Evaluating the Opportunity for Optimization of Various RF Parameters in IEEE 802.16e Multi-Cell Networks

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Abstract*— The likely sensitivity of an IEEE 802.16e system to optimization of sub-channel preamble power, antenna down-tilt, azimuth and beam-width is evaluated. A simple optimization scheme for these parameters is developed and an initial evaluation is performed. The various criteria by which an 802.16e system may be evaluated are identified and defined. These include signal-to-interference plus noise ratio, blocking and down link data rate and outage. A static model of the air interface is developed to predict these quantities. This model is simplified for reduced computation times, thus enabling a searcher-based optimization. The optimizer is a single-objective greedy local search scheme, driven by the air interface model and including intelligent hot-spot identification. This optimizer is employed to adjust various subsets of the sub-channel preamble power and antenna orientation parameters of the base stations in a simulated system based on a real cellular network. The performance improvements in the chosen criteria predicted by the simplified model are compared for the different scenarios. The predicted average down link rate is seen to increase by more than 50% when all degrees of freedom are exploited. Optimization of antenna parameters is predicted to be significantly more effective than preamble power optimization for enhancing predicted system performance.

I. INTRODUCTION

IEEE 802.16e is a standard for broadband wireless access designed to support mobility, which may bridge the gap between wireless local area networks and mobile cellular systems [1], [2]. This standard is based on orthogonal frequency division multiplexing (OFDM) and incorporates a variety of high-rate techniques such as adaptive modulation and coding, hybrid automatic repeat request (ARQ) and fast base station (BS) selection.

Considerations when designing an 802.16e system are similar to those for other cellular technologies. Sufficient signal coverage should be achieved while considering inter-cell interference via suitable choices of the BS location, antenna orientation and transmission power. In particular, this paper studies the potential to increase system performance by the control of the antenna down-tilt, azimuth and beam-width along with the power of the sub-carriers carrying the long preamble OFDM symbol at the start of each down link (DL) sub-frame. This type of optimization is ideal for situations where dynamic beam-forming with a per-user resolution such as *smart antenna* technologies are too costly or cannot be effectively applied, such as on DL map channels or other common channels.

There are various approaches to optimization of cellular air-interfaces in the literature. None of these report on the optimization of the 802.16e air-interface. A method of planning an OFDM broadcast system is presented in [3] although this does not cover the implications of cellular operation. References [4] and [5] show a method for optimization of coverage and handover in wide-band code division multiple access (WCDMA) via adjustment and minimization of pilot powers. In that approach, cells are assumed to transmit at full power. In contrast, [6] improves performance by minimizing the power in the system and sharing the load fairly between the cells. Reference [7] demonstrates a method for tuning the coverage within groups of cells by minimizing pilot power within that group while maintaining coverage. In all approaches it is clear that the pilot power adjustment is not as effective as antenna orientation. In contrast, our approach generalizes the optimization criteria by obtaining various metrics related to coverage and capacity and optimizing a weighted metric which allows for fine-tuned adjustment to blocking or DL data rate by modification of both power and antenna orientations. In [8] we have already shown the applicability of such an approach for code division multiple access (CDMA) and 1x evolution-data optimized (1xEV-DO) multi-cell systems. We now attempt to adapt it for 802.16e systems.

Here, we seek to understand the radio frequency (RF) performance of 802.16e multi-cell networks and what control we have over improving that performance. The approach is to build a simplified model of the air interface which is fast to evaluate yet accurate enough to capture the essential performance that would be realized on a real system. Such a model is ideal for a searcher-based optimization. To quantify the speed constraint for delivery of services to network operators, a system analysis and optimization should take a day or less.

The rest of this paper is organized as follows. Section II describes the characteristics of a static model of the 802.16e air interface used for the optimizations in this paper. Section III describes the optimization approach and how the system is designed to capture the effects of changing optimizable parameters. Section IV outlines the experiments used to increase understanding of the capabilities of the model and the optimizer. Results are presented in section V and conclusions are drawn in section VI.

