Mobile WiMAX – Deployment Scenarios Performance Analysis

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***Abstract* — In this paper, dynamic system level simulation methodology of mobile WiMAX (IEEE Std 802.16e) is described. The system level simulations scenarios (channel models, pathloss and shadow fading, sectorization, frequency reuse planning, system loading, etc) will be introduced. Evaluated performance of mobile WiMAX system such as signal-to-interference + noise ratio distributions, spectral efficiency and system outage in various scenarios of multi-cellular deployment will be presented and discussed.**

Keywords - Mobile and wireless vehicular communication systems, Mobile WiMAX, OFDM(A), system level simulations, PHY abstraction, network deployment scenarios

I. INTRODUCTION

Mobile broadband wireless technology WiMAX (IEEE Std 802.16e) is actively pushed forward in the IT market and rapidly finds proponents among network providers and telecommunication equipment manufacturers.

To evaluate performance capabilities of mobile WiMAX technology in realistic system deployment scenarios (encompassing such factors as base station (BS) and subscriber station (SS) configurations, channel models, pathloss and shadow fading, sectorization, frequency reuse planning, system loading, frequency-selective co-channel interference, etc), it is necessary to have quantitative characteristics obtained by the instrumentality of *system level simulations* (SLS).

This paper presents developed dynamic SLS methodology, outlines the main assumptions, parameters and structure of 802.16e WiMAX SLS, simulations scenarios (pathloss models, shadow fading models, frequency reuse, system loading, subscriber stations placement and assignment to serving BS). Output SLS performance metrics such as spectral efficiencies, user and system outage are defined. The SLS of Mobile WiMAX also take into consideration the essential features of IEEE Std 802.16e (PUSC permutation, repetition, downlink slot concatenation procedure) and some enhanced signal processing techniques such as multiple antennas and turbo-codes.

Evaluated performance metrics of WiMAX system operating in realistic frequency-selective interference-limited environment will be presented and analyzed for downlink transmission mode, different antenna configurations, coding schemes and system loading factors.

II. DESCRIPTON OF MOBILE WIMAX SYTEM LEVEL SIMULATION

In the SLS, the system deployment in terms of base station placement, sectorization and frequency reuse planning is modeled. A large number of users, placed throughout the cellular area, are considered and the effect of channel variations such as path loss and shadow fading are incorporated into the analysis. Various frequency reuse scenarios may be described by denotation "N_cxN_sxN_f", where N_c is number of independent frequency channels in the WiMAX network, N_s is the number of sectors per cell and N_f is the number of segments in exploited frequency channel. Fig. 1 shows WiMAX network deployment for 1x3x1 frequency reuse planning.

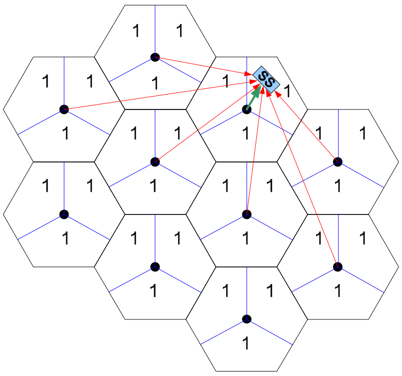

Figure 1. Illustration of 1x3x1 frequency reuse scenario

A. *Dynamic Downlink SLS Methodology*

To obtain output metrics of mobile WiMAX system in interference-limited environment we developed dynamic SLS methodology based on time-domain evolution to perform fast link adaptation in accordance with PHY abstraction model based on instantaneous channel capacity of realistic frequency-selective link layer channel. This dynamic downlink methodology can be shortly described as follows.

Several thousand of subscriber stations are evenly distributed in the hexagon area with radius of 3*R*, where *R* is the cell radius. For each SS, random shadow fading factors with 50% correlation between BSs are generated. SS received powers from all BS (taking into account attenuation factor including propagation pathloss, generated shadowing, BS and target SS antenna gains, angle loss (BS antenna pattern), cable loss, receiver noise, etc.). After that each SS is assigned to the home BS/sector, which provides maximal received power level (static hand-off).

