Control/Medium Access Control (RLC/MAC) protocol”.

[2] 3GPP TS 43.064, “General Packet Radio Service (GPRS); Overall description of the GPRS radio interface”.

[3] Draft IEEE Standard for local and metropolitan area networks, IEEE P802.16-REVd/D5-2004, “Air Interface for Fixed Broadband Wireless Access Systems”, 2004.

[4] Draft IEEE Standard for local and metropolitan area networks, IEEE P802.16e/D4, “Air Interface for Fixed and Mobile Broadband Wireless Access Systems; Amendment for Physical and Medium Access Control, 2004.

[5] C.F. Ball, K. Ivanov, P. Stöckl, C. Masseroni, S. Parolari, R. Trivisonno, “Link Quality Control Benefits from a Combined Incremental Redundancy and Link Adaptation in EDGE Networks“, IEEE VTC Spring, Milan, 2004.

[6] C.F. Ball, K. Ivanov, L. Bugl, P. Stöckl, “Improving GPRS/EDGE End-to-End Performance by Optimization of the RLC Protocol and Parameters“, IEEE VTC Fall, Los Angeles, 2004.

[7] T. Halonen, J. Romero and J. Melero, “GSM, GPRS and EDGE Performance“, Wiley & Sons, 2002.

[8] K. Ivanov, C.F. Ball, F. Treml, “GPRS/EDGE Performance on Reserved and Shared Packet Data Channels“, IEEE VTC Fall, Orlando, 2003.

[9] C.F. Ball, K. Ivanov, F. Treml, „Contrasting GPRS and EDGE over TCP/IP on BCCH and non-BCCH Carriers“, IEEE VTC Fall, Orlando, 2003.

[10] C.F. Ball, E. Humburg, K. Ivanov, F. Treml, “Performance Analysis of IEEE802.16 based cellular MAN with OFDM-256 in mobile Scenarios“, IEEE VTC Spring, Stockholm, 2005.

[11] C.F. Ball, E. Humburg, K. Ivanov, F. Treml, “Comparison of IEEE802.16 WiMax Scenarios with Fixed and Mobile Subscribers in Tight Reuse“, 14th IST Mobile & Wireless Communications Summit, Dresden, 2005.