II. 802.16E PROFILE

The IEEE 802.16e air-interface is a complex system at the scheduling and medium access control (MAC) layers. One common method of understanding air-interface performance for a particular configuration of BS parameters is to use dynamic simulation of the air-interface. This will typically simulate variations that occur on a short, frame-by-frame time scale. This is very time consuming to simulate and not suitable for a searcher-based optimization where many configurations must be evaluated in a tractable time if system performance is to be to enhanced. To address this issue, we first simplify the air-interface model. The model used in this paper is a timeless (static) snapshot. It does not consider mobile subscriber station (MSS) mobility, but does include inter-cell interference and uses a simple scheme to statically share the available resources between MSSs for the duration of the evaluation period. The inputs to this model include a static snapshot of traffic distribution over the entire coverage area, the associated propagation loss data, the site configuration and the permitted range of each tunable parameter over which each optimization is performed.

Our model assumes the following characteristics of the air interface:

1) All BSs use the same 5MHz frequency band and use the scalable orthogonal frequency division multiple access (OFDMA) physical layer.
2) Fully Utilized Sub-Channels (FUSC) mode is applied; the available sub-channels in the operating frequency band are fully reused in all sector-cells in the system.
3) The binary- and quadrature-phase shift keying and 16- and 64-quadrature amplitude modulation and coding schemes are used.
4) All sub-carriers in a sub-channel are treated in the same way; their modulation and coding schemes are identical.
5) All users are assumed to be in a continuous full buffer state, where there are always data to transfer. This eliminates the need for complicated per user queuing techniques.

Table I quantifies the sub-carrier and frame partition parameters.

Since ours is a timeless snapshot system, we assume identical BS-MSS channel conditions for all sub-carriers; Rayleigh fading effects are ignored and propagation loss is constant. This means that for each MSS, the channel conditions for each sub-carrier of a BS towards that MSS are identical.

A. BS-MSS Association

Each BS transmits a long preamble OFDM symbol at the start of each DL sub-frame. In our simplified model, each BS divides its total power equally among all non-guard preamble sub-carriers. Each MSS computes the signal to interference ratio of each received preamble sub-carrier (E_c/I_0), taking account of the combined effect of propagation loss and antenna gain. In order to preserve generality the average over all preamble sub-carriers is calculated for each BS that is a potential server. The MSS is then considered to have attached to that BS whose preamble sub-carrier E_c/I_0 is received the strongest. Thus each MSS attaches to one and only one BS. This is the BS-MSS association process and is invoked each time the model is evaluated in a given configuration. At the end of this attach procedure, each MSS knows its serving BS and each BS knows which MSSs it is serving.

B. Data Region and Power Allocations for an MSS in DL

Once BS-MSS association is complete, a data region is allocated for each MSS for a DL sub-frame. Reproducing the sophistication of a scheduler would make the model prohibitively slow so the model is simplified by allocating the same size data region to all MSSs. However, the data rate that is achievable by each MSS in its respective data region is determined by the signal-to-interference plus noise ratio (SINR), also referred to as E_c/N_T, achieved by that MSS on the sub-carriers in the data region. The 384 data sub-carriers are partitioned into equal sub-channels such that each sub-channel is allocated to a single user. In this case, eight equal sub-channels of 48 sub-carriers each are defined. Moreover, each sub-frame of 35 OFDM symbols is divided into five equal portions where each sub-channel in each sub-frame portion is allocated to the same MSS. Thus each frame can be shared

TABLE I

NUMEROLOGY OF THE 802.16E SIMULATION.

	Parameter	Value
Sub-carriers	System bandwidth	5MHz
	Total sub-carriers	512
	Total guard sub-carriers	85 (43 Left, 42 Right)
	DC sub-carriers	1
	Total used sub-carriers	426
	Total pilot sub-carriers	42
	Total data sub-carriers	384
Frame Partition	Frame size	5ms
	Down link/up link ratio	70/30
	Symbols per sub-frame	49
	Total DL symbols in a sub-frame	35

between five MSSs such that each MSS gets an allocation of seven OFDM symbols with eight sub-channels each. The number of MSSs associated with a BS thus determines the number of DL sub-frames required to support that traffic. In our model we set the number of sub-frames for a BS based on the number of MSSs associated with that BS. For instance, if the number of MSSs associated with a BS is between 11 and 15 inclusive, the number of DL sub-frames is set to 3.

Our model uses the following simple scheme for MSS power allocation in a DL frame. Our model assumes that 2% of the total power is allocated for all pilot sub-carriers. In each OFDM symbol, the total remaining BS power is allocated equally among all data sub-carriers. The motivation for this simplification is that there is no need to carry out per-MSS calculations, which reduces the run-time. It should be noted that even though each MSS gets an equal amount of data region and power, the amount of data carried to that MSS depends upon the induced SINR (E_c/N_T) and consequently the coding and modulation schemes used. Moreover, any MSS achieving a data-rate below 1Mbps is regarded as being blocked and does not have any data region allocated to it. This simplified scheduling and power allocation strategy makes SINR calculations conform to the timeless snapshot paradigm.