For each user assigned to the BS of the central cell (BS#1), the burst spanning 2 consecutive OFDMA symbols (1 PUSC symbol) and all loaded data subcarriers is transmitted. At the each burst transmission, the independent ITU-R link level channel realizations [1, 2] (one Monte-Carlo trial snapshot) are generated for serving BS and all interfering BSs. Subscriber movement (Doppler spread) is also taken into consideration. The post-processing signal-to-interference+noise ratios (SINR) per subcarrier are calculated in accordance with specific signal processing technique provided by IEEE Std 802.16e and exploited in current system configuration (e.g. repetition coding, MRC, STBC, spatial multiplexing, etc.).

Fast link adaptation. Calculated instantaneous post-processing SINR values are inputs of PHY abstraction model (introduced in section III) that is used for prediction of instantaneous link performance (PER). Modulation and coding scheme (MCS) with the highest spectral efficiency that provide PER less than target PER value (1%) is selected for transmission. For each SS that served by BS of the central cell, the fast link adaptation process is repeated in conditions of time-varying frequency-selective home BS channel and interference levels (over several Monte-Carlo trial snapshots). For each target user, time-averaged performance metrics (spectral efficiency and user outage) are evaluated on the base of instantaneous spectral efficiency and PER values collected over all the Monte-Carlo trials.

At the last stage, overall system performance metrics (normalized spectral efficiency per cell, system outage, etc.) are evaluated as described below.

B. Evaluated performance metrics

The *equal time spectral efficiency* is defined as the average data rate for all target subscribers (i.e. those served simultaneously by the central cell of the network) normalized by the total bandwidth required for the deployment:

$$\begin{aligned} SE^{1} &= k_F \cdot \left[\frac{1}{\tilde{N}_{SS}} \sum_{i=1}^{\tilde{N}_{SS}} SE_i\right] \cdot \left(\frac{N_s}{N_f}\right) \cdot K_{load} \\ &= k_F \cdot \left[\frac{1}{\tilde{N}_{SS}} \frac{1}{N_{tr}} \sum_{i=1}^{\tilde{N}_{SS}} \sum_{t=1}^{N_{tr}} se_{i,t}\right] \cdot \left(\frac{N_s}{N_f}\right) \cdot K_{load}, \end{aligned} \tag{1}$$

where k_F is the ratio of number of data subcarriers to the total number of subcarriers (720/1024 for 10 MHz DL PUSC), $\tilde{N}_{SS}$ is the number of target users served by the BS of the central cell for given shadow fading values, N_{tr} is number of trial snapshots with fixed shadow fading values, $se_{i,t}$ is the *instantaneous* spectral efficiency of the i^{th} subscriber for t^{th} snapshot, SE_i is the *averaged* (across snapshots) spectral efficiency of the i^{th} subscriber, K_{load} is the loading factor (the percentage of subchannels allocated by the BS for the given sector or given cell), N_s is the number of sectors per cell (1 or 3), N_f is the number of segments in exploited frequency channel (1 or 3).

The *user outage* is defined in [3] as the event where a connection of i^{th} subscriber has short-term $\text{PER}_{i,t}$ higher than target value PER_{out} more often than in t_{out} percent of all snapshots. Number N_{out} is defined as the number of users in outage. The *system outage percentage* is estimated as the fraction of users in outage from the total number of SS:

$$P_{out} = \frac{N_{out}}{\tilde{N}_{SS}} \cdot 100\% \tag{2}$$

The *system outage* [3] is occurred when system outage percentage is higher than target system outage value T_{out}.

Table I contains parameters for system outage calculation, which are used in our SLS simulations.

TABLE I. OUTAGE PARAMETERS

Outage Parameters	***Values***
Target PER for MCS selection	$\text{PER}_{\text{MCS}} = 1\%$
Target PER for user outage	$\text{PER}_{out} = 15\%$
Target value of user outage	$t_{out} = 1\%$
Target value of system outage	$T_{out} = 3\%$

Fig. 2-4 illustrate fast link adaptation procedure on the example of two users served by the BS of the central cell: near – User A and distant – User B. Fig. 3 and Fig 4 show PER evolution diagram and MCS selection across trial snapshots for User A and User B respectively.