There is similarity between the rate selection schemes for 802.16e and 1xEV-DO systems arising from the use of FUSC mode and averaging of the sub-channel signal. Moreover, these technologies share a lack of power control on the forward link. Thus we can borrow from the validation in [8] for the 802.16e technology. Although the mapping of SINR to a data rate is slightly different between the systems, the collection of the signal to noise of each user is equivalent. The validity of the simulation approach is thus based on the assumption that the differences between 1xEV-DO and 802.16e do not affect significantly the ability of the corresponding models to select better configurations.

III. OPTIMIZATION APPROACH

The optimization is based on a greedy local search method which seeks to increase system performance via control of the antenna orientation and sub-channel preamble powers. The simplified model of the air interface for the system in the current parameterization is invoked and is used to generate a performance metric for the whole system and also for each BS in the system. The BS which meets the criteria of having the worst performance metric while not having been previously optimized is then nominated as the hot-spot BS. The parameters of that hot-spot BS are then extensively searched and the best parameterization is chosen before the optimization proceeds to identify and optimize the next hot-spot BS.

The searcher is dependent upon a system to generate metrics based on the simplified model of the air interface. Per-MSS, per-BS and system-wide metrics that capture the air-interface performance are calculated once the data region and power allocations are complete. Although the searcher used is single-objective, individual metrics can be assigned different weights and combined to allow different characteristics to be optimized into the network. Though we collect numerous metrics from our model, we mention only a few important metrics here.

- The *sub-carrier SINR* for MSS m, Γ_m, is based on the E_c/N_T expression

  $$\Gamma_m = \frac{P_{S_m}^{BS} \times L_m^{S_m}}{\left(\sum_{i:i \neq S_m} P_i^{BS} \times L_m^i \right) + \eta_0}$$

  where $P_i^{BS}$is the data sub-carrier power transmitted by BS i, S_m is the serving BS for MSS m, L_m^i is the propagation loss between BS i and MSS m and η_0 is the thermal noise. This per-MSS data is used to compute DL data throughput rates along with per-cell and system-wide SINR average.
- The *DL data throughput rate* χ_m^{DL} for MSS m is given by the equation

  $$\chi_m^{DL} = \frac{N_S \times N_C \times N_Y \times \log(1 + \Gamma_m)}{P_F}$$

  where N_S is the number of sub-carriers per sub-channel (48), N_C is the number of sub-channels allocated to that MSS (8), N_Y is the number of OFDM symbols in each sub-frame portion (7), Γ_m is the SINR for MSS m (see above) and P_F is the frame duration; namely the duration of all sub-frames required to support all non-blocked MSSs on this BS.
- The *per-cell blocking* B_b for BS b is expressed as

  $$B_b = \frac{\max\left(N_b^{>=1Mbps} - (5 \times N_f), 0 \right)}{N_b}$$

  where $N_b^{>=1Mbps}$ is the number of MSSs associated to BS b able to achieve a data-rate of 1Mbps or above, N_b is the number of MSSs associated to BS b irrespective of data-rate achieved and N_f is the number of sub-frames per frame required to support the non-blocked MSSs.
- The *preamble* E_c/I_0 is the ratio of preamble OFDM symbol power to interference for a given MSS.
- A MSS is a *preamble orphan* if it does not receive the preamble from any sector with sufficient E_c/I_0, indicating that the MSS is possibly in an area of poor coverage. A high percentage of MSSs in this condition indicates that the coverage is poorly configured in the system.
- The *MSS received signal strength indicator (RSSI)* is used as a metric. A higher average value across the system indicates that the coverage area is well-illuminated.
- The *soft handoff (SHO) factor* is the average number of BSs from which the preamble E_c/I_0 is received above a threshold. A lower number indicates that the cell overlap is under control and inter-cell interference is more likely to be acceptable.

We generate the following two types of compound metrics using the above metrics.

- *BS discrimination metric:* For each configuration, the per-MSS metrics mentioned above are weight-combined for all MSSs served by a BS to obtain a discrimination metric for that BS. This metric is then used to identify the cell with the worst performance, or the *hot-spot* BS, which can then be optimized.
- *Configuration discrimination metric:* The BS discrimination metrics above are weight-combined to obtain a system-wide metric. This is used to identify the best configuration so far as the search progresses.

IV. EXPERIMENTAL VALIDATION

We aim to answer the question "What degree of performance improvement can be realized by exploiting freedom in antenna configuration and sub-frame preamble power?" To this end the performance of the optimizer in five modes will be assessed. Each scenario allows a different subset of the adjustable parameters to be modified as described in Table II. This approach provides an initial assessment of the trade-off between economic cost and performance benefit for various models of remote control antenna with increasing flexibilities. For reference, pricing guidelines from one manufacturer, KMW Communications, are roughly \$700 for 1-way, \$1100 for 2-way and \$2475 for 3-way, where exact pricing depends on forecast volumes and length of the contract.

In order to evaluate the optimizer under realistic conditions, a real system configuration and user traffic distribution should be used. A perfectly hexagonal layout will not suffice. The system used as the basis for study in this paper was created directly from a deployed CDMA-1X system comprising 88 3-sector sites or 284 sectors in total. The tower height, down-tilt and azimuth of each cell in the study were configured to coincide with the live system which was already optimized for CDMA-1X traffic. Most of the original antennas had 65 degree horizontal beam-width so this pattern was selected as the initial setting. A gain pattern corresponding to a typical remote control antenna was chosen. The distribution of CDMA-1X cellular users was used to generate 802.16e MSS users. The attributes in the cell layout and the subscriber profiles will vary between a cellular and an 802.16e system. Although this variation affects the final optimized configuration, any validity that can be demonstrated in the underlying algorithms will still hold for the 802.16e optimizer.

The range and flexibility of the antenna control available to the optimizer can be made realistic by reference to products available on the market. Remote controlled antennas are available that can adjust various combinations of down-tilt, azimuth and beam-width. The allowed variations in each parameter are shown in Table III.

The objective function in these experiments was configured such that the DL data rate only is increased. Other studies involved mixed forward and reverse metrics, but these tended to attenuate the improvement on the forward link.

V. RESULTS

Evaluation of each system configuration with 24,000 simulated MSSs takes the optimizer an average of around 1.2 seconds on a standard PC. Each sector has 18 different configurations in terms of tilt, azimuth, beam-width and power for the *PTAB* scenario. Consequently processing 284 sectors takes around 100 minutes. Total processing time is therefore well within the time-scale constraints for commercial service delivery.

Table IV shows various metrics that were gathered for each experiment along with the improvement margin for each metric with respect to the baseline. We note that the *PTAB* scenario induces maximum DL rate and SINR improvement and keeps other metrics under control. Although the preamble E_c/I_0 is apparently significantly lower, the lower power is associated with a reduction in preamble orphans, suggesting that the reduced preamble E_c/I_0 is associated with a more efficient distribution of the power to minimize interference. The *TAB* scenario induces improvements close to *PTAB*, although without the reduction of preamble orphans that the extra degree of freedom of preamble power apparently makes possible. The *P*, *T* and *TA* scenarios improve DL rate and SINR marginally. Looking at *PTAB* and *TAB*, we conclude that antenna parameter optimization has the most significant impact on the system performance while the impact of preamble power is somewhat less in comparison. This is consistent with the studies of WCDMA and CDMA-1X systems described previously.

To see whether the improvement is uniform across the coverage area, we look at how the DL rate metric, which expresses the capacity improvement, varies with BS location. Figs. 1 and 2 show the DL rate metric as a function of distance from the center of the network for the *TAB* and *PTAB* scenarios respectively. While there is a large variation in the degree of improvement over the entire coverage area, good improvements are seen distributed across the whole network. Moreover the change for each BS is almost exclusively an improvement

TABLE II
OPTIMIZATION SCENARIOS.

Designation	Degrees of freedom
P	preamble power only
T	down-tilt only (1-way)
TA	down-tilt, azimuth (2-way)
TAB	down-tilt, azimuth, beam-width (3-way)
PTAB	preamble, down-tilt, azimuth, beam-width

TABLE III
PARAMETER CONSTRAINTS.