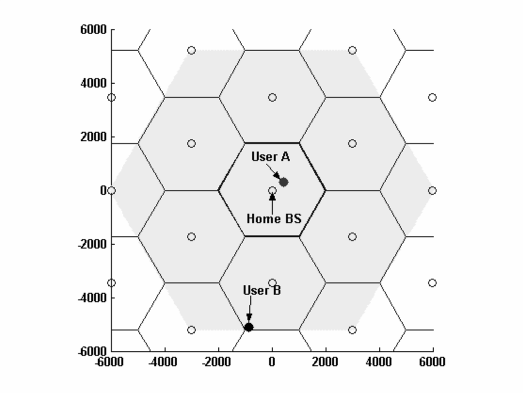

Figure 2. Geographical placement of two example users

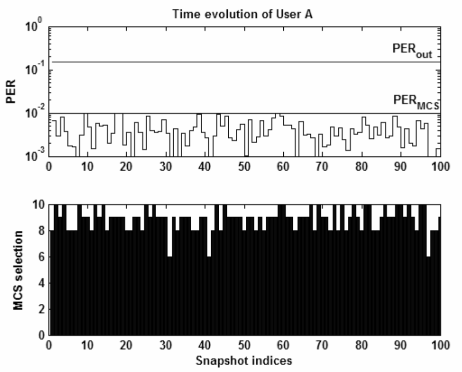

Figure 3. Example of MCS selection and PER evolution in time for near User A

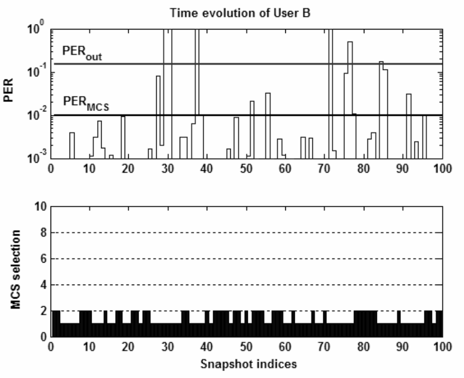

Figure 4. Example of MCS selection and PER evolution in time for distant User B

III. PHY ABSTRACTION METHODOLOGY FOR WIMAX SYSTEM LEVEL SIMULATION

One of the biggest challenges in the SLS simulator design is to develop a reliable *PHY abstraction methodology* that can support intensive SLS simulations. The objective of PHY abstraction methodology is to accurately predict link layer performance with a computationally simple model (which is critical for SLS). The link abstract model may be implemented as a look-up table (LUT) containing probabilistic model of a PHY station, which was obtained from PHY simulations (LLS) made in advance. In accordance with this approach the PHY abstraction model should represent the communication system as a set of the performance curves, which describe System Quality Indicator (SQI) dependence on Channel Quality Indicator (CQI).

This section presents description and analysis of PHY abstraction methodology for WiMAX system level simulations. The methodology summarizes previous approaches based on mean instantaneous capacity calculation [4, 5] and evolves them with focus to IEEE 802.16e systems operating in interference-limited environment.

A. Description of PHY Abstraction Methodology

The realization of a frequency selective channel transfer function and a time-frequency profile of interference levels are inputs of the PHY abstraction model for SLS simulator. For OFDM(A) WiMAX systems the frequency selectivity implies that each of the frequency subcarriers comprising an OFDM symbol, will experience different instantaneous channel conditions and the signal to interference+noise ratio (SINR) will vary within a code block. The PHY abstraction must predict with needed accuracy the error rate as a function of a vector of subcarrier SINR values.

The current post-processing SINR value on k^{th} subcarrier of j^{th} target user (subscriber station served by home BS#1) can be calculated in accordance with the following expression:

$$\gamma^{(j)}(k) = \frac{p_{RX}^{(1\to j)}(k)}{\sigma_n^2 + p_{CCI}^{(j)}(k)} = \frac{p_{RX}^{(1\to j)}(k)}{\sigma_n^2 + \sum\limits_{i=2}^{N_{CCI}} p_{CCI}^{(i\to j)}(k)}, \qquad (3)$$

where $p_{RX}^{(1\to j)}(k)$ is the current received signal power level (from home BS#1), N_{CCI} is a number of co-channel interfering sectors of all BS, $p_{CCI}^{(i\to j)}(k)$ is co-channel interference (CCI) power level (from the i^{th} interfering sector) and σ_n^2 is a per-subcarrier power level of the background AWGN. Note that the signal and CCI power levels for each subcarrier must be calculated in accordance with path loss value, shadow and fast fading gains.

System quality indicator. The system quality indicator is a value describing performance of a communication station for a given channel condition and CCI environment. For 802.16 systems a whole range of parameters can be considered as candidates for system quality indicating: bit error rate, slot error rate, FEC block error rate, packet (burst) error rate, etc. For description of PUSC mode of IEEE 802.16e system we propose to use a slot error rate (SLER) as system quality indicator. The PUSC slot consists of 48 symbol-tones (24 subcarriers in two consecutive OFDMA symbols).

Channel quality indicator. A mean instantaneous post-processing capacity for given portion of loaded subcarriers can be considered as a CQI candidate:

$$C_m = \frac{1}{N}\sum_{k=1}^{N} c(k), \qquad (4)$$

where N is a number of loaded subcarriers (across which averaging is performed), k is subcarrier index, $c(k)$ is the capacity of k^{th} subcarrier. Proposed channel quality indicator is measured in bps/Hz and actually represents mean (averaged across loaded subcarriers) spectral efficiency of given portion of loaded subcarriers of point-to-point channel realization between BS and SS

Capacity value $c(k)$ for each subcarrier is calculated in accordance with well-known Shannon's expression on the base of post-processing subcarrier SINR value $\gamma_{pp}(k)$:

$$c(k) = \log_2\left(1+\gamma_{pp}(k)\right) \qquad (5)$$

The post-processing subcarrier SINR should be calculated in accordance with specific signal processing technique exploited in current system configuration.

Currently IEEE 802.16 standard employs tail-biting convolutional code (TB-CC) as a mandatory coding scheme. Before encoding the standard slot concatenation procedure forms FEC blocks from slots. FEC blocks are encoded independently from each other. Therefore, CQI (mean capacity) should be calculated for each FEC block with taking into account the slot concatenation procedure.

In order to improve accuracy of PHY abstraction methodology for the receiver exploiting TB-CC we propose to use a modified CQI – "min-mean capacity". For each FEC block the modified CQI is calculated as follows: subcarrier-level metrics (capacities) are transformed to bit-level metrics (by using standard interleaving and M-QAM pseudo-mapping); the bit-level metrics are averaged within moving window and, then, the worst metric segment is searched for using as a current value of CQI.

Log-linear approximation of SQI–CQI curve. To reduce amount of LUT data we used log-linear approximation (minimum-mean-squared-error) of SLER vs. Capacity performance:

$$SLER_{appr}\left(C_m\right) = 10^{A_{Sl}\cdot C_m + B_{Sl}}, \qquad (6)$$

where fitting coefficients A_{Sl}, B_{Sl} were chosen to adjust log-linear curve for each modulation and coding scheme (MCS) within operational range for given channel model.

B. Validation of PHY Abstraction Methodology

To validate PHY abstraction methodology in CCI-free and CCI-limited environments we carried out a variety of link level simulations. We investigated WiMAX systems with various configuration parameters: loading factor, number of interfering stations, MCS, encoding type, number of antennas, etc. Fig. 5 and Fig. 6 illustrate some representative simulation results.