Parameter	Constraint
Antenna down-tilt	0 to 8, every 2 degrees
Antenna azimuth	± 30 degrees, every 15 degrees
Horizontal beam-width	35, 65, 90, 120 degrees
Preamble power	1, 2, 4, 6 watt total power

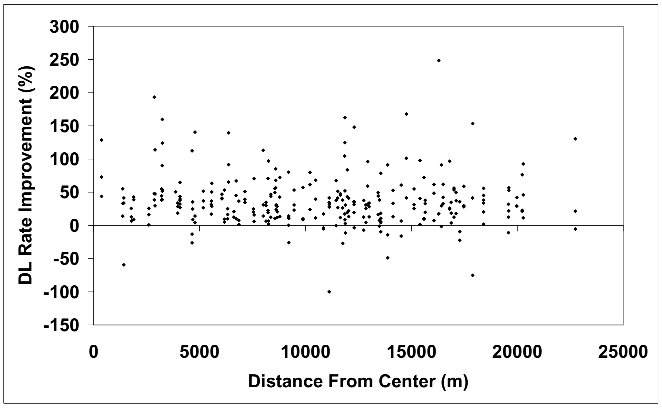

Fig. 1. DL rate improvement per sector as a function of distance from the center of the network for the tilt, azimuth and beam-width optimization.

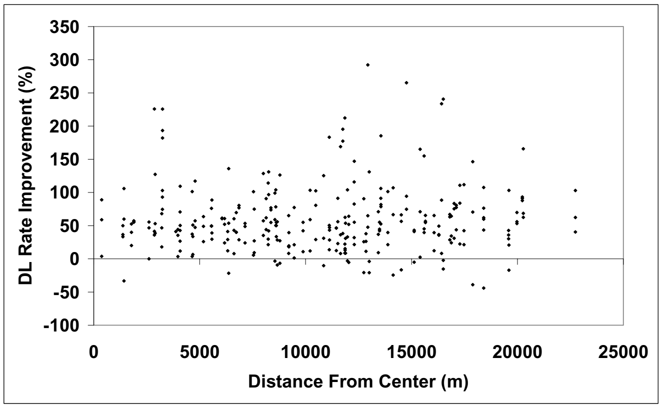

Fig. 2. DL rate improvement per sector as a function of distance from the center of the network for the power, tilt, azimuth and beam-width optimization.

and very few BSs are associated with a degradation in forward rate.

VI. CONCLUSIONS

In this work, we have looked at the problem of optimizing BS parameters of an IEEE 802.16e multi-cell system in order to improve the RF performance. As the search space for parameter optimization is extremely large, we used a simplified static air-interface model and an intelligent search process for identifying the settings that improve the RF performance. We showed the utility of our methods by carrying out experiments for one system based on a real CDMA-1X configuration. Based on model predictions, the optimizer was able to improve system performance. Since the results have not been validated either in a simulator or a real system, the next step will naturally be to carry out simulations and validate both the optimization approach and the underlying model.

The optimized settings obtained using this method are predicted to improve the RF performance in terms of capacity and coverage in all experiments. The main conclusion is that antenna parameter optimization in likely to have the most significant impact on the improvements whereas sub-channel preamble power settings are likely to be less effective. With remote control antennas available on the market, antenna settings produced by our methods can be easily deployed in a real system. This remote control capability can be coupled with intelligent optimization leading to schemes where the patterns and orientations of smart antennas can be modified in semi-real-time based on real traffic profiles. Better utilization of each site will result in enhanced throughput and quality for users.

TABLE IV

RF PERFORMANCE METRICS AND PERCENTAGE IMPROVEMENT FOR DIFFERENT DEGREES OF OPTIMIZATION FREEDOM.

	Baseline	Power	Tilt	TA	TAB	PTAB
Mean E_c/N_T (SINR) (dB)	11.1	12.5 +13%	13.3 +20%	14.8 +33%	18.3 +65%	19.4 +75%
Mean DL rate	643.1	744.7 +16%	671.8 +4%	766.8 +19%	896.7 +39%	991.2 +54%
Mean preamble E_c/I_0 (dB)	-4.7	-3.9 -17%	-4.7 0%	-4.2 -11%	-4.1 -13%	-3.4 -28%
Preamble orphans (%)	2.9	2.0 +31%	3.0 -3%	2.6 +10%	2.7 +7%	1.9 +34%
Mobile RSSI (dBm)	-67.8	-65.6 -3%	-66.5 -2%	-65.3 -4%	-65.6 -3%	-63.9 -6%
Mean SHO factor	1.3	1.3 0%	1.3 0%	1.2 +8%	1.2 +8%	1.2 +8%

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