Fig. 5 illustrates scattering diagrams (CQI–SQI dependence) for WiMAX system operating in ITU-R Pedestrian B (3 kmph) channel. Each point of scattering diagram represents SLER value for given FEC block (SLER for each point was estimated by 1500-2000 simulation runs of the FEC block for given channel realization). Light dots show scattering diagrams for the case of CCI-free environment. Dark stars represent scattering diagrams for the CCI environment: 3 interferers with 33% loading (CCI=3x33%). Solid lines represent PHY abstraction curves – approximated (log-linear fitting) SLER vs. Capacity curves calculated from scattering diagrams (CCI-free).

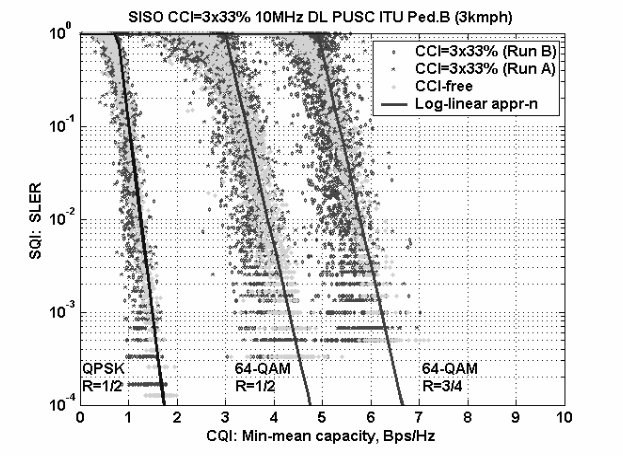

Figure 5. Scattering diagrams

In order to verify the proposed PHY abstraction methodology SLER vs. SINR curves were calculated in two ways: by using PHY abstraction model and by using direct LLS results. Fig. 6 illustrates SLER vs. ensemble averaged SNR (SINR) dependence for MCS: 64-QAM, R = 1/2. Solid curves show *simulated* results (obtained by direct LLS simulations), dashed curves – *predicted* performance (calculated by using proposed PHY abstraction methodology). Two cases of interference environment are shown: CCI-free (curves without markers) and CCI=3x33% (curves with markers).

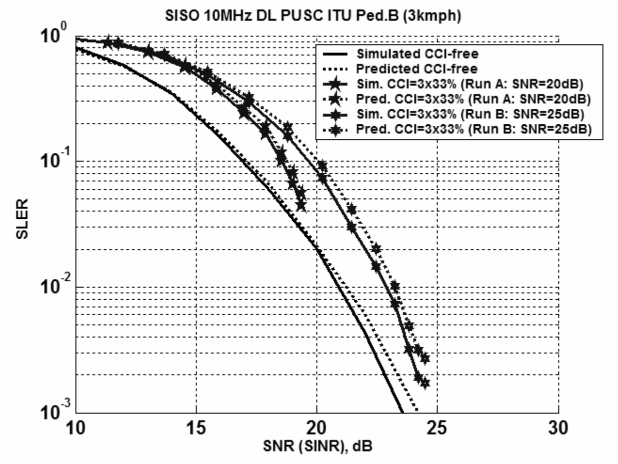

Figure 6. Predicted SLER dependence on SINR

It can be seen from the figures given above that proposed PHY abstraction methodology provides good accuracy of error rate prediction.

IV. SYSTEM LEVEL SIMULATION RESULTS

The following assumptions and parameters were used for system level simulation of mobile WiMAX system:

- Downlink transmission, 19 cells with radius of 2 km, 1x3x1 frequency reuse scenario;
- Antenna configurations: 1x1 single-input single output (SISO), 1x2 Maximum Ratio Combining (Optimum Combining – OC), 2x2 Space-Time Block Coding (STBC – Alamouti scheme) with Minimum Mean Square Error (MMSE) receiver;
- 2000 evenly distributed SS, 100 bursts for each SS (100 Monte-Carlo trials);
- Carrier frequency of 2.3 GHz, 10 MHz bandwidth, 1024-FFT, PUSC, loading factor of 20%, 40%, 60% and 100%;
- Frequency-selective channel model (for home and interfering stations): ITU-R Pedestrian B, user speed of 3 kmph;
- Pathloss model: ITU-R vehicular/outdoors [1];
- Shadow fading model: log-normal shadowing with 50% correlation amongst base stations with standard deviation of 8.9 dB [3];
- BS configuration: antenna height of 10 m (above average rooftop level), RMS power/sector of 42 dBm (39 dBm per antenna for 2-antenna system), 3GPP antenna pattern [2] with 120 degree beamwidth and backlobes of -30 dB, antenna gain of 15 dB, cable loss of 2 dB;
- SS configuration: antenna height of 1.5 m, omnidirectional antennas, SS receiver noise of 6 dB;
- PHY abstraction methodology: based on mean capacity calculation within moving window (for tail-biting convolutional code (TB-CC) FEC scheme) and based on mean capacity calculation within FEC block (for convolutional turbo-code (CTC) FEC scheme);
- MCS set: 1 – QPSK 1/12, 2 – QPSK 1/8, 3 – QPSK 1/4, 4 – QPSK 1/2, 5 – 16-QAM 1/2, 6 – 64-QAM 1/2, 7 – 64-QAM 2/3, 8 – 64-QAM 3/4, 9 – 64-QAM 5/6.

Fig. 7 and Fig. 8 show SINR distributions for all target users and 100% loading case. Fig. 7 illustrate geographical repartition of downlink SINR, Fig. 8 shows cumulative distribution functions for downlink SINR, SIR and SNR.

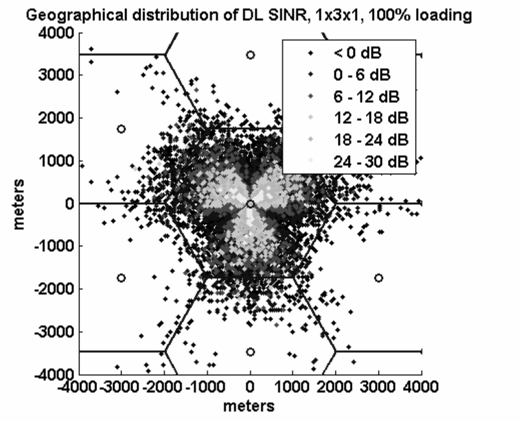

Figure 7. Geographical distribution of SINR for SISO system

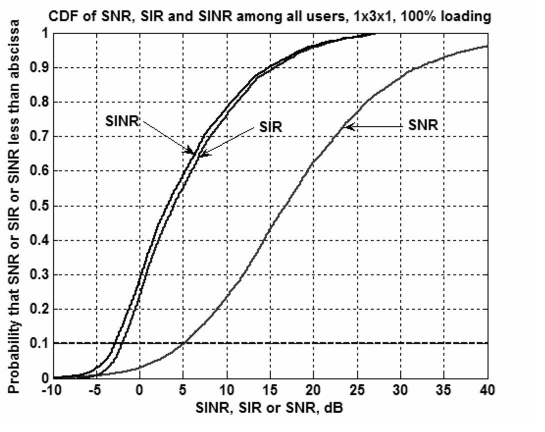

Figure 8. CDFs of SINR, SIR and SNR for SISO system

It is clear from Fig. 8 that for downlink mode of operation of WiMAX system the interference level significantly exceeds the background noise level. So, the interference from neighbouring base stations is main factor affecting downlink 802.16e system performance (so called "interference-limited environment"). Receivers with multiple antennas may significantly decrease (or even completely cancel) the interference from neighbouring BS by applying appropriate weights to the signals from different receiving antennas. Such interference aware techniques as OC and MMSE based on full knowledge of the interference + noise correlation matrix, can be used to mitigate impact of all or several strong interfering BS.

Fig. 9 and Fig. 10 show evaluated overall performance metrics (equal time spectral efficiency and system outage percentage) of mobile WiMAX system with the following antenna configurations: 1x1 SISO, 1x2 OC and 2x2 STBC with MMSE receiver.

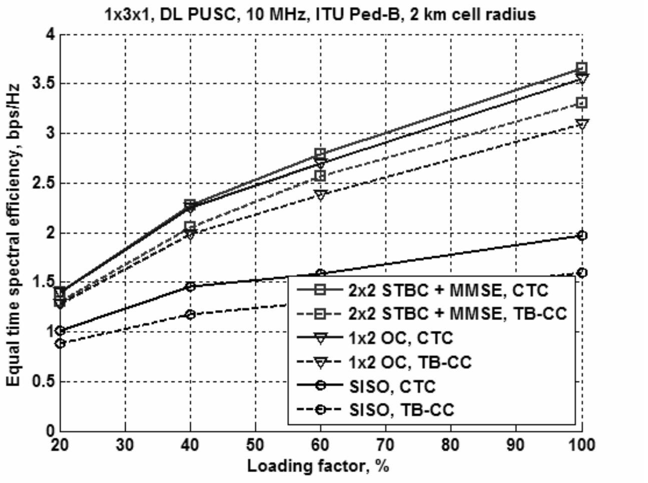

Figure 9. Equal time spectral efficiency vs. loading factor

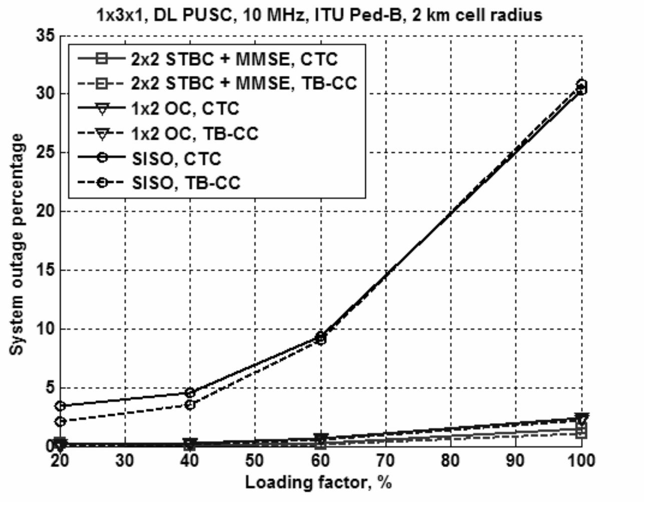

Figure 10. System outage percentage vs. loading factor

It is seen from figures above that 2 branch receive diversity significantly improves spectral efficiency (up to 100%) as well as the outage performance over SISO configuration. 1x2 OC and 2x2 STBC systems provide similar spectral efficiency improvement (due to similar receive diversity) but STBC system guarantees 2 times lower system outage percentage due to additional transmit diversity.

V. CONCLUSION

This paper presents dynamic system level simulation methodology of mobile WiMAX system (IEEE Std 802.16e). The performance characteristics of mobile WiMAX network, that allow to evaluate capabilities of this technology in realistic multicell deployment scenarios, are obtained for single-input single output and multiple antenna configurations.

Deployment of mobile WiMAX network with 1x3x1 frequency planning seems to be the most acceptable way for network providers and telecommunication equipment manufacturers because it doesn't require especial planning of frequency channels.

Exploiting CTC coding scheme in mobile WiMAX system with different antenna configurations gives equal time spectral efficiency improvement of about 20% in comparison with using TB-CC coding scheme.

Downlink system with 1 TX antenna and 2 RX antennas and OC RX processing provides substantial equal time spectral efficiency improvement of about 40 - 100% in comparison with SISO system for both TB-CC and CTC coding schemes.

Additional investigations have shown that only 2-3 most strong interferers significantly influence on performance of system with 2 branch receive diversity. Using OC scheme with suppression of 2 strongest interferers provide negligible equal time spectral efficiency degradation (about 0.2 bps/Hz) and system outage increasing (about 0.5%) in comparison with perfect cancellation of all 56 interferers.

System level simulation was also performed for other deployment scenarios. For example, it was found that decreasing cell radius up to 1 km leads to equal time spectral efficiency improvement of about 10% in comparison with deployment scenario with cell radius of 2 km.

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